GENETIC CHARACTERIZATION OF PEARL MILLET (*Pennisetum* glaucum (L.) R. Br.) GENOTYPES IN ZAMBIA

BY

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DECLARATION

I, Gloria Chitalu, declare that this dissertation represents a genuine research I carried out and that no part of this dissertation has been submitted for any other degree or diploma at this or another university or institution.

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Signature Date

APPROVAL FORM

This dissertation for Gloria Chitalu is approved as fulfilling part of the requirement for the award of the degree of Master of Science in Plant Breeding and Seed Systems (Plant Science Department) of the University of Zambia.

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DEDICATION

I dedicate this dissertation to my daughter, Mwila Buyano Chanda; my son, Mutale Busaka Chanda; my husband, Mr. Mutale Chanda; my parents Mr. and Mrs. Chitalu, my siblings and my nephews and nieces.

ABSTRACT

The most important objective in any crop improvement programme is to increase yield. Current grain yields of pearl millet among small-scale farmers in Zambia are very low (500 – 650kg/ha) due to the fact that farmers have continued to use landraces and varieties that are low yielding. There are no hybrid varieties that have been developed simply because the basis for developing hybrid varieties has not been established in Zambia. This study, therefore, aimed at characterising pearl millet genotypes in order to establish a basis for exploiting the genetic potential of pearl millet for development of high yielding varieties (hybrid varieties) in Zambia. To contribute to this realisation, the study involved the determination of combining ability for grain yield in cytoplasmic male sterile lines and restorer lines as well as determining the nature of gene action controlling grain yield and other important traits. A total of 104 crosses developed as lines x testers (i.e. 13 lines and 8 testers) combinations were evaluated during the 2012/2013 growing season at ZCA-Monze (52 crosses i.e. 13 x 4) and Longe (52 crosses i.e. 13 x 4) in a triple lattice design. Results showed that the performance of the crosses in terms of grain yield, days to 50% flowering, plant height, productive tillers per plant, panicle length, panicle girth, and panicle weight was variable. General combining ability (GCA) effects revealed that male parents; ZPMV 28001, ZPMV 28010 and ZPMV 28011 and female parents; NCD_2A_4 and $ICMA_4$ 02999 that showed significant ($P \leq 0.05$) positive GCA effects for grain yield, can be used for generating hybrid pearl millet varieties. On the other hand, specific combining ability (SCA) effects revealed that the five crosses; ZPMV 28010 x $ICMA_1$ 00444, ZPMV 28011 x $ICMA_1$ 92888, ZPMV 28011 x $ICMA_4$ 04777 and ZPMV 28013 x $ICMA_1$ 97111 and ZPMV 28015 x $ICMA_1$ 97111 that showed significant ($P \leq 0.05$) positive SCA effects for grain yield, can be utilized as high yielding hybrid varieties. The determination of the nature of gene action conditioning grain yield, productive tillers per plant and panicle weight was largely controlled by non-additive gene action while panicle girth and panicle weight were largely controlled by additive gene action. Since grain yield is largely controlled by non-additive gene action which can only be exploited by developing hybrid varieties, it can be concluded that these inbred

lines and cross combinations represent a good choice to make future strategy for the development of pearl millet hybrid varieties in Zambia.

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LIST OF ACRONYMS

CSO: Central Statistical Office

CMS: Cytoplasmic Male Sterility

FAO: Food and Agriculture Organisation of the United Nations

GCA: General Combining Ability

MACO: Ministry of Agriculture and Cooperatives

SCA: Specific Combining Ability

CHAPTER ONE

1.0 Introduction

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) belongs to the family poaceae (graminae) and genus *Pennisetum*. It is diploid (2x = 14) in nature and is commonly known as cattail millet or bulrush millet in English (Adam, 1996). It is the fifth most important cereal crop which is predominantly grown as a staple food grain and source of feed and fodder. It provides nutritionally superior and staple food for millions of people living in harsh environments characterised by erratic rainfall and nutrient-poor soils (Lakshmana, 2008). Pearl millet contributes to both rural food security and livelihood systems, as it provides good nutritional supplies and income sources to small-scale farmers (Rai et al., 2012). It is widely grown in Asia and Africa (Khairwal et al., 1999). In Zambia, current production of pearl millet is concentrated in the Northern, Western, North-western, and Southern Provinces (CSO, 2009).

The grain has high levels of protein (12 – 15%) content with balanced amino acids, carbohydrates (60 – 70%) and fats (5 – 10%) which are important in the human diet, and its nutritive value is considered to be comparable to rice and wheat (Lakshmana, 2008). Health wise, pearl millet is recommended for people suffering from celiac disease and diabetes. It is highly effective and recommended in cases of severe constipation and stomach ulcers. It helps in lowering cholesterol levels and is associated with bringing down the risk of cancer as well as supporting weight loss (http://www.lifemojo.com/lifestyle/healthbenefits--uses-of-pearl-millet, March 2013). Green fodder is more palatable because it does not have HCN (hydrogen cyanide) content as that of sorghum (Lakshmana, 2008). Feeding tests on cattle, swine, and particularly chickens have shown that pearl millet is at least equivalent to maize and often superior to sorghum in feed rations, generally because of high energy and protein levels (Andrews and Kumar, 1992).

Pearl millet has high yield potential and responds well to water and soil fertility (Poelhman, 1994). It is one of the most suitable and efficient crops for arid and semi-arid conditions because of its efficient utilization of soil moisture and higher level of heat tolerance than sorghum and maize (Harinarayana et al., 1999). It tolerates low soil pH better than sorghum (Myers, 2002). It also possesses unique genetic predisposition to withstand environmental stress and produce appreciable yield when grown on marginal soils (Wilson et al., 2006).

The increasing problem of food security in Africa and the recognition of pearl millet as a potential buffer against famine are expected to stimulate expansion of land devoted to pearl millet cultivation on the continent. However, available statistics demonstrate the reduction of pearl millet harvest area in several countries (FAOSTAT, 2003). In Zambia, millet production had declined by 22 percent to 37,644 metric tonnes in the 2010/2011 season from 47,997 metric tonnes in the 2009/2010 season. The total area planted for the 2010/2011 season decreased by 25 percent to 42,663 hectares from 56,789 hectares during the 2009/2010 (MACO and CSO, 2011). Several factors are responsible for the general decline in pearl millet production. One of the major reasons for the decline in pearl millet production is the low yields (Obeng et al., 2010).

The findings from this study will therefore, contribute to the improvement of the efficiency of plant breeding efforts to exploit the crop genetic resources for development of high yielding pearl millet (hybrid) varieties in Zambia.

Realising the multiple use potential of pearl millet grain, research projects are being designed to develop new pearl millet varieties and hybrids for high grain yield by utilizing cytoplasmic genetic male sterility system (Obeng et al., 2010). Burton (1958) was the first to develop cytoplasmic male sterile line Tift 23A. This opened up a new field for hybrid seed production in pearl millet. In India, the first pearl millet hybrid (HB-1) was released in 1965 and subsequently a number of promising hybrids have been developed and released for general cultivation in India. However, most of them failed in a short period due to their susceptibility to downy mildew disease. It was later realised that downy mildew susceptibility is associated with Tift 23A cytoplasm, which was common in all the hybrids. The utilisation of diverse sources of male sterility was then felt necessary and work in this direction led to the identification of several alternative sources like, A_1, A_2, A_3, A_4 and A_5 (Lakshmana, 2008).

Breeding strategies based on selection of hybrids require expected level of heterosis as well as specific combining ability (SCA). In breeding high yielding varieties of a crop plant, the breeder is often faced with the problem of selecting parents. Combining ability analysis is one of the powerful tools available to estimate the combining ability effects and aid in selecting the desirable parents for the exploitation of heterosis (Radish et al., 2007). To exploit maximum heterosis using cytoplasmic male sterile (CMS) techniques in a hybrid programme, it's important to know the combining ability of different male sterile and restorer lines (Nadali, 2008).

The performance of parents may not necessarily reveal it to be a good or poor combiner. Therefore, gathering information on the nature of gene effects and their expression in terms of combining ability is necessary. At the same time it also makes it easier to understand the nature of gene action involved in the inheritance of characters (Pradhan et al., 2006). General combining ability (GCA) is attributed to additive gene effect and additive x additive epistasis and is theoretically fixable. On the other hand, specific combining ability (SCA) attributable to non-additive gene action may be due to dominance (Griffing, 1956).

STATEMENT OF THE PROBLEM

Current grain yields of pearl millet among small-scale farmers in Zambia are very low (500 – 650kg/ha) due to the fact that farmers have continued to use landraces and varieties that are low yielding. There are no hybrid varieties that have been developed simply because the basis for developing hybrid varieties has not been established in the country.

OBJECTIVES

The main objective of this study was to characterise pearl millet genotypes in order to establish a basis for exploiting the genetic potential of pearl millet for the development of high yielding varieties (hybrid varieties) in Zambia.

The specific objectives were:

1) To determine combining abilities of selected cytoplasmic male sterile lines and restorer lines of pearl millet.
2) To determine the nature of gene action controlling grain yield and other important traits in pearl millet.

CHAPTER TWO

2.0 Literature Review

2.1 Pearl millet taxonomy and origin

Pearl millet is scientifically known as *Pennisetum glaucum* (L.) R. Br. It is an annual, allogamous cross-pollinated and diploidia cereal, belonging to the *Poaceae* family, subfamily *Panicoideae*, tribe *Paniceae*, subtribe *Panicinae*, section *Pennicillaria* and genus *Pennisetum* (Rai et al., 1997). The important wild relatives of cultivated pearl millet include the progenitor, *Pennisetum glaucum* subsp. *Monodii* Maire, *P. purpureum* K. Schumach, *P. pendicellatum* Trim., *P. orientale* Rich, *P. mezianum* Leeke, and *P. squamulatum* Fresen. Previous names are *P. typhoideum* L.C. Rich and *P. americanum* (L.) Leeke. The four cultivated forms of pearl millet are *typhoides* (found mainly in India and Africa), *nigritarum* (dominant on the eastern Sahel), *globosum* (dominant in the western Sahel) and *leonis* (dominant on the West African coast) (The Syngeta Foundation for Sustainable Agriculture, 2006).

The geographical origin and the centre of domestication of pearl millet are situated in Western Africa. The crop was subsequently introduced to India, where the earliest archeological records date back to 2000 B.C. (Oumar et al., 2008).

2.2 Utilisation and nutritional value of pearl millet

Pearl millet is a staple food crop in arid and semi-arid regions of Africa and Asia (Khairwal et al., 1999). It is also grown for feed and fodder purposes in many parts of the world (Ghazy et al., 2010). It is estimated that over 95% of pearl millet production is used as food grain, the remainder being divided between animal and poultry feed and other uses such as seed, bakery products, and snacks (http://vasat.icrisat.org/crops/pearl_millet/pm_production/html/m2_2.2/resources/2111.html -Sept 2013).

Pearl millet grain has high levels of protein (12 - 15%) content with balanced amino acids, carbohydrates (60 – 70%), and fats (5 – 10%) which are important in the human diet, and its nutritive value is considered to be comparable to rice and wheat (Lakshmana, 2008).

2.3. Pearl millet production

Pearl millet is the fifth most important cereal crop in the world after rice, wheat, maize, and sorghum. It is a widely grown rain-fed cereal crop in the arid and semi-arid regions of Africa and Southern Asia. In other countries, it is grown under intensive cultivation as a forage crop. Pearl millet is grown primarily for grain production on 26 million ha in the arid and semi-arid tropical regions of Asia and Africa (Rai et al., 2007). It accounts for almost half of global millet production, with 60% of the cultivation area in Africa, followed by 35% in Asian countries. European countries represent 4% of millet production and North America only 1% mainly for forage. Global production exceeds 10 million tons per year. In Sub-Saharan Africa, pearl millet is the third major crop with the major producing countries being Nigeria, Niger, Burkina Faso, Chad, Mali, Mauritania, and Senegal in the West and Sudan and Uganda in the East. In Southern Africa, maize has partially or completely displaced millet cultivation because of commercial farming (Basavaraj et al., 2010).

India is the largest producer of pearl millet, both in terms of area (9.3 million ha) and production (9.3 million metric tons) with an average yield of 1044kg/ha. The trend in area, production and productivity of pearl millet suggest that area has increased marginally (2%) and productivity has gone up by 19% (Yadav, 2011). In Zambia, millet production declined by 22% to 37,644 metric tons in the 2010/2011 growing season from 47,997 metric tonnes in the 2009/2010 growing season. The total area planted for 2010/2011 decreased by 25% to 42,663 hectares from 53, 789 hectares during the 2009/2010 season. The average yields during the 2010/2011 growing season ranged from 500-650 kg/ha (MACO & CSO, 2011).

2.4 Adaptation and climatic requirements of pearl millet

Like any grain crop, pearl millet yields best on fertile, well drained soils. However, it performs relatively well on sandy acidic soil conditions, and when available moisture and soil fertility are low. This adaptation reflects pearl millet origin in the Sahel regions of Africa, where growing conditions are difficult (Myers, 2002). It is tolerant to sub-soils that are acidic (pH 4-5) and high in aluminium content (Oushy, 2010).

Pearl millet is usually a short-day plant, although some varieties are day length neutral. It is generally sensitive to low temperatures at the seedling stage and at flowering. It germinates well at soil temperatures of 23 to 30^{o}C. Emergence occurs in 2 to 4 days under favorable conditions. High daytime temperatures are needed for the grain to mature. It can grow in areas receiving 200 – 1500 mm of rainfall. Despite its drought tolerance, pearl millet requires evenly distributed rainfall during the growing season (Oushy, 2010). According to Wilson (2011), drought stress during flowering through to grain fill results in low and unstable yields. Yadav (2010) also pointed out that post-flowering drought stress is one of the most important environmental factors reducing pearl millet grain yield as much as 70%. Too much rainfall at flowering can also cause crop failure (Oushy, 2010).

2.5 Yield potential of pearl millet

Pearl millet has high yield potential and responds well to water and soil fertility (Poelhman, 1994). Landraces open-pollinated cultivars of pearl millet usually exhibit high level of vegetative vigour and very high biomass production. However, the harvest index of these traditionally tall cultivars is only 15 – 20%. This is largely due to the fact that the photoperiod – mediated change in the total growth duration mostly affect the length of the vegetative period (Myers, 2002).

It has been reported that a crop of local variety of pearl millet, cv Ex – Borna, grown in Northern Nigeria under high fertility conditions without irrigation, could produce 22 tons/ha of above ground dry matter in 90 days after sowing although 3.2 tons of this (14.5%) was grain (Kassam and Kowal, 1975). In contrast, grain yield on a field basis of over 5 tons/ha was produced by semi-dwarf hybrids maturing in 85 days in India (Rachie and Majmadar, 1980). Experimental yields of up to 8 tons/ha have even been reported (Burton et al., 1972). In Zamia, five improved open-pollinated varieties with mean yield potential up to 2.8 tons/ha have been released. However, these improved varieties have low grain yield (less than 1.0 ton/ha) when grown under harsh conditions (Christiansen, 2008). Pearl millet being grown in erratic conditions of rainfall, earliness in maturity is desirable for escaping drought conditions (Dangariya et al., 2009 and Gowda et al., 2009).

2.6 Importance of pearl millet in climate change and food security

Agriculture is facing declining water availability, reduction in arable land, and strongly increasing demand for harvested products. Predictions of climate change indicate an increased variability of rainfall in the next 40 years and increased risk of high temperature (Battisti and Naylor, 2009), that will cause appreciable limitations of yield (Brisson et al., 2010). Food security requires investments in this domain, in particular with new genotypes that can at least maintain an acceptable productivity under reduced water availability (Tardieu, 2012). With regard to this, pearl millet has been identified as one of the crops that are useful in overcoming the adverse effects of climate change, and thereby reinforcing food and income security of the poor. This has prompted ICRISAT to boost the production of pearl millet through hybrid development (http://climate-iisd.org/news/icrisat-develops-resilie Sept 2013).

2.7 Pearl millet breeding

The floral morphology, breeding behavior and the structure of grain yield in pearl millet makes it a more flexible and responsive crop species to breed. It is possible to access genetic variability both from the secondary and tertiary germplasm pools (Hanna, 1990).

Pearl millet is a naturally cross-pollinating species, which is achieved through protogyny, since all the sessile flowers on each head are perfect (i.e. both male and female fertile). On any one head, all flowers first exert stigmas over a 1 to 3 day period progressing from the mid-top to the bottom of the head. Anthesis occurs one to as many as 4 days later, in the same sequence from the same flowers, and sometimes, later from the pedicellate flowers (Oushy, 2010). Thus, there is a period for each head, when flowers can only be fertilized by external pollen which is freely wind-born. Stigmas wither about 8 hours after pollination. Self-pollination can occur when stigma emergence on later flowering tillers overlaps with the anthesis of earlier heads on the same plant. In random-mating situations, the amount of self-pollination is influenced by the degree of tillering, relative size and flowering relationships of tillers, and whether all or only primary tillers are harvested. As a generality, about 20% selfing is normal (Chirwa, 1991).

Selfed seed in pearl millet can be produced simply by placing a bag over a head prior to stigma emergence. If the stigmas are not short lived, 100% selfed seed set will then occur. Similarly, 100% hybrid seed can be made by pollinating a previously bagged head once at full protogyny prior to anther emergence (Myers, 2002). The breeding opportunities in pearl millet can be illustrated by the following: each of 3 heads on one plant in a population can be used for different objectives i.e., one can be selfed, one crossed (full-sib, testcross, topcross) and one left to random-mate. Seed from each head will be sufficient to plant 20 plots each of 7.5 m^2 (Andrews et al., 1993).

Production of hybrids in pearl millet became practical since the finding of cytoplasmic genetic male-sterility. Burton (1958) developed the first cytoplasmic male-sterile line Tift 23A, which opened a new field for hybrid seed production in pearl millet. In India, the first pearl millet hybrid HB-1 was released in 1965 and since then a number of good hybrids have been developed and released for commercial cultivation (Lakshmana, 2008). Large-scale deployment of the single A_1 CMS source in all hybrids during the 1960s raised a concern regarding its potential vulnerability to pests and diseases. As a result efforts continued to search for alternative CMS sources. This led to the identification of A_2, A_3 (Athwal, 1966), A_4 sources from *Pennisetum glaucum* (monodii) accessions (Hanna, 1989), and A_5 CMS souces from gene pool (Sujata et al., 1994 and Rai, 1995). Based on the fertility restoration pattern on these sources, it was established that A_1, A_2, A_3, A_4, and A_5 were distinctly different CMS systems. Burton and Athwal (1967) studied the relationship between Tift 23A, L66A and L67A and concluded that these lines carried different cytoplasms and designated them as S_1, S_2 and S_3 respectively. Later, Basavaraj et al. (1980) redesignated these sources of sterile cytoplasm as A_1, (Tift 23A) and A_2 (L66A and L67A). Andrews and Rajewski (1994) observed that line NPM3 restored male sterility in 93 – 97% of the plants in the A_4 and 7-16% in A_1 test crosses and concluded that A_4 was superior to A_1 system and fertility was affected by temperature on A_4 source.

Among the various CMS systems reported so far, A_4 and A_5 CMS systems were found to have the most stable male sterility (Rai et al. 2009). Gupta et al. (2010) also observed that the fertility restoration ability of the A_4 CMS system restorer is less affected by the genetic background of the A-line than that of the A_1 CMS system restorers.

Restorer lines play a major role in the exploitation of hybrid vigour in pearl millet (Joshi et al. 1995). Rai (1995) reported that seven diverse restorer lines of the A_4 system produced hybrids were fertile (68-89% selfed seed set) in contrast, all the hybrids made with isonuclear line with LSGP (A_5) cytoplasm had fertility (>20% selfed seed set). In addition, Yadav and Manga (1995) reported that fertility restoration ability was highly variable for different cytoplasms and of the 12 lines, eleven were effective restorers for A_1, six lines restored on A_2 and A_3 and two lines restored on A_4 system.

The mean grain yield of hybrids possessing A_2, A_3, and A_4 cytoplasm was either similar to or significantly higher than hybrids with A_1 cytoplasm. Hybrids based on A_3 and A_4 cytoplasms recorded 8% higher grain yield compared to hybrids based on A_1 cytoplasm (Yadav, 1996). However, Chandra (2007) and Rai et al. (2007) stated that A_1, A_4, and A_5 CMS systems differ very little with respect to their effect on grain yield.

With the correct selection of parent lines in regard to phenotype and relative maturity, hybrids can be made in pearl millet by utilising the natural period of protogyny (Oushy, 2010). This method allows quicker hybrid development, greatly increases the range of possible parent combinations, and avoids diseases which are associated, particularly in Africa, with the use of CMS seed parents. These pro-hybrids, as they are termed, appear to have the most utility for developing countries where existing or reselected leading open-pollinated cultivars could be directly used as male parents for topcross hybrids (Andrews et al., 1993).

Heterotic effects in pearl millet are large and most completely expressed in single crosses, though yields from topcross hybrids are similar in all but the highest yielding situations. Topcross hybrids have several advantages including stability and durability of performance and ease of production (Andrews, 1986).

2.8 Variability and heritability

Genetic improvement of crops for quantitative traits requires reliable estimates of genetic variability, heritability and genetic advancement in respect to the breeding material that is presently at hand in order to plan an efficient breeding programme (Chand et al. 2002). The information on variability and heritability of characters is essential for identifying characters amenable to genetic improvement through selection (Vidya et al. 2002).

The most important objective in any crop improvement programme is to increase yield, which depends mainly on the magnitude of genetic variability present in the crop. The determination of genetic variability and its partitioning into various components is essential for understanding the genetic nature of yield and its components (Baskaran, 2009). Yield in pearl millet is the product of its component characters such as panicle length, panicle girth, panicle weight and number of seed per ear head. These in turn are influenced by the number of other characters like days to flowering, productive tiller per plant, and plant height. Any change in yield has to be brought about from one or more of its components (Lakshmana, 2008).

Heritability denotes the proportion of the phenotype that is due to the genotype (Singh, 2009). Quantitative characters are governed by a large number of genes and further influenced by environment. The phenotype observed is not transmitted to the next generation. Therefore, it is necessary to know the proportion of observed variability that is heritable (Lakshmana, 2008).

Some of the available literature pertaining to genetic variability and heritability in pearl millet are presented below.

Days to 50% flowering

The phenotypic coefficient of variation (PCV) estimates were reported to be higher than genotypic coefficient of variation (GCV) estimates for days to 50% flowering by Govidaraj et al. (2007), Subi and Idris (2010) and Reddy and Reddy (2011). High genetic variation for day to 50% flowering was reported by Yadav et al. (2001) and Yogendra (2002). However, low PCV and GCV were observed by Kulkarni et al. (2000) and Solanki et al. (2002).

High estimates of broad sense heritability (61% and 83.5%) were obtained for days to 50% flowering by Subi and Idris (2010) and Govidaraj et al. (2007) repectively. On the other hand, moderate broad sense heritability (40.4%) was obtained by Lakshmana (2008).

Plant height

The phenotypic coefficient of variation (PCV) estimates were higher than genotypic coefficient of variation (GCV) estimates for plant height (Govidaraj et al., 2007, Subi and Idris, 2010, Ghazy et al., 2010, and Reddy and Reddy, 2011).

High estimates of heritability (75.8% and 92.6%) were obtained by Ghazy et al. (2010) and Govindaraj et al. (2007), respectively, for plant height. However, low estimates of heritability (33%) were observed by Subi and Idris (2010).

Productive tillers per plant

The phenotypic coefficient of variation (PCV) was higher than genotypic coefficient of variation, for productive tillers per plant (Govindaraj et al., 2007, and Reddy and Reddy, 2011).

Low estimates of heritability (14%) were obtained by Subi and Idris (2010) while medium estimates (49.6%0 were obtained by Govindaraj et al., 2007.

Panicle length

Reddy and Reddy (2011) observed that the phenotypic coefficient of variation (PCV) was greater than the genotypic coefficient of variation (GCV) for panicle length and concluded that this showed the influence of environmental effect on the character. Lakshmana (2008) observed that both PCV and GCV were high for panicle length.

High heritability (90.8% and 93.9%) was observed for panicle length by Lakshmana (2008) and Govindaraj et al. (2007) respectively while low estimates of heritability (17%) were observed by Subi and Idris (2010).

Panicle girth

Both PCV and GCV were reported to be high for panicle girth (Lakshmana, 2008). On the other hand Borkhataria et al. (2005) reported a wide range of variation for panicle girth.

High estimates of heritability (93.4% and 94.2%) were observed for panicle girth (Lakshmana, 2008 and Govindaraj et al., 2007, respectively).

Panicle weight

Lakshmana and Guggari (2001) observed high phenotypic and genetic coefficient of variation, and heritability (79%) for panicle weight. High estimates of heritability (89.7%) were also observed by Lakshmana (2008).

Grain yield (t/ha)

Reddy and Reddy (2011) and Subi and Idris (2010) observed that the phenotypic coefficient of variation (PCV) was greater than the genotypic coefficient of variation (GCV) for grain yield (t/ha). On the other hand, high phenotypic and genetic coefficient variation for grain yield was observed by Vidyadhar et al. (2001) and Lakshmana (2008).

High estimates of heritability (99.7% and 88.5%) were observed for grain yield by Govindaraj et al. (2007) and Lakshmana (2008). However, low estimate of heritability (16%) was observed by Subi and Idris (2010).

2.9 Genetic diversity studies in pearl millet

The variability present among different genotypes of a species is known as genetic diversity. Genetic diversity arises either due to geographical separation or due to genetic barriers to crossability. Variability differs from diversity in the sense that the former has observable phenotypic differences, whereas the later may or may not have such an expression (Singh, 2009). The two biometrical techniques used in assessing the genetic diversity present in crops are Euclidean Distance Coefficient (D^2) statistics and Metroglyph analysis. D^2 statistics was proposed by Mahalanobis in 1936 while metroglyph analysis was proposed by Anderson in 1957 (Lakshmana, 2008). D^2 statistics is a proven powerful tool used in quantifying the degree of divergence between biological populations at the genotypic level and to assess relative contribution of different components to the total divergence (Singh and Choudhary, 1979).

Genetic diversity plays an important role in plant breeding because hybrids between lines of diverse origin generally display a greater heterosis than those between closely related strains. However, the maximum heterosis generally occurs at an optimal or intermediate level of diversity (Moll and Stuber, 1974).

Some of the available literature pertaining to genetic diversity in pearl millet is presented below.

Dave and Joshi (1995) observed no relationship between geographic and genetic divergence in pearl millet. The clustering pattern was affected by environment and the role of different characters varied with shift in season. The size of D^2 statistic had no effect on the magnitude of heterosis for the attributes studied.

Genetic diversity studies involving seventy-five genotypes in pearl millet Hendre (1998), grouped the genotypes into nine clusters. It was observed that plant height, panicle width, and grain yield were the main characters contributing to genetic divergence.

Lakshmana (2008) observed adequate genetic diversity among genotypes of all the three groups, which fell into 22 (maintainer + restorers), 11 (maintainers) and 19 (restorers) clusters. D^2 values were in general high in restorers group followed by combined and maintainer groups. In this study, the most important characters contributing towards divergence was days to maturity in all the three groups.

2.10 *Combining ability studies in pearl millet*

Combining ability is the ability of a strain to produce superior progeny upon hybridisation with other strains (Singh, 2009). There are two types of combining ability i.e. general combining ability (GCA) and specific combining ability (SCA). The concept of combining ability in terms of genetic variation was first given by Spraque and Tatum (1942) using single crosses in maize. They defined the term general combining ability as an average performance of a line in hybrid combinations and specific combining ability as the combinations which do relatively better or worse than that would be expected on the basis of the average performance of the lines involved.

According to Griffing (1956), general combining ability (GCA) is related to additive as well as additive x additive interaction, whereas specific combining ability (SCA) is related to the dominance variance and all the three types of interactions (additive x additive, additive x dominance and dominance x dominance).

Combining ability of genotypes serves as a guide to the plant breeder in the selection of materials for future breeding programmes (Yagya, 1996). Therefore, an attempt was made to review some of the literature available on combining ability studies in pearl millet.

Line x tester and diallel are single cross mating designs used for testing both general combining ability and specific combining ability. However, Line x tester analysis is an extension of the top cross method in which several testers are used (Kempthorne, 1957).

Combining ability studies involving a 10 x 10 half diallel for yield and yield attributes in pearl millet, Joshi et al. (1995) found that the inbred line J 2340 had significant ($P \leq 0.01$) positive GCA effects for grain yield (6.72), panicle weight (8.45), productive tillers per plant (0.44) and days to 50% flowering (-1.74) and was considered as the best general combiner. Out of the cross combinations, only three combinations J104 x J 2327, J 2257 x J 1188 and J 2349 x GP 619 showed significant ($P \leq 0.01$) positive SCA effects for grain yield (22.36, 13.39, and 14.30, respectively) and other yield attributing characters.

Estimates of combining ability for panicle length, panicle girth and grain yield using a 10 x 10 diallel analysis (Yagya et al., 1996) revealed that only three parents; RVPT 93 (102), ICMV 95778, and ICMV 95501 had significant ($P \leq 0.05$) positive GCA effects for all the three traits while ICMV 95778 with non-significant GCA effect (10.53) for grain yiled was found to be poor general combiner for grain yield. Only two crosses; HP 8601 x ICMV 95778 and ICMV 91450 x ICMV 95501 had significant ($P \leq 0.05$) positive SCA effects for all the three characters studied. They observed that most of the crosses with high SCA effects involved either one or both parents with significant positive GCA effects.

Yadav (1999) reported that lines with A_3 and A_4 cytoplasm were significantly better general combiners for grain yield than lines with either A_1 male sterile or fertile cytoplasm.

In a line x tester analysis involving eight lines and five testers in pear millet, Srikant et al. (2003) observed that only three female parents (ICMA 93333, ICMA 96111 and RMS-3A) and two male parents (RIB-20K-86 and RIB-3135-18) had significant positive GCA effects for grain yield and other agronomic traits. Among the 40 crosses, only two; ICMA 93333 x RIB-3135-18 and ICMA-9544 x RIB-3135 exhibited significant positive SCA effects for grain yield and at least one of the other agronomic traits.

Izge et al. (2004) evaluated 45 hybrids and 10 parental lines and observed that none of the parental lines exhibited any significant GCA effects for grain yield. Results revealed that BONKOK-SHORT and LCIC 9702 were the best general combiners for earliness because both the parental lines exhibited highly significant ($P \leq 0.01$) negative GCA effects (-4.11 and -1.57, respectively) for days to 50% flowering. No positive and significant SCA effects for grain yield were observed among all the hybrids. Results indicated that only two hybrids; BONKOK-SHORT x SOSAT-C88 and BONKOK-SHORT x EX-BORNO exhibited the highest significant ($P \leq 0.01$) positive SCA effects (4.49) and the highest significant ($P \leq 0.01$) negative SCA effects (-4.36) for days to 50% flowering respectively. It was observed that the hybrids with significant SCA effects in most cases involved at least one or two of the good general combiners as parents. However, other poor general combiners frequently gave good cross combinations when they were crossed with best general combiners.

In the evaluation of pearl millet populations by Haussmann et al. (2005), it was observed that the four parental population; ICMV IS 89305, MMC, SDGP 2025 and SDGP 2045 that showed significant ($P \leq 0.05$) positive GCA effects (51.2, 26.4, 21.2, and 21.2, respectively) for grain yield and number of productive tillers per plant also had significant ($P \leq 0.05$) positive GCA effects (4.1, 2.7, 6.5 and 3.1, respectively) for days to flowering and were considered as poor general combiners for day to 50% flowering. However, the parental populations; RCB-IC 625, RAJ II and EC-2 with significant ($P \leq 0.05$) negative GCA effects (-27.6, -36.1 and -20.0, respectively) for grain yield also had significant negative GCA effects (-4.7, -3.1 and -2.6, respectively) for days to 50% flowering.

Similarly, Sushir et al. (2005) studied combining ability for yield and yield components in pearl millet and observed significant positive SCA effects for grain yield and other traits in two crosses only.

Karad and Harer (2005) in a line x tester experiment revealed significant differences among the ten clusters of pearl millet genotypes. Among the females only one (ICMA-8911 had significant positive GCA effect for grain yield and was considered as the best general combiner for grain yield and panicle girth. Among the crosses, only one cross combination, ICMA 88006 x IPC 1470 had significant positive SCA effect for grain yield and productive tillers per plant.

Combining ability studies in pearl millet involving line x tester analysis (Dhuppe et al., 2006) revealed that variance due to lines, testers, and lines x testers interaction were significant. Only two female parents; 88004 A and 405 A and one male parents; IPC-274 Zim D showed significant positive GCA effects for grain yield and fodder yield and were considered as good general combiners for these traits. Among the crosses, only three; 862A x Zim D, 862A x PT 1890 and 841A x Zim T exhibited significant SCA effects for grain yield and other agronomic characters.

In a line x tester analysis involving five female parents and eight male parents of pearl millet, Shelke and Chavan (2007) observed significant positive GCA effects for grain yield in parent APMB 89. Among the testers, APMR 70 was good general combiner for grain yield, panicle length, panicle girth, number of productive tillers per plant and plant height except for days to 50% flowering while ICMB 90111 P-6 was good general combiner for grain yield, panicle girth, productive tillers per plant, plant height and days to 50% flowering except for panicle length. Only one parent; P 1449 P-1 was a good general combiner for yield and all the yield contributing traits in addition to days to 50% flowering. On the other hand, only one cross, APMB 89 x APMR 70 was significantly superior in per se performance with significant positive SCA effects for grain yield and yield contributing traits.

Lakshmana (2008) studied the influence of different CMS sources on heterosis and combining ability effects for yield and other traits in a line x tester and observed that the GCA effects for grain yield were significant and positive in A_4 cytoplasm and non-significant for A_1 and significant and negative for A_5. The lines with A_4 cytoplasm also expressed significant GCA effect for panicle weight, panicle length, and productive tillers per plant. The A_1 cytoplasm based lines showed positive and significant GCA effect for two traits and negative and significant GCA effect for three traits. The SCA effects indicated the differential nucleo-cytoplasm interaction in the expression of different quantitative traits in pearl millet. Of the three sources, A_1 and A_4 appeared to interact significantly with nuclear genes and influenced positively in the expression of panicle weight.

In a 10 x 10 half diallel excluding reciprocals, Dangariya et al. (2009) revealed that the estimates of GCA effects indicated that the two parents; D-23 and SB 220 that had significant ($P \leq 0.01$) positive GCA effects for grain yield (6.62 and 5.44, respectively), plant height (14.62 and 11.61, respectively), panicle girth (0.44), panicle length (1.14 and 5.26, respectively) and panicle weight (3.24 and 7.78, respectively) had significant ($P \leq 0.01$) positive GCA effects (1.43 and 2.02, respectively) for days to 50% flowering as well and were considered as poor general combiners for earliness. Only one parent; J-2467 with significant ($P \leq 0.01$) positive GCA effects for grain yield (7.71) and panicle girth (0.23), had significant ($P \leq 0.01$) negative GCA effects for days to 50% flowering (-0.43), plant height (-5.88), and panicle length (-0.87). Out of the 45 cross combinations, only thirteen cross combinations showed significant positive SCA effects for grain yield.

Mainassara (2012) observed that only one parent (HKB) showed the highest negative GCA effect for days to 50% flowering, indicating that the line could be used in improving early maturity. Ex-Borno exhibited the highest positive GCA effect for grain yield. SCA across locations indicated that seven crosses showed improved yields while ten crosses manifested earliness for days to 50% flowering.

2.11 Nature of gene action

Genetic variation in pearl millet has been partitioned into additive, dominance and epistatic effects using different types of mating designs. Estimates were obtained from line x tester analysis, diallel crosses, and North Carolina (NC) designs (Gill, 1991). The gene action has also been obtained by combining ability analysis in which σ^2_{gca} is equated to half the additive variance plus the additive x additive type of epistasis and σ^2_{sca} to dominance plus dominance x additive and dominance x dominance types of epistasis (Falconer, 1981).

Sprague and Tatum (1942) reported that GCA effects are due to additive gene action while SCA effects are due to non-additive gene action. However, both additive and non-additive (dominance) genetic components can interact with changes in the environment (Yadav et al., 2012). The interaction of GCA and SCA with the environment was also reported by Mukanga et al. (2010) who revealed that due to the interaction of GCA and SCA with the environment, different parents and cross combination were selected in each environment. In recent years, quantitative trait loci (QTL) analysis has become important in studying the genetic architecture of complex traits using molecular markers, facilitating estimation of the minimum number of genomic regions that affect a trait, the distribution of gene effects and the relative importance of additive, dominance and epistatic gene actions (Laurie et al., 2004).

Knowledge of various types of genes and their relative magnitudes in controlling various traits is basic to maximising efficiency of a breeding programme which led to the proposal of many breeding methods that capitalise on different types of gene action (Vengadessan, 2008). Therefore, an attempt was made to review some of the literature available on the nature of gene action controlling grain yield and other important traits in pearl millet.

Non-additive gene action was observed as a significant source of genetic variation for pearl millet grain (Kapoor et al., 1982) and straw fodder yields (Begg and Burton, 1971).

In contrast, panicle length and diameter are determined primarily by additive gene action (Gupta and Singh, 1971).

Singh and Murty (1974) obtained estimates of additive and dominance components of genetic variance for five characters: synchrony of tillering, days to 50% flowering, tiller number, and grain yield. Using the hierarchal system proposed by Horner et al. (1955), revealed that the magnitude of the additive component was low compared to the dominance component of genetic variance for all traits examined. The magnitude of dominance variance was highest for grain yield. It was pointed out that the low magnitude of additive genetic variance was probable due to the highly selected nature of the parents for yield and other characters, which might have resulted in the fixation of genes controlling these characters at many loci. Rachie and Majmudar (1980) suggested that the large component of non-additive (dominant) genes can be exploited by developing new hybrids using suitable recombinants of biparental progenies.

Lynch et al. (1995) studied the inheritance of days to flowering and plant height for pearl millet. They found that additive genetic effects were more important than non-additive gene effects for the two traits.

The estimates of specific combining ability were higher in magnitude than their respect general combining ability components suggesting predominance role of non-additive gene action for all characters studied (Joshi et al., 1995). Among the characters studied were days to 50% flowering, plant height, panicle length, effective tillers per plant, panicle weight, and grain yield.

High SCA variances relative to GCA variances were observed for grain yield, days to 50% flowering, plant height and panicle length by Haussmann et al. (2005) and concluded that non-additive gene effects are more important than additive gene effects in the inheritance of these traits.

Sushir et al. (2005) also reported that the GCA effects were higher than SCA effects for number of productive tillers per plant and panicle length, whereas it was reverse for days to 50% flowering, ear girth and grain yield, indicating the predominance of additive gene effects for productive tillers per plant and panicle length and the predominance of non-additive gene effects for days to 50% flowering, panicle girth and grain yield in pearl millet. However, both additive and non-additive gene effects were reported by Yagya et al. (2002) for days to 50% flowering.

The ratio of GCA:SCA mean variances were observed to be more than one (Eldie et al., 2006) for plant height and days to 50% flowering, indicating that inheritance of these traits was due to GCA effects and was largely controlled by additive gene action in the base material. However, the ratio of GCA: SCA for panicle weight and grain yield were less than one, suggesting that the inheritance of these traits was due to non-additive gene action.

Number of productive tillers per plant, plant height, and grain yield were found to be predominantly under the control of non-additive gene effects whereas panicle length was found to be predominantly under the control of additive gene effect (Izge et al., 2007).

Shelke and Chavan (2007) studied gene action in pearl millet and revealed the predominance of additive gene action in controlling traits such as grain yield, panicle length, panicle girth, number of productive tillers, and plant height while non-additive gene action was predominant in controlling days to 50% flowering.

The study by Chotaliya et al. (2010) revealed the importance of non-additive gene action in the inheritance of grain yield while additive gene action was predominant for plant height, panicle length, panicle girth, and panicle weight. However, for number of productive tillers per plant and days to 50% flowering, both additive and non-additive gene action were reported by them.

Yadav et al. (2012) observed that the magnitude of SCA was more important for traits such as number of productive tillers per plant, plant height, panicle length, panicle weight and grain yield, indicating that non-additive genetic variance (dominance variance) was mainly responsible in the inheritance of these traits. They further stated that the predominance of non-additive interaction is also sometimes caused by the presence of epistasis and /or a correlated gene distribution. They pointed out that a further bias may also be caused due to interaction of non-additive variance with the environment. Therefore, realizing that individual components of genetic variance also interact with the environment, it becomes important to evaluate these interactions also.

2.12 Correlation studies in pearl millet

Grain yield is a complex character and is the final product of actions and interactions of various characters, hence, understanding the relationship between yield and its components is of paramount importance. The extent of association between yield and yield attributes can be known through correlation studies (Vidyadhar et al., 2001). Correlation between grain yield and yield attributes assists in selecting the most important characters to select for high grain yield (Totok and Tomohiko, 1996). Therefore, an attempt was made to review some of the literature available on the correlation between grain yield and other important traits.

The correlation between grain yield and plant height as well as the direct cause of plant height on grain yield indicated that when other variables are held constant, increasing plant height could directly increase grain yield. The result indicated that indirect selection through plant height in pearl millet could be effective for high yielding (Mainassara, 2012). Positive correlation between grain yield and plant height was also observed by Siles et al. (2004) (r = 0.76) and Obeng et al. (2012) (r = 0.49) who pointed out that the taller the plant, the higher the grain yield and also observed that number of productive tillers was positively correlated (r = 0.25) with grain yield while panicle length was negatively correlated (r = -0.12) with grain yield.

Tiller number was significantly positively correlated (r = 0.60) with grain yield while time of flowering, plant height, and panicle length were negatively correlated (r =-0.93, r = -0.76, and r = -0.90 respectively) with grain yield (Adam, 1996).

Grain yield had positive and significant correlation with most characters under study except panicle length (r = 0.16), panicle girth (r = 0.09) and tiller number (r =0.07) (Vidyadhar et al., 2001) and therefore, it was suggested that selection should be based on days to flowering (r = 0.53), and plant height (r = 0.56) towards the development of dual purpose hybrids in pearl millet.

Panicle girth and panicle length were observed to have significant positive correlation (r = 0.25 and r = 0.38 respectively) with grain yield. The significant positive correlation (r = 0.56) between grain yield and panicle weight was attributed to the greater investment of assimilates into the panicle mass and individual grain mass (Van Oosterom, 2003). Significant positive correlation of both panicle length and panicle girth with grain yield was also reported by Kumar et al. (2002) and Salunke et al. (2006).

Plant height and panicle weight were positively and significantly correlated (r = 0.57) and r = 0.90 respectively) with grain yield while panicle length and panicle girth had non-significant correlation with grain yield (Rajesh et al., 2004).

Govindaraj et al. (2009) revealed that number of productive tillers and panicle girth were significantly and positively correlated (r = 0.66 and r = 0.32, respectively) with grain yield. Days to 50% flowering, number of productive tillers per plant, panicle length and panicle weight were positively associated (r = 0.37, r = 0.24, r = 0.31, r = 0.53, respectively) with grain yield (Eshag, 2009).

Although most of the studies in pearl millet have shown significant positive correlation between grain yield and the number of productive tillers per plant, Maman et al. (2004) reported that, reducing pearl millet productive tillers from 10 to 3 or 5 increased grain yield by 15-30%. Sile et al. (2004) also reported that non-tillering cultivars of millet produced larger seeds than the tillering ones.

CHAPTER THREE

3.0 Materials and Method

3.1 Plant materials

The plant materials used in this study consisted of 104 crosses (13 lines x 8 testers) that were produced according to the line x tester mating design described by Kempthorn (1957). The female parents (designated as lines) were the cytoplasmic male sterile lines while the male parents (designated as testers) were the restorer lines. The crosses were obtained from the Zambia Agriculture Research Institute (ZARI) in Kaoma, Western Province. This study was conducted during the 2012 – 2013 growing season. The 104 crosses were split and planted at two sites i.e. 52 crosses (13 x 4) at Zambia College of Agriculture-Monze (ZCA-Monze) and 52 (13 x 4) at Longe (in Kaoma). Therefore, the same lines but different testers were used for progenies tested at each site. The characteristic of the cytoplasmic male sterile (CMS) lines used as female parents in Line x tester crossing are given in Table 1 below.

Table 1: Characteristics of the 13 cytoplasmic male sterile lines (female parents) used in Line x tester crossing.

S/No	CMS LINES	DESCRIPTION
1	ICMA$_1$ 863	A$_1$ cytoplasm, medium tall, medium maturity Togo-type with anthocyanins, nodal tillers, short thin heads with grey grain. Down mildew resistance source.
2	ICMA$_1$ 88004	A$_1$ cytoplasm, viriliscent, profuse tillering, medium late with tiny heads, poor exertion with grey grain.
3	ICMA$_1$ 92888	A$_1$ cytoplasm, segregating, late maturity with good heads and light-grain.
4	ICMA$_1$ 95555	A$_1$ cytoplasm, tall and medium late with basal as well as nodal tillers, small heads and grey grain.
5	ICMA$_1$ 97111	A$_1$ cytoplasm, tall, medium late with basal as well as nodal tillers, medium heads and grey grain.
6	ICMA$_1$ 00444	A$_1$ cytoplasm, segregating medium early, tillering, medium tall with stubby heads, and grey grain.
7	ICMA$_4$ 99555	A$_4$ cytoplasm, uniform dwarf, medium maturity with synchronous tillers, long heads with grey grain.
8	ICMA$_4$ 01333	A$_4$ cytoplasm, uniform medium tall, profuse synchronous tillering, stubby heads with grey grain.
9	ICMA$_4$ 02999	A$_4$ cytoplasm, uniform medium tall, early, excellent long heads, stay-green with straight synchronous tillers and grey grain.
10	ICMA$_4$ 04777	A$_4$ cytoplasm, early good, strong uniform synchronous tillers with partial bristleness with good large heads and light-cream grain.
11	ICMA$_4$ 05222	A$_4$ cytoplasm, uniform tall, early, excellent long heads, synchronous tillers and grey grain
12	NCD$_2$ A$_4$	A$_4$ cytoplasm, good uniform early medium tall with profuse tillering, stay-green with short stubby heads and partial bristleness and grey grain.
13	LCIC A$_4$	A$_4$ cytoplasm, good uniform early, medium tall with partial bristleness and grey grain.

The restorer lines (male parents used in the study) were:

1. ZPMV28001: Bulk of selected open-pollinated conical plants from BC_3 S_3 top-cross progenies at Longe in 2008
2. ZPMV 28010: Bulk of selected open-pollinated cream-grain, cylindrical-shaped plants from BC_4 S_3 top-cross progenies at Longe in 2008
3. ZPMV 28011: Bulk of selected open-pollinated cream-grain, candle-shaped plants from BC_4 S_3 top-cross progenies at Longe in 2008
4. ZPMV 28013: Bulk of selected open-pollinated miscellaneous plants from BC_4 S_3 top-cross progenies at Longe in 2008.
5. ZPMV 28014: Bulk of bristle open-pollinated plants from BC_4 S_3 top-cross progenies at Longe in 2008
6. ZPMV 28015: Bulk of selected open-pollinated cylindrical-shaped plants from BC_4 S_3 top-cross progenies at Longe in 2008.
7. ZPMV 28017: Bulk of selected open-pollinated candle-shaped plants from BC_4 S_3 top-cross progenies at Longe in 2008.
8. $570028R_{1W}$: Cream/grey grain late maturing top-cross pollinator from University of Nebraska, USA.

3.2 Description of study areas

Monze is in the southern province of Zambia and lies on latitude 16°16'02'' south and longitudes 27°28'10'' east. The district is divided into three physiographical regions as follows: the south eastern part of the district with steep slopes bordering Lake Kariba whose altitude is between 600 and 650 meters above sea level; the central high plateau area consisting of soft undulating old plains; and the North West low flat plains. ZCA-Monze is located in the south-eastern part of the district. Monze lies in the agro-ecological zone IIa with average annual rainfall between 600 and 800mm. The mean temperature of the area varies from 10°C to 35°C.

On the other hand, Kaoma is found in the Western province of Zambia and lies between latitudes 14° and 16° south and between longitudes 24° and 26° east. Kaoma is in the agro-ecological zone IIb with average annual rainfall between 800mm and 1000mm. The mean temperature of the area varies from 12°C to 34°C.

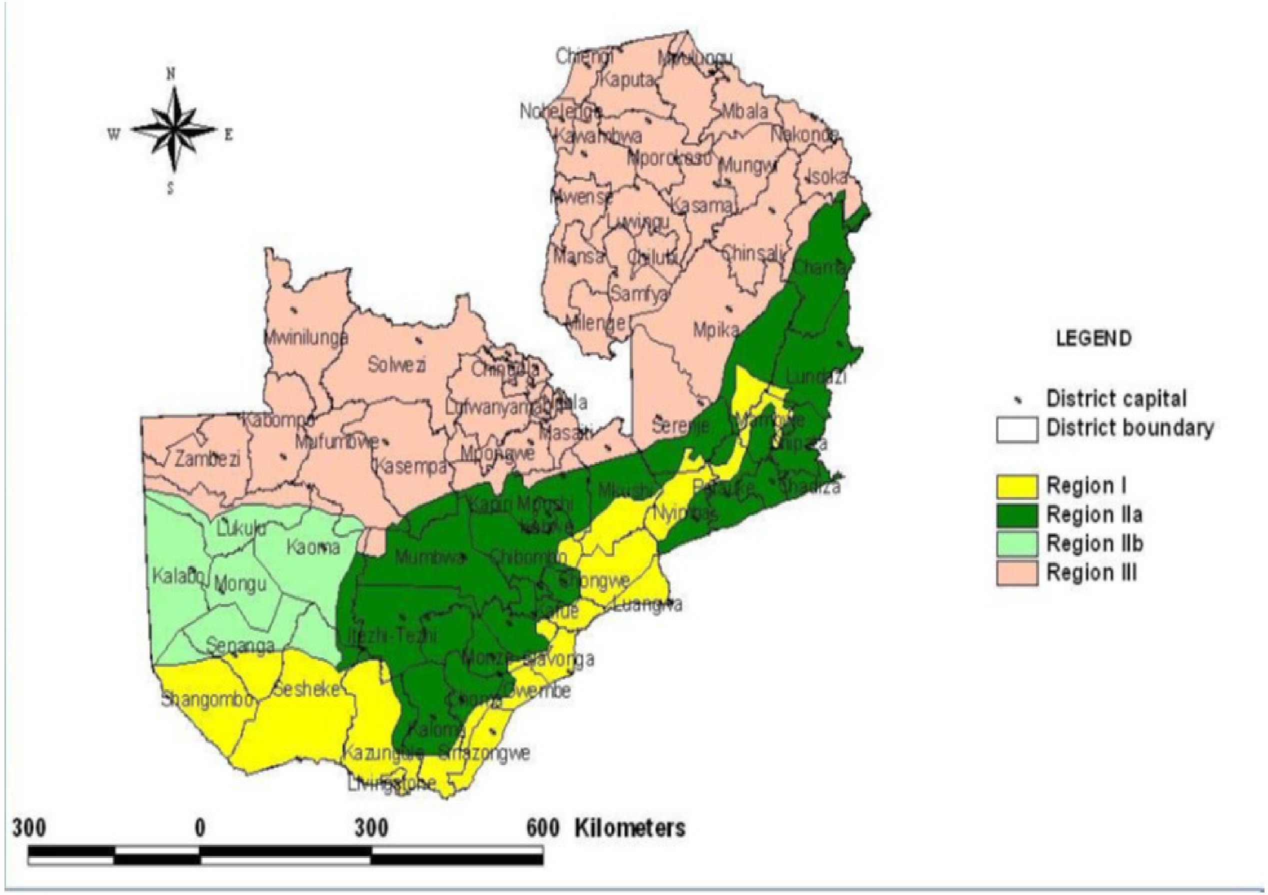

Figure 1: Agro-climatic distribution in Zambia

3.3 Field experiment

The field experiment for both Longe and ZCA-Monze involved the evaluation of the 104 crosses (hybrids) i.e. 52 crosses at Longe and 52 crosses at ZCA-Monze. The experiments were arranged in a triple lattice design with three replications.

Agronomic practices such as planting, weeding, thinning, fertiliser application, and harvesting were done as recommended. At Longe, planting was done in the 1st week of December while at ZCA-Monze it was done two weeks later due to the late commencement of the rainy season. Seeding was done in three rows per plot at the rate of 4kg/ha (i.e. four seeds per station). The plot size was 7.56m^2 (4.2m x1.8m) with intra-row spacing of 30cm and inter-row spacing of 60cm. Basal dressing fertiliser (D' compound) at 10-20-10 NPK was applied at the rate of 100kg/ha prior to planting while top dressing fertiliser (urea) at 46 N was applied at the rate of 50kg/ha two weeks after thinning. Thinning was done three weeks after seedling emergence in order to leave one seedling per station. Weeding was done manually by using a hoe. First weeding was done after thinning while the second weeding was done four weeks after the first weeding. Bird scaring was done for one month from anthesis to harvesting. The crop was harvested on per plot basis after physiological maturity. The panicles were sun dried for three weeks to reduce the moisture content of the grain to 9-12%. Threshing and winnowing were done to separate the grain and chaff.

Figure 2: Pearl millet field at ZCA-Monze

Figure 3: Pearl millet field at Longe (Kaoma)

3.4 Data collection

Data on phenological traits included days to 50% flowering and grain yield. Morpho-physiological traits measured included plant height, number of productive tillers, panicle length, panicle girth, and panicle weight. Stand count at harvest was taken by counting stands without plants and subtracting from the theoretical total plot count. Number of panicles per plot was taken by counting the panicles with grain from a plot heap at harvest. Measurement of the parameters was done as follows:

a) Days to 50% flowering – This was taken by counting the number of days from planting to when half the plants in a plot reached 50% stigma emergence.
b) Plant height – This was measured from the soil level to the apices of panicles using a height calibrated before lodging in a plot.
c) Number of productive tillers per plant – This was taken by dividing the number of panicles with grain by the stand count in a plot.

d) Panicle length – This was measured from base to the tip of 10 randomly selected panicles from a plot heap at harvest.

e) Panicle girth – This was measured by wrapping a tape around the middle of 10 randomly selected panicles from a plot heap at harvest.

f) Panicle weight – This was taken by weighing the panicles from each plot heap at harvest and then dividing by the number of panicles per plot.

g) Thresh percent – This was taken as grain weight per plot divided by panicle weight per plot.

h) Grain yield per (kg) – This was taken from threshed and winnowed grain for each plot. This was then converted to grain yield in tonnes per hectare at 11% moisture content by using the formula: $\frac{100-FMC}{100-RMC}\ x\ \frac{FW\ (Obtained)}{(Inter-row\ x\ Intra-row)\ x\ RL}$ x 10

Where: FMC = Field moisture content

RMC = Required Moisture Content

FW = Field weight

RL = Row length

3.5 Statistical analysis

Separate analyses of variance for data of the measured and derived parameters were done using GenStat statistical software package (13^{th} edition) adopting the randomised complete block design frame. The experiments were arranged in triple lattice design. However, the experiments were arranged in a triple lattice design. Similarly, analysis of combining ability and correlation analysis used the GenStat statistical software package (13^{th} edition). Means were compared by Fisher's Protected Least Significant Difference (LSD) test at $P\leq0.05$. Combining ability for the line x tester mating design was analysed using genotype means as input data and t-test was used to test the significance of the general and specific combining ability effects. The skeleton Line x Tester analysis of variance table used is as shown below.

Table 2: ANOVA for Line x Tester crossing

Source	df	MS	EMS	F-test denominator
Replication I	R-1		-----	
Males	(m-1)	MS_m	$\sigma^2_e + r\,\sigma^2_{m\,xf} + fr\,\sigma^2_m$	MS_m
Females	(m-1)	MS_f	$\sigma^2_e + r\,\sigma^2_{m\,xf} + mr\,\sigma^2_f$	MS_f
Male x Female	(f-1)(m-1)	MS_{mxf}	$\sigma^2_e + r\,\sigma^2_{m\,xf}$	MS_{mxf}
Error	mf-1	M4	σ^2_e	Mse

The statistical model for the line x tester analysis is:

$$Y_{ijk} = \mu + m_i + f_j + (m\ X\ f)_{ij} + e_{ijk}$$

Where;

Y_{ijk} = the k^{th} observation on I x j^{th} progeny

μ = the general mean

m_i = the effect of the i^{th} male

f_j = the effect of the j^{th} female

$(m\ X\ f)_{ij}$ = the interaction effect, and

e_{ijk} = the error associated with each observation

The relative importance of GCA and SCA was evaluated using a ratio of variance components as described by Baker (1978) as cited by Kwemoi (2010).

$$\text{Baker's ratio} = (\sigma^2_{GCAmale} + \sigma^2_{GCAfemale}) / (\sigma^2_{GCAmale} + \sigma^2_{GCAfemale} + \sigma^2_{SCA})$$

CHAPTER FOUR

4.0 Results

4.1 SITE 1 (ZCA-Monze)

4.1.1. Performance of crosses for yield and other agronomic traits at ZCA-Monze

Analysis of variance for grain yield (GYD), days to 50% flowering (DOF), plant height (PH), productive tillers per plant (PT/P), panicle length (PL), panicle girth (PG), panicle weight (PWT), and thresh percent (T%) showed significant differences (P<0.05) among the crosses (Table 3). The mean performance of the crosses for yield and other characters are presented in Table 4 while the mean performance of the parents at ZCA-Monze and Longe are presented in Appendices I and II, respectively.

Grain yield

Grain yield varied among the crosses averaging to 1.04 ton/ha. Cross ZPMV 28011 x $ICMA_1$ 92888 had the highest yield (1.52 ton/ha) while ZPMV 28001 x $ICMA_1$ 00444 had the lowest yield (0.44 ton/ha).

Days to 50% flowering

Days to 50% flowering varied among the crosses, averaging to 63 DOF. ZPMV 28010 x $ICMA_1$ 04777 flowered earliest (56 DOF) while ZPMV 28013 x $ICMA_1$ 863 was the latest to flower (69 DOF).

Plant height

Plant height among crosses varied between 158 cm and 287 cm averaging to 230 cm. The tallest cross was ZPMV 28001 x $ICMA_1$ 863 (287 cm) and the shortest was ZPMV 28013 x NCD_2 A_4 (158 cm).

Table 3: Mean squares of crosses, male and female parents for measured traits in pearl millet evaluated at ZCA-Monze in the rainy season 2012/2013.

		Mean squares							
Source	d.f	DOF	PH	PT/P	PL	PG	PWT	TP	GYD
Replication	2	85.5	7263.1	2.82	3.8	0.11	435.84	357.04	3.43
Crosses	51	30.8***	2517.3***	1.26***	16.3***	0.30***	99.11***	90.4*	0.16***
GCA_{Male}	3	31.8*	8053.8***	0.85	75.6***	1.16***	130.1***	198.88*	0.51***
GCA_{Female}	12	87.42***	4649.3***	2.54**	22.05***	0.52***	183.63***	101.92	0.11
$SCA_{Female\ X\ male}$	36	11.83	1345.2***	0.8656*	9.38***	0.15***	68.36***	77.53	0.15***
Error	102	8.5	327.0	0.48	4.03	0.03	23.57	55.86	0.07
CV%		4.6	7.8	7.4	7.6	5.7	14.7	10.5	25.0

DOF = days to 50% flowering, PH = plant height, PT/P = productive tillers per plant, PL = panicle length, PG = panicle girth, PWT = panicle weight, TP = threshing percent, GYD = grain yield.
***Significant at P≤0.001, **significant at P≤0.01, *significant at P≤0.05

Table 4: Mean performance of pearl millet crosses for eight quantitative traits evaluated at ZCA-Monze in the rainy season 2012/2013.

S/No.	CROSSES	DOF	PH	PT/P	PL	PG	PWT	TP	GYD
1	ZPMV 28001 x $ICMA_1$ 863	64	287	3	25.7	3.1	29.5	76.3	1.04
2	ZPMV 28001 x $ICMA_1$ 88004	66	278	3	24.4	3.6	32.4	77.7	1.05
3	ZPMV 28001 x $ICMA_1$ 92888	67	274	3	25.4	3.4	34.1	68.0	0.98
4	ZPMV 28001 x $ICMA_1$ 95555	64	252	3	24.4	3.2	29.1	72.0	1.14
5	ZPMV 28001 x $ICMA_1$ 97111	59	252	3	22.7	3.5	31.0	78.0	1.34
6	ZPMV 28001 x $ICMA_1$ 00444	68	213	4	27.7	3.2	31.0	61.3	0.44
7	ZPMV 28001 x $ICMA_4$ 99555	67	228	3	24.4	3.0	32.5	72.7	0.99
8	ZPMV 28001 x $ICMA_4$ 01333	63	227	3	23.7	3.4	48.1	62.0	0.86
9	ZPMV 28001 x $ICMA_4$ 02999	63	241	3	21.9	3.9	34.7	71.7	0.98
10	ZPMV 28001 x $ICMA_4$ 04777	66	223	5	24.6	3.8	38.5	71.3	0.61
11	ZPMV 28001 x $ICMA_4$ 05222	63	261	4	26.3	3.2	34.5	67.0	0.74
12	ZPMV 28001 x NCD_2 A_4	61	262	2	26.8	3.6	33.4	79.7	1.21
13	ZPMV 28001 x LCIC A_4	67	226	3	24.7	3.1	27.2	68.7	0.99
14	ZPMV 28010 x $ICMA_1$ 863	63	246	3	25.1	2.8	39.8	77.0	1.11
15	ZPMV 28010 x $ICMA_1$ 88004	61	283	3	25.2	3.4	49.3	67.3	1.23
16	ZPMV 28010 x $ICMA_1$ 92888	58	269	4	27.3	3.1	36.6	68.0	0.79
17	ZPMV 28010 x $ICMA_1$ 95555	68	226	4	28.5	2.9	27.1	68.3	0.89
18	ZPMV 28010 x $ICMA_1$ 97111	57	246	3	24.1	2.9	35.8	66.7	1.04
19	ZPMV 28010 x $ICMA_1$ 00444	58	241	3	30.5	3.0	28.1	76.3	1.37
20	ZPMV 28010 x $ICMA_4$ 99555	65	235	2	27.3	2.7	32.9	76.7	1.12
21	ZPMV 28010 x $ICMA_4$ 01333	62	207	4	23.4	3.1	44.8	63.3	0.98
22	ZPMV 28010 x $ICMA_4$ 02999	61	243	2	26.4	3.5	34.3	76.3	1.25
23	ZPMV 28010 x $ICMA_4$ 04777	56	226	2	23.8	3.4	30.1	79.0	1.21
24	ZPMV 28010 x $ICMA_4$ 05222	64	214	3	25.6	3.1	33.0	73.7	1.25
25	ZPMV 28010 x NCD_2 A_4	64	264	3	28.5	3.5	38.3	75.3	1.36
26	ZPMV 28010 x LCIC $A4_4$	64	229	3	28.3	3.1	27.8	68.7	1.17
27	ZPMV 28011 x $ICMA_1$ 863	66	249	3	26.4	2.8	38.8	70.0	1.06
28	ZPMV 28011 x $ICMA_1$ 88004	65	237	3	27.4	3.0	31.0	73.3	0.96
29	ZPMV 28011 x $ICMA_1$ 92888	59	270	3	26.8	3.2	31.3	79.0	1.52
30	ZPMV 28011 x $ICMA_1$ 95555	64	219	3	25.3	3.0	27.9	72.3	1.21
31	ZPMV 28011 x $ICMA_1$ 97111	57	225	4	26.1	3.1	25.9	64.0	0.89
32	ZPMV 28011 x $ICMA_1$ 00444	65	213	3	28.1	3.0	27.4	74.0	1.20

Table 4 continues

S/No.	CROSSES	DOF	PH	PT/P	PL	PG	PWT	TP	GYD
33	ZPMV 28011 x $ICMA_4$ 99555	63	221	3	27.3	3.1	28.3	80.0	1.23
34	ZPMV 28011 x $ICMA_4$ 01333	64	188	4	25.9	3.3	32.6	69.3	0.71
35	ZPMV 28011 x $ICMA_4$ 02999	62	206	3	26.3	3.4	29.1	68.3	1.01
36	ZPMV 28011 x $ICMA_4$ 04777	57	267	2	24.1	2.9	38.1	76.3	1.44
37	ZPMV 28011 x $ICMA_4$ 05222	62	214	4	28.6	3.0	31.6	75.0	1.31
38	ZPMV 28011 x NCD_2 A_4	65	241	4	24.3	3.4	34.8	81.0	1.18
39	ZPMV 28011 x LCIC A_4	61	198	3	26.7	3.0	29.9	68.0	1.12
40	ZPMV 28013 x $ICMA_1$ 863	69	262	4	29.0	3.0	35.0	62.7	0.70
41	ZPMV 28013 x $ICMA_1$ 88004	66	234	3	29.3	3.2	42.0	63.3	0.83
42	ZPMV 28013 x $ICMA_1$ 92888	58	237	4	35.7	3.0	30.6	73.3	0.80
43	ZPMV 28013 x $ICMA_1$ 95555	58	263	2	29.3	3.0	30.0	73.0	1.31
44	ZPMV 28013 x $ICMA_1$ 97111	60	238	3	26.7	3.6	38.5	67.0	1.34
45	ZPMV 28013 x $ICMA_1$ 00444	66	207	5	29.1	2.9	27.5	66.3	0.89
46	ZPMV 28013 x $ICMA_4$ 99555	64	231	3	25.4	3.0	34.4	73.7	1.17
47	ZPMV 28013 x $ICMA_4$ 01333	64	200	4	25.8	3.3	35.5	70.3	0.74
48	ZPMV 28013 x $ICMA_4$ 02999	65	217	3	29.9	3.4	37.1	65.3	0.99
49	ZPMV 28013 x $ICMA_4$ 04777	61	228	3	24.9	3.1	33.8	72.3	0.89
50	ZPMV 28013 x $ICMA_4$ 05222	61	170	3	27.2	2.3	21.8	57.0	0.69
51	ZPMV 28013 x NCD_2 A_4	64	158	3	28.2	2.6	22.3	67.0	1.02
52	ZPMV 28013 x LCIC A_4	61	160	4	26.4	2.5	22.8	71.3	0.74
	MEAN	63	233	3	26.5	3.1	32.9	71.1	1.04
	CV%	4.6	7.8	7.4	7.6	5.7	14.7	10.5	25.0
	LSD (5%)	4.7	29	1.12	3.2	2.9	7.9	12.1	0.42

DOF = days to 50% flowering, PH= plant height (cm), PT/P = productive tillers per plant, PL= panicle length (cm), PWT, PG = panicle girth (cm), PWT = panicle weight (g), TP = thresh percent, GYD = grain yield (ton/ha).

Productive tillers per plant

The number of productive tillers per plant varied among the crosses averaging to 3 productive tillers per plant. ZPMV 28001 x $ICMA_4$ 04777 and ZPMV 28013 x $ICMA_1$ 00444 had the highest number of productive tillers per plant (5 PT/P) while ZPMV 28001 x NCD_2 A_4, ZPMV 28010 x $ICMA_4$ 99555, ZPMV 28010 x $ICMA_4$ 02999, ZPMV 28010 x $ICMA_4$ 04777, ZPMV 28011 x $ICMA_4$ 04777, and ZPMV 28013 x $ICMA_1$ 95555 had the lowest number of productive tillers per plant (2 PT/P).

Panicle length

For panicle length, crosses averaged to 26.5 cm with ZPMV 28013 x $ICMA_1$ 92888 having the longest panicles (35.7 cm) and ZPMV 28001 x $ICMA_4$ 02999 having the shortest panicles (21.9 cm).

Panicle girth

Panicle girth varied among the crosses averaging to 3.1 cm. Cross ZPMV 28001 x $ICMA_4$ 02999 had panicles with largest girth (3.9 cm) while ZPMV 28013 x $ICMA_4$ 05222 had panicles with the smallest girth (2.3 cm).

Panicle weight

Panicle weight varied crosses (averaged to 32.9g). Among the crosses, ZPMV 28010 x $ICMA_1$ 88004 had the highest panicle weight (49.3 g) while ZPMV 28013 x $ICMA_4$ 05222 had the minimum panicle weight (21.8 g).

Thresh percent

Thresh percent varied among the crosses averaging to 71.1%. The highest thresh percent was observed on ZPMV 28011 x NCD_2 A_4 (81%) and the lowest thresh % of 57% on ZPMV 28013 x $ICMA_4$ 05222.

4.1.2 Analysis of general and specific combining ability effects at ZCA-Monze

Combining ability analysis was done to reveal the underlying genetic effects influencing yield and other traits in pearl millet. Table 5 and Table 6 represent individual estimates of general combining ability and specific combining ability effects, respectively, for males and females, and crosses.

The variance components and Baker's ratio are presented in Table 7.

Table 5: Estimates of GCA effects for measured characters in pearl millet evaluated at ZCAMonze in the rainy season 2012/2013.

GCA EFFECTS

	DOF	PH	PT/P	PL	PG	PWT	TP	GYD
Males								
1. ZPMV 28001	1.29**	15.13***	-0.21	-1.66***	0.24***	0.62	0.17	0.09*
2. ZPMV 28010	-0.68	7.92**	0.00	-0.02	-0.02	2.30**	0.97	0.10*
3. ZPMV 28011	-0.55	-5.96*	0.16	-0.07	-0.07	-1.63*	2.04*	0.10*
4. ZPMV 28013	-0.06	-17.10***	0.05	1.74***	-0.16***	-1.29	-3.19*	-0.11*
Standard error	0.47	10.44	0.11	0.32	0.03	0.78	1.04	0.04
Females								
1. $ICMA_1$ 863	4.42***	28.18***	-0.61**	0.07	-0.23***	2.84*	0.42	-0.06
2. $ICMA_1$ 88004	3.92***	25.26***	-0.58**	2.27***	0.15**	5.76***	-0.67	-0.02
3. $ICMA_1$ 92888	1.92*	29.91***	-0.38	-0.38	0.02	0.23	1.00	-0.02
4. $ICMA_1$ 95555	-0.67	7.03	0.17	-1.78**	-0.10	-4.40**	0.33	-0.10
5. $ICMA_1$ 97111	-0.25	7.36	-0.16	-0.35	0.13*	-0.13	-2.17	0.11
6. $ICMA_1$ 00444	-4.08***	-14.39**	0.84***	-2.13***	-0.12*	-4.40**	-1.59	-0.07
7. $ICMA_4$ 99555	-0.42	-4.22	0.17	0.45	-0.19***	-0.89	4.67*	0.09
8. $ICMA_4$ 01333	1.92*	-27.39***	0.17	0.47	0.12*	7.32***	-4.84*	-0.22**
9. $ICMA_4$ 02999	-0.75	-6.07	-0.51*	0.05	0.44***	0.87	-0.67	0.02
10. $ICMA_4$ 04777	1.75*	3.26	-0.18	0.10	0.16**	2.20	3.67	-0.001
11. $ICMA_4$ 05222	-3.25***	-17.84***	-0.01	2.32***	-0.24***	-2.71	-2.92	-0.04
12. NCD_2 A_4	-0.92	-1.49	0.37	0.40	0.12*	-0.72	4.67	0.15*

Table 5continues

	GCA EFFECTS							
	DOF	PH	PT/P	PL	PG	PWT	TP	GYD
Females								
13. LCIC A_4	-3.58***	-29.57***	0.72***	-1.58**	-0.24***	-6.00***	-1.92	-0.03
Se	0.84	5.22	0.20	0.58	0.05	1.40	2.16	0.08

DOF = days to 50% flowering, PH = plant height, PT/P = productive tillers per plant, PL = panicle length, PG = panicle girth, PWT = panicle weight, TP = threshing percent, GYD = grain yield, Se = standard error,
*, **, *** GCA significantly different from 0 at P≤0.05, P≤0.01, *significant at P≤0.001, respectively

Table 6: Estimates of SCA effects for six characters in pearl millet evaluated at ZCA-Monze in the rainy season 2012/2013.

	SCA EFFECTS					
CROSSES	GYD	PH	PT/P	PL	PG	PWT
ZPMV 28001xICMA$_1$ 863	0.15	-43.3***	0.285	0.81	-0.08	-6.89*
ZPMV 28001xICMA$_1$ 88004	0.12	-40.4***	-0.04	0.51	0.07	-6.93*
ZPMV 28001xICMA$_1$ 92888	0.05	-45.0***	0.06	-0.05	0.01	0.32
ZPMV 28001xICMA$_1$ 95555	0.09	-22.2*	0.01	0.66	-0.05	-0.02
ZPMV 28001xICMA$_1$ 97111	0.28	-22.5*	0.44	-2.57*	-0.01	-2.45
ZPMV 28001xICMA$_1$ 00444	-0.45***	-0.74	1.14**	1.91	-0.11	1.88
ZPMV 28001xICMA$_4$ 99555	-0.05	-10.9	0.01	1.03	-0.17	-0.12
ZPMV 28001xICMA$_4$ 01333	0.13	12.3	-0.89*	1.51	-0.12	7.23**
ZPMV 28001xICMA$_4$ 02999	0.01	-9.1	-0.12	-0.17	0.11	0.26
ZPMV 28001xICMA$_4$ 04777	-0.34*	-18.4	0.16	-0.52	0.25*	2.76
ZPMV 28001xICMA$_4$ 05222	-0.17	2.7	-0.42	-1.75	0.06	3.69
ZPMV 28001xNCD$_2$ A$_4$	0.11	-13.6	-0.19	-0.82	0.10	0.60
ZPMV 28001xLCIC A$_4$	0.07	14.4	-0.44	-0.55	-0.05	-0.33
ZPMV 28010xICMA$_1$ 863	0.04	-36.1***	0.18	-1.43	-0.06	1.70
ZPMV 28010xICMA$_1$ 88004	0.11	-33.2**	0.15	1.67	0.10	8.32**
ZPMV 28010xICMA$_1$ 92888	-0.33*	-37.8***	-0.95*	1.22	-0.01	1.17
ZPMV 28010xICMA$_1$ 95555	-0.34*	-14.9	0.2	-1.28	-0.11	-3.73
ZPMV 28010xICMA$_1$ 97111	-0.21	-15.3	-0.38	0.29	-0.39***	0.67
ZPMV 28010xICMA$_1$ 00444	0.30*	6.5	-0.28	-0.53	0.04	-2.70
ZPMV 28010xICMA$_4$ 99555	-0.10	-3.7	0.00	-1.31	-0.21*	-1.43
ZPMV 28010xICMA$_4$ 01333	0.06	19.5	0.40	1.57	-0.12	2.28
ZPMV 28010xICMA$_4$ 02999	0.10	-1.9	-0.28	1.79	-0.03	-1.79
ZPMV 28010xICMA$_4$ 04777	0.08	-11.2	0.55	-1.36	0.07	-7.30**
ZPMV 28010xICMA$_4$ 05222	0.16	9.9	0.18	-1.48	0.23*	0.45
ZPMV 28010xNCD$_2$ A$_4$	0.07	-6.4	-0.50	1.64	0.29**	3.82
ZPMV 28010xLCIC A$_4$	0.07	21.7*	0.15	-0.78	0.21*	-1.44
ZPMV 28011xICMA$_1$ 863	-0.02	-22.2*	0.02	-0.08	-0.08	4.66
ZPMV 28011xICMA$_1$ 88004	-0.16	-19.3	0.19	-0.68	-0.19	-6.02*
ZPMV 28011xICMA$_1$ 92888	0.39*	-24.0*	0.79*	1.27	0.06	-0.23
ZPMV 28011xICMA$_1$ 95555	-0.03	-1.1	-0.06	1.27	0.02	1.01
ZPMV 28011xICMA$_1$ 97111	-0.36*	-1.4	0.07	0.25	-0.13	-5.24
ZPMV 28011xICMA$_1$ 00444	0.12	20.4	-0.04	-0.18	-0.002	0.53
ZPMV 28011xICMA$_4$ 99555	0.00	10.2	0.44	1.75	0.21*	-2.07
ZPMV 28011xICMA$_4$ 01333	-0.21	33.4**	0.04	-2.58*	0.08	-6.02*
ZPMV 28011xICMA$_4$ 02999	-0.15	12.0	0.22	0.25	-0.07	-3.03
ZPMV 28011xICMA$_4$ 04777	0.30*	2.7	-0.41	0.90	-0.30**	4.61
ZPMV 28011xICMA$_4$ 05222	0.21	23.8*	-0.19	-1.93	0.13	2.98
ZPMV 28011xNCD$_2$ A$_4$	-0.11	7.5	-0.46	-1.51	0.16	4.22
ZPMV 28011xLCIC A$_4$	0.02	35.5***	-0.61	1.27	0.13	4.62
ZPMV 28013xICMA$_1$ 863	-0.17	-11.1	-0.48	0.71	0.22*	0.52
ZPMV 28013xICMA$_1$ 88004	-0.08	-8.2	-0.30	-1.50	0.02	4.64

Table 6 continue

	SCA Effects					
CROSSES	GYD	PH	PT/P	PL	PG	PWT
ZPMV 28013xICMA$_1$ 92888	-0.11	-12.8	0.1	-2.45*	-0.05	-1.27
ZPMV 28013xICMA$_1$ 95555	0.28	10.1	-0.15	-0.65	0.15	2.74
ZPMV 28013xICMA$_1$ 97111	0.30*	9.7	-0.13	2.03	0.53***	7.02**
ZPMV 28013xICMA$_1$ 00444	0.02	31.5**	-0.83*	-1.20	0.07	0.29
ZPMV 28013xICMA$_4$ 99555	0.15	21.3*	-0.45	-1.47	0.17	3.63
ZPMV 28013xICMA$_4$ 01333	0.03	44.5***	0.45	-0.50	0.16	-3.49
ZPMV 28013xICMA$_4$ 02999	0.04	23.2*	-0.38	-1.87	-0.01	4.57
ZPMV 28013xICMA$_4$ 04777	-0.04	13.8	-0.30	0.98	-0.02	-0.06
ZPMV 28013xICMA$_4$ 05222	-0.21	34.9**	0.43	5.16***	-0.42***	-7.13**
ZPMV 28013xNCD$_2$ A$_4$	-0.06	18.6	1.15**	0.68	-0.54***	-8.63**
ZPMV 28013xLCIC A$_4$	-0.15	46.7***	0.90*	0.06	-0.29**	-2.85
Standard error	0.15	10.44	0.40	1.16	0.10	2.8

DOF = days to 50% flowering, PH = plant height, PL = panicle length, PG = panicle girth, PWT = panicle weight, GYD = grain yield, Se = standard error,
*, **, ***, SCA effects significant at P≤0.05, P≤0.01 and P≤0.001 respectively

Table 7: Variance components and Baker's ratio for yield and other characters evaluated at ZCA-Monze in the rainy season 2012/2013.

	Variance Components			Baker's Ratio
CHARATER	$\sigma^2_{GCA(Male)}$	$\sigma^2_{GCA(Female)}$	σ^2_{SCA}	
GYD	0.009	0.00	0.027	0.18
DOF	0.51	6.30	1.11	0.86
PH	172.02	275.34	339.4	0.57
PT/P	0.00	0.140	0.386	0.26
PL	1.698	1.056	1.783	0.61
PG	0.026	0.031	0.040	0.59
PWT	1.583	9.606	14.93	0.43
T%	3.112	2.033	7.223	0.42

GYD = grain yield, DOF = days to 50% flowering, PH = plant height, PT/P = productive tillers per plant, PL = panicle length, PG = panicle girth, PWT = panicle weight

Grain yield

Significant ($P<0.05$) GCA effects for grain yield were observed for some parents. Male parent ZPMV 28013 was the only one that showed significant negative GCA effect (-0.11) for grain yield. Significant ($P<0.05$) positive GCA effects were observed for three male parents; ZPMV 28001 (0.09), ZPMV 28010 (0.10) and ZPMV 28011 (0.10). Female parent, NCD_2 A_4 had significant ($P<0.05$) positive GCA effect (0.15) while significant ($P<0.01$) negative GCA effects (-0.22) was observed on $ICMA_4$ 01333.

Four crosses, ZPMV 28010 x $ICMA_1$ 00444, ZPMV 28011 x $ICMA_1$ 92888, ZPMV 28011 x $ICMA_4$ 04777, and ZPMV 28013 x $ICMA_4$ 97111 had significant ($P<0.05$, $P<0.01$, $P<0.05$, and $P<0.05$, respectively) positive SCA effects (0.30, 0.39, 0.30, and 0.30, respectively). The crosses, ZPMV 28001 x $ICMA_1$ 00444, ZPMV 28001 x $ICMA_4$ 04777, ZPMV 28010 x $ICMA_1$ 92888, ZPMV 28010 x $ICMA_1$ 95555, and ZPMV 28011 x $ICMA_4$ 97111 exhibited significantly ($P<0.01$, $P<0.05$, $P<0.05$, $P<0.05$, and $P<0.05$, respectively) negative SCA effects (-0.45, -0.34, -0.33, -0.34 and -0.36, respectively) for grain yield.

The Baker's ratio for grain yield (0.18) was less than 0.50.

Days to 50% flowering

Significant ($P<0.05$) GCA effects were observed for some parents for days to 50% flowering. Male parent ZPMV 28001 was the only one that showed significant ($P<0.01$) positive GCA effect (1.29) for days to 50% flowering. Eight female parents had significant GCA effects for days to 50% flowering. Parents $ICMA_1$ 00444, $ICMA_4$ 05222 and LCIC A_4 had significant ($P<0.001$) negative GCA effect (-4.08, -3.25, and -3.58 respectively) while $ICMA_1$ 863 and $ICMA_1$ 88004 had significantly ($P<0.001$) positive GCA effect (4.42 and 3.92, respectively). In addition, $ICMA_1$ 92888, $ICMA_4$ 01333 and $ICMA_4$ 04777 had significant ($P<0.05$) positive GCA effects (1.92, 1.92, and 1.75, respectively) for days to 50% flowering.

None of the crosses exhibited significant SCA effects for the days of 50% flowering.

Baker's ratio for days 50%to flowering (0.86) was observed to be greater than 0.50.

Plant height

Significant ($P<0.05$) GCA effects were observed for some parents for plant height. Male parents ZPMV 28001 and ZPMV 28010 had significant ($P<0.001$ and $P<0.01$, respectively) positive GCA effects (15.13 and 7.92 respectively) while ZPMV 28011 and ZPMV 28013 had significant ($P<0.05$ and $P<0.001$, respectively) negative GCA effects (-5.96 and -17.10, respectively) for plant height. Female parents $ICMA_1$ 863, $ICMA_1$ 88004 and $ICMA_1$ 92888 had significantly ($P<0.001$) positive GCA effects (28.18, 25.26, and 29.91 respectively) while $ICMA_4$ 01333, $ICMA_4$ 05222 and LCIC A_4 had significantly ($P<0.001$) negative GCA effects (-27.39, -17.84, and -29.57, respectively) for plant height. In addition, $ICMA_1$ 00444 had significant ($P<0.01$) negative GCA effect (-14.39) for plant height.

Out of the ten crosses that had significantly positive SCA effects, three crosses ZPMV 28011 x LCIC A_4, ZPMV 28013 x $ICMA_4$ 01333, and ZPMV 28013 x LCIC A_4 showed highly significant ($P<0.001$) positive SCA effects (35.5, 44.5, and 46.7, respectively) for plant height. On the other hand, out of the ten crosses that exhibited significant negative SCA effects, five crosses, ZPMV 28001 x $ICMA_1$ 863, ZPMV 28001 x $ICMA_1$ 88004, ZPMV 28001 x $ICMA_1$ 92888, ZPMV 28010 x $ICMA_1$ 863, and ZPMV 28010 x $ICMA_1$ 92888 showed highly significant ($P<0.001$) negative SCA effects (-43.3, -40.4, -45.0, -36.1, and -37.8, respectively) for plant height.

Results showed that the Baker's ratio for plant height (0.57) was greater than 0.50.

Productive tillers per plant

Non-significant ($P>0.05$) GCA effects were observed for all the male parents for productive tillers per plant while significant ($P<0.05$) GCA effects were observed on five female parents. $ICMA_1$ 00444 and LCIC A_4 showed significant ($P<0.001$) positive GCA effects (0.84 and 0.72, respectively) while $ICMA_1$ 863, $ICMA_1$ 88004 and $ICMA_4$ 02999 had significant ($P<0.01$, $P<0.01$, and $P<0.05$) negative GCA effects (-0.61, -0.58, and -0.51, respectively) for productive tillers per plant.

Significant ($P<0.05$) SCA effects were observed on seven crosses for productive tillers per plant. Four crosses; ZPMV 28001 x $ICMA_4$ 00444, ZPMV 28011 x $ICMA_4$ 92888, ZPMV 28013 x NCD_2 A_4 and ZPMV 28013 x LCIC A_4 had significant ($P<0.01$, $P<0.05$, $P<0.01$, and $P<0.05$, respectively) positive SCA effects (1.14, 0.79, 1.15, and 0.90, respectively) for productive tillers per plant while three crosses; ZPMV 28001 x $ICMA_4$ 01333, ZPMV 28010 x $ICMA_1$ 92888, and ZPMV 28013 x $ICMA_1$ 00444 had significant ($P<0.05$) negative SCA effects (-0.89, -0.95, and -0.83, respectively).

The Baker's ratio for productive tillers per plant (0.26) was observed to be less than 0.50.

Panicle length

Significant ($P<0.05$) GCA effects were observed on some parents for panicle length. Male parent ZPMV 28001 had significantly ($P<0.001$) negative GCA effect (-1.66) while ZPMV 28013 had significantly ($P<0.001$) positive GCA effect (1.74) for panicle length. Female parents, $ICMA_1$ 88004, and $ICMA_4$ 05222 had significant ($P<0.001$) positive GCA effects (2.27 and 2.32, respectively) while $ICMA_1$ 95555, $ICMA_1$ 00444 and LCIC A_4 had significant ($P<0.01$, $P<0.001$, and $P<0.01$ respectively) negative GCA effects (-1.78, -2.13, and -1.58, respectively) for panicle length.

Significant ($P<0.05$) SCA effects were observed for panicle length in four crosses. ZPMV 28013 x $ICMA_4$ 05222 had significantly ($P<0.001$) positive SCA effect (5.16) while ZPMV 28001 x $ICMA_1$ 97111, ZPMV 28011 x $ICMA_4$ 01333 and ZPMV 28013 x $ICMA_4$ 92888 had significant ($P<0.05$) negative SCA effects (-2.57, -2.58, and –2.45, respectively) for panicle length.

The observed Baker's ratio (0.61) for panicle length was greater than 0.50.

Panicle girth

Male parent ZPMV 28001 had significant ($P<0.001$) positive GCA effect (0.24) while ZPMV 28013 had significant ($P<0.001$) negative GCA effect (-0.16) for panicle girth. The female parents, $ICMA_1$ 88004, $ICMA_1$ 97111, $ICMA_4$ 01333, $ICMA_4$ 02999, $ICMA_4$ 04777, and NCD_2 A_4 had significant ($P<0.01$, $P<0.05$, $P<0.05$, $P<0.001$, $P<0.01$, and $P<0.05$, respectively) positive GCA effects (0.15, 0.13, 0.12, 0.44, 0.16 and 0.12, respectively) while ICMA$_1$ 863, ICMA$_1$ 00444, ICMA$_4$ 99555, ICMA$_4$ 05222 and LCIC A$_4$ had significant (P<0.001, P<0.05, P<0.001, P<0.001 and P<0.001, respectively) negative GCA effects (-0.23, -0.12, -0.19, -0.24 and -0.24, respectively) for panicle girth.

For panicle girth, significant (P<0.05) SCA effects were observed in thirteen crosses. Out of the seven crosses that showed significant positive SCA effects, ZPMV 28010 x NCD$_2$ A$_4$ and ZPMV 28013 x ICMA$_1$ 97111 had significant (P<0.01 and P<0.001, respectively) positive SCA effects (0.29 and 0.53, respectively) while ZPMV 28010 x ICMA$_1$ 97111, ZPMV 28011 x ICMA$_4$ 04777, ZPMV 28013 x ICMA$_4$ 05222, ZPMV 28013 x NCD$_2$ A$_4$ and ZPMV 28013 x LCIC A$_4$ showed significant (P<0.01) negative SCA effects (-0.39, -0.30, -0.42, -0.54and -0.29, respectively) for panicle girth.

The Baker's ratio for panicle girth (0.59) was greater than 0.50.

Panicle weight

Significant (P<0.05) GCA effects for panicle weight were observed on some parents. Male parent ZPMV 28010 had significant (P<0.01) positive GCA effect (2.30) while ZPMV 28011 had significant (P<0.05) negative GCA effect (-1.63) for panicle weight. Female parents ICMA$_1$ 863, ICMA$_1$ 88004, and ICMA$_4$ 01333, were observed to have significant (P<0.05, P<0.001, and P<0.001, respectively) positive GCA effects (2.84, 5.76, and 7.32, respectively) while ICMA$_1$ 95555, ICMA$_1$ 00444, and LCIC A$_4$ were observed to have significant (P<0.01, P<0.01, and P<0.001, respectively) negative GCA effects (-4.40, -4.40, and -6.0, respectively) for panicle weight.

Significant (P<0.05) SCA effects were observed for panicle weight in ten crosses. ZPMV 28001 x ICMA$_4$ 01333, ZPMV 28010 x ICMA$_1$ 88004, and ZPMV 28013 x ICMA$_1$ 97111 had significantly (P<0.01) positive GCA effects (7.23, 8.32, and 7.02, respectively) while ZPMV 28001 x ICMA$_1$ 863, ZPMV 28001 x ICMA$_1$ 88004, ZPMV 28010 x ICMA$_1$ 04777, ZPMV 28011 x ICMA$_1$ 88004, ZPMV 28011 x ICMA$_4$ 01333, ZPMV 28013 x ICMA$_4$ 05222, and ZPMV 28013 x NCD$_2$ A$_4$ had significant (P<0.05, P<0.05, P<0.01, P<0.05, P<0.05, P<0.01, and P<0.01, respectively) negative SCA effects (-6.89, -6.93, -7.30, -6.02, -6.02, -7.13and –8.63, respectively) for panicle weight.

Results showed that the Baker's ratio for panicle weight (0.43) was less than 0.50.

Thresh percent

Significant (P<0.05) GCA effects for thresh percent were observed on some parents. Male parent ZPMV 28011 had significant (P<0.05) positive GCA effect (2.04) while ZPMV 28013 had significant (P<0.05) negative GCA effect (-3.19) for thresh percent. The female parent, $ICMA_4$ 99555 had significant (P<0.05) positive GCA effect (4.67) while $ICMA_4$ 01333 had significant (P<0.05) negative GCA effect (-4.84) for thresh percent.

None of the crosses exhibited significant SCA effects for the thresh percent.

The Baker's ratio for thresh percent (0.42) was observed to be less than 0.50.

4.1.3 Correlation between grain yield and other characters in pearl millet at ZCA-Monze

Phenotypic correlation between yield and other characters is presented in Table 8 below. A highly significant (P<0.01) positive correlation (r = 0.36) of grain yield was observed with plant height. Non-significant correlation of yield was observed with other characters.

Table 8: Correlation between yield and other characters in pearl millet evaluated at ZCA-Monze in the rainy season 2012/2013.

Days to 50% flowering	-0.18
Plant height	0.36**
Productive tillers per plant	-0.002
Panicle length	-0.07
Panicle girth	0.13
Panicle weight	0.003

*, **, *** Data significant at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively

4.2 SITE 2 (LONGE)

4.2.1. Performance of crosses for yield and other agronomic traits at Longe

Analysis of variance for grain yield (GYD), days to 50% flowering (DOF), plant height (PH), productive tillers per plant (PT/P), panicle length (PL), panicle girth (PG), and panicle weight (PWT) showed significant differences ($P<0.05$) among the crosses for most of the measured and derived parameters (Table 9).

Mean performance of the crosses for measured and derived characters are presented in Table 10.

Grain yield

Grain yield varied among the crosses averaging 0.97 ton/ha. Among the crosses, 57000R_1W x $ICMA_4$ 02999 had the highest yield (1.46 ton/ha) while ZPMV 28015 x LCIC A_4 had the lowest yield (0.57 ton/ha).

Days to 50% flowering

Results showed that days to 50% flowering (DOF) varied among crosses. Crosses averaged to 64 days to 50% flowering. Cross, ZPMV 28014 x $ICMA_1$ 00444 flowered earliest (52 DOF) while ZPMV 28015 x $ICMA_1$ 863 flowered latest (76 DOF).

Plant height

Plant height varied among crosses (averaging to 180 cm). ZPMV 28014 x $ICMA_1$ 88004 was the tallest (218 cm) while ZPMV 28014 x $ICMA_1$ 00444 was the shortest (142 cm).

Productive tillers per plant

Results showed that the number of productive tillers per plant (PT/P) varied among the crosses. Crosses averaged to 4 PT/P. Cross ZPMV 28015 x LCIC A_4 was observed to have the highest number of productive tillers per plant (7 PT/P) while ZPMV 28014 x $ICMA_1$ 88004 was observed to have the lowest (2 PT/P).

Table 9: Mean squares of crosses, male and female parents for eight characters in pearl millet evaluated at Longe in the rainy season 2012/2013.

		Mean squares							
Source	d.f	DOF	PH	PT/P	PL	PG	PWT	TP	GYD
Replication	2	41.10	3623.1	0.396	87.24	0.51	357.20	146.28	2.84
Crosses	51	77.58***	862.3***	2.80**	40.27***	0.26***	83.42***	36.09	0.12**
GCA $_{female}$	12	186.84***	790.8*	4.64**	109.55***	0.62***	173.81***	-	0.19**
GCA $_{male}$	3	45.82***	635.2	1.96	11.97	0.07	31.86	-	0.09
SCA $_{\text{Male x Female}}$	36	42.81***	905.1**	2.26	19.53**	0.15	57.59***	-	0.10
Error	102	6.55	427.8	1.53	9.38	0.11	18.33	26.86	0.07
CV%		4.0	11.5	2.2	10.4	12.9	10.5	7.7	24.2

DOF = days to 50% flowering (days), PH = plant height (cm), PT/P = productive tillers per plant, PL = panicle length (cm), PG = panicle girth (cm), PWT = panicle weight (g), TP = thresh percent, GYD = grain yield (ton/ha)
*, **, *** Data significant at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively

Table 10: Mean performance of pearl millet crosses for eight quantitative traits evaluated at Longe in the rainy season 2012/2013.

S/No.	CROSSES	DOF	PH	PT/P	PL	PG	PWT	TP	GYD
1	ZPMV 28014 x $ICMA_1$ 863	74	183	3	34.7	2.1	35.8	61.7	0.91
2	ZPMV 28014 x $ICMA_1$ 88004	73	218	2	39.0	3.0	35.8	64.0	1.12
3	ZPMV 28014 x $ICMA_1$ 92888	67	168	3	27.3	2.4	20.6	67.7	0.77
4	ZPMV 28014 x $ICMA_1$ 95555	61	168	4	28.3	2.7	26.2	67.7	1.06
5	ZPMV 28014 x $ICMA_1$ 97111	66	160	3	29.7	2.4	21.2	64.0	0.83
6	ZPMV 28014 x $ICMA_1$ 00444	52	142	5	22.0	2.5	14.8	65.7	0.75
7	ZPMV 28014 x $ICMA_4$ 99555	57	182	4	32.7	2.5	23.4	67.7	1.14
8	ZPMV 28014 x $ICMA_4$ 01333	64	177	5	34.7	2.5	39.7	69.0	0.74
9	ZPMV 28014 x $ICMA_4$ 02999	66	192	4	33.0	3.2	25.1	71.3	1.30
10	ZPMV 28014 x $ICMA_4$ 04777	63	208	3	30.7	3.0	28.7	68.7	1.13
11	ZPMV 28014 x $ICMA_4$ 05222	61	185	5	28.3	2.6	23.8	69.7	1.19
12	ZPMV 28014 x NCD_2 A_4	57	178	4	26.3	2.3	26.0	66.3	1.12
13	ZPMV 28014 x LCIC A_4	54	158	6	23.7	2.3	16.2	65.7	0.84
14	ZPMV 28015 x $ICMA_1$ 863	76	192	3	32.3	2.6	29.6	67.3	1.03
15	ZPMV 28015 x $ICMA_1$ 88004	68	168	5	34.0	3.3	26.2	68.0	0.78
16	ZPMV 28015 x $ICMA_1$ 92888	63	203	3	27.7	2.6	21.9	62.3	1.05
17	ZPMV 28015 x $ICMA_1$ 95555	61	188	5	30.0	2.7	22.3	61.7	1.00
18	ZPMV 28015 x $ICMA_1$ 97111	67	207	4	34.7	2.2	29.4	70.7	1.33
19	ZPMV 28015 x $ICMA_1$ 00444	64	163	6	24.3	2.4	23.5	67.7	0.80
20	ZPMV 28015 x $ICMA_4$ 99555	67	183	5	33.7	2.7	24.1	70.7	1.22
21	ZPMV 28015 x $ICMA_4$ 01333	61	148	3	30.7	2.5	23.3	62.7	0.71
22	ZPMV 28015 x $ICMA_4$ 02999	63	168	4	24.3	3.0	21.7	63.7	0.79
23	ZPMV 28015 x $ICMA_4$ 04777	72	155	3	31.3	2.8	26.6	70.0	0.73
24	ZPMV 28015 x $ICMA_4$ 05222	63	165	5	32.7	2.7	19.8	66.3	0.74
25	ZPMV 28015 x NCD_2 A_4	63	197	5	25.0	2.5	21.1	65.0	1.13
26	ZPMV 28015 x LCIC A_4	59	195	7	26.3	2.5	19.2	69.7	0.57
27	ZPMV 28017 x $ICMA_1$ 863	66	195	6	29.7	2.1	22.2	65.0	0.90
28	ZPMV 28017 x $ICMA_1$ 88004	65	198	3	36.7	3.2	37.7	69.0	1.33
29	ZPMV 28017 x $ICMA_1$ 92888	63	185	4	30.7	2.7	25.1	59.0	0.94
30	ZPMV 28017 x $ICMA_1$ 95555	55	175	4	27.0	2.6	24.2	70.3	1.10
31	ZPMV 28017 x $ICMA_1$ 97111	67	167	4	27.7	2.8	22.3	69.0	0.95
32	ZPMV 28017 x $ICMA_1$ 00444	60	167	4	26.7	2.4	21.3	74.3	1.03
33	ZPMV 28017 x $ICMA_4$ 99555	66	175	4	30.3	2.5	19.1	72.0	0.85

Table 10 continues

S/No.	CROSSES	DOF	PH	PT/P	PL	PG	PWT	TP	GYD
34	ZPMV 28017 x $ICMA_4$ 01333	62	178	4	27.7	2.9	27.8	70.0	1.10
35	ZPMV 28017 x $ICMA_4$ 02999	66	182	6	26.7	2.6	27.5	67.7	1.21
36	ZPMV 28017 x $ICMA_4$ 04777	64	165	5	26.0	3.2	24.0	71.3	0.84
37	ZPMV 28017 x $ICMA_4$ 05222	67	160	4	30.3	2.3	23.4	66.3	0.91
38	ZPMV 28017 x NCD_2 A_4	60	177	4	27.0	2.5	25.9	68.3	1.16
39	ZPMV 28017 x LCIC A_4	58	178	4	27.3	2.3	24.9	66.0	0.88
40	$57000R_1W$ x $ICMA_1$ 863	64	182	4	34.0	2.3	25.9	67.3	0.84
41	$57000R_1W$ x $ICMA_1$ 88004	74	177	3	30.3	2.7	29.1	67.7	0.86
42	$57000R_1W$ x $ICMA_1$ 92888	70	172	3	30.0	2.4	22.5	63.3	0.76
43	$57000R_1W$ x $ICMA_1$ 95555	66	207	4	28.7	2.3	30.2	72.0	1.16
44	$57000R_1W$ x $ICMA_1$ 97111	66	215	5	33.0	2.7	25.2	65.3	1.06
45	$57000R_1W$ x $ICMA_1$ 00444	59	167	6	25.3	2.5	19.2	64.0	0.66
46	$57000R_1W$ x $ICMA_4$ 99555	60	177	4	30.3	2.3	25.4	66.0	1.00
47	$57000R_1W$ x $ICMA_4$ 01333	62	187	4	29.0	2.8	25.6	69.3	1.10
48	$57000R_1W$ x $ICMA_4$ 02999	68	207	4	32.3	3.3	36.5	71.7	1.46
49	$57000R_1W$ x $ICMA_4$ 04777	64	188	4	30.3	2.3	26.9	60.7	1.00
50	$57000R_1W$ x $ICMA_4$ 05222	59	200	5	32.0	2.8	23.2	70.7	0.65
51	$57000R_1W$ x NCD_2 A_4	56	170	4	23.3	2.6	20.6	72.7	1.01
52	$57000R_1W$ x LCIC A_4	58	173	6	24.7	2.3	15.7	60.7	0.72
	MEAN	64	180	4	29.5	2.6	24.9	67.2	0.97
	CV%	4.0	11.5	2.2	10.4	12.9	10.5	7.7	24.2
	LSD (5% Level)	4.1	34	2	5.0	0.5	6.9	8.4	0.43

DOF = days to 50% flowering, PH = plant height (cm), PT/P = productive tillers per plant, PL = panicle length (cm), PG = panicle girth, PWT, panicle weight (g), TP = thresh percent, GYD, grain yield (ton/ha).

Panicle length

Variation was observed among the crosses for panicle length. Crosses averaged to 29.5 cm. ZPMV 28014 x $ICMA_1$ 88004 had the longest panicles (39 cm) while ZPMV 28014 x $ICMA_1$ 00444 had the shortest panicles (22 cm).

Panicle girth

Results showed that panicle girth varied among crosses averaging to 2.6 cm. Among the crosses, ZPMV 28015 x $ICMA_1$ 88004 and $57000R_1W$ x $ICMA_4$ 02999 were observed to have the largest girth (3.3 cm) while ZPMV 28014 x $ICMA_1$ 863 and ZPMV 28017 x $ICMA_1$ 863 were observed to have the smallest panicle girth (2.1 cm).

Panicle weight

Panicle weight varied among the crosses averaging 24.9 g. ZPMV 28014 x $ICMA_4$ 01333 had the heaviest panicles (39.7 g) while ZPMV 28014 x $ICMA_1$ 00444 had the lightest panicles (14.8 g).

4.2.2 Analysis of general and specific combining ability effects at Longe

Table 11 and Table 12 represent individual estimates of general combining ability and specific combining ability estimates, respectively for males, females and crosses.

The variance components and Baker's ratio are presented in Table 13.

Grain yield

Significant ($P<0.05$) GCA effects for grain yield were observed for some female parents. Parent $ICMA_4$ 02999 had significant ($P<0.01$) positive GCA effect (0.22) while $ICMA_1$ 00444 and LCIC A_4 had significant ($P<0.05$ and $P<0.01$ respectively) negative GCA effects (-0.16 and -0.22, respectively).

Significant ($P<0.05$) SCA effects for grain yield were observed only in two crosses ZPMV 28015 x $ICMA_1$ 97111 had significant ($P<0.05$) positive SCA effect (0.34) while ZPMV 28015 x $ICMA_4$ 02999 had significant ($P<0.05$) negative SCA effects (-0.35) for grain yield.

The Baker's ratio for grain yield (0.44) was less than 0.50.

Table 11: Estimates of GCA effects for seven characters in pearl millet evaluated at Longe in the rainy season 2012/2013.
GCA effects

	DOF	PH	PT/P	PL	PG	PWT	GYD
Males							
1. ZPMV 28014	-0.93***	-1.84	-0.28	0.52	-0.02	0.99	0.03
2. ZPMV 28015	1.48***	-0.81	0.17	0.26	0.04	-1.20	-0.05
3. ZPMV 28017	-0.67***	-3.23	-0.09	-0.76	0.03	0.09	0.05
4. $57000R_1W$	0.12	5.88	0.02	-0.02	-0.05	0.13	-0.02
Se	0.17	3.31	0.20	0.49	0.05	0.69	0.04
Females							
1. $ICMA_1$ 863	6.38***	7.64	-0.15	3.16***	-0.33**	3.41**	-0.05
2. $ICMA_1$ 88004	6.21***	10.11	-1.23***	5.49***	0.43***	7.27***	0.06
3. $ICMA_1$ 92888	1.63*	1.79	-0.53	-0.59	-0.07	-2.44	-0.09
4. $ICMA_1$ 95555	-2.46**	4.29	-0.14	-1.01	-0.03	0.78	0.11
5. $ICMA_1$ 97111	2.80***	6.81	-0.07	1.75	-0.07	-0.43	0.08
6. $ICMA_1$ 00444	-4.95***	-20.69***	0.43	-4.92***	-0.16	-5.25***	-0.16*
7. $ICMA_4$ 99555	-1.12	-1.11	0.60	2.24*	-0.09	-1.96	0.09
8. $ICMA_4$ 01333	-1.29*	-7.79	-0.48	1.00	0.06	4.16**	-0.06
9. $ICMA_4$ 02999	2.13**	6.81	0.32	-0.42	0.04	2.75*	0.22**
10. $ICMA_4$ 04777	2.21**	-1.14	-0.48	0.08	0.23*	1.61	-0.04

Table 11 continues

	GCA Effects						
	DOF	PH	PT/P	PL	PG	PWT	GYD
FEMALES							
11. ICMA$_4$ 05222	-0.96	-2.79	0.40	1.33	-0.02	-2.40	-0.09
12. NCD$_2$ A$_4$	-4.87***	0.14	0.04	-4.09***	-0.13	-1.56	0.14
13. LCIC A$_4$	-5.70***	- 4.06	1.26***	-4.01***	-0.23*	-5.96***	-0.22**
Se	0.74	5.97	0.36	0.88	0.10	1.23	0.08

DOF = days to 50% flowering, PH = plant height, PT/P = productive tillers per plant, PL = panicle length, PG = panicle girth, PWT = panicle weight, GYD = grain yield, Se = standard error

*, **, *** GCA significantly different from 0 at P≤0.05, P≤0.01, and P≤0.001, respectively

Table 12: Estimates of SCA effects for five characters in pearl millet evaluated at Longe in the rainy season 2012/2013.

	SCA EFFECTS				
CROSSES	GYD	DOF	PH	PL	PWT
ZPMV 28014 x $ICMA_1$ 863	-0.03	-5.45***	-2.8	1.48	6.48*
ZPMV 28014 x $ICMA_1$ 88004	0.07	-5.28***	29.7*	3.48	2.63
ZPMV 28014 x $ICMA_1$ 92888	-0.13	-0.70	-11.9	-2.11	-2.93
ZPMV 28014 x $ICMA_1$ 95555	-0.05	3.39*	-14.4	-0.69	-0.54
ZPMV 28014 x $ICMA_1$ 97111	-0.24	-1.87	-25.3*	-2.10	-4.34
ZPMV 28014 x $ICMA_1$ 00444	-0.09	5.88***	-16.1	-3.10	-5.89*
ZPMV 28014 x $ICMA_4$ 99555	0.07	2.05	4.4	0.40	-0.60
ZPMV 28014 x $ICMA_4$ 01333	-0.20	2.22	6.0	3.65*	9.63***
ZPMV 28014 x $ICMA_4$ 02999	0.08	-1.20	6.4	3.40	-3.58
ZPMV 28014 x $ICMA_4$ 04777	0.18	-1.28	31.0*	0.57	1.12
ZPMV 28014 x $ICMA_4$ 05222	0.29	1.89	9.3	-3.02	0.26
ZPMV 28014 x NCD_2A_4	-0.02	5.80***	-0.3	0.40	1.60
ZPMV 28014 x $LCICA_4$	0.06	6.63***	-16.1	-2.35	-3.77
ZPMV 28015 x $ICMA_1$ 863	0.16	-7.86***	4.6	-0.60	2.44
ZPMV 28015 x $ICMA_1$ 88004	-0.19	-7.69***	-21.3	-1.26	-4.78
ZPMV 28015 x $ICMA_1$ 92888	0.22	-3.11*	22.0	-1.51	0.56
ZPMV 28015 x $ICMA_1$ 95555	-0.02	0.98	4.5	1.24	-2.19
ZPMV 28015 x $ICMA_1$ 97111	0.34*	-4.28**	20.4	3.16	6.09*
ZPMV 28015 x $ICMA_1$ 00444	0.05	3.47*	4.5	-0.51	5.00*
ZPMV 28015 x $ICMA_4$ 99555	0.22	-0.36	4.9	1.66	2.29
ZPMV 28015 x $ICMA_4$ 01333	-0.15	-0.19	-23.4	-0.09	-4.57
ZPMV 28015 x $ICMA_4$ 02999	-0.35*	-3.61*	-18.0	-5.01**	-4.82
ZPMV 28015 x $ICMA_4$ 04777	-0.14	-3.69*	-23.3	1.49	1.25
ZPMV 28015 x $ICMA_4$ 05222	-0.08	-0.52	-11.7	1.58	-1.55
ZPMV 28015 x NCD_2A_4	0.08	3.39*	17.1	-0.67	-1.11
ZPMV 28015 x $LCICA_4$	-0.12	4.22**	19.6	0.57	1.39
ZPMV 28017 x $ICMA_1$ 863	-0.07	-5.71***	10.3	-2.24	-6.28*
ZPMV 28017 x $ICMA_1$ 88004	0.26	-5.54***	11.1	2.43	5.43*
ZPMV 28017 x $ICMA_1$ 92888	0.01	-0.96	6.2	2.51	2.53
ZPMV 28017 x $ICMA_1$ 95555	-0.03	3.13*	-6.3	-0.74	-1.61
ZPMV 28017 x $ICMA_1$ 97111	-0.14	-2.12	-17.2	-2.82	-2.33
ZPMV 28017 x $ICMA_1$ 00444	0.17	5.63***	10.3	2.85	1.54
ZPMV 28017 x $ICMA_4$ 99555	-0.25	1.79	-0.9	-0.66	-4.00
ZPMV 28017 x $ICMA_4$ 01333	0.14	1.96	9.0	-2.07	-1.42
ZPMV 28017 x $ICMA_4$ 02999	-0.03	-1.46	-2.2	-1.65	-0.31
ZPMV 28017 x $ICMA_4$ 04777	-0.13	-1.54	-10.9	-2.82	-2.61
ZPMV 28017 x $ICMA_4$ 05222	-0.01	1.63	-14.3	0.26	0.76
ZPMV 28017 x NCD_2A_4	0.01	5.54***	-0.5	2.35	2.46
ZPMV 28017 x $LCICA_4$	0.08	6.38***	5.3	2.59	5.83*

Table 12 continues

	SCA EFFECTS				
CROSSES	GYD	DOF	PH	PL	PWT
57000R_1W x $ICMA_1$ 863	-0.06	-6.50***	-12.1	1.35	-2.59
57000R_1W x $ICMA_1$ 88004	-0.14	-6.33***	-19.6	-4.65**	-3.27
57000R_1W x $ICMA_1$ 92888	-0.10	-1.75	-16.3	1.10	-0.17
57000R_1W x $ICMA_1$ 95555	0.10	2.34	16.2	0.19	4.35
57000R_1W x $ICMA_1$ 97111	0.04	-2.92	22.0	1.77	0.58
57000R_1W x $ICMA_1$ 00444	-0.13	4.83**	1.2	0.77	-0.66
57000R_1W x $ICMA_4$ 99555	-0.03	1.00	-8.4	-1.40	2.32
57000R_1W x $ICMA_4$ 01333	0.21	1.17	8.3	-1.48	-3.64
57000R_1W x $ICMA_4$ 02999	0.30	-2.25	13.7	3.27	8.71***
57000R_1W x $ICMA_4$ 04777	0.10	-2.33	3.3	0.77	0.24
57000R_1W x $ICMA_4$ 05222	-0.20	0.84	16.6	1.19	0.52
57000R_1W x NCD_2A_4	-0.07	4.75**	-16.3	-2.07	-2.94
57000R_1W x $LCICA_4$	-0.01	5.58***	-8.8	-0.81	-3.44
Standard error	0.15	1.48	11.94	1.77	2.47

GYD = grain yield, DOF = days to 50% flowering, PH = plant height, PL = panicle length, PWT = panicle weight, Se = standard error
*, **, ***, SCA effects significant at $p \leq 0.05$, $p \leq 0.01$ and $p \leq 0.001$ respectively

Table 13: Variance components and Baker's ratio for yield and other characters evaluated at Longe in the rainy season 2012/2013.

	Variance Components			Baker's Ratio
CHARATER	$\sigma^2_{GCA(Male)}$	$\sigma^2_{GCA(Female)}$	σ^2_{SCA}	
GYD	0.00	0.008	0.01	0.44
DOF	0.077	12.0	12.087	0.50
PH	0.00	0.00	159.1	0.11
PT/P	0.00	0.198	0.243	0.45
PL	0.00	7.502	3.383	0.68
PG	0.00	0.039	0.013	0.74
PWT	0.00	9.685	13.087	0.41

GYD = grain yield, DOF = days to 50% flowering, PH = plant height, PT/P = productive tillers per plant, PL = panicle length, PG = panicle girth, PWT = panicle weight

Days to 50% flowering

Significant (P<0.05) GCA effects for days to 50% flowering were observed for some male and female parents. Male parent ZPMV 28015 had significantly (P<0.001) positive GCA effect (1.48) while ZPMV 28014 and ZPMV 28017 had significantly (P<0.001) negative GCA effects (-0.93 and -0.67, respectively) for days to 50% flowering. Six female parents; $ICMA_1$ 863, $ICMA_1$ 88004, $ICMA_1$ 92888, $ICMA_1$ 97111, $ICMA_4$ 02999, and $ICMA_4$ 04777 had significant (P<0.001, P<0.001, P<0.05, P<0.001, P<0.01, and P<0.01, respectively) positive GCA effects (6.38, 6.21, 1.63, 2.80, 2.13 and 2.21, respectively) while $ICMA_1$ 95555, $ICMA_1$ 00444, $ICMA_4$ 01333, NCD_2 A_4 and LCIC A_4 had significant (P<0.01, P<0.001, P<0.05, P<0.001 and P<0.001, respectively) negative GCA effects (-2.46, -4.95, -1.29, -4.87 and -5.70, respectively) for days to 50% flowering.

Significant SCA effects for days to 50% flowering were observed in twenty six crosses. Out of the fourteen crosses that had significant (P<0.05) positive SCA effects, seven crosses; ZPMV 28014 x $ICMA_4$ 00444, ZPMV 28014 x NCD_2 A_4, ZPMV 28014 x LCIC A_4, ZPMV 28017 x $ICMA_1$ 00444, ZPMV 28017 x NCD_2 A_4, ZPMV 28017 x LCIC A_4, and, $57000R_1W$ x LCIC A_4, showed highly significant (P<0.001) positive SCA effects (5.88, 5.80, 6.63, 5.63, 5.54, 6.38 and 5.58, respectively) for days to 50% flowering. On the other hand, out of the twelve crosses that exhibited significant (P<0.05) negative SCA effects, eight crosses, ZPMV 28014 x $ICMA_1$ 863, ZPMV 28014 x $ICMA_1$ 88004, ZPMV 28015 x $ICMA_1$ 863, ZPMV 28015 x $ICMA_1$ 88004, ZPMV 28017 x $ICMA_1$ 863, ZPMV 28017 x $ICMA_1$ 88004, $57000R_1W$ x $ICMA_1$ 863 and $57000R_1W$ x $ICMA_1$ 88004 showed highly significant (P<0.001) negative SCA effects (-5.45, -5.28, -7.86, -7.69, -5.71, -5.54, -6.50 and -6.33, respectively) for days to 50% flowering.

The Baker's ratio for days to 50% flowering (0.50) was observed to be equal to 0.50.

Plant height

Only one female parent $ICMA_1$ 00444 had significantly (P<0.001) negative GCA effect (-20.69) for plant height.

Significant ($P<0.05$) SCA effects for plant height were observed in three crosses. ZPMV 28014 x $ICMA_4$ 88004 and ZPMV 28014 x $ICMA_4$ 04777 showed significant ($P<0.05$) positive SCA effects (29.7, and 31.0, respectively) while ZPMV 28001 x $ICMA_1$ 97111 exhibited significant negative SCA effect (-25.3) for plant height.

The observed Baker's ratio (0.11) for plant height was less than 0.50.

Productive tillers per plant

The female parent, LCIC A_4 exhibited significantly ($P<0.001$) positive GCA effect (1.26) while $ICMA_1$ 88004 showed significantly ($P<0.001$) negative GCA effect (-1.23) for productive tillers per plant.

None of the crosses showed significant SCA effects for number of productive tillers per plant.

Results showed that the observed Baker's ratio (0.45) for productive tillers per plant was less than 0.50.

Panicle length

Significant ($P<0.05$) GCA effects for panicle length were observed for some female parents. $ICMA_1$ 863, $ICMA_1$ 88004 and $ICMA_4$ 99555 had significant ($P<0.001$, $P<0.001$, and $P<0.05$, respectively) positive GCA effects (3.16, 5.49, and 2.24, respectively) while $ICMA_1$ 00444, NCD_2 A_4 and LCIC A_4 had significantly ($P<0.001$) negative GCA effects (-4.92, -4.09, and -4.01, respectively) for panicle length.

Significant ($P<0.05$) SCA effects for panicle length were observed in three crosses. ZPMV 28014 x $ICMA_4$ 01333 showed significant ($P<0.05$) positive GCA effect (3.65) while ZPMV 28015 x $ICMA_4$ 02999 and $57000R_1W$ x $ICMA_1$ 88004 showed significant ($P<0.01$) negative SCA effects (-5.01, and -4.65, respectively) for panicle length.

The observed baker's ratio (0.68) for panicle length was greater than 0.50.

Panicle girth

Four female parents had significant (P<0.05) GCA effects panicle girth. $ICMA_1$ 88004 and $ICMA_4$ 04777 had significant (P<0.001, and P<0.05, respectively) positive GCA effects (0.43 and 0.23, respectively) while $ICMA_1$ 863 and LCIC A_4 had significant (P<0.01 and P<0.05, respectively) negative GCA effects (-0.33 and -0.23, respectively) for panicle girth.

None of the crosses showed significant SCA effects for panicle girth.

The Baker's ratio for panicle girth (0.74) was greater than 0.50.

Panicle weight

Significant (P<0.05) GCA effects for panicle weight were observed on some female parents. $ICMA_1$ 863, $ICMA_1$ 88004, $ICMA_1$ 01333, and $ICMA_4$ 02999 had significant (P<0.01, P<0.001, P<0.01, and P<0.05, respectively) positive GCA effects (3.41, 7.27, 4.16 and 2.75, respectively) while $ICMA_1$ 00444 and LCIC A_4 had significantly (P<0.001) negative GCA effects (-5.25 and -5.96, respectively) for panicle weight.

Significant (P<0.05) SCA effects for panicle weight were observed in nine crosses. ZPMV 28014 x $ICMA_1$ 863, ZPMV 28014 x $ICMA_1$ 01333, ZPMV 28015 x $ICMA_1$ 97111, ZPMV 28015 x $ICMA_1$ 00444, ZPMV 28017 x $ICMA_1$ 88004, ZPMV 28017 x LCIC A_4, and 57000R_1W x $ICMA_4$ 02999 had significant (P<0.05, P<0.001, P<0.05, P,0.05, P<0.05, P<0.05, and P<0.001, respectively) positive SCA effects (6.48, 9.63, 6.09, 5.0, 5.43, 5.83, and 8.71, respectively) while ZPMV 28014 x $ICMA_1$ 00444 and ZPMV 28017 x $ICMA_1$ 863_4 showed significant (P<0.05) negative SCA effects (-5.89 and -6.28, respectively) for panicle weight.

Baker's ratio for panicle weight (0.41) was less than 0.50.

4.2.3 Correlation between grain yield and other characters in pearl millet at Longe

Phenotypic correlations between yield and other characters are presented in Table 14 below. A highly significant (P<0.001) strong positive correlation (r = 0.56 and r = 0.47) of grain yield was observed with plant height and panicle weight, respectively. In addition, significant (P<0.05) weak positive correlation (r = 0.27 and r =0.25) of grain yield was observed with panicle length and panicle girth. On the other hand, non-significant correlation of yield was observed days to 50% flowering and productive tillers per plant.

Table 14: Correlation between yield and other characters in pearl millet evaluated at Longe in the rainy season 2012/2013.

Days to 50% flowering	0.12
Plant height	0.56***
Productive tillers per plant	-0.07
Panicle length	0.27*
Panicle girth	0.25*
Panicle weight	0.47***

*, **, *** Data significant at $P \leq 0.05$, $P \leq 0.01$, and $P \leq 0.001$, respectively.

CHAPTER FIVE

5.0 Discussion

Pearl millet is an important cereal crop which is predominantly grown as a staple food grain and source of feed and folder in arid and semi-arid regions of Africa and Asia (Lakshmana, 2008). Due to the increase in the problem of food security in Africa, pearl millet has been recognized as a potential buffer against famine (FAOSTAT, 2003). However, available statistics have demonstrated the reduction of pearl millet production in Zambia (MACO & CSO, 2011). One of the major reasons for the decline in pearl millet production is the low yields.

5.1 Variation among pearl millet genotypes for yield and other selected important agronomic traits

Significant variability among the crosses for most of the characters studied at both sites offer an opportunity for genetic improvement as superior ones can be isolated from the rest (Table 3 and Table 9). Genetic variation has been found to be an important prerequisite to improvement of those traits showing variation (Lakshmana, 2008).

Increasing grain yield and yield stability is major breeding objective to improving pearl millet (Baskaran et al. 2009). Considerable variation in grain yield was observed among the crosses ranging from 0.44 tons/ha to 1.52 tons/ha at ZCA-Monze and from 0.57 tons/ha to 1.46 tons/ha at Longe (Table 4 and Table 10). ZPMV 28011 x $ICMA_1$ 92888 (1.52 ton/ha) and $57000R_1W$ x $ICMA_4$ 02999 (1.46 ton /ha) had the highest yields at ZCA-Monze and Longe, respectively while ZPMV 28001 x $ICMA_1$ 00444 (0.44 ton/ha) and ZPMV 28015 x LCIC A_4 (0.57 ton/ha) had the lowest yields at ZCA-Monze and Longe respectively. A higher average yield was obtained at ZCA-Monze (1.04 tons/ha) compared to that at Longe (0.97 tons/ha).

It is evident from the results that high yielding crosses tended to be the earliest at ZCA-Monze but latest at Longe, while the reverse was true for low yielding crosses (Table 4 and Table 10, respectively). The results at ZCA-Monze supports the general phenomenon that high yielding is enhanced by early flowering as it allows for an extended grain filling period. However, the situation at Longe is contrary to this expected phenomenon and this could only be attributed to the mid-season drought (though no rainfall data were obtained at both sites) that could have disadvantaged the early flowering material resulting in depressed yield due to drought effect on the critical reproductive stage. The observed results at Longe, therefore, are in line with Wilson (2011) who stated that drought stress during flowering through to grain fill results in low and unstable yields. Yadav (2010) also pointed out that post-flowering drought stress is one of the most important environmental factors reducing grain yield by as much as 70%.

In the current study, the high yielding crosses grew taller than the low yielding ones at both sites (Table 4 and Table 11). This result can be attributed to the fact that increased plant height results in increased amounts of assimilates stored in the stem, and hence the amount of assimilates channeled (and invested) to the reproductive parts of the crop leading to increased grain yield. Mainassara (2012) and Obeng et al. (2012) working on pearl millet also observed that increasing plant height had directly increased grain yield.

It was also observed that the high yielding crosses generally tended to have fewer numbers of productive tillers per plant than the low yielding ones. This is because as the number of tillers increased, assimilate translocation to the panicles also reduces leading to a smaller panicles (sink) and ultimately low grain yield. Sile et al. (2004) reported that, non-tillering cultivars of millet produced larger seeds than the tillering ones. Maman et al. (2004) also reported that, reducing pearl millet productive tillers from 10 to 3 or 5 increased grain yields by 15-30%. However, studies by Govindaraj et al. (2009) and Obeng et al. (2012) had shown significant positive correlation of grain yield with number of productive tillers per plant.

Panicle length, panicle girth and panicle weight are important components of grain yield. At ZCA-Monze, these traits had no significant correlation with grain yield, however, at Longe the high yielding crosses tended to have longer, larger and heavier panicles than the low yielding crosses as confirmed by the significant positive correlation between grain yield and these traits. This can be attributed to the high investment of assimilates into the panicles resulting in large and heavy panicles. Govindaraj et al. (2009) and Rajesh et al. (2004) also reported strong positive correlation for the correlation between grain yield and panicle girth and panicle weight respectively.

5.3 *Gene action controlling yield in pearl millet*

The male parents varied significantly ($P<0.01$) for their general combining ability (GCA) for grain yield at ZCA-Monze while the female parents varied significantly for their GCA for grain yield Longe (Table 3 and Table 9, respectively). This indicated variation among the female parents in terms of their GCA effects, as well as the male parents that were used at ZCA-Monze. In the current study, significant ($P<0.05$) positive GCA effects for grain yield observed (Table 5 and Table 11) in the three male parents; ZPMV 28001 (0.09), ZPMV 28010 (0.10), and ZPMV 28011 (0.10) and two female parents; NCD_2 A_4 (0.15) and $ICMA_4$ 02999 (0.22) suggest these parents are the best general combiners for grain yield and, therefore, can be used in hybrid combination to improve grain yield. On the other hand, the significant ($P<0.05$) negative GCA effects observed in the male parent; ZPMV 28013 (-0.11) and female parents $ICMA_4$ 01333 (-0.22), $ICMA_1$ 00444 (-0.16) and LCIC A_4 (-0.22) suggest that these parents are poor combiners for grain yield. The variation observed among parents for their ability as suitable combiners was similar to the observations by Dhuppe et al. (2006) and Shelke and Chavan (2007) who observed significant positive GCA effects for grain yield in some parents.

Therefore, inbred lines; ZPMV 28001, ZPMV 28010, ZPMV 28011, NCD_2 A_4 and $ICMA_4$ 02999 as judged by their significant positive GCA effects for grain yield, are identified as the superior inbred lines suitable for generating hybrids of pearl millet.

Since significant ($P<0.05$) positive SCA effects were observed for five crosses; ZPMV 28010 x $ICMA_1$ 00444 (0.30), ZPMV 28011 x $ICMA_1$ 92888 (0.39), ZPMV 28011 x $ICMA_4$ 04777 (0.30), ZPMV 28013 x $ICMA_1$ 97111 (0.30), and ZPMV 28015 x $ICMA_1$ 97111 (0.34) it can be deduced that these crosses are the best combinations (hybrids) for grain yield and can be used in the breeding programme for the improvement of grain yield (Table 6 and Table 12). This shows that out of the 104 crosses that were evaluated only a few (five crosses) were identified to be good combinations for yield. This could be attributed to G x E interaction as well as the type of parents that were used to generate the crosses. This observation was similar to what was observed by Karad and Harer (2005), and Dhuppe et al. (2006) who observed only a few crosses to be good combinations for grain in their line x tester crossing.

The inheritance of grain yield results revealed that the contribution of $\sigma^2_{GCAfemale}$ to total variance was lower than the contribution of the $\sigma^2_{GCAmale}$ at ZCA-Monze while the reverse was true at Longe (Table 7 and Table 13). The difference in the contribution of the female parents used in the study can be attributed mainly to the genotype x environment (G x E) interaction and, therefore, different female parents were selected in each environment. This is also seen in the non-significant GCA_{female} at ZCA-Monze and the significant (P<0.01) GCA_{female} at Longe (Table 3 and Table 9). The phenomenon observed above is similar to the one that was observed by Mukanga et al. (2008) who pointed out that high G x E made their selection difficult, and that, different sets of genotypes were selected in each environment. Yadav et al. (2012) also pointed out that both the additive and dominance genetic components can interact with changes in the environment. Therefore, this suggests the need to conduct multi-location trials in order to identify genotypes with stable grain yields. Males could also be a contributing factor, as different males were used for each site.

Furthermore, the higher contribution of SCA (82 % at ZCA-Monze and 56% at Longe) than GCA (18% at ZCA-Monze and 44% at Longe) contribution to total variance for grain yield, meant that non-additive gene effects are more important than additive effects in the inheritance of grain yield. This was further supported by Barker's ratio of 0.18 and 0.44 for ZCA-Monze and Longe, respectively indicating the predominance of SCA over GCA. This implies that high grain yields can only be realised by developing new hybrids using suitable recombinants of biparental progenies. This result is in agreement with Sushir et al. (2005), Izge et al. (2007) and Chotaliya et al. (2010) who revealed that non-additive gene action is more important than additive gene action in the inheritance of grain yield in pearl millet. However, the difference in the magnitude of the observed GCA and SCA at the two sites is an indication that there could be GCA x environment and SCA x environment interaction effects. This observation is similar to Mukanga et al. (2008), who observed significant GCA x environment and suggested that it was necessary to select parental lines to obtain crosses for specific environments.

The male and female parents used in the study had low contribution to total variance for grain yield (Table 7 and Table 13). Since grain yield is mainly controlled by non-additive gene action which can be exploited by developing hybrids using suitable recombinants of biparental progenies, the selected superior inbred lines and cross combinations represent a good choice for the development of high yielding varieties (hybrid varieties).

Among the parents that had significant positive GCA effects for grain yield; ZPMV 28001 and $ICMA_4$ 02999 had significant ($P<0.01$) positive GCA effects (1.29 and 2.13 respectively) for days to 50% flowering (Table 5 and Table 11). Similarly, ZPMV 28010 and NCD_2 A_4 had significant positive GCA effect for grain yield but non-significant negative GCA effect (-0.68 and -0.92) for days to 50% flowering. The positive contribution to grain yield is associated with contribution to early flowering. Earliness in maturity is desirable for escaping drought conditions (Dangariya et al., 2009 and Gowda et al., 2009). This result is in agreement with Haussmann et al. (2005) and Dangariya et al. (2009) who observed that most of the parents with significant positive GCA effects for grain yield had significant positive GCA effects for days to 50% flowering.

Among all the five crosses that showed significant positive SCA effects for grain yield only ZPMV 28015 x $ICMA_1$ 97111 had a significant ($P<0.001$) negative SCA effect (-4.28) for days to 50% flowering and was considered as the best combination for both grain yield and days to 50% flowering, indicating its potential for developing an early hybrid. Similar results were reported by Joshi et al. (1996) and Shelke and Chavan (2007) where some hybrids with significant positive SCA effects for grain yield and significant negative SCA effects for days to flowering were considered as the best combinations for grain yield and days to 50% flowering. However, the performance of the five crosses showed that they were either early or medium maturing, therefore they can be developed into acceptable hybrid varieties.

The inheritance of days to 50% flowering, results revealed variable contribution of the $\sigma^2_{GCAfemale}$ and $\sigma^2_{GCAmale}$ to total variance at both sites (Table 7 and Table 13). The female parents had a greater contribution to total variance than the male parents. This means that the female parents had played a greater role than the male parents in explaining variation of days to 50% flowering in the crosses.

In addition, results at ZCA-Monze showed that the contribution of SCA (14 %) to total variance was lower than GCA (86%), indicating that additive gene effects are more important than non-additive effects in the inheritance of days to 50% flowering. This was further confirmed by Barker's ratio of 0.86, indicating the predominance of GCA over SCA. On the other hand, results at Longe showed that the contribution of the GCA (50%) to total variance was equal to the contribution of SCA (50%), indicating the importance of both additive and non-additive gene effects in the inheritance of days to 50% flowering in pearl millet. This was further supported by Baker's ratio of 0.50. This result was as a result of the higher contribution of the GCA_{female} which was almost equivalent to the SCA to total variance. The above observation can also be attributed to the interaction of GCA and SCA with the environment at the two sites. Males could also be a contributing factor. The results at ZCA-Monze are in line with Lynch et al. (1995) and Eldie et al. (2006) who revealed that additive gene action is more important than non-additive gene action in the inheritance of days to 50% flowering in pearl millet while results at Longe are supported by Yagya et al. (2002) and Chotaliya et al. (2010) who revealed the importance of both additive and non-additive gene action gene action in the inheritance of days to 50% flowering in pearl millet. However, studies (in pearl millet) by Sushir et al. (2005), Haussmann et al. (2005) and Shelke and Chavan (2007) revealed that days to 50% flowering was largely controlled by non-additive gene effects.

The significant ($P<0.05$) positive GCA effects for plant height observed in the two male parents; ZPMV 28001 (15.13) and ZPMV 28010 (7.92) (Table 5) with significant positive GCA effects for grain yield suggests that these parents are the best general combiners for plant height and therefore can be used in hybrid combination to improve grain yield. However, male parent; ZPMV 28011 had significant ($P<0.05$) negative GCA effect (-5.96) for plant height and was considered as a poor general combiner for this trait. Since biological and economic yield of the crop can be influenced by the interaction of source and sink, increased plant height improves the photosynthetic rate of the source leaves and hence the amount of assimilates channeled to the reproductive parts of the crop leading to increased grain yield. Similar results were obtained by Shelke and Chavan (2007) and Dangariya et al. (2009) where genotypes with significant positive GCA effect for grain yield had significant positive GCA effects for plant height.

None of the four crosses with significant positive SCA effects for grain yield showed significant positive SCA effects for plant height (Table 6 and Table 12). However, only ZPMV 28011 x $ICMA_1$ 92888 had significant ($P<0.05$) negative SCA effect (-24.0) for plant height and was regarded as a poor specific combiner for plant height.

On the inheritance of plant height, results at ZCA-Monze indicated that the contribution of $\sigma^2_{GCAfemale}$ to total variance was higher than the contribution of the $\sigma^2_{GCAmale}$ (Table 7). However, results at Longe showed that the contribution of both $\sigma^2_{GCAfemale}$ and $\sigma^2_{GCAmale}$ to total variance were very low (Table 13). The difference in the contribution of the female parents to total variance can be attributed to the effect GCA x environment interaction on plant height.

Furthermore, the contribution of SCA (43 %) to total variance was lower in magnitude than GCA (57%) at ZCA-Monze, indicating the importance of additive gene effects in the inheritance of this trait. This was further supported by Barker's ratio of 0.57, indicating the predominance of GCA over SCA. At Longe, the contribution of the GCA (11%) to total variance was lower than the contribution of SCA (89%), indicating the importance of non-additive gene actions in the inheritance of plant height in pearl millet. This was further supported by Baker's ratio of 0.11. The difference in the nature of gene action responsible for the inheritance of plant height at the two sites can be attributed to the effects of both GCA x environment and SCA x environment interactions on plant height. Males could also be a contributing factor. The results at ZCA-Monze are in agreement with Eldie et al. (2006) and Chotaliya et al. (2010) who revealed that additive gene action is more important than non-additive gene action in the inheritance of plant height in pearl millet. The results at Longe are in agreement with Joshi et al. (1995) and Izge et al. (2007) who revealed the importance of non-additive gene action gene action in the inheritance of plant height in pearl millet.

The inbred lines; ZPMV 28001 and ZPMV 28010 can be used for indirect selection for grain yield. The contribution of the female parents to total variance was higher than the contribution of the male parents. Results from the two sites do not give a clear picture on the inheritance of plant height as they are in conflict probably due to the GCA x environment and SCA x environment interactions, suggesting the need to select parental lines to obtain crosses for specific environments. The other reason could be the fact different materials were used at the two sites.

In the current study, none of the inbreds with significant positive GCA effects for grain yield had significant ($P<0.05$) positive GCA effects for productive tillers per plant. This due to the fact that high tillering in pearl millet results in reduced grain yields due to the reduced sink size (panicle size). Maman et al. (2004) also reported that, reducing pearl millet productive tillers from 10 to 3 or 5 increased grain yields by 15-30%.

Since significant ($P<0.05$) positive SCA effect was observed for one cross; ZPMV 28011 x $ICMA_1$ 92888 (0.79), it can be deduced that this cross is the best hybrid combination for both grain yield and productive tillers per plant, and can be used in a breeding programme for the improvement of both fodder yield and grain yield (Table 6 and Table 12). Similar results were obtained by Haussmann et al. (2005) and Shelke and Chavan (2007) in which some crosses with significant positive SCA effects for grain yield had significant SCA effects for productive tillers per plant.

The inheritance of productive tillers per plant results revealed variable contribution of the $\sigma^2_{GCAfemale}$ and $\sigma^2_{GCAmale}$ to total variance at the sites used (Table 7 and Table 13). That is the contribution of the female parents to total variance was higher than the contribution of the male parents at both sites. This implies that the female parents played a greater role in explaining variation in the number of productive tillers per plant than the male parents.

In addition, results showed that the contribution of SCA at ZCA-Monze and Longe (74 % and 55 % respectively) to total variance was higher in magnitude than GCA (26% and 45% respectively), indicating that non-additive gene effects are more important than additive gene effects in the inheritance of productive tillers per plant. This was further supported by Barker's ratio of 0.45 and 0.26 for ZCA-Monze and Longe respectively, indicating the predominance of SCA over GCA. This means that a greater improvement for grain yield and number of productive tillers per plant may be brought about by developing hybrids and exploitation of hybrid vigour by other breeding methods such as recurrent selection. This result is in agreement with Shelke and Chavan (2007) and Izge et al. (2007) and who revealed that non-additive gene action is more important than additive gene action in the inheritance of productive tillers per plant in pearl millet.

The contribution of the female parents was greater than the contribution of the male parents for productive tillers per plant. Non-additive gene effects are more important than additive gene effects in the inheritance of number of productive tillers per plant in pearl millet. Therefore, the crosses ZPMV 28011 x $ICMA_1$ 92888 can be developed into hybrid varieties in order to improve both grain yield and fodder yield.

Panicle length, panicle girth and panicle weight are important components of grain yield. However, none of the male and female parents with significant positive GCA effects for grain yield had significant positive GCA effects for panicle length while only ZPMV 28001 showed significant ($P<0.001$) negative GCA effect (-1.66) (Table 5 and 11) for panicle length and was considered as the poor general combiner for this trait.

None of the crosses with significant positive SCA effects for grain yield had either negative or positive significant SCA effects for panicle length (Table 6 and Table 12).

The inheritance of panicle length results revealed variable contribution of $\sigma^2_{GCAfemale}$ and $\sigma^2_{GCAmale}$ to total variance at both sites (Table 7 and Table 13). Results indicated that the contribution of male parents to total variance was higher than the contribution of the female parents at ZCA-Monze whilst the reverse was true for Longe. This implies that the male parents played a greater role in explaining variation in the panicle length than the male parents at ZCA-Monze whilst the reverse was true for Longe.

Results also showed that the contribution of SCA for both ZCA-Monze and Longe (39 % and 32 %, respectively) to total variance was lower in magnitude than GCA (61% and 68%, respectively), indicating that additive gene effects are more important than non-additive effects in the inheritance of this trait (Table 7 and Table 13). This was further supported by Barker's ratio of 0.61 and 0.68 for ZCA-Monze and Longe, respectively, indicating the predominance of GCA over SCA. This means that panicle length can be further improved in the parental lines by selection. Similar results were reported by Sushir et al. (2005), Izge et al. (2007), Shelke and Chavan (2007) and Chitoliya et al. (2010) who revealed that additive gene action is more important than non-additive gene action in the inheritance of panicle length in pearl millet.

Additive gene effects are more important than non-additive gene effects in the inheritance of panicle length. Therefore, inbred lines ($ICMA_1$ 88004, $ICMA_1$ 863, $ICMA_1$ 05222 and $ICMA_4$ 99555) with significantly positive GCA effects for panicle length but non-significant GCA effects for grain yield can be used in a breeding programme for the improvement of panicle length.

Among the parents that showed significant positive GCA effects for grain yield, male parent ZPMV 28001 and female parent NCD_2 A_4 had significant ($P<0.001$ and $P<0.05$, respectively) positive GCA effects (0.24 and 0.12, respectively) for panicle girth suggesting that these parents are good general combiners for panicle girth and therefore, can be used in hybrid combination to improve both grain yield and panicle girth. This is due to fact that high grain yield potential can be realised more readily through investment in large panicles. Similar results were reported by Shelke and Chavan (2007) and Dangariya et al. (2009) where some genotypes with high grain yield had large panicle girth.

The cross combination ZPMV 28013 x $ICMA_1$ 97111 that showed significantly ($P<0.01$) positive SCA effects (0.53) for panicle girth (Table 6) was regarded as best cross combination for both panicle girth and grain yield and, therefore, can be used in a breeding programme for the improvement of both grain yield and panicle girth.

The inheritance of panicle girth results revealed variable contribution of $\sigma^2_{GCAfemale}$ and $\sigma^2_{GCAmale}$ to total variance at both sites (Table 7 and Table 13). Results indicated that the contribution of female parents to total variance was higher than the contribution of the male parents at both sites. This implies that the female parents played a greater role in explaining variation in the panicle girth than the male parents.

In addition, results showed that the relative importance between GCA and SCA was variable at both sites, indicating the predominance of one over the other. Results for both ZCA-Monze and Longe showed that the contribution of SCA (41 % and 26 %, respectively) to total variance was lower in magnitude than GCA (59% and 74%, respectively) indicating that additive gene effects are more important than non-additive effects in the inheritance of this trait. This was further supported by Barker's ratio of 0.59 and 0.74 for ZCA-Monze and Longe respectively, indicating the predominance of GCA over SCA. This means that panicle girth can be further improved in the parental lines by selection. Similar results were reported by Shelke and Chavan (2007) and Chitoliya et al. (2010) who revealed that additive gene action is more important than non-additive gene action in the inheritance of panicle girth in pearl millet.

Panicle girth is largely controlled by additive gene effects. The female parents had a greater contribution to total variance than the male parents, therefore, inbred line; NCD_2

A_4 represents a good choice for the improvement of both grain yield and panicle girth. On the other hand, the cross combinations ZPMV 28013 x $ICMA_1$ 97111 can be used as a hybrid variety to improve both panicle girth and grain yield.

The significant ($P<0.05$) positive GCA effects for panicle weight in the male parent ZPMV 28010 (2.30) and the female parent $ICMA_4$ 02999 (2.75) (Table 5 and Table 11) suggest that these parents were the best general combiners for panicle weight and therefore, can be used in hybrid combination to improve panicle weight and ultimately grain yield. However, the significant ($P<0.05$) negative GCA effect (-1.63) exhibited by male parent ZPMV 28011 suggest that this parent is a poor general combiner for panicle weight and cannot be useful in the improvement of panicle weight. Similar results were reported by Srikant et al. (2003) and Dangariya et al. (2009) were some parents with significant GCA effects for grain yield had significant positive GCA effects for panicle weight.

The crosses, ZPMV 28013 x $ICMA_1$ 97111 and ZPMV 28015 x $ICMA_1$ 97111 that showed significant ($P<0.01$ and $P<0.05$, respectively) positive SCA effects (7.02 and 6.09, respectively) (Table 6 and Table 12) for panicle weight were regarded as the best combinations (hybrids) for both grain yield and panicle weight and, therefore, can be used in a breeding programme for the improvement of panicle weight and most of all grain yield. This is due to the fact that panicle weight is related to high grain yield potential through a greater investment of assimilates into panicle mass and individual grain mass (Van Oosterom, 2003). Similar results were also obtained by Joshi et al (1995) and Dangariya et al. (2009) who observed significant positive SCA effects for panicle weight in crosses having significant SCA effects for grain yield.

The inheritance of panicle weight results revealed variable contribution of the $\sigma^2_{GCAfemale}$ and $\sigma^2_{GCAmale}$ to total variance at both sites (Table 7 and Table 13). Results indicated that the contribution of the female parents to total variance was higher in magnitude than the contribution of the male parents at both sites. This implies that the female parents played a greater role in explaining variation in the panicle weight than the male parents.

Furthermore, results for both ZCA-Monze and Longe showed that the contribution SCA (59 % and 57 % respectively) to total variance was higher in magnitude than GCA (41% and 43% respectively), indicating that non-additive gene effects are more important than additive effects in the inheritance of panicle weight. This was further supported by Barker's ratio of 0.41 and 0.43 for ZCA-Monze and Longe respectively, indicating the predominance of SCA over GCA. This means that a greater improvement for grain yield and panicle weight may be brought about by developing hybrids and exploitation of hybrid vigour by other breeding methods. Similar results were reported by Joshi et al. (1995) and Eldie et al. (2006) who revealed that non-additive gene action is more important than additive gene action in the inheritance of panicle weight in pearl millet.

Panicle weight is largely controlled by non-additive gene action. The female parents had a greater contribution to total variance than the male parents, therefore, inbred lines; $ICMA_4$ 0299 represents a good choice for the improvement of both grain yield and panicle weight. On the other hand, the cross combinations ZPMV 28013 x $ICMA_1$ 97111 and ZPMV 28015 x $ICMA_1$ 97111can be used as hybrid varieties to improve both panicle weight and grain yield.

CHAPTER SIX

6.0 Conclusions

This study which characterised pearl millet genotypes in order to establish a basis for exploiting the genetic potential of pearl millet for the development of high yielding (hybrid) varieties in Zambia revealed significant variability among the crosses for most of the characters studied pointing to potential for genetic improvement in pearl millet as superior ones can be isolated from the rest.

On the basis of GCA analysis for grain yield, the male parents; ZPMV 28001, ZPMV 28010 and ZPMV 28011 and female parents; NCD_2 A_4 and $ICMA_4$ 02999 were identified as the superior inbred lines suitable for generating hybrids in pearl millet.

On the basis of SCA analysis five crosses; ZPMV 28010 x $ICMA_1$ 00444, ZPMV 28011 x $ICMA_1$ 92888, ZPMV 28011 x $ICMA_4$ 04777, ZPMV 28013 x $ICMA_1$ 97111, and ZPMV 28015 x $ICMA_1$ 97111 were identified as superior hybrids that can be used in a breeding programme for producing high yielding hybrid varieties.

The determination of the nature of gene action according to Baker's ratio revealed that grain yield, productive tillers per plant and panicle weight are largely controlled by non-additive gene action while panicle girth and panicle length are largely controlled by additive gene action. Determination of gene action for days to 50% flowering and plant height was not consistent for the two sites.

Since grain yield is largely controlled by non-additive gene action which can only be exploited by developing hybrid varieties, it can be concluded that the selected inbred lines and cross combinations represent a good choice to make future strategy for the development of pearl millet hybrid varieties in Zambia.

To confirm the type of gene action and obtain information on heterosis, it is suggested that this trial be repeated in three locations for one or two seasons.

CHAPTER SEVEN

7.0 References

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Appendices

Appendix I: Means estimates for yield and other traits of four male and thirteen female parents at ZCA-Monze.

PARENTS	GYD	DOF	PH	PT/P	PL	PG	PWT	T%
MALE								
1. ZPMV 28001	0.95	64	2.48	2.9	25	3.38	33.6	74.2
2. ZPMV 28010	1.14	62	2.41	3.1	26	3.12	35.2	72.1
3. ZPMV 28011	1.14	62	2.27	3.5	26	3.07	31.3	73.1
4. ZPMV 28013	0.93	63	2.16	3.2	28	2.98	31.6	67.9
$LSD_{0.05}$	0.12	1.3	0.08	0.3	0.9	0.15	3.9	3.4
FEMALE								
1. $ICMA_1$ 863	0.98	67	2.61	2.5	27	2.91	35.8	71.5
2. $ICMA_1$ 88004	1.02	67	2.58	2.6	29	3.29	38.7	70.4
3. $ICMA_1$ 92888	1.02	65	2.63	2.8	26	3.16	33.2	72.1
4. $ICMA_1$ 95555	1.14	62	2.40	3.3	2 5	3.04	28.5	71.4
5. $ICMA_1$ 97111	1.15	63	2.40	3.0	26	3.27	32.8	68.9
6. $ICMA_1$ 00444	0.97	59	2.18	4.0	24	3.02	28.5	69.5
7. $ICMA_4$ 99555	1.13	62	2.29	3.3	27	2.95	32.0	75.8
8. $ICMA_4$ 01333	0.82	65	2.05	3.3	27	3.26	40.3	66.3

9. ICMA$_4$ 02999	1.06	62	2.27	2.6	27	3.58	33.8	70.4
10. ICMA$_4$ 04777	1.04	65	2.36	3.0	27	3.30	35.1	74.8
11. ICMA$_4$ 05222	1.0	60	2.15	3.1	29	2.90	30.2	68.2
12. NCD$_2$ A$_4$	1.19	62	2.31	3.5	27	3.26	32.2	75.8
13. LCIC A$_4$	1.01	59	2.03	3.9	25	2.90	22.9	75.8
LSD$_{0.05}$	0.21	2.4	0.29	0.2	1.6	0.15	3.9	69.2
Grand mean	1.04	63	2.33	3.0	26	3.14	32.9	71.1
CV%	25.0	4.6	7.8	22.0	7.6	5.7	14.7	10.5

DOF, days to 50% flowering, PH, plant height (m), PT/P, productive tillers per plant, PL, panicle length (cm), PG, panicle girth (cm), PWT, panicle weight (g), TP, threshing percent, GYD, grain yield.

Appendix II: Mean estimates for yield and other traits of four male and thirteen female parents at Longe

PARENTS	GYD	DOF	PH	PT/P	PL	PG	PWT	TP
MALE								
1. ZPMV 28014	0.99	63	1.79	3.9	30.0	2.58	25.9	71.2
2. ZPMV 28015	0.91	65	1.80	4.4	29.8	2.64	23.7	72.1
3. ZPMV 28017	1.02	63	1.77	4.1	28.7	2.62	25.0	73.1
4. 57000R_1W	0.94	64	1.86	4.4	29.5	2.55	25.1	67.9
$LSD_{0.05}$	0.12	1.2	0.09	0.6	1.4	0.15	1.9	3.4
FEMALE								
1. $ICMA_1$ 863	0.92	70	1.88	4.1	32.7	2.27	28.4	71.5
2. $ICMA_1$ 88004	1.02	70	1.90	3.0	35.0	3.03	32.2	70.4
3. $ICMA_1$ 92888	0.88	65	1.82	3.7	28.9	2.53	22.5	72.1
4. $ICMA_1$ 95555	1.08	61	1.85	4.1	28.5	2.56	25.7	71.4
5. $ICMA_1$ 97111	1.04	66	1.87	4.1	31.3	2.53	24.5	68.9
6. $ICMA_1$ 00444	0.81	59	1.60	4.6	24.6	2.44	19.7	69.5
7. $ICMA_4$ 99555	1.05	63	1.79	4.8	31.8	2.51	23.0	75.8
8. $ICMA_4$ 01333	0.91	62	1.73	3.7	30.5	2.65	29.1	66.3
9. $ICMA_4$ 02999	1.19	66	1.87	4.5	29.1	2.99	27.7	70.4

10. $ICMA_4$ 04777	0.92	66	1.79	3.7	29.6	2.83	26.6	74.8
11. $ICMA_4$ 05222	0.87	63	1.78	4.6	30.8	2.58	22.6	68.2
12. NCD_2 A_4	1.11	59	1.80	4.2	25.4	2.47	23.4	75.8
13. LCIC A_4	0.75	58	1.76	5.5	25.5	2.36	19.0	69.2
$LSD_{0.05}$	0.21	2.1	0.17	1.0	2.5	0.27	3.5	6.1
Grand mean	0.97	64	2.33	4.2	29.5	2.60	24.9	71.1
CV%	24.2	4.0	11.5	2.1	10.4	12.9	10.5	10.5

DOF, days to 50% flowering, PH, plant height (m), PT/P, productive tillers per plant, PL, panicle length (cm), PG, panicle girth (cm), PWT, panicle weight (g), TP, threshing percent, GYD, grain yield (tons/ha).