HETEROSIS AND COMBINING ABILITY FOR GRAIN YIELD AND OTHER AGRONOMIC TRAITS IN PEARL MILLET (*Pennisetum americanum* (L.) Leeke)

BY

MAINASSARA, HABIBOU
MSc./AGRIC/09777/2008-2009

A thesis submitted to the School of Postgraduate Studies, Ahmadu Bello University, in partial fulfillment of the degree of Master of Science in Plant Breeding

DEPARTMENT OF PLANT SCIENCE
FACULTY OF AGRICULTURE
AHMADU BELLO UNIVERSITY, ZARIA

MARCH, 2012

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DECLARATION

I hereby declare that, this thesis entitled "HETEROSIS AND COMBINING ABILITY FOR GRAIN YIELD AND OTHER AGRONOMIC TRAITS IN PEARL MILLET (*Pennisetum americanum* (L.) Leeke)" was written by me and is a documentation of my research findings. No part of this thesis has previously been submitted for a degree or any other qualification. References made to published and unpublished literature have been duly acknowledged.

MAINASSARA HABIBOU ……
……..

(Student) signature Date

CERTIFICATION

This thesis titled "HETEROSIS AND COMBINING ABILITY FOR GRAIN YIELD AND OTHER AGRONOMIC TRAITS IN PEARL MILLET (*Pennisetum americanum* (L.) Leeke)" by Maïnassara, Habibou meets the regulations governing the award of the degree of Master of Science of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation**.**

Prof. M. Y. Yeye …..…….…….. …….

Chairman, Supervisory Committee (Signature) (Date)

Prof. S. G. Ado …….……..

…….

Member, Supervisory Committee (Signature) (Date)

Prof. J.D. Olarewaju …….……..

…….

Member, Supervisory Committee (Signature) (Date)

Dr. I. S. Usman …….……..

…….

Head, Department of Plant Science (Signature) (Date)

Prof. A. A. Joshua	…….……..	…….
Dean, School of Postgraduate Studies	(Signature)	(Date)

DEDICATION

This work is dedicated to my late father Maïnassara, who gave me all his ultimate support.

May the Almighty ALLAH have mercy upon him (Amen).

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I would like to express my sincere gratitude to Allah, for granting me sufficient grace and mercies throughout my course of studies at Ahmadu Bello University (ABU), Zaria.

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ABSTRACT

Heterosis and combining ability for grain yield and other agronomic traits in 16 pearl millet hybrids were studied at Bengou and Maradi, Niger Republic, using the crosses obtained from two heterotic groups (Group A: Guerguera, HKB, HKP GMS, Souna3 and Group B: Ankoutess, Ex-Borno, Gamoji, Moro). The genetic populations were developed using factorial mating design. Two locations were used and the experiment was Randomized Complete Block Design with three replications. Analysis of variance showed significant differences among genotypes for plant height, peduncle length, spike length, spike diameter, days to 50% flowering and grain yield. This indicated presence of considerable influence of environment on the genotypes. At Bengou location, the hybrid Guerguera x Ex-Borno produced the highest positive heterosis for plant height (3.79%), stem diameter (3.16%), peduncle diameter (10.08%) and grain yield (128.72%). Across locations, HKB showed maximum negative GCA value for days to 50% flowering; the result showed that the line could be used in improving early maturity. Ex-Borno exhibited the highest positive GCA effects for grain yield. Specific combining ability across locations indicated that seven crosses showed improved grain yield while ten crosses manifested earliness for days to 50% flowering. Path coefficient analysis reveals that plant height, number of tillers per plant and peduncle diameter were the three factors that exerted the greatest influence both directly and indirectly upon grain yield. The correlation between grain yield and plant height as well as the direct cause of plant height on grain yield indicate that when other variables are held constant, increasing plant height could directly increase grain yield. The result indicated that indirect selection through plant height and more tillering in pearl millet could be effective for high yielding. Thus hybrids can be used to overcome the problem of recurrent production deficit over environments. It was observed from the study that Guerguera x Ex-Borno could be recommended as a good hybrid across the test locations.

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ABBREVIATIONS

DMRT: Duncan Multiple Range Test

F_1: hybrid

GCA: general combining ability

IAR: Institute for Agricultural Research, Samaru

ICRISAT: International Crops Research Institute for the Semi Arid Tropics

INRAN: National Institute for Agricultural Research of Niger

ISRA: Senegalese Agricultural Research Institute.

Loc: location

r_e: environmental correlation

r_g: genotypic correlation

r_p : phenotypic correlation

SAS : statistical analysis system

SCA: specific combining ability

σ^2: variance

CHAPTER 1

1 INTRODUCTION

Pearl millet (*Pennisetum americanum* (L.) Leeke) belongs to the family of Poaceae (formerly Gramineae) and is cultivated between 15^0 W-90^0E longitude and 5^0S-40^0N latitude which primarily includes the drier parts of the world. They are namely Indian sub-continent and East, West, North and Central Africa. In South Africa, U.S.A., Canada and Australia, pearl millet is grown as a minor fodder crop (Chahal and Gosal, 1994). Pearl millet is one of the most important West African cereals which were most likely domesticated once in the Sahelian zone of West Africa (Oumar *et al*., 2008). It was already being cultivated throughout Sahelian and tropical West African countries (D'andrea *et al*., 2001; D'andrea and Casey, 2002). The adaptation of pearl millet in West Africa was associated with an environmental gradient. Pearl millet is currently the world's sixth most important cereal grain and is grown extensively in Africa, Asia, and India (Karen, 1997). FAO STAT (2005) showed the contribution of the ten top producing countries as: India 10,610,000t; Nigeria 7,700,000t; Niger 2,781,928t; China 2,101,000t; Burkina Faso 1,104,010t; Mali 1,074,440t; Sudan 792,000t; Uganda 732,000t; Chad 550,000t and Ethiopia 500,000t.

In Niger, pearl millet is the main staple food. It dominates the agricultural production system and contributes about 75% to the national cereal production (Ben-Mohamed *et al*., 2002). The last 50 years have been characterized by a low annual millet production with growth rate of 0.6% compared to the human population growth rate of 3%.

Pearl millet is considered as a staple source of nutrition for millions of people. The grains are transformed into various local food for human: Frying (*Massa, tsala*), couscous (*dambou, bourabousco*), food *tuwo*, *fura, tukudi, dagué, koko* etc. Millet is also used in poultry feed and in

traditional Pharmacopeia for a lot of remedies. The stem is used as fodder in dry season for feeding livestock and as materials for construction and as fuel.

1.1 JUSTIFICATION

Breeding procedures used in pearl millet improvement in India and the USA are aimed at exploitation of hybrid vigour for both grain and forage yields. Selection efforts in Africa have been limited to intra-population improvement for grain yield. India has been the centre of research efforts to meet this challenge since the 1960s when the availability of cytoplasmic-genic male-sterile lines brought a succession of hybrids. Since the mid-1960s, when hybrid pearl millets were first introduced in India, average grain yields have nearly doubled despite a considerable shift to more marginal production environments.

Pearl millet breeding in Niger has gone through several phases since 1974.The National Institute for Agricultural Research of Niger (INRAN) has programme in sorghum and millet breeding which have released many varieties, among which are HKP, HKB, H-80-10GR and CT -6 released in 1978, 1983, 1985 and 1996, respectively. The Institute has also developed a commercial structure to produce and sell foundation seeds. Since then there has been no breeding activities to develop improved pearl millet varieties.

In planning breeding programme, the amount of production per unit area is a trait of primary importance and crop improvement through hybridization can increase yield considerably. So the value of Agriculture in Niger necessitates the investigation and possibilities of increasing pearl millet grain yield through hybridization. Hence, the research was conducted to achieve the following objectives:

1.2 OBJECTIVES

- ✓ To determine heterosis and combining ability for yield and other agronomic traits,
- ✓ To determine the correlation of grain yield with its components
- ✓ To suggest breeding strategy to develop improved cultivars of pearl millet in Niger.

CHAPTER 2

2 LITERATURE REVIEW

2.1 GENETIC DIVERSITY

The population used for the initial inbred lines development of a cross pollinated species were natural populations or open pollinated cultivars that evolved from selection by farmers using natural pollinations. Such populations are important sources of variability in the country of origin and in other countries with similar environmental conditions. Lakshmana (2008) reported that genetic divergence is a result of changes in the gene frequencies of different populations due to evolutionary forces, while the frequency of a given gene in turn is a function of its contribution to the total adaptation of individuals in natural populations. The individuals showing more fitness contribute more than those having less fitness to the population gene pool.

Allard (1961) concluded that genetic diversity and productivity were complexly related, while divergence and stability appeared to be more simply related. Wallace (1963) pointed out the importance of geographic barrier in changing breeding structure while Jain *et al*. (1981) concluded that geographical barriers preventing gene flow or intense natural or human selection for diverse, adaptive gene complexes may be responsible for genetic diversity. Joshi (1979) stated that genetic diversity involving genetically diverse parents in crossing would be advantageous as it would provide an opportunity for bringing together gene constellations of divergent origin. Isolation in space and time results in locking up genes in different constellations and these should be brought together in hybridization.

In Niger, several landraces were first described by Marchal (1950). Based on spike morphology, he defined three landrace types with spindle-shaped spikes, cylindrical spikes, and large spikes.

The diversity within the accessions of the three groups is equal to about 90% of the total diversity, confirming the genetic variation of Niger pearl millets among the cultivated pearl millets (Tostain and Marchais, 1989) and in similar species (Hamrick and Godt, 1990). An efficient employment of genetic diversity is key to any crop improvement program, Nigussie and Zelleke (2001) reported that in maize crosses which had divergent parent exhibited maximum heterosis. This observation suggests that heterosis in pearl millet tend to increase with increase in divergence among parents. Also Gallais (1984) made an observation which supports the principle. There was high heterosis in maize when parents with genetic distance were crossed (Paterniani and Lonnquist, 1963; Kim et *al*., 1987).

2.2 HETEROSIS

The term heterosis as defined by Shull (1914) refers to superiority of hybrids over their parents in terms of vigour, growth, yield or other characteristics that result from crossing genetically diverse individuals. The terms relative heterosis and heterobeltiosis refer to the heterosis over mid and better parental values respectively. There is heterosis or hybrid vigour when inbred lines are crossed; the progeny shows increase of characters that previously suffered reduction from inbreeding. In general terms, the fitness lost on inbreeding tends to be restored on crossing (Falconer 1981). Lakshmana (2008) reported that Burton (1951) was the first to report heterosis in pearl millet for grain yield.

Heterosis over the mid parent, better parent and check variety were reported earlier by various scientists. For area with short rainy season days to 50 per cent flowering and days to maturity, negative heterosis is desirable in pearl millet. According to Lakshmana (2008), Ahluwalia and Patnaik (1963) found that heterosis over better parent for days to flowering ranged from 7 to 23 per cent. Reddy and Arunachalam (1981) reported that heterosis for flowering time was pronounced and about 6-7 per cent crosses were heteorotic. Kushwah and Singh (1992) in a diallel set observed that out of 66 crosses 35 exhibited heterosis over mid parent to an extent of -23 per cent for days to flowering. Chavan and Nerkar (1994) reported -16.4 per cent better parent heterosis. Kulkarni *et al*. (1993) recorded -12.5 and -9.4 per cent heterosis over mid and better parent for the trait respectively. Low to medium magnitude of heterosis for flowering was reported by other workers viz, Tyagi *et al.* (1975), Bhamre *et al*. (1983), Shinde and Desale (1983), Hapse *et al*. (1986), Kunjir and Patil (1986a), Patel *et al*. (1987) and Ingale *et al*.(1997). However, Ugale *et al*. (1989) did not observe any significant desirable heterosis for days to flowering due to smaller differences in parents.

Lakshmana (2008), Sreenivasulu and Sreeramulu (1980), Subramaniam and Rathinam (1980), Bhamre *et al*. (1983), Hapse *et al*. (1986), Kunjir and Patil (1986a) and Harer *et al* (1990) observed variable magnitude of heterosis both in positive and negative direction for plant height. Patel *et al*. (1987) recorded heterobeltiosis for plant height in the range of -25 to 56 per cent, while Thete *et al*. (1985) and Chavan and Nerkar (1994) observed positive heterobeltiosis for plant height to an extent of 59.4 and 26.0 per cent, respectively, in line x tester crosses. Harer *et al*. (1990) observed that 95 per cent of the crosses in a line x tester set and 79 per cent of the crosses in a diallel set exhibited positive heterosis for plant height. Kushwah and Singh (1992) observed that 63 out of 66

crosses were heterotic over mid parent for the trait. Sheoran *et al*. (2000) reported that, the mean values of the hybrids for plant height was higher than those of the better parent, and significant positive heterobeltiosis was recorded.

Lakshmana (2008) and Mahadevappa (1968) report that in a diallel set noticed that 39 per cent of the crosses exhibited heterosis over better parent for peduncle length. Subramaniam and Rathinam (1980) observed that 7 out of 30 hybrids exceeded better parent values for peduncle length. Kushwah and Singh (1992) were of the opinion that excertion of ear from flag leaf is necessary to keep it free from mould infection. Longer internodes just below the ear would show better excertion. Heterosis for this character was observed to an extent of 76 per cent in 20 out of 66 crosses.

Productive tillers are a major grain yield contributing character in pearl millet. Ahluwalia and Patnaik (1963) reported that hybrids showing maximum heterosis for grain yield also exhibited heterosis for tillering. Lal and Singh (1972) also observed similar results. However, Murty *et al*. (1967) observed limited heterosis for tillering mainly because the parents themselves were high in tillering. Tyagi *et al*. (1975), Subramaniam and Rathinam (1980), Reddy and Arunachalam (1981), Bhamre *et al*. (1983) and Shinde and Desale (1983) reported medium to high heterosis for tillering. Harer *et al*. (1990) and Chavan and Nerkar (1994) recorded heterobeltiosis to an extent of 87.5 and 48.0 per cent, respectively, where Kushwah and Singh (1992) and Kulkarni *et al*. (1993) recorded heterosis to an extent of 93.0 and 61.0 per cent, respectively, for productive tillers. Manga and Dubey (2004) in a diallel study, observed good amount of heterosis for productive tillers per plant.

For grain yield per plant, positive heterosis was recorded by Burton (1951). Ahluwalia and Patnaik (1963) observed heterosis over superior parent to an extent of 69.9 percent. They noticed that, effects of yield components like length and girth of spike, seed size etc are multiplicative in nature and therefore, concluded that even a slight increase in some of these components would produce high heterosis for grain yield. These observations were also made by Lakshmana (2008), Ahluwalia and Patnaik (1963), Ugale *et al*. (1989) and Baviskar (1990) for combinations showing significant heterosis for grain yield. Very high magnitude of heterosis to an extent of 535 per cent for the trait was reported by Tyagi *et al*. (1975). In a line x tester analysis, high amount of heterosis to an extent of 69, 177 and 109.3 per cent was observed by Sarawate *et al*. (1986), Harer *et al*. (1990) and Chavan and Nerkar (1994), respectively. Pethani and Dave (1992) also reported pronounced grain yield heterosis. In a diallel analysis, Harer *et al*.(1990) reported grain yield heterosis to an extent of 98 per cent, whereas Kulkarni *et al*. (1993) recorded 208.3 and 170.5 per cent heterosis over mid and better parent, respectively, in crosses between Indian and exotic pearl millet. Shinde (1995) also found high magnitude of heterosis for the trait. Sheoran *et al*. (2000) recorded the maximum heterobeltiosis for this character among all the characters studied. Ingale *et al*. (1997) reported positive heterobeltiosis in 62 per cent crosses. Appreciable amount of heterosis for grain yield was also observed by Pokhriyal *et al*. (1967), Subramaniam and Rathinam (1980), Bhamre *et al*. (1983), Shinde and Desale (1983), Hapse *et al*. (1986), Kunjir and Patil (1986a), Ugale *et al*. (1989), Deshmukh (1990), Kulkarni *et al*. (1993) and Patil *et al*. (1994). However, Jain *et al*. (1961), Ahluwalia (1962), Shinde *et al*. (1984) and Sreenivasulu and Sreeramulu (1980) observed negative heterosis for the trait. Ramamoorthi and Govindarasu (2000) observed that hybrid PT3832 x 732B recorded significantly higher heterosis for grain yield than all crosses, while Blummel and Rai (2003) reported significant positive as well as negative heterosis. Pethani *et al*. (2004) recorded

heterosis over mid parent and better parent for various traits, the hybrid MS 2072A x J-2338 expressed the highest heterotic value for grain yield over mid parent (152.92 %) and over better parent (121.45%). Manga and Dubey (2004) in a diallel study, observed high heterosis (96.2 to 300.7%) for grain yield. Yadav (2000) reported heterosis up to 88% for grain yield. Earlier workers observed higher magnitude of heterosis over both mid parent and better parent for the trait. Hapse *et al*. (1986) and Shinde and Desale (1983) in a modified line x tester experiment, recorded high magnitude of heterobeltiosis for grain yield. According to Lakshmana (2008) Tyagi *et al*. (1975), Subramaniam and Rathinam (1980), Sreenivasulu and Sreeramulu (1980), Kunjir and Patil (1986a), Navale *et al*. (1987), Ugale *et al*. (1989), Aryana (1990), Ingale *et al*. (1997) and Patil *et al*. (1994) observed medium to low heterosis for grain size. Sheoran *et al*. (2000) also reported the positive and significant heterobeltiosis for the trait.

2.3 COMBINING ABILITY VARIANCE

Combining ability in inbred lines is the ultimate factor determining future usefulness of the lines for hybrids. The concept of combining ability in terms of genetic variation was first given by Sprague and Tatum (1942) using single crosses in maize. They defined the term general combining ability (GCA) as an average performance of a line in hybrid combinations and specific combining ability (SCA) as the combinations which do relatively better or worse than that would be expected on the basis of the average performance of lines involved. According to Griffing (1956), the general combining ability (GCA) is related to additive as well as additive x additive interaction, whereas specific combining ability is related to the dominance variance and all three types of interactions (additive x additive, additive x dominance and dominance x dominance). Bains *et al*. (1967) in a line x tester experiment reported that mean squares due to GCA were important for days to flowering, tiller number, head length and head thickness. On the other hand for a complex

character like yield, SCA was more important. He also observed that crosses with high SCA involved at least one good combining parent. Phul *et al*. (1973) in a diallel set reported that, magnitudes of GCA variances were larger than SCA variance for the characters, days to flowering, ear girth and grain yield. Jain and Majumdar (1975) in a line x tester experiment observed significant differences among hybrids for plant height, ear length and grain yield but not for ear girth. Tyagi *et al*. (1975) in a line x tester experiment reported that variance due to SCA was predominant for days to ear emergence, number of ears per plant, ear length, ear diameter and grain yield, indicating importance of non additive gene action. He also suggested that individual performances should not be taken as sole criterion for selection of parents. Pokhriyal *et al*. (1976) in a line x tester analysis reported high GCA variance for days to flower and plant height. However, for grain yield, ear length and tiller number, the SCA variance was predominant. Male sterile lines 5054A, 5071A and 5151A were the best general combiners for grain yield. Tyagi *et al*. (1978) in a diallel analysis found highly significant variance for both GCA and SCA for days to ear emergence, plant height, total and productive tillers, ear length and grain yield per plant. Sreenivasulu and Sreeramulu (1980) in a diallel experiment observed that GCA variance was significant for days to 50 per cent flowering, plant height, number of leaves per plant, stem girth, internode length, panicle length, panicle girth, panicle weight, grain yield and 1000 grain weight, whereas SCA variance was predominant for plant height, number of days to 50% flowering, stem girth and grain yield. Subramaniam and Rathinam (1980) in a diallel set observed that both GCA and SCA effects were highly significant for plant height and panicle length. Singh *et al*. (1980) in a diallel set observed high magnitude of GCA variance for plant height, number of tillers and grain yield and predominant SCA variance for ear length, ear girth, and 1000 seed weight. They also observed that at least one good general combiner is essential in cross producing high SCA effects. Tyagi *et al*. (1982) in a line x tester experiment in six environments found that SCA variance was predominant

for grain yield and number of days to first ear emergence. However, for 500 grain weight relative magnitude of GCA and SCA variances were inconsistent in different environments. Bhamre *et al*. (1983) in a line x tester set observed that GCA variance was significant for days to 50% flowering, plant height, maturity and tiller number, while SCA variances were significant for ear head length, ear head girth and 1000 grain weight.

2.4 COMBINING ABILITY EFFECTS

The estimation of the general combining ability and specific combining ability effects show the relative magnitude and sign of the effects for each parent and each cross. The information can be useful for the selection of parents that have good general combining ability in a series of crosses and good specific combining ability for specific pair of parents. One of the important criteria in heterosis breeding is the choice of appropriate parents to be used in hybridization programme. It is therefore, necessary to select parents with good general combining ability for yield and its components. The combining ability analyses assess the utility of the crosses and the parents. Gama *et al.* (1995) reported that on average, crosses produced by crossing inter population lines have more positive SCA effects than those produced by crossing intra population lines which tend to have more negative SCA effects. The desirable specific combining ability (SCA) is mostly from parent of good general combining ability effects and is environment specific. In sorghum, a number of studies have been conducted to assess the GCA and SCA effects for different characters. The GCA effects were found to be predominant for days to 50 per cent flowering in the study conducted by Jain *et al*. (1961). Mathur and Mathur (1983) in a line x tester set reported that

magnitude of SCA effects were higher than GCA effects for effective tiller, ear length, ear girth, 1000 grain weight and grain yield. Parents showing high SCA effects for yield were also found to show high GCA effects for one or more yield components, suggesting that GCA effects for grain yield were possibly related to GCA for yield contributing traits. Karad and Harer (2005) in a line x tester experiment revealed significant difference for all ten clusters. Among the females, ICMA-8911 was the best general combiner for yield, ear girth and 1000-grain weight. The combination ICMA 88006 x IPC 1470 (>27.19%) was the best specific combination for grain yield and weight of productive tillers/plant, whereas 841A x IPC-735 was the best specific combination for ear girth and plant height. Dhuppe *et al*. (2006) in a line x tester analysis reported that variance due to lines, testers and line x tester were significant. The female parents 88004 A and 405A, male parent IPC-274, Zim D were good general combiners for grain and fodder yields. The crosses 862A x Zim D, 862A x PT 1890 and 841 A x Zim T exhibited high SCA effect for most characters in general and grain yield in particular.

2.5 CORRELATION AMONG CHARACTERS

Correlation deal with the association between two metric characters in particular with characters whose values are related either positively or negatively in the individuals of a population. The cause of correlation can be genetic or environmental. The genetic cause of correlation is chiefly pleiotropy, through linkage it is a cause of transient correlation particularly in populations derived from crosses between divergent strains (Falconer, 1981). Pleiotropy is simply the property of a gene whereby it affects two or more characters, so that if the gene were segregating it cause simultaneous variation in the characters it affects. The degree of correlation arising from

pleiotropy expresses the extent to which two characters are influenced by the same gene. The correlation resulting from pleiotropy is the overall or net effect of all the segregating genes that affect both characters. Some gene may increase both characters while others increase one and reduce the other; the former tends to cause a positive correlation the later a negative one. So pleiotropy does not necessarily cause a detectable correlation. Again the correlation resulting from environmental cause is overall effect of all the environment factors that vary; some may tend to cause a positive correlation others a negative one. The association between two characters that can be directly observed is the correlation of phenotypic values, or phenotypic correlation (Falconer, 1981). In selecting high yielding genotypes, correlation studies supply reliable information on the nature, extent and direction of selection. The knowledge of correlation coefficients between different yield attributes helps the millet breeder to find out the nature and magnitude of the association between traits which are mostly used to attain better yield of the crop. Earlier research showed that genotypic correlation coefficients were higher than the phenotypic correlation coefficients. The genotypic, phenotypic and environmental correlation coefficients between ear weight and grain yield in population were about the same. In four associations in the same population, that is ear length and ear girth, ear girth and grain yield per ear, ear girth and threshing per cent and grain yield and threshing per cent, the phenotypic correlation coefficient were slightly higher than the genotypic correlation coefficients (Yeye, 2000). In yellow maize crosses, Ali, A et *al. (*2010) found significant and positive correlation coefficients between silking date and number of rows per ear, ear diameter, ear height, plant height and physiological maturity.

2.6 PATH ANALYSIS

Path coefficient analysis helps to partition the correlation between a dependent character on one hand and various characters on the other into direct and indirect effects. Path coefficient as a standard partial regression coefficient is directional and may be positive or negative and greater or less than unity. Furthermore the correlation coefficient between two variables is the sum of the entire path connecting them. It appeared to provide a clue to the contribution of various components of yield. Ado, et *al.,* (1988) found in pepper that if other variables are held constant, increasing fruit size will increase yield, also increasing the number of fruits and plant height will increase yield per plant.

CHAPTER 3

3 MATERIALS AND METHODS

3.1 DESCRIPTION OF THE PARENTS

The parental materials used in this study were lines used in many regions of Niger. Their description and origin are briefly given in the Table below.

Table 3.1 Sources and description of pearl millet lines used in the study

Serial Number	Heterotic Group	Lines	Source	Brief description
1	A	Guerguera	ICRISAT (Niger)	55-65 days to flowering, long and thin spike
2	A	HKB	INRAN (Niger)	80-85 days to flowering, long and thin spike
3	A	HKP GMS	INRAN (Niger)	75-90 days to flowering, slightly susceptible to smut, downy mildew and slightly susceptible to head miner. long and thin spike
4	A	Souna3	IRAT/ISRA (Senegal)	75-95 days to flowering, tolerant to head miner, to smut and to stem lodging, susceptible to mildew and to stem borer. Long and thin spike
5	B	Ankoutess	ICRISAT (Niger)	95 days to flowering, tolerant to downy mildew, Susceptible to stem borer and head miner, short thick spike
6	B	Ex-Borno	IAR (Nigeria)	95 days to flowering, susceptible to Striga, tolerant to smut and susceptible to downy mildew and had short and thick spike
7	B	Gamoji	INRAN (Niger)	68 days to flowering, short and thick spike
8	B	Moro	INRAN	80-90 days to flowering, susceptible to smut and to

			(Niger)	downy mildew, short and thick spike
9	Check	Zatib	INRAN (Niger)	80-90 days to flowering tolerant to smut and to head miner, susceptible to Striga, to drought and pseudoresistance to millet head miner (*Heliocheilus albipunctilla*)
10	Check	H80-10GR	INRAN (Niger)	80-85 days to flowering, tolerant to smut and to downy mildew

3.1.1 Development of the Genetic Population

3.1.2 Experimental Techniques

Sixteen hybrids developed from crosses between two heterotic groups of pearl millet were used in these studies. According to Tostain (1994) the heterotic groups are:

A, Guerguera, HKB, HKP GMS and Souna3

B, Ankoutess, Ex-Borno, Gamoji, and Moro

Check, Zatib and H80-10GR

The hybrids developed:

Guerguera x Ankoutess,

Guerguera x Gamoji,

Guerguera x Ex-Borno

Guerguera x Moro

HKB x Ankoutess

HKB x Ex-Borno

HKB x Gamoji

HKB x Moro

HKP GMS x Ankoutess

HKP GMS x Morro

HKP GMS x Ex-Borno

HKP GMS x Gamoji

Souna3 x Ankoutess

Souna3 x Ex-Borno

Souna3 x Gamoji and

Souna3 x Moro

3.1.3 Experimental Locations

The parents and the hybrids and the checks were evaluated under field conditions in Republic of Niger. Two locations were used, one at National Agronomic Research Institute of Niger (INRAN) at Bengou and the other one at Maradi. Maradi is situated in East-Central Niger Republic (15°26' North and 8°33' East) with a mean annual rainfall of 400–500 mm from June to end of September

(Kadi-Kadi *et al*., 2004.). Bengou in the Western part of Niger Republic (11° 42' North and 03°20' East) where the mean annual rainfall is >700mm, it is also from June to end of September.

3.1.4 Land Preparation, Experimental Design and Layout

The two locations were ploughed by tractor in the rainy season when the soils were moist. The trials were laid in a Randomized Complete Block Design with three replications in each location. A plot consisted of 10 plants per 9m row spaced 1m x 1m inter and intra row spacing. Thinning was done two weeks after sowing to one plant per hill, to give a final plant density of approximately 10,000 plants per hectare. Maradi and Bengou plantings were done at two days interval (2nd July 2010, and 4th July 2010, respectively). Two hoe weeding were done, the first one at three weeks after planting and the second one six weeks after planting. Di-Ammonium Phosphate fertilizer was applied at the rate of 50 kg/ha at sowing, 50 kg/ha of NPK 15-15-15 after thinning (two weeks after sowing) and Urea at the rate of 100 kg/ha.

3.2 DATA COLLECTED

Data were collected on the following traits.

1. **Days to 50% flowering** (days): Number of days between sowing and 50% flowering.
2. **Plant height** (cm): Average height of three plants from the base of the plant to the tip of spike at maturity.

3. **Stem diameter**(cm)**:** Thickness measured with tape on the middle third of the plant at maturity.

4. **Peduncle length**(cm): Measured from the attachment of flag leaf to the peduncle to the basal part of the panicle.

5. **Peduncle diameter**(cm)**:** Thickness measured on the peduncle from the middle of its length at maturity.

6. **Spike length:** (cm) Length of the useful part of the panicle at maturity: (Short = less than 45 cm, Medium = from 45 cm to 65 cm or Long = more than 65 cm).

7. **Spike diameter**(cm)**:** Thickness measured on the middle of the spike.

8. **Number of productive tillers:** Ability to develop fertile (or productive) tillers (Poor = 1 to 4 tillers/plant, Medium = 5 to 9 tillers per plant or Good = more than 9 tillers).

9. **Grain yield** (g)**:** Weight of seed per plot in kilograms.

3.3 STATISTICAL ANALYSES

Analyses of variance (ANOVA) for individual location as well as for combined locations were computed using Statistical Analysis System (SAS). The forms of general analysis of variances for individual location and combined over locations are presented in Table 3.2 and 3.3 respectively. Duncan Multiple Range Test (DMRT) was used to separate significant differences between means**.**

The entries (male, female, males x females) were analyzed based on (Bohren *et al*., 1963) linear models:

$X_{ijk} = \mu + r_i + g_j + e_{ijk}$

Where:

X_{ijk}= Observation of the i^{th} line and j^{th} line in k^{th} replication

μ = the population mean

r_i =effect of the i^{th} line due to replication

g_j = effect of j^{th} line due to genotype

e_{ijk} = experimental error

$X_{ijkl} = \mu + L_i + R_{ij} + G_k + (RL)_{ij} + (GL)_{ik} + e_{ijkl}$

Where:

X_{ijkl} = Observation of the i^{th} line and j^{th} line in k^{th} replication of the l^{th} location

μ = Overall mean

L_i = the effect of i^{th} location

R_{ij} = the effect of j^{th} replication in i^{th} location

G_k = the effect of k^{th} genotype

$(RL)_{ij}$ = the effect of Replication x location interaction

$(GL)_{ik}$= the interaction effect between k^{th} genotype in the i^{th} location

e_{ijk} = experimental error

i= number of location (1, 2)

j = number of replications (1,2,3)

k= number of genotypes (1,2….26)

Table 3.2. Form of analysis of variance for genotypes in one location

Source of variation	(df)	mean squares
Replications	r-1	
Genotypes	g-1	$M_{genotype}$
Error	(r-1) (g-1)	M_{error}
Total	rg-1	

(Gomez and Gomez, 1983)

Table 3. 3. Form of analysis of variance for genotypes over locations

Source	df	mean squares
Loc	l-1	
Rep	r-1	
Genotype	g-1	$M_{genotype}$
Rep x Loc	(r-1)(l-1)	$M_{rep\ x\ loc}$
Loc x G	(l-1)(g-1)	$M_{locxgenotype}$
Error	l(g-1)(r-1)	M_{error}
Total	lgr-1	

(Gomez and Gomez, 1983)

3.4 GENETIC ANALYSIS

Analysis was done using Griffing's method which involves one set of crosses (Griffing, 1956). The mathematical models for the combining ability analysis of variances were worked out by following the formula suggested by Hallauer and Miranda (1981)

The analysis was based on the following mathematical model:

$Y_{ijk} = \mu + m_i + f_j + s_{ij} + r_k + e_{ijk}$

Where,

Y_{ijk} = the performance of the cross between the i^{th} and j^{th} parent in the k^{th} replication.

μ = population mean

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

f_j = the effect of j^{th} female

s_{ij} = the effect of the j^{th} female mated to the i^{th} male

r_k = the replication effect and

e_{ijk} = experimental error.

Table 3.4. Form of analysis of variance for combining ability for one location

Source	df	mean squares	expected mean squares
Rep	r-1		
Male	m-1	M4	$\sigma^2 + r\,\sigma^2_{fm} + rf\,\sigma^2_m$
Fem	f-1	M3	$\sigma^2 + r\,\sigma^2_{fm} + rm\,\sigma^2_f$

Mal x Fem	(m-1) (f-1)	M2	$\sigma^2 + r\,\sigma^2_{fm}$
Error	(r-1)(mf-1)	M1	σ^2
Total	rmf-1		

Hallauer and Miranda 1981

The GCA and SCA variances were expressed as follow

$$\sigma^2_{GCA} = \frac{M_4 + M_3 - 2M_2}{r(m+f)}$$

$$\sigma^2_{SCA} = \frac{M_2 - M_1}{r}$$

Table 3.5. Form of analysis of variance of design II repeated over locations

Source	Df	Mean squares (MS)	Expected mean square (ems)
Location	l-1		

Rep/loc	l(r-1)		
Fem	f-1	M_7	$\sigma^2+r\,\sigma^2_{lfm} + r\,m\sigma^2_{lf} + rl\sigma^2_{fm} + rlm\,\sigma^2_f$
Male	m-1	M_6	$\sigma^2+r\,\sigma^2_{lfm} + rf\,\sigma^2_{lm} + rl\sigma^2_{fm} + rlf\,\sigma^2_m$
Fem x Mal	(f-1)(m-1)	M_5	$\sigma^2+r\,\sigma^2_{lfm} + rl\,\sigma^2_{fm}$
Loc x Fem	l(f-1)	M_4	$\sigma^2+r\,\sigma^2_{lfm}+rm\,\sigma^2_{lf}$
Loc x Male	l(m-1)	M_3	$\sigma^2+\sigma^2_{lfm}+rf\,\sigma^2_{lm}$
Loc x Fem x Male	l(f-1)(m-1)	M_2	$\sigma^2+r\,\sigma^2_{lfm}$
Error	l(r-1)(mf-1)	M_1	σ^2
Total	l(rmf-1)		

Hallauer and Miranda 1981

$\sigma^2_m = \frac{M_6 - M_5 - M_3}{rlf}$ =1/2σ^2_A; F=1

$\sigma^2_f = \frac{M_7 - M_5 - M_4}{rlm}$ =1/2σ^2_A; F=1

$\sigma^2_{fm} = \frac{M_5 - M_2}{rl}$ = σ^2_D; F=1

$\sigma^2_A = \sigma^2_f + \sigma^2_m$

$\sigma^2_D = \sigma^2_{fm}$

In order to test the general combining ability and specific combining ability effects were estimated according to the formula described in Singh and Chaudhary (1979).

The analysis was based on the following mathematical model:

$Y_{ijk} = \mu + m_i + f_j + S_{ij} + e_{ijk}$

Were

μ = population mean

m_i =GCA effect of i^{th} (male) parent

f_j = GCA effect of j^{th} (female) parent

S_{ij} = SCA of (i x j) th cross

e_{ijk} = random error effect associated with $(ijk)^{th}$ observation in k^{th} replication.

$$g_i = \frac{X_{i..}}{l_B rL} - \frac{X_{...}}{l_A l_B rL}$$

$$g_j = \frac{X_{.j}}{l_A rL} - \frac{X_{...}}{l_A l_B rL}$$

$$s_{ij} = \frac{X_{ij}}{rL} - \frac{X_{i..}}{l_B rL} - \frac{X_{.j}}{l_A rL} + \frac{X_{...}}{l_A l_B rL}$$

Where

l_A = number of lines derived heterotic group A

l_B =number of lines derived heterotic group B

r = number of replications

L = number of locations.

g_i = GCA effects from females

g_j = GCA effects from males

s_{ij} = SCA effects

Where $X_{i.}$, $X_{.j}$, and X_{ij} and $X_{.}$ are the totals of hybrids having the i^{th} female, j^{th} male, i^{th} female and j^{th} male as used as parents, and the grand total, respectively. The estimates of GCA and SCA effects were considered significant and highly significant if they were greater than two and three times, respectively, of their standard error of mean. (Jenweerawat *et al* 2009).

$$SE_f = \sqrt{\frac{MSE}{rLl_B}}$$

$$SE_m = \sqrt{\frac{MSE}{rLl_A}}$$

$$SE_{SCA} = \sqrt{\frac{MSE}{rL}}$$

3.5 HETEROSIS

High parent heterosis is the comparison of hybrid performance with that of the better parent in the cross. Formula suggested by Liang *et al.* (1972) was used for the estimation:

$$H(\%) = \frac{F_1 - HP}{HP} X100$$

H% = percentage increase or decrease of F_1 over better parent

HP = performance of the better parent.

F_1 = mean performance of hybrid formed between the i^{th} and the j^{th} parents

The heterosis was tested by least significant difference at 5% and 1% levels of significance for error degrees of freedom as follows.

For testing heterosis over better parent (HP),

S.E (diff) = $\sqrt{\frac{Me}{r}}$

Where Me = Error mean square

r = number of replications

Critical difference:

C.D = SE (diff) x t (at 5 and 1% level for error df)

Heterosis was considered significant when F_1 – HP was higher than the critical difference.

3.6 CORRELATIONS

The genotypic, phenotypic and environmental correlations were estimated for all pairs of characters measured. Correlation coefficients were calculated from component of variance and covariance according to Shivaji and Gritton (1975). The genotypic components were computed by equating the genotypic variances and covariances to the expected mean square and cross products, and from these the genotypic correlations were estimated using the formula:

Genotypic correlation:

$$r_g = \frac{\mathrm{cov}_{g1.2}}{\sqrt{(\sigma^2{}_{g1})(\sigma^2{}_{g2})}}$$

Where:

rg=genotypic correlation coefficient

cov $g_{1.2}$=the estimates of genotypic covariance for traits 1 and 2

$\sigma^2{}_{g1}$ = estimate of the genotypic variance of trait 1

$\sigma^2{}_{g2}$ = estimate of the genotypic variance of trait 2

Phenotypic correlations were calculated using the following equation:

$$r_p = \frac{Cov_{ph1.2}}{\sqrt{(\sigma^2{}_{ph1})(\sigma^2{}_{ph2})}}$$

Where:

rp =phenotypic correlation coefficient

$\mathrm{cov}_{ph1.2}$ = estimate of the phenotypic covariance for traits 1 and 2.

$\sigma^2{}_{ph1}$ = estimate of the phenotypic variance for trait 1

$\sigma^2{}_{ph2}$ = estimate of the phenotypic variance for trait 2

Environmental correlation was estimated thus:

$$r_e = \frac{\text{cov}_{e1.2}}{\sqrt{(\sigma^2{}_{e1})(\sigma^2{}_{e2})}}$$

Where:

re = environmental correlation coefficient

$\text{cov}_{e1.2}$ = the estimate of environmental covariance for traits 1 and 2

$\sigma^2{}_{e1}$ = estimate of the environmental variance for trait 1

$\sigma^2{}_{e2}$ = estimate of the environmental variance for trait 2

Test of significance:

The observed value of correlation coefficient is compared with the tabulated value for (n-2) degrees of freedom of simple linear correlation coefficients, r, at the 5% and 1% levels of significance. If the observed value is equal to or more than the tabulated one, the correlation is said to be significant.

3.7 PATH COEFFICIENT ANALYSIS

Path coefficient analysis is simply standardized partial regression coefficient which splits the correlation coefficient into the measure of direct and indirect effects of a set of independent variables on the dependent variable. It is undertaken in three steps viz calculation of direct effects, indirect effects and the residual effect. The different variables forming the diagram were computed according to Dewey and Lu, (1959).

CHAPTER 4

4 RESULTS

4.1 GENERAL ANALYSIS OF VARIANCE

The result of the analysis of variance for the nine traits measured at Bengou is presented inTable 4.1. The mean squares due to genotypes were highly significant ($p \leq 0.01$) for six traits and only significant ($p \leq 0.05$) for peduncle diameter and grain yield.

At Maradi (Table 4.2) the mean squares due to genotypes did not showed any significant difference for all traits study.

For the combined locations Table 4.3 the mean square due to locations were highly significant ($p \leq 0.01$) for days to 50% flowering, plant height, spike length, number of tillers and grain yield. Mean square due to genotypes for days to 50% flowering, spike length, spike diameter and grain yield were highly significant ($p \leq 0.01$) and only significant for plant height and peduncle length.

.

Table 4.1 Analysis of variance for nine traits at Bengou in 2010

Source	DF	Days to flowering	Plant height	Stem diameter	Peduncle length	Peduncle diameter	Spike length	Spike diameter	Number of tiller	Grain yield
rep	2	9.47	47.63	0.06*	9.04	0.09**	11.57	0.18	6.53*	1849621.9**
Genotype	25	21.52**	804.93**	0.03**	23.92*	0.02**	337.41**	0.40**	0.939	372966.7*
Error	50	4.79	256.18	0.02	13.86	0.007	39.53	0.14	1.64	181835.44
Total	77									

*,** significant at 0.05 and 0.01 levels of probability, respectively

Table 4.2 Analysis of variance for nine traits at Maradi in 2010

Source	DF	Days to	Plant height	Stem	Peduncle	Peduncle	Spike	Spike	Number	Grain

		flowering		diameter	length	diameter	length	diameter	of tiller	yield
rep	2	6	4747.37**	0.12*	70.67	0.016	89.58	0.31	0.89	467437.4
Genotype	25	33.55	659.28	0.02	30.36	0.016	133.15	0.23	1.25	316398.2
Error	50	12.73	638.14	0.03	26	0.029	88.16	0.28	0.88	187038.4
Total	77									

*,** significant at 0.05 and 0.01 levels of probability, respectively.

Table 4.3 Analysis of variance for combined data across location in 2010

Source	DF	Days to flowering	Plant height	Stem diameter	Peduncle length	Peduncle diameter	Spike length	Spike diameter	Number of tiller	Grain yield
Location	1	1583.39**	88452.72**	0.005	50.76	0.023	687.71**	0.642	32.44**	3277725.36**
Rep	4	8.16	2155.95*	0.17**	44.15	0.09*	25.28	0.261	2.787	2068905**
Genotype	25	42.56**	921.6*	0.03	37.67*	0.028	386.76**	0.59**	1.337	543444.3**

L x G	25	12.511	542.619	0.015	16.61	0.013	83.810	0.089	0.859	145920.670
Error	100	8.735	490.144	0.021	20.24	0.018	64.085	0.185	1.333	185686.300
Total	155									

*,** significant at 0.05 and 0.01 levels of probability, respectively.

4.2 MODE OF INHERITANCE

Estimates of components of genetic variances and heritability for grain yield and other agronomic traits of hybrids were showed in Tables 4.4. For days to 50% flowering and spike diameter, variance for GCA for females (σ^2_f) was greater than that for males (σ^2_m).

For some trait, such as plant height (41.284), peduncle length (0.00138), peduncle diameter (40.2986) and Spike length (0.06017) additive gene effect was predominant than dominant gene effect. In terms of genetic variances, it was found that the ratio of σ^2_D/σ^2_A was about -0.1521. For other traits days to 50% flowering, Plant height, Peduncle length, Peduncle diameter and Spike length, results were similar to grain yield. Broad sense heritability ranged from 0.001 to 0.6266 for number of tillers and spike length respectively.

Table 4.4 Estimates of components of genetic variances and heritability for grain yield and other agronomic traits of hybrids from data combined over locations.

Variance	Days to flowering	Plant height	Stem diameter	Peduncle length	Peduncle diameter	Spike length	Spike diameter	Grain yield
σ^2_f	-1.7072	-18.992	-0.0008	-0.0006	4.86167	0.00829	3.00829	-13786
σ^2_m	-3.4226	60.2755	0.00075	0.00196	35.4369	0.05188	-1.112	-3190.4
σ^2_{fm}	4.8355	-23.704	0.001	0.00067	-0.5983	-0.0055	3.57633	2582.77
σ^2_A	-5.1298	41.284	-0.00004	0.00138	40.2986	0.06017	1.89625	-16976
σ^2_D	4.8355	-23.704	0.001	0.00067	-0.5983	-0.0055	3.57633	2582.77
σ^2_D/σ^2_A	-0.9426	-0.5742	-24	0.48485	-0.0148	-0.0914	1.886	-0.1521
h^2	0.56347	0.22686	0.125	0.22303	0.15625	0.62664	0.42188	0.39107

4.3 MEAN PERFORMANCE

The mean performance of the parents, checks and crosses for traits measured at Bengou is presented in Table 4.6. For days to 50% flowering the cross HKP GMS x Gamoji took longest to flowering (61 days) although five other hybrids and five parents which flowered a few days earlier were statistically similar in the flowering date. The most early was found among the parents HKB (51 days). The check H80-10Gr and the hybrids HKB x Ex-Borno, HKB x Moro, Souna3 x Ankoutess and Sona3 x Moro were comparatively early. The cross HKP GMS x Morro (276.33 cm) was the tallest, eleven other hybrids, seven parents and checks were also tall and statistically similar for plant height. The shortest was found among the parents (Ankoutess 214.11) and four hybrids Guerguera x Ankoutess, Guerguera x Moro, HKB x Ankoutess and Souna3 x Ankoutess were similarly short. For stem diameter Souna3 (1.76 cm) was the thickest, while eleven hybrids, five parents and checks were statistically similar for stem diameter. The thinnest was Souna3 xMoro (0.56 cm). The hybrid HKP GMS x Morro (43.56) was the tallest for peduncle length, although three hybrids, the check H80-10Gr and the parent HKP GMS were tall and statistically similar. The hybrid Souna3 x Gamoji (32.11 cm) was the shortest and Ex-Borno was similarly statistically short. The check Zatib was the thickest although the check H80-10Gr, five parents and nine hybrids were statistically similar in thick for peduncle diameter. Ex-Borno (1.12 cm) was the thinnest. For spike length the parent HKB (69.11 cm) was the longest, although parent HKP GMS, check H80-10Gr and hybrid HKP GMS x Gamoji were statistically similar in spike length. Ankoutess and Ex-Borno were the shortest. For spike diameter the parent Ankoutess (4.04 cm) was the thickest statistically different all genotypes. Hybrid HKP GMS x Morro (2.50 cm) was the thinnest. The hybrid Guerguera x Ex-Borno (2239.60 g) showed the highest yielding, although thirteen hybrids, three

parents and checks which yielding nearly below were statistically similar for this trait. The parents Ankoutess and Ex-Borno were the less yielding.

Table 4.5 Mean performance of eight parents, two checks and sixteen crosses of pearl millet evaluated at Bengou in 2010.

Genotypes	Days to flowering	Plant height	Stem diameter	Peduncle length	Peduncle diameter	Spike length	Spike diameter	Grain yield
Parents								
Guerguera	58.33^{a-e}	254.44^{a-e}	1.58^{a-f}	33.33^{c-e}	1.19^{g-i}	48.00^{c-g}	2.74^{b-d}	979.20^{de}
HKB	51.00^{i}	274.67^{a}	1.58^{a-f}	35.78^{c-e}	1.37^{a-f}	69.11^{a}	2.59^{cd}	1645.80^{a-e}
HKP GMS	60.00^{a-c}	270.89^{a-c}	1.73^{ab}	39.22^{a-d}	1.46^{ab}	59.00^{a-c}	2.58^{cd}	1854.20^{a-d}
Souna3	55.33^{d-h}	273.78^{ab}	1.76^{a}	34.22^{c-e}	1.44^{a-c}	54.11^{b-d}	3.09^{bc}	2052.10^{a-c}
Ankoutess	57.33^{a-e}	214.11^{f}	1.43^{d-f}	31.78^{e}	1.26^{d-i}	25.33^{j}	4.04^{a}	854.20^{e}
Ex-Borno	58.67^{a-d}	254.89^{a-e}	1.40^{ef}	32.44^{de}	1.12^{i}	26.67^{j}	3.09^{bc}	854.20^{e}
Gamoji	60.67^{ab}	268.78^{a-d}	1.70^{ab}	33.67^{c-e}	1.46^{ab}	27.23^{g-i}	2.59^{cd}	1302.10^{c-e}
Moro	56.00^{c-g}	274.78^{a}	1.62^{a-d}	32.78^{de}	1.33^{a-h}	48.56^{c-g}	2.28^{cd}	1395.80^{b-e}
H80-10Gr^{+}	53.00^{f-i}	276.56^{a}	1.62^{a-d}	40.44^{a-c}	1.37^{a-f}	62.33^{ab}	2.70^{b-d}	1708.30^{a-e}
Zatib^{+}	52.67^{g-i}	271.56^{ab}	1.71^{ab}	33.11^{c-e}	1.48^{a}	49.22^{c-g}	2.81^{b-d}	1916.70^{a-c}
Crosses								
Guerguera x Ankoutess	57.33^{a-e}	229.00^{f}	1.56^{a-f}	35.78^{c-e}	1.29^{c-h}	29.44^{ij}	3.43^{b}	1562.50^{b-e}
Guerguera x Ex-Borno	56.33^{c-g}	264.56^{a-d}	1.63^{a-d}	36.11^{c-e}	1.31^{b-h}	33.56^{h-j}	3.16^{bc}	2239.60^{a}
Guerguera x Gamoji	57.00^{a-f}	267.00^{a-d}	1.69^{ab}	37.00^{b-e}	1.37^{a-f}	53.00^{b-e}	2.83^{b-d}	1645.80^{a-e}
Gueguera x Moro	57.67^{a-e}	242.44^{b-f}	1.60^{a-e}	37.78^{a-e}	1.37^{a-f}	41.44^{e-h}	3.03^{bc}	1833.30^{a-d}
HKB x Ankoutess	54.33^{e-i}	228.67^{ef}	1.54^{a-f}	36.33^{c-e}	1.33^{a-h}	45.00^{d-h}	3.07^{bc}	1979.20^{a-c}

HKB x Ex-Borno	51.67^{hi}	257.00^{a-e}	1.47^{c-f}	38.89^{a-e}	1.22^{f-i}	47.11^{d-g}	2.81^{b-d}	2135.40^{a-c}
HKB x Gamoji	55.33^{d-h}	253.11^{a-e}	1.73^{ab}	35.44^{c-e}	1.46^{ab}	54.22^{b-d}	2.78^{b-d}	1520.80^{b-e}
HKB x Moro	53.00^{f-i}	250.00^{a-e}	1.43^{d-f}	33.44^{c-e}	1.32^{a-h}	45.22^{d-g}	2.58^{cd}	1687.50^{a-e}
HKP GMS x Ankoutess	58.00^{a-e}	247.44^{a-e}	1.71^{ab}	36.67^{b-e}	1.34^{a-g}	39.44^{f-i}	3.19^{bc}	1666.70^{a-e}
HKPGMS x Ex-Borno	55.33^{d-h}	267.89^{a-d}	1.53^{b-f}	37.00^{b-e}	1.24^{f-i}	42.44^{e-h}	2.93^{b-d}	1854.20^{a-d}
HKP GMS x Gamoji	61.00^{a}	253.67^{a-e}	1.61^{a-e}	34.22^{c-e}	1.33^{a-h}	61.44^{ab}	2.70^{b-d}	1875.00^{a-c}
HKP GMS x Moro	56.67^{b-g}	276.33^{a}	1.57^{a-f}	43.56^{a}	1.23^{f-i}	43.00^{d-h}	2.50^{de}	1833.30^{a-d}
Soua3 x Ankoutess	55.00^{d-i}	239.89^{c-f}	1.54^{a-f}	35.89^{c-e}	1.40^{a-e}	39.56^{f-i}	3.40^{b}	1875.00^{a-c}
Souna3 x Ex-Borno	58.33^{a-e}	261.00^{a-d}	1.46^{c-f}	37.33^{b-e}	1.26^{d-i}	42.00^{e-h}	2.83^{b-d}	1729.20^{a-e}
Souna3 x Gamoji	56.33^{c-g}	258.00^{a-e}	1.66^{a-c}	32.11^{de}	1.41^{a-d}	50.22^{b-f}	3.00^{b-d}	1687.50^{a-e}
Souna3 x Moro	53.00^{f-i}	247.11^{a-d}	0.56^{f}	38.56^{a-e}	1.26^{d-i}	43.44^{d-h}	2.52^{cd}	1666.70^{a-e}

+: checks, Means followed by the same letters in a column are not significantly different

For the combined locations Table 4.6 presents the results. The parent Gamoji took longest to flowering (66.67 days) at the same time the hybrids Guerguera x Moro and HKP GMS x Gamoji flowered a few days earlier were statistically identical for the trait. The earlier was found among the parent (HKB 54.33 days). For plant height souna3 was the highest (253.06 days) also six parents, checks and fourteen hybrids were as tall as and were statistically similar. The shortest was observed among the parents (Ankoutess 200.56 cm). The parent HKP GMS was the longest peduncle (41.06 cm) although the parent HKB, check H80-10Gr, and eleven hybrids were statistically similar as the longest. The shortest were found among the parents as well as in the hybrids Ex-Borno and Souna3 x Gamoji (32.06 cm). For spike length the longest spike was HKB (58.61 cm) and also three parents, checks and two hybrids (HKB x Gamoji, Souna3 x Gamoji) were statistically similar. The parent Ankoutess was the thickest (3.78 cm) for spike diameter and was statistically the same as the hybrid Guerguera x Ankoutess. The parent with thin spike was Moro (2.34 cm). The cross Guerguera x Ex-Borno showed the highest value for grain yield (2066.7 g) on the other hand twelve hybrids, two checks and five parents which were nearly below the highest were statistically identical for the trait.

Table: 4.6 Mean performances of eight parents, two checks and sixteen crosses of pearl millet evaluated across locations in 2010

Genotypes	Days to flowering	Plant height	Peduncle length	Spike length	Spike diameter	Grain yield
Parents						
Guerguera	61.50^{b-e}	229.83^{a-d}	34.94^{b-e}	43.72^{c-g}	2.81^{b-g}	879.2^{f}
HKB	54.33^{i}	237.94^{a-c}	35.61^{a-e}	58.61^{a}	2.49^{e-g}	1476^{a-e}
HKP GMS	59.83^{c-h}	247.72^{ab}	41.06^{ab}	55.72^{ab}	2.42^{fg}	1709.4^{a-c}
Souna3	58.67^{d-h}	253.06^{a}	33.00^{de}	50.44^{a-e}	2.90^{b-g}	1820.8^{a-c}
Ankoutess	58.33^{d-h}	200.56^{d}	32.50^{de}	27.39^{h-j}	3.78^{a}	1068.8^{d-f}
Ex-Borno	60.17^{c-h}	223.56^{a-d}	32.06^{e}	30.89^{h-j}	3.14^{b-d}	907.3^{ef}
Gamoji	66.67^{a}	224.67^{a-d}	34.28^{c-e}	41.00^{d-i}	2.77^{b-g}	1034.4^{d-f}
Moro	59.00^{d-h}	236.56^{a-c}	31.22^{e}	42.28^{c-h}	2.34^{g}	1208.3^{c-f}
H80-10Gr^{+}	56.33^{g-i}	246.72^{ab}	38.61^{a-d}	52.28^{a-c}	2.72^{b-g}	1697.9^{a-c}
Zatib^{+}	57.33^{f-i}	244.28^{ab}	33.76^{de}	51.17^{a-e}	2.65^{d-g}	1855.2^{ab}
Crosses						
Guerguera x Ankoutess	60.83^{b-f}	207.67^{cd}	34.17^{de}	31.94^{h-j}	3.31^{ab}	1344.8^{b-f}
Guerguera x Ex-Borno	61.67^{b-d}	245.50^{ab}	35.22^{a-e}	38.67^{g-i}	2.96^{b-g}	2066.7^{a}
Guerguera x Gamoji	60.33^{c-g}	230.17^{a-d}	36.67^{a-e}	46.78^{b-g}	2.87^{b-g}	1386.5^{b-f}
Gueguera x Moro	63.67^{a-c}	222.06^{a-d}	36.28^{a-e}	41.89^{c-h}	2.80^{b-g}	1472.9^{a-e}

HKB x Ankoutess	57.50^{e-i}	219.89^{b-d}	34.06^{de}	42.00^{c-h}	3.04^{b-e}	1625^{a-d}
HKB x Ex-Borno	57.17^{f-i}	235.50^{a-c}	35.72^{a-e}	45.17^{c-g}	2.71^{b-g}	1785.4^{a-c}
HKB x Gamoji	58.33^{d-h}	243.11^{ab}	38.44^{a-d}	51.83^{a-d}	2.79^{b-g}	1722.9^{a-c}
HKB x Moro	56.33^{g-i}	233.00^{a-c}	32.33^{de}	45.06^{c-g}	2.40^{fg}	1513.5^{a-d}
HKP GMS x Ankoutess	59.50^{d-h}	224.78^{a-d}	36.06^{a-e}	37.33^{g-j}	3.02^{b-f}	1671.9^{a-c}
HKPGMS x Ex-Borno	59.17^{d-h}	237.67^{a-c}	33.50^{de}	41.61^{c-h}	2.77^{b-g}	1763.5^{a-c}
HKP GMS x Gamoji	64.17^{ab}	242.39^{ab}	35.28^{a-e}	58.11^{a}	2.68^{c-g}	1532.3^{a-d}
HKP GMS x Moro	59.00^{d-h}	240.67^{ab}	40.44^{a-c}	41.67^{c-h}	2.66^{d-g}	1563.5^{a-d}
Soua3 x Ankoutess	56.17^{hi}	225.39^{a-d}	36.72^{a-e}	36.17^{g-j}	3.29^{a-c}	1792.7^{a-c}
Souna3 x Ex-Borno	60.83^{b-f}	232.89^{a-c}	36.94^{a-e}	37.47^{g-j}	2.89^{b-g}	1558.3^{a-d}
Souna3 x Gamoji	59.17^{d-h}	244.28^{ab}	32.06^{e}	49.44^{a-f}	2.90^{b-g}	1692.7^{a-c}
Souna3 x Moro	57.17^{f-i}	228.61^{a-d}	36.22^{a-e}	41.61^{c-h}	2.48^{e-g}	1435.4^{b-f}

+: checks, Means followed by the same letters in a column are not significantly different

4.4 HETEROSIS

The estimate of heterosis for individual crosses expressed as percentage increase or decrease of hybrid mean over the high parent (%HP) for Bengou and across the two locations was computed. The heterosis for the crosses at Bengou is presented in Table 4.7.

For days to 50% flowering HKP GMS x Ex-Borno (-5.69%) Souna3 x Moro (-4.21%), Guerguera x Ex-Borno (-3.43%), HKP GMS x Ankoutess (-2.32%), Guerguera x Gomoji (-2.28%) and Souna x Ankoutess (-0.6%) showed negative heterosis and the others manifested positive heterosis. For plant height only Guerguera x Ex-Borno (3.79%) and HKP GMS x Moro registered positive heterosis while others had negative one. Two positives heterosis was recorded by Guerguera x Ex-Borno (3.16%) and HKB x Gamoji (1.76%) for stem diameter while the remains was negative. For peduncle length, all genotypes showed positive heterosis except for HKP GMS x Gamoji (-12.75%), HKB x Moro (-6.59%), HKP GMS x Ankoutess (-6.5%), Souna3 x Gamoji (-6.16%), HKP GMS x Ex-Borno (-5.66%) and HKB x Gamoji (-0.95%). For peduncle diameter Guerguera x Ex-Borno (10.08%), Guerguera x Moro (3.79%), Souna3 x Gamoji (3.42%) and Guerguera x Ankoutess (2.38%) showed the positive heterosis while the others were negative. Two crosses Guerguera x Gamoji (10.42%) and HKP GMS x Gamoji (4.13%) manifested positive heterosis for spike length and the others were negatives. For spike diameter Guerguera x Moro (10.42%), HKB x Gamoji (7.33%), HKP GMS x Gamoji (4.25%), Guerguera x Gamoji (3.28%) and Guerguera x Ex-Borno (2.26%) showed positive heterosis while the remains had negative heterosis. The highest positive value for grain yield was given by Guerguera x Ex-Borno (128.72%) followed by Guerguera x Ankoutess (59.6%), Guerguera x

Moro (31.34%), HKB x Ex-Borno (29.75%), Guerguera x Gamoji (26.39%), HKB x Ankoutess (20.25%), HKB x Moro (2.53%) and HKP GMS x Gamoji (1.12%). Souna3 x Moro (-18.78%) showed the highest negative heterosis for grain yield followed by Souna3 x Gamoji (-17.77%), Souna3 x Ex-Borno (-15.73%), HKP GMS x Ankoutess (-10.11%), Souna3 x Ankoutess (-8.63%) and HKB x Gamoji (-7.59%). Whereas zero (0) heterosis was recorded for days to 50% flowering, peduncle diameter and grain yield.

Table 4.**7** Percentage high parent heterosis of crosses for nine traits at Bengou in 2010

Crosses	Days to flowering	Plant height	Stem diameter	Peduncle length	Peduncle diameter	Spike length	Spike diameter	Grain yield
Guerguera x Ankoutess	0	-9.99**	-1.26	7.35	2.38	-38.66**	-15.1**	59.6**
Guerguera x Ex-Borno	-3.43	3.79	3.16	8.34	10.08**	-30.08**	2.26	128.72**
Guerguera x Gamoji	-2.28	-0.66	-0.59	9.89	-6.16	10.42	3.28	26.39
Gueguera x Moro	2.98	-11.77**	-1.24	13.35*	3.79	-15.63	10.58	31.34*
HKB x Ankoutess	6.53**	-16.75**	-2.53	1.53	-2.92	-34.88**	-24.01**	20.25
HKB x Ex-Borno	1.31	-6.42	-6.96	8.69	-10.95**	-31.83**	-9.06	29.75*
HKB x Gamoji	8.49**	-7.85*	1.76	-0.95	0	-21.54**	7.33	-7.59
HKB x Moro	3.92	-9.01**	-11.72**	-6.59	-3.65	-34.56**	-0.38	2.53
HKP GMS x Ankoutess	-2.32	-8.66**	-1.15	-6.5	-8.22**	-33.15**	-21.04**	-10.11
HKP GMS x Ex-Borno	-5.69**	-1.11	-11.56**	-5.66	-15.07**	-28.06**	-5.17	0
HKP GMS x Gamoji	1.66	-6.35	-6.93	-12.75*	-8.9**	4.13	4.25	1.12
HKP GMS x Moro	1.19	0.56	-9.25*	11.06	-15.75**	-27.11**	-3.1	-1.13
Soua3 x Ankoutess	-0.6	-12.37**	-12.5**	4.88	-2.77	-26.89**	-15.84**	-8.63
Souna3 x Ex-Borno	5.42*	-4.67	-17.04**	9.09	-12.5**	-22.38**	-8.41	-15.73

Souna3 x Gamoji	1.81	-5.76	-5.68	-6.16	3.42	-7.19	-2.91	-17.77
Souna3 x Moro	-4.21	-10.06**	-68.18**	12.68*	-12.5**	-19.72*	-18.45**	-18.78
SE±	1.26	9.24	0.08	2.15	0.048	3.62	0.21	246.19

*,** = significant at 0.05 and 0.01 levels respectively

The magnitude of the high parent heterosis of the crosses across locations for the traits studied is presented in Table 4.8. The result showed zero heterosis for spike diameter and only two positives heterosis for spike length. Females Guerguera and HKB produced positive heterosis while Souna3 gave negative one for grain yield. With regards to days to 50% flowering positive heterosis were recorded by Guerguera x Moro (3.53%), HKP GMS x Ankoutess (2%) and Souna3 x Ex-Borno (1.09%) while others produced negative heterosis for the trait. Guerguera x Ex-Borno (6.82%), HKB x Gamoji (2.17%) and Guerguera x Gamoji (0.15%) were the hybrids with positive heterosis for plant height and the others gave negative one. Eight crosses showed positive heterosis with regard to peduncle length in which Souna3 x Ex-Borno (11.94%) was the highest followed by Souna3 x Ankoutess (11.27%), Souna3 x Moro (9.76 %), HKB x Gamoji (7.95%), Guerguera x Gamoji (4.95%), Guerguera x Moro (3.83%), Guerguera x Ex-Borno (0.8%) and HKB x Ex-Borno (0.31%) while others had negative heterosis. For spike length, all the hybrids produced negative heterosis except for Guerguera x Gamoji (6.99%) and HKP GMS x Gamoji (4.29%). Five hybrids produced positive heterosis for spike diameter while others were negative. For grain yield, Guerguera x Ex-Borno (127.8%) was the highest followed by Guerguera x Gamoji (34.04%), Guerguera Ankoutess (25.82%), Guerguera x Moro (21.9%), HKB x Ex-Borno (20.96%), HKB x Gamoji (16.73%), HKB x Ankoutess (10.09%), HKP GMS x Ex-Borno (3.16%) and HKB x Moro (2.54%) while the others produced negative heterosis.

Table 4.8 Percentage high parent heterosis of crosses for nine traits across locations in 2010

Crosses	Days to flowering	Plant height	Peduncle length	Peduncle diameter	Spike length	Spike diameter	Grain yield
Guerguera x Ankoutess	-1.09	-9.64	-2.2	0.8	-26.94**	-12.43	25.82
Guerguera x Ex-Borno	-7.49**	6.82	0.8	6.4	-11.55	5.32	127.8**
Guerguera x Gamoji	-1.9	0.15	4.95	-2.14	6.99	21.36	34.04
Gueguera x Moro	3.53**	-6.13	3.83	4.7	-4.18	-0.35	21.9
HKB x Ankoutess	-1.42	-7.58	-4.35	4.72	-28.34**	-19.58	10.09
HKB x Ex-Borno	-4.98**	-1.02	0.31	-0.78	-22.93**	-13.69	20.96
HKB x Gamoji	-12.51**	2.17	7.95	1.43	-11.57	0.72	16.73
HKB x Moro	-4.52**	-2.07	-9.21	-0.03	-23.12**	-3.61	2.54
HKP GMS x Ankoutess	2	-9.26	-1.22	-7.91	-33**	20.1	-2.19
HKP GMS x Ex-Borno	-1.66	-4.07	-18.41**	-7.91	-25.32**	-11.78	3.16
HKP GMS x Gamoji	-3.75**	-2.15	-14.07	-2.86	4.29	-3.25	-10.36
HKP GMS x Moro	-1.39	-2.85	-1.51	-7.19	-25.21**	9.92	-8.53
Soua3 x Ankoutess	-4.26**	-10.93**	11.27	-3.52	-28.29**	-12.96	-1.54
Souna3 x Ex-Borno	1.09	-7.97	11.94	-11.27**	-25.71**	-7.96	-14.42
Souna3 x Gamoji	-11.25**	-3.47	-6.47	0.7	-1.98	0	-7.03

Souna3 x Moro	-3.1*	-9.66	9.76	-13.37**	-17.5	-14.48	-21.16
SE±	1.71	12.78	2.6	0.08	4.62	0.25	248.79

*,** = significant at 0.05 and 0.01 levels respectively

4.5 GENETIC ANALYSIS

4.5.1 Anova for Combining Ability

The result of analysis of variance for the nine traits measured at Bengou Table 4.9 indicating the mean square due to female were highly significant (p≤0.01) for days to 50% flowering and spike length but only significant (p≤0.05) for spike diameter. The mean square due to male were highly significant (p≤0.01) for plant height, stem diameter, spike length and spike diameter and only significant (p≤0.05) for peduncle diameter. The interaction female x male were not significant for all traits. Table 4.10 showed higher GCA values than SCA for plant height, stem diameter days to 50% flowering spike length and spike diameter while others characters recorded greater SCA than GCA values.

The analysis of variance for combining ability for nine traits measured across the two locations is presented in Table 4.11. The general combining ability (GCA) variances across locations were highly significant (p≤0.01). The female showed highly significant (p≤0.01) for grain yield and only significant (p≤0.05) for spike length. The male were highly significant (p≤0.01) across locations except for stem diameter, days to flowering, peduncle length and grain yield. Male x female was only significant for days to flowering, peduncle length and grain yield. All other interactions were not significance for any trait. Table 4.12 showed predominant of GCA over SCA for days to flowering, stem diameter, peduncle length, peduncle diameter, spike length, spike diameter and number of tillers while plant height and grain yield higher SCA values over GCA.

Table 4.9 Mean squares for combining ability analysis for nine traits at Bengou in 2010

Source	Df	Days to flowering	Plant height	Stem diameter	Peduncle length	Peduncle diameter	Spike length	Spike diameter	Grain yield
Rep	2	1.021	30.57	0.08**	17.28	0.05**	10.113	0.21	1287251.8*
Fem	3	40.74**	440.33	0.015	9.25	0.006	170.73**	0.23*	20236.5
Male	3	12.854	1591.96**	0.05**	29.43	0.04*	615.97**	0.8**	210612
Fem*Mal	9	9.5	231.15	0.02	19.86	0.01	42.33	0.06	115795
Error	30	5.69	222.63	0.011	16.27	0.01	35.41	0.07	244891
Total	47								

*,** significant at 0.05 and 0.01 levels of probability, respectively

Table 4.10 Ratio of GCA: SCA Variances for nine traits of pearl millet at Bengou in 2010

Genetic variance	Days to flowering	Plant height	Stem diameter	Peduncle length	Peduncle diameter	Spike length	Spike diameter	Grain yield

GCA	1.441	65.417	0.002	-0.044	0.001	29.252	0.038	-30.894
SCA	1.272	2.842	0.002	1.195	0.000	2.306	-0.006	-43031.9
GCA/SCA	1.133	23.018	1.000	-0.037	------	12.685	-6.333	0.001

Table 4.11 Mean squares for combining ability analysis for nine traits across locations in 2010

Source	Df	Days to flowering	Plant height	Stem diameter	Peduncle length	Peduncle diameter	Spike length	Spike diameter	Grain yield
Loc	1	96*	40727.4**	0.001	0.002*	212.504	0.521	975.375	3419678**
Rep/ loc	4	35.114	1945.7**	0.051	0.028	27.781	0.132	3.583	574309.9
Fem	3	5.914	419.583	0.007	0.003	202.697	0.294*	107.416	13260**
Male	3	5.594	2058.09**	0.058	0.074	927.798**	1.345**	16.306**	306290.6
Fem*Male	9	42.269*	263.463	0.014	0.012*	42.667	0.058	27.148	216592.9*
Loc *Fem	3	4.617	611.918	0.012	0.005	43.35	0.037	8.069	127523.2

Loc *Male	3	45.467	348.014	0.026	0.015	34.645	0.042	15.847	166267.8
Loc *F*m	9	13.256	405.686	0.008	0.008	46.257	0.091	5.69	201096.3
Error	60	20.971	347.493	0.024	0.018	63.252	0.167	11.028	168925.4
Total	95								

*,** significant at 0.05 and 0.01 levels of probability, respectively

Table 4.12 Ratio of GCA: SCA Variances for nine traits of pearl millet across locations

Genetic variance	Days to flowering	Plant height	Stem diameter	Peduncle length	Peduncle diameter	Spike length	Spike diameter	Number of tiller	Grain yield
GCA	1.4733	9.2850	0.0014	-0.0003	-0.9074	-0.0064	0.7835	0.0248	-6775.10
SCA	-3.8575	-29.0965	-0.0080	0.0050	-8.4975	-0.0380	-2.6690	-0.1435	16085.45
GCA /SCA	-0.3819	-0.3191	-0.1719	-0.0500	0.1068	0.1694	-0.2936	-0.1729	-0.42

4.5.2 Estimation of GCA and SCA Effects

The estimates of general combining ability (GCA) effects of parent for the traits measured in Bengou are presented in Table 4.13. From the results Ex-Borno was the good combiner among the parents because it recorded the highest positive GCA effects for grain yield (170.573) and plant height (9.917) but showed lowest values for stem diameter (-0.058) and peduncle diameter (-0.063). Gamoji gave higher GCA for stem diameter (0.092), peduncle diameter (0.07) and spike length (10.313), it recorded the lowest value for grain yield (-136.719). The greater GCA for spike diameter (0.349) was showed by Ankoutess and it had the lowest values for plant height (-16.444).

The estimates of specific combining ability (SCA) effects for Bengou trial are presented in Table .4.17. Eight crosses showed positive SCA effects for plant height of which HKP GMS x Moro (13.72) had the highest followed by Guerguera x Gamoji (11). Similarly the rest of crosses exhibited negative SCA effects for plant height. For stem diameter, seven crosses exhibited positive SCA effects of which HKP GMS x Ankoutess (0.097) and HKB x Gamoji (0.097) were the highest. The remaining nine crosses showed negative SCA effects. With respect to peduncle length, eight of crosses manifested positive SCA effects and the hybrid with longest exertion were HKP GMS x Moro (3.99) followed by Guerguera x Gamoji (2.27) and HKB x Ex-Borno (2.15). The remains eight crosses had negative SCA values. For peduncle diameter, eight crosses showed positive SCA effects of which Guerguera x Moro (0.06) followed by HKB x Gamoji (0.052) were the highest. Eight crosses had negative SCA effects. Eight crosses had positive SCA effects for spike length of which HKP GMS x Gamoji (4.54) was the longest followed by Guerguera x Gamoji (3.32), Guerguera x Moro (3.21) and HKB x Ankoutess (3.16). The rest of the crosses showed negative SCA effects. Eight

crosses showed small positive SCA effects for spike diameter Guerguera x Moro (0.18) being the highest, the remaining crosses manifested negative SCA effects. With respect to days to 50 flowering, ten crosses showed negative SCA effects while six crosses had positive SCA effects. The result for grain yield showed that eight crosses manifested positive SCA effects Guerguera x Moro (233.07) being the best followed by HKP GMS x Gamoji (204.42), HKB x Ankoutess (196.61), Souna3 x Ankoutess (183.59). The other eight crosses had negative SCA effects for the trait, Guerguera x Ankoutess (-287.76), Souna3 x Ex-Borno (-180.99), HKB x Gamoji (-173.17) recorded the highest negative SCA effects .

Table 4.13 Estimates of general combining ability (GCA) effects for grain yield and other traits in sixteen crosses of pearl millet at Bengou in 2010

Parents	Days to flowering	Plant height	Stem diameter	Peduncle length	Peduncle diameter	Spike length	Spike diameter	Grain yield
Guerguera	2.063	-1.944	0.039	0.035	0.012	-5.049	0.191	79.427
HKB	-2.771	-5.500	-0.036	-0.604	0.012	3.479	-0.115	11.719
HKP GMS	1.396	8.639	0.025	1.229	-0.033	2.174	-0.092	-11.719
Souna3	-0.688	-1.194	-0.028	-0.660	0.009	-0.604	0.016	-79.427
Ankoutess	-0.188	-16.444	0.008	-0.465	0.020	-6.049	0.349	-48.177
Ex-Borno	-0.938	9.917	-0.058	0.701	-0.063	-3.132	0.010	170.573
Gamoji	1.063	5.250	0.092	-1.938	0.070	10.313	-0.095	-136.719
Moro	0.063	1.278	-0.042	1.701	-0.027	-1.132	-0.265	14.323
Mean	0.00000	0.00025	0.00000	-0.0001	0.00000	0.00000	-0.00013	0.00006
CD	1.542	10.45	0.074	2.632	0.058	4.178	0.224	268.226

Table 4.14 Estimates of specific combining ability (SCA) effects for grain yield and other traits for sixteen crosses of pearl millet at Bengou in 2010

Crosses	Days to flowering	Plant height	Stem diameter	Peduncle length	Peduncle diameter	Spike length	Spike diameter	Grain yield
Guerguera x Ankoutess	-0.896	-5.306	-0.072	-0.424	-0.065	-3.868	-0.03	-287.76
Guerguera x Ex-Borno	-1.146	3.889	0.072	-1.257	0.041	-2.674	0.031	170.573
Guerguera x Gamoji	-2.479	11	-0.022	2.271	-0.037	3.326	-0.185	-115.885
Gueguera x Moro	4.521	-9.583	0.022	-0.59	0.06	3.215	0.184	233.073
HKB x Ankoutess	0.938	-2.083	-0.008	0.771	-0.02	3.16	-0.091	196.615
HKB x Ex-Borno	-0.979	-0.111	-0.019	2.16	-0.048	2.354	-0.008	134.115
HKB x Gamoji	0.688	0.667	0.097	1.354	0.052	-3.979	0.065	-173.177
HKB x Moro	-0.646	1.528	-0.069	-4.285	0.016	-1.535	0.034	-157.552
HKP GMS x Ankoutess	0.438	2.556	0.097	-0.729	0.035	-1.09	0.009	-92.448
HKP GMS x Ex-Borno	-1.479	-3.361	-0.014	-1.563	0.019	-1.007	0.092	-123.698

HKP GMS x Gamoji	2.188	-12.917	-0.086	-1.701	-0.026	4.549	-0.035	204.427
HKP GMS x Moro	-1.146	13.722	0.003	3.993	-0.028	-2.451	-0.066	11.719
Soua3 x Ankoutess	-0.479	4.833	-0.017	0.382	0.049	1.799	0.112	183.594
Souna3 x Ex-Borno	3.604	-0.417	-0.039	0.66	-0.012	1.326	-0.116	-180.99
Souna3 x Gamoji	-0.396	1.25	0.011	-1.924	0.01	-3.896	0.156	84.635
Souna3 x Moro	-2.729	-5.667	0.044	0.882	-0.048	0.771	-0.152	-87.24
Mean	0.000125	0	0	0	-0.00013	0	0	0.00006
CD	3.084	20.898	0.148	5.264	0.116	8.356	0.448	536.452

Across locations Table 4.15, the result showed that HKB was the good combiner for days to 50% flowering by having the lowest SCA value. HKP GMS had the highest GCA value for peduncle length. Gamoji recorded the largest positive GCA for plant height and spike length. The good combiner for grain yield was Ex-Borno by recording the highest GCA value.

The estimation of specific combining ability (SCA) effects for all traits across locations is presented in Table 4.16. Ten crosses out of sixteen manifested negative SCA effects for days to 50% flowering while the rest were positive. Seven crosses exhibited positive SCA effects for plant height while nine showed negative SCA effects. Highest positive effects were recorded for Guerguera x Ex-Borno (13.36), HKP GMS x Moro (5.3) and Souna3 x Ankoutess (5.26). Nine crosses showed positive SCA effects for peduncle length such as HKP GMS x Moro (3.43), HKB x Gamoji (3.32), Souna3 x Ex-Borno (1.6), Souna3 x Ankoutess (1.7) and Guerguera x Gamoji (1.1) whereas the remains crosses had negative SCA effects. For spike length, seven crosses manifested positive SCA effects HKP GMS x Gamoji (4.81) recorded the highest followed by Guerguera x Moro (2.43) and HKB x Ankoutess (2.04). The remains crosses showed negative SCA effects. With respect to spike diameter eight crosses had positive SCA effects of which the highest were shown by HKP GMS x Moro (0.14) and the other crosses showed negative SCA effects. With respect to grain yield, seven crosses manifested positive SCA effects of which the highest were Guerguera x Ex-Borno (296.67), Souna3 x Ankoutess (194.59), Souna3 x Gamoji (119.59), Guerguera x Moro (117.25) and HKB x Gamoji (107.87) while the remaining nine crosses had negative SCA effects .

Table 4.15 Estimates of general combining ability (GCA) effects for grain yield and other traits for eight parents of pearl millet across locations in 2010

parents	Days to flowering	Plant height	Peduncle length	Spike length	Spike diameter	Grain yield
Guerguera	2.5	-5.75	-0.049	-3.102	0.135	-23.503
HKB	-2.208	0.778	-0.493	3.092	-0.113	31.445
HKP GMS	0.917	4.278	0.688	1.759	-0.065	2.539
Souna3	-1.208	0.694	-0.146	-1.748	0.044	-10.482
Ankoutess	-1.042	-12.667	-0.382	-6.061	0.314	-21.68
Ex-Borno	0.167	5.792	-0.285	-2.193	-0.015	163.216
Gamoji	0.958	7.889	-0.021	8.62	-0.037	-46.68
Moro	-0.083	-1.014	0.687	-0.366	-0.263	-94.857
Mean	0.000125	0	-0.00013	0.000125	0	-0.00025
CD	1.414	10.242	2.398	4.142	0.2	212.414

Table 4.16 Estimates of specific combining ability (SCA) effects for grain yield and other traits for sixteen crosses of pearl millet across locations in 2010

Crosses	Days to flowering	Plant height	Peduncle length	Spike length	Spike diameter	Grain yield
Guerguera x Ankoutess	-0.167	-6.014	-1.034	-1.814	0.011	-240.3
Guerguera x Ex-Borno	-0.542	13.361	-0.076	1.04	-0.013	296.68
Guerguera x Gamoji	-2.667	-4.069	1.105	-1.661	-0.073	-173.63
Gueguera x Moro	3.375	-3.278	0.006	2.436	0.075	117.25

HKB x Ankoutess	1.208	-0.319	-0.702	2.047	-0.011	-15.04
HKB x Ex-Borno	-0.333	-3.167	0.868	1.345	-0.007	-39.52
HKB x Gamoji	0.042	2.347	3.326	-2.8	0.087	107.88
HKB x Moro	-0.917	1.139	-3.493	-0.592	-0.07	-53.32
HKP GMS x Ankoutess	0.083	1.069	0.118	-1.286	-0.083	60.74
HKP GMS x Ex-Borno	-1.458	-4.5	-2.535	-0.877	0.004	-32.49
HKP GMS x Gamoji	2.75	-1.875	-1.021	4.811	-0.063	-53.84
HKP GMS x Moro	-1.375	5.306	3.438	-2.648	0.142	25.59
Soua3 x Ankoutess	-1.125	5.264	1.618	1.054	0.084	194.6
Souna3 x Ex-Borno	2.333	-5.694	1.743	-1.509	0.016	-224.67
Souna3 x Gamoji	-0.125	3.597	-3.41	-0.349	0.049	119.6
Souna3 x Moro	-1.083	-3.167	0.049	0.804	-0.148	-89.52
Mean	-0.000062	0	0	0.000065	0	0.000625
CD	2.828	20.482	4.798	8.284	0.4	424.82

4.6 CORRELATIONS

The genotypic, phenotypic and environmental correlations for traits measured in Bengou are presented in Tables 4.22. Plant height had highly significant positive genotypic association with stem diameter, peduncle diameter, spike length and only significant with grain yield. The trait had negative association with spike length and number of tillers. Stem diameter showed highly significant positive genotypic association with peduncle diameter and spike length but only significant with days to 50% flowering. The trait also had negative genotypic association with spike diameter and number of tillers. Peduncle length showed highly significant genotypic association with number of tillers and grain yield but had high negative association with spike diameter and 50% days to flowering. Peduncle diameter had highly significant positive genotypic association with spike length and only significant with grain yield but highly significant negative association with number of tillers. Spike length showed highly significant positive genotypic association with grain yield and negatively with spike diameter, days to 50% flowering and number of tillers. Spike diameter had highly significant negative genotypic association with grain yield. Spike diameter had high negative association with grain yield. Days to 50%flowering showed high significant negative genotypic association with grain yield. Number of tillers showed high positive association with grain yield.

Plant height had highly significant positive phenotypic association with spike length and only significant positive association with stem diameter. Stem diameter showed significant positive phenotypic association with peduncle diameter and spike length. Peduncle diameter had

significant positive phenotypic association with spike length. Spike length showed significant negative phenotypic association with spike diameter. Number of tiller had significance positive association with grain yield.

Plant height had significant positive environmental association with peduncle length. Stem diameter showed significance positive environmental association with peduncle diameter. Peduncle length had only significant negative environmental association with peduncle diameter. Number of tillers had highly significant positive environmental association with grain yield.

Table 4.17 Genotypic (g), phenotypic (p) and environmental (e) correlations for nine characters of pearl millet at Bengou in 2010

		Stem diameter	Peduncle length	Peduncle diameter	Spike length	Spike diameter	days to flowering	Number of tiller	Grain yield
Plant height	g	0.841**	-0.106	0.519**	0.909**	-0.411*	-0.129	-0.657**	0.403*
	p	0.397*	0.268	0.248	0.534**	-0.382*	0.002	-0.069	0.047
	e	0.162	0.431*	0.071	0.186	0.154	0.097	0.071	-0.101
Stem diameter	g		-0.212	1.250**	0.698**	-0.487*	0.447*	-0.448*	0.233
	p		-0.176	0.783**	0.453*	-0.02	0.169	-0.321	0.021
	e		-0.162	0.501**	0.261	0.21	-0.018	-0.267	-0.063
Peduncle length	g			-0.171	0.342*	-0.76**	-0.522**	0.582**	0.508**
	p			-0.364*	0.105	-0.158	-0.178	0.199	0.304*
	e			-0.471*	-0.072	0.081	0.003	0.116	-0.079
Peduncle	g				0.676**	-0.204	0.087	-0.728**	0.386*
diameter	p				0.506**	-0.007	0.003	-0.193	0.111
	e				0.327	0.112	-0.068	-0.066	-0.019
Spike length	g					-0.999**	-0.399*	-0.618**	0.620**
	p					-0.543**	-0.266	-0.146	0.201
	e					-0.156	-0.092	0.039	-0.095
Spike diameter	g						0.253	-0.149	-0.576**

	p	0.148	-0.01	-0.08
	e	0.08	0.001	0.112
days to 50%	g		0.388*	-0.788**
flowering	p		-0.019	-0.302*
	e		-0.074	-0.056
Number of tiller	g			0.795**
	p			0.572**
	e			0.716**

g, p,e = genotypic, phenotypic and environmental respectively

Table 4.18 shows the correlations of the traits at Maradi.

Plant height showed highly significant positive genotypic association peduncle diameter, spike length and number of tiller but negative with stem diameter, spike diameter and days to 50% flowering. Stem diameter showed highly significant positive genotypic correlation with spike diameter and days to 50% flowering but negative with peduncle length. Peduncle length showed highly significant positive genotypic association for spike diameter but only significant with spike length and grain yield. Peduncle diameter showed highly significant positive genotypic association with days to 50% flowering and number of tiller. Spike length had significant positive genotypic correlation with days to 50% flowering. Spike diameter showed highly significant negative genotypic correlation with grain yield. Days to 50% flowering had high negative genotypic correlation with number of tillers and grain yield. Number of tiller manifested highly significant positive genotypic association with grain yield.

Plant height had also significant positive phenotypic association with peduncle diameter, spike length and grain yield. Stem diameter showed highly significant positive genotypic correlation with peduncle diameter and spike diameter. Peduncle diameter had significant positive phenotypic correlations with spike length and spike diameter. Spike length had negative phenotypic association with spike diameter. Days to 50% flowering showed significant negative phenotypic correlations with number of tillers. Number of tillers showed highly significant positive phenotypic correlation with grain yield.

Stem diameter showed highly significant positive environmental correlation with peduncle diameter and only significant with spike diameter. Peduncle diameter had highly significant positive environmental association with spike length and spike diameter. Days to 50 % flowering showed significant negative environmental association with number of tiller. Number of tiller showed highly significant positive environment association with grain yield.

Table 4.18 Genotypic (g), phenotypic (p) and environmental (e) correlations for nine characters of pearl millet at Maradi in 2010

		Stem diameter	Peduncle length	Peduncle diameter	Spike length	Spike diameter	days to flowering	Number of tiller	Grain yield
Plant height	g	-0.555**	0.006	0.411**	0.974**	-0.609**	-0.486*	0.397*	0.224
	p	0.188	0.273	0.359*	0.431*	-0.198	-0.205	0.223	0.41*
	e	0.217	0.28	0.314	0.275	-0.066	-0.218	0.136	0.224
Stem diameter	g		-0.684**	0.166	-0.21	0.56**	0.617**	-0.079	-0.12
	p		-0.146	0.597**	0.238	0.34*	0.104	-0.065	0.109
	e		-0.109	0.643**	0.295	0.33*	-0.009	0.057	0.142
Peduncle length	g			0.185	0.336*	0.73**	-0.175	0.234	0.431*
	p			-0.084	0.178	-0.187	-0.123	0.071	0.248
	e			-0.282	0.096	-0.258	-0.126	-0.009	0.237
Peduncle	g				-0.224	-0.161	0.78**	0.787**	0.191
diameter	p				0.494*	0.419*	0.155	-0.067	0.086
	e				0.571**	0.563**	0.042	-0.155	-0.048
Spike length	g					-0.114	0.351*	0.128	0.068
	p					-0.402*	0.152	-0.122	0.137

	e		-0.229	0.111	-0.152	0.002
Spike diameter	g			0.134	-0.422*	-0.774**
	p			0.057	0.01	-0.096
	e			0.053	0.037	-0.048
days to 50%	g				-0.565**	-0.647**
flowering	p				-0.436*	-0.387
	e				-0.424*	-0.327*
Number of tiller	g					0.792**
	p					0.666**
	e					0.65**

g, p,e = genotypic, phenotypic and environmental respectively

Table 4.19 shows combined results across locations for genotypic, phenotypic and environmental correlations.

Plant height showed highly significant positive genotypic correlation with stem diameter and only significant with peduncle diameter and spike length but negative genotypic correlation with spike diameter. Stem diameter had highly significant positive genotypic correlation with peduncle diameter, spike length, days to 50 % flowering but negative with number of tiller. Peduncle length had highly significant positive genotypic association with peduncle diameter, spike length, number of tiller and grain yield but significant negative correlation with spike diameter and days to 50 % flowering. Peduncle diameter showed highly significant positive genotypic association with spike length, days to 50% flowering and grain yield but negative with spike diameter and number of tillers. Spike length showed highly significant negative genotypic association with spike diameter, significant negative genotypic association with number of tiller and showed highly significant positive genotypic association with grain yield. Spike diameter showed significant negative genotypic correlation with grain yield. Days to 50% flowering had significant negative genotypic association with grain yield. Number of tiller showed significant positive genotypic association with grain yield.

Plant height had significant positive phenotypic correlation with stem diameter peduncle diameter and grain yield but negative phenotypic correlation with spike diameter. Stem diameter showed significant positive phenotypic correlation with peduncle diameter and spike length. Peduncle diameter had significant positive phenotypic correlation with spike length. Spike length had significant negative phenotypic association with spike diameter. Days to 50 % flowering showed

significant negative phenotypic association with grain yield while number of tillers showed highly significant positive phenotypic association with grain yield.

Plant height and stem diameter manifested significant positive environmental correlation with spike length. Peduncle length showed significant negative environmental correlation with peduncle diameter and the later one had significant positive environmental association with spike length. Spike length showed significant negative environmental association with spike diameter while number of tiller had highly significance positive correlation with grain yield.

Table 4.19 Genotypic (g), phenotypic (p) and environmental (e) correlations for nine characters of pearl millet across locations in2010

		Stem diameter	Peduncle length	Peduncle diameter	Spike length	Spike diameter	days to flowering	Number of tiller	Grain yield
Plant height	g	0.818**	0.175	0.31*	0.343*	-0.347*	-0.069	-0.262	0.182
	p	0.391*	0.255	0.378*	0.67**	-0.433*	-0.143	-0.002	0.315*
	e	0.247	0.275	0.236	0.356*	-0.089	-0.195	0.028	0.027
Stem diameter	g		-0.041	0.608**	0.595**	-0.188	0.527**	-0.56**	0.239
	p		-0.12	0.682**	0.462*	0.065	0.201	-0.225	0.132
	e		-0.147	0.53*	0.392*	0.187	-0.011	-0.049	0.088
Peduncle length	g			0.645**	0.579**	-0.33*	-0.302*	0.651**	0.937**
	p			-0.158	0.155	-0.256	-0.072	0.075	0.246
	e			-0.373*	-0.052	-0.234	0.04	-0.094	0.03
Peduncle	g				0.996**	-0.545*	0.782**	-0.75**	0.744**
diameter	p				0.516**	0.092	0.053	-0.117	0.178
	e				0.431*	0.243	-0.169	-0.074	-0.022
Spike length	g					-0.774**	-0.185	-0.468*	0.723**

	p	-0.64**	-0.144	-0.261	0.188
	e	-0.319*	-0.1	-0.28	-0.166
Spike diameter	g		0.121	-0.241	-0.427*
	p		0.15	0.108	-0.085
	e		0.175	0.176	0.075
days to 50%	g			-0.114	-0.591*
flowering	p			-0.21	-0.368*
	e			-0.284	-0.239
Number of tiller	g				0.541**
	p				0.663**
	e				0.730**

g, p, e = genotypic, phenotypic and environmental respectively

4.7 PATH COEFFICIENT ANALYSIS

The present studies showed that, grain yield was considered as the resultant variable whereas plant height, stem diameter, peduncle length, peduncle diameter, spike length, spike diameter, days to 50% flowering and number of tillers per plant as the causal variables. The direct and indirect contributions of the different plant characters measured on pearl millet are given in Table 4.20 and the path diagram is given in figure 4.1. (P) indicates direct effect, (R) the residual effect and (r) reveals the correlation among the characters. Plant height proved to have moderate direct effect on grain yield (0.174). The indirect effects of this character through the other traits were low (Table 4.20). However, the relative importance of direct and joint effects for plant height was 0.2567. The direct influence of peduncle length, peduncle diameter and days to 50% flowering on grain yield were low (0.1232, 0.138) or very low (0.057), respectively. Number of tillers had moderate direct effect on grain yield 0.1507. The indirect effects of this character through other traits were very low. The relative importance of direct and indirect effects for number of tillers was 0.1819. The data showed that the correlation coefficient of stem diameter, spike length and spike diameter to grain yield were negative even though the direct contributions were positive.

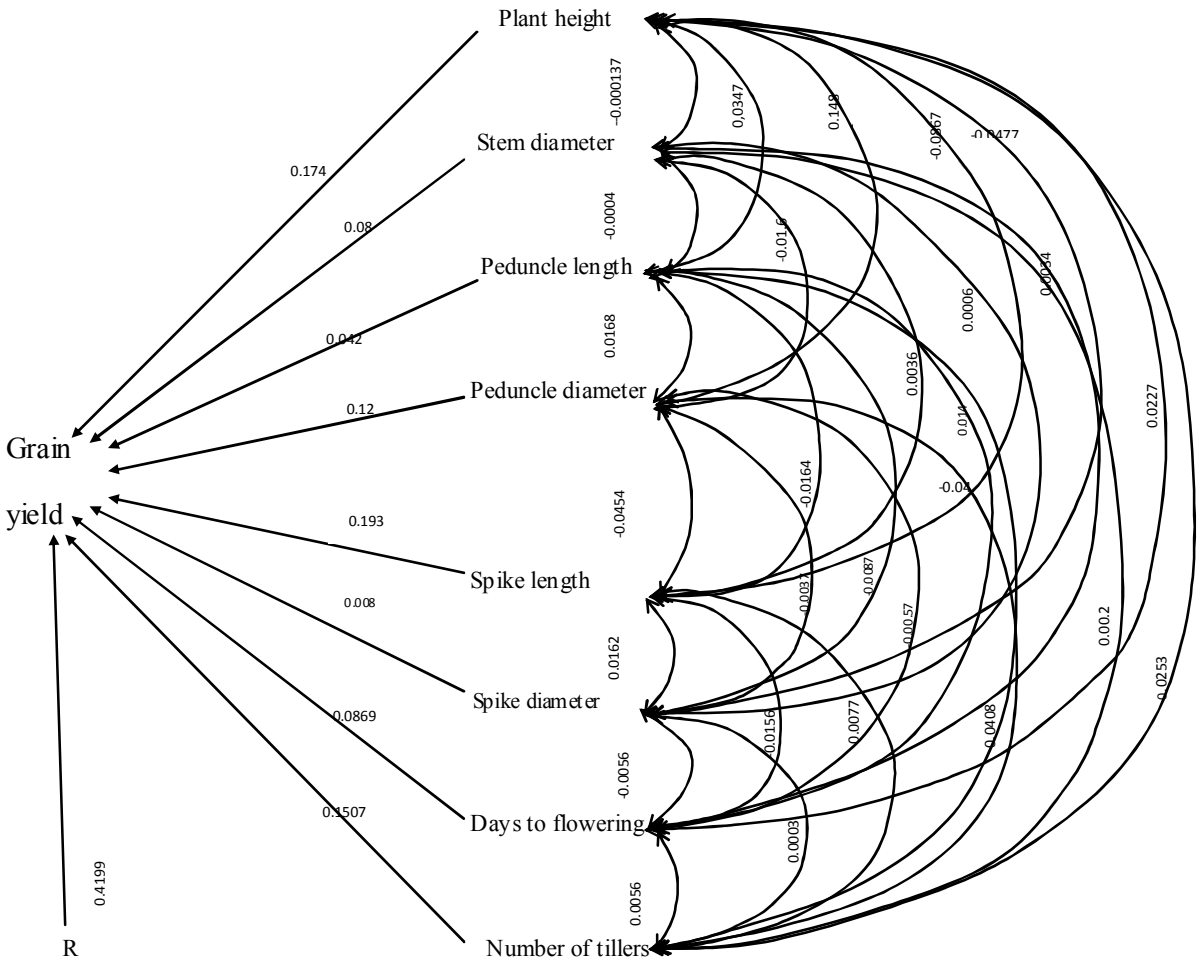


Figure 4.1 Path diagram and coefficients of factors influencing grain yield in pearl millet

Cause and effect	Correlation	Cause and effect	Correlation	Cause and effect	Correlation	Cause and effect	Correlation
planht vs yield.... r =	0. 2567	stemdt vs yield ...r =	-0.019	spiklth vs yield. r =	-0.1172	spikdt vs yield ….r =	- 0.0407
direct effect ……p =	0. 1741	direct effect. ..p =	0.0008	direct effect …… p =	0.0192	direct effect … p =	0.0080
indirect via stmdt …	-0.0137	indirect via plantht	-0.0137	indirect via plnth …	-0.0867	indirect via plnth ……..	-0.0477
indirect via pedlth …	0.0347	indirect via pedlth	-0.0004	indirect via stmdt …	0.0036	indirect via stmdt ……	0.0006
indirect via peddt .	0. 1482	indirect via peddt …	-0.0160	indirect via pelth …	-0.0163	indirect via pelth ……	-0.0087
indirect via spiklth ...	-0.0867	indirect via spikelth	0.0036	indirect via pedt ……	-0.0454	indirect via pedt …….	-0.0037
indirect via spikdt ……	-0.047	indirect via spikedt …	0.0006	indirect via spkdt ..	0.0162	indirect via spiklth …	0.0162
indirect via dflw …….	0.0226	indirect via dflw ……	0.0034	indirect via dflw ……	-0.0155	indirect via dflw ……	-0.0056
indirect via no tiller .	0.0252	indirect via no tiller	0.0027	indirect via no tiller …	0.0076	indirect via no tiller ..	0.0 002
TOTAL……	0.2567	TOTAL ……	-0.019	TOTAL ……	-0.1172	TOTAL ……	- 0.0407
peduncle length vs yield ..r =	0. 1232	pedunle diam vs yield r =	0.1380	dflw vs yield ……..r =	0.0573	tiller/pl vs yield ….r =	0.1819
direct effect …... p =	0.0424	direct effect ……... p =	0.1211	direct effect … p =	0.0869	direct effect …… p =	0.1507
indirect via planth …….	0.0347	indirect via planth ……	0.1482	indirect via plnth …	0.0226	indirect via plnth …	0.0252
indirect via stemdt ……	-0.0004	indirect via stmdt ……	-0.0160	indirect via stmdt …	0.0034	indirect via stmdt …	0.0027
indirect via peddt ……	0.0167	indirect via pedlth ……	0.0167	indirect via pelth …….	0.0140	indirect via pelth …	0.0408
indirect via spiklth ……..	-0.0163	indirect via spiklth ……	-0.0454	indirect via pedt ……	-0.0429	indirect via pedt ……	-0.04
indirect via spikdt …….	-0.0087	indirect via spikdt …	-0.0037	indirect via spkdt ..	-0.0056	indirect via spkdt …	0.0002

indirect via dflw ……. 0.0140	indirect via dflw …… -0.0429	indirect via spiklth … -0.0155	indirect via spiklth .. 0.0076
indirect via no tiller …... 0.0408	indirect via no tiller… -0.04	indirect via no tille …. -0.0056	indirect via dflw …… -0.0056
TOTAL …… 0. 1232	TOTAL …… 0.1379	TOTAL …… 0.0573	TOTAL …… 0.1819
			Residual. (R)..... 0.4199

Table 4.20. Path coefficient analysis showing the direct and indirect effects of characters on grain yield across locations.

5 CHAPTER 5

5.1 DISCUSSIONS

In the present study, there were significant differences among the genotypes in Bengou for all traits measured except number of tillers per plant. In Maradi the genotypes showed no significant differences but, across locations the genotypes manifested significant differences for all traits except for stem diameter, peduncle diameter and number of tillers per plant. This indicated presence of considerable influence of environment on the genotypes. On the other hand Falconer (1981) pointed out that the amount of improvement that could be achieved by selection among a number of crosses is dependent on the amount of variation between the crosses and the intensity of selection, since selection will be ultimately applied to the crosses. Therefore, this result implies that there is great variation among the genotypes on which selection can act.

Estimates of components of genetic variances and heritability for grain yield and other agronomic traits of hybrids were shown in Tables 4.4. For days to 50% flowering and spike diameter, variance for GCA of females (σ^2_f) was greater than that for males (σ^2_m) indicating that the higher additive gene effect was provided by female parents. Some character such as grain yield, spike diameter, days to flowering and spike length were highly heritable. Dabholkar (1992) classified heritability estimates as low (5-10%), medium (10-30%) and height (>30%). These results are in line with findings of Dang *et al.* (1985) and Kunjir *et al.* (1986b) who reported high heritability for 1000 grain weight in pearl millet

The mean performance of the hybrids in Bengou indicated that crosses which involved diverse genetic backgrounds of inbred lines combined well to produce good hybrids. For the following traits parent with high mean value combined well to produce higher hybrid for the trait. The highest mean value was recorded from HKP GMS x Moro cross which was produced from lines with similar trait. For stem diameter and peduncle diameter, HKB x Gamoji showed the highest mean value and was from parents with maximum mean value. HKP GMS x Gamoji and Guerguera x Ankoutess showed the highest mean value for spike length and spike diameter respectively. Most of the hybrids result from parents of different performance; this implies that in a single cross using parent with both higher performances is not necessary.

Across locations, for earliness in days to 50% flowering, the parents with similar backgrounds combined well for low mean value which implies earliness (Souna3 x Ankoutess). For plant height, Guerguera x Ex-Borno combination produced highest mean value and were from parent of good performance for the trait. For peduncle length and peduncle diameter, HKP GMS x Moro and Souna3 x Gamoji recorded the highest mean values respectively. HKP GMS x Gamoji gave the highest mean performance for spike length. With respect to spike diameter, Guerguera x Ankoutess was the combination which showed the highest mean value and was from the line of higher mean values for the trait. With respect to grain yield, the hybrid Guerguera x Ex-Borno was the best. This indicated that parent with the same or different performance can combine well to give desirable hybrid. Observation which supports the principle was: There was high heterosis when parents with genetic distance were crossed (Paterniani and Lonnquist, 1963; Gallais 1984; Kim et *al*., 1987).

As far as heterosis is concerned in this study, breeder of cross pollinated crop should consider the possibility of obtaining sufficient heterosis for a character of economic importance under consideration that will ensure high yield per unit area, and most importantly exploit the opportunity to maintain this heterosis into a few breeding lines.

From Bengou data, Guerguera x Ex-Borno produced highest positive heterosis for plant height, stem diameter, peduncle diameter and grain yield which might be as the result of parents of different backgrounds. Short plant height and long spike length were desired in pearl millet because this might reduce stem lodging of which Guerguera x Gamoji. Highest heterotic hybrid for peduncle length and spike diameter were obtained with Guerguera x Moro while the lowest one was recorded by HKP GMS x Ex-Borno. Table 4.7 indicates that heterosis for grain yield is mainly the result of heterosis for plant height stem diameter and peduncle diameter. This indicated that the hybrid produced in terms of vegetative part the greatest amount of biomass were also high yielding. Positive heterosis for these traits was reported earlier by Subramaniam and Rathinan (1980), Chavan and Nerkar (1994) and Pethani *et al.,* (2004).

From the combined data, the degree of heterosis showed variation from trait to trait but it remained significant for grain yield. For days to 50% flowering, the lowest value was recorded by Souna3 x Ankoutes. Guerguera x Ex-Borno cross emerge to be the best hybrid for plant height peduncle diameter and the highest yielding which might be as a result of parents of different backgrounds. The highest value for spike length and spike diameter was produced by Guerguera x Gamoji. Interestingly majority of the vegetative traits like plant height and peduncle diameter showed positive heterosis as well as high yielding. These results revealed that heterosis for grain yield in pearl millet is mainly contributed

through vegetative traits rather than panicle components. These results are contrary to the results of Lakshmana (2008), who found that heterosis for grain yield in pearl millet is mainly contributed through panicle components rather than vegetative traits. When the yield performances in each location and across locations were compared, the following information was obtained in terms of heterosis percentage: At Bengou the best yielding hybrid was Guerguera x Ex-Borno with 3583.3kgha^{-1} which was from the parent with low yielding (Guerguera and Ex-Borno). Across locations, Guerguera x Ex-Borno hybrid had the highest yield (2939.58kgha^{-1}). Furthermore the crosses involved lines Guereguera gave positive heterosis for grain yield. These results can probably be explain through genetic basis of heterosis by which heterosis can be expressed when the parents of a hybrid have different alleles at a locus and there is some level of dominance among those alleles. The high heterosis results from various relationships between levels of dominance.

The choice of appropriate parents to be used in hybridization programme is very important. Therefore, it is necessary to select parents with good general combining ability for yield and its components. The combining ability analyses assess the utility of the crosses and the parents. The study provides information on relative magnitude of GCA and SCA variances, which indicate the nature of gene action in terms of additive and non-additive genetic variances.

At Bengou location the results showed high values of GCA for days to 50% flowering, plant height, stem diameter, peduncle diameter, spike length, spike diameter and grain yield over SCA. The results indicated that these traits are governed by additive gene action. However peduncle length had greater SCA than GCA values, showing that this character is governed by non additive gene action.

Across locations the result showed highest GCA over SCA for days to 50% flowering, plant height, peduncle diameter, spike length and spike diameter indicating that these traits were governed by additive gene action. Whereas peduncle length and grain yield had higher SCA than GCA showing that these traits were governed by non additive gene action. On the other hand the result indicated that grain yield was governed by both additive and non additive gene action. Similar results were reported by Subramaniam and Rathinam (1980); Tyagi *et al*. (1978); Zambezi *et al.* (1986) and Ibitomi (2010).

The GCA effects in Bengou revealed HKB and Ex-Borno as the best general combiners because they had highest positive GCA effects for grain yield. They also had high negative GCA effects for days to 50% flowering which enhance earliness in pearl millet. These parents can be selected due to their ability to produce high yield and early maturity. The specific combining ability (SCA) effects gave various values among crosses, for plant height and peduncle length HKP GMS x Moro showed the highest SCA values indicating that tallest plant and peduncle were enhanced by this cross. With respect to stem diameter, HKB x Gamoji showed highest values of SCA effects indicating that these crosses combined well for the trait. Guerguera x Moro emerged as best combination by registering positive SCA effects for peduncle diameter, spike diameter and grain yield indicating that greater value of these traits could be found with the cross. The result implies that either one or both parents combined well to produce hybrid with high SCA effect. Similar results had been found by Mathur and Mathur (1983) who reported that parents showing high SCA effects for yield were also found to show high GCA effects for one or more yield components. For days to 50% flowering Souna3 x Moro showed the highest negative SCA value indicating that this cross had shorter number of days to flowering.

Across locations, Gamoji had the highest positive GCA values for plant height, peduncle diameter and spike length indicating that the line is a good source of taller and thick plant. HKB showed maximum negative GCA value for days to 50% flowering; the result showed that the line could be used in improving early maturity. On the other hand Ex-Borno exhibited the highest positive GCA effects for grain yield. Among males Ex-Borno recorded maximum GCA values for grain yield. Specific combining ability across locations indicated that seven out of the sixteen crosses showed improved grain yield while ten crosses manifested earliness for days to 50% flowering. For peduncle length HKP GMS x Moro had the highest SCA value. HKP GMS x Gamoji and Souna3 x Ankoutess showed the highest value of SCA for spike length and spike diameter, respectively. Most of the crosses with higher SCA results from parents with good GCA effects for the trait. The above result is in agreement with Gama *et al* (1995) and Lakshmana 2008 who reported that, one of the important criteria in heterosis breeding is the choice of appropriate parents to be used in the hybridization programme. It is therefore, necessary to select parents with good general combining ability for yield and its components.

The highest specific combining ability (SCA) for grain yield also exhibited high specific combining ability for other vegetative components indicating that improvement in grain yield could be achieved by improvement in vegetative components. It was also observed that, the cross with highest SCA effect for grain yield, also exhibited significant heterosis and had one parent with significant GCA effect. In addition >50% of the crosses showed positive SCA effect for grain yield and plant height indicating the potentiality for exploiting hybrid vigor in pearl millet breeding programme.

Correlation results in Bengou, plant height had highly significant positive genotypic association with stem diameter, peduncle diameter and spike length. The positive association indicates that increased plant height would simultaneously increase these traits. Plant height had also positive association with

grain yield, implying that increase in plant height may increase grain yield (Hallauer and Miranda, 1988). The strong genotypic, phenotypic and environmental association of stem diameter with peduncle diameter is indicative of simultaneous genetic improvement in these two traits. High negative association was found between stem diameter and number of tillers and this illustrate that the greater the number of tillers the smaller the diameter. Peduncle diameter was genotypically correlated with grain yield this showed that gene controlling the trait could be utilized for the development of high yielding genotype. This is in agreement with the findings of Khaliq *et al.,* (2004), Akhtar and Chaudhary (2006) and Saleem *et al.* (2006). High positive phenotypic and environmental associations of number of tillers with grain yield indicate that increased grain yield can be achieved by increasing number of tillers. At Maradi another correlation worthy of some attention is between number of tillers and grain yield. The trait had strong positive, genetic, phenotypic and environmental correlation with grain yield this indicated that the greater the number of tillers the higher the yield. Across locations high positive genotypic, phenotypic and environmental associations was observed between stem diameter and peduncle diameter indicated simultaneous genetic improvement in these two traits. Also the high positive genotypic, phenotypic and environmental association between number of tillers and grain yield showed that number of tillers play an important role in pearl millet breeding programme.

An examination of path coefficient analysis reveals that plant height, number of tillers per plant and peduncle diameter were the three factors that exerted the greatest influence both directly and indirectly upon grain yield. The correlation between grain yield and plant height as well as the direct cause of plant height on grain yield indicate that when other variables are held constant, increasing plant height could directly increase grain yield. The correlation was greatly reduced as a result of the indirect negative influence of spike length and spike diameter. This indicated that higher plant produced

more grain and the probable physiological explanation for such relationship is obvious since the more a plant is tall the more it develops vegetative part (leaves) and more will be the photosynthetic apparatus and hence the more the amount of photosynthate stored in the grain and the higher the grain yield. The results of this study are in close conformity with the findings of Dewey and Lu (1959) and Akbar *et al* (2008).

On the other hand positive contribution of number of tillers toward grain yield is obtained; this may probably be due to the fact that greater number of tillers gave more spikes and more of the latter gives more grain. The result indicates that indirect selection for higher grain yield may be accompanied by increasing these characters, such as plant height and number of tillers as had been shown by Khaliq *et al*. (2004) in bread wheat. However, in the case of stem diameter, spike length and spike diameter the indirect effects play a very important role in masking the direct influence giving a low negative correlation -0.0188, -0.1172 and -0.0407, respectively. The low correlation between yield and days to 50% flowering was due to the negative indirect contributions registered through the other characters. The residual variable R was appreciably large thus indicating that the importance on grain yield of other characters is not considered in this study.

6 CHAPTER 6

SUMMARY CONCLUSION AND RECOMMENDATIONS

6.1 SUMMARY

The results discussed above indicated presence of considerable influence of environment on the genotypes. It revealed that the line Ex-Borno showed good general combining ability and hybrid Guerguera x Ex-Borno outstanding performance. The preponderance of non additive gene action in the inheritance of quantitative characters such as grain yield can be effectively exploited for heterosis. Gamoji was the best combiner for plant height, peduncle diameter and spike length while HKB was the best one for days to 50% flowering.

Across locations the best yielding hybrid was Guerguera x Ex-Borno with 3583.3kgha^{-1}. The results indicate that Guerguera x Ex-Borno performed well across test locations. For grain yield, Guerguera x Ex-Borno showed that the performance of the parents can be used to predict the performance of the crosses, it was observed that in terms of grain yield and some related components, Ex-Borno had

appreciable general combining ability over locations. In the correlation study, it was observed that most traits were positively correlated with grain yield except days to 50% flowering and spike diameter which had negative correlation with grain yield. Therefore improvement of grain yield can be made through those characters. The correlation and path coefficient analysis indicated the importance of plant height, peduncle diameter and number of tiller for the improvement of grain yield.

6.2 CONCLUSION AND RECOMMENDATIONS

In conclusion, the highest heterotic cross showed also the best SCA. Not only that the hybrid with high SCA involve at least one parent with good GCA. So the performance of the hybrid can be predates from the parent. It was observed from the study that: Guerguera x Ex-Borno had the maximum heterosis for grain yield and other agronomic traits. But there is the need to improve on traits like high productive tillers. Therefore this problem gives room for further research to develop pearl millet varieties with good productive tillering as well as high yielding for the sahelian area where rainfall is limited. The genetic components of variance revealed that dominance and additive components showed the influence of gene action for the traits study. The inheritances of the character were computed and expressed high heritability for some traits.

Thus hybrids can be used to overcome the problem of recurrent production deficit over environments. It was also recommended to select highly heterotic genotypes in a large population followed by

intermating among good combiner and developed hybrids from cytoplasmic-genic male-sterile lines is suggested.

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