Study of Variability, Character Association and Heterosis in Pearl Millet [*Pennisetum glaucum* (L.) R. Br.] Hybrids

बाजरा [*पेनिसेटम ग्लॉकम* (एल.) आर.बीआर.] के संकरो में विविधता, सहसम्बन्ध और संकर ओज का अध्ययन

RAJESH KUMAR

THESIS

Master of Science in Agriculture
(Plant Breeding and Genetics)

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Department of Plant Breeding and Genetics
COLLEGE OF AGRICULTURE
SWAMI KESHWANAND RAJASTHAN AGRICULTURAL UNIVERSITY, BIKANER (RAJASTHAN)

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THESIS

Submitted to the
Swami Keshwanand Rajasthan Agricultural University,
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in partial fulfillment of the requirement for
the degree of

Master of Science in Agriculture
(Plant Breeding and Genetics)

By

RAJESH KUMAR

2017

M.Sc. Ag. (Plant Breeding and Genetics) THESIS 2017 RAJESH KUMAR

Swami Keshwanand Rajasthan Agricultural University, Bikaner

College of Agriculture, Bikaner

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This is to certify that **Mr. Rajesh Kumar** had successfully completed the Comprehensive Examination held on **31/05/2016** as required under the regulation for Master Degree.

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Dated: ___________

This is to certify that the thesis entitled **"Study of Variability, Character Association and Heterosis in Pearl Millet [*Pennisetum glaucum* (L.) R. Br.] Hybrids"** submitted for the degree of **Master of Science** in **Agriculture** in the subject **Plant Breeding and Genetics** embodies bonafide research work carried out by **Rajesh Kumar** under my guidance and supervision and that no part of this thesis has been submitted for any other degree. The assistance and help received during the course of investigation has been fully acknowledged. The draft of the thesis was also approved by the advisory committee on ________________.

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This is to certify that **Mr. Rajesh Kumar** of the **Department of Plant Breeding and Genetics, College of Agriculture, Bikaner** has made all corrections/modifications in the thesis entitled **"Study of Variability, Character Association and Heterosis in Pearl Millet [*Pennisetum glaucum* (L.) R. Br.] Hybrids"** which were suggested by the external examiner and the advisory committee in the oral examination held on ___/___/2017. The final copies of the thesis duly bound and corrected were submitted on ___/___/2017 are enclosed herewith for approval.

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Place:-
Date:- **(Rajesh Kumar)**

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1. INTRODUCTION

Pearl millet [*Pennisetum glaucum (L.) R. Br*.] 2n=14 is locally known as *bajra* belong to family gramineae. It is an allogamous crop with protogyny. It is believed to be originated in West Africa and from there introduced in to India. The pearl millet grains are very nutritious and form the staple diet of approximately 10 per cent of the population in India. It has high protein with slightly superior amino acid profile. It is a good source of protein (11.5%), fat (4.1-6.4%), carbohydrate (59.8-78.2%) and also has good amount of minerals particularly phosphorus and iron (2.8%).

Pearl millet is an important coarse grain cereal crop of dry land agriculture. It can be grown on light textured soil under low moisture condition. It is the most important and most potential crop among the millets. It is extensively cultivated as a dual purpose crop under large areas in Africa, Asia and Australia while grown as forage crop only in sub-tropics of USA. Globally, it ranks 6^{th} among cereal crops in importance after wheat, rice, maize, barley and sorghum. Pearl millet is traditionally grown as rain fed crop mostly under low fertility and rainfall condition. However, it also responses well to irrigation and improved management conditions. In India, it is the fourth most important cereal after rice, wheat and sorghum.

China, Nigeria, Pakistan, Sudan, Saudi Arabia are the major producers of this crop along with India. In India, it is grown on about 7.6 million hectares with an annual production of 9.5 million tones of grain and productivity of 1250 kg/ha (Anonymous, 2014-15). The main states of cultivation of pearl millet in India are Rajasthan, Gujarat, Maharashtra, Utter Pradesh, Haryana, Karnataka, Tamil Nadu, Madhya Pradesh, and Andhra Pradesh.

Rajasthan occupies first position in area and production of pearl millet in India. In Rajasthan, it is cultivated on 40.76 lakh hectares area with the production of 44.56 lakh tones and productivity of 971 kg/ha (Anonymous, 2014-2015). Major pearl millet producing districts of Rajasthan are Alwar, Bharatpur, Karoli, Dholpur, Swai Madhopur, Jaipur, Jhunjhunu, Churu, Bikaner, Jaisalmer and Barmer.

The average productivity of pearl millet in Rajasthan is 971 kg/ha, while the average productivity of pearl millet in Zone 1c (hyper arid and partially Irrigated western plains) comprising Bikaner, Jaisalmer and three tehsils of churu district is 465 kg/ha (Anonymous, 2015). The arable land is a precious and scarce resource, so among the options to increase production, the cropping intensity and efficient utilization of available resources seem more feasible over increasing area under cultivation. Therefore, there is need to improve production per unit area basis.

Hybrid varieties have undoubtedly an edge over composites and synthetic varieties in a cross-pollinated crop like pearl millet. Use of hybrids in pearl millet has paved a way of great success since the inception of using hybrids as commercial varieties. In India, attempts were made to produce pearl millet hybrids as early as 1951 (Rao *et al.,* 1951) and commercial exploitation of heterosis began after the availability of male sterile line Tift 23A from Georgia, USA (Burton, 1958), leading to development of a series of hybrids from HB-1 to HB-5. The grain yield of HB-1 was about 86 per cent higher than the best open-pollinated varieties (Athwal, 1965). Since then, breeding procedures used for pearl millet improvement have been aimed at exploitation of hybrid vigour both for grain as well as forage yield (Ouendeba *et al.,* 1993).

Development of high yielding varieties of pearl millet has led to increased productivity and stability largely in the regions with relatively better environments. While regions like Western Rajasthan with arid and semi arid environment still suffers from low productivity. This is because most of the hybrids recommended for this region resulted from the parents developed from programme not specifically meant for arid areas and hence lacked the desired adaptability and the characteristics required for these areas.

Assessment of genetic variability present among the selected genotypes will permit the plant breeder to make crosses for combining sufficient genetic variable characters for the rapid progress in breeding programme. The efficiency of selection depends upon the magnitude of genetic variability present in the plant population. Thus, the success of genetic improvement in any character depends on the nature of variability in the germplasm for that character. The evaluation also helps in determining the cooperative merit of different genotypes with respect to different characters. The lines with higher genetic variability gives better results for several parameters like higher adaptability, better disease resistance etc.

Correlation estimates between yield and its component characters are useful in selecting desired plant types in designing an effective breeding programme. When change in one variable causes the change on other variable, the variables are said to be correlated. Correlation coefficient measure the degree of association, genetic or non genetic relationship between two or more characters which forms the basis for selection.

Path coefficient estimation provides information about direct and indirect effect of yield attributes in relation to yield. It shows how attributing characters influences the yield by their path values, whether they affect yield directly or via influencing other inter-related characters.

Heterosis is a phenomenon, associates with increased yield and vigour which is obtained by crossing selected desirable inbred lines. Heterosis acts as an important aspect to know economic exploitation of hybrid vigour for desirable traits and also gives an idea about feasibility for commercial utilization of the hybrid. In pearl millet, standard heterosis plays a vital role to find out elite hybrids with improved yield and yield attributes for commercial utilization of these elite hybrids in form of new or improved varieties.

Keeping all this in view, the present study was undertaken to select superior genotypes under arid condition in an experiment entitled **“Study of variability, character association and heterosis in pearl millet [*Pennisetum glaucum* (L.) R. Br.] hybrids”** with the following objectives:-

- To estimate of different variability parameters for grain yield and its attributing traits.
- To determine the association of different characters with grain yield.
- To determine the economic heterosis for grain yield and its attributing traits to identify suitable hybrids.

2. REVIEW OF LITERATURE

Pearl millet is an allogamous crop. It was originated in West Africa and from there was introduced into India. Pearl millet has too many forms. To botanist pearl millet is a grass and to a geneticist, a challenging organism. To a farmer, it means a food crop. Animals browse and feed on it. To millions, it provides a livelihood and to millions, more a life giving food. Despite of its immense potential for supplementing the world's food resources, pearl millet is often grown on marginal lands under moisture stress condition and under poor management resulting in low yield.

The amount of variability for improving economic character in germplasm sets the limits of progress that can be achieved through selection. An assessment of the variability in the germplasm is therefore required to judge the potential of collection as base genetic material for genetic improvement. Informations on extent of heterosis are useful in formulating appropriate breeding programme for genetic improvement of a crop plant. However, the improvement of complex quantitative characters, such as grain yield depends upon improvement in yield associated components. Hence, the work done on the various aspects in pearl millet by different workers pertaining to the present investigation has been reviewed briefly under the following heads and a chronological order has been followed.

2.1 GENETIC VARIABILITY

Singh (1991) reported significant genetic variability for days to 50 per cent flowering, number of leaves per plant and number of tillers per plant.

Saraswati *et al.* (1993) observed wide range of variation for all the characters measured with highest coefficient of variation for grain yield per plant followed by ear length and productive tillers per plant.

Aryana *et al.* (1996) reported the highest genotypic and phenotypic variability for flag leaf area and plant height but the lowest variability for number of tillers per plant.

Bhatnagar *et al*. (1999) reported significant variability for days to 50 per cent flowering, days to maturity, plant height, grain yield and fodder yield per plant.

Kulkarni *et al.* (2000) evaluated five Indian, two Lebanese and one Nigerian white grain inbred lines along with 56 hybrids of pearl millet in Pune, India during *kharif* season (June-September). They observed maximum heritability for days to 50 per cent flowering, followed by plant height, test weight and grain number per cm^2.

Sachan and Singh (2001) tested 36 lines and 36 hybrids of pearl millet. They observed the highest phenotypic coefficient of variance (PCV) for fat content among the lines. The genotypic coefficient of variance (GCV) was high for seed fat, protein content, and grain yield. Among the hybrids, PCV was highest for 1000-grain weight and grain yield.

Yadav *et al.* (2001) evaluated 28 land races of pearl millet from Rajasthan to estimate genetic variation for nine traits including grain yield in two contrasting environments. They observed significant genetic variation for traits like time to flower, dry stover and total biomass yields. There was no genetic difference for panicles per plant and thereshing percentage while difference for grain yield *per se* was significant only at 10 per cent level of probability. However, an individual trait could explain only 22-34 per cent of variation in grain yield.

Sagar and Sagar (2002) evaluated a set of 108 inbreds of pearl millet for 6 characters namely, day to heading, plant height and number of effective tillers per plant, ear length, ear diameter and stem diameter. They observed highest variability for plant height and days to heading and medium to low variability for ear length, effective tillers, ear diameter and stem diameter.

Solanki *et al.* (2002) evaluated 24 genotypes of pearl millet composites for 5 productivity traits viz. days to heading, plant height, panicle number per m^2, fodder yield per m^2 and grain yield per m^2. They observed that the genetic and phenotypic coefficients of variation were highest for grain yield and panicle number and lowest for days to heading across the composites.

Lakshmana *et al.* (2003) evaluated 35 genotypes of pearl millet and reported significant genetic

Nagar *et al.* (2006) observed high genetic variability for days to heading, plant height, green fodder and dry matter yield in 30 genotypes of pearl millet. Higher GCV and PCV were also observed for green fodder yield, and plant height.

Shanmuganathan *et al.* (2006) studied genetic variability and diversity in pearl millet [*Pennisetum glaucum* (L.)R.Br.] with 104 germplasm accessions of different origin. Analysis of variance indicated significant variances among the accessions for all the characters studied. The maximum variation was recorded for number of tillers, number of leaves, leaf length and breadth, panicle length, leaf weight, stem weight, leaf stem ratio, green fodder yield, crude protein content and grain yield indicating the possibilities of improving these characters through phenotypic selection for the development of dual purpose cultivars (grain cum fodder yield).

Arulselvi *et al.* (2007) observed significant difference for grain yield in pearl millet. Similarly high magnitude of genotypic coefficient of variation was observed for various characters, which indicated low environmental influence and predominant role of genetic factor on the expression of these characters.

Bhoite *et al.* (2008) observed the genotypic and phenotypic variation in 26 genotypes of pearl millet. A wide range of variability was observed for all the characters studied. Higher heritability coupled with genetic advance as percentage of mean was noticed for ear head girth, grain yield, plant height, fodder yield, days to maturity and days to 50 per cent flowering indicating the presence of additive gene action and direct selection may be effective.

Yadav (2008) reported exploration of pearl millet [*Pennisetum glaucum* (L.) R. Br.] from arid and semi-arid parts of Rajasthan and their characterization and evaluation with respect to morphological descriptors and agronomic performance. In five explorations conducted during the crop seasons of 1999-2003, 169 landraces of pearl millet were collected from 18 districts of Rajasthan. There was a good amount of variation among them for various morphological descriptors. Majority of them had thin to medium-thin stems and possessed the ability to produce nodal tillers. Panicle compactness, seed covered either fully or partially in glume and good panicle exertion appeared to be the common feature of Rajasthan landraces.

Sumathi *et al.* (2010) evaluated the pearl millet genotypes to assess the magnitude of variability and to understand the heritable component of variation present in the biometrical characters. A field trial was laid out with 47 pearl millet genotypes and the observations were recorded on days to 50per cent flowering, plant height, number of tillers per plant, ear head length, ear head breadth, root length, shoot length, root shoot ratio and seed yield per plant. The phenotypic co-efficient of variation (PCV) was greater than genotypic co-efficient of variation (GCV) for all the characters studied, this showed the influence of the environment on the characters.

Subi and Idris (2013) evaluated 15 genotypes of pearl millet [*Pennisetum glaucum* (L). R. Br.] at Sudan, during the summer season 2009 and 2010 to assess the magnitude of genetic variability, heritability in broad sense and genetic advance for growth and grain yield characters. Highly significant differences ($P \leq 0.01$) were observed for days to 50per cent flowering and days to maturity in the both seasons, while for plant height, leaf area, number of grains per plant, 1000- grain weight and grain yield (t/ha) in the summer season only of 2009 and for panicle length in the summer season of 2010.

Sumathi, *et al.* (2016) evaluated hundred pearl millet genotypes to understand their diversity and association among the yield and yield attributing traits. The PCV was higher than the GCV for all the characters studied indicating the influence of environment in expression of characters. High heritability along with high genetic advance as per cent of mean was observed in single ear head weight, grain yield per ear head, 1000 seed weight, spike girth and days to 50 per cent flowering indicated that additive gene action for these characters. Single ear head weight, 1000 seed weight and days to 50 per cent flowering possessed high direct effect on grain yield. Hence, direct selection for these characters could be rewarding for the improvement of grain yield.

2.2 Correlation Coefficient

Correlation studies are very important in framing selection programme and also in breeding programme aiming at improving yield. It is essential to know, the degree of association between yield and other metric traits and magnitude of their direct and indirect effects on yield. Yield is complex character, which is contributed by many independent characters and improvement in yield depends upon improvement in its component characters. When change in one variable cause the change in another variable, the variable are said to be correlated. This association between the attributes is measured as "Correlation coefficients". If the change is in same direction, the correlation is positive and if it is in opposite direction, the correlation is negative. The value is zero when two variables are not related. In plant breeding, study of correlation is essential because most of the traits, such as yield, are the end products of interaction of several genetic factors among themselves and their individual and combined interaction with environmental factors.

Savery and Prasad (1994) studied variability and character association of grain yield in 41 genotypes of pearl millet and found that days to 50per cent flowering and plant height were positively correlated with grain yield.

Karthigeyan *et al.* (1995) crossed 4 male sterile lines of pearl millet with 19 sweet stalked testers and evaluated 76 hybrids for correlation. They observed that grain yield had a strong positive association with ear weight and plant height.

Navale *et al*. (1995) observed significant and positive association between days to 50 percent flowering and grain number per cm^2. However, productive tillers per plant were significantly and positively associated with fodder yield and grain yield. The studies revealed that ear length, ear girth and fodder yield should be considered when selecting high grain yielding types pearl millet.

Loga Sundari and Khan (1996) studied correlation analysis of fodder attributes in sweet pearl millet and reported that dry fodder yield per plant had highly significant and positive correlation with plant height, number of nodes, leaf length, leaf width and stem diameter.

Yadav (1996) observed that days to 50per cent flowering had positive and significant correlation with effective tillers per plant, total leaves per plant, stem diameter, leaf to stem ratio and leaf area, whereas a negative significant correlation of plant height was observed with days to 50per cent flowering, effective tillers per plant, stem diameter and leaf and stem ratio.

Singh (1997) observed that days to 50 percent flowering exhibited positive and non-significant association with leaf area and stem thickness, whereas, a negative non- significant association with effective tillers per plant and plant height.

Latha and Shanmuga (1998) studied character association in grain pearl millet and reported that grain yield possessed a high and positive association with number of effective tillers per plant, plant height, and test weight. Plant height, days to 50 percent flowering and ear length were mutually correlated. The following pairs were positively correlated, ear length and ear thickness, test weight and number of effective tillers per plant.

Chandolia and Sagar (1999) reported that grain yield per plant had significant positive association with ear weight per plant, ear girth, 500 grain weight, dry fodder yield per plant, plant height and ear diameter in genotypes of pearl millet.

Harer and Karad (1999) reported that grain yield was negatively correlated with maturity character but positively and highly significantly correlation with plant height, test weight, fodder yield per plant, ear girth and flag leaf area in genotypes of pearl millet.

Singh *et al.* (1999) studied character associations in pearl millet for different traits and observed that grain yield had significant positive correlation with ear weight, effective tillers per plant, number of grain per ear. Days to 50per cent flowering exhibited significant positive association with days to maturity, total number of tillers per plant and negative significant association with plant height. On the other hand, days to maturity was found to exhibit significant positive correlation with test weight. The positive association of grain yield with ear weight, effective tillers per plant and number of grains per ear, suggested that selection for these component characters might prove very effective.

Anarase and Ugale (2001) evaluated 40 different genotypes of pearl millet grown in Rahuri, Maharashtra, India, during the *kharif* season of 1994 and observed that all the characters assessed except the number of grains per cm^2 had significant positive correlation. Fodder yield per plant, plant height, ear length and ear girth had strong positive significant correlation with grain yield. These characters were also positively and significantly correlated among themselves.

Kumar *et al.* (2002) studied correlations among grain yield and its component in pearl millet hybrids at Hisar, India, during the kharif seasons of 2000 and 2001 and observed that the grain yield had significant positive correlation with all component characters under study except harvest index.

Pareek (2002) evaluated 108 hybrids of pearl millet with four checks grown in augmented design and reported that grain yield had positive and significant association with plant height, effective tillers per plant, panicle length, panicle girth and dry fodder yield.

Chaudhary *et al.* (2003) reported that genotypic correlation coefficients were higher than phenotypic correlation coefficients for almost all the traits. Grain yield per plot was positively and significantly correlated with plant height, leaf area, head length, head girth and biological yield per plot indicating the importance of biological yield, harvest index, head girth and plant height.

Chikurte *et al.* (2003) studied 15 inbreds of pearl millet for 12 characters and observed that panicle length, number of tillers per plant, number of grains per cm2, test weight and main stem girth were strongly and positively associated with grain yield.

Thangasamy and Gomathinayagam (2003) evaluated 21 parents and 110 F1s in pearl millet for 10 characters during kharif 1999 and reported that grain yield had high significant positive correlation with plant height, ear length, ear head girth and productive tillers. The leaf width showed very high positive association with ear head length, ear head girth and 1000-grain weight.

Unnikrishnan *et al.* (2004 b) studied genotypic correlation in 244 pearl millet genotypes during kharif season 2001 and reported highly significant positive correlation of ear girth, ear length, days to 50 per cent flowering, 1000- grain weight with grain yield.

Yadav *et al.* (2004) evaluated twenty- four pearl millet genotypes and reported that genotypic correlation coefficients were higher than their corresponding phenotypic correlation coefficients. Stover yield was significantly and positively correlated with biological yield and plant height.

Borkhataria *et al.* (2005) studied eighteen inbreed lines (male parents) and 11 male sterile line (female parents) and their 22 selected hybrids of pearl millet during *kharif* 1996 and reported highly significant and positive correlation for ear head girth, number of effective tillers per plant, plant height and 1000- seeds weight with grain yield which indicated the major role of these characters in grain yield.

Izge *et al*. (2006) evaluated 45 hybrids of pearl millet [*Pennisetum glaucum) (L.) R. Br*.]. Strong and significant genotypic and phenotypic correlation were observed between total grain yield with yield per plant, number of tillers per plant, number of leaves per plant, plant height, panicle length and number of seeds per panicle.

Vidyadhar *et al.* (2007) assessed the genetic variability and character association among the 14 advanced hybrids of pearl millet for 12 quantitative traits and reported grain yield have positive and significant correlation with most of the characters under study except leaf length, panicle width and tiller number.

Kele *et al.* (2011) studied variability, heritability, genetic advance, correlation and path co-efficient for fifteen metric traits in 60 F_3 progenies of pearl millet. Stover yield, grain yield, ear head weight plant, total biomass per plant and ear head girth showed high GCV, heritability and genetic advance as percentage of mean. Heritability (broad sense) ranged from 14.93 per cent (av. inter node length) to 92.38 per cent (total biomass per plant). The correlation of grain yield with ear head weight, average inter node length, total biomass per plant, stover yield, no. of leaves per plant and no. of productive tillers per plant was significant and positive. The path coefficient analysis revealed that stover yield, ear head weight, no. of leaves per plant and average inter node length had both direct and indirect effects to account for yield. The characters total biomass per plant and no. of productive tillers per plant showed negative direct effects but had positive indirect effects through no. of leaves per plant, ear head weight and stover yield per plant.

Abuali and Idris (2012) studied 15 genotypes of pearl millet *(Pennisetum glaucum* L.) at two locations of Sudan, during the years 2003 and 2004. The study was conducted to determine the interrelationship between yield and yield components and other quantitative traits, including days to 50per cent flowering, date to maturity, panicle length and plant height. Phenotypic and genotypic correlation coefficients were calculated. The results showed that strong positive significant genotypic and phenotypic correlations were observed between grain yield/plant and harvest index, grain yield/plant and biomass dry weight and grain yield/plant and number of seeds per panicle and with other quantitative characters. However, grain yield/plant has negative association with days to 50per cent flowering and date to maturity. It could be concluded that the number of effective tillers/plant, number of seeds/head, 1000-seeds weight and panicle length/main head could be identified as the most important characters associated with yield, and therefore, can be used as selection criteria for yield improvement of pearl millet.

Bikash *et al.* (2013) studied variability, correlation and path analysis in pearl millet in a set of 30 elite hybrids of pearl millet developed at CCS Haryana Agricultural University, Hisar. The results on correlation revealed that in general, the genotypic correlation coefficient were higher than their corresponding phenotypic correlations. The grain yield was significantly and positively correlated with harvest index, ear girth, effective tillers, dry fodder and biological yield in all the four environments.

2.3 Path Coefficient Analysis

Path coefficient is defined as the ratio of the standard deviation of the effect due to a given cause to the total standard deviation of the effect. The path analysis is simply standardized partial regression coefficient analysis which may be useful in choosing the characters that have direct and indirect effect on yield.

The correlation coefficient provides information about the degree of association between two characters. However, it is now known that almost all characters are polygenic and almost all genes are pleiotropic in action such that each gene, apart from its direct contribution to a particular character contributes to several other characters also. Therefore, correlation coefficient alone would not provide a clear picture about the contribution of a particular character. For example, the estimates of correlation coefficient between two characters may be positive but the direct effect of the characters to the correlation coefficient may be negative. In this case, indirect effects are the cause of correlation coefficient and have masked the direct effect of the character. In such instances, indirect effect should be taken into consideration in formulating a selection strategy. Path analysis was initially suggested by Wright (1921) and gave the concept and methodology of path analysis but was applied for the first time in plant breeding by Dewey and Lu (1959).

Kumar *et al.* (2002) evaluated hybrids (HHB 94, HHB 67, HHB 60, and HHB117 and HHB147) under 6 nitrogen rates (control, 30, 60, 90, 120, and 150 kg per ha). In this evaluation path coefficient analysis indicated that stover yield per plant and grain yield per plant had relatively higher and positive influence on final grain yield of pearl millet. Indirect effects of other characters on grain yield of pearl millet through stover yield per plant were also positive and comparatively higher.

Pareek (2002) reported that dry fodder yield had maximum direct effect on grain yield followed by panicle girth and effective tillers per plant. Effective tillers per plant had maximum indirect effects via fodder yield. Days to heading had maximum direct effect on grain yield.

Chaudhary *et al.* (2003) studied four CMS lines and four open pollinated promising strains of pearl millet and their 16 hybrids and reported the positive direct effect of biological yield per plot (0.7238), harvest index (0.5976) and plant height (0.1419) on grain yield per plot.

Yadav *et al. (*2004) evaluated 24 pearl millet genotypes and path coefficient analysis suggested the importance of biological yield, plant height and effective tillers, as these traits had positive direct and indirect effects on stover yield.

Izge *et al.* (2006) evaluated 45 hybrids of pearl millet and observed that grain yield per plant, days to 50 per cent flowering and plant height had the highest direct effect on total grain yield. The panicle length and threshing percentage had the least direct effect on total grain yield. The direct effect of yield per plant was highly reduced by the negative indirect effect through days to 50 per cent flowering and downy mildew incidence, even though it was not significant. Similarly, the direct effect of plant height was influenced by the negligible indirect effect of threshing percentage, downy mildew incidence and test weight. The grain yield per plant, number of seeds per panicle and plant height had been identified as selection criteria for obtaining good parental lines and hybrids in pearl millet breeding programmes.

Vidyadhar *et al*. (2007) reported that selection should be based on days to flowering, days to maturity, plant height, leaf length, panicle length, panicle width and fodder yield towards the development of dual purpose hybrids in pearl millet.

Govindaraj *et al.* (2011) studied Path coefficient analysis for grain minerals and quality traits in 61 indigenous germplasm lines of pearl millet. Maximum direct effect on grain yield was contributed by crude fat content which is positive and highly significant followed by number of productive tillers, hundred grain weight and panicle length. Productive tillers per plant, panicle length, 100-grain weight and crude fat content had positive and significant indirect effect on grain yield. It was also noted that, breeding for high grain minerals as well as other quality characters did reduce the yield potential of the cultivars.

Kele *et al.* (2011) studied path co-efficient for fifteen metric traits in 60 F_3 progenies of pearl millet. The path coefficient analysis revealed that stover yield, ear head weight, no. of leaves per plant and average inter node length had both direct and indirect effects to account for yield. The characters total biomass per plant and no. of productive tillers per plant showed negative direct effects but had positive indirect effects through no. of leaves per plant, ear head weight and stover yield per plant.

Ghazy *et al.* (2012) studied thirteen selected genotypes and check cultivar of pearl millet and reported that plant height, stem diameter and number of stems were useful tools for selecting high yielding genotypes.

Bikash *et al.* (2013) studied variability, correlation and path coefficient analysis in pearl millet in a set of 30 elite hybrids of pearl millet developed at CCS Haryana Agricultural University, Hisar. The results on path coefficient in the present study revealed the direct and indirect effects of various characters on grain yield. The path coefficient analysis suggested the importance of biological yield as it has direct and indirect positive effect on grain yield in all four environments. The characters such as harvest index, ear girth, effective tillers, dry fodder and biological yield have significant correlation on grain yield.

Kumar (2014) studied 50 genotypes of pearl millet for 10 characters and reported that grain yield per plant had significant and positive correlation with number of effective tillers per plant and harvest index at phenotypic and genotypic level. Path coefficient revealed that characters viz., harvest index, biological yield per plant, number of effective tillers per plant and test weight had direct positive effect on seed yield per plant.

9.4 Standard Heterosis

Heterosis and hybrid vigour indicates the superiority of F1 over its parents. The term hybrid vigour is used for superiority of hybrid over parents only in positive direction, while heterosis is measured in both positive and negative direction. Fonseca and Patterson (1968) coined a new term 'heterobeltiosis' as an improvement of heterozygote in relation to better parents. The most important aspect for the economic exploitation of hybrid vigour is to study the extent of heterosis present for agriculturally important traits and the feasibility of its commercial use. The available information on magnitude of standard heterosis in pearl millet is reviewed here.

Harer *et al.* (1990) reported higher magnitude of heterobeltiosis for grain yield in line × tester (176.6) as well as in diallel (98.2) mating designs in pearl millet followed by productive tillers per plant (87.5per cent) in line x tester and plant height (79.3per cent) in diallel crosses.

Quendeba *et al.* (1993) reported better parent heterosis for grain yield ranged from 25 to 81 percent in a study of 10 inter-population crosses of five populations of pearl millet. Six crosses showed significant heterosis, which gave 36 to 81 percent more grain yield over better parent.

Chavan and Nerake (1994) recorded high heterosis over better parent for days to 50 percent flowering (-16.44per cent), days to maturity (-4.17per cent), leaves per plant (50.14per cent), plant height (26.03per cent), number of effective tillers per plant (48.00per cent), spike length (23.87per cent), spike girth (19.90per cent), grain per cm^2 (40.95per cent) and grain yield per plant (109.26per cent).

Gartan *et al.* (1994) estimated low to moderate heterosis (over better parent) for various traits viz., plant height, number of ears per plant, ear girth and ear length in a study of 36 hybrids of pearl millet. However, substantial magnitude of heterosis was observed for grain yield per plant (-58.90 to 66.49per cent) and 1000-grain weight (-34.83 to 38.18per cent).

Deore *et al.* (1997) studied heterosis for physiological traits and grain yield in 24 F_1 hybrids of pearl millet. They observed significant average heterosis for grain yield and harvest index. In case of grain yield, heterosis was 73.3 percent over mid parent, 68.36 percent over better parent and 28.50 percent over control.

Azhaguvel and Jayraman (1998) crossed 9 female lines with 3 different cytoplasm (A_1, A_2 and 732A) with 10 testers as males to estimate heterosis in pearl millet F_1 hybrids. Relative heterosis, heterobeltiosis and standard heterosis was observed for number of productive tillers, panicle length, panicle girth, 1000-grain weight and grain yield per plant.

Rai *et al.* (1998) reported that A_1 and A_5 cytoplasmic-genetic male sterility (CMS) system provide access to more diverse germplasm and offer new opportunities for greater exploitation of heterosis of pearl millet hybrids. Their mean values are the increase in efficiency with parental lines can be identified and produced.

Bidinger *et al*. (1999) evaluated the utility of recessive 'el' allele for early flowering in pearl millet and observed that the said allele was a powerful tool for exploiting heterosis between early and late flowering parents.

Mohan *et al*. (1999) studied heterosis on 5 yield related traits in the parents and progenies of 5 lines x tester pearl millet crosses. ICMA 91777 x PT 5590 was considered to be best specific combination based on performance, SCA effects and standard heterosis for ear head length, ear head girth, 1000-grain weight and grain yield per plant.

Sheoran *et al*. (2000) studied heterobeltiosis and gene effects for different traits in pearl millet. The mean values of hybrids for plant height, girth and length of ear head, 1000-grain weight and grain yield per plant were higher than those of the better parent, including over dominance. Maximum heterobeltiosis was recorded for grain yield per plant in E1 (54.23per cent) and E2 (37.41per cent) followed by girth of ear head (28.18per cent) in E1 and (21.34per cent) in E2.

Ramamoorthi and Govindarasu (2001) studied the magnitude of heterosis over mid parent, better parent and best parent in ten pearl millet hybrids produced by crossing five inbred lines without reciprocals. They observed heterosis for grain yield per plant from -11.10 to 29.31 per cent over the mid parent, -10.43 to 21.30 per cent over the better parent and -24.25 to 6.78 per cent over the best parent. Heterosis for ear head length and width was significant in all the crosses except one cross.

Presterl and Weltzien (2003) evaluated the performance of six elite breeding population and three landraces of pearl millet and determined the heterosis pattern. Elite population generally showed higher grain yield (GY) then the among 36 diallel crosses of those population. Stover yield (SY) was similar in both population types. The landraces flowered earlier, had a higher tillering potential, and smaller seeds. Mean level of mid parent heterosis was generally low, ranging from 0.85 percent for time to flowering (TF) to 6.57 percent for SY.

Manga and Dubey (2004) reported good amount of heterosis for grain yield, earliness, productive tillers per plant, ear length, ear weight, 1000- grain weight, harvest index and biomass in a half diallel analysis involving nine inbreed lines of pearl millet. They reported a number of promising parents on the basis of high heterosis (96.2-300.7per cent).

Rathore *et al.* (2004) studied eleven genetically diverse restorers of pearl millet and reported positive heterosis effect for grain yield along with days to 50 percent flowering, days to maturity, panicle length, panicle girth, harvest index and protein content.

Patel *et al.* (2008) studied in a field experiment conducted in Anand, Gujarat, India. 5 hybrids exhibited higher relative heterosis, heterobeltiosis and standard heterosis for most of the fodder yield attributes, indicating their importance for commercial exploitation of heterosis. The analysis of combining ability variances indicated that only non additive gene action governed most of the fodder yield attributes. For the expression of days to maturity, both additive and non additive gene action were responsible. The estimates of general combining ability effects indicated that none of the parents was good general combiner for fodder yield.

Patel *et al.* (2008) in a line x tester experiment observed that the cross ICMA 92777 x 98 SB recorded significant relative heterosis for days to 50 per cent flowering, plant height, number of tillers, number of effective tillers and test weight. This cross also exhibited significant heterobeltiosis for days to 50 per cent flowering, plant height, number of effective tillers and significant desired heterosis over standard check for total number of tillers and number of effective tillers.

Vetriventhan *et al.* (2008) conducted experiment comprising of five male sterile lines and 30 inbred testers of pearl millet and their 150 hybrids for studying the extent of hybrid vigour in F_1 for grain yield and its components. Highest and significant negative relative heterosis, heterobeltiosis and standard heterosis were observed in the cross ICMA 94111A x PT 5259 and the same combination showed negative relative heterosis, heterobeltiosis and standard heterosis for the trait plant height. The cross combination ICMA 94111A x PT 5423 showed higher magnitude of positive relative heterosis and heterobeltiosis for total number of tillers. Highest and significant positive standard heterosis was recorded in ICMA 88004A x PT 5164 for total number of tillers. The hybrid cross combination ICMA 94111A x PT 5423 showed highest and significant relative heterosis, heterobeltiosis and standard heterosis for total productive tillers.

Vagadiya *et al.* (2010) studied four cytoplasmic genetic male sterile lines which were crossed with 12 diverse pollinators in line x tester design to study the nature and magnitude of heterosis for grain yield and its seven component traits in pearl millet. The extent of heterosis varied in each cross for all the characters studied. The high magnitude of heterosis was observed for grain yield per plant, fodder yield per plant and ear heads weight per plant; medium level of heterosis was exhibited for days to 50 per cent flowering, days to maturity, node number per plant and 1000-grain weight. While, low amount of heterosis was recorded only for threshing index. Among 48 crosses, 36 and 4 hybrids exhibited significant and positive heterosis for grain yield over better parent (heterobeltiosis) and standard check (GHB-719) (standard heterosis), respectively. The maximum positive heterosis of 105.71 and 11.30 per cent over better parent and standard check, respectively, was recorded for grain yield per plant.

Davda *et al*. (2012) reported that heterosis was observed in both directions for most of the characters. The high standard heterosis was obtained for grain yield, harvest index, days to 50per cent flowering, days to maturity and length of protogyny. Medium level of heterosis was found for plant height and threshing index and low for number of nodes per plant. The highest positive heterobeltiosis and standard heterosis for grain yield per plant is 262.15 and 41.05 per cent, respectively.

Bhadalia *et al.* (2013) reported that the magnitude of heterosis varied from cross to cross for all the characters studied. The high magnitude of standard heterosis was observed for grain yield per plant, number of effective tillers per plant, ear head weight and harvest index, while moderate to low heterosis over standard check hybrid (GHB-744) was found for rest of the traits under study. The highest positive heterosis for grain yield per plant over better parent and standard check was observed to be 77.82 and 42.91 per cent, respectively.

Kathale *et al.* (2013) observed significant positive effect over standard check GHB-558 for grain yield per plant in the hybrid MS-88004A × AIB-214 (35.58per cent) followed by MS-841A × IC-1179 (28.83per cent) and MS-99111× AIB-3354-2 (27.30per cent).

Bachkar *et al.* (2014) observed high standard heterosis for number of effective tillers per plant, grain yield per plant, ear head girth and number of grains per cm^2 while moderate to low heterosis over standard checks was found for plant height (cm), 1000-grain weight (g), ear head length (cm), total number of tillers per plant, fodder yield per plant (g), days to maturity and days to 50per cent flowering. The highest positive standard heterosis for grain yield per plant was 70.81per cent. Heterosis for grain yield might have resulted from heterosis for its component traits, mainly number effective tiller per plant, ear head girth and number of grains per cm^2.

Singh *et al.* (2015) concluded that the magnitude of heterotic effect was high for grain yield, biological yield, dry fodder yield and harvest index; moderate for days to 50per cent flowering, days to maturity, productive tillers per plant, plant height, panicle length, panicle girth and test weight and low for protein content in all the three environments. Fourteen crosses exhibited the significant heterobeltiosis for grain yield and related traits across the environments.

Pawar *et al.* (2015) concluded that the cross combinations RHRBI 138 x S-12/30088 and S-12/30109 x S-12/30088 exhibited significant negative heterosis and heterobeltiosis in desirable direction for days to 50 per cent flowering and days to maturity in all environments and over pooled values. So these cross combinations could be further exploited for obtaining desirable transgressive segregants and to identify early and high yielding superior genotypes.

Nandaniya *et al*. (2016) were crossed five CMS lines with nine testers in a line x tester design to study the extent of heterosis in pearl millet for yield and quality traits. They observed heterosis in both directions for most of the characters. High magnitude of heterosis was observed for plant height, ear head girth, ear head weight, grain yield per plant and harvest index. The heterosis was moderate for Fe content, Zn content and test weight. The heterobeltiosis for grain yield per plant ranged from -26.50 to 200.00 per cent, while the standard heterosis ranged from -53.38 to 37.79 per cent.

3. MATERIALS AND METHODS

The present experiment was carried out to appraise the "**Study of variability, character association and heterosis in pearl millet [*Pennisetum glaucum* (L.) R. Br.] Hybrids"** The experiment was conducted at Agricultural Research Station, Bikaner during *Kharif season*, 2015.

The Research farm is situated between 27^{0}11' N latitude and 71^{0} 54' E longitudes at an altitude of 228.5m above mean sea level. This region falls under agro climate zone I-C of state of Rajasthan. The climate of the region is typically arid which is characterized by extremes of temperature during summer and winter with aridity of atmosphere. The average rainfall of locality is about 260 mm, which is mostly received during July-September. The meteorological data on maximum and minimum temperature, relative humidity, wind velocity and rainfall during the investigation period has been presented in appendix- II

3.1 Experimental Materials

The experimental material for the present investigation consisted of 40 genotype of pearl millet [*Pennisetum glaucum* (L.) R.Br.] including check HHB-67 improved. These pearl millet genotypes were obtained from the AICRP on Pearl millet, ARS, Bikaner. The details of these genotypes are listed in Table 3.1.

3.2 Experimental Details

The experimental material was laid out in a Randomized Block Design (RBD) with two replications during *Kharif,* 2015. Each plot consisted of six rows each of 4.0 meter length. The spacing between row to row was 50 cm and between plant to plant was 15 cm. Normal and uniform cultural operations were followed during the crop season to raise a good crop. The experiment was sown on 21 July, 2015 with pre sowing irrigation with the basal application of 20 kg N + 20 kg P/ha. While 20 kg N/ha was applied as top dressed 30 DAS.

Table 3.1 List of 40 genotypes used in the present investigation

S. No.	Genotype
1	843-22A x ICMR 01004-P59-754
2	843-22A x ICMR 01004-P7-775
3	843-22A x ICMR 01004-P13-783
4	843-22A x (ICMR 01004-P59 x 863B-P2-P10)-808
5	843-22A x (ICMR 01004-P59 x P7-3-P4)-819
6	843-22A x (ICMR 01004-P59 x P7-3-P4)-822
7	843-22A x (ICMR 01004-P59 x P7-3P4)-828
8	843-22A x (ICMR 01004-P59 x P7-3-P4)-829
9	843-22A x (ICMR 01004-P59 x P7-3-P4)-830
10	843-22A x (ICMR 01004-P59 x P7-3P4)-831
11	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-834
12	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-835
13	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-836
14	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-837
15	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-838
16	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-839
17	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-840
18	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-841
19	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-842
20	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-843
21	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-844
22	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-845
23	843-22A x (ICMR 01004-P13-847
24	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-848
25	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-849
26	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-850
27	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-851
28	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-852
29	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-855
30	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-856
31	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-857
32	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-858
33	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-859
34	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-862
35	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-863
36	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864
37	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-865
38	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-866
39	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-867
40	HHB-67 imp.

3.3 Characters Studied and Observational Procedure

The observations were recorded on 10 randomly selected plants from each plot for 10 characters *viz.,* plant height (cm), number of effective tiller per plant, ear head length (cm), ear head diameter (cm), biological yield per plant (g), harvest index (%) and grain yield per plant (g). While for days to 50 % flowering, days to maturity and test weight (g) were recorded on whole plot basis. Detailed procedure adapted to record the observation for each character is given below.

1. Days to 50% flowering: The number of days taken from the date of sowing to the date at which 50% plants start stigmatic flowering in whole plot was recorded as days to 50% flowering.

2. Days to maturity: The days taken from the date of sowing to the date of physiological maturity of the plants in whole plot was recorded as days to maturity. The formation of black layer at the base of the seed indicates the physiological maturity.

3. Plant height (cm): Plant height was measured in cm from ground level to the top of the plant at the time of maturity.

4. Number of effective tillers per plant: The number of tillers bearing ear heads with grains of 10 randomly select plants was counted and averaged.

5. Ear head length (cm): The ear head length was measured in cm from the base of the ear to its tip.

6. Ear head diameter (cm): The ear head diameter was measured from the middle of the ear head of main tiller at the time of maturity with the help of Vernier caliper.

7. Test weight (g): A random sample of thousand seeds was drawn from the threshed seed of each hybrid in each replication and weighed in g and recorded as test weight.

8. Harvest index (%): Harvest index was computed by using following formula as suggested by Singh and Stoskoff (1971).

Harvest index % =Grain yield per plant (g) x 100 / Biological yield per plant (g)

9. Biological yield per plant (g): Ten randomly selected and tagged plants including all plant parts above ground was dried in sunlight and weighed in gram and averaged.

10. Grain yield per plant (g): The ear heads of the ten tagged plants was threshed together, weighed and averaged to obtain grain yield per plant.

3.4 Statistical Analysis

The overall mean values for 10 different characters of ten randomly selected plants were used for statistical analysis.

3.4.1 Analysis of variance

The data were subjected to analysis of variance adopting standard statistical methods (Panse and Sukhatme, 1985 and Singh and Choudhary, 1979). The analysis of variance including source of variations, their degree of freedom (D.F.) and expectations of mean squares are given below:

Sources of variations	D. F.	M. S.	Expectations of M.S.
Replication	(r-1)	Mr	$\sigma^2e + g\ \sigma^2r$
Genotypes	(g-1)	Mg	$\sigma^2e + r\ \sigma^2g$
Error	(r-1) (g-1)	Me	σ^2e
Total	r g - 1		

Where,

r = Number of replications

g = Number of genotypes

Mr = Mean sum of square due to replications

Mg = Mean sum of square due to genotypes

Me = Mean sum of square due to error

σ^2g = Genotypic variance

σ^2r = Replication variance

σ^2e =Error variance

3.4.2 Analysis of variance components

The genotypic, phenotypic and error variance were calculated as follows.

3.4.2.1 Genotypic variance (σ^2_g)

The genotypic variance is due to the differences among genotypes included in the study. It was calculated as under:

Genotypic variance (σ^2_g) = $M_g – M_e / r$

3.4.2.2 Phenotypic variance (σ^2_p)

It is the sum of variance contributed by genetic causes and environmental factors. It was calculated as under:

Phenotypic variance (σ^2_p) = $\sigma^2_g + \sigma^2_e$

3.4.2.3 Error variance (σ^2e)

The mean square of error represented by the variation attributed to environmental causes.

Environmental variance (σ^2_e) = M_e

3.4.3 Variability parameters

3.4.3.1 Range

It is the difference between the lowest and the highest value for each character.

3.4.3.2 Mean ($\bar{X}$)

It is computed by dividing the sum of all observations in a sample by their number.

$$\bar{X} = \quad X_{ij} / n$$

Where, $\bar{X}$ = General mean,

X_{ij}= Observed value in i^{th} genotype in j^{th} replication,

n= Number of observations,

3.4.3.3 Standard error of mean (S.Em.)

The standard error of mean (S.Em.) was calculated with the help of following formula.

$$S.Em. = \sqrt{\sigma_e^2 / r}$$

3.4.3.4 Critical difference (C.D.)

Critical difference for the characters was calculated by using the following formula.

$$C.D. = S.Em. \times \sqrt{2} \times 't' \text{ value at error d.f.}$$

3.4.3.5 Coefficient of variation (C.V. %)

The coefficient of phenotypic and genotypic variation was calculated by using the formula suggested by Burton (1952).

(a) Phenotypic coefficient of variation (PCV):

$$\text{P.C.V. (\%)} = \frac{\sqrt{\sigma_p^2}}{\overline{X}} \times 100$$

(b) Genotypic co-efficient of variation (GCV):

$$\text{G.C.V. (\%)} = \frac{\sqrt{\sigma_g^2}}{\overline{X}} \times 100$$

3.4.3.6 Heritability in broad sense ($H_{(b)}$)

Heritability refers to the proportion of variability out of the total variability which is heritable in nature. It is due to the genetic causes. Heritability in broad sense ($H_{(b)}$) was calculated according to the following formula suggested by Burton and De Vane (1953).

$$H_{(b)}\% = (\sigma^2_g / \sigma^2_p) \times 100$$

3.4.3.7 Genetic Advance (GA)

Expected genetic advance represents the shift in a population mean towards superior side under selection pressure after single generation of selection. This was estimated as per the formula suggested by Johnson *et al*. (1955).

G.A. $= H_{(b)} \times k \times \sigma_p$

Where,

G.A.	=	Genetic Advance
$H_{(b)}$	=	Heritability broad sense
k	=	Selection differential, (k = 2.06 at 5 per cent selection intensity)
σ_p	=	Phenotypic standard deviation

3.4.3.8 Genetic advance expressed as percentage of mean

The expected genetic advance (G.A.) expressed in percentage of mean was calculated by using the method suggested by Johnson *et al.* (1955).

Genetic advance as percent of mean = $\frac{\text{G.A.}}{\overline{\text{X}}} \times 100$

3.4.4 Correlation coefficients

The phenotypic and genotypic correlation coefficients were computed from the phenotypic and genotypic variance and covariances according to Searle (1961).

- **Genotypic correlation coefficient :**

$$r_{xy}(g) = \frac{Cov.xy(g)}{\sqrt{Vx(g).Vy(g)}}$$

- **Phenotypic correlation coefficient :**

$$r_{xy}(p) = \frac{Cov.xy(p)}{\sqrt{Vx(p).Vy(p)}}$$

Where,

$r_{xy}(g)$	=	Genotypic correlation between x and y traits
$r_{xy}(p)$	=	Phenotypic correlation between x and y traits
Cov. xy (g)	=	Genotypic covariance for x and y traits
Cov. xy (p)	=	Phenotypic covariance for x and y traits

$V_x(g)$ = Genotypic variance for x trait

$V_y(g)$ = Genotypic variance for y trait

$V_x(p)$ = Phenotypic variance for x trait

$V_y(p)$ = Phenotypic variance for y trait

Test of significance

The significance of correlation coefficient was tested using the following formula:

$$t = \frac{r}{\sqrt{(1 - r^2)}} \times \sqrt{(n - 2)}$$

Where,

r = Correlation coefficient

n = Number of pairs of observation

3.4.5 Path Coefficient Analysis:

The direct and indirect effects were estimated through path coefficient analysis as suggested by Wright (1921) and elaborated by Dewey and Lu (1959). The following equations were solved for estimating the various direct and indirect effects.

$r_{1y} = P_{1y} + r_{12}P_{2y} + \ldots\ldots\ldots\ldots + r_{1p}P_{py}$

$r_{2y} = r_{21}P_{1y} + P_{2y} + \ldots\ldots\ldots\ldots + r_{2p}P_{py}$

……………………………………….

……………………………………….

$R_{py} = r_{p1}P_{1y} + r_{p2}P_{2y} + \ldots\ldots\ldots\ldots + P_{py}$

Where,

P_{1y}, P_{2y}……………P_{py} are direct effects of character 1,2, ………..p on y and r_{1y}, r_{2y}…………r_{py} denote correlation coefficient between independent characters 1,2……..p and dependent character 'Y'.

Residual effect was calculated using the following formula:

$$1 = P^2Ry + P_{iy}R_{iy}$$

$$P_{Ry} = 1- (P_{1y}r_{1y}) – (P_{2y}r_{2y})……………(P_{iy}r_{iy})$$

Where, P_{Ry} is the residual effect

3.4.5 Standard Heterosis:

Standard heterosis was calculated for grain yield per plant as deviation of hybrid (F_1) from the check included in the trial and was expressed as % superiority over check.

$$\text{Std. heterosis (\%)} = F_1 – BST (C) \times 100/ BST(C)$$

Where, BST(C) = Mean of check

Test of significance:

The significance of the heterosis estimates was done using t- test. The SE for testing the significance was calculated using the formula.

$$SE (F_1- BST(c)) = (\sqrt{2xEMS})$$

$$t = F_1 – BST (c)/ SE (F_1- BST(c))$$

The calculated't' value was compared with the table value at error degree of freedom.

Where,

$F_1 =$ Mean of hybrid,

BST(C) = Mean of best check used in the trial,

EMS = Error mean squares,

4. RESULTS

Experimental material for the present study consists of 40 hybrids of pearl millet [Pennisetum glaucum (L.) R.Br.] which were utilized to find out information about variability, character association and heterosis. These genotypes were grown during *kharif,* 2015 at Research farm, Agriculture Research Station, Bikaner. The data were recorded on 10 metric characters and analyzed statistically. The results of present investigation are presented under following sub-heads:

4.1 Analysis of variance

4.2 Variability, heritability and genetic advance

4.2 Correlation coefficient

4.3 Path coefficient

4.4 Heterosis

4.1 Analysis of variance:

The Analysis of variance for 40 pearl millet hybrids exhibited significant mean sum of squares for all the characters except harvest index (Table-4.1). This indicated the presence of good amount of genetic variability among the hybrids for all the characters used in study except harvest index. Replications mean sum of squares were non-significant for all the characters indicating good homogeneity among replications.

Table 4.1 Analysis of variance for different characters in pearl millet

S.No.	Characters	Mean sum of squares		
		Replications (df= 1)	Treatment (df=39)	Error (df=39)
1	Days to 50 % flowering	0.45	2.58*	1.45
2	Days to maturity	0.11	3.42*	1.70
3	Plant height (cm)	292.61	236.82**	76.55
4	No. of effective tillers/plant	0.33	0.43**	0.16
5	Ear head length (cm)	2.46	5.77**	2.39
6	Ear head diameter(cm)	0.05	0.04**	0.02
7	Test weight (g)	1.43	1.31**	0.35
8	Harvest index (%)	0.18	14.03	9.92
9	Biological yield/plant (g)	3.29	29.97*	15.51
10	Grain yield/ Plant (g)	0.16	18.15*	8.59

**, * indicates significant at 5 and 1 per cent level, respectively.

4.2 Variability, heritability and genetic advance:

The mean of different characters along with their range, the estimates of variability including genotypic (GCV) and phenotypic coefficient of variation (PCV), heritability and genetic advance are presented in Table 4.2 and the results are elaborated in the following text.

High range was observed for most of the characters *viz.,* **plant height** (136.30 - 190.00 cm), **harvest index** (39.45 - 53.35 %), **biological yield per plant** (21.50 – 36.49 g), **grain yield per plant** (17.13 – 28.25g), **ear length per plant** (23.12 - 29.48 cm), **days to maturity** (73 - 78 days) **and days to 50 percent flowering** (43.00 – 47.50). Comparatively narrow range was observed for the characters *viz.,* **number of effective tillers per plant** (1.15 to 3.00), **ear head diameter** (1.70 to 2.45 cm) and **test weight** (5.60 – 9.05 g). The moderate GCV (10-20%) was found for **number of effective tillers per plant** (16.88). **Days to 50% flowering, days to maturity, plant height, ear head length, ear head diameter, test weight, biological yield per plant, harvest index and grain yield per plant** had low GCV(<10%).

Phenotypic coefficient of variance (PCV) was high (>20%) for **number of effective tillers per plant** (25.40). While moderate values (10-20%) were observed for **test weight** (12.94), **grain yield per plant** (17.34) and **harvest index** (15.74). Rest of characters *viz*., days to 50% flowering, days to maturity, plant height, ear head length, ear head diameter and biological yield per plant had low values (<10%).

The heritability estimate were moderate (50-90%) for **plant height and test weight.** Low heritability estimate (>50%) were observed for days to 50% flowering, days to maturity, number of effective tillers per plant, ear head length, ear head diameter, harvest index, biological yield per plant, and grain yield per plant.

Estimated of genetic advance were moderate for **plant height** (13.18). Low estimates of genetic advance (<10%) were observed for days to 50% flowering, days to maturity, number of effective tillers, ear head length, ear head diameter, test weight, harvest index, biological yield per plant and grain yield per plant.

Estimates of genetic advance as percent over mean was the highest for number of **effective tiller per plant** (23.12). Whereas genetic advance as percent of mean was medium for **test weight** (15.41), **grain yield per plant** (11.35), and **harvest index** (11.58). Low genetic advance as per cent over mean were observed for days to 50% flowering (1.85), days to maturity (1.48), plant height (8.29), ear head length (6.69), ear head diameter (6.85) and biological yield per plant (2.67).

4.2 CORRELATION COEFFICIENT:

The breeder is always concerned with the selection of superior genotypes on the basis of phenotypic expression. Often selection based on phenotypic performance does not lead to the expected genetic advance mainly due to presence of genotype and environmental interactions as well as due to undesirable association between component characters at genotypic level. Thus, knowledge of correlations between complex character like grain yield and its components is of prime importance. With this view, the genotypic and phenotypic correlation coefficients of various components characters with

Table 4.2: Overall mean value of genotypes, their range, genotypic and phenotypic coefficient of variation, heritability (broad sense %) and genetic advance for different characters in pearl millet.

Character		Mean	Range	G.C.V.	P.C.V.	Heritability (%)	Genetic advance	GA % of Mean
(1)	Days to 50% flowering	44.50	43.00-47.50	1.69	3.19	28	0.82	1.85
(2)	Days to maturity	74.53	73.00-78.00	1.24	2.14	33	1.10	1.48
(3)	Plant height (cm)	159.08	136.30-190.00	5.62	7.86	51	13.18	8.29
(4)	No. of effective tillers/plant	2.15	1.15-3.00	16.88	25.40	44	0.49	23.12
(5)	Ear head length (cm)	25.97	23.12-29.48	5.00	7.78	41	1.72	6.69
(6)	Ear head diameter (cm)	2.14	1.70-2.45	5.39	8.73	38	0.14	6.85
(7)	Test weight (g)	7.04	5.60-9.05	9.84	12.94	57	1.08	15.41
(8)	Harvest index (%)	23.24	17.13-28.25	9.40	15.74	35	2.69	11.58
(9)	Biological yield/plant (g)	45.85	39.45-53.35	3.12	7.54	17	1.22	2.67
(10)	Grain yield/plant (g)	27.50	21.50-36.29	9.77	17.34	31	1.12	11.35

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each other as well as with grain yield /plant were calculated (Table 4.3). Since, suitable test for significance of genotypic correlation coefficients is not available, therefore, major emphasis has been put on phenotypic correlation coefficients, which are tested by ‘t-test’. In general, the estimates of genotypic correlation were higher than the phenotypic correlation coefficient for most of the characters. The results of genotypic and phenotypic correlation coefficients between yield and its component characters are given in Table 4.3 and described as follow.

Days to 50% flowering:

The character was positively and significantly correlated with days to maturity at both phenotypic and genotypic level (rp=0.976** & rg=1.002**). The correlation of days to 50% flowering was positive and significant with No. of tillers per plant, test weight, biological yield per plant and grain yield per plant at genotypic level. It had significant and negative correlation with harvest index at genotypic level.

Days to maturity:

None of the character is significantly correlated with days to maturity at phenotypic level. The correlation of days to maturity was positive and significant with No. of tillers per plant, test weight, biological yield per plant and grain yield per plant at genotypic level. It had significant and negative correlation with harvest index at genotypic level.

Plant height (cm):

Plant height had significant and positive correlation with ear head diameter both at phenotypic (Rp= 0.250**) and genotypic level (rg=0.438**). Plant height had positive and significant correlation with grain yield per plant at phenotypic level only (rp=0.233*). At genotypic level, It had significant correlation with biological yield per plant (rg=0.287**) and harvest index (rg= -0.364**).

Table 4.3: Estimation of Phenotypic (P), Genotypic (G) and Environmental (E) Correlation coefficient for 60 characters in pearl millet

S.No.		Days to 50% flowering	Days to Maturity	Plant height(cm)	No. of effective tiller per plant	Ear head length (cm)	Ear head diameter (cm.)	Test weight (g)	Harvest Index (%)	Biological yield per plant (g)	Grain yield per plant (g)
(1) Days to 50% flowering	P	1.000	0.976**	0.088	0.115	-0.109	0.139	0.133	-0.050	0.064	0.022
	G	1.000	1.002**	0.181	0.605**	-0.060	-0.118	0.341**	-0.717**	1.115**	0.711
(2) Days to maturity	P		1.000	0.068	0.129	-0.107	0.102	0.106	-0.103	0.083	-0.001
	G		1.000	0.174	0.581**	-0.055	-0.199	0.309**	-0.510**	0.987**	0.678
(3) Plant height (cm)	P			1.000	0.121	-0.003	0.250*	0.062	0.079	0.149	0.233*
	G			1.000	0.125	0.139	0.438**	0.058	-0.364**	0.287**	0.129
(4) No. of effective tillers /plant	P				1.000	0.079	-0.017	0.217	0.159	-0.035	0.109
	G				1.000	0.027	-0.136	0.330**	0.145	-0.185	-0.073
(5) Ear head length (cm)	P					1.000	0.128	0.034	0.119	0.123	0.264*
	G					1.000	0.280*	-0.100	0.765**	-0.000	0.474
(6) Ear head diameter(cm)	P						1.000	0.199	-0.183	0.148	0.009
	G						1.000	0.493**	-1.154	0.846**	0.178
(7) Test weight (g)	P							1.000	-0.120	0.080	-0.008
	G							1.000	-0.697**	-0.005	-0.325
(8) Harvest index (%)	P								1.000	-0.444**	0.377**
	G								1.000	-0.440**	0.279
(9) Biological yield/plant (g)	P									1.000	0.653**
	G									1.000	0.753
(10) Grain yield/ Plant (g)	P										1.000
	G										1.000

*Significant at 5% probability level of significance
**Significant at 1% probability level of significance

No. of effective tillers per plant:

None of the characters is significantly correlated with no. of effective tillers per plant at phenotypic level. However, It had positive and significant correlation with test weight (0.330**) at genotypic level only.

Ear head length (cm):

This character was positively and significant correlated with grain yield per plant at phenotypic level (rp=0.264*). However, it had positive and significant correlation with ear head diameter (rg=0.280*), harvest index (rg=0.765**) and grain yield per plant (rg=0.474**) at genotypic level.

Ear head diameter (cm):

This character was positively and significant correlated with plant height at phenotypic level (rp=0.250*) only. It had positive and significant correlation with plant height (rg=0.438**), days to maturity (rg=0.309**), Test weight (rg=0.493**) and biological yield per plant (rg=0.846**) at genotypic level.

Test weight (g):

None of the characters is significantly correlated with test weight at phenotypic level. At genotypic level, It had positive and significant correlation with days to 50% flowering (rg=0.341**), test weight (0.330**), no. of effective tillers per plant (rg=0.330**), ear head diameter (rg=0.493**) at genotypic level. It had negative and significant correlation with harvest index (rg=-0.697**) and grain yield per plant (rg=-0.325**) at genotypic level only.

Harvest index

This character was positively and significantly correlated with grain yield per plant (rp=0.377**) and negatively and significantly correlated with biological yield per plant (rp=-0.444) at phenotypic level. It had positive and significant correlation with ear head length (rg=0.765**) and grain yield per plant (rg=0.279*) at genotypic level. However, it had negative and significant correlation with days to 50% flowering (rg=-0.717**), days to maturity (rg=-0.510**), plant height (rg=-0.364**) and test weight (rg=-0.697**) at genotypic level.

Biological yield per plant:

This character was positively and significantly correlated with grain yield per plant (rp=0.653**) and negatively and significantly correlated with harvest index (rp=-0.444) at phenotypic level. It had positive and significant correlation with days to 50% flowering (rg=1.115**), days to maturity (rg=0.987**), plant height (rg=0.287**), ear head diameter (rg=0.849**) and grain yield per plant (rg=0.0.753**) at genotypic level. However, it had negative and significant correlation with harvest index (rg=-440**) at genotypic level.

Grain yield per plant:

Grain yield per plant was positively and significantly correlated at phenotypic level with plant height (rp=0.233*), ear head length (rp=0.264*), harvest index (rp=0.377**) and biological yield per plant (rp=0.653**). It was also was positively and significantly correlated at genotypic level with days to 50% flowering (rg=0.711**), days to maturity (rg=0.678**), ear head length (rg=0.474**), harvest index (rg=0.279*) and biological yield per plant (rg=0.753**). However, grain yield per plant had negative and significant correlation at genotypic level with test weight (rg=-0.325**).

4.4 PATH COEFFICIENT ANALYSIS:

Path-coefficient analysis was used to partition the genotypic and phenotypic correlation coefficient of different character studied in to direct and indirect effect. Since correlation studies alone are not adequate to establish a clear relationship among the characters, therefore, the assessment of real contribution of individual character toward the seed yield become essential. Path-coefficient provides a clear and more realistic picture of complex situation that exists at correlation levels. It measures the direct as well as indirect effect of independent variables (characters) on dependent variable through other traits. The direct and indirect effects of various characters along with phenotypic and genotypic correlation coefficient with seed yield per plant are presented in Table 4.4.

At phenotypic level, highest direct positive effect on grain yield was observed for **dry fodder yield per plant** (1.0111) followed by **harvest index**

(0.8218), **ear head length** (0.0396), **days to maturity** (0.0193), **plant height** (0.0163), **number of effective tiller per plant** (0.0074), **test weight** (0.0049) and **ear head diameter** (0.0002). While negative direct effect was recorded for **days to 50% flowering** (-0.0181).

At genotypic level, highest direct positive effect on grain yield was observed for days to maturity (1.0459) followed by dry yield per plant (0.6683), ear head length (0.2781), harvest index (0.2473) and ear head diameter (0.0356).While the highest direct negative effect was recorded for days to 50% flowering (-0.7779) followed by test weight (-0.1735), number of effective tillers per plant (-0.0621) and plant height (-0.0504).

4.4.1 Days to 50 percent flowering:

Path analysis revealed that **days to 50 % flowering** had negative direct effect (-0.0181). Its correlation with the grain yield per plant was positive and non-significant (0.022) due to its positive indirect effect via **days to maturity** (0.0188), **plant height** (0.0014), **No. of effective tillers per plant** (0.0009), **test weight** (0.0007) and **dry fodder yield per plant** (0.0651). **Days to 50% flowering** exhibited negative indirect effect on **grain yield per plant via ear head length** (-0.0043) and **harvest index** (-0.0418).

4.4.2 Days to maturity:

It had positive direct effect (0.0193). However, the correlation with grain yield per plant was negative and non-significant (-0.001). It had low negative indirect effect via days to 50% flowering (-0.0177), ear head length (-0.0042) and harvest index (0.0853). Whereas, it had positive indirect effect via plant height (0.0011), No. of effective tillers per plant (0.001), test weight (0.0005) and dry fodder yield per plant (0.0843).

Table: 4.4 Direct (diagonal) and indirect effects (non-diagonal) of different characters on seed yield per plant in pearl millet

S.No.		Days to 50% flowering	Days to Maturity	Plant height	No. of effective tiller per	Ear head length	Ear head diameter	Test weight	Harvest Index (%)	Biological yield /plant	Correlation coefficient with grain yield per plant
(1) Days to 50% Flowering	P	**-0.0181**	0.0188	0.0014	0.0009	-0.0043	0	0.0007	-0.0418	0.0651	0.022
	G	**-0.7779**	1.0489	-0.0091	-0.0376	-0.0167	-0.0042	-0.0592	-0.1775	0.7452	0.711
(2) Days to maturity	P	-0.0177	**0.0193**	0.0011	0.001	-0.0042	0	0.0005	-0.0853	0.0843	-0.001
	G	-0.78	**1.0459**	-0.0088	-0.0361	-0.0155	-0.0071	-0.0536	-0.1263	0.6602	0.678
(3) Plant height	P	-0.0016	0.0013	**0.0163**	0.0009	-0.0001	0.0001	0.0003	0.0651	0.1511	0.233
	G	-0.141	0.1826	**-0.0504**	-0.0078	0.0388	0.0156	-0.0101	-0.0901	0.1923	0.129
(4) No of effective tiller/plant	P	-0.0021	0.0025	0.002	**0.0074**	0.0032	0	0.0011	0.131	-0.0357	0.109
	G	-0.471	0.6085	-0.0063	**-0.0621**	0.0077	-0.0049	-0.0574	0.036	-0.1239	-0.073
(5) Ear head length(cm)	P	0.002	-0.0021	-0.0001	0.0006	**0.0396**	0	0.0002	0.0984	0.1253	0.264*
	G	0.0467	-0.0582	-0.007	-0.0017	**0.2781**	0.01	0.0174	0.1893	-0.0005	0.474
(6) Ear head diameter(cm)	P	-0.0025	0.002	0.0041	-0.0001	0.0051	**0.0002**	0.001	-0.151	0.1503	0.009
	G	0.0922	-0.2085	-0.0221	0.0085	0.0781	**0.0356**	-0.0856	-0.2854	0.5655	0.178
(7) Test weight(g)	P	-0.0024	0.0021	0.001	0.0016	0.0014	0	**0.0049**	-0.099	0.0816	-0.008
	G	-0.2656	0.3233	-0.0029	-0.0205	-0.0279	0.0176	**-0.1735**	-0.1726	-0.0037	-0.325
(8) Harvest index (%)	P	0.0009	-0.002	0.0013	0.0012	0.0047	0	-0.0006	**0.8218**	-0.4494	0.377*
	G	0.5583	-0.534	0.0184	-0.009	0.2129	-0.0411	0.1211	**0.2473**	-0.2943	0.279
(9 Biological yield/ plant (g)	P	-0.0012	0.0016	0.0024	-0.0003	0.0049	0	0.0004	-0.3652	**1.0111**	0.653*
	G	-0.8673	1.0332	-0.0145	0.0155	-0.0002	0.0301	0.001	-0.1089	**0.6683**	0.753

Residual effect: Phenotype = 0.1169 Genotype = 0.2802

4.4.3 Plant height (cm):

Plant height had positive direct effect (0.0163). Plant height exhibited positive and significant correlation with grain yield per plant (0.233*) because of its positive indirect effect via days to 50% flowering (0.0014), days to maturity (0.0013), no. of effective tillers per plant (0.0009), ear head diameter (0.0001),test weight (0.0003), harvest index (0.0651) and dry fodder yield per plant (0.1511). Plant height exhibited negative indirect effect on grain yield per plant via Days to 50% flowering (-0.0016) and ear head length (-0.0001).

4.4.4 Number of effective tillers per plant:

No. of effective tillers per plant exhibited low direct effect on grain yield per plant (0.0074).It had non-significant correlation with grain yield per plant (0.109) due to positive indirect effect via days to maturity (0.0025), plant height (0.002), ear head length (0.0032), test weight (0.0011) and harvest index (0.131).It exhibited negative indirect effect on grain yield per plant via days to 50% flowering (-0.0021) and dry fodder yield per plant (-0.0357).

4.4.5 Ear head length (cm):

It had high positive direct effect (0.0396). It exhibited positive and significant correlation with grain yield per plant (0.264*) due to its positive direct effects and positive indirect effect via days to 50% flowering (0.002), No. of effective tillers per plant (0.0396), test weight (0.0002), harvest index (0.0984) and dry fodder yield per plant (0.1253).

4.4.6 Ear head diameter (cm):

This character had low positive direct effect (0.0002). It had positive correlation with grain yield per plant (0.009) due to positive indirect effect via days to maturity (0.002), plant height (0.0041), ear head length (0.0051), ear head diameter (0.0002), test weight (0.001) and dry fodder yield per plant (0.1503).Ear head diameter had negative indirect effect via days to 50% flowering (-0.0025), No. of effective tillers per plant (-0.0001) and harvest index (-0.151).

4.4.7 Test weight (g):

It showed positive direct effect (0.0049). Test weight had negative and non-significant correlation with grain yield per plant (-0.008) due to negative indirect effect via days to 50% flowering (-0.0024) and harvest index (-0.099). However, test weight had positive indirect effect on grain yield per plant via days to maturity, plant height, no. of effective tillers per plant, ear head length and dry fodder yield per plant.

4.4.8 Harvest index (%):

It had very high positive direct effect (0.8218). It exhibited positive and significant correlation with grain yield per plant (0.377*) as well as positive indirect effect via days to 50% flowering (0.0009), plant height (0.0013), number of effective tillers per plant (0.0012) and ear head length per plant (0.0047).Harvest index had negative indirect effect on grain yield per plant via days to maturity, test weight and dry fodder yield per plant.

4.4.9 Biological yield per plant (g):

This character had very high positive and direct effect (1.011). It had positive and significant correlation with grain yield per plant (0.653**) due its high positive direct effect. Biological yield per plant also exhibited positive indirect effect via days to maturity, plant height, ear head length and test weight. It exhibited negative indirect effective via harvest index (-0.3652) and days to 50 % flowering (-0.0012).

Residual factors:

The phenotypic residual effect was very low (0.1169) which indicated that seed yield per plant is ultimate result of the characters studied.

Heterosis:

The commercial exploitation of heterosis is considered to be an outstanding application of genetics in plant breeding. The extent of heterosis depends on the magnitude of non-additive gene action and wide genetic diversity among parents. Mackey (1976) described that superiority of hybrid over better parent might be either due to dominance or epistasis or over dominance or combined effects of two or more of these phenomenon. The possibility of commercial exploitation of hybrid vigour depends on the magnitude of heterosis and feasibility of hybrid seed production. For commercial exploitation of standard heterosis, superiority of F_1 over standard check is more useful than over better parent. In the present study, standard heterosis was observed for yield and yield attributes over best check HHB-67 imp.

Earliness in pearl millet is desirable phenomenon for sustainable pearl millet production in the harsh environment. In the present experiment, out of 40 hybrids, four hybrid *viz.,* 843-22A x (ICMR 01004-P59 x P7-3-P4)-8195, 843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-834, 843-22A x (ICMR 01004-P59 x P7-3-P4)-830 and 843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-840 exhibited negative but non-significant standard heterosis for days to 50 % flowering. However, none of the cross combinations depicted negative heterosis for days to maturity.

Tallness is desirable character in pearl millet which is reflected by positive values for standard heterosis. The heterosis for plant height ranged from 26.07% (843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-65) to -9.56% (843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-835). Three hybrids exhibited positive and significant heterosis over the best commercial check. Maximum heterosis was depicted in the cross combination 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-865 followed by 843-22A x (ICMR 01004-P13-847 and 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-857. These crosses exhibited 26.07, 21.96 and 17.65 % superiority for plant height over the best check.

For number of effective tillers per plant, none of the hybrids was found positively significant superior over the best check. However, 19 hybrids showed positive but non significant value for standard heterosis. Maximum standard heterosis for this trait was recorded in 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-857 (50.00) followed by 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-858 (50.00) and 843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-845 (35.00).

None of the cross combinations expressed significant heterosis for ear head length. However, eight cross combinations expressed positive but non-significant heterosis for this trait. The Highest positive standard heterosis for ear head length was recorded in 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-862 (8.70) followed by 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864 (8.18) and 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-859 (6.27).

Out of 40 crosses, none of the cross combinations expressed significant heterosis for ear head diameter. The highest positive standard heterosis for ear head diameter was recorded in 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-862 (8.699) followed by 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864(8.183) and 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-859 (6.266).

Out of 40 crosses, seven cross combinations expressed positive heterosis for test weight. The highest positive standard heterosis for test weight was recorded in 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-862 (8.699) followed by 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864(8.183) and 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-859 (6.266).

Higher biological yield coupled with high harvest index is desirable. Therefore, positive and significant values were considered. The heterosis ranged between 62.56% (843-22A x (ICMR 01004-P59 x P7-3P4)-831) to -3.67% (843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-865). Among crosses combination, hybrid 843-22A x (ICMR 01004-P59 x P7-3P4)-831 exhibited maximum heterosis (62.56%) followed by 843-22A x (ICMR 01004-P59 x 863B-P2-P10)-808 (57.322) and 843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-839 (53.292). Hence, theses cross were considered to be desirable for this trait. However, 34 cross combinations showed positive standard heterosis for this trait.

The heterosis for grain yield varied from 64.91% (843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864) to 0.53% (843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-865). Out of 40 F_1, 11 crosses *viz.,* 843-22A x ICMR 01004-P7-775, 843-22A x (ICMR 01004-P59 x 863B-P2-P10)-808, 843-22A x (ICMR 01004-P59 x P7-3P4)-831, 843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-839, 843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-845, 843-22A x (ICMR 01004-P13-847, 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-850, 843-

22A x (ICMR 01004-P13 x P1449-2-P1-P2)-859, 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-862, 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864 and 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-866 possessed significantly positive heterosis. while 29 crosses had only positive heterosis. Maximum heterosis was depicted in cross 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864 (64.062%) followed by 843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-845 (63.407%). Hence these cross combination considered to be desirable for this trait.

High harvest index coupled with high grain yield is favourable for higher grain yield. This is reflected by positive heterosis. A total of 34 cross combinations exhibited positive value for harvest index. The cross 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864 exhibited positive and significant heterosis over commercial check. This cross exhibited 23.92% heterosis over the commercial check. The heterosis varied from 23.92% (843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864) to -8.36% (843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-848).

Table 4.5 Standard heterosis for grain yield per plant (g)

S. NO.	Genotypes	Days to 50% flowering	Days to Maturity	Plant height (cm)	No. of effective tiller per plant	Ear head length (cm)	Ear head diameter (cm.)	Test weight (g)	Harvest Index (%)	Biological yield per plant (g)	Grain yield per plant (g)
1	843-22A x ICMR 01004-P59-754	0.00	0.00	3.45	0.00	-14.78	-14.781	-14.781	8.13	13.75	28.66
2	843-22A x ICMR 01004-P7-775	8.046*	61.64*	9.16	37.50	-12.20	-12.201	-12.201	9.52	31.03	52.423**
3	843-22A x ICMR 01004-P13-783	0.00	0.69	12.01	12.50	-4.42	-4.423	-4.423	14.29	6.40	34.21
4	843-22A x (ICMR 01004-P59 x 863B-P2-P10)-808	0.00	0.69	3.78	0.00	4.35	4.349	4.349	1.63	57.322**	58.884*
5	843-22A x (ICMR 01004-P59 x P7-3-P4)-819	-1.15	0.00	1.79	32.50	-13.64	-13.638	-13.638	8.25	6.31	21.02
6	843-22A x (ICMR 01004-P59 x P7-3-P4)-822	0.00	0.69	8.56	-37.50	-5.53	-5.529	-5.529	-2.56	43..53	33.63
7	843-22A x (ICMR 01004-P59 x P7-3P4)-828	0.00	0.69	12.21	32.50	-4.98	-4.976	-4.976	6.97	20.20	33.92
8	843-22A x (ICMR 01004-P59 x P7-3-P4)-829	3.45	2.74	-3.78	25.00	-4.57	-4.571	-4.571	1.86	15.23	17.16
9	843-22A x (ICMR 01004-P59 x P7-3-P4)-830	-1.15	0.00	-2.99	25.00	-9.58	-9.583	-9.583	6.85	5.20	14.54
10	843-22A x (ICMR 01004-P59 x P7-3P4)-831	2.30	2.06	4.25	-12.50	-8.26	-8.257	-8.257	-2.44	62.562*	52.306*
11	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-834	-1.15	0.00	-4.91	0.00	-1.40	-1.401	-1.401	5.69	19.12	30.59
12	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-835	1.15	1.37	-9.56	25.00	-3.13	-3.133	-3.133	10.80	7.61	27.79
13	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-836	4.60	3.43	5.24	25.00	-1.36	-1.364	-1.364	6.04	16.44	27.55

14	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-837	1.15	1.37	0.46	30.00	-13.75	-13.749	-13.749	11.61	9.94	32.69
15	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-838	6.90	6.164*	3.98	25.00	-0.85	-0.848	-0.848	1.97	33.86	36.72
16	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-839	4.60	3.43	10.02	5.00	-0.70	-0.7	-0.7	5.11	53.292*	64.215*
17	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-840	-1.15	0.00	3.98	0.00	0.41	0.405	0.405	9.87	12.36	31.35
18	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-841	9.195*	6.849**	15.46	25.00	-8.15	-8.146	-8.146	-2.09	44.34	38.18
19	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-842	3.45	2.74	-0.73	-42.50	-8.22	-8.22	-8.22	3.83	27.81	34.44
20	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-843	1.15	1.37	11.88	-42.50	-2.40	-2.396	-2.396	4.07	31.44	39.23
21	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-844	4.60	3.43	4.58	25.00	-7.15	-7.151	-7.151	3.60	28.53	34.38
22	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-845	1.15	1.37	5.11	35.00	-2.14	-2.138	-2.138	11.27	36.19	63.407**
23	843-22A x (ICMR 01004-P13-847	2.30	2.06	21.96**	35.00	-0.55	-0.553	-0.553	5.81	43.48	56.684*
24	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-848	2.30	2.74	-0.66	0.00	-5.27	-5.271	-5.271	-8.36	37.22	16.29
25	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-849	3.45	2.06	0.80	-10.00	-2.99	-2.986	-2.986	0.23	14.55	14.01
26	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-850	4.60	2.74	8.30	-5.00	-8.48	-8.478	-8.478	8.83	39.01	59.953*
27	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-851	5.75	4.80	2.85	0.00	-13.93	-13.933	-13.933	1.51	26.02	26.04
	843-22A x (ICMR 01004-	1.15	1.37	6.11	-25.00	-11.61	-11.611	-11.611	13.47	2.24	27.26

28	P13 x P1449-2-P1-P2)-852										
29	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-855	1.15	1.37	8.96	-12.50	-4.42	-4.423	-4.423	9.06	4.75	20.72
30	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-856	3.45	2.74	0.73	-7.50	2.32	2.322	2.322	10.22	16.03	36.84
31	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-857	4.60	3.43	17.65*	50.00	4.90	4.902	4.902	15.10	14.87	46.00
32	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-858	2.30	2..06	12.28	50.00	3.61	3.612	3.612	2.90	7.84	11.73
33	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-859	0.00	0.69	10.29	0.00	6.27	6.266	6.266	5.11	45.32	57.268*
34	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-862	2.30	2.06	5.84	12.50	8.70	8.699	8.699	18.47	14.06	55.867*
35	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-863	1.15	1.37	2.12	0.00	-8.40	-8.404	-8.404	10.11	24.68	45.94
36	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864	0.00	0.69	3.38	-12.50	8.18	8.183	8.183	23.926*	11.24	64.915*
37	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-865	0.00	0.69	26.07**	-10.00	-13.82	-13.822	-13.822	2.21	-3.67	0.53
38	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-866	4.60	3.43	6.90	25.00	-8.33	-8.33	-8.33	6.27	46.35	61.062*
39	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-867	5.75	4.80	-4.91	0.00	-3.61	-3.612	-3.612	11.73	-0.05	20.90
40	HHB-67 imp.	-	-	-	-	-	-	-	-	-	-

*, ** Significant at 5% and 1% level of significance, respectively

5. DISCUSSION

Pearl millet [*Pennisetum glaucum (L.)* R. Br.] , the most drought tolerant cereal crop, is widely grown across the arid and semi-arid tropics of Asia and Africa. It is highly cross pollinated crop with the advantages of huge genetic variability, protogyny and availability of efficient cytoplasmic genetic male sterility system. These characteristics offer great possibilities of crop improvement through commercial exploitation of heterosis. The average yield of pearl millet in North-Western part of Rajasthan comprising of Bikaner, Jaisalmer and part of Churu Districts is very low ranging from 445 to 471 kg/ha as against 750 kg/ha of Rajasthan (Anonymous, 2014-2015). Due to unavailability of the high yielding genotypes suitable for moisture stress condition, the productivity of pearl millet in North-Western Rajasthan is quite low. The harsh conditions prevailing in the north western part of Rajasthan require development of such genotypes which can give higher grain as well as fodder yield under moisture stress conditions. This is important as about 90 per cent of total area under pearl millet is rain fed.

The main objective in any plant breeding programme is to develop promising and desirable genotypes possessing high yielding potential. Sufficient success has been achieved by genetic manipulation in the improvement of pearl millet in relatively better environment and it is now possible to augment the grain yield potential of pearl millet in poor environment as well. Success of any plant breeding programme is largely dependent on the extent of genetic variability present in the population. The genetic facts are inferred from phenotypic observations. This observed variability may be grouped with the help of suitable parameters like phenotypic and genotypic coefficient of variation, heritability and genetic advance to ascertain the basis for selection.

The present investigation was undertaken to determine the variability parameters, character association and heterosis among 40 genotypes of pearl millet. Data on various morphological characters *viz.* days to 50 per cent flowering, days to maturity, plant height (cm), number of effective tillers per plant, ear head length (cm), ear head diameter (cm), test weight(g), harvest index (%), biological yield per plant (g) and grain yield per plant (g) were recorded. The results thus obtained have been discussed with respect to the pertinent literature under the following heads:

5.1 VARIABILITY, HERITABILITY AND GENETIC ADVANCE

Variability refers to the presence of differences among the individuals of a plant population. Variability results due to the differences either in the genetic constitution of the individuals of a population or in the environment in which they are grown. The knowledge of the nature and magnitude of variation present in base material is of great importance for effective selection of superior genotypes from breeding material. Hence, it is essential that base population should possess a large amount of heritable variation.

Analysis of variance had indicated existence of significant variability among the genotypes for all the ten characters used in the study. The significant variation for these yield and yield related traits observed in the base population could be utilized to improve this crop.

The range of phenotypic variability was high for most of the characters. High range was observed for plant height (136.30 - 190.00 cm), harvest index (39.45 - 53.35 %), biological yield per plant (21.50 – 36.49 g), grain yield per plant (17.13 – 28.25g), ear length per plant (23.12 - 29.48 cm), days to maturity (73 - 78 days) and days to 50 percent flowering (43.00 – 47.50). Comparatively narrow range was observed for the characters viz., number of effective tillers per plant (1.15 to 3.00), ear head diameter (1.70 to 2.45 cm) and test weight (5.60 – 9.05 g). A wide range of variability for various traits has been observed earlier by Shanmuganathan *et al*. (2006), Vidyadhar *et al.* (2007), Bhoita *et al.* (2008), Sumathi *et al.* (2010), and Govindaraj *et al.* (2011).

The phenotypic variation is not a precise criterion for judging the amount of genotypic variation present in population. Therefore, the genetic parameters such as genotypic and phenotypic coefficient of variation, heritability and genetic advance were worked out in the present study because these provide a better picture and amount of genetic variability present for each trait in the experimental material.

Comparison of coefficient of variance indicated that the phenotypic coefficient of variance was higher than the genotypic coefficient of variance for all the characters which indicated effect of environment on the characters expression. Among all the characters, The moderate GCV (16.88) and high PCV (25.40) was found for number of effective tillers per plant , while low GCV and PCV were observed for days to 50 per cent flowering, days to maturity , plant height (cm), ear head length (cm), ear head diameter (cm) and biological yield per plant. The significant variability for most of the traits is commonly reported in natural populations of pearl millet. The similar results were found by Sagar and Sagar (2002), Laxshmana *et al.* (2003), Sharma *et al.* (2003), Unnikrishnan *et al.* (2004), Nagar *et al.* (2006) and Lakshmana *et al.*(2009); Bhorkhataria et al.(2005), Vidyadhar et al.(2007), and Sumathi et al.(2010); Yadav *et al.* (2001) , Sharma (2002) and Vidyadhar *et al*.(2007).

The heritability estimate of a quantitative character is very important as phenotypic expression of a genotype may be altered by environment at various stages of its growth and development. Heritability indicates the effectiveness with which selection for genotypes can be done on the basis of its phenotypic variation. It expresses the extent to which individual phenotypes are determined by their genotypes. The heritability estimates serve as a useful guide to the breeder because selection would be fairly easy for the characters with high heritability. Thus, for characters governed by high heritability, there would be a close correspondence between the genotypes and phenotypes due to a relatively smaller contribution of the environment to the phenotype. But for a character with low heritability, selection may not be effective due to the masking effect of environment on genotypic effect. The response to selection depends upon the relative magnitude of heritable variation present in relation to the phenotypic variation. Therefore, it is desirable to partition observed variability into its heritable and non-heritable components. The heritability estimate were moderate (50-90%) for plant height and test weight. Low heritability estimate (>50%) were observed for days to 50% flowering, days to maturity, number of effective tillers per plant, ear head length, ear head diameter, harvest index, biological yield per plant, and grain yield per plant.

The heritability estimates alone do not provide reliable information about the genes governing the expression of a particular character and also do not provide the information of the amount of genetic progress that would result from the selection of best individuals. Johanson *et. al.* (1995) pointed about that the heritability estimates along with genetic advance were more useful than heritability estimates alone in predicting the response to selection. In the present investigation genetic advance was estimated for all the traits. Estimates of genetic advance as percent over mean was the highest for number of effective tiller per plant (23.12). Whereas genetic advance as percent of mean was medium for test weight (15.41), grain yield per plant (11.35), and harvest index (11.58). Low genetic advance as per cent over mean were observed for days to 50% flowering (1.85), days to maturity (1.48), plant height (8.29), ear head length (6.69), ear head diameter (6.85) and biological yield per plant (2.67). These results are in accordance with the earlier findings of Shanmuganathan *et al.* (2006), Sumathi *et al.* (2010), Kumari *et al*. (2013), Kumar et al. (2014), Bika and Shekhawat (2015), Ezeaku *et al.* (2015) and Sowmiya *et al.* (2016).

Heritability and genetic advance are two complementary concepts. Thus, heritability values may be used to estimate the genetic advance through selection for predicting the utility and value of selection. In the present investigation, moderate heritability along with moderate genetic advance was observed for plant height. Low heritability with low genetic advance was observed for days to 50% flowering, days to maturity, number of effective tillers per plant, ear head length, ear head diameter, harvest index, biological yield per plant and grain yield per plant.

5.2 CORRELATION COEFFICIENTS

The potential productivity of any crop is basically valued in term of grain yield per unit area. Its improvement by direct selection is generally difficult because yield is a complex polygenic character largely influenced by its various component characters as well as by the environment. Hence, it becomes essential to estimate association of grain yield with component characters and among themselves. The efficiency of selection thus can be increased if it is simultaneously practiced for characters which are correlated with yield. In the quantitative traits, the genotype is influenced by the environment, thereby affecting the phenotypic expression as well as association and consequently direction of association between the characters.

The knowledge of magnitude and direction of correlation is used for judging how improvement in one character will cause simultaneous change in the other characters. High magnitude of positive correlation coefficient at genotypic level between component characters and grain yield is important for indirect selection for grain yield per plant. Since, suitable test for significance of genotypic correlation coefficients is not available therefore, major emphasis has been put on phenotypic correlation coefficients, which are tested by'‘t-test’.

The genotypic correlation coefficients were higher than the respective genotypic correlation coefficients which might be from the modifying effect of environment on the association of characters at genotypic level. Selection of yield as such may not be effective since there may be number of genes for yield *per se* and yield may be resultant of interaction among various components. Knowledge of relation between yield and its components is essential and selection for one component may bring about a simultaneous change in the other. Therefore, for a rational approach to improve yield, it may be useful to collect information on character association. Hence, under the present investigation the phenotypic and genotypic correlation coefficients were worked out for grain yield per plant and other quantitative characters (Table 4.4).

At phenotypic level, correlation of grain yield per plant was positive and significant with plant height, ear head length, harvest index and biological yield per plant. Similar findings of positive and significant correlation with grain yield had been reported by Navale *et al*. 1995; Latha and Shanmuga 1998; Pareek 2002; Thangasamy and Gomathinayagam 2003; Borkhataria *et al.* 2005 and Izge *et al.* 2006.

5.3 PATH COEFFICIENT ANALYSIS

The correlation analysis provide an information which is incomplete in the sense that it does not throw light on the underlying cause that are operative for the various interrelationship. The expression of a complex character such as seed yield per plant (g) depends upon the interplay of a number of component attributes. A better picture of the contribution of each component building up the total genetic architecture of a complex character may be obtained through the analysis of causal schemes. Hence, in such a situation path coefficient analysis devised by Wright (1921) had been useful in partitioning direct and indirect causes of association which allow a detailed examination of specific forces acting to produce a given correlation and measures the relative importance of each causal character. Such a study provides a realistic basis for allocation of weightage to each attributes in deciding a suitable criterion for genetic improvement. The aim of the analysis in the present investigation was to compare the results obtained from simple correlation to determine the true nature of character association.

In the present study, path coefficient analysis was computed both at phenotypic and genotypic levels for all the characters. Path coefficient analysis was carried out by taking grain yield per plant (g) as dependent variable to partition the correlation coefficient into direct and indirect effect in order to determine the contribution of different characters towards the grain yield per plant (g). Direct and indirect effect of various characters on grain yield per plant (g) indicated that there is agreement between direction and magnitude of direct effect of various characters and correlation with grain yield per plant (g). Thus a significant improvement in grain yield can be expected through selection in the component traits with high positive direct effect.

At phenotypic level, highest direct positive effect on grain yield was observed for biological yield per plant (1.0111) followed by harvest index (0.8218), ear head length (0.0396), days to maturity (0.0193), plant height (0.0163), number of effective tiller per plant (0.0074), test weight (0.0049) and ear head diameter (0.0002).While negative direct effect was recorded for days to 50% flowering (-0.0181). At genotypic level, highest direct positive effect on grain yield was observed for days to maturity (1.0459) followed by biological yield per plant (0.6683), ear head length (0.2781), harvest index (0.2473) and ear head diameter (0.0356).While the highest direct negative effect was recorded for days to 50% flowering (-0.7779) followed by test weight (-0.1735), number of effective tillers per plant (-0.0621) and plant height (-0.0504).

Path analysis further revealed that direct effect of biological yield per plant (g) and harvest index were of high magnitude. The high positive association of other characters with grain yield per plant (g) was also due to high indirect effect through these characters. This indicated that grain yield was mainly a product of direct effects of biological yield per plant (g) and harvest index but was also affected indirectly through these two characters like no. of effective tillers per plant, ear head length, ear head diameter and test weight. Path analysis further revealed that days to maturity and test weight were negatively associated with grain yield per plant (g) which was also due to the indirect effects of these two characters. These results are in accordance with the earlier findings of Saraswathi *et al.* (1993), Kumar *et al.* (2002), Pareek (2002), Choudhary *et al.* (2003), Yadav *et al.* (2004), Kele *et al.* (2011), Bikash *et al.* (2013) and Kumar (2014).

5.4 HETEROSIS

The commercial exploitation of heterosis is considered to be an outstanding application of genetics in plant breeding. The extent of heterosis depends on the magnitude of non-additive gene action and wide genetic diversity among parents. Mackey (1976) described that superiority of hybrid over better parent might be either due to dominance or epistasis or over dominance or combined effects of two or more of these phenomenon. The possibility of commercial exploitation of hybrid vigour depends on the magnitude of heterosis and feasibility of hybrid seed production. For commercial exploitation of standard heterosis, superiority of F_1 over standard check is more useful than over better parent. In the present study standard heterosis was observed for yield and yield attributes over best check HHB-67 improved.

Earliness in pearl millet is desirable phenomenon for sustainable pearl millet production in the harsh environment. In the present experiment, four hybrid *viz.,* 843-22A x (ICMR 01004-P59 x P7-3-P4)-8195, 843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-834, 843-22A x (ICMR 01004-P59 x P7-3-P4)-830 and 843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-840 exhibited negative but non-significant standard heterosis for days to 50 % flowering. However, none of the cross combinations depicted negative heterosis for days to maturity.

Tallness is desirable character in pearl millet which is reflected in the cross combination 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-865 followed by 843-22A x (ICMR 01004-P13-847 and 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-857. These crosses exhibited 26.07, 21.96 and 17.65 % superiority for plant height over the best check.

Seven cross combinations expressed positive heterosis for test weight. The highest positive standard heterosis for test weight was recorded in 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-862 (8.699) followed by 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864(8.183) and 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-859 (6.266).

Higher biological yield coupled with high harvest index is desirable. Among crosses combination, hybrid 843-22A x (ICMR 01004-P59 x P7-3P4)-831 exhibited maximum heterosis (62.56%) followed by 843-22A x (ICMR 01004-P59 x 863B-P2-P10)-808 (57.322) and 843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-839 (53.292). Hence, theses cross were considered to be desirable for this trait.

The heterosis for grain yield varied from 64.91% (843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864) to 0.53% (843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-865). Eleven crosses *viz.,* 843-22A x ICMR 01004-P7-775, 843-22A x (ICMR 01004-P59 x 863B-P2-P10)-808, 843-22A x (ICMR 01004-P59 x P7-3P4)-831, 843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-839, 843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-845, 843-22A x (ICMR 01004-P13-847, 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-850, 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-859, 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-862, 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864 and 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-866 possessed significantly positive heterosis. The maximum heterosis was depicted in cross 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864 (64.062%) followed by 843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-845 (63.407%). Hence these cross combination considered to be desirable for this trait.

High harvest index coupled with high grain yield is favourable for higher grain yield. The cross 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864 exhibited positive and significant heterosis over commercial check. This cross exhibited 23.92% heterosis over the commercial check. Earlier various workers viz., Deore *et al.* (1997), Azhaguvel and Jayraman (1998), Mohan *et al*. (1999), Ramamoorthi and Govindarasu (2001), Patel *et al.* (2008), Vetriventhan *et al.* (2008), Vagadiya *et al.* (2010), Davda *et al*., (2012), Bhadalia *et al.* (2013), Kathale *et al*. (2013), Bachkar *et al.* (2014) and Nandaniya *et al*. (2016) had reported standard heterosis for yield and yield attributing attributes.

Based on heterosis for grain yield and early maturity, the hybrid 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864, 843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-839 , 843-22A x (ICMR 01004-P59 x 863B-P2-P10)-808 and 843-22A x (ICMR 01004-P59 x P7-3P4)-831 were identified as potent crosses for the commercial exploitation of heterosis in pearl millet. Theses crosses depicted 64.91, 64.21, 58.88 and 52.30 superiority, respectively in terms of grain yield over the check hybrid HHB-67 improved. Not only this, the maturity duration of these hybrids were at par to the check hybrid HHB-67 improved.

Implications of the present study in plant breeding

1. In present investigation, the experimental material was evaluated to obtain information on the extent of various variability parameters, genotypic and phenotypic correlations and standard heterosis in 40 genotypes of pearl millet for 10 characters. The following implications in breeding are suggested.
2. Analysis of variance had indicated existence of significant variability among the genotypes for all the ten characters used in the study. The significant variation for these yield and yield related traits observed in the base population could be utilized to improve this crop.
3. Among all the characters, the moderate GCV (16.88) and high PCV (25.40) was found for number of effective tillers per plant. The heritability estimate were moderate (50-90%) for plant height and test weight. Estimates of genetic advance as percent over mean was the highest for number of effective tiller per plant (23.12). Whereas genetic advance as percent of mean was medium for test weight (15.41), grain yield per plant (11.35), and harvest index (11.58). The above mentioned traits can be used in selection programme for the improvement of respective characters.

4. At phenotypic level, correlation of grain yield per plant was positive and significant with plant height, ear head length, harvest index and biological yield per plant. The correlation of days to maturity with grain yield was negative which is desirable for the development of early maturing and high yielding hybrids in pearl millet.
5. Path analysis revealed that direct effect of biological yield per plant (g) and harvest index were of high magnitude. The high positive association of other characters with grain yield per plant (g) was also due to high indirect effect through these characters. This indicated that grain yield was mainly a product of direct effects of biological yield per plant (g) and harvest index but was also affected indirectly through these two characters like no. of effective tillers per plant, ear head length, ear head diameter and test weight. Path analysis further revealed that days to maturity and test weight were negatively associated with grain yield per plant (g) which was also due to the indirect effects of these two characters. Thus a significant improvement in grain yield can be expected through selection in the component traits with high positive direct effect.
6. Based on heterosis for grain yield and early maturity, the hybrid 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864, 843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-839 , 843-22A x (ICMR 01004-P59 x 863B-P2-P10)-808 and 843-22A x (ICMR 01004-P59 x P7-3P4)-831 were identified as potential crosses for the commercial exploitation of heterosis in pearl millet. Theses crosses depicted 64.91, 64.21, 58.88 and 52.30 superiority, respectively in terms of grain yield over the check hybrid HHB-67 improved. Not only this, the maturity duration of these hybrids were at par to the check hybrid HHB-67 improved.

6. SUMMARY AND CONCLUSION

Pearl millet [*Pennisetum glaucum (L.)* R. Br.], The most drought tolerant cereal crop, is widely grown across the arid and semi-arid tropics of Asia and Africa. It is highly cross pollinated crop with the advantages of huge genetic variability, protogyny and availability of efficient cytoplasmic genetic male sterility system. These characteristics offer great possibilities of crop improvement through commercial exploitation of heterosis. The average yield of pearl millet in North-Western part of Rajasthan comprising of Bikaner, Jaisalmer and part of Churu districts is very low ranging from 445 to 471 kg/ha as against 750 kg/ha of Rajasthan (Anonymous, 2014-2015). Due to unavailability of the high yielding genotypes suitable for moisture stress condition, the productivity of pearl millet in North-Western Rajasthan is quite low. The harsh conditions prevailing in the north western part of Rajasthan require development of such genotypes which can give higher grain as well as fodder yield under moisture stress conditions. This is important as about 90 per cent of total area under pearl millet is rain fed.

The present investigation was, therefore, undertaken to determine the variability parameters, character association and heterosis among 40 genotypes of pearl millet. Data on various morphological characters *viz.* days to 50 per cent flowering, days to maturity, plant height (cm), number of effective tillers per plant, ear head length (cm), ear head diameter (cm), test weight (g), harvest index (%), biological yield per plant (g) and grain yield per plant (g) were recorded.

1. Analysis of variance had indicated existence of significant variability among the genotypes for all the ten characters used in the study. The significant variation for these yield and yield related traits observed in the base population could be utilized to improve this crop.
2. The range of phenotypic variability was high for most of the characters. High range was observed for plant height (136.30 - 190.00 cm), harvest index (39.45 - 53.35 %), biological yield per plant (21.50 – 36.49 g), grain yield per plant (17.13 – 28.25 g), ear length per plant (23.12 - 29.48 cm), days to maturity (73 - 78 days) and days to 50 percent flowering (43.00 –

47.50). Comparatively narrow range was observed for the characters viz., number of effective tillers per plant (1.15 to 3.00), ear head diameter (1.70 to 2.45 cm) and test weight (5.60 – 9.05 g).

3. Comparison of coefficient of variance indicated that the phenotypic coefficient of variance was higher than the genotypic coefficient of variance for all the characters which indicated effect of environment on the characters expression. Among all the characters, The moderate GCV (16.88 %) and high PCV (25.40 %) was found for number of effective tillers per plant , while low GCV and PCV were observed for days to 50 per cent flowering, days to maturity , plant height (cm), ear head length (cm), ear head diameter (cm) and biological yield per plant.

4. The heritability estimate were moderate (50-90%) for plant height and test weight. Low heritability estimate (>50%) were observed for days to 50% flowering, days to maturity, number of effective tillers per plant, ear head length, ear head diameter, harvest index, biological yield per plant, and grain yield per plant.

5. Estimates of genetic advance as percent over mean was the highest for number of effective tiller per plant (23.12). Whereas genetic advance as percent of mean was medium for test weight (15.41 g), grain yield per plant (11.35 g), and harvest index (11.58). Low genetic advance as per cent over mean were observed for days to 50% flowering (1.85), days to maturity (1.48), plant height (8.29), ear head length (6.69), ear head diameter (6.85) and biological yield per plant (2.67).

6. The genotypic correlation coefficients were higher than the respective genotypic correlation coefficients which might be from the modifying effect of environment on the association of characters at genotypic level.

7. At phenotypic level, correlation of grain yield per plant was positive and significant with plant height, ear head length, harvest index and biological yield per plant.

8. Among the component characters, the correlation of days to 50 per cent flowering was significant with days to maturity. Plant height (cm) showed positive significant association with ear head diameter (cm) at

phenotypic level. Harvest index had negative and significant correlation with biological yield at phenotypic level. The correlation of days to maturity with grain yield was negative which is desirable for the development of early maturing and high yielding hybrids in pearl millet.

9. In the present study, path coefficient analysis was computed both at phenotypic and genotypic levels for all the characters. Direct and indirect effect of various characters on grain yield per plant (g) indicated that there is agreement between direction and magnitude of direct effect of various characters and correlation with grain yield per plant (g). Thus a significant improvement in grain yield can be expected through selection in the component traits with high positive direct effect.

10. At phenotypic level, highest direct positive effect on grain yield was observed for biological yield per plant (1.0111) followed by harvest index (0.8218), ear head length (0.0396), days to maturity (0.0193), plant height (0.0163), number of effective tiller per plant (0.0074), test weight (0.0049) and ear head diameter (0.0002).While negative direct effect was recorded for days to 50% flowering (-0.0181). At genotypic level, highest direct positive effect on grain yield was observed for days to maturity (1.0459) followed by biological yield per plant (0.6683), ear head length (0.2781), harvest index (0.2473) and ear head diameter (0.0356).While the highest direct negative effect was recorded for days to 50% flowering (-0.7779) followed by test weight (-0.1735), number of effective tillers per plant (-0.0621) and plant height (-0.0504).

11. Path analysis further revealed that direct effect of biological yield per plant (g) and harvest index were of high magnitude. The high positive association of other characters with grain yield per plant (g) was also due to high indirect effect through these characters. This indicated that grain yield was mainly a product of direct effects of biological yield per plant (g) and harvest index but was also affected indirectly through these two characters like no. of effective tillers per plant, ear head length, ear head diameter and test weight. Path analysis further revealed that days to maturity and test weight were negatively associated with grain yield per plant (g) which was also due to the indirect effects of these two characters.

12. In the present study standard heterosis was observed for yield and yield attributes over best check HHB-67 improved.

13. In the present experiment, four hybrid *viz.,* 843-22A x (ICMR 01004-P59 x P7-3-P4)-8195, 843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-834, 843-22A x (ICMR 01004-P59 x P7-3-P4)-830 and 843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-840 exhibited negative but non-significant standard heterosis for days to 50 % flowering.

14. Tallness is desirable character in pearl millet which is reflected in the cross combination 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-865 followed by 843-22A x (ICMR 01004-P13-847 and 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-857. These crosses exhibited 26.07, 21.96 and 17.65 % superiority for plant height over the best check.

15. Seven cross combinations expressed positive heterosis for test weight. The highest positive standard heterosis for test weight was recorded in 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-862 (8.699) followed by 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864(8.183) and 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-859 (6.266).

16. Among crosses combination, hybrid 843-22A x (ICMR 01004-P59 x P7-3P4)-831 exhibited maximum heterosis (62.56%) followed by 843-22A x (ICMR 01004-P59 x 863B-P2-P10)-808 (57.322) and 843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-839 (53.292). Hence, theses cross were considered to be desirable for this trait.

17. The heterosis for grain yield varied from 64.91% (843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864) to 0.53% (843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-865). Eleven crosses *viz.,* 843-22A x ICMR 01004-P7-775, 843-22A x (ICMR 01004-P59 x 863B-P2-P10)-808, 843-22A x (ICMR 01004-P59 x P7-3P4)-831, 843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-839, 843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-845, 843-22A x (ICMR 01004-P13-847, 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-850, 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-859, 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-862, 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864 and 843-22A x (ICMR 01004-

P13 x P1449-2-P1-P2)-866 possessed significantly positive heterosis. The maximum heterosis was depicted in cross 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864 (64.062%) followed by 843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-845 (63.407%). Hence these cross combination considered to be desirable for this trait.

18. High harvest index coupled with high grain yield is favourable for higher grain yield. The cross 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864 exhibited positive and significant heterosis over commercial check. This cross exhibited 23.92% heterosis over the commercial check.

19. Based on heterosis for grain yield and early maturity, the hybrid 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864, 843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-839 , 843-22A x (ICMR 01004-P59 x 863B-P2-P10)-808 and 843-22A x (ICMR 01004-P59 x P7-3P4)-831 were identified as potent crosses for the commercial exploitation of heterosis in pearl millet. Theses crosses depicted 64.91, 64.21, 58.88 and 52.30 superiority, respectively in terms of grain yield over the check hybrid HHB-67 improved. Not only this, the maturity duration of these hybrids were at par to the check hybrid HHB-67 improved.

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"Study of Variability, Character Association and Heterosis in Pearl Millet [*Pennisetum glaucum* (L.) R. Br.] Hybrids"

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ABSTRACT

The present investigation was carried out to estimate variability, divergence, character association and heterosis among 40 genotypes of pearl millet for 10 characters. The hybrids were evaluated in RBD during *kharif* 2015 at ARS, Bikaner. Analysis of variance indicated presence of considerable variability for all 10 characters. Number of effective tillers per plant had high estimate of PCV and moderate estimate of GCV. It also had low heritability association with high genetic advance as per cent of mean. Thus, It should be given due emphasis while making a direct selection through this trait. Test weight had moderate estimate of GCV, PCV, heritability and genetic advance. Therefore, selection for this characters would also be effective.

The result from character association indicated that grain yield per plant had significant and positive correlation with ear head length, harvest index and biological yield per plant at phenotypic level.

The results for standard heterosis showed that eleven hybrids, 843-22A x ICMR 01004-P7-775, 843-22A x (ICMR 01004-P59 x 863B-P2-P10)-808, 843-22A x (ICMR 01004-P59 x P7-3P4)-831, 843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-839, 843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-845, 843-22A x (ICMR 01004-P13-847, 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-850, 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-859, 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864, 843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-866, exhibited positive and significant standard heterosis over best check (HHB 67 Improved) for seed yield per plant.

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** Thesis submitted in partial fulfillment of the requirement for M.Sc. (Ag.) Degree in Plant Breeding and Genetics under the supervision of Dr. P.C Gupta, Professor, College of Agriculture, S. K. Rajasthan Agricultural University, Bikaner.

''बाजरा [*पेनिसेटम ग्लॉकम* (एल.) आर.बी.आर.] के संकरो में विविधता, सहसम्बन्ध और संकर ओज का अध्ययन''

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वर्तमान अनुसंधान कार्य ''बाजरा [*पेनिसेटम ग्लॉकम* (एल.) आर.बी.आर.] के संकरो में विविधता, सहसम्बन्ध और संकर ओज का अध्ययन'' शीर्षक के अन्तर्गत बाजरे के 40 संकरों को लेकर 10 लक्षणों के लिए किया गया। इसके लिए इन संकरों को कृषि अनुसंधान केन्द्र, बीकानेर में खरीफ ऋतु, 2015 में पूर्ण यादृच्छिक खण्ड अभिकल्पना में उगाया गया। विचरण विश्लेषण से ज्ञात हुआ कि संकरों में सभी 10 लक्षणों के लिए सार्थक अन्तर था जो कि इनमें परस्पर पर्याप्त मात्रा में विभिन्नता को व्यक्त करता है। प्रति पौधा प्रभावी कल्लों की संख्या उच्चस्तरीय आनुवांशिक विभिन्नता गुणांक दर्शाता है। यह लक्षण उच्चस्तरीय वंशानुगति और आनुवांशिक लाभ भी रखता है। अतः इसे सुधार हेतु सीधा चयन कर सकते हैं। **परीक्षण भार** माध्यम आनुवंशिक विभिन्नता गुणांक वंशानुगति और आनुवांशिक लाभ दर्शाते है, इसलिए इन लक्षणें का चयन भी प्रभावी हो सकता है।

साहचर्य अध्ययन से ज्ञात हुआ कि प्रति पौधा बीज उपज का सिट्टे की लम्बाई**,** जैविक उपज और **उपज सूचकांक** के साथ प्रबल धनात्मक साहचर्य था।

मानक संकर–ओज के अध्ययन से ज्ञात हुआ कि प्रति पौधा दाना उपज के लिए सार्थक मानक (एच. एच.बी. 67) के ऊवा ग्यारह संकर 843.22ए × आई.सी.एम.आर. 01004–पी 7–775, 843–22ए × (आई.सी.एम. आर.) 01004–पी 59 × 863बी–पी2–पी10)–808, 843–22ए × (आई.सी.एम.आर. 01004–पी59 × (पी 7–3पी4)–831, 843–22ए × (आई.सी.एम.आर. 01004–पी7 × पी1449–2–पी1–पी6)–839, 843–22ए × (आई. सी.एम.आर. 01004–पी7 × पी1449–2–पी1–पी6)–845, 843–22ए × (आई.सी.एम.आर. पी–13–847, 843–22ए) × (आई.सी.एम.आर. 01004–पी 13 × पी1449–2–पी 1–पी2)–850, 843–22ए × (आई.सी.एम.आर. 01004–पी13 × पी1449–2–पी1–पी–2)–859, 843–22ए × (आई.सी.एम.आर. 01004–पी13 × पी1449–2–पी1–पी2)–864, 843–22ए × (आई.सी.एम.आर. 01004–पी13 × पी1449–2–पी1–पी2)–866 धनात्मक संकर ओज रखते है।

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** पादप प्रजनन एवं आनुवंशिकी में स्नातकोत्तर (कृषि) की आंशिक आवश्यकता की पूर्ति के संदर्भ में प्रस्तुत शोध ग्रन्थ डा. पी.सी. गुप्ता प्राध्यापक कृषि महाविद्यालय, एस. के. राज. कृषि विश्वविद्यालय, बीकानेर के निर्देशन में।

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Appendix-I

Mean Performance of 40 genotypes of pearlmillet

S.No.	Treatment no.	Days to 50% flowering	Days to Maturity	Plant height(cm)	No. of effective tiller per plant	Ear head length (cm)	Ear head diameter (cm)	Test weight (g)	Harvest Index (%)	Biological yield per plant (g)	Grain yield per plant (g)
1.	843-22A x ICMR 01004-P59-754	43.50	73.00	155.90	2.00	23.12	2.10	7.90	22.04	46.55	25.39
2.	843-22A x ICMR 01004-P7-775	47.00	77.50	164.50	2.75	23.82	2.25	8.20	26.10	47.15	29.26
3.	843-22A x ICMR 01004-P13-783	43.50	73.50	168.80	2.25	25.93	2.25	7.25	22.98	49.20	23.75
4.	843-22A x (ICMR 01004-P59 x 863B-P2-P10)-808	43.50	73.50	156.40	2.00	28.31	2.35	7.00	27.20	43.75	35.12
5.	843-22A x (ICMR 01004-P59 x P7-3-P4)-819	43.00	73.00	153.40	2.65	23.43	2.10	5.80	20.72	46.60	23.74
6.	843-22A x (ICMR 01004-P59 x P7-3-P4)-822	43.50	73.50	163.60	1.25	25.62	2.30	5.80	22.89	41.95	32.04
7.	843-22A x (ICMR 01004-P59 x P7-3P4)-828	43.50	73.50	169.10	2.65	25.75	2.25	7.85	22.94	46.05	26.84
8.	843-22A x (ICMR 01004-P59 x P7-3-P4)-829	45.00	75.00	145.00	2.50	25.88	2.15	7.05	20.07	43.85	25.73
9.	843-22A x (ICMR 01004-P59 x P7-3-P4)-830	43.00	73.00	146.20	2.50	24.53	1.95	6.55	19.62	46.00	23.48
10.	843-22A x (ICMR 01004-P59 x P7-3P4)-831	44.50	74.50	157.10	1.75	24.89	2.25	5.60	26.08	42.00	36.29
11.	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-834	43.00	73.00	143.30	2.00	26.75	1.90	8.00	22.36	45.50	26.60
12.	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-835	44.00	74.00	136.30	2.50	26.27	1.95	6.85	21.88	47.70	24.02
13.	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-836	45.50	75.50	158.60	2.50	26.76	2.30	7.40	21.85	45.65	26.00
14.	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-837	44.00	74.00	151.40	260	23.40	2.15	6.85	22.72	48.05	24.54
15.	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-838	46.50	77.50	156.70	2.50	26.90	1.95	7.10	23.41	43.90	29.89
16.	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-839	45.50	75.50	165.80	2.10	26.93	2.15	7.30	28.12	45.25	34.22
17.	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-840	43.00	73.00	156.70	2.00	27.23	2.25	7.70	22.50	47.30	25.08
18.	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-841	47.50	78.00	174.00	2.50	24.92	2.25	7.20	23.66	42.15	32.23
19.	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-842	45.00	75.00	149.60	1.15	24.89	2.30	7.70	23.02	44.70	28.54
20.	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-843	44.00	74.00	168.60	1.15	26.48	2.40	6.65	23.85	44.80	29.34
21.	843-22A x (ICMR 01004-P7 x P1449-2-P1-P6)-844	45.50	75.50	157.60	2.50	25.29	2.20	7.65	23.02	44.60	28.69
22.	843-22A x (ICMR 01004-P7 x	44.00	74.00	158.40	2.70	26.55	2.00	6.60	27.92	47.90	30.40

	P1449-2-P1-P6)-845										
23.	843-22A x (ICMR 01004-P13-847	44.50	74.50	183.80	2.70	26.97	2.30	9.05	26.83	45.55	32.03
24.	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-848	44.50	75.00	149.70	2.00	25.69	2.10	7.95	19.92	39.45	30.63
25.	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-849	45.00	74.50	151.90	1.80	26.31	2.20	7.10	19.53	43.15	25.57
26.	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-850	45.50	75.00	163.20	1.90	24.83	2.10	6.90	27.39	46.85	31.03
27.	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-851	46.00	76.50	155.00	2.00	23.34	2.05	7.95	21.59	43.70	28.14
28.	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-852	44.00	74.00	159.90	1.50	23.98	1.70	6.15	21.79	48.85	22.83
29.	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-855	44.00	74.00	164.20	1.75	25.93	2.15	5.85	20.68	46.95	23.38
30.	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-856	45.00	75.00	151.80	1.85	27.71	2.10	7.65	23.43	47.45	25.91
31.	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-857	45.50	75.50	177.30	3.00	28.46	2.10	6.25	25.00	49.55	25.65
32.	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-858	44.50	74.50	169.20	3.00	28.10	2.15	7.70	19.13	44.30	24.08
33.	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-859	43.50	73.50	166.20	2.00	28.82	.25	6.15	26.93	45.25	32.44
34.	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-862	44.50	74.50	159.50	2.25	29.48	2.25	6.80	26.70	51.00	25.47
35.	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-863	44.00	74.00	153.90	2.00	24.85	1.90	6.30	24.99	47.40	27.84
36.	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-864	43.50	73.50	155.80	1.75	29.34	1.90	6.05	28.25	53.35	24.84
37.	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-865	43.50	73.50	190.00	1.80	23.38	2.10	6.70	17.22	44.00	21.50
38.	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-866	45.50	75.50	161.10	2.50	24.87	2.25	7.15	27.58	45.75	32.68
39.	843-22A x (ICMR 01004-P13 x P1449-2-P1-P2)-867	46.00	76.50	143.30	2.00	26.15	2.05	5.95	20.70	48.10	22.31
40.	HHB-67 imp.	43.50	73.00	150.70	2.00	27.12	2.45	8.30	17.13	43.05	22.32
	Mean	**57.66**	**78.48**	**184.45**	**2.800**	**25.25**	**1.41**	**11.28**	**29.31**	**100.78**	**41.52**
	S.Em.±	**2.582**	**1.802**	**10.126**	**0.118**	**1.324**	**0.112**	**0.270**	**3.047**	**13.534**	**5.112**
	CD(5%)	**7.306**	**5.100**	**28.655**	**0.335**	**3.746**	**0.317**	**0.766**	**8.622**	**38.30**	**14.462**
	CV(%)	**6.332**	**3.247**	**7.763**	**5.990**	**7.413**	**11.206**	**3.395**	**14.700**	**18.992**	**17.410**

Appendix-II

Table 1: Weekly Meteorological data of Bikaner for Kharif 2015

Standard Week	Duration	Temperature (℃)		R.H.(%)		Total Rainfall (mm.)*	No.of Rainy days*	Wind Velocity (km./hr.)	Evaporation (mm/day)	BSSH
		Max.	Min.	Max.	Min.					
27	2.7.15 - 8.7.15	37.9	27.08	69.8	41.7	0	0	11.9	8.6	6.4
28	9.7.15- 15.7.15	38.4	25.4	80.4	42.2	10.2	1	9.5	8.8	7.6
29	16.7.15 - 22.7.15	38.9	27.04	74	41.5	8.3	1	9.4	8.6	7.1
30	23.7.15 - 29.7.15	33.6	24.7	88.2	69.4	104.5	4	7.7	5.5	5.8
31	30.7.15 - 5.8.15	33.6	25	89.1	66.7	93.6	4	10.9	5.2	2.6
32	6.8.15 - 12.8.15	37.5	26.2	78.1	54.8	43.3	2	8.4	9	7.6
33	13.8.15 - 19.8.15	35.9	25.4	86.4	55.2	62.5	2	6.7	7.7	6.8
34	20.8.15 - 26.8.15	36.2	25.6	75.2	53	0	0	12.09	8.6	10.1
35	27.8.15 -2.9.15	37.4	25.2	74.1	49.5	0	0	9.2	9.1	9.9
36	3.9.15 - 9.9.15	37.4	23.4	62.5	39	0	0	8.1	8.7	9.9
37	10.9.15- 16.9.15	40.2	23.2	59	29.5	0	0	5.02	9.08	9.8
38	17.9.15 - 23.9.15	34.6	23.8	78.1	50	2.2	0	7.2	6.9	5.9
39	24.9.15 - 30.9.15	35.9	22.1	69.2	31.7	0	0	6.7	6.5	8.9
40	1.10.15 - 7.10.15	38	20.4	70.1	39	0	0	5.2	6.5	9.7
41	8.10.15 -14.10.15	37.7	20	77.5	44.2	0	0	8.1	5.9	9.7
42	15.10.15 - 21.10.15	36.1	19.2	69.4	41	0	0	3.8	5.4	9.4
43	22.10.15 - 28.10.15	32.5	14.3	65.8	30.5	4.2	1	4.2	4.2	9.1