2. REVIEW OF LITERATURE

The studies conducted utilizing sorghum for hybrid breeding based on the heterosis and inbreeding depression are briefly reviewed hereunder:

2.1 HETEROSIS

Exploitation of hybrid vigour in economic crop plants is the latest attempt being made for quantum jump increase in productivity. Heterosis is a complex biological phenomenon often manifested in the superiority of a hybrid over parental forms according to the rate of development of one or more complex characters. Hybrid vigour or heterosis can be regarded as the converse of deterioration that accompanies inbreeding or hybrid vigour may be defined such that on F₁ hybrids falls outside the range of the parents, which respect to some character or characters usually applied to size, rate of growth or general fitness (Allard, 1960). The term hybrid vigour or heterosis was first coined by Shull (1914). Although the term hybrid vigour and heterosis are often used synonymous a more precise definition would be “hybrid vigour” as manifestation of heterosis and use the term “heterosis” to refer to the mechanism by which the superiority is developed. Williams and Gilbert (1960) emphasized that the heterosis over better parent helps the breeder in eliminating the less productive crosses at F₁ itself. Heterosis could be used as an indicative of the crosses, which are likely to generate productive transgressive segregents (Singh and Jain, 1970). Mather and
Jinks (1971) defined heterosis as the amount by which the mean of any F₁ family exceeds its better parent. Heterosis manifestation of increased size, greater vigour in development, higher productivity and similar intensifying effects have been observed by several biologists in many hybrids of plants and animals. Therefore, all the components characters of yield needs to be studied together with regard to heterosis manifestation in order to assess the worth of a cross [Grafus, 1956]. Moll et al. (1962) stated that the success of heterosis breeding depend upon the amount of genetic diversity present in the material.

Heterosis in sorghum was identified and described in the literature even before hybrid sorghum became commercially important. In sorghum, heterosis was first reported by Conner and Karper (1927) and they have provided evidence of sorghum hybrids surpassing their parents in grain yield and plant height. Later several investigators have demonstrated that certain sorghum crosses produced vigorous hybrids and observed marked heterosis in many morphological characters and yield [Karper and Quinby, 1937; Bartel, 1949; Stephens and Quinby, 1952; Quinby and Martin, 1954].

Hirayoshi et al. (1956) reported heterosis in sorghum hybrids in respect to plant height, leaf length and straw yield.

Agrawal and Chavan (1957) observed marked heterosis for plant height, girth of stem, number of internodes/plant, length and breadth of leaf, length and breadth of panicle, seed yield and 1000-grain weight.

Moll et al. (1962) stated that the success of heterosis breeding depends on the amount of diversity present in the genetic material.
Heterosis in sorghum was recorded as high as 100 per cent in respect to grain yield.

Subramanian et al. (1962) observed increased vigour for length, width, number of grains and weight of panicle.

Quinby (1963) reported increased grain yield form two hybrids with greater tillering and more of seeds per panicle. They also reported earliness in F₁ hybrids.

Kambel and Webster (1965) noted that high yield in hybrids was due to increase in seed weight and seed number.

Liang (1967) reported increased stalk diameter, leaf area, earliness of flowering in F₁ hybrids of sorghum also reported negative heterosis for protein content.

significant average heterosis was observed by Kirby and Atkins (1968) in sorghum hybrids for grain yield, plant height, stalk diameter and earliness.

Rao (1970a) observed that, in general, ms CK 60 x Indian combinations were not as ms CK 60 x exotic combinations. However, heterosis for yield in some exotic x Indian crosses was recorded.

Yestrebov and Tsybul-Ko (1971) observed that F₁’s had short day photoperiodic reaction and higher grain yield compared to parental forms.

According to Collins and Pickett (1972) heterosis for yield was exhibited by most of the hybrids in a study involving 48 F₁ hybrids.
Dremlyuk (1972) observed that hybrids surpassed both parental
forms in plant height and leaf length. Marked heterosis was observed with
respect to grain yield.

Shankargouda et al. (1972) reported a positive heterosis for plant
height and significant negative heterosis for day to flowering in most of the
hybrids. Heterosis for 100-grain weight was very low as compared to grain
yield.

Tomar and Pena (1972) reported a high degree of heterosis in grain
yield and seeds per panicle.

Hybrid tended to be taller having more number of leaves with
increased leaf length and increased ear length and girth. Heterosis for grain
yield was also noticed by Goud et al. (1973a).

Kulkarni and Sreeramulu (1973) observed higher heterotic effects
for plant height and day to 50 per cent blooming.

A constant degree of heterosis in yield over mid parent was due to
higher number of seeds per panicle and heavier grains was observed by

Vasudeva Rao (1973) reported that a substantial degree of
heterosis occurred for plant height, panicle length, days to 50 per cent
flowering, grain number per panicle and grain yield per plant.

Goud and Krishna Sastry (1974) reported heterosis for number of
grains per panicle, panicle weight and grain yield.
Grewal and Paroda (1974) observed that the performance of parents and the expression of heterosis were higher in *kharif* season than in summer for most of the characters studied including grain yield.

Rana *et al.* (1974) tested the heterosis of the derivatives of temperate x tropical crosses and demonstrated the superiority of derived dwarfs over original male parents used in hybrid development in India.

Hybrids, which produced highest yield, were having higher magnitude of heterosis for all the components of panicle including panicle length and weight of grains. Test weight and number of whorls were most important as was reported by Goyal and Joshi (1976).

Subbarao *et al.* (1976a, b) observed heterosis over better-parents of American x African and Indian x exotic crosses in respect of days to flowering, plant height, ear head weight and 1000-grain weight.

Shinde (1977) observed positive heterosis for grain yield 51-79 per cent in crosses between Indian x derivative and derivative x derivative.

Lodhi *et al.* (1978) studied heterosis for forage characters and recorded heterosis of 124.4 and 195.1 per cent over the better parent for fodder yield and dry matter yield, respectively.

Rana and Murthy (1978) reported that the yield heterosis in long x long vs. long x compact panicles crosses brought out the superiority of better crosses for yield, number of panicle branches, seed weight and size with large variation for *gca* and higher heritability for most of the characters studied.
Rao et al. (1978) noted that heterosis for grain yield was highest in the American x African cross IS 3797 x IS 8622 (86.6%) followed by American x American cross IS 1884 x IS 511 (47.7%).

Sodani and Chaturvedi (1978) studied, that heterosis was significant for number of grains per panicle and 100-grain weight.

Shahane (1980) observed heterosis and heterobeltiosis for number of primary branches per panicle.

Singhania (1980) observed heterosis for plant height, days to 50 per cent flowering, panicle length, number of grains per panicle and 100-grain weight.

Giriraj and Goud (1981) studied the magnitude of heterosis for days to flowering, plant height components and leaf characteristics in eight parental diallel cross of grain sorghum and found highest degree of heterosis for plant height components and lowest for leaf characters. They recorded negative heterosis for days to flowering and number of leaves.

Indi and Goud (1981) reported maximum heterosis for grain yield per plant and lowest heterosis for days to 50 per cent flowering in rabi sorghum. Heterosis for number of primaries, panicle weight and grain yield was due to the presence of over dominance.

Sarada Mani (1981) studied heterosis in three F₁ hybrids and found positive heterosis for plant height, leaf number, leaf length, leaf width, leaf area, nodal tiller number, panicle length, length of last panicle branch
and number of whorls per panicle, and negative heterosis for basal tiller number.

Maximum heterosis for plant height, ear head length followed by seed size, days to maturity, panicle width, grain yield and days to 50 per cent flowering were reported by Thanky et al. (1981).

Harer and Bapat (1982) investigated heterosis and heterobeltiosis and observed appreciable amount for almost all the characters, except number of leaves. They noticed highest heterosis (197.10%) for the trait grain yield, followed by weight of panicle (147.18%). They found the increase in grain yield to be mainly due to the increase in panicle weight and some extent due to 1000-grain weight. They also noticed that crosses between high yielding and bold grained parents resulted in high yielding and bold grained hybrids.

Patil et al. (1982) reported high heterosis over the mean parental values and over the better parent in respect of panicle girth, number of primaries, ear head weight, test weight and grain yield.

Patel et al. (1982) observed positive heterosis for plant height, grain yield, 100-grain weight and panicle length while negative heterosis for days to 50 per cent flowering.

Rana et al. (1983) explained heterosis in grain yield. The temperate parents originally contributed maximum yield heterosis in temperate x tropical crosses. Yield per se and heterosis in derivative x tropical crosses was the highest due to diversity of genes and heterosis for
plant height, panicle length, number of panicle branches and number of seeds in panicle branches at the bottom. These characters predominantly governed by additive genes.

Gao (1984) studied heterosis for grain yield and found it close, positive correlation with heterosis for number of days to maturity, plant height, leaf area/plant and grain number/ear.

Mal et al. (1984) found that the hybrids 296 A x S 1049 had high heterosis and heterobeltiosis for all the characters except plant height. They also found hybrids 2219 A x S 1049 and 2219 A x IS 4776, both with high heterosis and heterobeltiosis for green fodder yield and had promising traits for commercial exploitation.

Nayeen and Bapat (1984) showed that heterosis was 8.95 per cent for grain yield/plant, 13.2 per cent for 250-grain weight and 0.07 per cent for protein, the heterosis over mid-parent being 21.06, 20.51 and 10.31 per cent for these attributes.

Jagadeshwar (1985) studied heterosis in rabi sorghum with eight parents in a diallel mating design and found that out of 28 crosses, 16 crosses were superior over better parent for grain yield, 250-seed weight and reported negative heterosis for days to 50 per cent flowering.

Patil and Thomber (1985) found the cross combination CS 3541 x R 16 (kharif x rabi) with highest heterosis followed by CS 3541 x IS 4308 (Kharif x Kharif) and CS 3541 x SPV 86 (Kharif x rabi) for grain yield.
Franca et al. (1986) observed that average heterosis over the better parent for plant height, panicle length and number of grains per anicle was positive for both seasons. Average heterosis for days to 50 per cent flowering and 1000-grain weight was negative in both seasons. Yield/panicle showed positive heterosis only on the post rainy season.

Patil and Thomber (1986) found the cross combinations SPV 151 x 16 (rabi x rabi) and SPV 151 x IS 4308 (rabi x kharif) to produce the highest heterosis for grain yield and majority of yield components.

Geeta and Rana (1987) observed positive heterosis for grain yield over superior parent, 100- seed weight, plant height and number of primary ranches. The 27.32 per cent heterosis for grain yield was highest, followed by 23.77 per cent for 100- seed weight.

Hussain Sahib et al. (1988) observed heterosis in two crosses (SPV 32 x SPV 104 and M 35-1 x 2219 B) for grain yield, panicle length, panicle readth and number of primaries. They identified one cross showing heterosis for plant height and 100-grain weight and no heterotic cross for ays to flowering, number of leaves, peduncle length and number of whorls.

Jebrai et al. (1988) recorded maximum relative heterosis of hybrids for plant height and single plant yield and also observed significant heterosis for panicle length.

Nimbalkar et al. (1988) observed heterosis over mid-parent was highly significant in all the crosses for number of primaries and secondaries,
panicle length and weight, grain yield and 1000-grain weight indicating a predominance of non-additive gene action.

Swarnalata and Rana (1988) reported heterosis in 35 crosses, which varied from 109-147 per cent for yield characters and 9.2 per cent for harvest index.

Amsalu and Bapat (1990) observed higher magnitude of heterosis for 1000-grain weight and number of branches/panicle, while low to high for leaf traits. Also identified the combination, R 6672-2 x RSR 11-2 exhibiting the highest per cent increase over the standard check (CSH 9), for grain yield.

Choudhari (1992) studied six quantitative characters in the parents and their 24 F1 hybrids and observed heterosis in plant height, green stem weight at physiological maturity, juice yield and grain yield.

Dremble and Galiba (1993) in their studies involving two male sterile and four restorer lines reported better heterosis for plant height, panicle girth and grain yield.

Reddy and Joshi (1993) studied on heterosis, inbreeding depression and combining ability derived from data on grain yield and five component traits in six varieties (5 Indian and 1 exotic) and their F1 to F4 generations. Grain yield/plant recorded the highest heterosis (87.5%) over the better parental value in the F1 and also showed significant gca and sca in all generations.
Sankarapandian et al. (1994) derived the information on heterosis from data on 6 yield components in 42 hybrid and noticed some 20 hybrids with significant positive heterosis for grain yield.

Manickam and Vijendra Das (1995) found positive heterobeltiosis in most of the hybrids for fodder yield and quality characters. They recorded the hybrid 2219 A x Co 4 with maximum heterosis for green fodder yield (60.1%) and dry matter yield (65.7%).

Salunke and Pawar (1996) studied heterosis for grain yield and physiological traits in rabi sorghum and found appreciable amount of heterosis for grain yield (73.2%), dry matter production at maturity (65.5%) and leaf area index at 50 per cent flowering (33.4%). They also observed moderate heterosis (33.4%) for harvest index.

Swarnalata Kaul et al. (1996) resulted that heterosis from 1.5 - 65.6 per cent over mid-parent and (-) 5.3 - 51.1 per cent over better parent. Heterosis over better parent for this trait was (-) 27.0-33.4 per cent. Higher amount of yield heterosis over better parents was related to positive heterosis for seeds per panicle and panicle length. Yield heterosis primarily governed by additive genes in four crosses.

Ghorade et al. (1997) observed that most of the hybrids exhibited profitable heterosis and heterobeltiosis for the economically important characters like 50 per cent bloom, plant height, grain yield and its directly contributing characters.
Gite et al. (1997) studied the heterosis and found two hybrids viz.,
ms 101A x GMPR-4 (51.47%) and 53A x GMPR-4 (49.26%) with high degree
of useful heterosis (over check CSH-14) for panicle weight as well as for grain
yield per plant. They observed good heterosis effects in combinations among

Kaul and Rana (1997) reported that in rabi sorghum hybrids
involving genetic stocks or KxK derivatives as R lines were high yielding in
general and exhibited 39.32-44.3 per cent heterosis for grain yield
respectively.

Salunke and Deore (1998a) studied heterosis in 60 hybrids of rabi
sorghum resulting hybrid vigour for grain yield, length and girth of panicle,
1000-grain weight, number of grains per plant and plant height. They found
higher magnitude of heterosis for grain yield, 1000-grain weight and number
of grains per plant and low for threshing percentage.

The hybrids which exhibited heterosis for leaf area index and dry
matter production were heterotic for grain yield and exhibited high per cent
performance (Salunke and Deore, 1998b).

Scapim et al. (1998) reported positive heterosis for grain yield and
dry matter and was negative for protein and fibre content for the two
hybrids.

Shreenivasa et al. (2000) found that the crosses exhibited good
standard heterosis for most of the characters viz., plant height, stem
diameter, number of leaves, total leaf area, green forage yield and dry folder yield in both first and second cut.

Hovny et al. (2000) found high estimates of heterosis (71.28%) over the better parent in the cross ATX 629 x 22808-13 for grain yield.

Laxman (2001) recorded highest significant heterosis (101.18%), heterobeltiosis (91.01%) and standard heterosis (33.00%) for grain yield per plant in the cross ICSA 91001 x ICSR 90017.

Prabhakar (2001) observed high estimate of heterosis (109.09%) over the better parent in the cross NIC 19751 x M 35-1 for grain yield per plant with significant heterosis over the check (CSV 14R).

2.2 INBREEDING DEPRESSION

Inbreeding (genetic assortive mating) a converse phenomenon of heterosis is the most powerful of all mating system in all self pollinated crops to lower the percentage of heterozygosity in the population leading to fixation of alleles and thus the phenotype to the extent that it is under genetic control (Alland, 1960). Precisely assortive mating or inbreeding reduces the proportion of heterozygous loci by half in each generation and homozygous types are correspondingly increased. Thus the most striking observed consequence of inbreeding is the reduction of mean phenotypic value. The phenomenon is known as inbreeding depression. In 1876, Darwin published his book Cross and Self Fertilisation in Vegetable Kingdom, he concluded that progeny obtained from self-fertilisation were weaker than those derived from out-crossing. Darwin also reported the
results from his experiments on self and cross-fertilization in maize, these are the first published accounts of inbreeding depression in maize (*Zea mays*). After that detailed and precise information on inbreeding in maize was published by East (1908) and Shull (1908). Inbreeding depression is often manifested as smaller size, lessened vigour, and reduced yield. Measurement of inbreeding depression over different environments provides information useful in selection of lines for hybridization.

The literature on inbreeding depression in sorghum (*Sorghum bicolor* (L.) Moench) crop is briefly reviewed hereunder:

Liang *et al.* (1972) found that, heterosis for grain yield showed the highest heterosis as averaged over the 10 sets and had the greatest inbreeding depression. Heterosis was low for plant height and negative for days to first-bloom and kernel weight indicated lower seed weight.

Vasudeva Rao and Goud (1975) observed significant deviation in the desired directions in *F*$_1$’s from the mid-parental breadth and grain weight per plant indicating dominance for these characters. A high amount of dominance and interactions existed for flowering date, leaf number and panicle breadth as indicated by significant inbreeding depression and *F*$_2$’s deviations from additive model.

Goyal and Joshi (1976) observed that, the hybrids showed maximum heterosis in *F*$_1$ also showed maximum inbreeding depression in *F*$_2$ for all the characters except number of grains per secondary. Inspite of maximum yield heterosis in CSH-2, CSH-3 and CSH-5, the drastic
inbreeding depression for grain yield in F2 suggests that the recommendation of F2 seed for general cultivation is not advisable.

Jhorer and Paroda (1976) found that heterosis for leaf weight, leaf breadth, stem weight and green and dry matter yield. These traits also showed least inbreeding depression in the F2 and F3 populations.

Rubaihaya and Mukumbi (1976) observed high heterosis for grain yield per head, number of grains per head and 'head capacity'. In the F2 inbreeding depression was significant for grain yield, number of grains per head, ear length and flag-leaf area.

Kulkarni et al. (1977) found that, the hybrid CSH-5 exhibited maximum yield potentiality, the inbreeding depression was very high. The F2 and F3 of the hybrid CSH-6, can be used for commercial cultivation as the inbreeding depression of grain yield is very low.

Paroda et al. (1978) found that, the crosses S. sudanense x S. roxburghii and S. roxburghii x S. durra exhibited minimum depression in F2 and F3 generations. These crosses also had higher heterosis (81-91%) for green fodder and dry matter yield. Therefore, exploitation of these crosses in varietal breeding programme is advocated in view of their better performance in segregating generations.

Dangi and Paroda (1979) from their study on the heterosis over the better parent in the F1, extent of depression in yield in the F2 compared with the F1.
Patel et al. (1983) studied on heterosis related to the mid parental value and inbreeding depression for grain yield. They also observed and four related characters in crosses between three female parents and eight male parents and reported that, the highest yielding hybrids showed high heterosis for panicle length and 100 grain weight and the most heterotic $F_1$ hybrids showed the most inbreeding depression in the $F_2$ generations.

Goyal and Joshi (1984) found that, a marked depression in $F_2$ and $F_3$ generations over $F_1$ was observed in all the eight hybrids for grain yield, the magnitude of depression in general being associated with the magnitude of heterosis. Highest inbreeding depression was observed in SPH 10 and CSH-2 followed by CSH-4 and CSH-1 in $F_2$ as well as in $F_3$ generation.

Kulkarni and Shinde (1985) recorded high heterosis for grain yield (65.5%) and plant height (49.4%). They also observed high heterosis and low inbreeding depression for grain yield in case of hybrids CSV 7 R x 2077 B and CSV 5 x 2219 B.

Geeta and Rana (1987) revealed that $F_1$ hybrids were followed by successive depressions in $F_2$ and $F_3$ generations for grain yield.

Rathore and Singhania (1987) reported that magnitude of heterosis and inbreeding depression were high for plant height, number of leaves, leaf width and yield.

Nimbalkar et al. (1988) reported that maximum crosses exhibited non significant inbreeding depression. It was significant in IS 2146 x CS
3541 for number of primaries and 1000-grain weight and in SPV 102 x IS 2146 for number of secondaries.

Reddy and Joshi (1993) studied that, heterotic hybrids for grain yield exhibited high inbreeding depression in F₂ as well as in F₃ generations. The magnitude of inbreeding depression varied from 3.5-36.3 per cent in F₂ and from 12.0-28.1 per cent in F₃ generation. All the heterotic crosses for number of whorls/panicle and panicle length depicted significant inbreeding depression in F₂ and other later segregating generation.

Swarnalata Kaul et al. (1996) reported higher inbreeding depression in the F₃ than the F₂. Inbreeding depression in F₂ ranged 6.5 to 19.9 per cent for grain yield and was more pronounced in F₃ generation (6.5 to 27.8%).

Scapin et al. (1998) reported positive inbreeding depression for grain yield, making F₂ seeds unsuitable for commercial utilization.

2.3 YIELD COMPONENT ANALYSIS

A study of inter-relationship of grain yield with the yield components themselves will be useful in improving the grain yield. Correlation studies provide information on the association of characters with yield and help plant breeder to predict superior combinations and to select desirable genotypes for yield in early generations as the goal is usually a rapid assessment of yield potential based on some measurable characteristics other than yield itself.
In the correlation studies of Kolhe [1951] it was reported that increase in plant height, number of internodes, thickness and weight of ear, resulted in increase of yield of grain and fodder.

Yashoda Swamp and Changade [1962] recorded that, fodder yield was positively correlated with number of days for panicle emergence, plant height, stalk diameter and number of leaves. While Rohewal et al. [1964] observed that, fodder yield was positively and significantly correlated with stem diameter and height, the former correlation, being highly significant, the correlation with internode number was positive but non-significant.

Sindagi et al. [1970a] reported that grain yield was positively correlated with flowering days, plant height, 100 grain weight and fodder yield. They suggested that flowering days, 100-grain weight and fodder yield were the best individual characters on which selection for higher grain yield could be based.

Sindagi et al. [1970b] also found higher magnitude of genotypic correlation than phenotypic correlation values for most of the characters studied.

Badwal [1971] observed significant and positive correlation between grain yield and yield of dry stalks, number of grained ears, dry stalks per plant, stalk diameter and plant height, leaf number and plant height, days to flowering, days to harvest and plant height.
Kulkarni and Sreeramulu (1973) reported significant positive correlations between green and dry fodder yield and number of leaves, leaf area, stem diameter, plant height and time to 50 per cent bloom.

Pokle et al. (1973) reported that, the grain yield was positively correlated with height, leaf area and leaf number. They suggested that panicle weight, plant height and leaf area were important attributes for higher grain yield.

Rao et al. (1973) noted that days to 50 per cent bloom was more important to yield than plant height in sorghum. Patel et al. (1973) indicated that fodder yield was positively correlated with height, stem diameter and total leaf area.

Goud and Krishna Sastry (1974) observed association between grain-yield and days to blooming and plant height to be positive and significant.

Chauhan and Singh (1975) reported that, the grain yield was positively correlated with fodder yield, panicle length, panicle weight, 100-seed weight and number of seeds per panicle.

Kambal and Abu-el-gesim (1976) have stated that in both the parents and hybrids yield was positively and strongly correlated with days to flowering and leaf area and its components.

Goud and Asawa (1978) reported that yield was positively correlated with plant height and ear length. Among the two, ear length with yield was strongly correlated.
Kandaswamy and Subramanian (1980) revealed that all the components viz., ear length, grain number per ear, 1000-grain weight and leaf area index had a positive relationship with grain yield.

Srivastava and Singh (1980) reported that the grain yield was significantly associated with ear weight, grains per ear, 1000-grain weight and plant height. While, Patel et al. (1980) suggested days to 50 per cent flowering, 100-grain weight and number of grains per panicle could be used as selection criteria for yield.

Thomber et al. (1982) reported that, the number of primaries and secondaries, panicle weight and 100-seed weight were highly correlated with grain yield, whereas panicle length and girth had positive correlation with grain yield but it was non-significant. 100-seed weight had significant correlation with panicle weight.

Dabholkar et al. (1983) reported that, the grain yield was positively correlated with number of primaries per panicle, panicle weight and 100-grain weight.

Studies by Heinrich et al. (1983) have revealed that, the stable hybrids had more seeds per head and seed weight in poor environments and contributed to yield stability with favourable significant correlations.

Sayeed et al. (1986) observed that number of seeds and test weight were the major contributing components of grain yield.

Swarnalata and Rana (1988) observed correlation coefficients of rain yield with fodder yield and total biological yield in hybrids were found
to be 0.53 per cent and 0.69 per cent, respectively. These correlations were also positive but slightly higher in parents. Fodder yield and total biological yield were highly correlated in parents (r=0.96%) and hybrids (r=0.70%), but these traits were negatively correlated with harvest index.

Cheralu and Rao (1989b) reported that grain yield in winter sorghum showed significant positive association with ear weight, number of primaries and secondaries and total dry matter, whereas ear head length showed significant negative correlation with harvest index.

Dubey (1992) reported that yield was positively and significantly correlated with the plant height, number of leaves, leaf length and total leaf area would be beneficial for varietal improvement as well as for parental selection for hybrid improvement.

Veerabadhiran et al. (1994) reported positive and significant relationship between yield and panicle weight, number of grains per panicle, number of leaves and days to 50 per cent flowering, also number of grains per panicle had the greatest positive effect on yield.

Senthil and Palanisamy (1995) reported that, the days to 50 per cent flowering was positively and highly significant correlation with number of leaves and panicle length.

Jayaprakash et al. (1997) reported that grain yield was positively and significantly correlated with panicle weight, panicle length and dry fodder yield. Plant height also had a positive, significant association with grain yield at the phenotypic level.
Rao et al. (1998) characterised the sorghum hybrids and varieties for growth parameters, biomass accumulation and yield potential in sorghum. Correlations of various growth parameters with biomass and yield components were positive and significant. The hybrids were found superior by 23 per cent, 7 per cent, 11 per cent, 20 per cent and 12 per cent in panicle mass, 1000-seed weight, grain number, harvest index and grain yield as compared to their parental lines. The grain number has a high positive correlation with grain yield.

Rao and Rana (1998) have compared performance of sorghum hybrids and varieties for growth and yield attributes. They have reported 18 per cent and 49 per cent superiority hybrids in grain yield and harvest index over *kharif* varieties. Significant and negative relationship was observed between sink size (1000-seed weight) and sink number (grain per panicle) in *kharif* hybrids and varieties ($r= -0.528$ and $-0.668$), respectively.

Kumaravadivel and Amirthadevarathinam (2000) observed significant positive correlation and regression for selection around mean level in four out of five crosses for grain yield. At the same level, for the unselected characters, significant positive correlation and regression were observed in four crosses for days to 50 per cent flowering, three crosses for harvest index, two crosses for panicle length and one cross for plant height. The present study indicated that selection was likely to be more effective when exercised around mean level rather than the extreme level.

Navale et al. (2000) reported significant positive correlation coefficient between grain yield and ear weight was highest followed by
association between grain yield and ear girth. Other characters viz., plant height and harvest index have also showed positive correlation with grain yield but were non-significant.

Iyanaar et al (2001) reported that seed yield was significantly and positively correlated with panicle weight (0.993%) and panicle length (0.467%).

Lata Chaudhrary and Arora (2001) observed that grain yield was positively correlated with biological yield, stover yield and number of leaves per plant.

2.4 HERITABILITY

Heritability estimates provide information on the transmission of characters from parent to progeny. Such estimates facilitate evaluation of hereditary and environmental effects in phenotypic variation and thus aid in selection. Heritability estimates can be used to predict genetic advance under selection so that, breeders can anticipate improvement from different types and intensities of selection.

Heritability has been described as proposition of heritable variation to the total phenotypic variation, and can be defined as the ratio of additive genetic variance to phenotypic variance, (Falconer, 1960). Heritability of a matrix character happened to be one of its most important properties. This will also determine degree of resemblance between relatives and can play a predictive role.
The literature on heritability in sorghum crop is briefly reviewed here under:

George et al. (1968) reported heritabilities of grain yield, kernel number, head weight, kernel weight (g/1000) and half bloom were of lower magnitude. Additive gene effects seemed to have a minor contribution to the inheritance for these traits.

Rana and Murthy (1978) estimated high heritability in temperate x tropical crosses as compared to temperate x temperate crosses.

Panchal et al. (1979) reported that, the panicle length gave the highest broad-sense heritability.

Patel et al. (1980) observed broad-sense heritability values for all characters ranged from 54.4 per cent for days to 50 per cent flowering to 98.42 per cent for ear length. Grain yield/plant, ear length and height showed the highest expected genetic gain accompanied by high heritability values.

Ross et al. (1981) estimated broad-sense heritabilities in six sorghum populations, which were high for all traits. Heritability estimates ranged from 0.41 to 0.66 for grain yield, from 0.46 to 0.65 for protein yield and from 0.71 to 0.83 for protein percentage.

Ross and Hookstra (1983) reported high heritability for yield (0.77), height (0.88), flowering (0.74), seed weight (0.77), protein percentage (0.74) and seeds per heads (0.80).
Wankhade et al. (1985) reported that 100 grain weight, panicle width and panicle length also recorded high estimates of expected genetic advance and high to moderate estimates of heritability.

Phul and Allah Rang (1986) reported high heritability (>75%) for days to 50 per cent flowering, maturity span, 100-grain weight and grain protein content. Expected genetic advance was highest for grain yield.

Cheralu and Rao (1989a) reported high heritability for grain yield, total dry matter, ear length and ear weight.

Spivakov (1990) studied that yield was closely correlated with head weight \( (r=0.88 \pm 0.07) \) and number of grains per panicle \( (r= 0.93 \pm 0.05) \). The coefficients of heritability for these two yield components were high (respectively, 0.78 and 0.83), suggesting that selection for them in early generations would be effective.

Potdukhe et al. (1994) recorded highest genetic advance for plant height and lowest for 100-grain weight. The characters plant height, grain yield and number of primaries per panicle showed high estimates of genetic advance accompanied by high estimates of heritability. Selection is, thus, likely to yield beneficial results in improving these characters.

Singh (1994) reported high estimates of heritability for days to 50 per cent flowering, plant height, days to maturity, panicle length and medium to low estimates for panicle girth, number of primaries per panicle and grain yield per plant in sorghum.
Birader et al. (1996) observed that, the components of grain yield like plant height, number of leaves per plant, panicle length, number of whorls per panicle, number of primaries per panicle, length of primary and ear weight exhibited high genetic advance over mean, coupled with high estimates of broad-sense heritability values indicating that selection will be effective for these characters.

Gururaja Rao and Patil (1996) reported that heritability values were highest for plant height followed by grain yield per plant, grains per panicle, panicle length and panicle width. High heritability associated with high genetic advance was observed for grains per panicle, grain yield per plant and panicle weight in all the three $F_2$ populations. Based on genetic parameters, the $F_2$ population of SB 905 x E 36-1 was considered as the best population.

Amit Dadheech et al. (1999) observed high heritability between days to maturity, peduncle length, biological yield per plant and panicle weight. Thus, there is substantial scope for improvement of these characters.

Narkhede et al. (2000b) reported that high value of heritability for panicle length, number of primaries/panicle, ear weight, number of grains/panicle and grain yield are useful to plant breeder, for making effective selection for these traits on phenotypic basis. Earliness showed low estimates of genetic advance coupled with high estimates of broad-sense heritability.
Lata Chaudhary et al. (2001) reported high estimates of heritability for ear head length and days to maturity range varied from 56.04 to 97.80 per cent. All the characters except ear head length and days to 50 per cent flowering showed more than 75 per cent heritability.

2.5 VARIABILITY

Genetic variability present in the base population is essential for crop improvement. Since many characters of economic importance are highly influenced by environmental conditions, progress of breeding attempts mainly depends on the genetic variability present in the population. This variability can be enhanced in segregating populations through hybridization. It is important to note that high genotypic coefficient of variability alone can not be the best criterion for selection (Burtton, 1952). One has to take into account the heritability values. It is the degree of transmission of characters from the parent to offspring or the extent to which the variability of quantitative character is transferred to the progeny.

Information on the genetic variation and interrelationship of plant characters with seed yield and yield contributing characters themselves is of great importance to a breeder in selecting a desirable genotype.

The literature on variability in sorghum crop is briefly reviewed here under:

Quinby and Karper (1954) observed the height genes between temperate and tropical are separately distributed and their combinations may result some of the forms taller than either of parental lines.
Goud et al. (1980) observed highest genotypic and phenotypic coefficient of variation (GCV/PCV) for ear length, followed by ear weight.

Rao and Rana (1982) the hybridization between tropical vs. temperate groups from the basis of genetic improvement in sorghum.

Kumar and Singh (1986) reported high genotypic and phenotypic coefficients of variability (GCV/PCV) for grain yield/plant, as were heritability (90.62%) and genetic advance (73.14%), indicating that selection for these traits should lead to crop improvement.

Pathak and Sanghi (1992) observed that the male parents showed greater variability for green fodder and dry matter yield, plant height, stem weight, whereas the females exhibited greater variability then the male with respect to flowering, stem diameter, number of inter-nodes and leaf area per plant.

Poddukhe et al. (1994) reported that genotypic and phenotypic coefficients of variation were highest for number of primaries/panicle, panicle weight and grain yield/plant. Grain yield was positively and significantly correlated at genotypic and phenotypic level with the panicle length, panicle weight and 100-grain weight.

Biradar et al. (1996) observed that, the characters inter-node length, length, breadth and length of panicle, number of whorls per panicle, number of primaries per panicle, ear weight, number of grains per panicle and grain yield per plant showed high values of genotypic and phenotypic coefficient of variation.
Lata Chaudhary et al. (2001) showed that highest phenotypic and genotypic coefficient of variation (PCV and GCV) were recorded for ear head width, grain yield per plant, days to maturity, number of primaries per panicle, plant height, ear length and peduncle exertion.

2.6 GENETIC DIVERGENCE

The genetic diversity is the basis for any crop improvement programme. The hybrid involving the parents with more diversity among them are expected to exhibit higher amount of heterotic expression and broad spectrum of variability in segregating generation. However, postulation to rational criteria for identification of such parent is still a live problem in plant breeding. To consider geographic diversity among the parents as an index of genetic diversity has been acclaimed. Several methods for multivariate analysis such as D^2 analysis (Murthy and Arunachalam, 1966), cluster analysis principal amount analysis and meteroglyph analysis has been shown to be useful in selecting genetically distant parents for hybridization. The multivariate analysis (D^2-statistic) for selection of parents has an important bearing on the assessment of genetic divergence for use in conventional breeding programmes (Bhatt, 1970).

The importance of genetic divergence of yield improvement and heterosis in sorghum has been emphasised by several workers is briefly reviewed hereunder:

Niehaus and Pickett (1966) reported that direct relationship between geographical distribution and genetic diversity as reflected in heterosis between crosses has been observed in sorghum.
Malm (1968) studied the genetic diversity appears to be the key to obtaining hybrid vigour because the crosses involved geographically and genetically diverse parents which produced high yielding hybrids.

Govil and Murthy (1973) observed the clusters, which contained varieties having high protein content also showed wide inter-cluster divergence also observed heterosis for grain quality character.

Rana et al. (1983) observed genetic improvement in heterotic systems.

The relationship between genetic distance and standardized potency (heterosis) was seemingly influenced by genetic material. In order to obtain promising crosses, it is advisable to select parents from inter-cluster rather than intra-cluster materials were reported by He Zhong-hu (1991).

Biradar et al. (1997) observed no parallelism between geographic diversity and genetic diversity. It was suggested that, divergent restorer pairs can be crossed to obtain superior restorer lines on one or more diverse cytoplasmic sources.

Asthana et al. (1998) using D²-statistic, into 13 clusters. A comparison of the clustering pattern revealed the absence of any relationship between geographic distance and genetic diversity. The character panicle size contributed the most towards genetic divergence for grain yield followed by grains per panicle, gross panicle weight and leaf area.

Narkhede et al. (2000a) observed no parallelism between geographic diversity and genetic diversity. The 13 quantitative characters
were studied for days to 50 per cent flowering contributed most to divergence, followed by plant height, 1000-grain weight, inter-node length and panicle length.

Gurpreet Singh et al. (2001) studied no definite relationship between geographic and genetic diversity and geographic diversity can not be used as an index of genetic diversity.