Effect of Panicle Surface Area on Grain Number, Size and Yield in Pearl Millet

By

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Doctor of Philosophy
in
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ICRISAT

1998

To my daughter

CERTIFICATE I

This is to certify that this thesis entitled, "**Effect of panicle surface area on grain number, size and yield in pearl millet**" submitted for the degree of Doctor of Philosophy in the subject of Plant Breeding of the Chaudhary Charan Singh Haryana Agricultural University, is a bonafied research work carried out by ***Yash Pal Singh Solanki*** under my 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.

(Khairwal, I.S.)
Major Advisor

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Co-Major Advisor

CERTIFICATE II

This is to certify that this thesis entitled, "**Effect of panicle surface area on grain number, size and yield in pearl millet**" submitted by ***Shri Yash Pal Singh Solanki*** to the Chaudhary Charan Singh Haryana Agricultural University in partial fulfillment of the requirements for the degree of Doctor of Philosophy in the subject of Plant Breeding has been approved by the Student's Advisory Committee after an oral examination on the same, in collaboration with an External Examiner

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Y Solanki

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HISAR

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INTRODUCTION

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is the fourth most important crop after Wheat, Rice and Maize for feeding the world population. Globally, it is grown on about 26 million ha of land and annual grain production is 16 million tonnes (FAO, 1996). India and Africa together contribute about 93 per cent of the total production of pearl millet in the world. It is a dual purpose crop with wide ecological adaptability. It is cultivated primarily as a food crop in several countries of East and West Africa and Indian subcontinent (Brunken et al., 1977; Pearson, 1985). Pearl millet is used as a forage crop in the United States, Australia and Southern Africa and its hybrid with elephant grass (Napier grass), is widely used as a perennial forage crop in East and Southern Africa, Brazil and India where it is principally propagated by cuttings.

Pearl millet is a rich source of protein, calcium, phosphorus and iron. It also contains fairly high amount of riboflavin and niacin. The protein content in pearl millet ranges from 6 to 24 per cent (Jambunathan and Subramanian, 1988).The relatively higher protein content available in pearl millet is especially important from the nutritional point of view to the people who depend on millet for food and consequently pearl millet is the "way of life" in countries like Nigeria. It is considered as the "food of the people" in Sudan.

Pearl millet has a number of advantages that have made it the traditional staple cereal crop in subsistence or low-resource agriculture in hot, arid and semi-arid regions like the West African Sahel and Rajasthan in north western India. These advantages include tolerance to drought, heat and leached acid sandy soils with very low clay and organic matter content.

However, it has the ability to grow rapidly in response to brief periods of favourable conditions - a feature of such semi-arid tropical regions. In ideal conditions, it has one of the highest growth rates of all cereals (Kassam and Kowel, 1975; Craufurd and Bidinger, 1989). Its grain is generally superior to sorghum as human food and at least equals maize in value as feed grain. Whereas, grain is the main purpose of cultivation in Africa and Asia, the forage, or stover, at harvest is an important secondary product in subsistence agriculture for animal feed, fuel or construction.

Pearl millet plays an important role in economy of Indian agriculture as its grain forms a staple diet of an estimated 10 per cent population of the country. It supplies energy equivalent to 360 k cal 100^{-1} g of grain, which is higher than many other cereals (Krishnaswamy, 1962; Rachie and Majumdar, 1980). It will continue to play an important role in the Indian economy, particularly in the arid and semi-arid regions of the country.

In India, pearl millet is grown over an area of 10 million ha and annual grain production is 7 million tonnes (Anonymous, 1994). The states of Rajasthan, Maharashtra, Gujarat, Uttar Pradesh and Haryana account for 92 per cent of the area and contribute about 91 per cent of the total production in the country. The state of Rajasthan alone contributes about 36 per cent of the total production of pearl millet in the country. In Haryana, pearl millet is grown over an area of 0.60 million ha with a production of 0.74 million tonnes.

India witnessed a spectacular increased in production and productivity of pearl millet, after the release of first hybrid HB-1 in 1965. Unfortunately, the increase in production was short lived due to downy mildew disease despite the availability of large number of hybrids and varieties with high production potential (35-40 q ha^{-1}). The production as well as productivity continue to be not only low but also highly unstable. The fluctuations in production and productivity have mainly due to biotic and abiotic stresses despite the fact that the crop is capable of producing very high biomass in a short growing season .

Pearl millet is endowed with a rich reservoir of genetic variability for various yield components, adaptation and quality traits. Exploitation of the immense genetic variability in the available germplasm holds the promise of producing high yielding hybrids and open-pollinated varieties adapted to a wide range of both traditional and non-traditional agro-ecological environments. The more diverse the parents, the greater are the chances of obtaining new combinations of genes and thus more are the chances of improvement. Fisher (1918), Lush (1940), Panse (1940), Frankel (1946), Mather (1949), and Allard (1956, 1960) have emphasised the utility of estimating the genetic component of the total variance for the prediction of response to selection in breeding programmes.

It is important to understand the inheritance of yield and yield contributing traits before initiating any efficient breeding programme. By and large, heritability estimates for grain yield components are higher than yield *per se* . Heritability estimates may be high for grain yield (Navale et al., 1991; Bhamre and Harinarayana, 1992a), grain yield per panicle (Pokhriyal et al., 1967), grain weight (Kunjir and Patil, 1986; Dass, 1989), grain number per unit area (Vyas and Srikant, 1984; Aryana et al., 1996) and panicle surface area (Rattunde et al., 1989). Generally, heritability estimates are high when data are based on a single environment but low when data are based from two or more environments (Singh, 1974; Sandhu et al., 1980).

Grain yield is the ultimate criterion for the plant breeder in his attempts to evolve improved varieties. Grain yield is a complex trait and is the result of interaction of various yield components. Correlation studies are very helpful in making effective selection, since higher the correlation between grain yield and an individual trait more reliable is the selection based on that trait. Positive correlations of grain yield with panicle surface area (Mahadevappa and Ponnaiya, 1967; ICRISAT, 1986; Rattunde et al., 1989b.Bidinger et al., 1993), grain number per unit area (Shankar et al., 1963; Navale et al., 1995), grain weight (Diz et al., 1994; Tomar et al., 1995), grain number per panicle (Diz and Schank, 1995) and grain yield per panicle (Mahadevappa and Ponnaiya, 1967; Diz and Schank, 1995) have been reported in pearl millet.

A study of correlations between yield components is also an important for assessing the feasibility of joint selection for two or more traits at a time. Positive correlation of grain weight with panicle surface area (Bidinger et al., 1993) and grain number per panicle (Diz et al, 1994; Diz and Schank 1995) have been reported. A positive correlation between two desirable traits make the job of plant breeder easy for improving both traits simultaneously. However, a negative correlation between two desirable traits impedes or makes it impossible to achieve a significant improvement in both traits, depending upon the intensity of linkage between the two traits.

Differences in grain yield among cereals are more often related to differences in grain number per unit area than to differences in grain size. Direct selection for grain number per unit area, however, is not a practical approach to breed for increased yield potential because i) its high cost of measurement on large numbers of progeny rows and ii) its probable lack of relevance when measured in spaced plants.

Panicles with large surface area had a different grain number-grain size relationship than panicles with a small surface area (Bidinger et al., 1993). Individual grain size was greater for a given grain number in large surface area type of panicles than in small panicle surface area, leading to 20 per cent increase in grain yield in former types.

Keeping this in view, the present study was, therefore, carried out with the following objectives:

1. To determine the effect of panicle surface area on panicle grain number, grain size and grain yield in pearl millet.

2. To predict and measure gain in grain yield improvement from selection criterion based on panicle surface area.

MATERIALS AND METHODS

BASE GENETIC MATERIAL

In the present investigation, three composites of pearl millet viz., Early Composite 1987 (EC 87), Early Composite 1991 (EC 91) and High Head Volume B Composite (HHVBC) were chosen considering wide ranges in their panicle surface area (panicle length x panicle diameter x π, assuming the panicle to be a perfect cylinder).

The EC 87 was constituted by random mating Early Composite II (ECII C1), two Bold Seeded Early Composite (BSEC) varieties (ICMV 87901 and ICMV 87902) and one variety (ICMV 87119) from Early Composite (EC).

The EC 91 was developed by random mating Early Composite II (ECII C1) and Early Smut Resistant Composite II (ESRCII CO).

The HHVBC was bred from crosses of elite breeding lines and selected germplasm accessions having long and thick panicles. Distinguishing features of the three composites are given in Table 1 (see also Fig.1).

Table 1. Distinguishing features of the three composites of pearl millet used in present study.

Composite	Origin	Panicle surface area (cm^2)	Major features
EC 87	ICRISAT	111-448	Early maturity, medium height, large seed size, moderate tillering.
EC 91	ICRISAT	145-441	Early maturity, medium height, long panicles, moderate tillering.
HHVBC	ICRISAT	100-667	Late maturity, dwarf height, large seed size, maintainer of A_m cms (20-30% plants maintainer of A_1 cms).

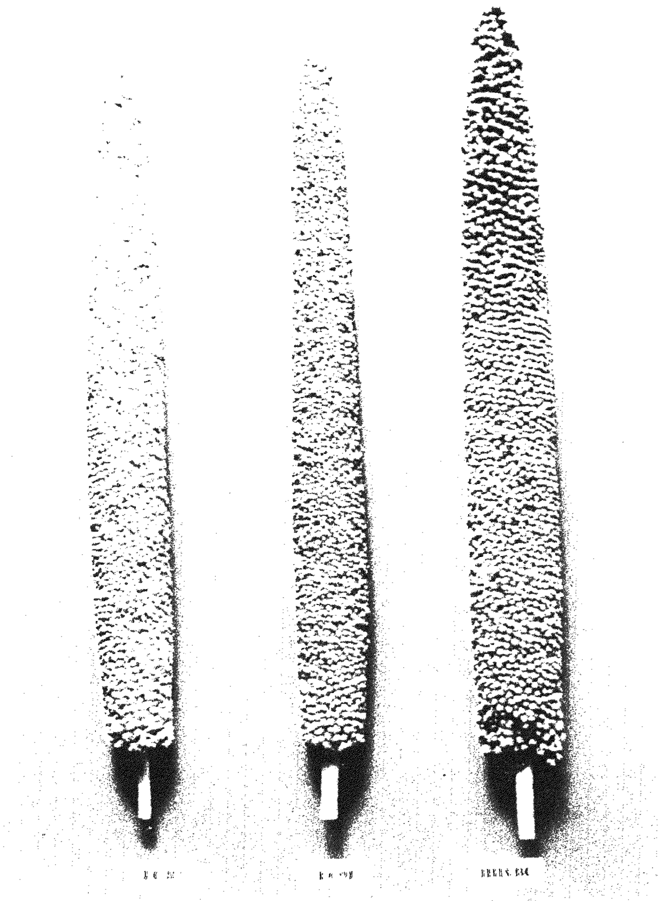


Fig. 1. Representative panicles of EC 87, EC 91 and HHVBC.

S_0 PLANT EVALUATION

Approximately 1000 plants (spaced 75 x 75 cm) from each of the three composites were grown in rainy season 1993 (June-September) at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru. The main panicle of each plant was left for open pollination to measure panicle surface area and a tiller panicle was selfed to produce S_1 seed. At maturity, off type plants were discarded and panicle length and diameter were recorded on main panicles. Also, plants from the original composites were visually evaluated for yielding ability by the breeder who bred the original composite. Approximately 800 selfed panicles were harvested from each of the three composites.

The experimental material consisted of two sets of experiment.

- S_1 progeny evaluation.
- Experimental varieties evaluation.

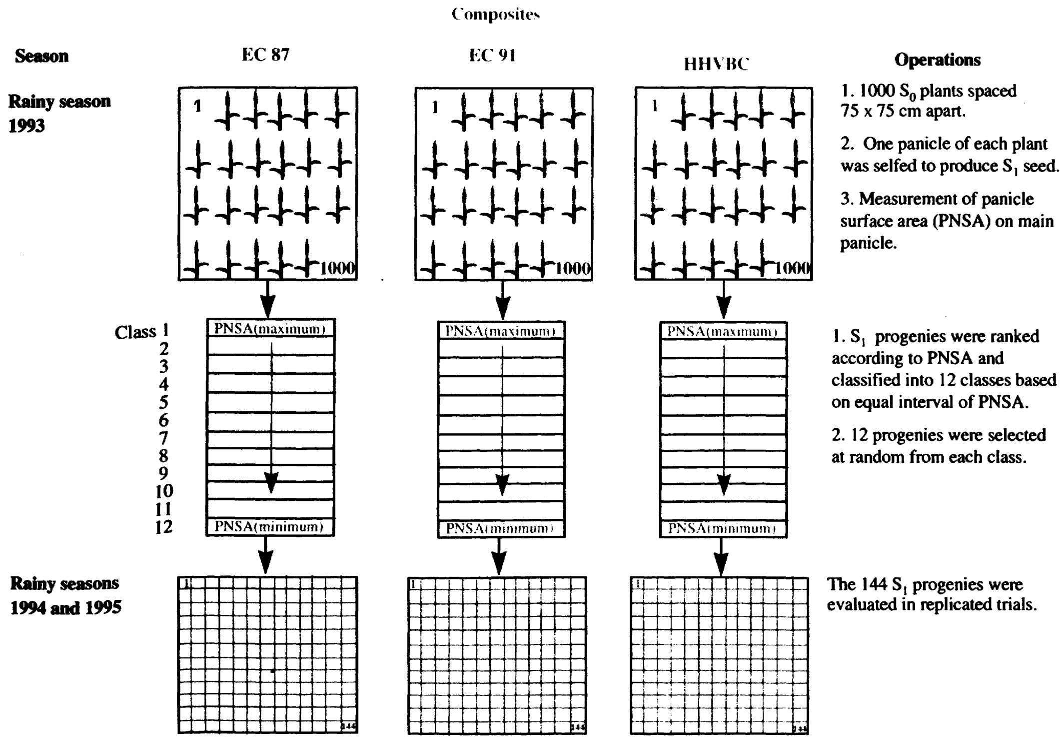
S_1 PROGENY EVALUATION

Selection of S_1 progeny

S_1 progeny from each population were ranked according to panicle surface area and the total distribution was divided into 12 classes of equal interval (Fig. 2).

Twelve progenies were selected at random from each class for field evaluation to: (i) assess the genetic variation in panicle surface area (ii) estimate heritability of panicle surface area and compared to other yield related traits and (iii) assess the genetic correlations of panicle surface area with grain yield and its components.

Fig. 2. Procedure for S_0 plant and S_1 progeny evaluation.



Site and Season

The S_1 progenies were evaluated at ICRISAT-Patancheru during rainy seasons of 1994 and 1995 The seasonal rainfall in 1994 and 1995 was 550 mm and 747 mm, respectively

Design and Layout

The 144 S_1 progenies from each composite representing full range of panicle surface area were grown in Completely Randomized Block Design (CRBD) replicated three times, keeping a plot size of one row of 4.0 m length with 75 cm inter-row spacing and 10 cm plant to plant distance.

Crop management

The S_1 progenies were planted by seed drill mounted on tractor. Irrigation was not given throughout cropping season in both of the years. A basal dose of 42 Kg N ha^{-1} and 42 Kg P_2O_5 ha^{-1} fertilizers was applied. An additional 46 Kg N ha^{-1} in the form of urea was side dressed 25-30 days after seedling emergence. Interculture and one hand weeding were done to control weeds

Traits assessed

Traits measured on S_1 progenies, their abbreviations, units and method of measurement are presented in Table 2. Traits were measured at the time of harvest in all the three replications and in each set of S_1 progenies. Panicle length and diameter were recorded on five randomly selected plants per plot and panicle number, grain weight and grain yield were recorded on plot basis.

Table 2. Traits measured on S_1 progenies of pearl millet, their abbreviations, units and method of measurement.

Trait	Abbreviation	Unit	Method of measurement or calculation
Panicle length	PNLN	cm	Measured from the base of the panicle to the tip of the panicle
Panicle diameter	PNDA	cm	Measured with the help of vernier calliper at three positions (top, middle and bottom) and averaged
Panicle surface area	PNSA	cm^2	Panicle length x panicle diameter x π
Panicle number m^{-2}	$PNNM^{-2}$	no	Number of panicles / net harvested area
Grains panicle^{-1}	$GNPN^{-1}$	no	[(Grain yield panicle^{-1}) / (1000grain wt)] x1000
Grain number m^{-2}	GNM^{-2}	no	[(Grain yield m^{-2}) / (1000 grain wt)] x1000
1000 grain weight	TGWT	g	100 grain counts were made on three randomly selected samples, averaged and multiply by 10
Grain yield panicle^{-1}	$GYPN^{-1}$	g	Grain weight / panicle number
Grain yield m^{-2}	GYM^{-2}	g	Grain weight / net harvested area

Statistical analysis

Statistical analysis for each trait was done according to Completely Randomized Block Design (CRBD) Pooled analysis involving two environments was carried out using Genstat package

Analysis of variance

Analysis of variance were computed in order to find out differences among S_1 progenies for different traits on the basis of the model described by Panse and Sukhatme (1967)

$$X_{ij} = \mu + g_i + b_j + e_{ij}$$

Where, X_{ij} = Observations on the i^{th} genotype in the j^{th} block

μ = General mean

g_i = Effect of i^{th} genotype

b_j = Effect of j^{th} block

e_{ij} = Error associated with i^{th} genotype in j^{th} block

Analysis of variance tables for all traits in each experiment were constructed as given in Table 3

Table 3. Analysis of variance for 144 S_1 progenies.

Source of variation	d f	M S
Replication	(r-1)	MSr
Genotype	(g-1)	MSg
Error	(r-1)(g-1)	MSe

Where, r = Number of replications

g = Number of genotypes

MSr, MSg and MSe stand for the mean squares due to replication, genotype and error, respectively

Pooled analysis of variance of involving two environments for each trait was done as per partitioning of degrees of freedom given in Table 4

Table 4. Pooled analysis of variance for 144 S_1 progenies involving two environments.

Source of variation	d f
Environment	(e-1)
Replication in environment	e(r-1)
Genotype	(g-1)
Genotype x Environment	(g-1)(e-1)
Pooled error	e(r-1)(g-1)

Where e, r and g stand for the number of environments, replications and genotypes, respectively

FORMATION OF EXPERIMENTAL VARIETIES

Selection of S_1 progeny

The S_0 plants of each population ranked by panicle surface area were divided into five classes as described below (see also Fig. 3).

PCV1 < [mean - 1.75 (s.d.)]

PCV2 > [mean - 1.25 (s.d.)], < [mean - 0.75 (s.d.)]

PCV3 > [mean - 0.25 (s.d.)], < [mean +0.25 (s.d.)]

PCV4 > [mean + 0.75 (s.d.)],< [mean +1.25 (s.d.)]

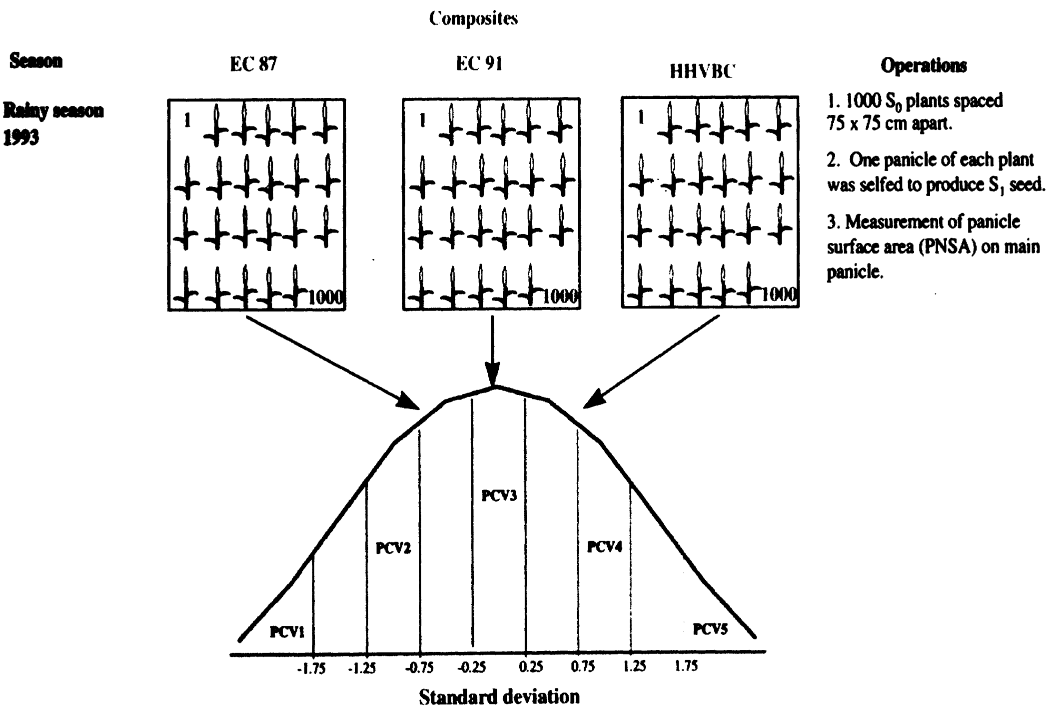
PCV5 > [mean + 1.75 (s.d.)]

As per description given above 22 S_0 plants were selected from each class at random and then S_1 progenies were used to make PCV1 (with minimum panicle surface area) to PCV5 (with maximum panicle surface area) for each population. Equal number of S_1 progenies were also selected at random from the entire set of S_1 progenies of each population for recombination to make random control experimental variety (RNDV). The highest ranked 22 S_0 plants as selected by the breeder from each population were also recombined to make a breeder selection control (BRDV). In addition, a bulks of the original populations were also planted for seed increase, to represent a fresh seed source from the same seed production environment as of the experimental varieties.

Recombination procedure

A total of 22 S_1 progenies selected to make each experimental variety viz., PCV1, PCV2, PCV3, PCV4, PCV5, RNDV, BRDV along with a mixture of 22 selected S_1 progenies of each variety from each population were grown in summer 1996 at ICRISAT-Patancheru.

Fig. 3. Procedure for selection of S_1 progeny for recombination.



Each S_1 progeny was sown in one row and mixture of the progenies in six rows with 5 m length The pollens from the mixture of the progenies were collected and used to pollinate each progeny in each variety in three composites Equal quantity of seed from 22 S_1 progenies were mixed in each variety in all the three composites and thus 24 experimental varieties were made (Fig 4) as given below

1 EC87 PCV1	9 EC91 PCV1	17 HHVBC PCV1
2 EC87 PCV2	10 EC91 PCV2	18 HHVBC PCV2
3 EC87 PCV3	11 EC91 PCV3	19 HHVBC PCV3
4 EC87 PCV4	12 EC91 PCV4	20 HHVBC PCV4
5 EC87 PCV5	13 EC91 PCV5	21 HHVBC PCV5
6 EC87 RNDV	14 EC91 RNDV	22 HHVBC RNDV
7 EC87 BRDV	15 EC91 BRDV	23 HHVBC BRDV
8 EC87 ORIG	16 EC91 ORIG	24 HHVBC ORIG

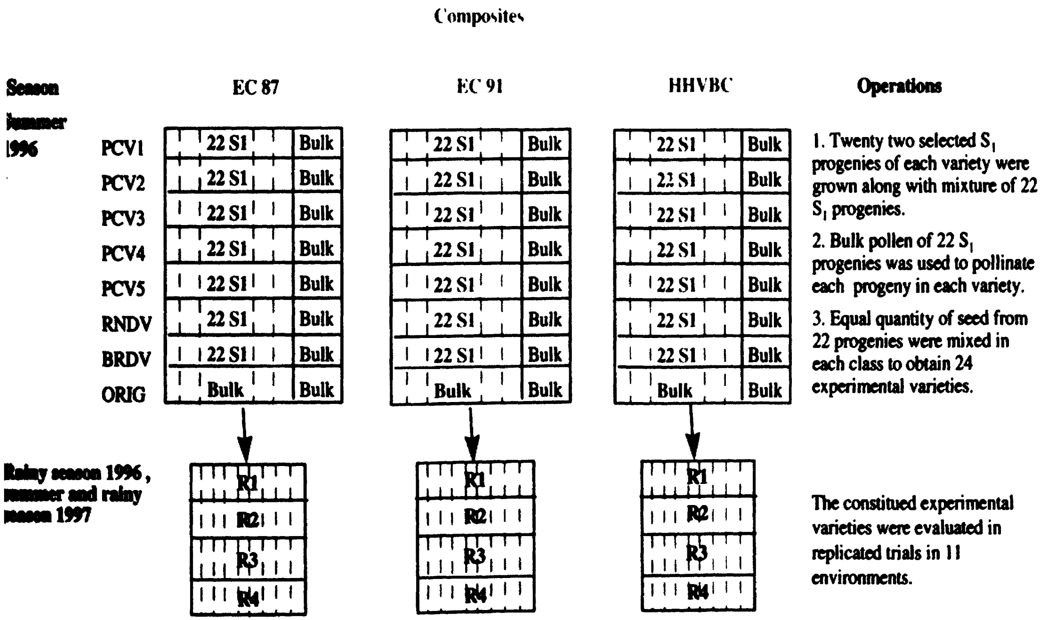
EXPERIMENTAL VARIETIES EVALUATION

The experimental varieties obtained above were evaluated at three locations (Table 5)

Table 5. Location, condition, season and year for the evaluation of experimental varieties.

Location	Condition	Season	Year
Hisar	Irrigated	Rainy	1996, 1997
Rohtak	Irrigated	Rainy	1996, 1997
ICRISAT-Patancheru	Irrigated	Summer	1997
	Low fertility	Rainy	1996, 1997
	High fertility	Rainy	1996, 1997
	Extended day length	Rainy	1996, 1997

Fig. 4. Procedure for formation and evaluation of experimental varieties.



Hisar

Hisar is situated at the latitude of 29° N, longitude 75° E and an altitude 215.2 m above mean sea level and falls in the semi-tropical region of north India. The experiments were carried out at the research farm, Department of Plant Breeding, Chaudhary Charan Singh Haryana Agricultural University, Hisar.

Rohtak

Rohtak is situated at the latitude of 28° N, longitude 76° E and an altitude 219.84 m above mean sea level and falls in the semi-tropical region of north India. The experiments were conducted at Research Station Rohtak, Chaudhary Charan Singh Haryana Agricultural University, Hisar.

Patancheru

Patancheru is situated at the latitude of 18° N, longitude 78° E and an altitude 545 m above mean sea level and falls in the semi-arid tropical region of south India. The experiments were carried out at ICRISAT-Patancheru, Andhra Pradesh.

Design and Layout

The experimental varieties were grown in Completely Randomized Block Design (CRBD) with four replications at all locations. The plot size was four rows of 4.0 m length with row to row and plant to plant distance 45 cm and 10 cm, respectively at Hisar and Rohtak whereas, the inter-row spacing was 75 cm at Patancheru. Harvest area was two central rows of 3.0 m length at all locations.

Crop management

Planting at Hisar and Rohtak was done by dibbling method Diammonium phosphate (DAP) at the rate of 60 kg N ha^{-1} and 60 kg P_2O_5 ha^{-1} was applied as a basal dose and 60 Kg N ha^{-1} in the form of urea was side dressed 25-30 days after seedling emergence in each experiment. Interculture was done manually to control weeds. At Patancheru, the experimental varieties were planted by seed drill mounted on tractor.

Under low fertility conditions, ammonium phosphate at the rate of 21 kg N ha^{-1} and 9 kg P ha^{-1} was applied as basal dose. Irrigation was not given throughout the cropping season.

Under high fertility conditions, ammonium phosphate at the rate of 42 kg N ha^{-1} and 18 kg P ha^{-1} was applied as a basal dose and 46 kg N ha^{1} in the form of urea was side dressed at 25-30 days after seedling emergence in each experiment. Irrigation was not given during the cropping season. Plots were intercultivated to control the weeds.

In extended day length experiment, the day length was extended to 14.30 hr, using flood lights (100 watt tungsten filament bulbs) mounted on a 3 x 5 m grid about 2 m above the ground. The fertilizer doses were the same as in case of high fertility conditions. In this experiment sprinkler irrigation was applied up to 40 days and then furrow irrigation was given.

In summer crop, the doses of fertilizer as a basal dose and side dressing was also same as applied in high fertility condition. But furrow irrigation was given throughout the dry season.

Traits assessed

Traits were measured in experimental varieties on panicle and plot basis, their abbreviations, units and method of measurement are presented in Table 6 and 7, respectively.

Table 6. Traits measured on 24 experimental varieties of pearl millet on panicle basis, their abbreviations, units and method of measurement.

Trait	Abbreviation	Unit	Method of measurement or calculation
Panicle length	PNLN	cm	Measured from the base of the panicle to the tip of the panicle
Panicle diameter	PNDA	cm	Measured with the help of vernier calliper at three positions (top, middle and bottom) and averaged
Panicle surface area	PNSA	cm^2	Panicle length x panicle diameter x π
Grain number cm^{-2}	$GNCM^{2}$	no	Number of grains were counted per square cm at three positions (top, middle and bottom) and averaged
1000 grain weight	TGWT	g	100 grain counts were made on three randomly selected samples, averaged and multiply by 10
Grains $panicle^{-1}$	$GNPN^{-1}$	no	[(Grain yield $panicle^{-1}$) / (1000 grain wt.)] x1000
Grain yield $panicle^{-1}$	$GYPN^{-1}$	g	Grain weight / panicle number

Table 7.Traits measured on 24 experimental varieties of pearl millet on plot basis, their abbreviations, units and method of measurement.

Trait	Abbreviation	Unit	Method of measurement or calculation
Panicle number m^{-2}	$PNNM^{-2}$	no	Number of panicles / net harvested area
Grains panicle^{-1}	$GNPN^{-1}$	no	[(Grain yield panicle^{-1}) / (1000 grain wt)] x1000
Grain number m^{-2}	GNM^{-2}	no	[(Grain yield m^{-2}) / (1000 grain wt)] x1000
1000 grain weight	TGWT	g	100 grain counts were made on three randomly selected samples, averaged and multiply by 10
Grain yield panicle^{-1}	$GYPN^{-1}$	g	Grain weight / panicle number
Grain yield m^{-2}	GYM^{-2}	g	Grain weight / net harvested area
Days to flowering	DAFL	days	Days after sowing when 50% of plants had panicles with emerged stigma
Plant height	PLHT	cm	Measured from the base of the plant to the tip of primary panicle
Fodder yield m^{-2}	FYM^{-2}	g	Weight of vegetatively dry matter/net harvested area

On panicle basis, traits were measured on ten randomly selected primary panicle at maturity. Traits on plot basis were measured at harvest except for days to flowering (DAFL), which was recorded at 50% flowering. Dry weights were recorded after plant materials were dried for 48 hr at 70^0 C

Statistical analysis

Pooled analysis involving 11 environments was carried out using Genstat package.

Analysis of variance

The analysis of variance for each trait was done as per partitioning of degrees of freedom given in Table 8. The analysis of variance for individual population was also done for each trait following partitioning of degrees of freedom presented in Table 9.

Assessment of variability

The simple measures of variability include mean, range, standard error and coefficient of variation were assessed. The analysis of variance permits estimation of phenotypic and genetic coefficients of variability for various traits as given below:

Phenotypic coefficient of variability (PCV) = $[(VP)^{1/2}/X] \times 100$

Genetic coefficient of variability (GCV) = $[(VG)^{1/2}/X] \times 100$

Where VP, VG and X stand for phenotypic variance, genetic variance and mean respectively.

Table 8. Pooled analysis of variance for 24 experimental varieties of pearl millet.

Sourse of variation	d.f.
Environment	(e-1)
Replication in environment	e(r-1)
Genotype	(g-1)
Population	(p-1)
Selection	(s-1)
Population x Selection	(p-1)(s-1)
Genotype x Environment	(g-1)(e-1)
Population x Environment	(p-1)(e-1)
Selection x Environment	(s-1)(e-1)
Population x Selection x Environment	(p-1)(s-1)(e-1)
Pooled error	e(r-1)(g-1)

Where e, r, g, p and s stand for number of environments, replications, genotypes, populations and selections.

Table 9. Pooled analysis of variance for 8 experimental varieties in each population.

Sourse of variation	d.f.
Environment	(e-1)
Replication in environment	e(r-1)
Genotype (Selection)	(g-1)
Genotype x Environment	(g-1)(e-1)
Pooled error	e(r-1)(g-1)

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It also permits estimation of broad sense heritability and expected genetic advance under selection as follows

Broad sense heritability = V_G / V_P

Where, $V_P = V_G + V_{GE} / E + V_E / RE$

V_G = Genetic variance

V_{GE} = Genetic and Environment interaction variance

V_E = Environmental variance

E = Number of environments

R = Number of replications

Hallauer and Miranda (1981) classified the heritability value as,

Very high = > 0 7

High = 0 5-0 7

Moderate = 0 3-0 5

Low = < 0 3

Expected genetic advance = $i \times h^2 \times (VP)^{1/2}$

Where, i = Standardised selection differential and its value is 2 06 at 5% level

h^2 = Heritability in broad sense

VP = Phenotypic variance

Genetic advance (GA) in per cent of mean = (GA/X) x 100

Where, X = Mean

Estimated gain from indirect selection = $i \times r_{g\,xy} \times h_x \times (v_{g\,y})^{1/2}$

Where, i = Standardised selection intensity at 5%

$r_{g\,xy}$ = Genetic correlations between x (secondary trait) and y (primary trait)

h_x = Square root of heritability of secondary trait

$v_{g\,y}$ = Genetic variance of primary trait

Genetic correlation coefficients

Genetic correlation coefficients were estimated according to the procedure given by Johanson et al., (1955)

$$r(g) = GCOV(XY)/[GV(X) \times GV(Y)]^{1/2}$$

Where, r(g) = Genetic correlation between X and Y

GCOV(XY) = Genetic covariance between X and Y

GV(X) = Genetic variance of X

GV(Y)= Genetic variance of Y

RESULTS - S_1 PROGENY

The 144 S_1 progenies of three composites viz., EC 87, EC 91 and HHVBC were evaluated in Completely Randomized Block Design (CRBD) with three replications at ICRISAT-Patancheru in rainy seasons of 1994 and 1995. The traits studied were panicle length, panicle diameter, panicle surface area, panicle number per m^2, grain number per m^2, 1000 grain weight, grain number per panicle, grain yield per panicle and grain yield per m^2. The results obtained are described below:

Analysis of variance

Mean squares among 144 S_1 progenies revealed significant variability for all traits of the three composites in 1994 and 1995 crop seasons (Table 10 and 11). Pooled analysis of variance indicated highly significant mean squares due to genotype for all traits and genotype x environment for grain yield per m^2 in the three composites, panicle surface area in EC 87 and EC 91 and panicle number per m^2 in EC 87 only (Table 12).

Mean performance (composites)

A summary of mean, range, standard error and coefficient of variation measured on S_1 progeny of three composites are presented in Table 13.

Composite HHVBC has the greatest mean panicle length, panicle diameter, panicle surface area, 1000 grain weight, grain number per panicle and grain yield per panicle. EC 87 has the maximum mean values for panicle number per m^2, grain number per m^2 and grain yield per m^2.

Table 10. Mean squares obtained from the analysis of variance in trial conducted during rainy season 1994 at ICRISAT-Patancheru for panicle length (PNLN), panicle diameter (PNDA), panicle surface area (PNSA), panicle number per m^2 (PNNM^{-2}), grain number per m^2 (GNM^{-2}), 1000 grain weight (TGWT), grain number per panicle (GNPN^{-1}), grain yield per panicle (GYPN^{-1}) and grain yield per m^2 (GYM^{-2}) in 144 S_1 progenies of three pearl millet composites.

Source	d.f.	Composite	PNLN (cm)	PNDA (cm)	PNSA (cm^2)	PNNM^{-2} (no)	GNM^{-2} (x10^7)	TGWT (g)	GNPN^{-1} (x10^5)	GYPN^{-1} (g)	GYM^{-2} (g)
Replication	2	EC 87	8.93	0.09	1425	215.3	26.4	0.25	9.25	88.9	30066
		EC 91	2.88	0.02	12	656.3	92.3	1.87	7.22	110.1	57562
		HHVBC	17.13	0.31	1949	12.6	6.2	2.69	1.78	53.8	9673
Genotype	143	EC 87	22.25**	0.22**	3359**	99.4**	24.1**	6.87**	7.97**	72.8**	16559**
		EC 91	36.35**	0.14**	3223**	40.3**	15.9**	3.71**	6.09**	40.8**	11730**
		HHVBC	43.97**	0.27**	9432**	33.2**	15.3**	6.03**	4.47**	49.9**	13223**
Error	286	EC 87	3.67	0.03	514	19.9	5.7	0.90	1.77	12.8	4257
		EC 91	2.98	0.02	366	17.6	5.7	0.91	1.65	12.5	4280
		HHVBC	4.50	0.03	1091	12.6	5.7	1.16	1.37	14.8	4820

**: Significant at $P = 0.01$.

Table 11. Mean squares obtained from the analysis of variance in trial conducted during rainy season 1995 at ICRISAT-Patancheru for panicle length (PNLN), panicle diameter (PNDA), panicle surface area (PNSA), panicle number per m^2 (PNNM^{-2}), grain number per m^2 (GNM^{-2}), 1000 grain weight (TGWT), grain number per panicle (GNPN^{-1}), grain yield per panicle (GYPN^{-1}) and grain yield per m^2 (GYM^{-2}) in 144 S_1 progenies of three pearl millet composites.

Source	d.f.	Composite	PNLN (cm)	PNDA (cm)	PNSA (cm^2)	PNNM^{-2} (no)	GNM^{-2} (x10^7)	TGWT (g)	GNPN^{-1} (x10^5)	GYPN^{-1} (g)	GYM^{-2} (g)
Replication	2	EC 87	1.99	0.38	930	1.9	14.4	2.28	6.39	89.2	19672
		EC 91	0.94	0.17	1452	68.0	13.0	0.40	3.25	32.7	7406
		HHVBC	16.97	3.77	40034	37.6	8.2	1.65	0.65	16.1	13277
Genotype	143	EC 87	28.27**	0.24**	4949**	36.5**	19.8**	6.58**	8.11**	69.9**	10461**
		EC 91	31.49**	0.16**	3887**	29.9**	11.2**	4.14**	6.63**	52.5**	8867**
		HHVBC	45.19**	0.36**	10839**	18.0**	10.2**	5.24**	4.86**	47.3**	9243**
Error	286	EC 87	3.93	0.04	625	12.1	4.2	0.77	1.68	17.2	3430
		EC 91	3.88	0.04	650	10.1	5.7	0.76	1.71	12.5	3670
		HHVBC	3.29	0.07	1090	9.8	3.8	1.10	1.82	15.4	3300

**: Significant at P = 0.01.

Table 12.Mean squares obtained from the analysis of variance in trials conducted during rainy seasons 1994 and 1995 at ICRISAT-Patancheru, for panicle length (PNLN), panicle diameter (PNDA), panicle surface area (PNSA), panicle number per m² (PNNM^{-2}), grain number per m² (GNM^{-2}), 1000 grain weight (TGWT), grain number per panicle (GNPN^{-1}) grain yield per panicle (GYPN^{-1}) and grain yield per m² (GYM^{-2}) in 144 S_1 progenies of three pearl millet composites.

Source	d.f.	Composite	PNLN (cm)	PNDA (cm)	PNSA (cm²)	PNNM^{-2} (no)	GNM^{-2} (x10^7)	TGWT (g)	GNPN^{-1} (no)	GYPN^{-1} (g)	GYM^{-2} (g)
Environment	1	EC 87	172.8**	46.32**	347461**	4653.8**	114.8	12.66*	199.5**	2525.3**	48234**
		EC 91	181.1**	32.92**	313736**	2888.7**	136.7	27.40**	140.4**	1987.5**	32367
		HHVBC	6.2	4.81	45649	2779.4**	824.7**	8.80	13.0*	18.4	906647*
Replication in Environment	4	EC 87	5.5	0.23	7528	108.7	20.5	1.27	7.8	89.1	4867
		EC 91	1.9	0.09	732	362.1	52.6	1.13	5.2	71.4	32484
		HHVBC	17.0	2.04	20992	25.1	7.2	2.17	1.2	35.0	11465
Genotype	143	EC 87	46.8**	0.42**	7528**	110.2**	36.9**	12.40**	14.1**	127.0**	21336**
		EC 91	62.7**	0.25**	6481**	53.3**	19.5**	6.82**	10.7*	79.4**	15235**
		HHVBC	85.2**	0.57**	19288**	39.0**	20.1**	9.69**	7.7**	84.9**	17652**
Genotype x Enviroment	143	EC 87	4.3	0.04	780**	25.6**	6.9	1.04	1.9	15.7	5385**
		EC 91	5.1	0.04	629*	16.9	7.5	1.03	2.0	14.0	5363**
		HHVBC	3.5	0.06	994	12.6	6.0	1.52	1.9	15.4	5379**
Pooled error	572	EC 87	3.8	0.03	570	15.9	5.0	0.83	1.7	15.1	3840
		EC 91	3.4	0.03	509	13.8	5.6	0.83	1.6	12.5	3974
		HHVBC	3.8	0.05	1091	11.2	4.7	1.13	1.6	15.1	4033

*,**: Significant at = 0.05 and 0.01, respectively.

The range of variation in panicle surface area among the 144 S_1 progenies in each composite was more than two fold. The variation in panicle surface area was due to the effects of variation in panicle length as well as in panicle diameter. Ranges among S_1 progenies in grain number per panicle and grain yield per panicle was also more than two fold in the three composites.

Genetic variation

The phenotypic coefficient of variation (PCV) and genetic coefficient of variation (GCV) are shown in Table 14.

Estimates of phenotypic coefficient of variation and genetic coefficient of variation revealed that the PCV was generally higher than GCV for most of the traits, but in some cases, the two values differed slightly. The lowest values of PCV and GCV were shown by panicle diameter in EC 87 and EC 91. The highest values of PCV and GCV were shown by grain yield per panicle in HHVBC followed by grain yield per panicle and grain number per panicle in EC 87, panicle diameter in HHVBC, grain number per m^2 and panicle number per m^2 in EC 87.

Heritability and Genetic advance

Estimates of heritability and genetic advance are given in Table 15. The heritability estimate ranged from 63% (grain number per m^2) in EC 91 to 95% (panicle length) in HHVBC. High heritability estimates were also observed for panicle diameter, panicle surface area, 1000 grain weight, grain number per panicle and grain yield per panicle in the three composites.

Lowest estimates of heritability were shown by panicle number per m^2 in HHVBC and grain yield per m^2 in EC 91 and HHVBC.

Table 13. Mean, range, standard error (SE) and coefficient of variation (CV) for nine traits among 144 S_1 progenies in three pearl millet composites averaged over two environments.

Trait	Composite	Mean	Range	SE(±)	CV(%)
Panicle length (cm)	EC 87	22.2	16-29	1.12	8.8
	EC 91	25.1	17-32	1.06	7.4
	HHVBC	27.3	18-37	1.13	7.2
Panicle diameter (cm)	EC 87	2.79	2.0-4.0	0.11	6.9
	EC 91	2.56	2.0-3.0	0.10	7.1
	HHVBC	3.32	2.0-4.0	0.13	7.1
Panicle surface area (cm^2)	EC 87	196.6	124-278	13.7	12.1
	EC 91	203.4	111-269	13.0	11.1
	HHVBC	287.2	162-435	19.0	11.5
Panicle number per m^2	EC 87	18.6	10-32	2.29	21.6
	EC 91	17.5	13-24	2.15	21.5
	HHVBC	14.3	11-20	1.93	23.5
Grain number per m^2	EC 87	34025	17391-53457	4085	20.8
	EC 91	33681	22336-45052	4344	22.3
	HHVBC	28958	18677-39778	3972	23.7
1000 grain weight (g)	EC 87	9.80	6-13	0.52	9.3
	EC 91	9.30	7-11	0.52	9.8
	HHVBC	9.90	7-13	0.61	11.8
Grain number per panicle	EC 87	1993	722-3115	239	21.5
	EC 91	2004	1214-3185	237	20.2
	HHVBC	2081	1269-2835	231	19.2
Grain yield per panicle (g)	EC 87	18.7	9-29	2.24	20.9
	EC 91	18.4	11-28	2.04	19.2
	HHVBC	20.4	12-29	2.24	19.2
Grain yield per m^2 (g)	EC 87	324.6	204-465	35.7	19.1
	EC 91	308.3	203-394	36.4	20.4
	HHVBC	282.4	185-407	36.6	22.5

Table 14. Phenotypic coefficient of variation (PCV) and genetic coefficient of variation (GCV) for nine traits among 144 S_1 progenies in three pearl millet composites averaged over two environments.

Trait	Composite	PCV(%)	GCV(%)
Panicle length (cm)	EC 87	12.5	11.9
	EC 91	12.5	12.3
	HHVBC	13.8	13.5
Panicle diameter (cm)	EC 87	9.5	8.7
	EC 91	7.8	6.8
	HHVBC	22.9	22.1
Panicle surface area (cm^2)	EC 87	18.1	17.1
	EC 91	16.2	15.4
	HHVBC	19.8	19.2
Panicle number per m^2	EC 87	23.0	20.2
	EC 91	47.3	41.5
	HHVBC	17.4	14.4
Grain number per m^2	EC 87	23.0	20.7
	EC 91	16.9	13.5
	HHVBC	19.6	16.4
1000 grain weight (g)	EC 87	14.7	14.0
	EC 91	11.5	10.6
	HHVBC	12.9	11.8
Grain number per panicle	EC 87	24.2	22.4
	EC 91	21.2	19.2
	HHVBC	17.0	14.6
Grain yield per panicle (g)	EC 87	24.6	22.9
	EC 91	19.8	18.0
	HHVBC	48.8	43.9
Grain yield per m^2 (g)	EC 87	18.3	15.7
	EC 91	16.4	13.2
	HHVBC	18.8	15.6

The expected genetic advance in per cent of mean, varied from 13.3% (panicle diameter) in EC 91 to 43.9% for the same trait in EC 87. Relatively low values of genetic advance in per cent of mean were shown by panicle length, 1000 grain weight and grain yield per m^2 in the three composites. Comparatively high expected genetic advance were observed for panicle surface area, grain number per panicle and grain yield per panicle in the three populations.

Correlations

The genetic correlations between panicle surface area and other traits are presented in Table 16. Panicle length, panicle diameter and grain yield per panicle showed highly significant and positive associations with panicle surface area in the three composites. Grain number per panicle, 1000 grain weight and grain yield per m^2 also showed significant and positive association with panicle surface area whereas, panicle number per m^2 showed significant and negative association with panicle surface area in the three composites. Grain number per m^2 had no association with panicle surface area in EC 87 and HHVBC whereas, it showed significant and positive association with panicle surface area in EC 91.

Genetic correlations among various other pairs of the S_1 progeny traits are presented in Table 17. Grain yield per m^2 had significant positive association with panicle length, panicle diameter, grain number per m^2, grain number per panicle and grain yield per panicle in the three composites.

Grain number per m^2 showed significant and positive association with panicle number per m^2 in EC 87 and HHVBC. 1000 grain weight showed significant negative association with grain number per m^2 in the three composites while, it showed significant negative association with panicle number per m^2 in EC 87 and HHVBC.

Table 15. Heritability (H), genetic advance (GA) and genetic advance in per cent of mean (GA%) for nine traits among 144 S_1 progenies in three pearl millet composites averaged over two environments.

Trait	Composite	H(%)	GA	GA(%)
Panicle length (cm)	EC 87	91	5.22	23.4
	EC 91	92	6.13	24.4
	HHVBC	95	7.38	27.0
Panicle diameter (cm)	EC 87	90	0.49	17.6
	EC 91	81	0.34	13.3
	HHVBC	93	1.46	43.9
Panicle surface area (cm^2)	EC 87	89	64.9	33.0
	EC 91	90	60.9	30.0
	HHVBC	94	109.9	38.3
Panicle number per m^2	EC 87	77	6.79	36.5
	EC 91	77	4.12	28.7
	HHVBC	68	3.43	24.4
Grain number per m^2	EC 87	81	3063	38.4
	EC 91	63	7330	22.1
	HHVBC	70	8181	28.2
1000 grain weight (g)	EC 87	91	2.69	27.4
	EC 91	85	1.87	20.1
	HHVBC	84	2.19	22.2
Grain number per panicle	EC 87	86	854	43.9
	EC 91	82	719	35.9
	HHVBC	74	538	25.8
Grain yield per panicle (g)	EC 87	87	8.21	43.8
	EC 91	83	6.24	33.9
	HHVBC	81	6.21	30.5
Grain yield per m^2 (g)	EC 87	73	89.3	27.5
	EC 91	65	67.5	21.9
	HHVBC	69	75.3	26.7

Table 16. Genetic correlation coefficients between panicle surface area and other S_1 progeny traits in 144 pogenies of EC 87, EC 91 and HHVBC pearl millet composites averaged over two environments.

Panicle surface area with	EC 87	EC 91	HHVBC
Panicle length	0.88	0.89	0.92
Panicle diameter	0.78	0.64	0.78
Panicle number per m^2	-0.57	-0.48	-0.48
Grain number per m^2	0.07	0.17	0.04
1000 grain weight	0.40	0.39	0.19
Grain number per panicle	0.49	0.45	0.50
Grain yield per panicle	0.74	0.70	0.56
Grain yield per m^2	0.41	0.47	0.17

Coefficients with an absolute value 0.15 or 0.20 are significant at P = 0.05 and 0.01, respectively.

Grain number per panicle had significant positive association with grain number per per m^2. But it showed significant negative association with 1000 grain weight and panicle number per m^2 in the three composites.

Table 17. Genetic correlation coefficients among panicle length (PNLN), panicle diameter (PNDA), panicle number per m² ($PNNM^{-2}$), grain number per m² (GNM^{-2}), 1000 grain weight (TGWT), grain number per panicle ($GNPN^{-1}$), grain yield per panicle ($GYPN^{-1}$) and grain yield per m² (GYM^{-2}) in 144 S_1 pogenies of three pearl millet composites averaged over two environments.

Traits	Composite	PNDA	$PNNM^{-2}$	GNM^{-2}	TGWT	$GNPN^{-1}$	$GYPN^{-1}$	GYM^{-2}
PNLN	EC 87	0.38	-0.42	0.19	0.18	0.49	0.59	0.37
	EC 91	0.23	-0.41	0.21	0.23	0.44	0.61	0.40
	HHVBC	0.48	-0.38	0.07	0.13	0.42	0.45	0.15
PNDA	EC 87		-0.55	-0.10	0.54	0.32	0.65	0.31
	EC 91		-0.34	0.03	0.42	0.23	0.48	0.35
	HHVBC		-0.51	-0.03	0.25	0.46	0.57	0.15
$PNNM^{-2}$	EC 87			0.16	-0.22	-0.56	-0.72	0.09
	EC 91			0.07	0.01	-0.64	-0.65	0.10
	HHVBC			0.56	-0.25	-0.25	0.39	0.40
GNM^{-2}	EC 87				-0.63	0.69	0.30	0.74
	EC 91				-0.45	0.70	0.49	0.67
	HHVBC				-0.40	0.65	0.31	0.75
TGWT	EC 87					-0.35	0.26	0.03
	EC 91					-0.37	0.21	0.36
	HHVBC					-0.26	0.47	0.29
$GNPN^{-1}$	EC 87						0.80	0.59
	EC 91						0.82	0.41
	HHVBC						0.72	0.49
$GYPN^{-1}$	EC 87							0.62
	EC 91							0.68
	HHVBC							0.67

Coefficients with an absolute value 0.15 or 0.20 are significant at P = 0.05 and 0.01, respectively.

RESULTS - PANICLE DATA

The 24 experimental varieties of three composit es viz., EC 87, EC 91, and HHVBC were evaluated in Completely Randomized Block Design (CRBD) with four replications in 11 environments at Hisar, Rohtak and ICRISAT-Patancheru during rainy season of 1996 and the summer and rainy seasons of 1997. The panicle traits studied in detail were length, diameter, surface area, grain number per cm^2, 1000 grain weight (grain size), grain number and grain yield. The detailed studies were based on sample of 10 primary panicles per plot. The results obtained are described below:

Analysis of Variance

Mean squares among 24 experimental varieties revealed significant variability for panicle length, panicle diameter, panicle surface area, grain number per cm^2 and 1000 grain weight at all locations, grain number per panicle at three locations and grain yield per panicle at four locations in rainy season of 1996 (Table 18). Genotype effects were influenced by difference in populations for all traits except possibly grain number per panicle. Effect of selections were constantly significant for panicle length, panicle surface area, 1000 grain weight and grain yield per panicle. Population x selection effects were generally not significant for any of the panicle traits.

Mean squares among 24 experimental varieties revealed significant variability for all traits in summer 1997 and except grain number per panicle at all locations in rainy season of 1997 (Table 19). Genotype effects were influenced by difference in populations for all traits except possibly grain number per panicle. Effects of selection were constantly significant for panicle length, panicle diameter, panicle surface area and grain yield per panicle. Population x selection effects were

Table 18. Mean squares obtained from the analysis of variance in trials conducted at five locations during rainy season 1996 for panicle length (PNLN), panicle diameter (PNDA), panicle surface area (PNSA), grain number per cm^2 ($GNCM^{-2}$), 1000 grain weight (TGWT), grain number per panicle ($GNPN^{-1}$) and grain yield per panicle ($GYPN^{-1}$) in 24 experimental varieties of pearl millet. The effect of genotype (23 d.f.) has been subdivided in the effects of population (2 d.f.), selection (7 d.f.) and population x selection (14 d.f.).

Source	d.f.	Location	PNLN (cm)	PNDA (cm)	PNSA (cm^2)	$GNCM^{-2}$ (no)	TGWT (g)	$GNPN^{-1}$ ($x10^5$)	$GYPN^{-1}$ (g)
Replication	3	HSR	9.12	0.07	932.9	94.43	0.91	5.46	39.86
	3	RTK	3.35	0.06	753.1	6.45	0.95	7.48	59.95
	3	ILF	4.28	0.03	784.6	2.54	2.02	6.68	52.10
	3	IHF	2.41	0.03	230.1	2.95	0.76	7.02	20.42
	3	IEDL	0.79	0.09	834.3	0.23	4.77	2.93	12.36
Genotype	23	HSR	26.43**	0.14**	3483.8**	8.37**	1.71**	0.72	6.33
	23	RTK	10.52**	0.09**	1650.5**	9.52**	1.40**	1.09**	11.61**
	23	ILF	22.73**	0.20**	4118.7**	13.10**	4.37**	4.63*	69.90*
	23	IHF	18.56**	0.22**	3834.5**	11.41**	3.50**	2.72	85.95**
	23	IEDL	21.90**	0.23**	2305.2**	12.80**	2.51**	7.04**	85.16**
Population	2	HSR	163.46**	1.21**	25879.5**	74.55**	5.54**	0.28	16.32**
	2	RTK	71.79**	0.93**	13511.0**	92.01**	1.56*	3.27**	34.77**
	2	ILF	84.92**	1.84**	26152.4**	91.31**	23.92**	0.11	123.08*
	2	IHF	56.45**	2.08**	22819.2**	91.51**	12.34**	1.50	200.89**
	2	IEDL	56.27**	1.88**	12995.9**	99.33**	7.49**	43.59**	602.78**

continued...

Table 18. continued...

Selection	7	HSR	28.76**	0.03	2340.3**	1.70	0.94*	0.84	4.16
	7	RTK	11.31**	0.03**	1419.3**	3.08	2.36**	0.67	10.25**
	7	ILF	38.62**	0.07*	4430.1**	4.87	3.17**	7.52*	136.07**
	7	IHF	39.55**	0.06*	5086.5**	5.92	3.79*	3.51	136.05**
	7	IEDL	25.91**	0.09	2659.6**	4.16	2.61**	5.89**	43.26*
Population x Selection	14	HSR	5.69*	0.04	856.2	2.26	1.54**	0.72	5.76
	14	RTK	1.37	0.01	72.0	0.95	0.90*	0.98 *	8.99
	14	ILF	5.90*	0.03	815.4 *	6.04*	2.18*	3.68	29.23
	14	IHF	2.65	0.03	562.1	2.71	2.08	2.51	44.48
	14	IEDL	4.44	0.05	600.8	4.76	1.75	2.39	32.15
Error	69	HSR	3.03	0.03	478.2	1.96	0.53	0.74	4.56
	69	RTK	1.84	0.01	193.2	1.95	0.48	0.45	3.06
	69	ILF	2.57	0.02	386.5	2.38	0.98	2.73	34.94
	69	IHF	2.21	0.02	349.9	4.44	0.38	2.33	25.10
	69	IEDL	2.16	0.07	889.8	3.66	0.88	2.01	18.26

*,**: Significant at P = 0.05 and 0.01, respectively.

HSR: Hisar; RTK: Rohtak; ILF, IHF, IEDL: ICRISAT low fertility, high fertility and extended day length, respectively.

Table 19. Mean squares obtained from the analysis of variance in trials conducted at six locations during summer and rainy season 1997 for panicle length (PNLN), panicle diameter (PNDA), panicle surface area (PNSA), grain number per cm^2 (GNCM^{-2}), 1000 grain weight (TGWT), grain number per panicle (GNPN^{-1}) and grain yield per panicle (GYPN^{-1}) in 24 experimental varieties of pearl millet. The effect of genotype (23 d.f.) has been subdivided in the effects of population (2 d.f.), selection (7 d.f.) and population x selection (14 d.f.).

Source	d.f.	Location	PNLN (cm)	PNDA (cm)	PNSA (cm^2)	GNCM^{-2} (no)	TGWT (g)	GNPN^{-1} (x10^5)	GYPN^{-1} (g)
Replication	3	ISU	1.56	0.05	382.2	2.80	1.68	1.35	30.72
	3	HSR	7.70	0.77	5331.7	4.29	0.54	2.86	18.67
	3	RTK	4.40	0.03	642.6	10.55	0.82	1.13	10.42
	3	ILF	2.16	0.02	603.4	5.55	5.89	1.24	23.32
	3	IHF	2.12	0.02	461.5	0.90	1.90	0.46	21.29
	3	IEDL	1.87	0.02	432.1	1.53	0.56	2.02	16.33
Genotype	23	ISU	22.84**	0.33**	5822.4**	13.83**	2.89**	2.79**	63.19**
	23	HSR	28.78**	0.12**	3062.5**	5.54**	1.89**	3.72	4.55**
	23	RTK	18.00**	0.15**	2737.8**	12.97**	2.99*	1.21	34.89**
	23	ILF	26.96**	0.32**	6520.4**	17.63**	2.98**	2.38	59.20**
	23	IHF	22.01**	0.36**	6339.1**	13.16**	1.47*	2.13*	37.64*
	23	IEDL	20.92**	0.19**	3852.0**	20.44**	2.29*	2.68	54.05**
Population	2	ISU	105.00**	2.94**	45168.0**	128.42**	26.33**	6.08**	464.73**
	2	HSR	229.95**	0.93**	25183.7**	11.68**	3.36**	0.14	9.05*
	2	RTK	83.48**	1.29**	15713.8**	105.94**	4.63*	2.18	59.54**
	2	ILF	141.36**	3.33**	53838.4**	114.66**	9.23**	6.36	80.46*
	2	IHF	127.72**	3.44**	52195.0**	115.98**	7.72**	1.05	114.87*
	2	IEDL	79.62**	1.55**	22609.9**	116.16**	14.65**	5.73*	283.39**

continued...

Table 19. continued...

Selection	7	ISU	41.20**	0.09**	4658.7**	4.32	0.39	4.11**	38.28**
	7	HSR	17.43**	0.04	1620.8**	4.64*	2.97**	0.68	6.81**
	7	RTK	30.89**	0.06**	3728.2**	3.32	4.40**	1.94*	73.34**
	7	ILF	38.80**	0.03*	4398.0**	13.79**	1.90*	4.25	119.66**
	7	IHF	29.89**	0.12**	5103.5**	6.07*	0.29	3.18**	66.33*
	7	IEDL	43.02**	0.10**	5600.0**	14.63**	1.48	3.32	63.00**
Population x Selection	14	ISU	1.93	0.08**	783.5**	2.21	0.79**	1.65	18.28
	14	HSR	5.72*	0.04*	623.2**	5.11**	1.14*	0.25	2.78
	14	RTK	2.21	0.03*	388.9	4.51	2.06	0.71	12.16
	14	ILF	4.69**	0.03	821.9**	5.68**	2.63**	1.69	25.95
	14	IHF	2.97*	0.04	406.0	2.01	1.18	1.76	12.26
	14	IEDL	1.49	0.03	298.2	2.52	0.94	1.93	16.81
Error	69	ISU	1.30	0.02	319.8	3.29	0.33	1.18	12.91
	69	HSR	2.66	0.02	224.0	2.14	0.49	0.40	2.09
	69	RTK	1.79	0.01	213.2	2.87	1.16	0.76	8.78
	69	ILF	1.26	0.01	237.8	1.94	0.78	1.44	18.38
	69	IHF	1.53	0.02	6723	2.78	0.82	1.08	24.17
	69	IEDL	1.56	0.02	257.4	3.12	1.23	1.65	13.77

*,**: Significant at $P = 0.05$ and 0.01, respectively.

HSR: Hisar; RTK: Rohtak; ISU, ILF, IHF, IEDL: ICRISAT summer, low fertility, high fertility and extended day length, respectively.

generally not significant for any of the panicle trait.

Pooled analysis of variance of 24 experimental varieties indicated highly significant mean squares due to genotype for all traits. All three source of variation in genotype (base population, selection and their interaction) were also significant for all the traits (Table 20). The population effects were much greater than the selection and population x selection effects for all the traits except grain number per panicle and grain yield per panicle.

Interactions of genotype and environment was also significant for all the traits, with population x environment mean squares again being greater than the selection x environment or population x selection x environment (Table 20).

Pooled analysis of variance for individual population indicated highly significant mean squares due to environment and genotype for all traits and genotype x environment for panicle length, panicle surface area and 1000 grain weight in the three composites, grain number per panicle and grain yield per panicle in EC 87 and panicle diameter in EC 91 (Table 21).

Mean performance (composites)

A summary of mean, range, standard error and coefficient of variation for eight experimental varieties in each composite have been given in Table 22.

The means of panicle surface area were similar in EC 87 and EC 91, but considerably smaller than that of HHVBC. HHVBC again has the greatest mean panicle length and panicle diameter, with EC 87 having a greater diameter but shorter length than EC 91. The means of grain number per cm^2 were similar in EC 87 and EC 91. EC 87 has the greatest mean 1000 grain weight and grain yield per panicle while, EC 91 has the maximum grain number per panicle.

Table 20. Mean squares obtained from the analysis of variance in 11 environments for panicle length (PNLN), panicle diameter (PNDA), panicle surface area (PNSA), grain number per cm^2 (GNCM^{-2}), 1000 grain weight (TGWT), grain number per panicle (GNPN^{-1}) and grain yield per panicle (GYPN^{-1}) in 24 experimental varieties of pearl millet. The effect of genotype (23 d.f.) has been subdivided in the effects of population (2 d.f.), selection (7 d.f.) and population x selection (14 d.f.).

Source	d.f.	PNLN (cm)	PNDA (cm)	PNSA (cm^2)	GNCM^{-2} (no)	TGWT (g)	GNPN^{-1} (no)	GYPN^{-1} (g)
Environment	10	175.82**	6.56**	79639**	300.27**	246.62**	503.00**	10232.5**
Replication in environment	33	3.62	0.11	1035	12.02	1.89	2.94	27.7
Genotype	23	189.83**	1.96**	37291**	99.30**	10.45**	8.75**	188.1**
Population	2	1037.93**	20.30**	296087**	1007.57**	63.17**	6.90**	335.3**
Selection	7	309.28**	0.43**	35156*	24.87**	9.81**	19.00**	452.4**
Population x Selection	14	8.95**	0.11**	1388**	6.77**	3.25**	3.88**	34.9**
Genotype x Environment	230	4.34**	0.04**	647**	3.95**	1.76**	1.90**	32.4**
Population x Environment	20	16.21**	0.11**	1998**	8.40**	5.36**	5.87**	165.4**
Selection x Environment	70	3.61**	0.03**	588**	4.17**	1.45**	1.69	24.5**
Population x Selection x Environment	140	3.01**	0.03**	483**	3.20	1.40**	1.44	17.3
Pooled error	759	1.99	0.02	354	2.78	0.83	1.34	15.0

*,**: Significant at P = 0.05 and 0.01, respectively.

Table 21. Mean squares obtained from the analysis of variance in 11 environments for panicle length (PNLN), panicle diameter (PNDA), panicle surface area (PNSA), grain number per cm² (GNCM^{-2}), 1000 grain weight (TGWT), grain number per panicle (GNPN^{-1}) and grain yield per panicle (GYPN^{-1}) in eight experimental varieties of three pearl millet composites.

Source	d.f.	Composite	PNLN (cm)	PNDA (cm)	PNSA (cm²)	GNCM^{-2} (no)	TGWT (g)	GNPN^{-1} (x10^{5})	GYPN^{-1} (g)
Environment	10	EC 87	70.30**	1.96**	23302**	115.77**	81.97**	173.00**	3696.1**
		EC 91	103.05**	1.75**	26937**	110.78**	74.42**	193.00**	332.7**
		HHVBC	34.88**	3.07**	33395**	90.52**	100.96**	148.00**	3540.1**
Replication in environment	33	EC 87	2.10	0.09	656	5.41	1.31	1.40	13.7
		EC 91	2.77	0.05	533	5.88	0.95	2.24	17.1
		HHVBC	2.59	0.06	723	5.73	1.21	1.61	23.4
Genotype (Selection)	7	EC 87	100.49**	0.26**	13400**	21.72**	4.59**	12.50**	194.7**
		EC 91	121.64**	0.09**	9210**	8.51*	5.28**	9.66**	188.2**
		HHVBC	105.04**	0.29**	15323**	8.18**	8.43**	4.58**	139.4**
Genotype x Environment	70	EC 87	2.92**	0.02	385**	3.17	1.44*	2.09**	25.7**
		EC 91	2.95**	0.03*	409**	4.53	0.89*	1.09	14.07
		HHVBC	3.77**	0.05	762**	2.86	1.91**	1.40	19.51
Pooled error	231	EC 87	1.76	0.02	238	2.77	0.96	1.34	16.3
		EC 91	1.92	0.02	241	3.49	0.63	1.32	13.0
		HHVBC	2.32	0.04	599	2.14	0.89	1.43	16.4

*, **: Significant at P = 0.05 and 0.01, respectively.

Table 22. Mean, range, standard error (SE) and coefficient of variation (CV) for seven panicle traits for eight experimental varieties of three pearl millet composites averaged over 11 environments.

Trait	Composite	Mean	Range	SE(±)	CV(%)
Panicle length (cm)	EC 87	23.4	20.6-25.6	0.66	5.7
	EC 91	25.6	22.6-27.8	0.69	5.4
	HHVBC	26.8	25.0-29.6	0.76	5.7
Panicle diameter (cm)	EC 87	2.49	2.36-2.60	0.07	5.8
	EC 91	2.32	2.24-2.39	0.07	5.9
	HHVBC	2.79	2.65-2.89	0.10	7.2
Panicle surface area (cm^2)	EC 87	184.5	153.3-210.5	7.71	8.4
	EC 91	188.0	160.0-205.0	7.76	8.3
	HHVBC	236.4	211.3-264.2	12.23	10.0
Grain number per cm^2	EC 87	19.2	17.8-20.1	0.83	8.7
	EC 91	19.2	18.6-19.9	0.93	9.7
	HHVBC	16.2	15.4-16.7	0.73	9.0
1000 grain weight (g)	EC 87	10.7	10.3-10.8	0.48	9.2
	EC 91	9.9	9.50-10.3	0.39	8.1
	HHVBC	10.5	9.83-11.2	0.47	9.0
Grain number per panicle	EC 87	2769	2410-2906	184	13.2
	EC 91	2804	2514-2953	182	13.0
	HHVBC	2716	2600-2877	190	13.9
Grain yield per panicle (g)	EC 87	30.3	26.2-33.3	2.02	13.3
	EC 91	28.4	24.3-30.0	1.80	12.7
	HHVBC	29.2	26.6-32.3	2.02	13.9

The range in panicle surface area among the eight experimental varieties was good in each population. Ranges among experimental varieties in panicle productivity traits in the three composites was great for 1000 grain weight, grain number per panicle and grain yield per panicle.

Mean performance (experimental varieties)

Mean performance of 24 experimental varieties of three pearl millet composites are presented in Table 23. The experimental variety PCV5 has the greatest mean panicle surface area, 1000 grain weight and grain yield per panicle indicating that selection for large panicle surface area was effective for these traits in EC 87. The response to selection from PCV1 with minimum panicle surface area to PCV5 with maximum panicle surface area was 37% for panicle surface area (Fig. 5).

In EC 91, PCV5 has the maximum mean value for panicle surface area. The RNDV and PCV5 were almost similar for grain number per panicle and grain yield per panicle. The response to selection from PCV1 to PCV5 was 28% for panicle surface area (Fig. 6).

PCV5 showed maximum mean values for panicle surface area, 1000 grain weight and grain yield per panicle in HHVBC while, BRDV has the maximum mean values for grain number per panicle. The response to selection from PCV1 to PCV5 was 23% for panicle surface area (Fig. 7).

Genetic variation

The phenotypic coefficient of variation (PCV) and genetic coefficient of variation (GCV) are shown in Table 24. Estimates of PCV and GCV revealed that panicle surface area had the highest PCV and GCV whereas, panicle diameter and grain number per cm^2 had the lowest PCV and GCV followed by grain number per cm^2 and 1000 grain weight .

Table 23. Mean performance of 24 experimental varieties of three pearl millet composites for seven panicle traits averaged over 11 environments.

Source	Experimental variety	PNLN (cm)	PNDA (cm)	PNSA (cm^2)	GNCM^{-2} (no)	TGWT (g)	GNPN^{-1} (no)	GYPN^{-1} (g)
EC 87	PCV1	20.6	2.36	153.2	19.5	10.7	2410	26.2
	PCV2	22.4	2.42	171.0	20.1	10.4	2806	29.8
	PCV3	23.6	2.45	183.1	19.4	10.3	2842	30.0
	PCV4	24.8	2.54	200.0	18.9	10.7	2886	31.9
	PCV5	25.6	2.60	210.5	17.8	11.3	2873	33.3
	RNDV	23.3	2.54	186.7	19.6	10.4	2906	31.2
	BRDV	23.8	2.54	191.0	18.7	10.8	2799	30.8
	ORIG	23.2	2.47	180.5	18.9	10.8	2628	29.2
	SE	0.66	0.07	7.7	0.8	0.5	184	2.0
EC 91	PCV1	22.6	2.24	160.0	19.9	9.5	2514	24.4
	PCV2	23.8	2.30	173.1	19.2	9.6	2673	26.0
	PCV3	25.9	2.34	191.4	18.6	10.3	2845	29.9
	PCV4	26.5	2.36	197.5	18.7	10.2	2782	29.2
	PCV5	27.8	2.33	205.0	19.1	9.9	2950	30.0
	RNDV	25.6	2.39	193.6	19.4	9.9	2953	30.0
	BRDV	26.7	2.28	192.9	19.5	9.8	2838	28.4
	ORIG	25.9	2.32	190.4	19.1	9.9	2877	29.1
	SE	0.69	0.07	7.8	0.9	0.4	182	1.8
HHVBC	PCV1	25.0	2.72	215.2	16.5	9.8	2636	26.6
	PCV2	25.2	2.65	211.3	16.7	10.1	2600	27.2
	PCV3	26.5	2.76	230.2	16.0	10.4	2674	28.8
	PCV4	28.1	2.85	252.7	16.0	10.8	2745	30.4
	PCV5	29.6	2.83	264.2	15.4	11.2	2837	32.3
	RNDV	26.1	2.78	229.0	16.5	10.4	2741	29.1
	BRDV	27.6	2.89	251.4	16.4	10.1	2877	29.9
	ORIG	26.2	2.87	237.3	16.3	10.7	2620	28.9
	SE	0.76	0.10	12.23	0.73	0.47	190	2.02

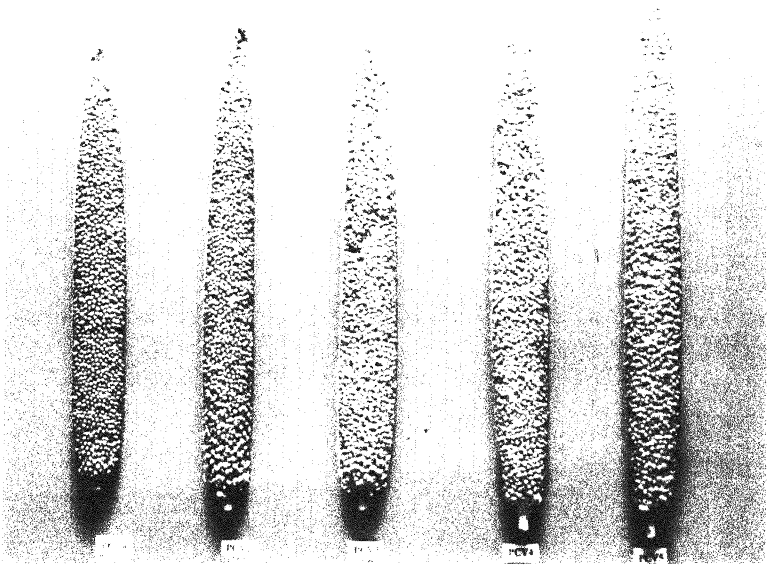

Fig 5. Panicles of five experimental varieties of EC 87 selected on the basis of panicle surface area.

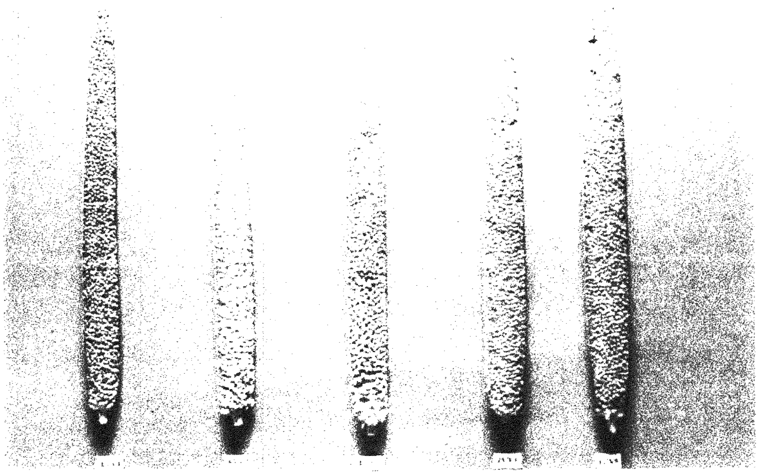

Fig 6. Panicles of five experimental varieties of EC 91 selected on the basis of panicle surface area.

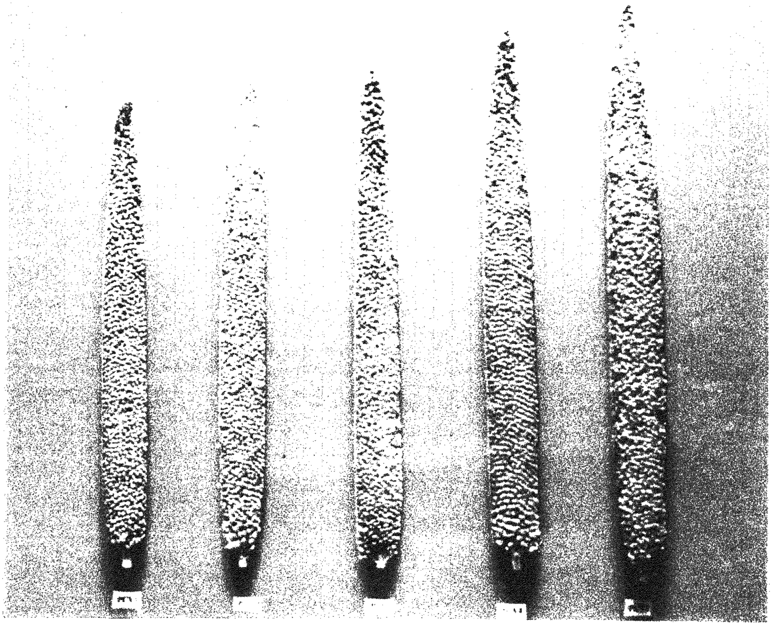

Fig 7. Panicles of five experimental varieties of HHVBC selected on the basis of panicle surface area.

Table 24. Phenotypic coefficient of variation (PCV) and genetic coefficient of variation (GCV) for seven panicle traits among eight experimental varieties in three pearl millet composites averaged over 11 environments.

Trait	Composite	PCV(%)	GCV(%)
Panicle length (cm)	EC 87	6.46	6.34
	EC 91	6.51	6.41
	HHVBC	5.77	5.66
Panicle diameter (cm)	EC 87	3.13	3.11
	EC 91	1.49	1.36
	HHVBC	3.34	2.53
Panicle surface area (cm^2)	EC 87	9.46	9.32
	EC 91	7.72	7.52
	HHVBC	7.89	7.69
Grain number per cm^2	EC 87	3.65	3.38
	EC 91	2.27	1.56
	HHVBC	2.61	2.13
1000 grain weight (g)	EC 87	2.96	2.47
	EC 91	2.68	2.26
	HHVBC	4.17	3.70
Grain number per panicle	EC 87	6.60	6.01
	EC 91	5.21	4.98
	HHVBC	3.77	3.13
Grain yield per panicle (g)	EC 87	6.93	6.46
	EC 91	7.31	7.01
	HHVBC	6.10	5.67

Heritability and Genetic advance

Estimates of heritab ility and genetic advance are given in Table 25. Heritability estimate ranged from 47% for grain number per cm^2 to 97% for panicle length and panicle surface area. High heritability estimates were also observed for grain yield per panicle in the experimental varieties of three composites. Relatively low estimates were found for grain number per cm^2 and 1000 grain weight in the three composites.

The expected genetic advance in per cent of mean, varied from 2.19% for grain number per cm^2 to 18.9% for panicle surface area. Relatively low values were shown by panicle diameter, grain number per cm^2 and 1000 grain weight in the three composites. Comparatively high expected genetic advance were observed for panicle length, panicle surface area and grain yield per panicle in the three composite varieties.

Correlations

The genetic correlations between panicle surface area and other panicle traits are presented in Table 26. Panicle surface area was positively correlated with grain number per panicle, 1000 grain weight (grain size) and grain yield per panicle in the three composites (Figs. 8,9 and 10) whereas, panicle surface area showed significant and negative association with grain number per cm^2 in the three composites.

Grain yield per panicle had highly significant and positive association with grain number per panicle in the three composites (Table 27). Grain number per cm^2 showed highly significant and negative association with grain yield per panicle while, 1000 grain weight showed highly significant and positive association with grain yield per panicle in EC 91 and HHVBC.

Table 25. Heritability (H), genetic advance (GA), and genetic advance in per cent of mean (GA%) for seven panicle traits among eight experimental varieties in three pearl millet composites averaged over 11 environments.

Trait	Composite	H(%)	GA	GA(%)
Panicle length (cm)	EC 87	97	3.02	12.9
	EC 91	97	3.34	13.0
	HHVBC	96	3.07	11.4
Panicle diameter (cm)	EC 87	94	0.15	6.00
	EC 91	68	0.06	2.58
	HHVBC	82	0.04	4.90
Panicle surface area (cm^2)	EC 87	97	34.9	18.9
	EC 91	95	28.4	15.1
	HHVBC	95	36.5	15.4
Grain number per cm^2	EC 87	85	1.24	6.47
	EC 91	47	0.42	2.19
	HHVBC	65	0.58	3.57
1000 grain weight (g)	EC 87	69	0.46	4.30
	EC 91	73	0.41	4.15
	HHVBC	77	0.70	6.69
Grain number per panicle	EC 87	83	389	10.5
	EC 91	89	270	9.66
	HHVBC	69	146	5.38
Grain yield per panicle (g)	EC 87	87	3.76	12.4
	EC 91	92	3.94	13.8
	HHVBC	86	3.15	10.8

Table 26. Genetic correlation coefficients between panicle surface area and other panicle traits in eight experimental varieties of EC 87, EC91 and HHVBC pearl millet composites averaged over 11 environments.

Panicle surface area with	EC 87	EC 91	HHVBC
Panicle length	0.99	0.98	0.97
Panicle diameter	0.98	0.74	0.85
Grain number per cm^2	-0.81	-0.88	-0.88
1000 grain weight	0.54	0.79	0.83
Grain number per panicle	0.82	0.97	0.95
Grain yield per panicle	0.99	0.97	1.00

Coefficients with an absolute value 0.70 or 0.83 are significant at P = 0.05 and 0.01, respectively.

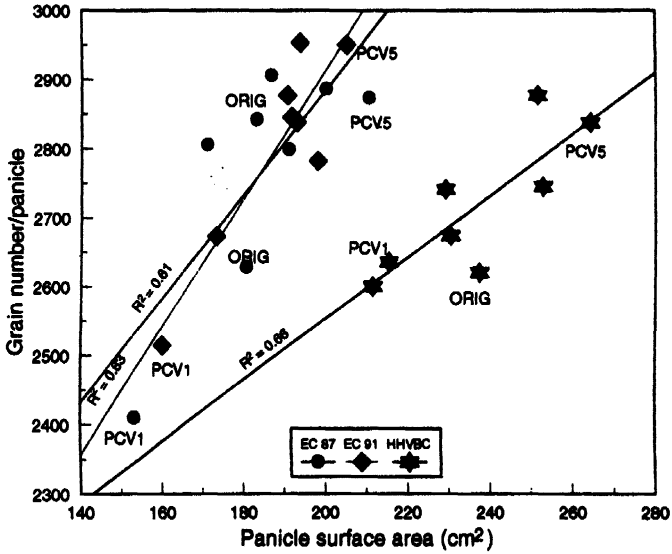

Fig. 8. Relationship between panicle surface area and grain number/panicle.

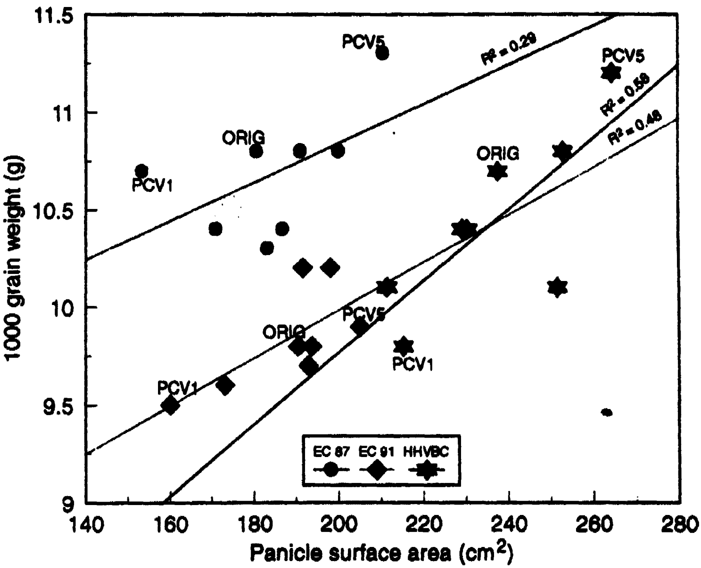

Fig. 9. Relationship between panicle surface area and 1000 grain weight.

Table 27. Genetic correlation coefficients among panicle length (PNLN), panicle diameter (PNDA), grain number per cm² (GNCM^{-2}), 1000 grain weight (TGWT), grain number per panicle (GNPN^{-1}) and grain yield per panicle (GYPN^{-1}) in eight experimental varieties of three pearl millet composites averaged over 11 environments.

Traits	Composite	PNDA	GNCM^{-2}	TGWT	GNPN^{-1}	GYPN^{-1}
PNLN	EC 87	0.96	-0.78	0.51	0.83	0.99
	EC 91	0.60	-0.76	0.71	0.91	0.90
	HHVBC	0.71	-0.98	0.87	0.95	1.00
PNDA	EC 87		-0.80	0.52	0.80	0.97
	EC 91		-0.97	0.76	0.86	0.90
	HHVBC		-0.52	0.59	0.75	0.75
GNCM^{-2}	EC 87			-1.00	-0.26	-0.67
	EC 91			-1.00	-0.83	-0.98
	HHVBC			-1.00	-0.72	-1.00
TGWT	EC 87				-0.08	0.34
	EC 91				0.74	0.87
	HHVBC				0.58	0.93
GNPN^{-1}	EC 87					0.91
	EC 91					0.97
	HHVBC					0.83

Coefficients with an absolute value 0.70 or 0.83 are significant at P = 0.05 and 0.01, respectively.

RESULTS - PLOT DATA

The 24 experimental varieties of three composites viz., EC 87, EC 91 and HHVBC were evaluated in Completely Randomized Block Design (CRBD) with four replications in 11 environments at Hisar, Rohtak and ICRISAT-Patancheru during rainy season of 1996 and the summer and rainy seasons of 1997. The traits studied were panicle number per m^2, grain number per m^2, 1000 grain weight (grain size), grain number per panicle, grain yield per panicle, grain yield per m^2, days to 50% flowering, plant height and fodder yield per m^2. The results obtained are described below:

Analysis of variance

Mean squares among 24 experimental varieties revealed significant differences for panicle number per m^2, grain yield per m^2 and days to 50% flowering at all locations, grain yield per panicle and plant height at four locations, 1000 grain weight and fodder yield per m^2 at three locations and grain number per m^2 and grain number per panicle at two locations during rainy season of 1996 (Table 28). Genotype effects were influenced by differences in populations for panicle number per m^2, grain yield per m^2, days to 50% flowering and plant height at all locations, fodder yield per m^2 at four locations, grain number per m^2, 1000 grain weight and grain yield per panicle at three locations. Effect of selections were constantly significant for panicle number per m^2 and grain yield per m^2. Population x selection effects were generally not significant for any of the traits.

Mean squares among 24 experimental varieties revealed significant differences for days to 50% flowering at all locations, panicle number per m^2, grain yield per m^2 and plant height at five locations, grain number per m^2, 1000 grain weight, grain number per panicle and grain yield per

Table 28. Mean squares obtained from the analysis of variance in trials conducted at five locations during rainy season 1996 for panicle number per m^2 (PNNM^{-2}), grain number per m^2 (GNM^{-2}), 1000 grain weight (TGWT), grain number per panicle (GNPN^{-1}), grain yield per panicle (GYPN^{-1}), grain yield per m^2 (GYM^{-2}), days to 50% flowering (DAFL), plant height (PLHT) and fodder yield per m^2 (FYM^{-2}) in 24 experimental varieties of pearl millet. The effect of genotype (23 d.f.) has been subdivided in the effects of population (2 d.f.), selection (7 d.f.) and population x selection (14 d.f.).

Source	d.f.	Location	PNNM^{-2} (no)	GNM^{-2} (x10^7)	TGWT (g)	GNPN^{-1} (x10^5)	GYPN^{-1} (g)	GYM^{-2} (x10^{3}g)	DAFL (days)	PLHT (x10^{2}cm)	FYM^{-2} (x10^{3}g)
Replication	3	HSR	2.58	42.70	8.40	7.91	5.72	3.50	0.69	9.43	1.15
	3	RTK	24.89	38.25	4.11	3.35	0.36	15.20	0.59	1.93	37.64
	3	ILF	29.96	1.98	1.75	8.74	44.51	3.85	10.95	5.83	45.47
	3	IHF	20.53	1.49	0.71	2.65	22.06	2.06	32.17	5.29	24.14
	3	IEDL	1.41	5.80	1.33	5.14	54.68	4.70	2.20	7.46	4.59
Genotype	23	HSR	2.80*	10.83**	1.87	2.76**	4.93**	1.55**	25.60**	21.39**	6.30
	23	RTK	4.67**	2.50	1.41**	1.36**	3.60*	1.96*	57.77**	61.32**	31.71**
	23	ILF	8.93**	3.09	1.75**	1.67	17.70**	1.62**	16.29**	43.07**	9.62**
	23	IHF	11.17**	2.70**	1.35	2.20	22.95**	2.51**	20.09**	47.98**	6.26*
	23	IEDL	8.29**	6.91	2.62*	4.96	36.71	6.47**	26.23**	105.33	8.99
Population	2	HSR	9.14**	3.63	1.55	3.66	16.06**	1.52**	260.54**	225.88**	27.49*
	2	RTK	7.97**	4.37	0.86	1.13	0.91	5.80**	618.26**	699.63**	15.01
	2	ILF	52.23**	18.81**	10.33**	0.01	44.26**	4.97**	122.69**	472.99**	20.29*
	2	IHF	59.63**	6.50**	3.89*	2.71	17.02	5.92**	140.29**	524.89**	16.22*
	2	IEDL	24.35**	19.03*	8.00**	0.37	67.22*	4.02**	254.13**	1116.22**	14.32*

continued...

Table 28. continued...

Selection	7	HSR	2.17*	15.75**	1.96	4.14**	8.16**	3.38**	4.16*	3.34*	6.25
	7	RTK	4.37**	1.45	2.16**	1.97**	3.28	1.84*	3.43	0.69	14.50
	7	ILF	6.87**	1.19	1.51*	3.29*	36.98**	0.93*	9.27*	3.33	6.94
	7	IHF	11.62*	3.19**	1.61	3.36	46.10*	4.54**	12.44**	2.26	9.95*
	7	IEDL	7.64**	2.83	1.67	5.40	51.92	2.22	7.18**	1.65	12.04*
Population x Selection	14	HSR	2.21	9.39	1.87	1.95	1.73	0.66	2.75	1.21	3.30
	14	RTK	4.36**	2.76	1.11**	1.09	4.15	1.48	4.86**	0.45	42.71**
	14	ILF	3.79	1.79**	0.63	1.09	7.61	1.49**	4.60	1.53	9.43*
	14	IHF	4.03	1.91	0.86	1.55	12.22	1.01*	6.76	2.71	2.99
	14	IEDL	6.32**	7.22	2.32	5.40	24.72	3.77	45.57**	5.62	6.72
Error	69	HSR	1.54	4.04	1.12	1.17	1.91	0.44	1.75	1.39	7.26
	69	RTK	1.46	1.70	0.41	0.60	1.95	8.69	1.65	0.57	12.30
	69	ILF	2.26	0.56	0.68	1.15	6.08	4.18	3.46	2.08	4.49
	69	IHF	3.67	1.08	1.03	1.88	10.34	4.45	3.64	1.45	3.53
	69	IEDL	2.52	4.34	1.28	3.58	17.84	2.62	1.56	6.24	4.18

*,**: Significant at P = 0.05 and 0.01, respectively.

HSR: Hisar; RTK: Rohtak; ILF, IHF, IEDL: ICRISAT low fertility, high fertility and extended day length, respectively.

Table 29. Mean squares obtained from the analysis of variance in trials conducted at six locations during summer and rainy season 1997 for panicle number per m^2 (PNNM^{-2}), grain number per m^2 (GNM^{-2}), 1000 grain weight (TGWT), grain number per panicle (GNPN^{-1}) grain yield per panicle (GYPN^{-1}), grain yield per m^2 (GYM^{-2}), days to 50% flowering (DAFL), plant height (PLHT)and fodder yield per m^2 (FYM^{-2}) in 24 experimental varieties of pearl millet. The effect of genotype (23 d.f.) has been subdivided in the effects of population (2 d.f.), selection (7 d.f.) and population x selection (14 d.f.).

Source	d.f.	Location	PNNM^{-2} (no)	GNM^{-2} (x10^7)	TGWT (g)	GNPN^{-1} (x10^5)	GYPN^{-1} (g)	GYM^{-2} (x10^{3}g)	DAFL (days)	PLHT (x10^{2}cm)	FYM^{-2} (x10^{3}g)
Replication	3	ISU	0.72	4.32	0.12	3.82	37.94	44.37	1.17	2.59	15.47
	3	HSR	5.04	3.74	0.20	0.46	2.38	21.43	3.34	0.68	13.15
	3	RTK	0.41	3.50	8.99	1.37	4.26	18.33	14.92	3.04	9.67
	3	ILF	21.55	1.43	1.36	2.02	18.48	47.40	5.45	0.80	13.62
	3	IHF	8.24	6.14	2.39	1.01	29.19	33.87	2.34	6.71	6.09
	3	IEDL	26.08	7.89	2.72	1.22	25.24	34.44	4.47	10.05	20.65
Genotype	23	ISU	27.68**	4.08**	1.85**	1.81**	24.76**	21.20	14.34**	38.55**	17.54**
	23	HSR	2.13	1.24	1.33**	0.80	2.63	7.00**	39.11**	20.91**	9.65**
	23	RTK	3.28**	6.39**	13.14	0.34**	4.02	35.73**	41.70**	32.77**	17.46*
	23	ILF	11.21**	2.61**	2.36*	2.81**	43.94**	18.64*	24.01**	34.35	2.50
	23	IHF	15.53**	3.05	1.19	1.44	24.14**	25.20*	24.20**	33.14**	3.10
	23	IEDL	15.99**	5.72*	1.59**	2.62**	24.68**	54.28**	33.25**	98.39**	8.16
Population	2	ISU	136.62**	17.16**	17.44**	3.44*	150.47**	34.36	122.69**	42.78**	85.64**
	2	HSR	3.22	7.87**	0.93*	1.82	6.59	31.91**	430.51**	230.05**	44.29**
	2	RTK	12.73**	1.51	2.40	6.94*	3.35	49.66**	427.53**	361.00**	16.36
	2	ILF	41.10**	3.64*	10.85**	3.99	139.40**	21.22	240.04**	378.66**	4.61
	2	IHF	50.46**	4.29	1.69	3.05	68.30**	24.73	242.88**	370.60**	5.29
	2	IEDL	62.00**	32.20**	5.34	0.26	23.20	384.58**	341.26**	1115.01**	16.07

continued...

Table 29. continued...

Selection	7	ISU	29.61	5.93	0.35	1.45	10.42	40.80	5.80**	2.51**	12.51*
	7	HSR	2.90	1.05	3.73**	1.05	3.50	12.80**	2.39	1.70**	9.96**
	7	RTK	16.51**	12.40**	11.65	2.03	4.89	99.22**	1.92	1.86*	29.90**
	7	ILF	14.36**	2.39*	2.35**	5.93**	83.84**	30.92**	4.70**	2.90	1.21
	7	IHF	12.47*	0.89	1.91	1.57	38.36*	12.71	3.96**	1.21	3.17
	7	IEDL	23.46**	5.05	0.87	6.35**	56.49**	40.34	6.35**	2.91**	10.66
Population x Selection	14	ISU	11.15	1.28	0.36	1.76	13.98	9.47	3.13**	1.68**	10.33*
	14	HSR	1.58	0.39	0.19	0.53	1.62	0.54	1.57	0.64	4.55
	14	RTK	1.24	4.08	15.42	3.58**	3.68	2.00	6.47**	1.34*	11.40
	14	ILF	5.36	2.58*	1.14	1.08	10.27	12.13	2.80**	0.89	2.84
	14	IHF	12.08	3.96	0.76	1.14	10.72	31.52	3.08**	0.89	2.75
	14	IEDL	5.69	2.28	1.41	1.10	8.98	14.06	2.70	0.91	5.78
Error	69	ISU	4.38	1.50	0.45	0.84	8.13	13.34	1.19	0.62	4.96
	69	HSR	6.15	0.93	0.28	0.72	2.65	3.08	2.01	0.50	3.24
	69	RTK	2.09	2.94	9.18	1.45	3.64	7.84	1.78	0.71	9.70
	69	ILF	3.88	1.11	1.15	0.94	10.60	10.23	0.46	1.60	2.05
	69	IHF	3.22	1.86	0.90	0.91	10.74	13.83	1.09	0.78	3.38
	69	IEDL	2.97	3.01	0.64	1.07	8.39	22.07	1.72	0.92	5.41

*,**: Significant at $P = 0.05$ and 0.01, respectively.

HSR: Hisar; RTK: Rohtak; ISU, ILF, IHF, IEDL: ICRISAT summer, low fertility, high fertility and extended day length, respectively.

panicle at four locations and fodder yield per m^2 at three locations during summer and rainy seasons of 1997 (Table 29). Genotype effects were influenced by differences in populations for panicle number per m^2, days to 50% flowering and plant height. Effect of selections were significant for panicle number per m^2, grain yield per panicle, grain yield per m^2 and days to 50% flowering. Population x selection effects were generally not significant for all traits except days to 50% flowering.

Pooled analysis of variance for 24 experimental varieties indicated highly significant mean squares due to genotype for all traits. All three source of variation in genotype effect (base population, selection and their interaction) were also significant for all the traits (Table 30). Interaction of genotype and environment were significant for all traits. Population x environment, selection x environment and population x selection x environment were also significant for all the traits except plant height.

Pooled analysis of variance for individual population indicated highly significant mean squares due to environment for all traits. Differences among experimental varieties in the three populations were also significant for all traits except panicle number per m^2 and grain number per m^2 in HHVBC and fodder yield per m^2 in EC 87 (Table 31). Genotype x environment was also significant for most of the traits.

Mean performance (composites)

A summary of mean, range, standard error and coefficient of variation for eight experimental in each composite have been given in Table 32.

Table 30. Mean squares obtained from the analysis of variance in 11 environments for panicle number per m^2 (PNNM^{-2}), grain number per m^2 (GNM^{-2}), 1000 grain weight (TGWT), grain number per panicle (GNPN^{-1}), grain yield per panicle (GYPN^{-1}), grain yield per m^2 (GYM^{-2}), days to 50% flowering (DAFL), plant height (PLHT) and fodder yield per m^2 (FYM^{-2}) in eight experimental varieties of three pearl millet composites.

Source	d.f.	PNNM^{-2} (no)	GNM^{-2} (x10^7)	TGWT (g)	GNPN^{-1} (x10^5)	GYPN^{-1} (g)	GYM^{-2} (x10^{3}g)	DAFL (days)	PLHT (x10^{2}cm)	FYM^{-2} (x10^{4}g)
Environment	10	550.84**	309.00**	140.22**	75.50**	1774.77**	307.22**	2392.50**	295.45**	207.02**
Replication in environment	33	13.00	10.80	2.21	3.38	21.05	4.44	7.12	4.89	1.74
Genotype	23	42.29**	12.90**	5.64**	6.73**	84.29**	11.00**	275.98**	487.43**	2.79**
Population	2	253.04**	78.00**	25.50**	2.05**	127.72**	66.46**	2987.65**	553.81**	11.50**
Selection	7	40.79**	9.39**	5.95**	13.0**	201.49**	14.85**	31.49**	9.60**	3.73**
Population x Selection	14	12.93**	5.31**	2.23**	4.27**	19.50**	1.16**	10.85**	4.82**	1.07**
Genotype x Environment	230	6.99**	3.64**	1.57**	2.09**	14.19**	1.99**	4.66**	4.98**	0.93**
Population x Environment	20	19.20**	4.46**	4.79**	2.59**	43.67**	5.48**	21.32**	42.96**	1.50**
Selection x Environment	70	8.56**	4.29**	1.46**	2.74**	16.85**	2.22**	3.01**	1.48	0.79**
Population x Selection x Environment	140	4.46**	3.20**	1.17**	1.70**	8.64**	1.38**	3.11**	1.30	0.92**
Pooled error	759	2.67	2.01	0.86	1.31	7.41	1.02	1.85	1.53	0.55

**: Significant at P = 0.01.

Table 31. Mean squares obtained from the analysis of variance in 11 environments for panicle number per m² (PNNM^{-2}), grain number per m² (GNM^{-2}), 1000 grain weight (TGWT), grain number per panicle (GNPN^{-1}), grain yield per panicle (GYPN^{-1}), grain yield per m² (GYM^{-2}), days to 50% flowering (DAFL), plant height (PLHT) and fodder yield per m² (FYM^{-2}) in eight experimental varieties of three pearl millet composites.

Source	d.f.	Composite	PNNM^{-2} (no)	GNM^{-2} (x10^7)	TGWT (g)	GNPN^{-1} (x10^5)	GYPN^{-1} (g)	GYM^{-2} (g)	DAFL (days)	PLHT (cm)	FYM^{-2} (g)
Environment	10	EC 87	144.95**	103.00**	52.82**	24.14**	570.18**	110.70**	623.16**	151.87**	617.37**
		EC 91	161.82**	98.20**	45.66**	28.44**	698.95**	103.18**	757.41**	195.31**	753.68**
		HHVBC	282.46**	117.10**	51.31**	28.16**	662.97**	104.29**	1054.58**	34.18**	729.30**
Replication in environment	33	EC 87	7.56	2.67	1.41	1.81	10.78	1.69	4.06	3.60	9.13
		EC91	5.88	7.08	1.11	2.56	11.31	2.15	5.78	3.28	11.46
		HHVBC	5.44	4.96	1.34	2.17	16.38	2.57	4.30	1.55	8.83
Genotype	7	EC 87	22.76**	7.51**	3.13**	9.09**	106.46**	8.30**	20.38**	7.30**	8.61
		EC 91	40.26**	9.45**	3.83**	9.10**	85.63**	4.31**	11.24**	4.24**	22.81**
		HHVBC	3.64	3.05	3.44**	3.33*	48.38**	4.56**	21.56**	7.71**	27.49**
Genotype x Environment	70	EC 87	6.38**	3.56**	1.38**	1.97**	11.26*	1.87**	2.49**	1.69	8.02*
		EC 91	7.49**	3.39**	0.82	1.67*	11.53**	1.84**	1.72	1.31	10.00**
		HHVBC	3.62	3.74	1.60*	2.48**	11.34**	1.26*	5.02**	1.08	8.36**
Pooled error	231	EC 87	2.95	1.94	0.79	1.08	7.48	0.91	1.58	1.75	5.67
		EC 91	3.01	1.88	0.70	1.22	6.74	1.18	1.25	1.34	5.65
		HHVBC	1.98	2.21	1.09	1.57	7.64	0.98	2.24	1.45	5.04

*,**: Significant at $P = 0.05$ and 0.01, respectively.

EC 87 has the greatest mean 1000 grain weight and grain yield per m^2 whereas, EC 91 has the maximum mean panicle number per m^2, grain number per m^2, plant height and fodder yield per m^2. Composite HHVBC has maximum grain number per panicle and grain yield per panicle. HHVBC was also found to be later flowering by five days than other composites and had shortest plant height.

The range in grain yield per m^2 among the eight experimental varieties was good in each composite. In EC 91 the variation for grain number per panicle, grain number per m^2 and grain yield per panicle was maximum. The range in developmental traits days to 50% flowering, plant height and fodder yield per m^2 were almost similar in EC 87 and EC 91.

Mean performance (experimental varieties)

Mean performance of 24 experimental varieties of three composites are presented in Table 33. In EC 87, PCV5 variety has maximum mean values for 1000 grain weight, grain yield per panicle and grain yield per m^2 while, BRDV has maximum grain number per panicle and days to 50% flowering. The response to selection from PCV1 (with minimum panicle surface area) to PCV5 (with maximum panicle surface area) was 18% for grain yield per m^2.

PCV5 showed maximum mean values for grain yield per panicle, grain yield per m^2, grain number per panicle, grain number per m^2 and plant height whereas, RNDV and BRDV has maximum panicle number per m^2, days to 50% flowering and fodder yield per m^2 . The response to selection from PCV1 to PCV5 was 10% for grain yield per m^2 in EC 91.

Table 32. Mean, range, standard error (SE) and coefficient of variation (CV) for nine plot traits for eight experimental varieties of three pearl millet composites averaged over 11 environments.

Trait	Composite	Mean	Range	SE(±)	CV(%)
Panicle number per m^2	EC 87	13.7	12.7-14.9	0.85	12.5
	EC 91	13.8	12.7-15.3	0.86	12.5
	HHVBC	12.3	11.9-12.7	0.70	11.4
Grain number per m^2	EC 87	28799	27237-30422	2210	15.3
	EC 91	29236	27533-31892	2173	14.9
	HHVBC	26467	25391-27894	2362	17.8
1000 grain weight (g)	EC 87	9.47	9.17-9.89	0.44	9.4
	EC 91	8.91	8.50-9.43	0.41	9.4
	HHVBC	9.30	8.96-9.80	0.52	11.3
Grain number per panicle	EC 87	2130	1881-2285	164	15.5
	EC 91	2148	1967-2442	175	16.3
	HHVBC	2178	2027-2292	198	18.2
Grain yield per panicle (g)	EC 87	20.0	17.1-21.7	1.36	13.6
	EC 91	19.1	16.7-21.3	1.29	13.6
	HHVBC	20.2	18.8-21.8	1.38	13.7
Grain yield per m^2 (g)	EC 87	269.1	247.0-292.1	15.1	11.2
	EC 91	257.7	242.4-275.0	17.2	13.4
	HHVBC	241.7	226.9-259.4	15.7	13.0
Days to 50% flowering	EC 87	46.6	43.3-47.3	0.62	2.7
	EC 91	46.8	46.2-47.6	0.55	2.4
	HHVBC	51.8	51.3-53.5	0.74	2.9
Plant height (cm)	EC 87	210.1	203.6-217.0	6.61	6.3
	EC 91	215.2	211.8-219.8	5.79	5.4
	HHVBC	144.1	139.0-152.5	6.02	8.4
Fodder yield per m^2 (g)	EC 87	465.7	442.3-487.6	37.6	16.2
	EC 91	466.4	429.3-495.6	37.5	16.1
	HHVBC	434.8	405.6-488.8	35.5	16.3

Table 33. Mean performance 0f 24 experimental varieties of three pearl millet composites for nine plot traits averaged over 11 environments.

	Experimental variety	$PNNM^{-2}$ (no)	GNM^{-2} (no)	TGWT (g)	$GNPN^{-1}$ (no)	$GYPN^{-1}$ (g)	GYM^{-2} (g)	DAFL (days)	PLHT (cm)	FYM^{-2} (g)
EC 87	PCV1	14.9	27237	9.17	1881	17.1	247.0	43.3	203.6	442.3
	PCV2	14.2	29071	9.24	2074	19.2	266.7	46.1	206.9	450.5
	PCV3	13.9	30422	9.16	2206	20.3	277.6	47.1	209.4	487.6
	PCV4	13.2	29913	9.47	2267	21.5	279.2	47.0	213.7	474.1
	PCV5	13.8	30156	9.89	2218	21.7	292.1	47.2	217.0	470.5
	RNDV	13.0	27290	9.58	2130	20.4	259.8	46.8	210.6	465.2
	BRDV	12.7	28695	9.47	2285	21.3	263.6	47.3	210.8	466.4
	ORIG	14.1	27606	9.75	1977	19.2	266.5	46.3	208.8	469.4
	SE	0.8	2210	0.44	164	1.3	15.1	0.6	6.6	37.6
EC 91	PCV1	15.2	29700	8.50	1967	16.7	251.2	46.4	211.1	429.3
	PCV2	15.3	30608	8.62	2040	17.6	263.1	46.2	211.6	479.3
	PCV3	13.6	29010	9.13	2172	19.7	262.3	46.9	216.0	467.9
	PCV4	13.6	27533	9.43	2061	19.5	259.3	46.5	213.9	443.6
	PCV5	13.2	31892	8.77	2442	21.3	275.0	47.4	219.8	491.0
	RNDV	12.7	28100	8.88	2222	19.7	242.4	47.6	219.0	456.1
	BRDV	13.9	29077	8.93	2127	19.1	258.3	47.1	215.5	495.6
	ORIG	13.2	27968	9.04	2150	19.5	250.2	46.7	214.8	468.2
	SE	0.9	2173	0.41	175	1.3	17.2	0.5	5.8	37.5
HHVBC	PCV1	12.5	25743	9.00	2105	18.8	226.9	51.8	143.5	405.6
	PCV2	12.7	25391	9.21	2027	19.0	235.4	51.4	139.0	418.6
	PCV3	12.4	26662	9.33	2169	20.3	243.8	51.5	146.1	447.1
	PCV4	12.6	27894	9.29	2226	20.5	250.8	51.4	141.6	436.6
	PCV5	12.3	26870	9.80	2223	21.8	259.4	51.5	140.6	428.3
	RNDV	12.3	25885	9.22	2130	19.5	233.9	51.7	145.6	425.5
	BRDV	11.9	27159	8.96	2292	20.6	239.8	53.5	152.5	488.8
	ORIG	11.9	26129	9.59	2251	21.3	243.5	51.5	143.8	427.5
	SE	0.7	2362	0.52	198	1.4	15.7	0.7	6.0	35.5

The experimental variety PCV5 has the greatest mean grain number per m^2, 1000 grain weight, grain yield per panicle and grain yield per m^2 while. BRDV showed maximum grain number per panicle, days to 50% flowering, plant height and fodder yield per m^2 in HHVBC. The response to selection from PCV1 to PCV5 was 14% for grain yield per m^2.

Genetic variation

The phenotypic coefficient of variation (PCV) and genetic coefficient of variation (GCV) are given in Table 34.

Estimates of phenotypic coefficient of variation and genetic coefficient of variation indicated that the PCV was generally higher than GCV for most of the traits. The lowest values (PCV and GCV) were shown by the developmental traits, days to 50% flowering and plant height in the three composites and the highest values were shown by grain yield per panicle in EC 87 followed by the same trait in EC 91, panicle number per m^2 and grain number per panicle in EC 91.

Heritability and Genetic advance

The estimates of heritability and genetic advance (%) for nine traits in three pearl millet composites are presented in Table 35.

The heritability estimate ranged from 7% for fodder yield per m^2 (EC 87) to 89% for grain yield per panicle in the same composite. High heritability estimates were also observed for days to 50% flowering and plant height in the varieties of three composites, panicle number per m^2 and grain number per panicle in EC 87 and EC 91. Very low estimate of heritability was shown by grain number per panicle in HHVBC.

Table 34. Phenotypic coefficient of variation (PCV) and genetic coefficient of variation (GCV) for nine plot traits among eight experimental varieties in three pearl millet composites averaged over 11 environments.

Trait	Composite	PCV(%)	GCV(%)
Panicle number per m^2	EC 87	5.25	4.43
	EC 91	6.68	6.21
	HHVBC	2.29	-
Grain number per m^2	EC 87	4.53	3.29
	EC 91	5.01	4.01
	HHVBC	3.20	-
1000 grain weight (g)	EC 87	2.79	2.11
	EC 91	3.36	2.97
	HHVBC	3.04	2.15
Grain number per panicle	EC 87	6.75	5.97
	EC 91	6.69	6.05
	HHVBC	4.00	2.01
Grain yield per panicle (g)	EC 87	7.74	7.31
	EC 91	7.30	6.77
	HHVBC	5.15	4.53
Grain yield per m^2 (g)	EC 87	5.10	4.49
	EC 91	3.84	2.91
	HHVBC	4.21	3.58
Days to 50% flowering	EC 87	1.45	1.37
	EC 91	1.07	1.00
	HHVBC	1.35	1.17
Plant height (cm)	EC 87	1.93	1.70
	EC 91	1.44	1.20
	HHVBC	2.90	2.69
Fodder yield per m^2 (g)	EC 87	3.00	0.78
	EC 91	4.80	3.66
	HHVBC	5.75	4.79

Table 35. Heritability (H), genetic advance (GA) and genetic advance in per cent of mean (GA%)for nine plot traits a mong eight experimental varieties in three pearl millet composites averaged over 11 environments.

Trait	Composite	H(%)	GA	GA(%)
Panicle number per m^2	EC 87	71	1.06	7.71
	EC 91	81	1.60	11.54
	HHVBC	-	-	-
Grain number per m^2	EC 87	52	1415	4.91
	EC 91	64	1993	6.82
	HHVBC	-	-	-
1000 grain weight (g)	EC 87	56	0.31	3.24
	EC 91	78	0.48	5.39
	HHVBC	50	0.29	3.12
Grain number per panicle	EC 87	78	232	10.9
	EC 91	82	242	11.3
	HHVBC	25	45	2.1
Grain yield per panicle (g)	EC 87	89	2.86	14.3
	EC 91	86	2.48	13.0
	HHVBC	77	1.65	8.2
Grain yield per m^2 (g)	EC 87	77	21.9	8.15
	EC 91	57	11.6	4.53
	HHVBC	72	15.1	6.27
Days to 50% flowering	EC 87	88	1.23	2.64
	EC 91	88	0.91	1.94
	HHVBC	75	1.09	2.10
Plant height (cm)	EC 87	77	6.44	3.07
	EC 91	69	4.41	2.05
	HHVBC	86	7.41	5.13
Fodder yield per m^2 (g)	EC 87	7	2.0	0.42
	EC 91	56	26.3	5.65
	HHVBC	69	35.8	8.24

Table 36.Genetic correlation coefficients between panicle surface area and other plot traits in eight experimental varieties of EC 87, EC 91 and HHVBC of pearl millet composites in 11 envirovments.

Panicle surface area with	EC 87	EC 91	HHVBC
Panicle number per m^2	-0.74	-0.90	-0.70
Grain number per m^2	0.89	-0.13	1.00
1000 grain weight	0.69	0.74	0.59
Grain number per panicle	0.88	0.83	1.00
Grain yield per m^2	0.89	0.38	0.93
Days to 50% flowering	0.93	0.71	0.29
Plant height	1.00	0.99	0.20
Fodder yield per m^2	1.00	0.51	0.50

Coefficients with an absolute value 0.70 or 0.83 are significant at P = 0.05 and 0.01, respectively.

Table 37. Genetic correlation coefficients among panicle number per m^2 ($PNNM^{-2}$), grain number per m^2(GNM^{-2}), 1000 grain weight (TGWT), grain number per panicle ($GNPN^{-1}$), grain yield per panicle ($GYPN^{-1}$), days to 50% flowering (DAFL), plant height (PLHT), fodder yield per m^2(FYM^{-2}) and grain yield per m^2(GYM^{-2}) in eight experimental varieties of three pearl millet composites averaged over 11 environment

Traits	Composite	GNM^{-2}	TGWT	$GNPN^{-1}$	$GYPN^{-1}$	DAFL	PLHT	FYM^{-2}	GYM^{-2}
$PNNM^{-2}$	EC 87	-0.27	-0.41	-0.85	-0.83	-0.89	-0.73	-0.95	-0.33
	EC 91	-0.35	-0.66	-0.74	-0.90	-0.85	-1.00	-0.28	0.07
	HHVBC	-1.00	-0.24	-1.00	-0.78	-0.87	-1.00	-0.70	-0.52
GNM^{-2}	EC 87		0.21	0.74	0.61	0.78	0.82	1.00	0.91
	EC 91		-0.71	0.38	0.01	0.10	0.15	0.52	0.73
	HHVBC		0.94	0.81	0.98	0.52	0.46	1.00	0.90
TGWT	EC 87			0.37	0.61	0.48	0.92	0.45	0.59
	EC 91			0.20	0.59	0.12	0.32	-0.10	-0.06
	HHVBC			0.74	0.94	-0.70	-0.68	-0.40	1.00
$GNPN^{-1}$	EC 87				0.96	1.00	0.94	1.00	0.72
	EC 91				0.59	0.91	1.00	0.69	0.51
	HHVBC				0.92	0.71	0.79	1.00	0.68
$GYPN^{-1}$	EC 87					1.00	1.00	1.00	0.80
	EC 91					0.81	1.00	0.54	0.38
	HHVBC					0.07	0.09	0.44	0.94
DAFL	EC 87						0.96	1.00	0.79
	EC 91						1.00	0.47	0.02
	HHVBC						0.99	0.96	-0.22
PLHT	EC 87							1.00	1.00
	EC 91							0.61	0.24
	HHVBC							0.20	-0.33
FYM^{-2}	EC 87								1.00
	EC 91								0.58
	HHVBC								0.19

Coefficients with an absolute value 0.70 or 0.83 are significant at $P = 0.05$ and 0.01, respectively.

Grain yield per panicle showed highly significant and positive association with grain number per panicle in EC 87 and HHVBC, 1000 grain weight and grain number per m^2 in HHVBC. Panicle number per m^2 showed significant and negative association with grain yield per panicle in the three composites.

DISCUSSION S_1 PROGENY

For bringing desired improvement in the crop plants, the first pre-requisite is the genetic variability with which a plant breeder has to work. Broad spectrum of variability in the initial breeding material ensures better chances of producing new desired forms of crop plant (Vavilov, 1951). With the available genetic variability, the crop breeder has to make profitable selection of new strains to be used as such or as parents in the hybridization programme.

Yield *per se* or any other trait of the plant is the result of various components. Each component in turn behaves genetically in its own way (Grafius, 1959). These complexities lead to breeders to obtain basic information on the inheritance pattern of each trait.

In the present study, 144 S_1 progenies of EC 87, EC 91 and HHVBC were evaluated in two years for nine traits viz., panicle length, panicle diameter, panicle surface area, panicle number per m^2, grain number per m^2, 1000 grain weight, grain number per panicle, grain yield per panicle and grain yield per m^2 to obtain information on genetic variability, heritability, expected genetic advance and genetic correlations for these traits. The results obtained are discussed here in the light of the available literature.

Significant variation was observed for all the traits in the three composites indicating that there was enough genetic variability present in the material under investigation, despite the deliberate selection on the basis of panicle surface area for choosing the S_1 progenies. The grain yield per panicle, grain number per panicle, panicle surface area, grain number per m^2 area and grain yield per m^2 possessed high PCV and GCV, offering ample scope for improvement through selection.

High GCV for grain yield per panicle and slight difference between PCV and GCV indicated a small influence of environment on the expression of this trait. Pokhriyal et al. (1967) also reported the same result for grain yield per panicle in pearl millet.

The estimates of GCV alone may not be adequate for selection and hence heritability estimates and genetic advance in per cent of mean should also be considered (Johnson et al., 1955). Knowledge of heritability and possible genetic gain have been of importance in breeding programmes. The estimates of heritability are very useful in predicting the reliance on selection procedure. Heritability estimates would indicate the heritable portion of phenotypic variance, whereas, the estimation of genetic advance would show the extent of genetic gain that would be achieved by selection.

Panicle surface area had high heritability which indicated that selection for this trait would be effective. Similar result was reported by Rattunde et al. (1989) for panicle surface area. Heritability estimate was also high for grain yield per panicle. This is in agreement with the results reported by Mahadevappa and Ponnaiya (1967). Grain number per panicle also showed high heritability. In contrary, moderate heritability was reported by Diz and Schank (1995) for this trait in pearl millet.

High heritability estimates have been reported by other researchers for 1000 grain weight (Burton, 1951 ; Kunjir and Patil, 1986; Pathak and Ahmad, 1988; Dass, 1989), grain number per m^2 (Gopinath, 1980; Kukadia and Patel, 1982, Vyas and Srikant, 1984; Aryana et al., 1996), panicle number (Gupta and Athwal, 1966; Lal and Singh, 1970; Singh et al., 1978; Kunjir and Patil, 1986), grain yield (Jindla, 1981; Mukherji et al.,1982; Navale et al., 1991 ; Bhamre and Harinarayana, 1992a; Saraswathi et al., 1995) , panicle length and diameter

(Pokhriyal et al., 1967; Sangha and Singh 1973; Nanda and Phul 1974; Reddy and Sharma 1982, and Ghorpade and Metta 1993) in pearl millet.

High heritability estimates for all traits in the present study, may be due to high genetic variability present in the base material and this would br true only for surface area. The fact that both test environments were similar and the expression of the traits were less influenced by the environmental effects.

In the present study, high genetic advance in per cent of mean was recorded for grain number per panicle followed by grain yield per panicle and panicle surface area. High heritability accompanied by high genetic advance for grain number per panicle, grain yield per panicle and panicle surface area suggested that these traits might be governed by additive gene action and improvement with respect to these traits could be brought about by phenotypic selection.

The inter-relationships between different traits also helps plant breeder to better plan the improvement improving of productive traits. Economic yield of a crop plant, as such, is not unitary trait but only a consequence of the combined contribution of its components. As the final yield being the function of various components and interactions among them, the breeding of component attributes should be the basic philosophy to improve yield.

From the correlation coefficients, it was observed that panicle surface area was positively correlated with all traits except panicle number. Mahadevappa and Ponnaiya (1967) also observed positive correlation between panicle surface area and grain yield per panicle. Singh and Ahluwalia (1970) and Bidinger et al. (1993) reported positive correlation between panicle surface area and 1000 grain weight in pearl millet.

Panicle surface area however, was negatively correlated to panicle number per m^2. This negative correlation offset a part of the positive effect of the grain size , in individual panicle productivity on grain yield. Due to this reason the genetic correlation between panicle surface area and grain yield per panicle was greater than the correlation between panicle surface area and grain yield per m^2. The correlation between panicle surface area and grain yield per m^2 is in agreement with the results reported by Mahadevappa and Ponnaiya (1967) and Bidinger et al. (1993). Results obtained here suggest that selection for large panicle surface area needs be combined with selection for higher tiller number to be effective in increasing yield.

The correlation coefficients among traits indicated that grain yield per m^2 exhibited significant positive correlations with most of the traits. The positive correlations of grain number per m^2, grain number per panicle and 1000 grain weight with grain yield per m^2 indicated that all of these traits contributed to grain yield in the set of S_1's

The results of positive association between 1000 grain weight and grain yield per m^2 is in agreement with Shankar et al. (1963), Gupta and Dhillon (1974), Sachdeva et al. (1982),

Singh and Govila (1989) and Diz and Schank (1995). Grain number per unit area was positively correlated with grain yield per m^2 in the study reported by Navale et al. (1995).

Mahadevappa and Ponnaiya (1967) and Diz et al. (1994) also observed positive association of grain yield per m^2 with grain number per panicle. Maximum contribution towards yield at genotypic level was by grain number per m^2 followed by grain number per panicle, panicle surface area and 1000 grain weight suggesting that selection pressure applied for increasing these traits will eventually increase yield.

DISCUSSION - PANICLE DATA

From the evaluation of S_1 progeny of three composites we concluded that i) there was sufficient genetic variability for panicle surface area ii) the heritability of panicle surface area was high and iii) panicle surface area was genetically correlated to panicle grain yield and its components.

In the present study, 24 experimental varieties of three composites were evaluated in 11 environments at three locations for seven main shoot panicle traits viz., panicle length, panicle diameter, panicle surface area, grain number per cm^2, 1000 grain weight (grain size), grain number per panicle and grain yield per panicle to obtain information regarding realized genetic gain on the basis of selection for panicle surface area, and the effect of variation in panicle surface area on grain number, grain size and grain yield per panicle in pearl millet.

Significant variation among genotypes was observed for all panicle traits. Effects due to base population, selection and population x selection interaction within the genotype source of variation were also significant. Population was the main source of variation for panicle diameter, panicle surface area, grain number per cm^2 and grain size among the experimental varieties , accounting for 53 to 90% of the variation in genotype sum of squares (SS) in the analysis of variance (Table 20). In contrast, the selection was the most important determinant of genotype differences in panicle length (50%SS), in grain number per panicle (66%SS) and in grain yield per panicle (73%SS). The effect of population x selection interaction was lesser in magnitude as compare to effects due to population and selection on all traits (3-27%).

The significant interaction of population x selection suggested that the selection for panicle surface area was not consistent across the populations and it has been changed from one population to another. The response to selection in PCV5 (with maximum panicle surface area) over PCV1 (with minimum panicle surface area) varied from 23-37% for panicle surface area, 8-19% for grain number per panicle, 4-14% for grain size and 21-26% for grain yield per panicle in the three composites..

Breeder selection was effective in improving grain yield per panicle and grain number per panicle over the original population by 2% and 5%, respectively across the populations while, it was ineffective in increasing grain size in any of the three populations. The selection for increased panicle surface area i.e. PCV5 was more effective over breeder selection for panicle surface area, grain size and grain yield per panicle in all the three populations. For grain number per panicle PCV5 was effective in EC 87 and EC 91 whereas,breeder selection was effective in HHVBC only. There was not so much difference in random check and original population for all traits in the three populations.

Comparison of experimental variety PCV5 (with maximum panicle surface area) with original population indicated that the experimental variety PCV5 has the maximum mean values for panicle length and panicle surface area in all the three populations and for panicle diameter in EC 87 only. The actual gain in PCV5 over the original was 17, 8 and 11% for panicle surface area and 11, 7, and 13% for panicle length in EC 87, EC91 and HHVBC, respectively whereas, the gain in panicle diameter was 4 % in EC 87 only. This indicated that the variation in panicle surface area was only due to variation in panicle length in EC 91 and HHVBC while, the variation in panicle surface area in EC 87 was due to both panicle length and diameter but former being the major component. The differences among composites were due to large variation in length and diameter of panicle, both of which components were genetically correlated with panicle surface area.

The actual gain (PCV5 over original population) in panicle grain yield and its components and estimated gain from indirect selection for panicle surface area in S_1 progeny for the same traits are given in Table 38.

Table 38. Estimated and actual gains in grain yield per panicle and its components.

Trait	Composite	Estimated gain (%)	Actual gain (%)
Grain yield per panicle	EC 87	33.6	14.0
	EC 91	24.7	3.1
	HHVBC	49.0	11.8
Grain number per panicle	EC 87	21.4	9.3
	EC 91	16.9	2.5
	HHVBC	14.6	8.3
1000 grain wt. (Grain size)	EC 87	10.8	4.6
	EC 91	18.1	1.0
	HHVBC	4.4	4.7

This table shows that the actual gain in grain yield per panicle and its components was less in EC 91 as compared to EC 87 and HHVBC. These two gains were different because estimated gain depends upon heritability, phenotypic variation and selection intensity. Here, the actual gain depends upon selection of panicle surface area which in turn depends upon its two components i.e. panicle length and diameter. In EC 91 actual gain was less because the gain in PCV5 over the original population for panicle length was lesser as compared to EC 87 and HHVBC, and also there was no gain in panicle diameter in this composite. The actual gain is still good of considerable magnitude for grain yield per panicle in EC 91. Because panicle length is easy to measure in a number of progeny rows and it does not require much resources.

Grain yield in crop plants is the ultimate complex expression of interactions between a number of contributory traits as are governed by gene action and are also subject to effects of environment and genotype x environment interaction. The knowledge of the degree of association of yield with different yield components and inter-relationship between them is of great importance for making effective selections. Genetic correlations are useful as they give real associations after excluding the environmental effects.

In general, genetic correlations were higher than phenotypic correlations and this points to the efficiency of genotypic estimates. Such findings were also reported by Weber and Moorthy (1952), Johnson et al. (1955b), Anand and Torrie (1963), Tyagi (1965) and Badwal (1965).

Panicle surface area was positively correlated with grain number per panicle, grain size and grain yield per panicle among experimental varieties in the three populations (Figs.8,9 and 10). For example, an increase of 29% in panicle surface area resulted in a corresponding increase of 15% in grain number per panicle, 8% in grain size and 23% in grain yield per panicle across three populations. Positive correlation of panicle surface area and grain size has been reported earlier (Singh and Ahluwalia, 1970; Bidinger et al., 1993). The positive correlation between panicle surface area and grain yield per panicle is in agreement with the results reported by Mahadevappa and Ponnaiya (1967).

Greater panicle surface area often associated with a looser arrangement of spikelets at the surface of the panicle which may allow more space for grain growth. Grain growth in pearl millet major affected by the space available for grain expansion, as an increase in grain number per unit panicle surface area has been reported to be associated wit decrease in grain size (Alagarswamy and Bidinger, 1985). In the present study higher panicle surface area increased grain number per panicle without decreasing grain size, because it did not increase the packing of grains on the panicle surface. Genetically, both grain number per panicle and grain size were positively correlated to grain yield per panicle. The positive association of grain number per panicle and grain size with grain yield per panicle has been reported previously (Diz et al., 1994; Diz and Schank, 1995). Hence, selection for increased panicle surface area was effective in increasing grain yield per panicle as it simultaneously increased grain number per panicle and grain size.

DISCUSSION - PLOT DATA

From the evaluation of S_1 progeny of three composites we concluded that i) there was sufficient genetic variability for plot traits ii) the heritability of plot traits was high and iii) panicle surface area was genetically correlated to grain yield per m^2 and its components.

In the present study, 24 experimental varieties of three composites were evaluated in 11 environments at three locations for nine plot traits viz., panicle number per m^2, grain number per m^2, 1000 grain weight (grain size), grain number per panicle, grain yield per panicle, grain yield per m^2, days to 50% flowering, plant height and fodder yield per m^2 to obtain information regarding realized genetic gain in grain yield per m^2 on the basis of selection for panicle surface area, and the effect of variation in panicle surface area on grain number per m^2, grain size and grain yield per m^2 in pearl millet.

Significant variation among genotypes was observed for all plot traits. Effects due to base population, selection and population x selection interaction within the genotype source of variation were also significant for all the traits. Population was the main source of variation for days to 50% flowering, plant height, panicle number per m^2, grain number per m^2, grain yield per m^2 and 1000 grain weight among the experimental varieties, accounting for 44% to 99% of the variation in genotype sum of squares (SS) in the analysis of variance (Table 30). In contrast, selection was the most important determinant of genotype differences in fodder yield per m^2 (41% SS), in grain number per panicle (59% SS) and in grain yield per panicle (73% SS). The effect of population x selection interaction was lesser in magnitude as compare to effects due to population and selection on most of the traits (1%-39%).The significant interaction of population x selection suggested that the effects of selection for panicle surface area were not consistent across the populations.

The response to selection in PCV5 (with maximum panicle surface area) over PCV1 (with minimum panicle surface area) ranged from 4% to11% for grain number per per m^2, 3% to 9% for grain size and 10% to 18% for grain yield per m^2 in the three composites. Breeder selection was effective in improving grain yield per m^2 over the original population by 3% in EC 91 while, it was ineffective in EC 87 and HHVBC for the same trait. Breeder selection was also effective in improving grain number per m^2 by an average of 4% across the populations. There was no change in grain size due to breeder selection in any of the three populations. The selection for increased panicle surface area i.e. PCV5 was more effective than breeder selection for grain yield per m^2 in all three populations and for grain number per m^2 in EC 87 and EC 91. Breeder selection was more effective than PCV5 for grain number per m^2 in HHVBC. There was not so much difference in random check and original population for most of the traits in the three populations. Hence, there was no effect of making the S_1,s *per se* or a random-mated random sample did not differ from the original population.

The actual gain in PCV5 over original population in grain yield per m^2 and its components and estimated gain from indirect selection for panicle surface area in S_1 progeny for the same traits are given in Table 39.

It is clear from the table that actual gain on the basis of panicle surface area was more effective (3 times) in increasing grain number per m^2 than predicted gain, but much less effective (4 times) in increasing grain size than predicted gain. The net effect increase in grain yield per m^2 was almost similar to the prediction (+8.7% vs prediction of 10%).

Table 39. Estimated and actual gains in grain yield per m^2 and its components.

Trait	Composite	Estimated gain (%)	Actual gain (%)
Grain number per m^2	EC 87	2.8	9.2
	EC 91	4.5	14.0
	HHVBC	1.3	2.8
1000 grain wt (Grain size)	EC 87	10.8	1.4
	EC 91	18.1	4.1
	HHVBC	4.4	2.1
Grain yield per m^2	EC 87	12.5	9.6
	EC 91	12.2	9.9
	HHVBC	5.3	6.5

Panicle surface area was highly genetically correlated to grain yield per m^2 in EC 87 and EC 91 (S_1 data). That was the reason the predicted gain in grain yield per m^2 was more in EC 87 and EC 91 than HHVBC.

The actual gain is still good of considerable magnitude for grain yield and it was more than the realized gain for grain yield (4%) per cycle of mass selection reported by Rattunde, 1988, respectively. The selection for panicle surface area on plant basis is good as compare to progeny basis for yield, because panicle surface area depends upon its two components i.e.panicle length and diameter. Panicle length and diameter is easy to measure in a number of plants and it does not require much resources.

Panicle surface area was positively correlated with grain number per m^2, grain size and grain yield per m^2 among five experimental varieties (PCV1 to PCV5) selected on the basis of panicle surface area in the three populations. For example, an increase of 29% in panicle surface area resulted in a corresponding increase of 7% in grain number per m^2, 7% in grain size and 14% in grain yield per m^2 with decrease of 7% in panicle number per m^2 across three populations. The positive correlation between panicle surface area and grain yield per m^2 is in agreement with the results reported by Bidinger et al. (1993). Positive correlation between panicle surface area and grain size has been reported earlier (Singh and Ahluwalia, 1970).

Panicle surface area however, was negatively correlated to panicle number per m^2.The negative association of panicle length and diameter with panicle number has been reported previously (Navale and Harinarayana, 1992; Navale et al., 1995). The negative correlation between panicle surface area and panicle number per m^2 offset a part of the grain size in individual panicle productivity on grain yield. Results obtained here supported that selection for large panicle surface area needs to be combined with selection for higher tiller number to be effective in increasing grain yield. Normally increasing grain number by conventional selection results in a decrease in grain size (Alagarswamy and Bidinger, 1985). Increasing panicle surface area resulted in an equal increase in grain number per m^2 and grain size. Grain number per m^2 was positively correlated with grain yield per m^2 in the study reported by Shankar et al. (1963) and Mahadevappa and Ponnaiya (1967). The results of positive association between grain size and grain yield per m^2 is in agreement with the results reported by, Gopinath (1980), Kamala et al. (1986), Diz et al. (1994), Letitia and Palanisamy (1995) and Tomar et al. (1995).

Substantial increase in grain yield in this experiment due to one cycle of mass selection due to a significant increase (7%) in grain number per m^2 and grain size.

SUMMARY

The present study was carried out to investigate the effect of panicle surface area on panicle grain number, grain size and grain yield in pearl millet. The experimental material consisted of two sets of experiment.

- S_1 progeny evaluation.
- Experimental varieties evaluation.

S_1 PROGENY EVALUATION

The 144 S_1 progenies of three composites viz., EC 87, EC 91 and HHVBC were evaluated in Completely Randomized Block Design (CRBD) with three replications at ICRISAT-Patancheru in rainy seasons of 1994 and 1995 for nine traits viz., panicle length, panicle diameter, panicle surface area, panicle number per m^2, 1000 grain weight (grain size), grain number per panicle, grain yield per panicle and grain yield per m^2. The salient features of the results obtained are summarised below:

- Significant variation was observed for all the traits in the three composites, indicating that there was enough genetic variability present in the material under investigation despite the selection on the basis of panicle surface area for choosing the S_1 progenies.
- Panicle surface area had high heritability (91%) as compared to grain yield (70%) and other yield components across three composites which indicated that selection for panicle surface area would be effective.

- Panicle surface area was genetically positively correlated to grain number per panicle (0.48), grain size (0.33), grain yield per panicle (0.67), and grain yield per m^2 (0.35) across three composites. But it was negatively correlated to panicle number per m^2 (-0.51)
- The difference in the strength of the correlation of panicle surface area with grain number per panicle and grain number per m^2 was due to the negative correlation between panicle surface area and panicle number per m^2.
- Estimated gain from indirect selection of panicle surface area for grain number per panicle (18%), grain size (11%), grain yield per panicle (36%) and grain yield per m^2 (10%) across three composites.

EXPERIMENTAL VARIETIES EVALUATION

Panicle traits

The 24 experimental varieties of three composites viz., EC 87, EC 91, and HHV BC were evaluated in Completely Randomized Block Design (CRBD) with four replications in 11 environments at Hisar, Rohtak and ICRISAT-Patancheru during rainy season of 1996 and the summer and rainy seasons of 1997 for seven panicle traits viz., panicle length, panicle diameter, panicle surface area, grain number per cm^2, 1000 grain weight (grain size), grain number per panicle and grain yield per panicle. These detailed studies were based on ten randomly selected primary panicles per plot. The salient features of the results obtained are summarised below:

- Significant variation among experimental varieties was observed for all panicle traits. Effects due to base population, selection and their interaction with in the genotype source of variation was also significant for all the traits.
- The actual gain in PCV5 (with maximum panicle surface area) over the original population was 12% for panicle surface area, 7% for grain number per panicle, 3% for grain size and 10% for grain yield per panicle across the composites.
- Breeder selection was effective in improving grain yield per panicle and grain number per panicle over the original population by an average of 2% and 5%, respectively, in the three composites.
- The net effect increase in grain yield per panicle was less than the prediction (+10% vs prediction of 36%)
- The selection for large panicle surface area i.e. PCV5 was more effective than breeder selection for grain yield per panicle by an average of 7% in the three composites.
- Panicle surface area was genetically positively correlated with grain number per panicle (0.91), grain size (0.72) and grain yield per panicle (0.98) across three composites.

EXPERIMENTAL VARIETIES EVALUATION

Plot traits

The 24 experimental varieties of three composites viz., EC 87, EC 91 and HHVBC were evaluated in Completely Randomized Block Design (CRBD) with four replications in 11 environments at Hisar, Rohtak and ICRISAT-Patancheru during rainy season of 1996 and the summer and rainy seasons of 1997 for the effect of selection for panicle surface area on nine plot traits viz., panicle number per m^2, grain number per m^2, 1000 grain weight (grain size), grain number per panicle, grain yield per panicle, grain yield per m^2, days to 50% flowering, plant height and fodder yield per m^2. The salient features of the results obtained are summarised below:

- Significant variation among experimental varieties was observed for all plot traits. Effects due to base population, selection and population x selection interaction within the genotype source of variation were also significant for all the traits.
- The actual gain in PCV5 (with maximum panicle surface area) over the original population was 7% for grain number per m^2 and 8.7% for grain yield per m^2 across the composites.
- Breeder selection was not effective in improving grain yield per m^2 over the original population. Breeder selection was effective in improving grain number per m^2 by an average of 4% across the composites. There was no change in grain size due to breeder selection in any of the three composites.
- The net effect increase in grain yield per m^2 was almost similar to the prediction (+8.7% vs prediction of 10%)
- The selection for large panicle surface area i.e. PCV5 was more effective than breeder selection for grain yield per m^2 by an average of 9% in the three composites.
- Panicle surface area was genetically positively correlated with grain number per m^2 (0.37), grain size (0.30) and grain yield per m^2 (0.73).

Panicle surface area was positively correlated with grain number per panicle , grain size and grain yield per panicle among experimental varieties (PCV1 to PCV5) selected on the basis of panicle surface area in the three composites. For example, an increase of 29% in panicle surface area resulted in a corresponding increase of 15% in grain number per panicle, 8% in grain size and 23% in grain yield per panicle across three composites. Hence, selection for increased panicle surface area was effective in increasing grain yield per panicle as it simultaneously increased grain number per panicle and individual grain size.

On plot basis the panicle surface area was also positively correlated with grain number per m^2, grain size and grain yield per m^2 among experimental varieties (PCV1 to PCV5) selected on the basis of panicle surface area in three composites. For example, an increase of 29% in panicle surface area resulted in a corresponding increase of 7% in grain number per m^2, 7% in grain size and 14% in grain yield per m^2 with decrease of 7% in panicle number per m^2 across three composites. Hence, selection for large panicle surface area needs to be combined with selection for higher tiller number to be effective in increasing grain yield.

From this study it is concluded that the selection for increased panicle surface area was effective for increasing grain yield per panicle as well as grain yield per plot.

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