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Effect of Drought Stress on Seed Yield and Bio-physical Characters in Mungbean (*Vignaradiata* (L.) Wilczek

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ABSTRACT: *This study was carried out to investigate the effect of drought stress at pod filling period on photosynthesis, gas exchange parameters and grain yield in ten parents and forty hybrids. An experiment was laid out in a randomized complete blocks design (RBD) with three replications at the Experimental Farm, Department of Genetics and Plant Breeding, Faculty of Agriculture, Annamalai University. The results showed that post anthesis water deficiency caused considerable reduction in grain yield. In addition, drought stress at grain filling period also considerably decreased leaf photosynthesis rate (Pn), stomatal conductance (gs) and transpiration rate (Tr), and increased sub-stomatal CO2 concentration (Ci). The decrease in the net photosynthetic rate in the grain filling stage of drought stress was related to the closure of stomata and decreased stomatal conductance.*

Keywords *:Mungbean, Drought, Gas-exchange,* Per se, Gca, Sca, *Heterosis.*

INTRODUCTION

Under both natural and agricultural conditions plants are often exposed to various environmental stresses. Sunil Kumar [1], Afzal [2], Kusvuran [3], Farahani [4], Yordanov [5], ZlatevandYordanov [6] reported that drought is a multi dimensional stress affecting plants at various levels of their organization. Bray [7] and Wang [8] also reported that it is one of the major causes of croploss worldwide, reducing average yields form ostmajor cropplants by more than 50 per cent.

Naveen Choudary [9], Jaleel [10], Nakayama [11] recorded that during their life cycle, plants may experience frequent periods of water deficit even outside arid and semi-arid areas, for example in temperate regions with low rainfall. Some differences found between species with respect to growth and survival can be attributed more to different abilities for water acquisition, transport and conservation, than to differences in metabolism. Mafakheri [12] reported that the regulation of photosynthetic metabolism is also dependent on processes that can be affected by water stress, such as CO_2 diffusion into the leaf, allocation of carbon to non-photosynthetic organs, the production of osmoprotectants and several aspects of leaf biochemistry. Early responses to water stress can be seen as a first line of defense allowing survival in a short time scale. To survive more persistent stress periods, plants need to undergo an acclimation process resulting in changes in metabolism and/or structure mediated by changes in regulation of gene expression.

Chaves [13] reported that in C_3 plants like mungbean, the gradual implementation of moderate water deficits leads almost leads to decreased stomatal conductance. As water deficit increases, stomata close in response to a decreased turgor and/or leaf water potential was reported by Yordanov [5].

The dehydration process during droughti scharacterized by fundamental changes in water relations, biochemical and physiological processes, membrane structure, and ultrastructure of subcellular organelles was recorded by Sarafis [14] and Yordanov [5]. Drought frequently causes rapid closure of stomata, thusreducing water loss through transpiration. These results indecrease of internal CO_2 concentration, therefore leading to a decline in leaf photosynthesis was observed by Campos [15]. Lawlor [16] showed that concomitantly inhibition or damage in the photosynthetic machinery may occur under prolonged water stressphoto synthesis may

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decreaseas a consequence of limitations at the level of the chloroplast photochemistry or biochemistry, namely in photo systems, electron transferre actions, photophosphorylation and several enzymes of carbon fixation path way. The response to drought at the whole plant and croplevelsis complex because it reflects the integration of stress effects and responses at all underlying levels of organization over space and time was reported by Blum [17] and Yordanov [18]. Drought is one of the most important constrains for crop production but improvement of drought tolerance is very difficult because of the set of mechanisms involved. The genus Vigna includes many species and varieties that present a large possibility to arid and semi-arid conditions, therefore constituting an appropriate genetic pool to study of mechanisms underlying plant response to drought.

MATERIALS AND METHODS

A two year pot experiment was conducted at the Experimental Farm, Department of Genetics and Plant Breeding, Faculty of Agriculture, Annamalai University, Chidambaram, India. The site is located at 11° 24′ N latitude and 79°44′ E longitude. The altitude of Annamalai Nagar is + 5.79 meter above sea level. The mean annual temperature is 30°C. The minimum annual temperature is 24°C and the maximum annual temperature is 32°C.

The experimental material consisted of 44 genotypes of mungbean which were collected from different parts of the country. From these 44 genotypes ten best performing patents were selected and used as lines; 4 locally adapted parents were used as testers. Using these 10 lines and 4 testers, 40 F_1 hybrids were derived by crossing them in Line x Tester Fashion.

The trial was laid out in a Randomized Block Design (RBD) with three replications. One row of each genotype was dibbled keeping 35 and 10 cm spacing between and within rows, respectively. Basal fertilizer dose of NP (@ 25 kg N + 60 kg P2O5 per hectare) was applied during crop growth period. Agronomic practices were used as recommended for mungbean crop. The irrigation among the genotypes was stopped at the initiation of 50 percent of the flowering. Need based irrigation was given to prevent permanent wilting.

The following data were collected from the central two rows both per plot and per plant basis.

Seed yield plant^{-1}

Five plants were randomly selected and their full plant yield was estimated and expressed in grams.

Relative water content

Three individual leaves of the plants were collected and immediately weighed (fresh weight, FW). Intact leaves were transferred to sealed amber flask, rehydrated in 1 L of distilled water for 5 h until fully turgid at 4°C. They were surface dried and reweighed (turgid weight, TW). Leaf samples were then oven dried at 72°C for 48 h and re-weighed (dry weight, DW). The RWC was calculated by the following formula

$$RWC = \frac{\text{Fresh weight} - \text{Dry weight}}{\text{Turgid weight} - \text{Dry weight}} \times 100.$$

Gas exchange parameters

Gas exchange parameters were assessed at midway of either vegetative or reproductive growth stages. Net photosynthesis rate (Pn, in μ mol. $m^{-2}.s^{-1}CO_2$), transpiration rate (Tr, in $mmol.m^{-2}.s^{-1}H_2O$), leaf temperature (T, in °C), internal CO_2 ratio (Ci, in $\mu l\ l^{-1}$), and stomatal conductance to water vapour (gs, in mol $m^{-2}s^{-1}H_2O$.) were recorded using Gas exchange measurements were made with an LI-6400 (LI-COR, Inc.) portable gas exchange system. Photosynthesis was induced with saturating light (PAR-1500 μ mol $m^{-2}s^{-1}$). This light was fitted to the standard 6 cm^2 clamp on the leaf chamber. Sample CO_2, flow rate, and temperature were kept constant at 362 mbar, 500 μ mol s^{-1}, and 25°C, respectively. Leaves were inserted into leaf chamber of 1 cm^2 cross section. For each selected plant measurements were made on the abaxial surface of the second fully-expanded leaf in the upper canopy, three times during the morning between 07:30 and 11:30 h, so that each set of recordings on each plant was taken as average values for gas exchange parameters.

The physiological observations have taken by using portable photosynthesis system of Infra-Red Gas Analyzer (IRGA), which measures gas exchange parameters apart from environmental parameters There are several methods of measuring CO_2 fixation or exchange in plants but, the modern techniques of determining CO_2 fixation using infra-red gas analysis (IRGA) of CO_2 is most widely employed owing to the precision of detecting very small changes in CO_2 concentrations. This method is very sensitive for CO_2 uptake by small leaves or even segments of leaves. The IRGA records the change in CO_2 concentration in the system and the rate of change with time gives an estimate of the CO_2 or water exchange rate. The main advantage of this method is that it can be used at a wide range of CO_2 concentrations, light, relative

humidity and temperature and for studying the effects of these environmental factors that parameters influencing photosynthesis or gas exchange parameters.

Photosynthetic rate (ìmol CO_2 m^{-2} s^{-1})

Photosynthesis, the conversion of light energy to chemical energy and the utilization of the chemical energy. The rate of photosynthesis is affected by a number of factors including light levels, temperature, availability of water, and availability of nutrients. Ifthe conditions that the plant needs are improved the rate of photosynthesis increases.

Transpiration rate (mmol H_2O m^{-2} s^{-1})

Loss of water in the form of water vapour from the internal living tissue of the leaf through the aerial parts such as leaf, green stem, etc., under the influence of sunlight is called as transpiration. The excess amount is transpired through the aerial parts of the plants. Thus, only 5 per cent of the absorbed water is retained in the plants and remaining 95 per cent is lost through aerial parts the leaves are most important for transpiration.

Stomatal conductance (ìmol m^{-2} s^{-1})

Stomatal conductance, measured in ìmol m^{-2} s^{-1} is the measure of the rate of passage of carbon dioxide CO_2 entering, or water vapor exiting through the stomata of a leaf. Stomata are small pores on the top and bottom of a leaf that are responsible for taking in and expelling CO_2 and moisture from and to the outside air. The rate of stomatal conductance, or its inverse, stomatal resistance, is directly related to the boundary layer resistance of the leaf and the absolute concentration gradient of water vapor from the leaf to the atmosphere.

Leaf temperature

Leaf temperature is an essential factor affecting both the transport of gaseous substances into and inside a leaf and all biochemical processes occurring inside a leaf. The temperature dependence of photosynthesis is often studied using detailed biochemical models for which CO_2 conductance, and consequently intercellular CO_2 concentration (Ci) can be modified. Recently there have been several studies addressing the effect of temperature on the variables in the model of Farquhar [19]. Substantial variation in the temperature dependence of essential biochemical reactions in photosynthesis has been recorded among and within species were reported by Wullschleger [20], Dreyer [21], Leuning [22] and Medlyn [23]. However, the temperature response of the apparent CO_2 assimilation results from all its component processes within the boundaries set by the leaf structure. This creates a contradiction as the biochemical variables are usually determined at the leaf level assuming that the CO_2 concentration in the chloroplasts equals that in intercellular air spaces proposed by Ethier and Livingston [24].

Statistical analyses

For all measurements of gas exchange, on each sampling date, the observations on individual leaves per plant were averaged to calculate a single value per plant. All measurements were compared among treatments. Data on different parameters analyzed statistically and effects of developmental stage on each parameter were evaluated by analysis of variance (ANOVA)

Heterosis of F_1 over mid parent (MP) was calculated by methods as given below.

Per cent heterosis in F_1 over mid parent (MP) = $(F_1\text{-MP})/MP \times 100$

Where, Mid parent (MP) = (P1 + P2)/2

Mean sum of squares due to error from RBD analysis was considered to compute standard error (S.E.) of estimated heterosis as follows.

S.E. for heterosis over mid parent

S.E. (Hmp) = $[(3/2 \times EMS)/r]$ 0.5

Where, EMS = Error mean sum of squares

The critical difference values in each case were worked out by multiplying their corresponding S.E. values with table 't' value at error degree of freedom at 5 and 1 per cent levels of significance.

RESULTS AND DISCUSSION

Heterosis is the superiority of F_1 over the mean of the parents or over the better parent or over the standard check by the method, with respect to agriculturally useful traits. The primary objective of heterosis breeding is to achieve a quantum jump in yield and quality of crop plants.

Mungbean improvement programmes primarily lay emphasis on development of hybrids, which have contributed in improving their productivity. Hybridization is the most potent technique for breaking yield barriers. Selection of parents on the basis of phenotypic performance alone is not a sound procedure, since phenotypically superior lines may yield poor combinations. It is therefore essential that parents should be chosen on the basis of their

combining ability. Combining ability analysis is the most widely used biometrical tool for identifying prospective parents and for formulating breeding procedures most likely to succeed.

Out of the forty four lines, ten lines and four testers were selected for creating re-combinational variability for combining ability. The ten lines selected based on various parameters were utilized to assess re-combinational variability for combining ability by crossing them with 4 testers. These results are presented below.

Analysis of variance

The preliminary RBD analysis was carried out for six characters under study for all genotypes involved in the present investigation *viz*., 40 crosses (Line x Tester), 10 lines, 4 testers. Mean sum of squares for six characters are presented in Table 1. 'F' test indicated highly significant variation among the genotypes for all the characters (Table 1).

The greater magnitude of SCA variance than GCA variance indicated the role of non-additive genes for all the twenty one characters studied. The estimates of additive and dominance variance revealed that dominance variance (σ^2D) was greater than the additive genetic variance (σ^2A) for all the characters under study (Table 2).

Per se performance

Mean per se performance of four females and 10 males (Table 2) and derived F_1 crosses (Table 3). Further, results of heterosis values over mid parent for various characters were studied to assess the variability for combining ability were given in Table 4.

Seed yield plant^{-1} (g)

The grand mean for this trait was 9.12 g for lines and 7.40 g for testers. Five lines (Pusa 9072, IPM 306-1, IPM 306-6, IPM 9901-03, IPM 9901-125) and two testers (HUM 12andIPM 9901-10) recorded significantly higher values than their respective grand means. The seed yield plant^{-1} ranged from 6.66 (PDM 11) to 12.36 g (IPM 9901-125) and 6.69 (LGG 410) to 8.16 g (IPM

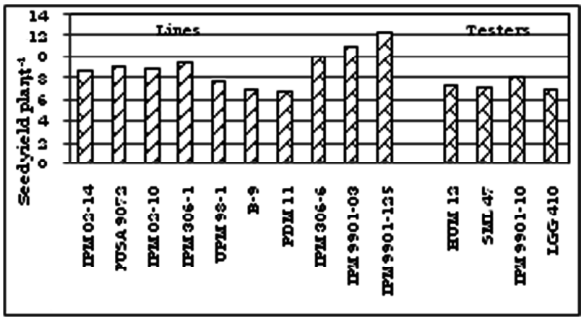

Figure 1: Mean values for parents for seed yield plant^{-1}

Table 1
Analysisofvarianceforgrainyield plant^{-1}and bio-physical parameters

		MSS						
Source	*df*	*Seed yield plant^{-1}*	*Relative water content*	*Photo-synthetic rate*	*Trans-piration rate*	*Stomatal conductance*	*Leaf temperature*	*Intercellular Co_2 concentration ratio*
Replication	2	53.09	43.64	54.81	9.46	0.04	250.83	2266.20
Cross	39	1.95**	24.40	184.72**	0.68**	0.03	6.26**	4125.96**
Line	9	7.23**	90.33	151.66**	1.54**	0.06	23.64**	617.49**
Tester	3	3.18**	44.23	13.34**	0.22**	0.11	5.63	51776.77**
L X T	27	2.56**	0.21	214.02**	0.44**	0.01	0.53	0.92
Error	78	0.42	9.60	3.04	0.44	0.01	5.58	359.78

Table 2
Combining ability variances and gene action for biophysical characters

Variance	*Seed yield plant^{-1}*	*Relative water content (RWC)*	*Photosynthetic rate (Pn)*	*Transpiration rate (Tr)*	*Stomatal conductance (gs)*	*Leaf temperature (LT)*	*Intercellular Co_2 concentration ratio (Ci)*
GCA	0.03	0.05	0.45	0.01	0.01	0.09	67.70
SCA	0.12	2.75	92.11	0.01	0.01	1.68	119.62
s2 A (F=1)	0.06	0.11	0.81	0.01	0.01	0.18	135.41
s2 D (F=1)	0.12	11.00	368.47	0.01	0.01	6.73	478.48
s2 A / s2 D	0.50	0.01	0.21	21.98	21.98	0.02	0.28
GCA/SCA	0.25	0.01	0.48	21.98	21.98	0.05	0.56

Table 3
***Per se* performance of 40 mungbean hybrids for seed yield and bio-physiological parameters**

Hybrids	*Seed yield plant^{-1} (g)*	*Relative water content*	*Photosynthetic rate*	*Transpiration rate*	*Stomatal conductance*	*Leaf temperature*	*Intercellular Co_2 concentration ratio*
IPM 02-14/HUM 12	8.74	78.57	26.35	6.14*	0.66	35.60*	254.49
IPM 02-14/SML 47	8.83	78.61	26.08	5.31*	0.5	36.41*	338.15**
IPM 02-14/IPM 9901-10	8.34	79.11*	27.03	6.52*	0.70*	36.63*	257.95
IPM 02-14/LGG 410	8.56	79.81**	28.35*	6.29*	0.62	35.66	252.56
PUSA 9072/HUM 12	10.10*	79.39*	30.78**	6.21*	0.68*	36.69*	344.11**
PUSA 9072/SML 47	9.18	78.43	21.84	5.28*	0.37	37.50*	260.45
PUSA 9072/IPM 9901-10	7.69	78.93*	25.93	6.04*	0.5	37.73**	263.92
PUSA 9072/LGG 410	8.91	79.63*	23.68	5.67*	0.36	36.75*	258.53
IPM 02-10/HUM 12	8.87	77.15	27.32	6.44*	0.57	36.83*	261.59
IPM 02-10/SML 47	8.95	77.54	25.03	5.99*	0.5	37.64**	345.24**
IPM 02-10/IPM 9901-10	9.47	78.04	26.06	6.84	0.6	37.86**	265.05*
IPM 02-10/LGG 410	10.68**	78.74	26.02	5.86*	0.54	36.89*	259.66
IPM 306-1/HUM 12	10.20*	79.77**	27.55	5.59*	0.69*	38.35**	338.33**
IPM 306-1/SML 47	8.29	77.21	26.63	6.30*	0.49	39.16**	254.69
IPM 306-1/IPM 9901-10	9.80*	78.31	29.12**	6.20*	0.61	39.39**	258.14
IPM 306-1/LGG 410	8.02	79.01*	30.06**	5.58*	0.51	38.41**	252.76
UPM 98-1/HUM 12	8.43	74.35	30.32**	5.28*	0.43	36.81*	246.23
UPM 98-1/SML 47	8.51	74.29	30.55**	5.42*	0.45	37.62**	329.88**
UPM 98-1/IPM 9901-10	9.03	74.36	14.32	4.75*	0.54	37.85**	249.69
UPM 98-1/LGG 410	8.24	75.16	12.13	5.36*	0.52	36.87*	244.3
B-9/HUM 12	7.96	77.23	30.58**	5.38*	0.53	34.81*	239.61
B-9/SML 47	8.04	77.26	29.86**	5.31*	0.39	35.62*	323.26**
B-9/IPM 9901-10	8.55	77.67	32.02**	5.05*	0.47	35.84*	243.07
B-9/LGG 410	7.77	78.47	30.88**	4.71*	0.37	34.87*	237.68
PDM 11/HUM 12	7.68	76.35	7.96	5.26*	0.37	36.97*	250.7
PDM 11/SML 47	7.76	76.39	21.22	5.94*	0.37	37.78**	334.35**
PDM 11/IPM 9901-10	8.28	76.89	32.56**	5.72*	0.64	38.00**	254.16
PDM 11/LGG 410	7.50	77.59	31.89**	6.13*	0.45	37.02*	248.77
IPM 306-6/HUM 12	9.74*	75.08	32.59**	5.52*	0.47	34.06*	245.23
IPM 306-6/SML 47	9.82*	76.02	17.15	5.23*	0.4	34.87*	248.68
IPM 306-6/IPM 9901-10	10.34*	78.12	4.42	5.83*	0.76**	35.09*	328.88**
IPM 306-6/LGG 410	8.55	77.22	27.97	6.14*	0.53	34.12*	283.30*
IPM 9901-03/HUM 12	10.58**	78.87*	34.79**	5.73*	0.78**	36.05*	287.80*
IPM 9901-03/SML 47	9.82*	76.02	34.56**	5.77*	0.76**	34.87*	328.88**
IPM 9901-03/IPM 9901-10	10.34*	76.08	35.07**	5.55*	0.53	35.09*	248.68
IPM 9901-03/LGG 410	9.55	77.22	17.49	5.08*	0.58	34.12*	243.3
IPM 9901-125/HUM 12	10.38*	80.32**	9.2	5.65*	0.64	36.05*	247.8
IPM 9901-125/SML 47	9.82*	78.87*	32.53**	5.82*	0.58	34.87*	243.3
IPM 9901-125/IPM 9901-10	10.34*	76.02	35.91**	5.61*	0.55	35.09*	248.68
IPM 9901-125/LGG 410	10.55**	76.52	36.99**	5.48*	0.69*	34.12*	328.88**
Mean	8.45	76.90	26.20	5.70	0.52	36.40	271.77
SEd	0.33	0.65	1.02	0.54	0.08	0.62	5.48
CD (0.05)	0.53	1.28	1.79	1.06	0.15	1.18	10.35
CD (0.01)	1.35	2.14	2.67	1.4	0.2	2.47	19.95

9901-10) among lines and testers, respectively. Among the hybrids, the mean values of seed yield plant^{-1} ranged from 7.50 (PDM 11/LGG 410) to 10.68 g (IPM 02-10/LGG 410). Twenty seven hybrids out of forty were significantly superior than the general mean (8.45 g) (Table 4).

Relative water content

The grand mean for this trait was 78.34 for lines and 75.74 for testers. Six lines (IPM 02-14, Pusa 9072, IPM 02-10, IPM 306-1, B-9, IPM 9901-03) and three testers (Hum 12, IPM 9901 and LGG 410) recorded significantly higher values than their respective grand means. The relative water content ranged from 73.23 (UPM 98-1) to 81.90 (IPM 02-14) and 71.91 (SML 47) to 78.32 (LGG 410) in lines and testers, respectively. The hybrid IPM 9901-03/HUM 12 (80.32) recorded the maximum mean value, while the hybrid UPM 98-1/ SML 47 recorded least relative water content of 74.29. Higher percentage of relative water content over grand mean of 76.90 was observed in twenty seven hybrids.

Photosynthetic rate

Among the parents, the photosynthetic rate was the maximum in IPM 9901-125 (39.42) and minimum in IPM 306-6 (10.31). Among the testers, photosynthetic rate ranged from 10.84 (LGG 410) to 40.96 (IPM 9901-10). The grand mean observed was 28.46 for lines and 29.56 for testers. Six lines and two testers exceeded their respective grand means. The photosynthetic rate ranged between 36.99 (IPM 9901-125/LGG 410) to4.42 (IPM 306-6/IPM 9901-10). The grand mean for this trait was 26.20. A total of twenty five hybrids showed significantly higher photosynthetic rate over the grand mean (Table 12).

Transpiration rate

The grand mean for this trait was 6.66 for lines and 6.48 for testers. Two lines (Pusa 9072 andB-9) and three testers (HUM 12, SML 47 and LGG 410) recorded

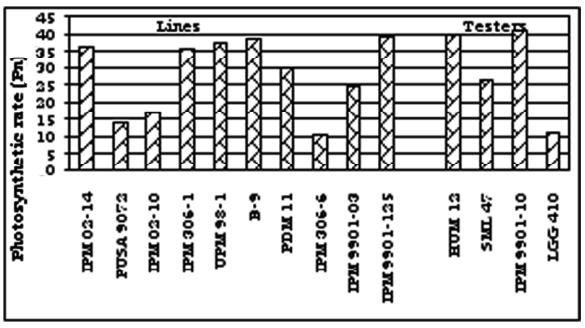

Figure 2: Mean values for parents for photosynthetic rate

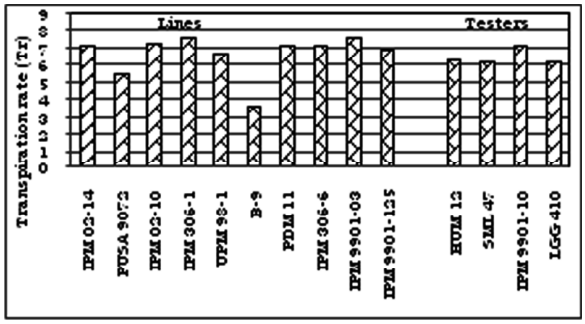

Figure 3: Mean values for parents for transpiration rate

significantly lower values than their respective grand means. The transpiration rate ranged from 3.68 (B-9) to 7.64 (IPM 9901-03) and 6.21 (SML 47) to 7.11 (IPM 9901-10) among lines and testers, respectively. Among the hybrids, the transpiration rate ranged between 4.71 (B-9/LGG 410) and 6.84 (IPM 02-10/IPM 9901-10). The grand mean for this trait was 5.70. A total of twenty three hybrids showed lower transpiration rate over the grand mean.

Stomatal conductance

The grand mean for this trait was 0.54 for lines and 0.35 for testers. Four lines (IPM 02-14, IPM 02-10, IPM 306-1and IPM 9901-03) and two testers (HUM 12and IPM 9901-10) recorded significantly higher values than their respective grand means. The stomatal conductance ranged from 0.22 (PDM 11) to 0.79 (IPM 9901-03) and 0.25 (SML 47) to 0.45 (IPM 9901-10) among lines and testers, respectively. The hybrid, IPM 9901-03/HUM 12 recorded maximum value for stomatal conductance (0.78), while the hybrid Pusa 9072/LGG 410 recorded the minimum value of 0.36. A higher stomatal conductance over grand mean of 0.52 was observed in twenty two hybrids.

Leaf temperature

The grand mean for this trait was 36.52°C for lines and 37.16°C for testers. Five lines (IPM 02-14, B-9,IPM 306-6, IPM 9901-03and IPM 9901-03) and two testers (HUM 12 and LGG 410) recorded lower values than their respective grand means. The relative growth ranged from 31.90 (IPM 306-6) to 40.48°C (PDM 11) and 36.21 (HUM 12) to 38.84°C (SML 47) among lines and testers, respectively. The leaf temperature of the hybrids varied from 39.39 (IPM 306-1/IPM 9901-10) to 34.06°C (IPM 306-6/HUM 12). Eighteen hybrids showed lower values from the grand mean of 36.40°C.

Intercellular Co_2 concentration

The intercellular Co_2 concentration ratio ranged from 224.30 (B-9) to 269.48 (Pusa 9072) and 238.50 (LGG

410) to 410.81 (SML 47) among lines and testers, respectively. The lines and testers had a grand mean of 246.34 and 285.71, respectively. Higher values than their respective grand means were recorded by the lines IPM 02-14, Pusa 9072, IPM 02-10 and IPM 306-1 and none of the testers recorded higher means over the general mean. The intercellular Co_2 concentration ratio for different hybrids ranged between 237.68 (B-9/LGG 410) and 345.24 (IPM 02-10/SML 47). The grand mean 271.77 was exceeded by twelve hybrids for this trait.

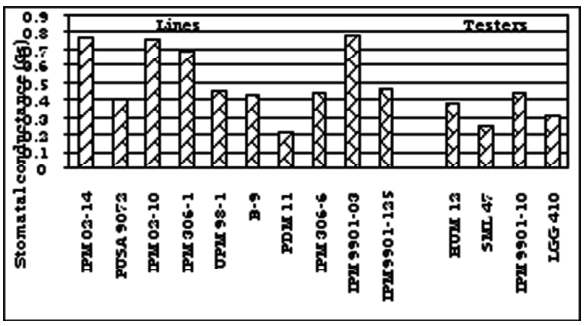

Figure 4: Mean values for parents for stomatal conductance

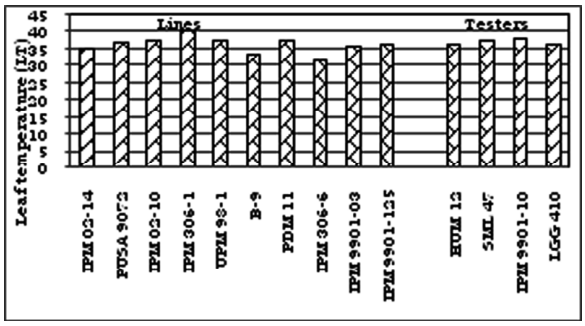

Figure 5: Mean values for parents for leaf temperature

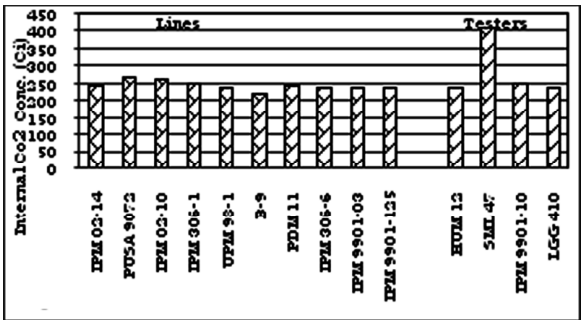

Figure 6: Mean values for parents for internal Co_2 Concentration

Combining ability effects (*gca* and *sca*)

The average performance of the particular inbred in a series of hybrid combinations is known as general combining ability (*gca*) whereas the performance of two specific inbreds in a particular cross is known as specific combining ability (*sca*). The term specific combining ability is used to designate those cases in which certain combinations do relatively better than the expected would do on the basis of average performance of the lines involved. A successful breeding programme routinely evaluates parental lines for the *gca* effects. The general combining ability includes both additive effects as well as additive x additive interaction of epistasis.

The general combining ability effects (*gca*) of the ten lines and four testers for twenty one traits are presented in the Table 4. The specific combining ability effects (*sca*) of the forty hybrids for various traits are presented in table

Seed yield plant^{-1}

Five parents recorded positive *gca* effects for seed yield plant^{-1}. The lowest and highest *gca* effects were recorded by the lines PDM 11 (-1.27) and IPM 9901-03 and IPM 9901-125 (0.95) and among the testers it ranged from LGG 410 (-0.34) to IPM 9901-10 (0.44) for seed yield plant^{-1}. Three lines IPM 306-6, IPM 9901-03 and IPM 02-14 and one tester IPM 9901-10 recorded significant positive *gca* effects. Three lines UPM 98-1 B-9 and PDM 11 and one tester LGG 410 registered significant negative *gca* effects for this trait.

The *sca* effects ranged from -0.13 (IPM 9901-03/ IPM 9901-10, IPM 9901-03/LGG 410, IPM 9901-125/ SML 47and IPM 9901-125/IPM 9901-10) to 1.39 (IPM 9901-03/HUM 12). Among the forty hybrids studied, eleven hybrids *viz*.,Pusa 9072/HUM 12, IPM 306-1/ HUM 12, IPM 306-1/IPM 9901-10, UPM 98-1/IPM 9901-10, B-9/IPM 9901-10, PDM 11/IPM 9901-10, IPM 306-6/IPM 9901-10, IPM 9901-03/HUM 12, IPM 9901-03/SML 47, IPM 9901-125/HUM 12 and IPM 9901-125/LGG 410 showed positive significant *sca* effects for seed yield plant^{-1}.

Relative water content

For relative water content, among the lines the *gca* effects ranged from UPM 98-1 (-2.50) to IPM 02-14 (1.52) and in the testers it varied from -0.35 (SML 47) to 0.50 (LGG 410). Six lines IPM 02-14 Pusa 9072, IPM 02-10 IPM 306-1 B-9and IPM 9 and two testers HUM 12and LGG 410 recorded positive *gca* effects. Four lines UPM 98-1 PDM 11, IPM 306-6 and IPM 9901-03 and the testers SML 47and IPM 9901-10registered negative *gca* effects for this trait.

The significant *sca* effect was maximum and minimum in the hybrids IPM 9901-125/HUM 12 (2.34) and IPM 901-125/LGG 410 (-1.90). None of the hybrid recorded positively significant *sca* effect.

Table 4
General combining ability (*gca*) effects of mungbean genotypes for grain yield plant-1 and bio-physical parameters

Parents	*Seed yield plant^{-1}*	*Relative water content*	*Photosynthetic rate*	*Transpiration rate*	*Stomatal conductance*	*Leaf temperature*	*Intercellular Co_2 concentration ratio*
LINES							
IPM 02-14	-0.21	1.52	0.76	0.37	0.10**	-0.32	4.02
PUSA 9072	0.15	1.34	-1.89**	0.10	-0.10**	0.77	9.99
IPM 02-10	-0.08	0.45	0.42	0.58**	0.04	0.90	11.12*
IPM 306-1	0.25	0.72	2.15**	0.22	0.02	2.43**	4.21
UPM 98-1	-0.52**	-2.50**	-4.36**	-0.49*	-0.03	0.89	-4.24
B-9	-1.00**	0.17	4.28**	-0.59**	-0.08**	-1.12	-10.86*
PDM 11	-1.27**	-0.70	-2.79**	0.06	-0.06*	1.04	0.23
IPM 306-6	0.79**	-1.07	-5.66**	-0.02	-0.03	-1.86**	-5.25
IPM 9901-03	0.95**	-0.35	4.64**	-0.17	0.10**	-1.37*	-4.60
IPM 9901-125	0.95**	0.42	2.46**	-0.06	0.02	-1.37*	-4.60
SE (*gca* for lines)	0.19	0.93	0.50	0.19	0.03	0.68	5.47
TESTERS							
HUM 12	-0.03	0.04	-0.95	0.02**	0.02	-0.18	-20.91**
SML 47	-0.07	-0.35	0.35	-0.06	-0.07**	0.24	62.23**
IPM 9901-10	0.44**	-0.19	0.05	0.11	0.07**	0.46	-17.97**
LGG 410	-0.34**	0.50	0.55	-0.07	-0.01	-0.52	-23.35**
SE (*gca* for testers)	0.12	0.59	0.31	0.12	0.02	0.43	3.46

Photosynthetic rate

The range of *gca* effects was from 5.66 to 4.64 for the lines IPM 306-6 and IPM 9901-03, respectively. The testers had the range between -0.95 and 0.55 as recorded by the testers HUM 12 and LGG 410, respectively. The lines IPM 306-1, B-9, IPM 9901-03andIPM 9901-125 recorded significant positive *gca* effects while the lines Pusa 9072, UPM 98-1, PDM 11, IPM 306-6 and the tester HUM 12registered negative *gca* effects for this trait.

The *sca* effect for this trait varied between -10.25 (UPM 98-1/LGG 410) to 9.10 (PDM 11/IPM 9901-10). The Seventeen hybrids *viz*,Pusa 9072/HUM 12, IPM 306-1/HUM 12, UPM 98-1/HUM 12, UPM 98-1/SML 47, PDM 11/HUM 12, PDM 11/IPM 9901-10, PDM 11/LGG 410, IPM 306-6/HUM 12, IPM 306-6/SML 47, IPM 306-6/IPM 9901-10, IPM 306-6/LGG 410, IPM 9901-03/HUM 12, IPM 9901-03/SML 47, IPM 9901-03/IPM 9901-10, IPM 9901-125/SML 47, IPM 9901-125/IPM 9901-10and IPM 9901-125/LGG 410 recorded positive significant *sca* effects.

Transpiration rate

The range of *gca* effects was from -0.59 to 0.58 for the lines B-9 and IPM 02-10, respectively. The testers had the range between -0.07 and 0.11 as recorded by the testers LGG 410 and IPM 9901-10 respectively. The line IPM 02-10 and the tester HUM 12 recorded significant positive *gca* effects. The lines UPM 98-1 and B-9 registered significant negative *gca* effects for this trait.

The *sca* effect for this trait varied between -0.88 (IPM 9901-03/HUM 12) and 0.64 (IPM 02-10/IPM 9901-10). The eight hybrids *viz* , IPM 02-14/SML 47, IPM 306-1/HUM 12, UPM 98-1/IPM 9901-10, B-9/IPM 9901-10, PDM 11/HUM 12, IPM 306-6/IPM 9901-10, IPM 306-6/LGG 410 and IPM 9901-25/LGG 410 recorded positive significant *sca* effects.

Stomatal conductance

The range of *gca* effects was from -0.10 (Pusa 9072) to 0.10 (IPM 9901-03 and IPM 02-14) for the lines and from -0.07 (SML 47) to 0.07 (IPM 9901-10) for the testers. The line IPM 9901-03 and the tester IPM 9901-10 recorded positive *gca* effects. While the lines Pusa 9072 B-9, PDM 11 and the tester SML 47recorded significant negative *gca* effects for this trait.

The *sca* effect for this trait varied between -0.10 (PDM 11/HUM 12) and 0.15 (IPM 02-10/LGG 410). The ten hybrids *viz,* Pusa 9072/HUM 12, IPM 306-1/HUM 12, IPM 306-1/IPM 9901-10, UPM 98-1/LGG 410, PDM 11/IPM 9901-10, IPM 306-6/IPM 9901-10, IPM 9901-03/HUM 12, IPM 9901-03/SML 47, IPM 9901-03/IPM 9901-10and IPM 9901-125/LGG 410 recorded positive significant *sca* effects.

Table 5
Specific combining ability (sca) effects of mungbean genotypes for seed yield plant-1 and bio-physical parameters

Hybrids	*Seed yield plant^{-1}*	*Relative water content*	*Photosynthetic rate*	*Transpiration rate*	*Stomatal conductance*	*Leaf temperature*	*Intercellular Co_2 concentration ratio*
IPM 02-14/HUM 12	-0.10	-0.50	0.35	0.05	0.03	-0.30	-0.39
IPM 02-14/SML 47	0.03	-0.06	-1.22	-0.69**	-0.05	0.10	0.13
IPM 02-14/IPM 9901-10	0.03	0.27	0.02	0.34	0.01	0.10	0.13
IPM 02-14/LGG 410	0.03	0.29	0.85	0.39*	0.01	0.10	0.13
PUSA 9072/HUM 12	1.10**	-0.50	2.42**	0.49**	0.11**	-0.30	1.39**
PUSA 9072/SML 47	0.03	-0.06	-2.82**	-0.46	0.02	0.10	0.13
PUSA 9072/IPM 9901-10	0.03	0.27	1.58	0.13	0.01	0.10	0.14
PUSA 9072/LGG 410	0.03	0.29	-1.18	-0.06	-0.04	0.10	0.18
IPM 02-10/HUM 12	-0.10	-0.50	1.66	0.14	0.01	-0.30	1.39**
IPM 02-10/SML 47	0.03	-0.06	-1.93*	-0.23	0.02	0.10	0.13
IPM 02-10/IPM 9901-10	0.03	0.27	-0.60	0.64**	-0.02	0.10	0.13
IPM 02-10/LGG 410	0.03	-0.50	0.86	-0.35	-0.01	0.10	0.13
IPM 306-1/HUM 12	1.10**	0.29	2.16**	-0.55**	0.14**	-0.30	1.38**
IPM 306-1/SML 47	0.03	-0.06	-2.06*	0.44	0.02	0.10	0.13
IPM 306-1/IPM 9901-10	0.83**	0.27	0.73	0.17	0.11**	0.10	0.13
IPM 306-1/LGG 410	0.03	0.29	1.17	-0.27	-0.02	0.10	0.13
UPM 98-1/HUM 12	-0.10	-0.50	4.44**	0.06	-0.08	-0.30	1.39**
UPM 98-1/SML 47	0.03	-0.06	3.37**	0.28	0.04	0.10	0.13
UPM 98-1/IPM 9901-10	0.83**	0.27	-7.56**	-0.56**	-0.01	0.10	0.13
UPM 98-1/LGG 410	0.03	0.29	-10.25**	0.23	0.10**	0.10	0.13
B-9/HUM 12	-0.10	-0.50	0.70	0.25	0.07	-0.30	-0.38
B-9/SML 47	0.03	-0.06	-1.33	0.26	0.08	0.10	0.13
B-9/IPM 9901-10	0.73**	0.27	1.14	-0.58**	-0.04	0.10	0.13
B-9/LGG 410	0.03	0.29	-0.51	-0.33	-0.05	0.10	0.13
PDM 11/HUM 12	-0.10	-0.50	4.50**	-0.52**	-0.10**	-0.30	1.39**
PDM 11/SML 47	0.03	-0.06	-2.54**	0.24	-0.01	0.10	0.13
PDM 11/IPM 9901-10	0.83**	0.27	9.10**	-0.15	0.11*	0.10	0.13
PDM 11/LGG 410	0.03	0.29	7.93**	0.43	0.01	0.10	0.13
IPM 306-6/HUM 12	-0.10	-0.50	4.01**	-0.18	-0.04	-0.30	-0.38
IPM 306-6/SML 47	0.03	-0.06	3.73**	-0.39	-0.01	0.10	0.13
IPM 306-6/IPM 9901-10	1.03**	0.27	6.16**	-0.84**	0.14**	0.10	1.33**
IPM 306-6/LGG 410	0.03	0.29	6.88**	-0.63**	0.05	0.10	0.13
IPM 9901-03/HUM 12	1.39**	1.66	5.26**	-0.88	0.11*	1.20	1.54**
IPM 9901-03/SML 47	1.13**	-0.78	3.73**	0.30	0.12**	-0.40	1.52**
IPM 9901-03/IPM 9901-10	-0.13	-0.45	4.55**	-0.09	0.14**	-0.40	-0.51
IPM 9901-03/LGG 410	-0.13	-0.43	-4.54**	-0.39	0.06	-0.40	1.54**
IPM 9901-125/HUM 12	1.09**	2.34	-4.51**	-0.01	0.01	1.20	1.54**
IPM 9901-125/SML 47	-0.13	1.29	3.52**	0.25	0.04	-0.40	-0.52
IPM 9901-125/IPM 9901-10	-0.13	-1.73	5.21**	-0.14	0.01	-0.40	-0.54
IPM 9901-125/LGG 410	1.03**	-1.90	5.78**	-0.79**	0.15**	-0.40	1.51**
SE (*sca*)	0.37	1.88	1.01	0.38	0.05	1.36	0.95

Leaf temperature

The *gca* effects ranged from -1.86 to 2.43 for the line IPM 306-6 and IPM 306-1 respectively. The *gca* effects ranged from -0.52 to 0.46 for testers LGG 410 and IPM 9901-10, respectively. Five lines Pusa 9072, IPM 02-10, IPM 306-1, UPM 98-1 and PDM 11 exhibited positive *gca* effects, while negative *gca* effects was exhibited by the five lines IPM 02-14, B-9, IPM 306-6, IPM 9901-03, IPM 9901-125 and two testers SML 47 and LGG 410.

The *sca* effect for this trait varied between -0.40 (IPM 9901-03/SML 47, IPM 9901-03/IPM 9901-10, IPM 9901-03/LGG 410, IPM 9901-125/SML 47,IPM 9901-125/IPM 9901-10 and IPM 9901-125/LGG 410) and 1.20 (IPM 9901-03/HUM 12and IPM 9901-125/HUM 12). None of the hybrid recorded positive significant value.

Intercellular Co_2 concentration

The *gca* effects of the lines varied from -10.86 (B-9) to 11.12 (IPM 02-10) and the *gca* effects of the testers ranged from -23.35 (LGG 410) to 62.23 (SML 47). The line *viz.*, IPM 02 and the tester SML 47 recorded

Table 6
Heterosis over mid parent for seed yield-1 and bio-physical characters in derived F1 crosses

Hybrids	*Seed yield plant^{-1}*	*Relative water content*	*Photosynthetic rate*	*Transpiration rate*	*Stomatal conductance*	*Leaf temperature*	*Intercellular Co_2 concentration ratio*
IPM 02-14/HUM 12	1.90	-3.36	-34.34**	-13.88	-15.05	-1.69	3.22
IPM 02-14/SML 47	2.87	-3.32	-36.32**	-22.53*	-36.23	-3.76	-17.69 **
IPM 02-14/IPM 9901-10	8.90	-2.69	-26.24**	-8.56	-10.61**	-4.31	2.83
IPM 02-14/LGG 410	-0.23	-1.83	-22.63**	-11.73	-21.06*	-1.84	2.44
PUSA 9072/HUM 12	-0.55	-3.15	-35.76**	-2.77	8.07	-1.27	-16.23**
PUSA 9072/SML 47	0.36	-3.10	-46.68**	-14.93	-9.37	-0.88	-3.35
PUSA 9072/IPM 9901-10	5.94	-2.48	-1.46	-15.01	12.11	-1.45	-2.06
PUSA 9072/LGG 410	-2.59	-1.62	-67.54**	-9.13	-11.00	-1.12	-4.06
IPM 02-10/HUM 12	-0.78	-2.10	-31.35**	-11.01	-24.29*	-1.63	-1.57
IPM 02-10/SML 47	0.11	-2.05	-38.89**	-17.14	-33.57**	-0.52	-15.16**
IPM 02-10/IPM 9901-10	5.89	-1.41	-0.97	-5.48	-20.55*	-1.10	-0.26
IPM 02-10/LGG 410	-2.87	-0.53	65.84**	-18.99	-28.95**	-1.47	-2.29
IPM 306-1/HUM 12	-3.53	-2.42	-31.35**	-26.51*	-21.90*	-5.27	-17.64**
IPM 306-1/SML 47	-2.66	-2.38	-34.98**	-17.22	-29.63**	-3.26	0.58
IPM 306-1/IPM 9901-10	2.73	-1.74	-19.47**	-18.49	-11.53	-2.71	1.95
IPM 306-1/LGG 410	-3.49	-0.86	-16.87**	-26.60*	-26.85*	-5.12	-0.18
UPM 98-1/HUM 12	8.08	-1.69	-24.44**	-21.00	-7.72	-1.59	1.46
UPM 98-1/SML 47	4.33	1.80	-25.43**	-18.85	-2.67	-0.56	-19.70**
UPM 98-1/IPM 9901-10	15.73	-2.37	-61.98**	-33.11**	16.31	-1.14	-0.46
UPM 98-1/LGG 410	5.68	-3.22	-67.79**	-19.75	12.77	-1.43	2.34
B-9/HUM 12	9.60	-1.77	-23.78**	-15.77	24.08	-3.88	-1.27
B-9/SML 47	-1.47	-1.72	-27.11**	-14.45	-89.65	-5.87	-21.31**
B-9/IPM 9901-10	18.80	-1.08	-17.15**	-28.99*	4.63	-6.38	-31.10
B-9/LGG 410	10.73	-0.19	-20.12**	-24.52	-12.86	-4.03	-0.35
PDM 11/HUM 12	5.83	-0.66	-80.17**	-26.39*	-4.03	-1.98	2.75
PDM 11/SML 47	-4.86	-0.62	-48.19**	-16.92	50.40	-0.16	-18.61**
PDM 11/IPM 9901-10	15.00	-0.04	8.95*	-19.95	42.83*	-0.74	1.32
PDM 11/LGG 410	7.71	-0.93	6.71**	-14.31	40.40	-1.83	1.96
IPM 306-6/HUM 12	-3.37	-0.19	-18.79**	-22.99	7.29	-5.95	1.05
IPM 306-6/SML 47	-2.55	-0.14	-58.12**	-27.04*	-8.05	-7.84	-0.86
IPM 306-6/IPM 9901-10	2.55	-0.52	-83.21**	-18.57	24.59	-8.33	-19.94**
IPM 306-6/LGG 410	-5.26	-1.40	158.09**	-14.29	20.14	-6.08	1.27
IPM 9901-03/HUM 12	-6.00	-3.70	-13.31**	-25.00*	-15.72	-0.44	12.10
IPM 9901-03/SML 47	-11.07	-7.18*	-15.62**	-24.48*	-53.86**	-7.84	-19.94**
IPM 9901-03/IPM 9901-10	-6.43	-6.56*	33.27**	-27.31*	-32.87**	-8.33	-0.86
IPM 9901-03/LGG 410	-13.55*	-5.70	-2984**	-33.55**	-26.97**	-6.08	0.83
IPM 9901-125/HUM 12	-15.99**	5.91	-77.08**	-18.01	36.40*	-0.46	2.10
IPM 9901-125/SML 47	-20.52**	4.28	-20.59**	-15.44	23.16	-7.84	-19.94**
IPM 9901-125/IPM 9901-10	-16.37**	-1.18	-8.89**	-21.11	46.53**	-8.33	-0.86
IPM 9901-125/LGG 410	-22.73**	-2.30	-6.15	-20.43	16.57	-6.08	1.39

significant positive *gca* effects. Significant negative *gca* effects was recorded by B-9 in the lines; HUM 12, IPM 9901-10 and LGG 410 in the testers.

The *sca* effect for this trait varied between -0.54 (IPM 9901-125/IPM 9901-10) and 1.54 (IPM 9901-03/HUM 12, IPM 9901-3/LGG 410and IPM 9901-125/HUM 12). The eleven hybrids *viz*,Pusa 9072/HUM 12, IPM 02-10/HUM 12, IPM 306-1/HUM 12, UPM 98-1/HUM 12, PDM 11/HUM 12, IPM 306-6/IPM 9901-10, IPM 9901-03/HUM 12, IPM 9901-03/SML 47, IPM 9901-03/LGG 410, IPM 9901-125/HUM 12and IPM 9901-125/LGG 410 recorded positive significant *sca* effects.

DISCUSSIONS

Drought stress at the reproductive stage is the most important in terms of economic yield. The development of reproductive organs, which is under the control of photo-assimilate production and partitioning by the source tissues, is at this stage the most critical.

The mean performance is the primary criterion to evaluate the value of hybrid. The *per se* performance of hybrids appeared to be an useful index for judging the hybrids. In the present study, among the lines, IPM 9901-125 registered high mean for seed yield plant^{-1} and photosynthetic rate.

Among the forty hybrids, thirty nine hybrids revealed significant mean value for transpiration and leaf temperature. Nineteen hybrids showed higher values for photosynthesis rate; fourteen hybrids namely PUSA 9072/HUM 12, IPM 02-10/LGG 410, IPM 306-1/HUM 12, IPM 306-1/IPM 9901-10, IPM 306-6/HUM 12, IPM 306-6/SML 47, IPM 306-6/IPM 9901-10, IPM 9901-03/HUM 12, IPM 9901-03/SML 47, IPM 9901-03/IPM 9901-10 IPM 9901-125/HUM 12, IPM 9901-125/SML 47, IPM 9901-125/IPM 9901-10 and IPM 9901-125/LGG 410 showed high mean performance for seed yield plant^{-1}.

From the perusal of *sca* effects of the hybrids, it was evident that all types (significantly positive or negative or non- significant) of *sca* effects could be obtained in hybrids with different types (high x high, high x low, low x high and low x low) of parental *gca* combinations. For example, high *sca* effect was produced by high x low or low x high combinations of parental *gca* effects. The interaction between recessive alleles from poor combiners and dominant alleles from good combiner could have resulted in such potential crosses from good x poor parental combiners.

The hybrids IPM 02-14/IPM 9901-10for stomatal conductance, IPM 02-10/SML 47for leaf temperature showed poor performance even when both the parents involved were good general combiners. The inconsistency between *gca* and *sca* effects might be due to complex interaction of genes.

Hence, from the foregoing discussion it may be concluded that, PUSA 9072/HUM 12, IPM 306-1/IPM 9901-10, IPM 306-1/HUM 12 and IPM 9901-03/HUM 12 and IPM 9901-01/SML 47, IPM 9901-125/LGG 410 can be rated as better hybrids based on the magnitude of heterosis.

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