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GENOTYPIC ADAPTABILITY FOR SEED YIELD AND PHYSIOLOGICAL TRAITS IN SESAME (*SESAMUM INDICUM* L.)

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ABSTRACT

A study was carried out using thirty six sesame genotypes under four environments to assess the genotype × environment interaction and their stability across the environments for seed yield and physiological traits. The pooled analysis of variance due to genotypes, environments as well as genotype × environment interactions were highly significant for all the characters except for photosynthetic rate at 40 days after sowing (DAS) for genotypes, environments and genotype × environment interaction. Genotype × environment (linear) variance component was more than that of pooled deviations for mostly characters including seed yield. Grain yield per plant had significant positive correlation with harvest index (0.82) and leaf area index at 60 DAS (0.32) at low fertility condition, whereas it was also positive and highly significant with harvest index (0.55), leaf area index at 60 DAS (0.58) and photosynthetic rate at 60 DAS (0.44) at high fertility condition. It indicated that these physiological traits had greater magnitude of correlation with seed yield under high input conditions irrespective of timely and late sown environments. Therefore, selection under high fertility conditions leads to genetic improvement of physiological traits.

INTRODUCTION

Sesame (*Sesamum indicum* L.) belongs to the family Padaliaceae, and is one of the oldest crops in the world, and is under cultivation in Asia for over 5000 years (Bisht *et al*., 1998). This is evidenced by presence of archaeological remnants of the crop dating back to 5500 BC in the Harappa Valley in the Indian subcontinent (Weiss, 2000; Ashri, 2007). Sesame seed is rich in oil, protein, carbohydrate, fiber and minerals. The chemical composition of sesame shows that the seed is an important source of oil (44-58%), protein (18-25%), carbohydrate (~13.5%) and ash (~5%) (Borchani *et al*., 2010). Globally it is cultivated in an area about 6.63 million ha with production of 4.09 million ton. In India, it occupies in an area of 1.78 million ha with production of 0.77 million ton. The productivity of sesame is very low (432 kg/ha) in India compared to world average (617 kg/ha) (FAOSTAT, 2011).

Sesame is short day plant and sensitive to photoperiod, temperature and moisture stress, the yield is not stable and varies widely (Velu and Shunmugavallic, 2005). Although sesame is grown in different seasons in different regions of the country covering practically all agro-ecological zones (Sharma, 1994). Seed yield is influenced by many morphological and physiological characters. As it is a quantitative trait, governed by number of genes, thus direct selection for high yield may often be misleading. In addition to yield contributing characters, physiological traits also play a considerable role for increasing yield (Mehrotra *et al*., 1976). Loomis (1993) suggested crop yields can be raised by optimization of crop structure and physiology. Physiological traits such as leaf area index and photosynthetic rate are important physiological components of yield, and efforts should be made to utilize these characters in breeding programs (Kumaresan and Nadarajan, 2002). Ramkrishnan and Soundarapandian (1990) reported that significant positive correlation of seed yield with photosynthetic efficiency in sesame. Physiological traits like harvest index and leaf area index had direct effect on seed yield in sesame (Pawar *et al*., 2002; Babu *et al*., 2004). Liu *et al*. (2005) and Yoshida *et al*. (2007) reported that strong influence of leaf area index on yield in soybean and rice, respectively. Harvest index could be used as a selection criterion in segregating generations to identify physiologically superior lines with improved partitioning of total assimilate into grain (Sharma *et al*., 1991).

It is common observation that the relative performance of different genotypes varies from one environment to another *i.e*. a genotype × environment (G × E) interaction always play important role. G × E interaction results in change of the relative ranking of the genotypes and also in altering the magnitude of differences in performance among genotypes. Progress from selection is also reduced due to the effects of large G × E interaction, as shown by Comstock and Moll (1963). Since the distribution of rainfall is a major environmental factor and early and late date of sowing can often be used to obtain an extra environment at each location. Similarly medium and high dose of fertilizers can be used to increase the number of environments possible from a fixed number of locations, and at the same time provide a greater range of environmental conditions (Eberhart and Russell, 1966). The studies on genotype × environment interaction and phenotypic stability for different morphological characters are very common in sesame (John *et al*., 2001; Boshim *et al*., 2003; Mekonnen and Mohammed, 2009; Suvarna *et al*., 2011). But currently sufficient information is lacking on the use of stability parameters for assessment of genotypic stability and their response under different environmental conditions for physiological traits in sesame. Hence, there is the need to understand environmental response of genotypes towards the stability of physiological traits. Keeping above in the view, the present study has been hypothesized to understand the differential genotype × environment interactions of cultivars and their hybrids over the environments and to assess the stability of different genotypes under timely and late sowing conditions with recommended and high dose of fertilizers with a view to identify high yielding genotypes with stable performance in ideal and specific environments for seed yield and physiological traits.

MATERIALS AND METHODS

The experimental material consisted of 36 genotypes, of which eight cultivars (GT-1, GT-2, GT-10, TMV-3, Pbtil-1, PT-64, AT-124 and C-1013) and 28 F_1 hybrids were produced utilizing 8 × 8 half diallel mating design following method-2, model-I (Griffing, 1956). A set of 36 genotypes comprising of eight cultivars and their 28 F_1 hybrids were sown in a randomized complete block design with three replications in four environments at Main Castor and Mustard Research Station, Sardarkrushinagar Dantiwada Agricultural University, Sardarkrushinagar, Gujarat, India. The four environments were created by two dates of sowing (one month interval) and two fertility levels *viz.,* E_1: low input timely sowing (N: 25 kg/ha, P_2O_5: 25 kg/ha, S: 20 kg/ha), E_2: high input timely sowing (N: 50 kg/ha, P_2O_5: 50 kg/ha, S: 40 kg/ha), E_3: low input delayed sowing (N: 25 kg/ha, P_2O_5: 25 kg/ha, S: 20 kg/ha) and E_4: high input delayed sowing (N: 50 kg/ha, P_2O_5: 50 kg/ha, S: 40 kg/ha). Sardarkrushinagar is located at 24°12' N Latitude, 72°12' E Longitude and 154.5 m above mean sea level. The climate of this area is typical sub-tropical type characterized by semi-arid and arid conditions. The soil texture of experimental plot was sandy loam with pH 7.5. The average weather data during the period of crop growth were as follows: maximum and minimum temperature (27.8-40.2°C) and (10.3–29.3°C), respectively, relative humidity (68.1-95.9%) and sunshine hours (1.510.1 h/day) with total rainfall of 873.1mm.

The cultivars and F_1 crosses were grown in one row of 5 meters length per plot keeping the distance of 45 cm between rows and 15 cm within rows. The experimental area was provided with border rows on all the side of each block. The recommended agronomical practices and plant protection measures were adopted for raising a good crop. The observations were recorded on ten competitive randomly selected plants of each genotype in each replication for seed yield/plant (g), harvest index (%) and five randomly selected plants for leaf area index at 40 and 60 days after sowing (DAS) and photosynthetic rate at 40 and 60 DAS (μmol/m²/s). To measure leaf area index, destructive sampling was done by uprooting whole plants from one meter row length in each replication of each environment. Leaf area of all the selected genotypes was recorded with a leaf area meter. Leaf area index was calculated as the ratio of the cumulative leaf area per plant to the total ground area. LAI: A/L

Where, A: leaf area/plant and L: ground area covered by the leaves.

The photosynthesis rate (P_N) was measured by computerized Portable Photosynthetic System CI-310 (CID Inc., USA). The photosynthetic rate was measured twice (40 and 60 days after sowing) at fourth fully opened leaves from the top at 10:00 hrs in the field. Mean values of genotypes were computed and statistically analyzed to assessed genotype × environment interaction and stability parameters for seed yield and physiological traits across the environments following the method of Eberhart and Russell (1966). The phenotypic correlation for seed yield and physiological traits under different environments were worked out according to Miller *et al*. (1958).

RESULTS AND DISCUSSION

The pooled analysis of variance revealed that the mean squares due to genotypes as well as environments were found to be highly significant for all the characters for genotypes except for photosynthetic rate (P_N) at 40 DAS, indicating that significant amount of variations exist among genotypes and environments under studied characters (Table 1). These results are in agreement with the findings of Shim-Kangbo *et al*. (2003). He also reported that environment had largest effects on the yield of the crop followed by genotype × environment and genotype. The mean squares due to G × E interaction were found significant for all characters, which suggested that genotypes reacted differentially to different environments for physiological traits. For seed yield these results are in agreement with the findings of Laurentin *et al*. (2007) and Kumar *et al*. (2008). The mean sums of square due to G × E interaction were partitioned into linear and non-linear components. The mean sum of squares due to G × E (linear) were significant for all the characters except for photosynthetic rate at 40 DAS, suggested that the behavior of the genotypes could be predicted over the environments more accurately for these traits as the G × E interaction was the outcome of the linear function of the environmental components.

The mean sums of squares due to pooled deviation (non-linear) were highly significant for all the characters except for harvest index and leaf area index at 40 DAS. This indicated the role of unpredictable factors affecting stability because the unpredictable factors differ from environment to environment and cannot be predicted in advance. Hence, prediction of genotypes over environments based on regression analysis for these traits might not be very reliable. Eberhart and Russell (1966) and Westerman (1971) emphasized that both linear (b_i) and non-linear (S^2d_i) components of G × E interaction should be considered in judging the phenotypic stability of a particular genotype. Kumaresan and Nadarajan (2005) also reported that both linear and nonlinear components were significant for seed yield. The variance of G × E (linear) variance component was more than the magnitude of pooled deviations (non-linear) component for all the characters including seed yield, suggested that possibility of prediction of performance for seed yield and physiological traits over the environments (Table 1). The higher magnitude of linear components for seed yield as compared to non-linear was also reported by Raghuwanshi *et al*. (2003); Anuradha and Reddy (2005) and Kumaresan and Nadarajan (2005), but the Suvarna *et al*. (2011) observed that the magnitude of the pooled deviations was more than the G × E (linear) variance for seed

Table 1: Pooled analysis of variance for phenotypic stability of seed yield and physiological traits under four environments in sesame

Sources of variation	Genotype (G)	Genotype × Environments	Environments (E)	Environment (linear)	Genotype × Environment (linear)	Pooled deviation (Non-linear)	Pooled error
d.f.	35	105	3	1	35	72	280
Seed yield/plant (g)	4.529**	0.920**	142.521**	427.566**	1.899**	0.418*	0.289
Harvest index (%)	10.763**	2.744*	505.274**	1515.839**	4.198**	1.960	1.823
Leaf area index at 40 DAS	0.251**	0.104**	213.450**	64.035**	0.141*	0.082	0.029
Leaf area index at 60 DAS	1.339*	0.848**	104.873**	314.619**	1.610**	0.454**	0.090
Photosynthetic rate at 40 DAS (μmol/m^2/s)	0.483	0.374**	73.499**	220.496**	0.297	0.402**	0.084
Photosynthetic rate at 60 DAS (μmol/m^2/s)	3.751**	1.010**	246.365**	739.097**	1.423*	0.781**	0.317

*significant at P = 0.05 level, **significant at P = 0.01 level. df = Degree of freedom

Table 2: Estimates of stability parameters of different genotypes for seed yield and leaf area index in sesame

Genotypes	Seed yield/plant (g)			Leaf area index at 40 DAS			Leaf area index at 60 DAS		
	Mean	b_i	s^2d_i	Mean	b_i	s^2d_i	Mean	b_i	s^2d_i
GT-1	7.05	0.94	0.30	3.33	0.89	0.23**	5.60	1.37	0.79**
GT-2	7.58	0.96	0.55	3.30	1.02	0.02	5.82	1.24	1.08**
GT-10	7.25	1.06	0.38	3.37	1.10	0.02	4.83	1.06	0.09
TMV-3	7.38	1.30*	0.48	3.26	0.91	0.22**	5.33	1.11	0.36
Pbtil-1	5.99	0.40**	0.14	3.37	1.09**	0.00	5.49	0.94	0.59*
PT-64	6.54	0.78*	0.24	3.41	0.86	0.22**	4.78	0.96	0.05
AT-124	6.52	0.94	0.08	3.32	0.96	0.03	5.39	0.92	0.71**
C-1013	5.49	0.30**	0.18	3.30	0.84	0.30**	5.08	0.67	0.55*
GT-1 × GT-2	6.42	0.82	1.36*	3.19	1.18	0.30**	4.24	0.23**	0.22
GT-1 × GT-10	6.90	0.59**	0.00	3.16	0.94	0.47**	3.99	0.40**	0.22
GT-1 × TMV-3	6.39	0.87	0.38	3.24	1.18	0.23**	4.83	0.41**	0.27
GT-1 × Pbtil-1	5.60	0.30**	0.08	2.83	0.53	0.68**	3.92	0.43**	0.69**
GT-1 × PT-64	5.97	0.59**	0.30	3.02	1.00	0.01	4.34	1.01	0.08
GT-1 × AT-124	6.35	0.60**	0.11	3.34	1.08	0.38**	5.27	0.97	1.48**
GT-1 × C-1013	5.83	0.46**	0.35	2.97	0.72	0.10	4.87	0.75	0.35
GT-2 × GT-10	7.58	1.38	2.05**	3.07	1.02	0.16*	5.98	1.46**	0.09
GT-2 × TMV-3	7.01	1.06	0.85	3.15	1.25**	0.03	5.54	1.17	1.01**
GT-2 × Pbtil-1	7.28	0.92	0.05	3.09	1.25	0.11	5.08	0.99	0.13
GT-2 × PT-64	8.79	2.00**	1.48*	2.84	0.64	0.18*	4.80	0.70	2.90**
GT-2 × AT-124	7.18	0.94	1.17	2.94	0.80	0.06	5.44	1.00	1.32**
GT-2 × C-1013	7.61	1.35**	0.13	2.93	0.69**	0.03	5.59	1.60**	0.29
GT-10 × TMV-3	9.44	1.57**	0.57	3.00	1.04	0.00	5.67	1.26	1.24**
GT-10 × Pbtil-1	9.30	1.71**	1.45*	3.34	1.28	0.47**	6.44	1.09	3.36**
GT-10 × PT-64	7.86	1.15	0.16	3.68	1.36**	0.01	5.53	1.41	1.00**
GT-10 × AT-124	9.00	1.23	1.70*	3.37	1.43*	0.16*	5.30	1.57**	0.03
GT-10 × C-1013	6.96	1.27	2.93**	3.36	0.93	0.17*	6.26	1.73*	1.42**
TMV-3 × Pbtil-1	8.73	1.37	1.00	3.48	1.07	0.11	5.46	1.89*	3.38**
TMV-3 × PT-64	7.48	0.94	0.08	3.35	1.40*	0.10	4.96	1.28	0.67**
TMV-3 × AT-124	7.20	1.35	2.14**	3.20	1.55**	0.13*	5.97	1.01	1.06**
TMV-3 × C-1013	9.26	1.44**	0.07	3.11	1.28*	0.04	5.74	1.21	0.93**
Pbtil-1 × PT-64	7.69	1.08	0.07	3.22	0.91	0.06	4.98	0.51	1.18**
Pbtil-1 × AT-124	8.39	1.19	8.95**	2.60	0.36	0.40**	5.17	0.29**	0.49*
Pbtil-1 × C-1013	6.63	0.45**	0.05	3.08	0.86**	0.00	4.85	0.12**	1.27**
PT-64 × AT-124	6.03	0.51**	0.03	2.57	1.19**	0.00	4.60	0.99	1.17**
PT-64 × C-1013	7.43	1.03	0.09	2.62	0.28**	0.20**	5.41	1.37	1.58**
AT-124 × C-1013	7.62	0.99	0.03	3.05	0.95	0.15*	5.22	0.72	0.50*
Mean	7.27	1.00		3.15	1.00		5.22	1.00	
S.E. ±	0.37	0.188		0.16	0.21		0.38	0.22	

*significant at P = 0.05 level, **significant at P = 0.01 level. DAS = Days after sowing

Table 3: Estimates of stability parameters of different genotypes for photosynthetic rate and harvest index in sesame

Genotypes	Photosynthetic rate at 40 DAS(μmol/m^2/s)			Photosynthetic rate at 60 DAS(μmol/m^2/s)			Harvest index (%)		
	Mean	b_i	s^2d_i	Mean	b_i	s^2d_i	Mean	b_i	s^2d_i
GT-1	6.52	1.20**	0.04	13.61	1.02	2.18*	31.29	0.91	0.29
GT-2	6.74	0.91	0.04	14.16	0.98	0.11	32.08	1.17	5.46
GT-10	6.57	0.78	0.23	14.69	0.78*	0.42	30.71	1.03	1.09
TMV-3	5.84	0.68**	0.01	13.84	0.50**	0.37	30.87	0.98	2.56
Pbtil-1	6.17	1.14	0.89**	13.68	0.67*	0.81	30.13	0.87	7.50
PT-64	6.20	0.65**	0.09	13.12	1.06	0.25	30.03	0.73*	1.33
AT-124	6.42	0.67	1.09**	13.36	1.22	3.75**	30.43	0.90	0.94
C-1013	6.50	0.73	0.23	13.76	0.86	0.93	29.71	0.89	5.12
GT-1 × GT-2	5.81	1.06	0.04	11.20	1.22**	0.14	30.19	1.09	1.11
GT-1 × GT-10	5.85	1.07	0.09	10.98	0.84	1.50*	28.42	-0.06	27.49**
GT-1 × TMV-3	6.12	0.97	0.85**	12.11	1.24	8.24**	29.84	0.83	1.54
GT-1 × Pbtil-1	6.21	1.39	1.18**	11.11	0.79	2.86**	30.33	0.89	0.64
GT-1 × PT-64	6.01	1.00	0.04	12.12	0.74**	0.03	30.18	1.02	1.35
GT-1 × AT-124	6.07	1.16**	0.02	13.36	1.05	1.05	30.80	1.21	5.59
GT-1 × C-1013	5.13	0.69	5.62**	13.23	1.14	1.50*	30.64	1.01	0.81
GT-2 × GT-10	5.95	0.93	0.02	13.42	1.52**	0.43	32.21	1.34**	0.87
GT-2 × TMV-3	6.37	0.62	0.50*	13.21	0.66**	0.04	32.69	0.84**	0.04
GT-2 × Pbtil-1	6.18	0.89	0.16	12.45	0.76*	0.56	33.05	0.88	5.77
GT-2 × PT-64	6.40	1.20*	0.11	14.28	0.73**	0.34	33.62	1.70*	7.34
GT-2 × AT-124	6.99	1.34	2.43**	11.89	0.87*	0.12	31.91	1.17	0.83
GT-2 × C-1013	6.55	1.25	1.07**	12.84	1.12	1.60*	31.91	1.37**	0.37
GT-10 × TMV-3	6.11	1.17	0.15	14.31	1.43**	0.93	34.67	1.45*	4.20
GT-10 × Pbtil-1	6.17	1.13**	0.02	14.13	1.03	0.05	34.04	1.13	3.09
GT-10 × PT-64	6.42	0.95	0.33	12.67	1.11	0.92	33.25	0.85	1.74
GT-10 × AT-124	6.30	0.88	1.87**	14.53	1.45	6.55**	33.87	1.30**	0.12
GT-10 × C-1013	6.60	1.05	0.19	12.30	0.94	4.36**	31.34	1.26	7.07
TMV-3 × Pbtil-1	6.72	1.00	0.08	14.22	0.77	0.72	34.27	0.68	2.58
TMV-3 × PT-64	6.28	0.78	0.48*	13.34	0.62	2.82**	32.92	0.89	15.20**
TMV-3 × AT-124	6.49	1.44**	0.22	12.67	0.75	2.49**	31.53	1.36**	0.13
TMV-3 × C-1013	6.43	1.12	0.97**	14.39	1.12	1.66*	33.33	0.57	20.30**
Pbtil-1 × PT-64	6.52	1.15	0.80**	14.13	0.91	0.14	32.58	1.09	1.28
Pbtil-1 × AT-124	6.42	1.22	0.31	13.84	0.95	0.07	35.41	0.54**	0.54
Pbtil-1 × C-1013	6.10	0.71	3.71**	13.34	1.36	3.00**	33.25	0.56*	2.53
PT-64 × AT-124	6.83	0.92	0.95**	12.79	0.89	3.02**	30.56	1.04	0.05
PT-64 × C-1013	6.56	1.10	0.07	13.14	1.52**	1.20	32.71	1.20	1.99
AT-124 × C-1013	5.94	0.89	3.86**	12.95	1.20	0.95	32.96	1.14	2.13
Mean	6.29	1.00		13.20	1.00		31.88	1.00	
S.E. ±	0.36	0.25		0.51	0.19		0.80	0.21	

*significant at P = 0.05 level, **significant at P = 0.01 level. DAS = Days after sowing

yield.

Eberhart and Russell (1966) suggested three stability parameters *viz*., regression coefficient (b_i) and deviation from regression (S^2d_i) along with mean performance (μ) of genotypes for various characters to assess the stability and suitability of performance over the location. He defined a stable genotype as one, which produces high mean yield, depicts regression coefficients (b_i) around unity and deviations from regression (S^2d_i) near zero. The perusal of stability parameters for seed yield/plant revealed that among the cultivars, GT-2, GT-10 and GT-1 had high mean than average (7.2 g/plant) along with non-significant regression coefficient near to unity (bi = 0.9 to 1.0) and least deviation from regression (S^2d_i = 0.3 to 0.5), indicated average stable across all the environments (Table 2). Therefore, these cultivars considered to be most stable with wide adaptability in all the environments. The cultivar TMV-3 was highly responsive to favourable environments *ie*., high fertility, which registered high mean (7.3 g/plant), significant regression coefficient more than unity (bi = 1.3*) and non-significant least deviations from regression (S^2d_i = 0.4). Therefore, this cultivar could be suitable for high input and good management conditions. Rajarathinam and Muppidathi (1996) studied that TMV 3 was the most stable genotype with high mean yield and average response in changing environmental conditions. Kumaresan and Nadarajan (2005) also reported that the genotype TMV 3 was identified as stable which exhibited high mean, unit regression coefficient and non significant mean square deviation.

Physiological traits like leaf area index and photosynthetic rate have received little attention in breeding programme because of sequential and destructive methods of sampling from leaves at different growth stages. The information on the stability parameters is very limited on these traits in sesame. In general, the cultivars found stable for seed yield also depicted their stability of performance across the environments for physiological traits. Harvest index is the ratio of grain yield and biological yield. The high yielding cultivars namely GT-2, TMV-3, GT-10 and GT-1 had high mean (32%, 30.8%, 30.7%

Table 4: Stable cultivars and top ten stable hybrids for seed yield and physiological traits in sesame

Parents	Seed yield/ plant (g)	Average stable	Favorable environment	Unfavorable environment
GT-2	7.59	SY, LAI 40, P_N 40, P_N 60, HI		
TMV-3	7.39	LAI 60, HI	SY	P_N 40, P_N 60
GT-10	7.26	SY, LAI 40, LAI 60, HI		P_N 40, P_N 60
GT-1	7.05	SY, HI	P_N 40	
PT-64	6.54	LAI 60, P_N 60		SY, P_N 40, HI
AT-124	6.52	SY, LAI 40		HI
Pbtil-1	6.00	LAI 40		SY, P_N 60, HI
C-1013	5.49			SY, P_N 40, P_N 60, HI
F_1 hybrids				
GT-10 × TMV-3	9.45	LAI 40, P_N 40	SY, P_N 60, HI	
TMV-3 × C-1013	9.26		SY, LAI 40	
GT-10 × PT-64	7.86	SY, P_N 40, P_N 60	LAI 40	HI
Pbtil-1 × PT-64	7.70	SY, LAI 40, P_N 60, HI		
AT-124 × C-1013	7.63	SY, HI	P_N 60	
GT-2 × C-1013	7.61		SY, LAI 60, HI	LAI 40
TMV-3 × PT-64	7.48	SY	LAI 40	
PT-64 × C-1013	7.43	SY, P_N 40	P_N 60	
GT-2 × Pbtil-1	7.29	SY, LAI 60	LAI 40	P_N 40, P_N 60, HI
GT-2 × TMV-3	7.01	SY	LAI 40	P_N 60, HI

SY = Seed yield/plant (g), HI = Harvest index (%), LAI = Leaf area index at 40 and 60 days after sowing; P_N = Photosynthetic rate at 40 and 60 days after sowing (μmol/m^2/s)

and 31.2% respectively) along with regression coefficient near to unity (b_i = 1) and least deviation from regression (Table 3). Hence, these cultivars had wider adaptability for harvest index along with seed yield under studied environments. The cultivars GT-2, GT-10, AT-124 and Pbtil-1 had high mean than the average (3.1), unit regression coefficient (b_i = 1) and least deviation from regression, indicating more stable in diverse environment for leaf area index at 40 days after sowing (DAS) while, the cultivars TMV-3, GT-10 and PT-64 were found average stable for leaf area index at 60 DAS as they had high or at par mean than the average (5.2), near to unity (b_i = 1) and non significant deviation from regression, indicating more stable in diverse environment (Table 2). The cultivar GT-2 was more stable for photosynthetic rate at 40 and 60 DAS as it had high mean along with regression coefficient near unity (b_i = 1) and least deviation from regression (S^2d_i) whereas, the cultivars TMV-3, GT-10 and C-1013 were insensitive to environment changes and had high adaptability to poor environments for photosynthetic rate at 40 and 60 DAS (Table 3), as it had registered with regression coefficient (b_i < 1) and non significant least deviation from regression (S^2d_i = 0). Similarly the stable genotypes were also identified in sesame for seed yield by Manivannan and Ganesan (2001); Iwo *et al.* (2002); Chaudhari *et al.* (2005); Kumar *et al.* (2006); Kumar *et al.* (2008) and Kumaresan and Nadarajan (2010).

The most stable hybrids based on high yield were presented in Table 4 revealed that none of the hybrids were stable for all the traits. However, trait wise results of genotypes showing specific adaptation to average, favourable (better management conditions) and unfavourable (poor management conditions) environments were presented. For seed yield/plant, ten hybrids were found stable for ideal and specific environments (Table 4), as they recorded high mean than the than average (7.2 g/ plant). For harvest index, the hybrid Pbtil-1 × PT-64 and AT-124 × C-1013 were found stable for average environment, while the hybrid GT-10 × TMV-3 and GT-2 × C-1013 were more sensitive to environmental changes. Therefore these hybrids were found stable for favourable environment and hybrids GT-10 × PT-64, GT-2 × Pbtil-1 and GT-2 × TMV-3 had above average stability. Hence, these hybrids were considered to be stable under poor environmental conditions for harvest index.

The hybrids, GT-10 × TMV-3 and Pbtil-1 × PT-64 for leaf area index at 40 DAS and hybrid GT-2 × Pbtil-1 for leaf area index at 60 DAS were found stable and had wide adaptability for these traits. The hybrids GT-10 × TMV-3, GT-10 × PT-64 and PT-64 × C-1013 for photosynthetic rate at 40 DAS and the hybrids GT-10 × PT-64 and Pbtil-1 × PT-64 for photosynthetic rate at 60 DAS were found average stable, as they had high mean, non significant regression coefficient near to unity (b_i = 1) and least deviation from regression. Therefore, these hybrids could be considered stable in diverse environments (Table 4). The potential yield of each hybrid can be realized under a particular set of agronomical practices. It is suggested that in order to identify stable hybrid, actual testing under variable environments, including average, favourable and unfavourable, would be advantageous. During the selection process, the focus should be on stability of characters for getting the maximum stability for seed yield in sesame.

Phenotypic correlation coefficients (r_p) under timely sown at recommended dose of fertilizers namely N, P, S (E_1) showed that seed yield was significant and positively correlated with harvest index (0.82**) and leaf area index at 60 DAS (0.32*), whereas it was also positive and highly significant with harvest index (0.55**), leaf area index at 60 DAS (0.58**) and photosynthetic rate at 60 DAS (0.44**) at high dose of fertilizers application (E_2). It indicated that harvest index, leaf area index and photosynthetic rate had high correlation with seed yield under high input environment (Table 5). Similarly under late sown condition at recommended dose of fertilizers (E_3) revealed that seed yield was significant and positively correlated with harvest index (0.65**) and photosynthetic rate at 60 DAS (0.34*), however it was highly significant correlation with

Table 5: Correlation coefficient of seed yield and physiological traits under E_1 (below diagonal) and E_2 (above diagonal) environments in sesame

	SY	HI	LAI 40	LAI 60	P_N 40	P_N 60
SY	-	0.554**	0.084	0.585**	0.227	0.440**
HI	0.825**	-	-0.276	0.482**	0.463**	0.471**
LAI 40	-0.274	-0.324*	-	0.248	-0.354*	-0.062
LAI 60	0.317*	0.341*	-0.161	-	0.196	0.338*
P_N 40	0.036	0.007	-0.021	0.074	-	0.119
P_N 60	0.289	0.211	-0.129	0.100	-0.131	-

*significant at P < 0.05 level, **significant at P < 0.01 level.SY = Seed yield/plant (g); HI = Harvest index (%), LAI = Leaf area index, P_N = Photosynthetic rate (μmol/m^2/s)

Table 6: Correlation coefficient of seed yield and physiological traits under E_3 (below diagonal) and E_4 (above diagonal) environments in sesame

	SY	HI	LAI 40	LAI 60	P_N 40	P_N 60
SY	-	0.641**	0.224	0.070	0.411**	0.373*
HI	0.657**	-	0.162	0.070	0.459**	0.337*
LAI 40	-0.025	0.065	-	0.104	0.447**	0.419**
LAI 60	0.071	0.301	0.096	-	-0.141	0.158
P_N 40	-0.133	0.136	0.219	-0.186	-	0.445**
P_N 60	0.336*	0.143	0.360*	-0.022	0.307	-

harvest index (0.64**), photosynthetic rate at 40 DAS (0.41**) and photosynthetic rate at 60 DAS (0.37*) at high dose of fertilizers application (E_4). It also showed that harvest index and photosynthetic rate at 40 and 60 DAS had high correlation with seed yield under high input conditions in late sown environments (Table 6).

This was observed that all the traits had greater magnitude of correlation under high input conditions irrespective of timely and late sown environments. Reduction in leaf area and photosynthetic rate under low input environment (N,P,S) was because of nitrogen and phosphorus are essential components of virtually all the key molecules and tissues that make plant life possible. Deficiencies in either element result in quantitative decreases in the physiological activity of the crop. Leaf area development is one of the more sensitive responses of crop growth to N and P deficiencies. Photosynthesis rates are also decreased in response to severe limitations of N and P accumulation in the plant (Sinclair and Vadez, 2002). Physiological characters like leaf area index, photosynthetic rate had positively significant association with seed yield was reported by Ramakrishnan and Soundarapandian (1990); Reddy *et al*. (1993) and Kumaresan and Nadarajan (2002). It was observed that leaf area index and harvest index showed a significant and positive association with yield per plant in sesame. These results were in agreement with those of Pawar (2002); Babu *et al*. (2004) and Mohammed (2009). Haruna *et al*. (2012) reported positive and significant correlation between leaf area index and the yield (r = 0.15*). Kurdistan *et al*. (2011) reported that seed yield was positive and significantly correlated with harvest index.

It was very interesting that seed yield had no correlation with leaf area index at 40 DAS and photosynthetic rate at 40 DAS under all the environments except for photosynthetic rate at 40 DAS under late sown and high fertilizer applications environment (E_4). Hence, selection for these traits could not much reliable for improving seed yield in sesame. Leaf area index at 60 DAS was positive and significantly correlated with seed yield in environment E_1 (0.31*) and E_2 (0.58**), whereas it had no correlation with seed yield under late sown environment (E_3 and E_4). However, the photosynthetic rate at 60 DAS was significant and positively correlated with seed yield under the environment E_3 and E_4 (late sown at normal and high fertilizer application respectively), and environment E_2 (timely sown at high fertilizer application). Liu *et al*. (2005) recorded that LAI at reproductive stage strongly influenced yield in soyabean. This suggested that leaf area index at 60 DAS could be used as selection criteria for improving seed yield under timely sown environments irrespective of low and high fertility conditions, while for photosynthetic rate at 60 DAS under high fertility even though timely and late sown environments. Thus, these physiological traits are very important in sesame breeding programme and improvement in yield may be possible while selecting for these traits.

It is concluded that the high yielding cultivars like GT-2, GT-10 and GT-1 had stable performance over the environment with broad adaptability and cultivar TMV-3 had specific adaptability to favourable environments for seed yield/plant. The cultivar GT-10 for leaf area index at 40 and 60 DAS and the cultivar GT-2 for photosynthetic rate at 40 and 60 DAS were found most stable across the environments. The hybrids like GT-10 × TMV-3, TMV-3 × C-1013, GT-10 × PT-64, Pbtil-1 × PT-64, AT-124 × C-1013, GT-2 × C-1013, TMV-3 × PT-64, PT-64 × C-1013, GT-2 × Pbtil-1 and GT-2 × TMV-3 were found most stable across the environments for seed yield/plant and physiological traits. Therefore, these hybrids could be valuable for large scale testing over the environments and subsequently for further exploited through the isolation of transgressive segregants for seed yield and physiological traits to develop high yielding stable sesame cultivars with broad adaptability over the environments.

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