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RESEARCH ARTICLE

Estimate of genetic components for yield and its component under normal and heat stress conditions in pea (*Pisum sativum* L.)

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Abstract

This investigation was carried out to study the gene action in pea (*Pisum sativum* L.) under normal and heat stress conditions, at experimental farm faculty of Agriculture, south valley university, Qena, Egypt during the two seasons (2021-2022) and (2022- 2023), respectively. The results showed that the mean squares of 45 genotypes were highly significant for all studied traits, reflecting a great wide genetic variability among them. The analysis revealed, there were high significant additive and non-additive effects over normal and heat stress conditions as indicated by the significance of (a) and (b) items. The additive mean square was greater than non-additive for all the studied traits under both environmental conditions. Additive genetic variance (D) and Non-additive (H_1 and H_2) components were highly significant for all traits under normal and heat stress conditions. The values of heritability in broad senses and narrow senses were estimated for all studied. The results of narrow sense (h^2_N) heritability h^2_N value was higher than 50% for most traits except fresh pod yield/plant. Finally, it could be concluded that the additive and non- additive gene action played a major role in controlling for all traits under normal and heat stress conditions, and useful for breeding and selection programs. Also, it is possible predict the existence of super genetic isolation in future generations.

Keywords: Additive and Non-additive genetic; Diallel; Heat stress; Pea; Wr/Vr relationship.

1. Introduction

In Egypt, pea (*Pisum sativum* L.) is one of the most important vegetable crops for both local consumption and exportation. Therefore, it is of interest to increase its yield's quality and quantity to fulfill the exportable and/or locality demands (Mousa, 2010; Elsaman, 2022). At global level, garden pea is cultivated over an area of 2.3 million hectares with production of 17.43 million metric tonnes (Anonymous, 2018). Heat stress (HS) is considered abiotic constrains in plant production (El-Rawy *et al.*, 2018).

(*Pisum sativum* L.) is sensitively to high temperature (Guilioni *et al.*, 1997) and the most damaging effect on younger reproductive growth flowers and pods developed later (Krishna Jagadish, 2020). Overall productivity of pea (*Pisum sativum* L.) is being threatened by several abiotic stress including heat stress. Heat stress causes severe yield losses by adversely affecting several traits in peas (Elshazly *et al.*, 2023). When the mean daily temperature is between 30.5 and 33 degrees Celsius, especially during the reproductive phase, it is known to significantly lower both seed yield and germination, resulting in a drop in pod yield of 11.1% to 17.5% (DEVI *et al.*, 2023). Diallel mating fashion widely used to obtain information on the inheritance of quantitative traits to select the best parental

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combination for crosses (El Ameen *et al.,* 2020), and to determine the heterotic responses and heterotic patterns (Hayman, 1954a; 1954b). Genotype interaction of environment was highly significant for all traits in Pea (Goa and Ashamo, 2014). Also, Bocianowski *et al.* (2019) investigated the genotype by environment interaction in Pea. The aims of the present study are to determine the response of some parental and F_1 populations of pea to seasonal changes to choose the best parents and lines to grow in upper Egypt. Among the objectives, also was to study the type of gene action controlling the studied traits and consequently identify the most efficient breeding procedure leading to maximum genetic improvement for these traits under the environmental changes of Qena Governorate.

2. Materials and methods

The field experiments of the present study were carried out at the Experimental Farm of the Faculty of Agriculture, South Valley University, Qena, Egypt. The initial plant material used in the present study consisted of nine genotypes of pea (*Pisum sativum* L.) i.e., Super 2 (P_1), L-33 (P_2), Sweet 2 (P_3), Dwarf Gray Sugar (P_4), Mammoth Melting Sugar (P_5), L-24 (P_6), L-10 (P_7), Sweet 1 (P_8) and Master B (P_9). P_2, P_6 and P_7 are lines from the breeding program of El-Dakkak *et al.* (2015).

2.1. Experimental procedure

In 2021/2022 winter, season, the nine parental genotypes were crossed in a half diallel pattern without reciprocals to produce 36 F_1 hybrids. In 2022/2023 winter, season, seeds of the parental genotypes and their F_1 hybrids (45 entries) were planted on 25st September 2022 as a sowing (Heat stress condition) and as an optimal sowing date 20st November 2022 (Normal condition). The recorded temperatures at the experimental site during September, October, November, December, January, February and March 2022/2023. (Fig.1).

All genotypes were subjected to statistical analysis of variance for days to 50% flowering, Pod length, Pod width, Number of seeds/pod, Number of pods/plant, 100-fresh seed weight, Fresh pod yield/plant and Fresh seed yield/plant (Jiang *et al.,* 2020).

2.2. Statistical analysis

2.2.1. Analysis of variance

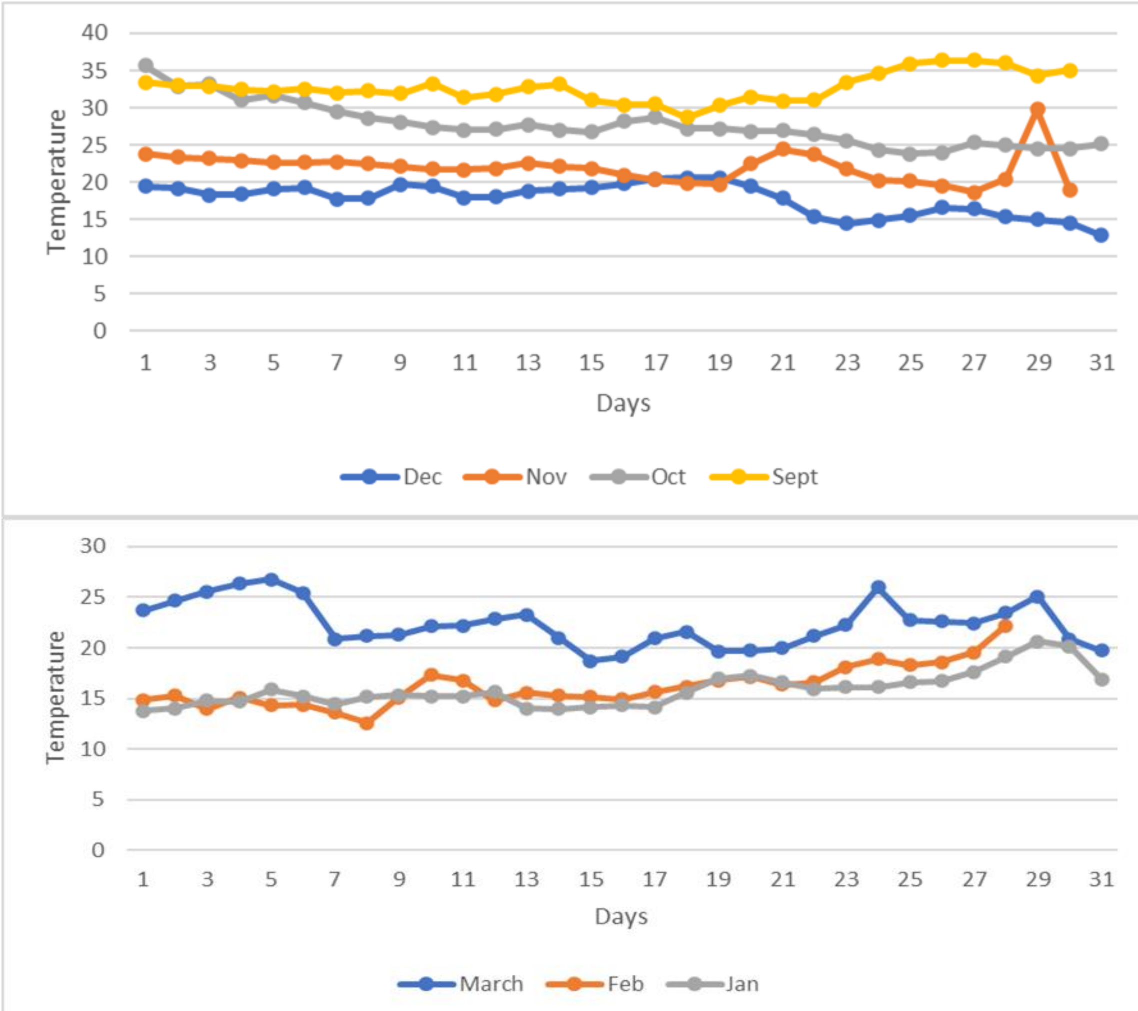
Data were subjected to general analysis of variance for (RCBD) according to Steel and Torrie (1960) and Cochran and Cox (1957).

2.2.2. The diallel analysis

Analysis of variance was carried out following Jones (1965) modification for the half diallel cross. The parental and F_1 data were analyzed using the diallel analysis as developed by Hayman (1954 a; b) and Mather and Jinks (1971). Moreover, The Wr / Vr graph for each trait was constructed following the method suggested by Hayman (1954b). Also, the statistics were evaluated for each replicate and then averaged over all to provide the following calculates of variance components as outlined by Mather and Jinks (1971).

2.2.3. Stress Tolerance Indices

Five stress tolerance indices were derived for each hybrid based on the average yield of fresh pod yield/plant (g) under normal (Yn) and heat stress (Ys) conditions. Table 1 displays the names, formulae, and references for the stress tolerance indexes. Where Yn and Ys represented, respectively, each genotype's yield under stress-free and stressful conditions. $\hat{Y}n$ and $\hat{Y}s$ stand for yield mean under non-stress and stress conditions, respectively for all F_1 hybrids, respectively.



provided by South Valley University Meteorological Research Station

Figure 1. The recorded temperatures at the experimental.

Table 1. List of the heat stress tolerance indexes and formula.

Item	The high values of these indexes indicated to stress tolerance						The high values of these index indicated to stress susceptibility	
Index	Mean productivity	Relative heat stress index	Yield Index	Heat stress resistance index	Modified Stress Tolerance Index 1	Modified stress tolerance index 2	Stress Susceptibility percentage index	Abiotic tolerance index
Abbr.	MP	RHSI	YI	HSI	$MSTI_1$	$MSTI_2$	SSPI	ATI
Formula	(Yn+Ys)/2	$(Ys/Yn)/(\bar{Y}s/\bar{Y}n)$	$Ys/\bar{Y}s$	$(Ys\times(Ys/Yn))/\bar{Y}s$	$[(Yn)^2/(\bar{Y}n)^2]\times STI$	$[(Ys)^2/(\bar{Y}s)^2]\times STI$	$[(Yn-Ys)/(2\times\bar{Y}n)]\times 100$	$[(Yn-Ys)/(\bar{Y}n/\bar{Y}s)]\times\sqrt{Yn\times Ys}$
References	Fernandez (1992)	Fischer and Wood (1979)	Gavuzzi *et al.* (1997)	Lan (1998)	Farshadfar and Sutka (2002)		Moosavi *et al.* (2008)	

3. Results and discussion

2.2. The Genotypic Variation Analysis

Nine parents and 36 hybrids of pea were evaluated to estimate the magnitudes of genotypic variation which are presented among them. 45 genotypes were planted under Normal condition and Heat stress conditions. The results of analysis of variance for all traits under normal and heat stress conditions are given in (Table 2 and 3). The results showed that mean square of environment (E) was highly significant for all traits under study. Also, the mean square of Genotypes (G) was highly significant for all traits. Moreover, mean square due to genotype x environment (GxE) was highly significant for all traits except pod diameter was non- significant. Similar results were obtained by (Jiang *et al.,* 2020; Lamichaney *et al.,* 2021; Seepal *et al.,* 2022; Huang, 2022).

2.3. Mean performance

The mean of nine parents and their F_1's hybrids for all studied traits showed in Table (4 and 5). Day 50% flowering under normal and heat stress conditions are shown in (Table 4) the parent average of flowering ranged from 50 under normal to 55.15 under stress condition. However, the mean over all F_1's hybrids increased from 51.5 to 55.17 under normal and heat stress. The mean of nine parents and their F_1's hybrids for pod length under normal and heat stress conditions. the parent average of pod length ranged from 9.93 cm under normal to 8.97 cm under stress condition. However, the mean over all F_1's hybrids increased from 10.20 to 9.14 cm under normal and heat stress. Moreover, The mean of nine parents and their F_1's hybrids for pod diameter under normal and heat stress conditions. the parent average of pod diameter ranged from 14.89 mm under normal to 14.28 mm under stress condition. Moreover, the mean over all F_1's hybrids increased from 14.58 to 14.04 mm under normal and stress. The mean of nine parents and their F_1's hybrids for No. of seeds/pod under normal and heat stress conditions. the parent average of No. of seeds ranged from 7.70 under normal to 6.68 under stress condition. However, the mean over all F_1's hybrids increased from 7.85 to 7.25 cm under normal and heat stress (Table 4). The mean of nine parents and their F_1's hybrids for No. of pods/plant under normal and heat stress conditions (Table 5). the parent average of No. of pods ranged from 8.48 under normal to 6.08 under stress condition. However, the mean over all F_1's hybrids increased from 11.24 to 6.57 under normal and stress. The mean of nine parents and their F_1's hybrids for 100-fresh seed weight (g) under normal and heat stress conditions. the parent average of 100-fresh seed weight (g) ranged from 54.09 g under normal to 45.03 g under stress condition. However, the mean over all F_1's hybrids increased from 53.86 to 49.00 g under normal and stress. The mean of nine parents and their F_1's hybrids for Fresh seeds yield/plant (g) under normal and heat stress conditions are shown in Table 5. the parent average of Fresh seeds yield (g) ranged from 50 under normal to 55.15 g under stress condition. However, the mean over all F_1's hybrids increased from 51.5 g to 55.17 g under both normal and stress conditions. Also, the mean of nine parents and their F_1's hybrids for Fresh pod yield/plant (g) under normal and heat stress conditions are shown in (Table 5) the parent average of Fresh pod yield/plant (g) ranged from 61.66 g under normal to 41.46 g under stress condition. However, the mean over all F_1's hybrids increased from 82.92 to 42.76 g under normal and stress. Similar results were obtained by (Mohapatra *et al.,* 2020; Lamichaney *et al.,* 2021; Seepal *et al.,* 2022; Elsaman, 2022).

Table 2. Analysis of variances and mean squares of the nine parents and their 36 F_1 hybrids for the studied traits under normal (N), Heat stress (HS) conditions and Environment interaction (EI).

S.V.O.	D.F		Mean squares											
			Days to 50% Flowering (Day)			Pod length (cm)			Pod diameter (mm)			Number of seeds/pod		
	S	EI	N	HS	EI	N	HS	EI	N	HS	EI	N	HS	EI
Environment (E)	--	1	--	--	704.06**	--	--	72.70**	--	--	20.49**	--	--	31.23**
Replication (R)	2	4	25.87	0.90	13.38	2.56	1.72	2.14	0.35	0.63	0.49	0.24	0.08	0.16
Genotypes (G)	44	44	97.08**	71.75**	120.28**	3.13**	2.68**	5.11**	8.31**	8.39**	16.00**	2.09**	2.65**	3.39**
G x E	--	44	--	--	48.55**	--	--	0.69*	--	--	0.70	--	--	1.35**
Error	88	176	6.45	1.53	3.99	0.30	0.35	0.33	0.20	0.52	0.36	0.04	0.31	0.18

**, ** Significant at 5 and 1% levels of probability, respectively.*

Table 3. Analysis of variances and mean squares of the nine parents and their 36 F_1 hybrids for the studied traits under normal (N), Heat stress (HS) conditions and Environment interaction (EI).

S.V.O.	D.F		Mean squares											
			Number of pods/plant			100-fresh seed weight (g)			Fresh seed yield (g/plant)			Fresh pod yield (g/plant)		
	S	EI	N	HS	EI	N	HS	EI	N	HS	EI	N	HS	EI
Environment (E)	--	1	--	--	1197.44 **	--	--	2193.33 **	--	--	33161.40 **	--	--	88295.60 **
Replication (R)	2	4	1.23	0.37	0.80	8.93	8.03	8.48	1.08	18.12	9.60	7.00	10.91	8.95
Genotypes (G)	44	44	19.31**	5.57**	16.65 **	243.84**	390.88**	487.16**	396.81**	80.66**	271.29 **	1214.96**	563.62**	1212.45 **
G x E	--	44	--	--	8.23 **	--	--	147.56 **	--	--	206.18 **	--	--	566.13 **
Error	88	176	0.60	1.84	1.22	16.61	0.77	8.69	10.53	3.55	7.04	11.36	7.82	9.59

**, ** Significant at 5 and 1% levels of probability, respectively.*

Table 4. Mean performance of the nine parents and their 36 F_1 hybrids under Normal (N) and Heat stress (HS).

Traits / Genotypes	Days to 50% Flowering (Day)		Pod length (cm)		Pod width (mm)		Number of seeds/pod	
	N	HS	N	HS	N	HS	N	HS
P_1	56.33	50.67	10.31	9.08	14.34	13.10	8.46	7.33
P_2	56.67	59.67	9.63	9.02	13.35	13.10	7.88	6.84
P_3	59.33	54.33	10.24	9.61	15.57	15.09	6.00	5.62
P_4	59.00	62.67	7.64	6.82	13.63	12.55	5.73	6.00
P_5	59.33	61.33	10.90	10.03	19.37	18.53	9.00	6.33
P_6	45.00	56.33	11.09	9.80	14.57	13.31	9.10	8.33
P_7	43.00	51.33	9.74	8.49	13.86	14.50	8.45	7.00
P_8	36.00	50.33	10.31	9.43	15.74	15.34	6.88	6.67
P_9	35.33	46.67	9.53	8.41	13.58	13.03	7.81	5.99
P's Means	**50.00**	**54.81**	**9.93**	**8.97**	**14.89**	**14.28**	**7.70**	**6.68**
P_1XP_2	56.00	48.67	9.68	8.22	13.41	12.37	8.25	7.75
P_1XP_3	55.67	50.67	10.99	8.72	14.95	14.63	7.31	7.98
P_1XP_4	50.33	58.67	8.88	7.60	13.05	12.70	8.04	6.37
P_1XP_5	52.00	54.67	11.56	9.23	16.29	16.82	8.00	6.33
P_1XP_6	54.33	56.67	10.70	10.45	14.18	13.09	8.63	7.67
P_1XP_7	49.67	53.33	10.53	10.10	14.07	13.63	8.88	8.67
P_1XP_8	53.00	54.67	10.53	9.57	14.87	13.61	7.50	7.67
P_1XP_9	49.33	55.67	10.12	9.05	13.06	12.77	8.88	8.50
P_2XP_3	54.00	60.67	10.02	9.33	15.10	13.81	7.75	7.83
P_2XP_4	53.67	52.33	8.41	8.05	12.04	12.42	7.94	5.33
P_2XP_5	56.00	47.33	10.25	9.90	15.76	16.06	7.31	7.78
P_2XP_6	56.00	59.33	9.87	9.67	13.50	13.33	7.67	7.34
P_2XP_7	52.33	53.33	9.68	8.84	12.99	12.27	8.25	8.40
P_2XP_8	54.33	53.00	9.88	9.29	14.29	13.18	7.50	7.02
P_2XP_9	56.00	53.33	9.50	9.51	13.42	13.15	7.50	7.49
P_3XP_4	54.67	55.33	8.63	8.26	14.49	13.97	7.06	6.83
P_3XP_5	53.00	56.00	10.53	9.49	16.99	16.60	6.44	6.67
P_3XP_6	53.00	60.00	11.33	10.77	15.71	16.24	7.31	7.33
P_3XP_7	59.00	61.67	10.09	10.07	13.83	14.06	7.75	7.57
P_3XP_8	50.33	44.00	11.13	8.67	15.97	15.57	7.17	5.53
P_3XP_9	54.00	60.67	11.10	8.91	14.49	13.12	7.69	5.72
P_4XP_5	54.33	52.33	8.43	8.53	15.68	15.73	5.78	6.78
P_4XP_6	52.67	60.00	8.59	7.11	12.00	11.64	7.60	5.67
P_4XP_7	50.00	62.67	8.63	7.39	12.18	12.33	7.69	8.00
P_4XP_8	51.00	54.33	9.70	8.73	15.04	13.90	7.91	6.67
P_4XP_9	44.67	47.67	8.23	8.22	11.38	11.88	6.94	6.67
P_5XP_6	51.33	52.00	11.71	10.54	17.69	16.64	8.10	8.27
P_5XP_7	49.67	52.00	11.06	9.53	17.27	17.70	8.05	7.83
P_5XP_8	52.33	53.33	11.10	9.58	17.02	15.00	7.67	8.00
P_5XP_9	48.67	52.33	11.39	9.60	17.57	15.88	8.00	7.33
P_6XP_7	48.00	61.33	10.66	9.88	13.63	12.52	9.25	7.33
P_6XP_8	50.33	59.67	12.11	11.15	15.89	15.59	8.94	8.50
P_6XP_9	48.00	49.33	10.22	9.37	13.67	13.43	8.25	7.67
P_7XP_8	47.33	54.67	11.13	9.58	15.27	15.05	8.55	8.50
P_7XP_9	42.67	44.33	10.26	8.10	13.89	12.40	9.06	6.83
P_8XP_9	38.33	52.00	10.46	8.07	14.19	12.35	8.00	5.33
F_1's Means	**51.56**	**54.39**	**10.20**	**9.14**	**14.58**	**14.04**	**7.85**	**7.25**
$L.S.D_{5\%}$	4.11	2.00	0.89	0.96	0.72	1.17	0.32	0.90
$L.S.D_{1\%}$	5.43	2.64	1.17	1.26	0.96	1.54	0.43	1.19

Table 5. Mean performance of the nine parents and their 36 F_1 hybrids under Normal (N) and Heat stress (HS).

Traits / Genotypes	Number of pods/plant		100-fresh seed weight (g)		Fresh seed yield/plant (g)		Fresh pod yield/plant (g)	
	N	HS	N	HS	N	HS	N	HS
P_1	7.69	6.44	48.67	27.00	28.20	20.09	60.42	50.48
P_2	9.45	7.61	53.86	43.95	36.85	20.58	64.64	48.74
P_3	9.47	7.83	59.00	51.64	27.92	18.15	67.58	53.66
P_4	10.48	5.92	32.67	29.42	23.89	11.35	34.78	19.57
P_5	7.96	6.61	55.24	50.47	36.23	17.05	80.65	62.94
P_6	10.77	7.06	62.35	46.54	48.84	22.26	95.36	51.42
P_7	8.47	5.17	48.84	42.56	29.58	23.66	57.55	28.11
P_8	6.39	4.28	68.60	63.21	27.39	16.53	51.94	33.43
P_9	5.64	3.81	57.59	50.48	23.34	15.82	42.07	24.81
P's Means	8.48	6.08	54.09	45.03	31.36	18.39	61.67	41.46
P_1XP_2	9.44	7.83	50.57	58.73	44.73	19.42	75.35	41.35
P_1XP_3	10.72	6.42	56.39	45.13	41.17	17.02	89.48	44.99
P_1XP_4	14.84	8.50	44.77	35.72	45.23	12.69	82.85	29.16
P_1XP_5	11.05	7.92	65.22	59.60	52.22	18.31	89.74	67.99
P_1XP_6	11.37	7.61	58.60	39.23	60.78	28.21	96.40	76.31
P_1XP_7	8.11	7.00	59.37	41.76	42.58	21.79	73.54	43.84
P_1XP_8	8.58	6.50	61.31	51.46	36.82	25.76	65.32	43.51
P_1XP_9	11.03	6.56	54.49	39.82	48.30	19.71	81.64	36.99
P_2XP_3	12.80	7.00	57.63	48.73	47.91	28.19	94.27	56.42
P_2XP_4	10.22	8.80	37.76	52.70	25.50	23.57	48.80	40.40
P_2XP_5	9.86	6.67	48.07	61.87	30.65	26.37	71.43	51.65
P_2XP_6	9.89	6.50	47.27	40.13	46.57	21.41	58.92	47.14
P_2XP_7	9.88	6.56	49.41	37.63	39.52	23.97	72.93	43.92
P_2XP_8	7.72	7.08	53.81	43.80	30.25	23.44	65.79	45.91
P_2XP_9	9.54	7.69	49.08	53.09	33.95	27.22	68.76	50.09
P_3XP_4	16.85	9.11	49.07	47.77	51.16	24.33	102.31	45.72
P_3XP_5	16.00	5.38	62.00	55.17	68.61	19.61	98.93	39.93
P_3XP_6	14.07	7.44	59.06	48.92	62.98	32.90	119.73	65.10
P_3XP_7	8.33	4.83	44.95	44.37	25.77	20.90	52.62	37.20
P_3XP_8	11.16	6.00	68.79	85.06	59.70	22.84	101.48	42.46
P_3XP_9	10.43	4.44	55.32	58.36	56.49	9.04	81.20	22.75
P_4XP_5	11.96	7.17	41.88	56.04	37.11	16.11	61.56	39.67
P_4XP_6	14.86	6.31	35.86	41.76	38.27	14.40	71.11	31.39
P_4XP_7	15.86	7.17	39.86	31.76	44.70	13.47	72.66	27.51
P_4XP_8	13.11	7.89	49.19	37.70	45.88	22.58	84.57	36.78
P_4XP_9	13.25	6.83	37.30	34.93	35.59	18.37	60.94	30.00
P_5XP_6	10.82	7.50	61.27	67.19	59.14	25.63	100.96	57.89
P_5XP_7	11.66	4.30	58.88	58.63	48.74	13.19	101.56	24.74
P_5XP_8	11.18	4.67	59.64	67.57	45.72	19.32	102.88	37.94
P_5XP_9	11.88	8.39	63.45	42.05	54.67	24.20	123.90	51.71
P_6XP_7	11.06	5.06	54.60	40.12	47.50	18.16	96.39	35.83
P_6XP_8	10.11	6.25	61.96	48.63	51.13	22.39	96.08	55.57
P_6XP_9	11.08	4.17	54.57	31.97	53.58	10.52	99.20	22.60
P_7XP_8	9.92	5.83	65.27	58.76	42.15	27.01	84.51	66.80
P_7XP_9	9.71	4.83	53.17	42.35	44.80	20.07	80.22	23.70
P_8XP_9	6.11	4.33	69.03	55.40	28.14	15.22	57.17	24.51
F_1's Means	**11.24**	**6.57**	**53.86**	**49.00**	**45.22**	**20.76**	**82.92**	**42.76**
L.S.D $_{5\%}$	1.25	2.19	6.59	1.42	5.25	3.05	5.45	4.52
L.S.D $_{1\%}$	1.66	2.90	8.71	1.88	6.93	4.03	7.20	5.98

3.3. The diallel analysis of variation

The analysis revealed, there were high significant additive and non-additive effects over normal and heat stress conditions as indicated by the significance of (a) and (b) items. The additive mean square was greater than non-additive for all the studied traits under both environmental conditions (Table 6 and 7). On partitioning the non-additive item (b) in to its components, it was evident from the significance of item (b_1) for all traits under normal except 100-fresh seed weight. Moreover, high significant for Number of seeds/pod, 100-fresh seed weight, Fresh seed yield and Fresh pod yield (g/plant) but non-significance for under heat stress for Days to 50% Flowering, Pod length and Pod width, respectively. The highly significant (b_2) items indicated asymmetrical distribution of genes affecting for all traits under normal and heat stress conditions except Pod length at loci showing dominance, while highly significance of (b_3) under both environmental conditions indicated further dominance effects due to specific combination and / or epistasis. Similar results were exhibited by (Kandeel *et al*., 2005; Mousa, 2010; Esho *et al.*, 2012; Kosev, 2013; Esho *et al.*, 2014; Kosev and Georgieva, 2016; El-Rawy *et al.*, 2018).

Table 6. The diallel analysis of variance of the F_1 diallel for all traits under normal condition.

Item	d.f	M.S							
		Days to 50% Flowering	Pod length	Pod width	Number of seeds/pod	Number of pods/plant	100-fresh seed weight	Fresh seed yield	Fresh pod yield
a	8	486.5**	26.17**	70.04**	11.49**	96.31**	1873.1**	1395.71**	4531.00**
b	36	59.16**	1.11**	2.34*	1.51**	19.71**	110.4**	513.93**	1492.14**
b_1	1	58.07**	1.66*	2.33*	0.54**	182.1**	1.321	4612.55**	10845.11**
b_2	8	99.77**	1.00**	1.45*	2.33**	13.49**	116.6**	301.59**	568.64**
b_3	27	47.17**	1.12**	2.60*	1.31**	15.54**	112.6**	425.003**	1419.36**
B X a	16	14.04	1.04	0.16	0.05	1.27	41.62	23.59	21.70
B X b	72	11.64	0.47	0.39	0.09	1.10	29.22	18.95	20.88
B X b_1	2	3.82	0.01	0.10	0.024	0.12	8.92	0.29	3.43
B X b_2	16	7.86	0.21	0.21	0.03	0.70	11.71	9.35	15.33
B X b_3	54	13.05	0.56	0.45	0.11	1.25	35.16	22.48	23.17
Block interaction	88	12.07	0.57	0.35	0.08	1.13	31.47	19.78	21.02

*, ** *Significant at 5 and 1% levels of probability, respectively.*

Table 7. The diallel analysis of variance of the F_1 diallel for all traits under heat stress condition.

Item	d.f	M.S							
		Days to 50% Flowering	Pod length	Pod width	Number of seeds/pod	Number of pods/plant	100-fresh seed weight	Fresh seed yield	Fresh pod yield
a	8	180.4**	17.33**	65.22**	9.99**	27.02**	2018.6**	214.84**	2507.4**
b	36	114.7**	2.04**	3.62**	3.63**	6.15**	414.2**	137.10**	666.1**
b_1	1	4.354	0.72	1.44	7.93**	5.77	377.9**	135.02**	40.58*
b_2	8	86.64**	0.43	1.43**	1.21*	5.72**	254.4**	43.32**	136.6**
b_3	27	127.1**	2.57**	4.35**	4.19*	6.29**	462.9**	164.96**	846.2**
B X a	16	4.06	0.50	0.46	0.31	3.50	2.01	7.25	13.77
B X b	72	2.47	0.67	1.01	0.61	3.34	0.96	6.16	14.82
B X b_1	2	1.14	0.53	0.29	0.23	2.15	2.12	2.21	9.58
B X b_2	16	1.96	0.30	0.93	0.25	1.82	1.40	3.98	7.50
B X b_3	54	2.67	0.78	1.07	0.72	3.83	0.79	6.96	17.11
Block interaction	88	2.76	0.64	0.91	0.55	3.37	1.16	6.36	14.63

*, ** *Significant at 5 and 1% levels of probability, respectively*.

3.4. The Wr/Vr relationship

The joint regression analysis of the covariance (Wr) on the variance (Vr) for traits studied under normal condition are showed in Table 8. The results exhibited that the slope of the regression line was significantly deviating from zero but not from unity for Days to 50% Flowering (b = 1.21±0.12), Number of seeds/pod (b = 0.82±0.30), 100-fresh seed weight (b = 0.77±0.12) and Fresh pod yield (b = 0.52±0.20) indicating full adequacy of an additive-dominance model. However, the regression coefficients were significantly different from zero and also from unity for Pod length (b = 0.61±0.07) and Pod width (b = 0.67±0.05), indicating partial adequacy of the genetic model. However, non-adequate additive-dominance model was observed for Number of pods/plant (b = 0.25±0.20) and Fresh seed yield (b = 0.17±0.14) under normal condition.

Highly significant or significant (Wr + Vr) mean squares were observed in all the traits, indicating the presence of a significant dominance variance. Meantime, the differences in (Wr – Vr) values were significant in most traits under study, except Pod length, Pod width and 100-fresh seed weight, indicating of epistasis, respectively. (Table 8).

Table 8. Joint regression analysis and mean squares of (Wr+Vr) and (Wr–Vr) for the traits studied under normal condition.

Traits	Days to 50% Flowering	Pod length (cm)	Pod width (mm)	Number of seeds/pod	Number of pods/plant	100-fresh seed weight (g)	Fresh seed yield (g/plant)	Fresh pod yield (g/plant)
Joint regression (b ± se)	1.21±0.12	0.61±0.07	0.67±0.05	0.82±0.30	0.25±0.20	0.77±0.12	0.17±0.14	0.52±0.20
Test for b = 0	10.08**	8.71**	13.40**	2.73*	1.25 ns	6.42**	1.21 ns	2.63*
Test for b = 1	1.75 ns	-5.57**	-6.60**	-0.60 ns	-3.75**	-1.92 ns	-5.93**	-2.40 ns
Mean squares of (Wr + Vr)	3787.9**	0.683**	5.10**	0.79**	21.68**	2697.2*	13839.28**	147531.13**
Mean squares of (Wr - Vr)	85.19*	0.0599 ns	0.20 ns	0.15**	11.93**	115.4 ns	7998.27**	30559.45**
Fitness of the model	Fully Adequate	Partially adequate	Partially adequate	Fully Adequate	Non adequate	Fully Adequate	Non adequate	Fully Adequate
Dominance degree	partial dominance	partial dominance	partial dominance	Complete dominance	complemental non-allelic gene interaction	partial dominance	complemental non-allelic gene interaction	Over dominance

**, ** Significant at 5 and 1% levels of probability, respectively.*

The joint regression analysis of the covariance (Wr) on the variance (Vr) for traits studied under heat stress condition are showed in Table 9. The results exhibited that the slope of the regression line was significantly deviating from zero but not from unity for Pod width (b = 0.83±0.15), Number of seeds/pod (b = 0.84±0.20), 100-fresh seed weight (b = 0.72±0.25) and Fresh pod yield (b = 0.52±0.22) indicating full adequacy of an additive-dominance model. However, the regression coefficients were significantly different from zero and also from unity for Pod length (b = 0.59±0.11), indicating partial adequacy of the genetic model. However, non-adequate additive-dominance model was observed for Days to 50% Flowering (b = 0.39±0.18), Number of pods/plant (b = 0.39±0.22) and Fresh seed yield (b = 0.133±0.131) under heat stress condition.

Highly significant or significant (Wr + Vr) mean squares were showed in all the traits (Table 9), except Number of seeds/pod and Number of pods/plant indicating the presence of a significant dominance variance.

Table 9. Joint regression analysis and mean squares of (Wr+Vr) and (Wr–Vr) for the traits studied under heat stress condition.

Traits	Days to 50% Flowering	Pod length (cm)	Pod width (mm)	Number of seeds/pod	Number of pods/plant	100-fresh seed weight (g)	Fresh seed yield (g/plant)	Fresh pod yield (g/plant)
Joint regression (b ± se)	0.39±0.18	0.59±0.11	0.83±0.15	0.84±0.20	0.39±0.22	0.72±0.25	0.133±0.131	0.52±0.22
Test for b = 0	2.17 ns	5.36**	5.53**	4.20**	1.77 ns	2.88*	1.02 ns	2.60*
Test for b = 1	-3. 39**	-3.73**	-1.13 ns	-.80 ns	-2.77 *	-1.12 ns	-6.62 **	-2.18 ns
Mean squares of (Wr + Vr)	483.66**	1.187*	6.348**	1.00 ns	3.469 ns	19758.94**	670.16**	50702.40**
Mean squares of (Wr - Vr)	131.96**	0.154 ns	0.774 ns	0.08 ns	1.855 ns	2949.17**	464.07*	11518.70**
Fitness of the model	Non adequate	Partially adequate	Fully Adequate	Fully Adequate	Non adequate	Fully Adequate	Non adequate	Fully Adequate
Dominance degree	complemental non-allelic gene interaction	partial dominance	partial dominance	Over dominance	super-duplicate non-allelic gene interaction	Over dominance	super-duplicate non-allelic gene interaction	Over dominance

**, ** Significant at 5 and 1% levels of probability, respectively.*

Meantime, the differences in (Wr – Vr) values were highly significant in Days to 50% Flowering, 100-fresh seed weight, Fresh seed yield and Fresh pod yield, confirming of epistasis and non-significant in Pod length, Pod width, Number of seeds/pod and Number of pods, confirming the absence of epistasis, respectively (Table 9). These results are agreeing with those obtained by (Kandeel *et al*., 2005; Mousa, 2010; Esho *et al.*, 2012; Kosev, 2013; Esho *et al.*, 2014; Kosev and Georgieva, 2016; El-Rawy *et al*., 2018).

3.5. The graphical analysis of Wr/Vr relationships

The graphical analysis of Wr/Vr relationships under normal conditions (Fig. 2). The intercept of the regression line on the Wr axis above the origin indicating a partial dominance for Days to 50% Flowering, Pod length, Pod width and 100-fresh seed weight However, the slope of the Wr/Vr regression line closely passed through the origin indicating the complete dominance for Number of seeds/pod. Moreover, the intercept of the regression line on the Wr axis below the origin indicating over dominance for Fresh pod yield. In contrast, Wr value, which indicate the complemental non-allelic gene interaction for Number of pods/plant and Fresh seed yield.

The graphical analysis of Wr/Vr relationships under heat stress conditions (Fig. 3). The intercept of the regression line on the Wr axis above the origin indicating a partial dominance for Pod length and Pod width. Moreover, the intercept of the regression line on the Wr axis below the origin indicating over dominance for Number of seeds/pod 100-fresh seed weight and Fresh pod yield. In contrast, resulted in a curvilinear relationship with the line being concave up words with array number (1) showing positive Wr value which indicate the complemental non-allelic gene interaction for Days to 50% Flowering. Moreover, Wr value, which indicate the super-duplicate non-allelic gene interaction for Number of pods/plant and Fresh seed yield These results are agreeing with those obtained by (El-ameen, 1994; Zayed *et al*., 1999 a,b; Kandeel *et al*., 2005; Mousa, 2010; Esho *et al.*, 2012; Kosev, 2013; Esho *et al.*, 2014; Kosev and Georgieva, 2016; El-Rawy *et al*., 2018).

3.6. Genetic parameters

Genetic components estimate for 50% Flowering, Pod length, Pod width, Number of seeds per pod, 100-fresh seed weight and Fresh pod yield/plant are given in Table 10. Additive genetic variance (D) was high significant for all traits under normal condition. Non-additive (H_1 and H_2) components were highly significant under normal condition except Pod length. However, the value of additive effect (D) was higher in magnitude than the (H_1) component for all traits, except Fresh pod yield/plant under normal condition, suggesting that the additive gene effect was predominant for most traits. The average degree of dominance measured by $(H_1/D)^{0.5}$ were low than unity, indicates that most traits exhibit a partial dominance under normal conditions except Number of seeds per pod was complete dominance and Fresh pod yield/plant was overdominance, respectively. In addition to ($H_2/4H_1$) was smaller than the theoretical maximum of 0.25 for all traits, indicating that the ratio of alleles increasing and decreasing were not equally distributed among the parents. The (F) parameter is positive for 50% Flowering, Number of seeds per pod and Fresh pod yield/plant, indicating that there were more dominant than recessive alleles. Moreover, the (F) parameter was negative for Pod length, Pod width and 100-fresh seed weight indicating that there were more recessive than dominant alleles under normal condition, respectively. Narrow sense (h^2_N) heritability h^2_N value was higher than 50% On for most traits except Fresh pod yield/plant was low. the other hand broad sense (h^2_B) heritability was high for all traits under normal condition (Table 10).

In contrast, genetic components estimate for Pod length, Pod width, Number of seeds per pod, 100-fresh seed weight and Fresh pod yield/plant are given in Table 11. Additive genetic variance (D) was high significant for all traits under heat stress condition except Number of seeds per pod. Non-additive (H_1 and H_2) components were highly significant under heat stress condition for all traits. However, the value of additive effect (D) was higher in magnitude than the (H_1) component for Pod length and Pod width and was low for Number of seeds per pod, 100-fresh seed weight and Fresh pod yield/plant under heat stress condition, suggesting that predominant effect the additive gene was for most traits. The average degree of dominance measured by $(H_1/D)^{0.5}$ were high than unity, indicates that most traits exhibit overdominance for Number of seeds per pod, 100-fresh seed weight and Fresh pod yield/plant under heat stress condition and Pod length and Pod width were a partial dominance, respectively. In addition to ($H_2/4H_1$) was smaller than the theoretical maximum of 0.25 for all traits, indicating that the ratio of alleles increasing and decreasing were not equally distributed among the parents. The (F) parameter is positive for 100-fresh seed weight and Fresh pod yield/plant, indicating that there were more dominant than recessive alleles. Moreover, the (F) parameter was negative for Pod length, Pod width and Number of seeds per pod indicating that there were more recessive than dominant alleles under normal condition, respectively.

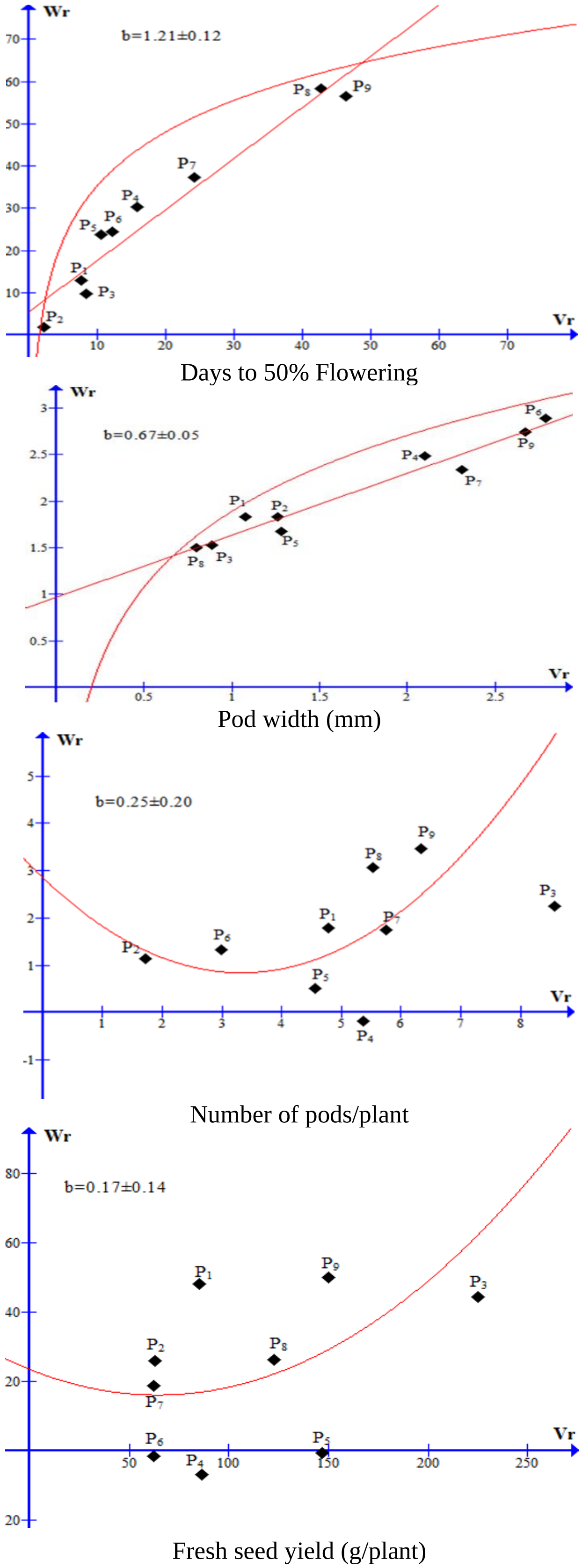


Figure 2. The Wr/Vr graphs of all traits under normal condition

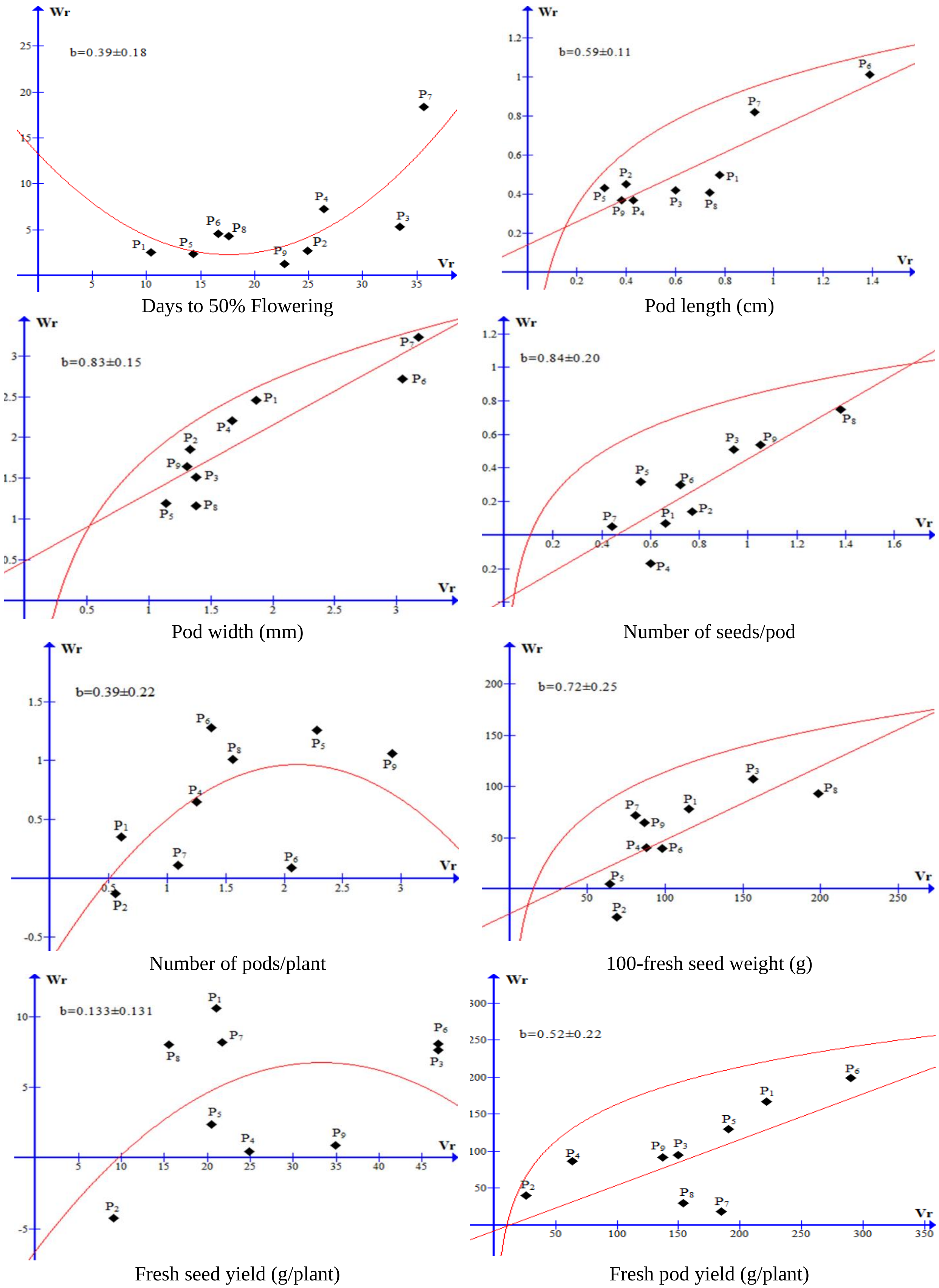


Figure 3. The Wr/Vr graphs of all traits under heat stress condition

Table 10. The genetic parameters under normal condition.

Item	Parameters (E ± SE)					
	50% Flowering	Pod length	Pod width	Number of seeds per pod	100-fresh seed weight (g)	Fresh pod yield/plant
D	96.47**±3.32	0.71**±0.09	3.36**±0.13	1.49**±0.09	86.73**±10.97	333.38**±35.67
H_1	46.86**±7.32	0.13±0.21	1.41**±0.28	1.49**±0.19	55.77**±24.22	1110.06**±78.74
H_2	26.32**±6.29	0.12±0.18	1.18**±0.24	0.92**±0.16	39.43±20.82	971.92**±67.70
F	82.61**±7.74	-1.14**±0.22	-1.56**±0.30	1.22**±0.20	-31.40±25.59	138.75±83.22
E	6.64**±1.05	0.31**±0.03	0.19**±0.040	0.04±0.03	17.31**±3.47	11.54±11.28
	Proportion of components of variance					
$(H_1/D)^{0.5}$	0.70	0.42	0.65	1.00	0.81	1.82
$(H_2/4H_1)$	0.14	0.23	0.21	0.16	0.18	0.22
h^2_B	0.78	0.75	0.94	0.94	0.82	0.97
h^2_N	0.57	0.72	0.84	0.61	0.71	0.40

**, ** Significant at 5 and 1% levels of probability, respectively.*

Table 11. The genetic parameters under heat stress condition.

Item	Parameters (E ± SE)				
	Pod length	Pod width	Number of seeds per pod	100-fresh seed weight (g)	Fresh pod yield/plant
D	0.61**±0.19	3.03**±0.43	0.38±0.24	125.8**±3.21	222.2**±15.08
H_1	0.50±0.41	1.39**±0.95	1.89**±0.53	340.3**±7.09	457.1**±33.28
H_2	0.67±0.35	1.42**±0.82	1.82**±0.46	274.9**±6.09	428.2**±28.61
F	-0.76±0.44	-1.71±1.00	-0.22±0.56	41.91**±7.49	67.46±35.18
E	0.35**±0.06	0.50**±0.14	0.30**±0.08	0.634±1.02	8.047±4.769
	Proportion of components of variance				
$(H_1/D)^{0.5}$	0.91	0.68	2.23	1.64	1.42
$(H_2/4H_1)$	0.21	0.25	0.24	0.20	0.23
h^2_B	0.69	0.84	0.72	0.996	0.96
h^2_N	0.54	0.73	0.31	0.52	0.44

**, ** Significant at 5 and 1% levels of probability, respectively.*

Narrow sense (h^2_N) heritability h^2_N value was higher than 50% On for most traits except Number of seeds per pod and Fresh pod yield/plant was low. the other hand broad sense (h^2_B) heritability was high for all traits under normal condition (Table 11). results were obtained by (Sharma and Kalia, 2002; Kandeel *et al.*, 2005; Parvez Sofi and Wini, 2006; Mousa, 2010; Esho *et al.*, 2012; Kosev, 2013; Punia *et al.*, 2013; Esho *et al.*, 2014; Kosev and Georgieva, 2016; El-Rawy *et al.*, 2018; Elsaman, 2022).

3.7. Stress Tolerance Indices

According to the MP index, the highest value of MP was recorded by $P_3 \times P_6$ (92.415 g) as the average of both normal and heat stress conditions, whereas, the least values (40.84 g) was expressed by $P_8 \times P_9$ (Table 4). According to Farshadfar and Sutka (2002) and Khaled *et al.* (2020), hybrids with high pod yield under both normal and stressful heating conditions had high MP index values. Shirazi *et al.* (2009) disagreed, stating that the MP index increased as a result of the greater yield in the non-stress condition and that this cannot be used as a reliable signal for locating therapies that lessen the effects of stress. As shown in Fig 4, P_1XP_6 followed by P_7XP_8 and P_1XP_5 F_1 hybrids recorded the highest stress tolerance indices as well as the lowest stress susceptibility indices as compared with other hybrids suggesting more stress tolerance mechanism. Several stress indices, including RHSI, YI, HSI, MP, MSTI-1, MSTI-2, and both SSPI and ATI, were computed in this study based on yield under both normal and heat stress conditions. The hybrids P_5XP_7, P_6XP_9, P_5XP_8,

P_6XP_7, P_3XP_5, P_3XP_9, P_7XP_9, P_1XP_4 and P_4XP_7 recorded the highest values for SSPI, ATI and TOL (Fig. 4). These hybrids were identified as heat sensitive because they had high yield under normal (non-stressed) conditions and low yield under heat stress conditions. Hence, they are suitable for normal sowing conditions. With low values of SSPI, ATI and TOL, the F_1 hybrids P_2XP_4, P_2XP_6, P_3XP_7, P_7XP_8, P_2XP_9, P_2XP_5, P_2XP_8, P_1XP_6, P_1XP_5 and P_1XP_8 were thought to be more heat tolerant. However, the low values of these indicators are due to the narrow difference in yield between the two cases, so pod yield must be taken into account, and low values do not necessarily indicate excellent performance. For MSTI (1&2), MP, the crosses P_1XP_6 had the maximum value. Thus, under the two conditions, this genotype was thought to be the most stable and prominent of all the crosses; however, P_8XP_9 displayed the lowest value for the same stress indicators. The F_1 crosses P_1XP_6 and P_1XP_5 had the greatest YI values, while P_6XP_9 had the lowest. The cross designated as heat tolerant was the one with the highest value of MSTI-1, MSTI-2, and MP, whereas P8XP9, which had the lowest value of these indices, was classified as a heat susceptible cross. The P_2XP_4 F_1 hybrid had the lowest percent yield drop, followed by P_2XP_6, P_1XP_6, P_7XP_8, P_1XP_5, P_2XP_9, and P_2XP_5. Under both conditions, there was less of a yield differential in these crosses.

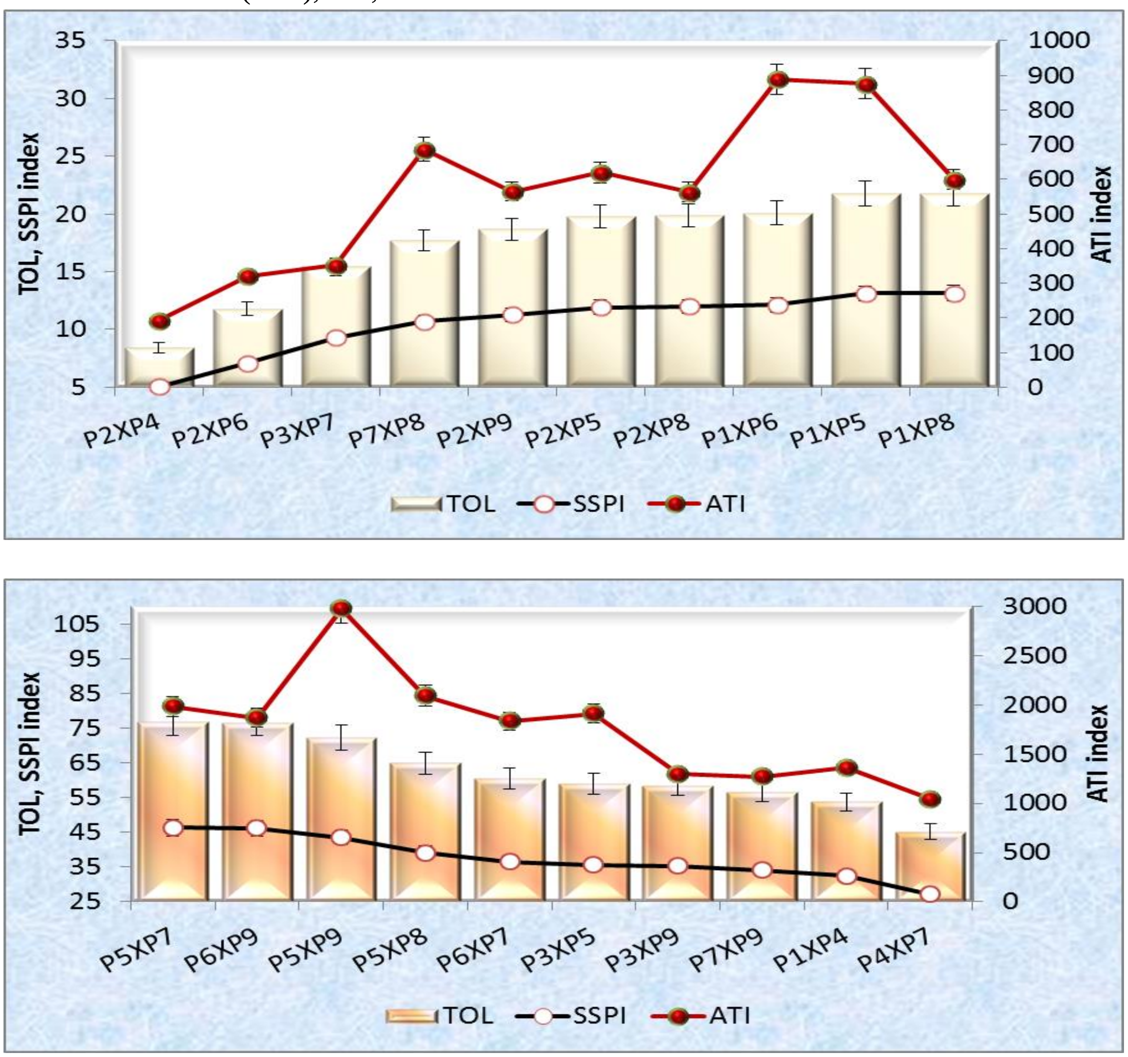


Figure 4. The ten crosses that are more tolerant to heat stress (Upper) and the ten that are more susceptible (Lower)

4. Conclusion

P_1XP_6 followed by P_7XP_8 and P_1XP_5 F_1 hybrids recorded the highest RHSI, YI and HSI (stress tolerance indices) as well as the lowest SSPI (stress susceptibility indices) as compared with other hybrids suggesting more stress tolerance mechanism. Generally, it could be concluded that the additive and non - additive gene action played a major role in controlling for all traits under normal and heat stress conditions, and useful for breeding and selection programs. Also, it is possible predict the existence of super genetic isolation in future generations.

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Data presented in this study are available on fair request from the respective author.
Ethics Approval and Consent to Participate
Not applicable
Consent for Publication
Not applicable.
Conflicts of Interest
The authors disclosed no conflict of interest.

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