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Research Article

Combining ability studies on resistance to pink stem borer (*Sesamia cretica*) in new yellow maize (*Zea mays*) hybrids

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Abstract
Maize (*Zea mays* L.) is the third most important staple crop in Egypt. *Sesamia cretica* (*S. cretica*), the most prevalent corn borer in Egypt attacks young maize plants after emergence, causing death of these plants (dead hearts) and its capable of damaging older plants causing drastic yield losses. This study was carried out at the Experimental Research Station of Moshtohor, Benha University, Al-Qalyubiyah Governorate, Egypt during the two successive seasons 2014 and 2015. A half diallel cross between nine yellow inbred lines of maize (*Zea mays* L.) was evaluated in under two environments i.e. (under borer artificial infestation conditions and normal conditions) in RCBD with three replications to estimate the combing ability and the interaction of hybrids under the artificial infestation. Artificial infestation was done by newly hatched larvae of the pink stem borer *S. cretica*. Highly significant crosses mean squares were detected for all the studied traits indicating the wide diversity between the parental materials used in this study. General and specific combining ability (GCA and SCA) were significant for all the studied traits except SCA for days to 50% tasselling and ear height at the infestation condition. The parental inbred line P_6 and P_9 were considered as good combiners for grain yield under infestation and non-infestation conditions as well as the combined over them. Six crosses i.e. ($P_1 \times P_6$, $P_1 \times P_7$, $P_2 \times P_4$, $P_3 \times P_5$, $P_5 \times P_7$, and $P_8 \times P_9$) exhibited positive significant SCA effects (favourable). Therefore, they could be utilized for future breeding work as well as for direct release after confirming the stability of their performances across different environments.

Key words
Zea mays, *Sesamia cretica*, Borer, Combining ability.

Introduction

Maize (*Zea mays* L.) is one of the most important cereals in Egypt as well as worldwide due to its vast grown area, total production and cash value. It is essential for human consumption and livestock. Moreover, it is also used for industrial purposes such as manufacturing starch and cooking oils. Many efforts are devoted nowadays to increase its productivity through genetical improvement. In Egypt, maize plants are severely attacked by different species of Lepidoptera pests, referred to as corn borers. The corn borers attacking maize in Egypt are; the pink stem borer *Sesamia cretica* Led. (Noctuidae), the European corn borer (ECB) *Ostrinia nubilalis* Hubn (pyroustidae) and the purple-lined corn borer *Chilo Agamemnon* Bles. (Crambidae). *Sesamia cretica*, the most prevalent corn borer in Egypt attacks young maize plants after emergence, causing death of these plants dead hearts and its capable of damaging older plants causing drastic yield losses. These losses are mainly attributed to the decrease in number of plants population at harvest because of the large number of dead hearts, increase in plant lodging, ear drops and predisposing infested plants to disease organisms.

One of the most important methods for controlling insect pests in the context of integrated pest control is to grow insect-resistant cultivars (Pathak 1991). The first step in designing an efficient breeding program for resistance to a certain insect is to identify sources of resistance and to determine how plant behaviour under insect attack is transmitted from the original parents to the improved cultivars (Pathak and Othieno 1992). Considerable efforts have been devoted to identify and develop corn germplasm with resistance to damage by the pink stem borer *Sesamia cretica* (Al-Naggar *et al.*, 2000, Saafan 2003, Soliman 2003). The objectives of this work were to estimate GCA and SCA effects and identify superior genotypes resistance to *S. cretica* in maize and high yielding ability. It is hoped that the present study may help maize breeders to produce new corn hybrids having high yield potential as well as borer tolerant.

Materials and Methods

This study was carried out at the Experimental Research Station of Moshtohor, Benha University, Al-Qalyubiyah Governorate, Egypt during the two successive seasons 2014 and 2015. Nine maize inbred lines diverge in resistance to corn borer were used in this study. These lines were selected on showing clear differences in their reaction to corn borer *S. cretica* and other desirable plant aspects. In the first early summer season 2014, inbred lines seeds were planted. All possible cross combinations without reciprocals were made between the nine inbred lines by hand method giving a total of 36 crosses seeds. In the second summer season 2015, two experiments were conducted in two environments i.e. (under borer artificial infestation conditions and normal conditions). Each experiment included the nine inbred lines, 36 crosses as well as check hybrid Single Cross 166 (SC.166). A randomized complete block design with three replications was used. Each plot consisted of two ridges of 6.0 m. length, 70 cm. width and 0.25 m between hills. The recommended packages of agronomic practices were followed to achieve a good growth.

In the artificial infestation experiment, all plants after thinned were artificially infested by newly hatched larvae of the pink stem borer *S. cretica* artificially reared in the corn Borer Research Lab., Maize Research Department, Agricultural Research Center. Infestation was done using the Bazooka as a mechanical dispenser, such that each plant receives approximately 6-8 larvae at the early whorl stage of plant development (25 days after sowing). The data were collected on days to 50% tasseling, number of days to silk emergence (DTS), Plant height (PH), Ear height (EH) and Grain yield per feddan (GYPF) was estimated and adjusted at 15.5% grain moisture and expressed kilo gram (kg) per feddan (Feddan= 4200 m^2) of maize grains. The ordinary analysis of variance for RCBD was firstly performed according to (Snedecor and Cochran 1989). General and specific combining ability were estimated by **(**Griffing 1956) method 2 model I.

Results and Discussion

The analysis of variance for the studied traits in two environments and the combined over them are presented in (Table 1). Environment mean squares were significant for all the studied traits with mean values in normal condition being higher than those in artificial infestation of borer for all the studied traits except for tasselling and silking date traits. The earliness of these traits at normal condition may be due to the desirable condition for growing corn and the late flowering in infested plants may be due to more energy were needed by plant for making recovery. Crosses mean squares were significant for all the studied traits at both environments as well as the combined analysis. This indicates the wide diversity between the parental materials used in this study. Significant interaction mean squares between Crosses and environments were detected for all studied traits indicating that, these Crosses behaved somewhat differently from environment to another.

The mean squares associated with general combining ability (GCA) and specific combining ability (SCA) were significant for all the studied traits except SCA for days to 50% tasselling and ear height at the infestation condition (Table 1) It is evident that both additive and non-additive gene effects were involved in determining the performance of the single cross progeny. High GCA/SCA ratio, which exceeded the unity, was obtained for all traits, revealing the predominance of additive and additive by additive gene effects for all traits. The same trend results were reported by (Soliman *et al.*, 2005, El-Hosary *et al.*, 2006, Akbar *et al.*, 2008, Motawei and Mosa 2009, and GuangJauh 2009). The mean squares of interaction between environment and both types of combining ability were significant for days to 50% silking and grain yield. Such results showed that the magnitude of all types of gene action varied from environment to another. It is fairly evident that the ratio for SCA×E/SCA was higher than ratio of GCA×E/GCA for these traits. This result indicated that non-additive genetic effects were more influenced by the environmental conditions than additive genetic effects of these traits. Meanwhile, SCAxE mean squares were only significant for days to 50% tasseling, plant height and ear height. the ratio of SCA×E/SCA was higher than ratio of GCA×E/GCA for these traits indicating non-additive genetic effects were more influenced by the environmental condition than additive genetic effects .

1- General combining ability effects:

Estimates of general combing ability (GCA) effects for individual parental inbred lines for each trait at both environments as well as the combined analysis are presented in (Table 2).

The parental line P_3 exhibited significant negative (favorable) GCA effects for tasseling date at infestation environment and the combined analysis. While, P_8 and P_9 showed significant negative GCA at both environments and their combined for this trait. With respect to days to 50% silking, The inbred line P_8 showed significant negative (favorable) GCA effects at both infestation, normal conditions and their combined. While P_6 and P_9 were the best combiner at infestation environment and P_5 at normal environment. The parental inbred lines $P_{1,}$ P_2 and P_5 showed significant negative (favorable) GCA effects for plant height at both infestation, normal conditions as well as their combined. Whereas, $P_{1,}$ P_2 and P_7 showed significant negative (favorable) GCA ear height at both infestation, normal conditions as well as their combined. Regarding to grain yield only two parental inbred line P_6 and P_9 showed significant positive (favorable) GCA effects at both infestation, normal conditions as well as their combined. Therefore, they could be used as a good combiner for high yielding.

2- Specific combining ability:

Specific combining ability effects were only estimated whenever significant SCA variances were obtained (Table 3). As for days to 50% tasselling; crosses $P_3{\times}P_5$ and $P_5{\times}P_7$ exhibited significant negative (favorable) SCA effects and had the best desirable SCA values at normal environment. With regard to silking date, five, seven and two crosses expressed significant negative (favorable) SCA effects at infestation, normal environments as well as the combined analysis, respectively. Also, results indicated that the crosses $P_2{\times}P_7$ and $P_8{\times}P_9$ gave the highest desirable SCA values in the combined analysis. Regarding plant height, two crosses namely, $P_1{\times}P_2$ (-44.75**) and P_6xP_8 (-20.91**) gave the highest significant negative (favorable) SCA effects in the combined analysis. Also, four crosses ($P_1{\times}P_2$, $P_2{\times}P_4$, $P_6{\times}P_8$ and $P_7{\times}P_8$) and three crosses ($P_1{\times}P_2$, $P_3{\times}P_7$ and $P_5{\times}P_8$) had significant negative (favorable) SCA effects for plant height at infestation and normal environment, respectively. The hybrid $P_1{\times}P_2$ expressed the highest significant negative (favorable) SCA effects recording –14.69** and –15.23** at the normal and the combined data, respectively for ear height. Therefore, this hybrid was considered the best among studied crosses for ear height. This may suggest the immediate used to decrease lodging, and, in turn, increase the yield potentiality. With regard to grain yield (kg/feddan) eight, twelve and nine crosses showed significant positive (favorable) SCA effects at infestation, normal and the combined analysis, respectively. The best combinations were $P_1{\times}P_6$, $P_1{\times}P_7$, $P_2{\times}P_4$, $P_3{\times}P_5$, $P_5{\times}P_7$, and $P_8{\times}P_9$ for grain yield (kg/feddan) at the combined analysis. These crosses also, had the highest mean values in the combined analysis. It could be concluded that the previous crosses seemed to be the best combinations, where they had significant SCA effects for grain yield (kg/feddan).

It is concluded that the parental inbred lines (P_6 and P_9) possess high GCA effects for grain yield while the parental (P_8) possess high GCA effects for earliness. They can be utilized as promising inbred lines in a hybridization programs to develop high yielding and early maturity maize hybrids. the six crosses ($P_1{\times}P_6$, $P_1{\times}P_7$, $P_2{\times}P_4$, $P_3{\times}P_5$, $P_5{\times}P_7$, and $P_8{\times}P_9$) which had out-yielded significantly the check hybrid SC.166. These crosses could be utilized for future breeding work as well as for direct release after confirming the stability of their performances across different environments. Hence, the information from this study may possibly be useful for researchers who would like to develop high yielding hybrids of maize tolerance to borer attack.

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Table 1. Analysis of variance for the traits at infestation, normal environments and their combined.

Traits	d.f		Tasseling date (d)			Silking date (d)			Plant height (cm)			Ear height (cm)			Yield (kg/feddan)		
S.O.V	S.	C.	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.
Environment (E)		1			27.09 **			43.11 **			23115.7**			22759.1 **			60819.8**
blocks/E.	2	4	0.02	2.53	1.27	0.60	2.40	1.50	176.64	60.73	118.68	625.54 **	19.43	322.48 **	67.21	98.70	82.95
crosses	35	35	6.00**	7.90**	10.73**	11.49 **	7.18 **	9.37 **	1109.0 **	1069.4 **	1950.6 **	214.80 **	279.32 **	396.12 **	980.14 **	1306.4 **	1605.43 **
Crosses x E.		35			3.17*			9.30 **			227.88 *			98.00 *			681.06 **
Error/E.	70	140	2.29	1.57	1.93	2.20	1.26	1.73	150.80	124.60	137.70	81.09	45.13	63.11	44.75	47.79	46.27
GCA	8	8	5.57**	7.45**	12.09**	5.26 **	3.40 **	6.64 **	924.20 **	920.03 **	1793.4 **	191.42 **	222.05 **	380.73 **	917.33 **	654.65 **	1317.54**
SCA	27	27	0.94	1.20 **	1.05*	3.41 **	2.10 **	2.08 **	205.37 **	189.50 **	311.46 **	36.10	54.90 **	58.35 **	151.72 **	370.50 **	303.32 **
GCA x E.		8			0.93			2.03 **			50.83			32.74			254.44 **
SCA x E.		27			1.09*			3.42 **			83.41 *			32.64 *			218.90 **
Error	70	140	0.76	0.52	0.64	0.73	0.42	0.58	50.27	41.53	45.90	27.03	15.04	21.04	14.92	15.93	15.42
GCA/SCA				6.18	11.48	1.54	1.62	3.18	4.50	4.85	5.76		4.04	6.52	6.05	1.77	4.34
GCA x E/GCA					0.08			0.31			0.03			0.09			0.19
SCA x E./SCA					1.04			1.64			0.27			0.56			0.72

* and ** significant at 0.05 and 0.01 levels of probability, respectively.

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Table 2. General combining ability effects for the traits at both environments and their combined.

Traits	Tasseling date (d)			Silking date (d)			Plant height (cm)			Ear height (cm)			Yield (kg/feddan)		
Parents	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.
P1	0.93**	1.57**	1.25**	0.97**	0.87**	0.92**	-6.45*	-8.59**	-7.52**	-4.76*	-4.49**	-4.62**	-8.98**	-12.6**	-10.7**
P2	0.88**	1.52**	1.20**	1.16**	1.01**	1.08**	-14.7**	-8.92**	-11.8**	-3.83*	-3.37*	-3.60*	-7.55**	2.45	-2.55
P3	-0.90**	-0.38	-0.64*	-0.20	0.77**	0.29	-0.69	-5.22*	-2.96	-0.96	-4.97**	-2.96	5.98**	-4.42**	0.78
P4	1.00	0.43	0.71*	0.56	-0.08	0.24	15.09**	18.22**	16.6**	10.17**	6.98**	8.58**	-8.13**	1.86	-3.13*
P5	0.57	0.14	0.36	0.42	-0.66**	-0.12	-16.6**	-13.2**	-14.9**	-3.57	-3.47*	-3.52*	1.80	-4.38**	-1.29
P6	-0.33	-0.43	-0.38	-0.77*	-0.23	-0.50	8.15**	10.07**	9.11**	6.15**	6.74**	6.45**	14.24**	20.1**	17.2**
P7	0.05	-0.43	-0.19	0.08	-0.70**	-0.31	-3.89	-9.41**	-6.65**	-4.67*	-6.73**	-5.70**	-17.3**	-10.2**	-13.8**
P8	-0.90**	-1.38**	-1.14**	-0.82**	-0.66**	-0.74**	13.4**	12.26**	12.8**	2.09	3.46*	2.78	2.80*	1.72	2.26
P9	-1.29**	-1.05**	-1.17**	-1.39**	-0.32	-0.86**	5.77*	4.83*	5.30*	-0.63	5.84**	2.60	17.17**	5.47**	11.32**
LSD 5% (gi)	0.62	0.51	0.57	0.61	0.46	0.54	5.02	4.56	4.79	3.68	2.74	3.25	2.73	2.82	2.78
LSD 1% (gi)	0.82	0.68	0.75	0.80	0.61	0.71	6.65	6.04	6.35	4.87	3.64	4.30	3.62	3.74	3.68
LSD 5% (gi-gj)	0.93	0.77	0.85	0.91	0.69	0.81	7.53	6.84	7.19	5.52	4.12	4.87	4.10	4.24	4.17
LSD 1% (gi-gj)	1.23	1.02	1.13	1.20	0.91	1.07	9.97	9.06	9.53	7.31	5.45	6.45	5.43	5.61	5.52

* and ** significant at 0.05 and 0.01 levels of probability, respectively.

Table 3. Specific combining ability effects for the traits at both environments and their combined.

Traits	Tasseling date (d)			Silking date (d)			Plant height (cm)			Ear height (cm)			Yield (kg/feddan)		
Crosses	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.
P1 × P2	2.15	0.74	1.44*	5.08**	-1.95**	1.56*	-42.35**	-47.15**	-44.75**	-15.77	-14.69**	-15.23**	-20.49**	6.35	-7.07*
P1 × P3	-0.57	-1.02	-0.79	-2.4**	1.29*	-0.56	-7.73	11.98*	2.13	5.22	6.40	5.81	5.15	-16.34**	-5.59
P1 × P4	-0.80	0.50	-0.15	-0.83	-0.86	-0.84	-0.18	2.38	1.10	-0.34	-1.71	-1.03	0.45	-14.43**	-6.99*
P1 × P5	1.29	-1.21	0.04	2.32**	-1.29*	0.51	-10.12	12.49*	1.19	-3.54	8.07*	2.27	-6.36	-0.35	-3.36
P1 × P6	-1.80	-0.31	-1.06	-2.5**	0.29	-1.10	16.73**	10.52	13.62*	7.01	1.19	4.10	28.41**	35.97**	32.19**
P1 × P7	-0.18	0.02	-0.08	-0.02	1.43*	0.71	17.70**	5.18	11.44	0.89	8.00*	4.45	9.71**	14.65**	12.18**
P1 × P8	-0.23	1.31*	0.54	0.22	0.71	0.47	19.88**	2.17	11.02	6.90	-4.02	1.44	-11.92**	-4.88	-8.40*
P1 × P9	0.15	-0.02	0.06	-1.87*	0.38	-0.75	6.08	2.43	4.25	-0.37	-3.24	-1.80	-4.95	-20.97**	-12.9**
P2 × P3	0.15	0.02	0.09	1.08	-0.52	0.28	2.45	-5.85	-1.70	1.30	-9.05**	-3.88	-9.37**	23.14**	6.89*
P2 × P4	0.58	0.55	0.56	-1.02	0.33	-0.34	-13.03*	5.37	-3.83	-10.70	-1.50	-6.10	10.99**	6.42	8.70*
P2 × P5	-0.33	0.50	0.09	-1.21	-1.10	-1.15	10.90	9.02	9.96	4.71	3.15	3.93	3.67	-7.13*	-1.73
P2 × P6	-1.09	-0.93	-1.01	-0.35	0.14	-0.10	3.35	5.52	4.43	-1.68	6.74*	2.53	-4.91	19.71**	7.40*
P2 × P7	-0.80	-0.60	-0.70	-3.2**	-1.38*	-2.29**	8.72	13.00*	10.86	5.80	8.54*	7.17	6.47	-9.04*	-1.29
P2 × P8	-0.18	-0.98	-0.58	-0.64	2.57**	0.97	16.47**	28.66**	22.56**	5.71	11.19**	8.45*	0.67	-7.20*	-3.27
P2 × P9	-0.47	0.69	0.11	0.27	1.90**	1.09	13.50*	-8.58	2.46	10.64	-4.36	3.14	12.97**	-32.25**	-9.64**
P3 × P4	0.36	0.79	0.57	1.01	-1.76**	-0.38	0.79	3.01	1.90	-2.74	6.09	1.68	-5.23	-1.83	-3.53
P3 × P5	-0.21	-1.26*	-0.74	-0.85	0.14	-0.35	5.78	10.96	8.37	-2.63	3.21	0.29	14.37**	27.11**	20.74**
P3 × P6	0.03	-0.36	-0.16	0.34	1.38*	0.86	3.20	-4.85	-0.83	2.35	-1.67	0.34	0.07	-28.71**	-14.3**
P3 × P7	-0.68	1.98**	0.65	-0.52	-0.48	-0.50	-0.86	-12.60*	-6.73	-0.70	-13.83**	-7.27	-15.92**	-5.06	-10.٥**
P3 × P8	0.60	-1.07	-0.24	0.05	0.14	0.10	0.79	-6.37	-2.79	-2.19	1.62	-0.29	22.00**	-10.19**	5.91
P3 × P9	0.32	0.93	0.62	1.29	-0.19	0.55	-4.42	3.72	-0.35	-0.60	7.24*	3.32	-11.08**	11.89**	0.40
P4 × P5	-0.45	-0.40	-0.43	-0.28	0.00	-0.14	-0.10	1.68	0.79	6.54	5.26	5.90	-3.50	1.82	-0.84
P4 × P6	0.46	-0.83	-0.19	0.24	0.90	0.57	9.11	-2.95	3.08	2.65	-4.28	-0.82	5.92	-9.30**	-1.69
P4 × P7	-0.59	1.17	0.29	0.39	-0.62	-0.12	-6.12	-10.63	-8.38	-0.73	-10.81**	-5.77	7.83*	-6.28	0.77
P4 × P8	-0.64	-0.88	-0.76	-1.38	1.00	-0.19	4.74	-4.48	0.13	5.88	0.34	3.11	-3.23	11.46**	4.12
P4 × P9	1.08	-0.88	0.10	1.86*	1.00	1.43*	4.80	5.62	5.21	-0.56	6.62	3.03	-13.23**	12.14**	-0.55
P5 × P6	-0.11	1.79**	0.84	0.05	-1.19*	-0.57	0.27	-10.17	-4.95	-1.41	-5.84	-3.62	-8.68*	-21.62**	-15.1**
P5 × P7	0.17	-1.55*	-0.69	-0.14	1.62**	0.74	-6.12	-1.35	-3.74	-0.59	2.97	1.19	3.60	21.63**	12.61**
P5 × P8	-0.54	2.07**	0.76	-1.23	1.57**	0.17	0.63	-15.70**	-7.53	-0.68	-8.55*	-4.62	-7.70*	-7.63*	-7.67*
P5 × P9	0.17	0.07	0.12	1.34	0.24	0.79	-1.24	-6.93	-4.09	-2.39	-8.26*	-5.33	4.60	-13.82**	-4.61
P6 × P7	2.41	0.69	1.55*	2.39**	-0.14	1.12	9.73	8.51	9.12	3.58	3.93	3.75	-4.68	-4.56	-4.62
P6 × P8	0.03	0.31	0.17	0.63	-1.52**	-0.45	-30.8**	-11.00	-20.91**	-7.61	-1.59	-4.60	-9.26**	10.31**	0.53
P6 × P9	0.08	-0.36	-0.14	-0.80	0.14	-0.33	-11.56	4.43	-3.57	-4.88	1.53	-1.68	-6.87*	-1.81	-4.34
P7 × P8	0.98	-1.02	-0.02	2.77**	-0.71	1.03	-13.78*	2.65	-5.57	-7.22	0.88	-3.17	-8.07*	-24.01**	-16.0**
P7 × P9	-1.30	-0.69	-1.00	-1.66*	0.29	-0.69	-9.25	-4.75	-7.00	-1.03	0.33	-0.35	1.06	12.68**	6.87*
P8 × P9	-0.02	0.26	0.12	-0.42	-3.76**	-2.09**	2.10	4.07	3.08	-0.79	0.15	-0.32	17.51**	32.15**	24.83**
LSD5%(sij)	Ns	1.24	1.38	1.47	1.11	1.31	12.19	11.08	11.65	Ns	6.67	7.89	6.64	6.86	6.75
LSD1%(sij)	Ns	1.65	1.83	1.95	1.47	1.73	16.15	14.68	15.44	Ns	8.84	10.45	8.80	9.09	8.95
LSD5%(sij-sik)	Ns	1.88	2.09	2.23	1.68	1.97	18.44	16.76	17.62	Ns	10.08	11.93	10.04	10.38	10.21
LSD5%(sij-ski)	Ns	1.71	1.90	2.03	1.54	1.80	16.83	15.30	16.08	Ns	9.21	10.89	9.17	9.47	9.32

* and ** significant at 0.05 and 0.01 levels of probability, respectively.