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Diallel analysis for yield and component traits in maize (*Zea mays*) under infestation and non-infestation with pink stem borer (*Sesamia cretica*)

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ABSTRACT

A half diallel cross between nine yellow inbred lines of maize (*Zea mays* L.) was evaluated under two environments, viz. borer artificial infestation conditions and normal conditions in RCBD with three replications in 2015 to estimate general and specific combining ability effects and identify superior genotypes resistant to *Sesamia cretica*. Highly significant cross mean squares were detected for all the studied traits indicating the wide diversity in 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 number of rows/ear in normal condition revealing that both additive and non-additive gene effects were involved in determining the performance of the single cross progeny. The parental inbred line P_6, P_8 and P_9 can be considered as good combiners for grain yield and some of its component traits under infestation and non-infestation conditions as well as the combined over them. 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 $P_8{\times}P_9$) selected based on desirable SCA effects also had high mean performance for grain yield and out-yielded the check hybrid SC 166. Therefore, these crosses could be utilized for future breeding work as well as for direct release after confirming the stability of their performance across different environments. The information from this study may be useful for researchers who would like to develop high yielding hybrids of maize tolerant to borer attack.

Key words: Artificial infestation, Borer, Combining ability, *Sesamia cretica*, *Zea mays*

Maize (*Zea mays* L.) is one of the most important cereals in Egypt as well as worldwide due to 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 studies are devoted to increase its productivity through genetic 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. Its capable of damaging older plants causing drastic yield losses (Simeada 1985). These losses are mainly attributed to the decrease in number of plant population at harvest because of the large number of dead hearts, increase in plant lodging, ear drops etc.

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 insects 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 for identifying and developing corn germplasm resistant to damage by the pink stem borer *Sesamia cretica* (Al-Naggar *et al.* 2000, Saafan 2003, Soliman 2003). It has been reported that both additive and non-additive gene action are responsible for the inheritance of resistance to *Sesamia nonagrioides* and *Ostrinia nubilalis* (Velasco *et al.* 2002). Scott *et al.* (1967) and Sadehdel *et al.* (1983) showed that the magnitude of non-additive gene action was greater than that of additive gene action in controlling maize resistance to the second generation of European corn borer (ECB). On the other hand, general combining ability (GCA) was more important than specific combining ability (SCA) in the inheritance of resistance to *Sesamia* spp. (Tususz and Koe 1995). The objectives

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of this work were to estimate GCA and SCA effects and identify superior genotypes resistant to *S. cretica* in maize and having high yielding ability. The study may help maize breeders to produce new hybrid varieties having high yield potential as well as tolerance to borer.

MATERIALS AND METHODS

The study was carried out at the Experimental Research Station of Moshtohor, Benha University, Al-Qalyubiyah Governorate, Egypt during 2014 and 2015. Nine maize inbred lines showing clear differences in their reaction to corn borer *S. cretica* and other desirable plant aspects were used.

In the first early summer season of 2014, the seeds were planted. All possible cross combinations without reciprocals were made between the nine inbred lines by hand method giving seeds of total 36 crosses.

In the second summer season of 2015, two experiments were conducted, i.e. under borer artificial infestation conditions and normal conditions.

Each experiment included the nine inbred lines and 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 m length, 70 cm width and 0.25 m distance between hills. Two seeds were planted per hill and later thinned out to one plant per hill before the first irrigation. The recommended packages of agronomic practices were followed to achieve a good growth.

In the experiment under artificial infestation, all plants after thinning were artificially infested by newly hatched larvae of 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 received approximately 6-8 larvae at the early whorl stage of plant development (25 days after sowing). The data were collected from samples of 10 ears for each plot to assess ear length (cm), ear diameter (cm), number of rows/ear and number of kernels/ear. Grain yield per feddan (GYPF) was estimated and adjusted at 15.5% grain moisture and expressed in kilogram (kg) per feddan (Feddan= 4200 m^2) of maize grains. The ordinary analysis of variance for RCBD was performed according to Snedecor and Cochran (1989). General and specific combining ability were estimated by Griffing (1956) method 2 model I.

RESULTS AND DISCUSSION

Analysis of variance: Environment mean squares were significant for all the studied traits with mean values in normal condition higher than those in artificial infestation of borer for all the studied traits (Table 1). The increase in traits at normal condition may be due to favourable condition leading to great vegetative growth, yield and its components of corn plants. Mean squares of crosses were significant for all the studied traits in both conditions and the combined analysis which reflects the wide diversity

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

SOV	d.f		Ear length (cm)			Ear diameter (cm)			No. of rows/ear			No. of kernels/row			Yield (kg/feddan)		
	S.	C.	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.
Environment (E)		1			24.13**			1.33 **			7.15 **			516.1 **			60819.8**
Blocks/E	2	4	0.10	3.41	1.75	0.01	0.16 *	0.08	0.31	1.10	0.71	7.03	15.71	11.37	67.21	98.70	82.95
Crosses	35	35	11.9 **	6.31 **	14.72 **	0.32 **	0.13 **	0.31 **	8.46 **	5.71 **	12.82 **	71.57 **	32.9 **	70.22 **	980.14**	1306.4**	1605.43 **
Crosses × E		35			3.58 **			0.14 **			1.34			34.32 **			681.06 **
Error/E.	70	140	2.33	1.36	1.85	0.08	0.04	0.06	1.00	0.97	0.98	9.20	10.19	9.69	44.75	47.79	46.27
GCA	8	8	7.35 **	4.31 **	11.10 **	0.23 **	0.08 **	0.28 **	10.3 **	6.93 **	16.45 **	45.01 **	14.2 **	44.66 **	917.33**	654.65**	1317.54**
SCA	27	27	3.00 **	1.45 **	3.07 **	0.07 **	0.03 **	0.05 **	0.61 *	0.41	0.67 **	17.59 **	10.0 **	17.11 **	151.72**	370.50**	303.32 **
GCA × E.		8			0.57			0.03			0.75 *			14.54 **			254.44 **
SCA × E.		27			1.38 **			0.05 **			0.36			10.52 **			218.90 **
Error	70	140	0.78	0.45	0.62	0.03	0.01	0.02	0.33	0.32	0.33	3.07	3.40	3.23	14.92	15.93	15.42
GCA/SCA			2.45	2.98	3.61	3.10	2.76	5.46	16.70		24.60	2.56	1.41	2.61	6.05	1.77	4.34
GCA×E/GCA					0.05			0.12			0.05			0.33			0.19
SCA ×E/SCA					0.45			1.03			0.54			0.62			0.72

* and ** indicate significant at 0.05 and 0.01 probability levels respectively.

between the parental materials used in this study (Table 1). Significant interaction mean squares between crosses and the conditions were detected for all studied traits except, No. of rows/ear indicating that these crosses behaved somewhat differently from one environment to another. Insignificant interaction mean squares between crosses and environment for no. of rows/ ear were detected, revealing the performance of crosses responded similarly to environmental changes.

Combining ability: The mean squares associated with general combining ability (GCA) and specific combining ability (SCA) were significant for all the studied traits except SCA for number of rows/ear at normal condition (Table 2). 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 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 El-Hosary and El-Badawy (2005), Mosa and Motawei (2005), Motawei (2005), 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 no. of kernels/row and grain yield. Such results showed that the magnitude of all types of gene actions varied from environment to environment. 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, SCA×E mean squares were only significant for ear length and ear diameter traits. 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. On the other hand GCA×E mean squares were only significant for no. of rows/ ear, revealing that non-additive effects were more influenced by the environmental conditions than additive genetic effects.

General combining ability effects: Estimates of GCA effects for individual parental inbred lines for each trait in both environments as well as the combined analysis are presented in Table 2. The parental P4, P8 and P9 exhibited significant positive GCA effects for ear length in both environments as well as the combined analysis. Whereas P2 under artificial infestation condition as well as the combined analysis and P6 in normal condition were the best combiner for this trait.

The data showed that P6 had significant positive GCA effects for ear diameter in both environments as well as the combined data. While, P8 and P9 showed significant positive GCA under artificial infestation and combined date for the same trait.

Regarding No. of rows/ear, P8 and P9 possessed significant positive GCA in both environments as well as the combined analysis. Moreover, P2 was the best combiner for this trait in normal environment. The parental P6 had

Table 2 General combining ability effects for all the studied traits

Parent	Ear length (cm)			Ear diameter (cm)			No. of rows/ear			No. of kernels/row			Yield (kg/feddan)		
	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.
P1	-0.67*	-0.42	-0.55	-0.23**	-0.16**	-0.19**	0.00	-0.23	-0.12	-0.80	-0.50	-0.65	-8.98**	-12.6**	-10.7**
P2	0.95**	0.34	0.64*	-0.03	0.03	0.00	-0.55**	0.48*	-0.03	-3.06**	-1.12	-2.09**	-7.55**	2.45	-2.55
P3	-0.64*	-0.56*	-0.60*	0.07	0.00	0.04	-0.40	-0.37	-0.39	2.26**	-0.05	1.11	5.98**	-4.42**	0.78
P4	1.39**	0.90**	1.14**	-0.18**	0.11**	-0.15**	-2.0**	-1.74**	-1.87**	-1.16	1.03	-0.07	-8.13**	1.86	-3.13*
P5	-1.14**	-1.10**	-1.12**	0.00	0.06	0.03	0.40	0.39	0.40	0.62	-1.26	-0.32	1.80	-4.38**	-1.29
P6	0.16	0.68**	0.42	0.18**	0.17**	0.18**	-0.04	-0.26	-0.15	2.35**	2.87**	2.61**	14.24**	20.1**	17.2**
P7	-1.51**	-1.05**	-1.28**	-0.22**	-0.12**	-0.17**	-0.93**	-0.90**	-0.92**	-4.47**	-1.64*	-3.05**	-17.3**	-10.2**	-13.8**
P8	0.62*	0.71**	0.67*	0.15*	0.07	0.11*	1.84**	1.20**	1.52**	2.13**	1.02	1.57*	2.80*	1.72	2.26
P9	0.84**	0.50*	0.67*	0.25**	0.06	0.16**	1.69**	1.41**	1.55**	2.15**	-0.34	0.90	17.17**	5.47**	11.32**
LSD 5% (gi)	0.62	0.48	0.56	0.12	0.08	0.10	0.41	0.40	0.41	1.24	1.30	1.27	2.73	2.82	2.78
LSD 1% (gi)	0.83	0.63	0.74	0.16	0.11	0.13	0.54	0.53	0.54	1.64	1.73	1.69	3.62	3.74	3.68
LSD 5% (gi-gj)	0.94	0.72	0.83	0.18	0.12	0.15	0.61	0.60	0.61	1.86	1.96	1.91	4.10	4.24	4.17
LSD 1% (gi-gj)	1.24	0.95	1.10	0.23	0.16	0.20	0.81	0.80	0.81	2.46	2.59	2.53	5.43	5.61	5.52

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

significant positive GCA effects for no. of kernels/row in both environments as well as the combined analysis. Whereas P3, P9 under artificial infestation and P8 under artificial infestation and the combined data were the best combiners for this trait. For grain yield only two parental inbred lines P_6 and P_9 showed significant positive GCA effects under artificial infestation, normal conditions as well as combined condition. Whereas, P3 and P8 under artificial infestation were the best combiner for this trait. Therefore, they could be used as a good combiner for high yield. It is worth noting that the inbred line which possessed high GCA effects for grain yield/plant showed the same effect for one or more of the traits contributing to grain yield.

Specific combining ability: Specific combining ability effects were only estimated whenever significant SCA variances were obtained (Table 3). Seven, six and three crosses had significant positive specific combining ability (SCA) effects for ear length under artificial infestation environment, normal environment as well as the combined analysis respectively. It was seen that the crosses $P_2 \times P_8$, $P_1 \times P_6$ and $P_1 \times P_7$ had the best significant positive SCA effects in the combined analysis. As for ear diameter, the cross $P_1 \times P_6$ expressed significant positive SCA effects under artificial infestation environment, normal environment as well as the combined analysis. With respect to no. of rows/ear three crosses ($P_1 \times P_6$, $P_2 \times P_8$ and $P_3 \times P_7$) under the artificial infestation and one cross ($P_2 \times P_3$) in the combined analysis expressed highest desirable significant positive SCA effects. With regard to no. of kernels/row, six, four and three crosses expressed significant positive SCA effects in both environments as well as the combined analysis. The results indicated that crosses $P_1 \times P_6$, $P_1 \times P_7$ and $P_2 \times P_8$ recorded the highest desirable SCA effects in the combined analysis.

With regard to grain yield (kg/feddan) eight, twelve and nine crosses showed significantly positive 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 (P6, P8 and P9) possessed high GCA effects for grain yield and its components. They can be utilized as promising inbred lines in a hybridization programs to develop new yellow hybrids with high yield potential as well as borer tolerance. Most of crosses that were selected based on desirable SCA effects also had high mean performance for grain yield, namely 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 $P_8 \times P_9$) 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 can useful for researchers who would like to develop high yielding hybrids of maize tolerant to borer attack.

Table 3 Specific combining ability effects for all the studied traits

Cross	Ear length (cm)			Ear diameter(cm)			Number of rows/ear			Number of kernels/row			Grain yield (kg/feddan)		
	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.
P1×P2	-3.00**	-1.97**	-2.49**	-0.34*	-0.06	-0.20	-1.11*	-0.89	-1.00*	-5.9**	-0.39	-3.19*	-20.49**	6.35	-7.07*
P1×P3	0.96	0.22	0.59	0.16	0.04	0.10	-0.06	0.36	0.15	1.62	-1.43	0.10	5.15	-16.34**	-5.59
P1×P4	-0.91	-1.50*	-1.20	-0.15	-0.22*	-0.19	-0.70	0.07	-0.31	-2.22	-3.30*	-2.76	0.45	-14.43**	-6.99*
P1×P5	-1.54*	0.60	-0.47	-0.07	0.08	0.01	0.70	0.33	0.52	1.60	-0.72	0.44	-6.36	-0.35	-3.36
P1×P6	2.53**	1.48*	2.00**	0.42**	0.20*	0.31*	1.38**	-0.15	0.62	6.00**	6.82**	6.41**	28.41**	35.97**	32.19**
P1×P7	1.63*	1.48*	1.55*	0.38**	-0.07	0.15	0.47	0.30	0.38	5.19**	3.50*	4.34**	9.71**	14.65**	12.18**
P1×P8	1.16	0.86	1.01	-0.28	0.32**	0.02	-0.67	0.19	-0.24	-4.0**	0.04	-1.98	-11.92**	-4.88	-8.40*
P1×P9	-0.82	-1.17*	-0.99	-0.12	-0.29**	-0.21	-0.02	-0.22	-0.12	-2.20	-4.5**	-3.36*	-4.95	-20.97**	-12.9**
P2×P3	-1.70*	0.43	-0.63	-0.18	0.22*	0.02	0.79	1.22	1.00*	-3.12*	2.86	-0.13	-9.37**	23.14**	6.89*
P2×P4	2.60**	-0.02	1.29	0.21	0.06	0.14	-0.12	0.09	-0.01	-5.9**	-1.59	-3.77*	10.99**	6.42	8.70*
P2×P5	0.80	-0.63	0.09	0.16	-0.11	0.03	0.81	-0.07	0.37	4.76**	1.40	3.08	3.67	-7.13*	-1.73
P2×P6	-2.40**	0.52	-0.94	-0.36*	-0.02	-0.19	-1.11*	0.34	-0.38	0.50	0.57	0.53	-4.91	19.71**	7.40*

Contd.

Table 3 (*Concluded*)

Cross	Ear length (cm)			Ear diameter(cm)			Number of rows/ear			Number of kernels/row			Grain yield (kg/feddan)		
	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.	Infest.	Normal	Comb.
P2×P7	1.27	-0.21	0.53	0.18	0.11	0.14	-0.32	-0.45	-0.39	1.68	-1.22	0.23	6.47	-9.04*	-1.29
P2×P8	2.20**	2.20**	2.20**	0.32*	0.11	0.21	1.38**	0.55	0.96	7.25**	1.02	4.14**	0.67	-7.20*	-3.27
P2×P9	0.22	-0.32	-0.05	0.01	-0.31**	-0.15	-0.31	-0.79	-0.55	0.90	-2.65	-0.88	12.97**	-32.25**	-9.64**
P3×P4	-1.70*	0.14	-0.78	-0.16	-0.01	-0.08	-0.10	-0.59	-0.34	-1.78	1.48	-0.15	-5.23	-1.83	-3.53
P3×P5	0.86	1.13	1.00	0.13	0.03	0.08	-0.46	0.84	0.19	-1.80	2.27	0.24	14.37**	27.11**	20.74**
P3×P6	1.93*	-0.85	0.54	0.01	-0.19	-0.09	0.21	-0.14	0.04	2.14	-3.76*	-0.81	0.07	-28.71**	-14.3**
P3×P7	0.10	-0.88	-0.39	0.18	-0.13	0.02	1.00*	-0.59	0.20	-1.98	-2.85	-2.41	-15.92**	-5.06	-10.°**
P3×P8	-0.37	-1.07	-0.72	0.05	-0.09	-0.02	-0.60	-0.67	-0.63	5.93**	-0.91	2.51	22.00**	-10.19**	5.91
P3×P9	-0.08	0.87	0.39	-0.19	0.12	-0.04	-0.79	-0.44	-0.61	-1.02	2.35	0.66	-11.08**	11.89**	0.40
P4×P5	-1.64*	1.51*	-0.06	-0.55**	0.13	-0.21	0.27	0.08	0.17	-2.47	3.62*	0.58	-3.50	1.82	-0.84
P4×P6	0.06	-0.54	-0.24	0.23	-0.05	0.09	-0.29	-0.53	-0.41	4.97**	-2.27	1.35	5.92	-9.30**	-1.69
P4×P7	1.73*	0.50	1.11	0.27	-0.02	0.12	0.60	0.11	0.35	2.61	-0.43	1.09	7.83*	-6.28	0.77
P4×P8	-0.07	0.00	-0.03	0.07	0.05	0.06	0.50	0.34	0.42	2.69	1.55	2.12	-3.23	11.46**	4.12
P4×P9	-0.08	-0.09	-0.08	0.07	0.06	0.06	-0.16	0.43	0.14	2.17	0.94	1.55	-13.23**	12.14**	-0.55
P5×P6	-0.67	-1.34*	-1.01	0.12	-0.13	0.00	0.14	-1.17	-0.51	-3.58*	-6.1**	-4.87**	-8.68*	-21.62**	-15.1**
P5×P7	0.86	1.32*	1.09	-0.05	0.14	0.05	-0.30	0.48	0.09	1.10	4.19*	2.64	3.60	21.63**	12.61**
P5×P8	-0.30	-1.67**	-0.98	0.09	-0.25*	-0.08	-1.14*	-0.59	-0.87	-1.86	-3.53*	-2.70	-7.70*	-7.63*	-7.67*
P5×P9	1.62*	-0.92	0.35	0.15	0.11	0.13	-0.02	0.10	0.04	2.25	-1.07	0.59	4.60	-13.82**	-4.61
P6×P7	-0.37	-0.12	-0.25	-0.50**	0.08	-0.21	-1.00*	-0.10	-0.55	-0.86	-0.17	-0.52	-4.68	-4.56	-4.62
P6×P8	-1.14	0.25	-0.44	0.04	0.04	0.04	0.54	1.09	0.81	-5.6**	2.67	-1.48	-9.26**	10.31**	0.53
P6×P9	0.05	0.60	0.32	0.03	0.08	0.06	0.12	0.65	0.38	-3.54*	2.30	-0.62	-6.87*	-1.81	-4.34
P7×P8	-2.90**	-1.85**	-2.38**	-0.39**	-0.27**	-0.33**	-0.81	-0.47	-0.64	-6.7**	-3.25*	-5.01**	-8.07*	-24.01**	-16.0**
P7×P9	-2.32**	-0.24	-1.28	-0.07	0.17	0.05	0.37	0.73	0.55	-0.96	0.24	-0.36	1.06	12.68**	6.87*
P8×P9	1.42	1.27*	1.34	0.11	0.08	0.09	0.80	-0.45	0.18	2.41	2.42	2.41	17.51**	32.15**	24.83**
LSD 5% (sij)	1.52	1.16	1.35	0.29	0.19	0.24	0.99	Ns	0.99	3.01	3.17	3.09	6.64	6.86	6.75
LSD 1% (sij)	2.01	1.54	1.79	0.38	0.26	0.32	1.31	Ns	1.31	3.99	4.20	4.10	8.80	9.09	8.95
LSD 5% (sij-sik)	2.29	1.75	2.04	0.43	0.29	0.37	1.50	Ns	1.49	4.55	4.79	4.67	10.04	10.38	10.21
LSD 5% (sij-ski)	2.09	1.60	1.86	0.39	0.27	0.34	1.37	Ns	1.36	4.16	4.37	4.27	9.17	9.47	9.32

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

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