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Estimates of Combining Ability and Gene Action in Maize (*Zea mays* L.) Under Water Stress and Non-stress Conditions

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Abstract
Combining ability and gene action for grain yield and other traits in maize were estimated under water stress and non-stress conditions at the Institute for Agricultural Research farms located at Samaru (11°11'N; 07°38'E) and Kadawa (11°39'N; 08°02'E) using North Carolina mating design II. Seven drought susceptible maize inbred lines used as females were crossed to six drought tolerant maize inbred lines used as males. The experiment was laid out using 7 x 8 simple lattice design with two replications under each condition at each location. Results of the combining ability analysis revealed that both additive and non-additive gene actions were responsible for the control of grain yield and other traits studied under water stress and non-stress conditions. However, the values of dominance genetic variance were greater than additive genetic variance for all traits which depicts the importance of non-additive gene action for controlling these traits. The low narrow sense heritability estimates also indicate the importance of non-additive gene action. The study showed that the female parents S1, S6 and S7 and the male parents P2, P7 and P8 could be considered as good combiners for grain yield and other traits under the water stress and non-stress conditions. The crosses S1 x P2, S6 x P7 and S7 x P8 were the best among the hybrids for grain yield under water stress and non-stress conditions. Considering the dwindling amount of annual rainfall in the area where the study was carried out, these hybrids show potential for exploitation of grain yield and other desirable traits.
Keywords: Combining ability, gene action, water stress, non-stress, heritability

1. Introduction

Maize (*Zea mays* L.) is one of the most widely cultivated cereal crops around the world and the third most important after wheat and rice. It is cultivated worldwide on more than 160 million hectares every year and production was put at 785 million tons. The United States as the largest producer produces 42% of the production (IITA 2011). Up to 29 million hectares of maize is cultivated in Africa annually, and Nigeria is the 10th largest producer in the world and the main producing country in tropical Africa (USAID 2010). As such it has assumed considerable significance in meeting the increasing demand for food and feed in Nigeria. Growth and yield of crops are generally restricted under soil water deficits. Maize suffers from soil moisture deficit which may cause drastic yield reduction, especially if it occurs during the reproductive phase (Basseti & Westgate, 1993). In the Nigerian savanna, where annual rainfall amount and distribution are erratic and the soil is characterized by low moisture holding capacity, maize yields are usually low even under well-managed experiments (Olaoye & Omueti, 2006). Since reduction in drought susceptibility will provide added stability to rural economy and reduce level of chronic food deficit in more marginal production areas (Edemeades *et al.* 1997), development of drought tolerant maize varieties for cultivation in the drought prone ecologies will likely boost maize production beyond its present level. Knowledge of the genetic make-up of complex quantitative traits and the magnitude of genetic variability that exists among available germplasm are important for selection and genetic improvement of crop plants. Selection of parents based on combining ability has been used as an important breeding approach in crop improvement. Developing of high yielding hybrids along with other favourable traits is receiving considerable attention. The combining ability and gene effects of yield and its components were studied by several researchers. Basbag *et al.* (2007) suggested that combining ability analysis is an important tool for selection of desirable parents together with the information regarding nature and magnitude of gene action controlling quantitative traits. Aminu *et al.* (2014) reported significant differences of general combining ability (GCA) effects of parents and that of specific combining ability (SCA) effects of hybrids for grain yield and other agronomic traits and that both additive and non-additive gene effects controlled most traits, but non-additive genetic effect was more prevalent. Majid *et al.* (2010) showed both additive and dominance variances were important for grain yield and other traits under drought stress conditions and that the ratios of GCA to SCA variances were less than unity for all studied traits which showed the predominant role of non-additive gene action in the inheritance. Aminu & Izge (2013) also reported that both additive and non-additive gene actions were responsible for the control of traits evaluated but the effects of non-additive genetic actions were preponderant in respect of the genetic control of grain yield and yield component traits. Shahrokhi *et al.* (2013) also showed the importance of dominance relative to additive genetic effects in maize. Thus, the information regarding combining ability and nature of gene action governing the inheritance of desirable traits are basic requirements for breeding high yielding drought tolerant maize genotypes. Therefore, this study was set out with the objectives of estimating the general combining ability effects of parents and specific combining ability effects of crosses under water stressed and non-stressed conditions. The study was also conducted to estimate additive and non-additive variances as well as narrow sense heritability.

2. Materials and Methods

The study was carried in two locations: Samaru (11°11'N and 07°38'E) in the northern Guinea Savanna ecological zone of Nigeria and Kadawa (11°39'N and 08°02'E) in the Sudan Savanna ecological zone of Nigeria under water stress at grain filling and non-stress conditions. Experimental materials for the study consisted of seven drought susceptible inbred lines used as female parents *viz*., S1, S2, S3, S4, S5, S6 and S7 crossed to six drought tolerant testers used as male parents *viz*., P1, P2, P3, P4, P7 and P8 using North Carolina mating design II according to Comstock & Robinson (1948) to produce 42 hybrids during 2012 rainy season. Parents and their resulting 42 F_1s along with a commercial check were evaluated in a 7 x 8 simple lattice design with two replications under each condition during the 2012/2013 dry season. Each replication had one row of 5m length for each genotype while plant-to-plant and row to row distance was 0.25 m and 0.75 m, respectively. All agronomic practices were kept uniform in both experiments except the irrigations. Non-stress plot continued to receive irrigation water once every week until the end of physiological maturity. In the stress plot, water stress was imposed by withdrawing irrigation water as from six weeks after planting until the end of the growing season, to ensure drought stress at grain filling stage. The crop was allowed to mature only on stored soil water. The two conditions were separated from each other by 2.5 m alley to prevent spill-over at the water stress site during the period of imposed water stress. Non experimental crop was raised at the beginning and end of each replication to minimize border effects. Observations and measurements were recorded from each plot for the following characters: days to 50% tasseling, days to 50% silking, anthesis-silking interval, plant height (cm), ear height (cm), number of ears per plant and grain yield (kgha^{-1}). Data from each location was subjected to analysis of variance separately before subjecting to combined analysis of variance using Statistical Analysis System (SAS Institute 2004). Combining ability analysis was carried out according to Comstock & Robinson (1948) based on North Carolina mating design II general linear model for combined locations as described by Kang (1994):

$$Y_{ijkl} = \mu + m_i + f_j + (mf)_{ij} + s_l + m_{il} + f_{jl} + (mf)_{ij,l} + r_{kl} + e_{ijk}$$

Where:

Y_{ijkl} =observation made on ixj^{th} progeny in the k^{th} replication at the l^{th} location

μ =general mean

f_j =GCA effect of the j^{th} female

m_i =GCA effect of the i^{th} male

$(mf)_{ij}$ =SCA effect of ixj^{th} progeny

s_l = effect of l^{th} location

m_{il} =GCA effect of the i^{th} male in l^{th} location

f_{jl} =GCA effect of the j^{th} female in l^{th} location

$(mf)_{ij,l}$ =SCA effect in the l^{th} location

r_{kl} = effect of k^{th} replication in the l^{th} location

e_{ijk} =experimental error

General combing ability (GCA) and specific combining ability (SCA) effects and their standard errors (SE) were estimated according to Singh & Chaudhary (1985). The estimates of variances due to GCA_f, GCA_m and SCA were also computed from mean squares according to Singh & Chaudhary (1985).

Narrow sense heritability was estimated according to Grafius *et al*. (1952):

$$h^2_{ns}(\%) = \frac{\sigma^2_f + \sigma^2_m}{\sigma^2_f + \sigma^2_m + \sigma^2_{fm} + \sigma^2_e / r\,l} x\,100$$

Where:

σ_f^2 = genetic variance of female
σ_m^2 = genetic variance of male
σ_{fm}^2 = genetic variance of females x males
σ_e^2 = error variance
r = number of replications,
l= number of locations

3. Results and Discussion

3.1 Analysis of Combining Ability and Variances

The analysis of variance for combining ability of traits studied under water stress and non-stress environmental conditions across locations is presented in Table 1. The mean squares due to locations were highly significant (P<0.01) for all traits under both conditions except anthesis-silking interval and number of ears per plant under non-stress condition which were significant at P<0.05 and was not significant for number of ears per plant under water stress. This indicates that the conditions in the two locations were not similar in many ways and that is why the genotypes did not perform in the same way in the locations. These findings agreed with those reported by Aly & Amer (2008). For that reason, suitable hybrids could be developed for specific locations. The mean squares due to GCA_f were highly significant (P<0.01) for days to 50% tasseling, days to 50% silking and anthesis-silking interval under non-stress. Also, the mean squares due to GCA_f for days to 50% tasseling, days to 50% silking and anthesis-silking interval under water stress, plant height, ear height and grain yield under both conditions were significant (P<0.05) and were not significant for other traits. The means squares due to GCA_m were highly significant (P<0.01) for days to silking under non-stress and days to 50% tasseling, anthesis-silking interval, plant height and grain yield under both conditions. The mean squares due to GCA_m was significant (P<0.05) for days to 50% silking under stress and ear height under non-stress and were not significant for the other traits. The mean squares due to SCA was highly significant (P<0.01) for days to 50% silking under non-stress while for days to 50% tasseling, anthesis-silking interval and grain yield under both conditions were significant at P<0.05. The mean squares due to SCA were also significant at P<0.05 for days to 50% silking, plant height and ear height under non-stress condition. Therefore, the result indicated that both additive and non additive gene actions were important and responsible in the genetic expression of these traits and this shows existence of tremendous variability in the genetic materials evaluated. These results are in general agreement with those reported by Aminu & Izge (2013) and Aminu *et al*. (2014). The GCA_f x location mean squares were only significant (P<0.05) for days to 50% tasseling, days to 50% silking, anthesis-silking interval and plant height under non-stress and for grain yield under both stress and non-stress conditions. The GCA_m x location mean squares was highly significant for plant height under non-stress condition while for plant height and ear height under stress condition and grain yield under both stress and non-stress conditions were significant at P<0.05. The SCA x location mean squares were only significant (P<0.05) for days to 50% silking and grain yield under non stress condition. These results were consistent with the findings of Mhike *et al*. (2011). This indicates that G x E effects would present challenges in breeding materials for different environments which highlights the need to use several environments in the estimation of genetic effects.

Estimates of genetic components of variance and heritability for the traits studied under water stress and non-stress environmental conditions across locations are presented in Table 2. The estimates of SCA variances were higher than the GCA variances for all the traits and all the GCA/SCA ratios were less than unity. This revealed the preponderance of non-additive gene effect over additive gene effect for all the traits studied. This corroborates the findings of Meseka *et al*. (2006), Majid *et al*. (2010), Aminu & Izge (2013) and Aminu *et al*. (2014). The use of recurrent selection for improvement of these traits is therefore suggested. Narrow sense heritability was low for all the traits studied and ranged from 1.95% (anthesis-silking interval under water stress) to 20.42% (days to silking under non-stress condition). This also indicates that the studied traits are mainly controlled by non-additive genes. Similar results were recorded by Shahrokhi *et al.* (2013) who also showed the importance of dominance relative to additive genetic effects in maize using generation mean analysis. The best exploitation of this type of gene action would be in the F_1 hybrids implying that breeding gain can be made through inbreeding then crossbreeding, with selection made among the inbred lines.

3.2 General Combining Ability Effects of Parents

Estimates of GCA effects of parents for the traits studied under water stress and non-stress conditions across locations are presented in Table 3. The female parent S7 recorded significant GCA effects for grain yield and days to 50% tasseling under both conditions, days to 50% silking under non-stress and ear height under water stress conditions. In this study negative GCA effects are desirable for days to 50% tasseling, days to 50% silking, anthesis-silking interval, plant height and ear height, while in case of the other traits positive GCA effects are desirable. Minimum days to 50% tasseling, days to 50% silking, plant height and ear height are needed for early maturity and lodging resistance. Hence, it is the highest general combiner. Similarly, S5 is the second highest general combiner with negative significant GCA effects for days to 50% tasseling and days to 50% silking and anthesis-silking interval under both the conditions, plant height under water stress and ear height under non-stress conditions. Anthesis-silking interval is one of the drought tolerant traits recommended for use in a drought breeding programme by Banzinger *et al*. (2000). It is a measure of synchronization of pollen shed with silking as reported by Paul & Debenth (1999). Therefore, S7 and S5 had exhibited highly significant GCA effects in desirable direction for most of the traits. The results for the male parents indicated that P8 had the highest significant GCA effects for grain yield under both conditions, anthesis-silking interval under non-stress and number of ears per plant under water stress conditions. The GCA is considered as the intrinsic genetic value of a parent for a trait which is due to additive genetic effects and is fixable (Simmondes 1979). The parents with high GCA effects for traits could produce superior segregants in the F_2 and later generations. Presence of high GCA effects indicates that continued progress could be possible when selecting for grain yield. Griffing (1956) suggested that high GCA effects might be due to additive gene action as well as additive x additive type of epitasis gene action. The female parents S7 and S5 and the male parent P8 could be considered as good combiners for yield and most of the yield attributing traits under the different conditions. Therefore, these parents could be utilized in a recurrent selection programme for developing drought tolerant inbreds and extensively testing their specific combining ability with a set of proven inbred lines under different conditions for selection of superior hybrids. Majid *et al*. (2010), Aminu & Izge (2013) and Aminu *et al*. (2014) have also identified good general combiners in different populations of maize.

3.3 Specific Combining Ability Effects of Hybrids

The estimates of specific combining ability effects in respect of the forty two hybrids under water stress and non-stress conditions are presented in Table 4. The hybrids, S7 x P1 under both conditions, S5 x P2 under water stress and S3 x P4 and S7 x P8 under non-stress conditions expressed negative and significant SCA effects for days to 50% tasseling. S3 x P2 and S7 x P7 under both conditions and S6 x P1 under non-stress condition expressed negative and significant SCA effects for days to 50% silking. S1 x P7 expressed significant negative SCA effects for days to 50% tasseling under both conditions and days to 50% silking under water stress condition. S6 x P3 under both conditions expressed significant negative SCA effects for days to 50% tasseling and days to 50% silking. Negativity of these traits is important, implying that these hybrids could mature early and could escape drought. Similar results were reported by Aminu & Izge (2013) and Aminu *et al*. (2014). With respect to anthesis-silking interval, S6 x P1, S7 x P3 and S7 x P8 under water stress and S6 x P1 and S7 x P4 under non-stress condition had the highest significant negative SCA effects. Anthesis-silking interval is a measure of synchronization of pollen shed with silking. S6 x P8 expressed significant negative SCA effects for plant height under both conditions and for ear height under non-stress condition. S4 x P3 under both conditions and S5 x P2 and S7 x P4 under water stress expressed significant negative SCA effects for plant height. S1 x P2, S2 x P7, S3 x P4, S4 x P1 and S6 x P1 under non-stress condition expressed significant negative SCA effects for plant height. Negative plant height and ear height are desirable especially in drought prone and windy areas as these traits are important against stem breakage and lodging (Aminu & Izge, 2013 and Aminu *et al*. 2014). S2 x P8 under both conditions, S5 x P7 and S6 x P1 under non-stress condition expressed significant positive SCA effects for number of ears per plant. The hybrids S1 x P2, S6 x P7 and S7 x P8 under both conditions, S2 x P4 under water stress and S1 x P8 under non-stress conditions exhibited significant positive SCA effects for grain yield. These are good hybrids for drought tolerance and grain yield. Other researchers also obtained crosses which showed desirable SCA effects for different characters using different genotypes (Majid *et al*. 2010, Aminu & Izge 2013 and Aminu *et al*. 2014). Better specific combining hybrids might involve two good general combining parents but this is not a rule for all crosses. Sometimes two poor combiners may ensue to good specific combination. Some of the superior hybrids were from both parents with high x high general combiners or either one of the parents with high GCA effect (high x low or low x high) or parents that are low × low general combiners. It therefore means that the parents with either high GCA or low GCA would have a higher chance of having excellent complimentarity with other parents. These findings are similar to those of Aminu & Izge (2013) and Majid *et al*. (2010). In some of the crosses observed, it appears that high SCA effect of any cross combination does not necessarily depend on GCA effects of the parents involved and this was similar to the findings of Sharma & Mani (1998). The superior hybrid combinations involving low x low GCA parents could result from over dominance or epistasis gene action (Hallauer and Miranda 1988 and Majid *et al*. 2010). Such type of gene action may be exploited in cross pollinated crops like maize.

4. Conclusion

In selection followed by hybridization, GCA and SCA are important because GCA effects are attributed to preponderance of genes with additive effects while SCA indicates predominance of genes with non-additive effects. However, both GCA and SCA effects are dependent on germplasm set, evaluation method and specific environments hence they cannot be generally applied. In this study, non-additive genes are predominant in all the traits studied. Similarly, heritability values are specific to the population and environments under study. The female parents S7 and S5 and the male parent P8 could be considered as good combiners for grain yield and other traits under water stress and non-stress conditions. The crosses S1 x P2, S6 x P7 and S7 x P8 were the best among the hybrids for grain yield under water stress and non-stress conditions. The presence of significant mean squares for G and E for some of the measured traits indicates that the test environments in this study were unique and that there was adequate genetic variability among the genotypes to allow good progress from selection for improvement in most of the traits under water stress and non-stress conditions. The results of this investigation further suggest that parents and crosses should be evaluated under different drought stress conditions in target environment in order to obtain precise genetic information. This information will help in optimizing the breeding strategy under drought stress conditions.

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Table 1 Combined ANOVA for combining ability of traits studied under water stress and non-stress conditions across locations

		Days to 50% tasseling		Days to 50% silking		Anthesis-silking interval		Plant height	
Source of variation	df	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress
Rep (Location)	2	38.49**	23.6**	40.40**	17.26*	5.77**	2.14*	976.99*	3177.77**
Location	1	272.50**	1126.34**	141.17**	1131.52**	27.52**	2.88*	103934.22**	65547.09**
GCA_f	6	13.42*	30.37**	14.56*	45.92**	2.41*	3.81**	896.16*	317.96*
GCA_m	5	14.85*	23.34*	19.79*	19.67**	1.90*	2.27*	869.22*	287.57*
SCA	30	10.70*	20.18*	13.17*	22.95**	2.06*	2.08*	647.10*	262.13
GCA_f x L	6	8.87	14.01*	8.88	16.22*	1.80	2.06*	389.83	331.33*
GCA_m x L	5	2.98	2.97	6.11	2.87	1.98	0.90	665.19*	806.25**
SCA x L	30	8.66	13.75	10.15	14.69*	0.83	0.83	438.12	197.02
Error	82	4.23	5.25	5.20	4.83	0.55	0.42	248.84	141.66

		Ear height		Number of ears per plant		Grain yield	
	df	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress
Rep (Location)	2	559.03**	395.74*	0.06	0.20**	7258100.49**	13434462.43**
Location	1	26149.85**	34720.80**	0.03	0.06*	90869039.57**	38095190.48**
GCA_f	6	159.46*	536.52*	0.01	0.05	2137663.48*	3472460.99*
GCA_m	5	140.80	238.08*	0.02	0.05	2773663.21*	3148619.42*
SCA	30	138.50	314.92*	0.03	0.04	1570646.44*	2813089.89*
GCA_f x L	6	97.54	261.67	0.01	0.03	2436118.86*	3154212.11*
GCA_m x L	5	203.09*	163.94	0.04	0.02	1026929.54*	1859610.93*
SCA x L	30	124.56	169.45	0.01	0.03	971093.99	1770447.67*
Error	82	75.14	120.90	0.01	0.02	709440.15	1138182.65

*, ** Significant at 0.05 and 0.01 probability level, df=degree of freedom, Rep=replication, L=location; GCA_f=general combining ability due to females, GCA_m=general combining ability due to males, SCA=specific combining ability

Table 2 Estimates of genetic components of variance and heritability for traits studied under water stress and non-stress conditions across locations

	σ^2_{GCA}		σ^2_{SCA}		$\sigma^2_{GCA}/\sigma^2_{SCA}$		$h^2_n(\%)$	
Traits	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress	Stress	Non-stress
Days to 50% tasseling	0.242	0.513	0.343	1.070	0.705	0.480	12.720	15.540
Days to 50% silking	0.308	0.757	0.461	1.225	0.669	0.618	12.530	20.420
Anthesis-silking interval	0.007	0.074	0.299	0.234	0.024	0.316	1.950	15.890
Plant height	18.122	3.126	33.935	13.043	0.534	0.240	13.790	5.890
Ear height	0.895	5.568	2.530	29.878	0.354	0.186	4.110	8.880
Number of ears per plant	0.001	0.001	0.004	0.002	0.308	0.446	14.290	9.330
Grain yield	68078.223	38265.409	83297.518	221203.562	0.817	0.173	16.910	6.750

σ^2_{GCA} =GCA variance, σ^2_{SCA} =SCA variance, $h^2_n(\%)$ =Narrow sense heritability

Table 3 Estimates of GCA effects of parents for traits studied under water stress and non-stress conditions across locations

	DYTS		DYSK		ASI		PLHT		EHT		EPP		GY	
Parents	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS
Females														
S1	-0.55	1.55*	0.02	1.92**	0.12	0.27	-11.78**	0.57	5.03*	0.83	-0.01	-0.01	-464.15*	-1052.90**
S2	1.31*	0.67	1.27	0.77	0.14	0.40*	10.48*	7.60*	5.01*	7.67*	0.01	-0.02	-527.12*	-182.54
S3	1.09	0.24	0.16	1.27*	0.06	0.17	-3.52	0.32	1.44	-3.17	0.00	0.05	528.44*	243.39
S4	1.20*	1.03	0.06	-0.25	-0.15	-0.10	10.79*	-7.69*	-1.06	3.83	0.00	-0.12**	697.88*	-173.28
S5	-1.18*	-1.58*	-1.40*	-1.83**	-0.58**	-0.39*	-9.53*	-0.24	-3.83	-8.55**	0.01	0.02	-354.89	-164.02
S6	-1.17*	-0.04	-0.15	-0.11	-0.01	-0.44*	-6.02	-1.90	-1.42	-1.90	0.00	0.09*	-364.15	187.83
S7	-1.61**	-1.87**	0.04	-1.77**	0.42*	0.09	9.58*	1.34	-5.17*	1.29	-0.01	-0.01	483.99*	1141.53**
SE±	0.59	0.66	0.66	0.63	0.21	0.19	4.55	3.44	2.50	3.17	0.03	0.04	243.15	307.97
Males														
P1	-0.06	1.15	-1.25*	0.27	-0.04	0.23	-0.37	8.79**	0.40	-0.88	0.08**	0.01	145.63	419.39
P2	-0.20	-1.57**	-0.13	-1.39*	1.05**	-0.11	-0.82	-0.71	-0.09	-0.35	-0.07*	0.03	-625.79*	-468.78
P3	-0.10	0.72	-0.21	1.72**	-0.16	0.17	-8.45*	-8.22**	-0.53	-1.70	-0.01	0.00	-165.48	-468.78
P4	1.18*	-0.38	0.43	-0.23	0.23	0.08	-0.31	-0.78	-5.45*	-6.65*	-0.07*	0.01	-461.51*	645.84*
P7	-1.15*	-1.38*	-0.16	-0.30	-1.04**	0.25	7.43	-0.25	0.51	1.82	0.00	-0.02	513.89*	34.39
P8	0.33	1.46*	1.32*	-0.07	-0.04	-0.52**	2.52	1.17	5.16*	7.76**	0.07*	-0.03	593.26*	676.72
SE±	0.55	0.61	0.61	0.59	0.20	0.17	4.22	3.18	2.32	2.94	0.03	0.04	225.11	285.13

*, ** Significant at 0.05 and 0.01 probability level, respectively DYTS=Days to 50% tasseling, DYSK=Days to 50% silking, ASI=Anthesis-silking interval, PLHT=Plant height, EHT=Ear height, EPP=Number of ears per plant, GY=Grain yield, S=Stress, NS=non-stress

Table 4 Estimates of SCA effects of hybrids for traits studied under water stress and non-stress conditions across locations

	DYTS		DYSK		ASI		PLHT		EHT		EPP		GY	
Hybrids	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS	S	NS
S1 x P1	-0.46	-0.30	-0.38	-0.38	-1.05*	0.01	-0.39	5.13	1.95	0.02	-0.04	-0.25*	-54.90	187.83
S1 x P2	-0.19	-0.03	-0.38	-0.11	-0.24	-0.10	4.01	-17.61*	1.39	15.33	0.05	0.01	1294.31*	1557.67*
S1 x P3	1.07	3.88*	4.09*	1.40	0.08	0.37	-5.48	-3.03	-4.17	-5.07	-0.01	-0.04	0.66	-320.11
S1 x P4	-0.69	-0.14	-0.43	-0.40	0.31	-0.17	2.46	16.54*	1.55	1.05	0.01	0.05	-1225.53*	-89.95
S1 x P7	-4.50*	0.61	-0.59	0.92	-0.05	0.37	-4.40	0.38	1.18	-3.92	-0.02	-0.01	-1300.92*	-312.17
S1 x P8	0.77	-1.03	3.68*	-1.43	-0.05	-0.49	3.80	-2.41	-1.90	2.59	0.01	0.03	286.38	1976.72**
S2 x P1	0.58	1.70	-0.38	1.64	-0.07	0.01	-5.95	-0.48	0.01	-3.78	0.00	0.05	74.74	-182.54
S2 x P2	0.72	0.72	1.00	0.91	0.11	0.28	1.37	-3.60	-1.60	6.32	-0.02	-0.05	-76.06	-1534.92*
S2 x P3	-0.01	-1.24	0.09	-1.32	-0.07	-0.26	26.88*	16.11*	-0.32	1.84	-0.03	-0.02	-36.38	-79.37
S2 x P4	-0.28	0.61	-0.05	3.50*	1.04*	-0.04	-5.38	3.72	3.19	-4.84	-0.03	0.02	1126.32*	39.68
S2 x P7	-0.58	-0.51	-0.59	-0.68	-0.19	-0.13	3.37	-25.10**	-1.73	2.07	-0.01	-0.02	50.93	-349.20
S2 x P8	-0.44	-1.28	-0.07	-1.04	0.18	0.14	-0.29	1.35	0.45	-1.62	0.18**	0.22*	-139.55	1106.35
S3 x P1	-0.57	3.76*	-0.02	0.64	0.39	-0.26	0.52	2.77	0.83	1.40	-0.03	0.01	-91.93	613.76
S3 x P2	4.20*	-0.59	-4.15**	-3.59*	-0.31	-0.12	1.80	1.28	1.36	-1.71	0.03	0.06	-131.61	-1560.85*
S3 x P3	-0.65	0.94	-0.68	3.55*	0.01	0.22	-0.41	3.24	5.17	1.10	-0.01	0.04	241.40	494.71
S3 x P4	0.95	-4.32**	3.68*	-1.00	-0.25	0.19	-2.46	-20.32*	-6.40	-1.41	0.03	-0.05	15.21	-330.69
S3 x P7	0.65	-0.95	4.14*	-0.81	0.51	-0.03	-4.58	-0.98	-2.90	-2.01	-0.01	-0.03	-115.74	2.64
S3 x P8	-0.58	4.16*	-0.97	0.21	-0.36	-0.01	5.13	3.02	1.94	2.64	-0.01	-0.03	82.67	-219.58
S4 x P1	0.48	-0.90	0.58	-0.46	-0.03	0.26	2.87	-16.90*	0.04	0.36	-0.15*	0.02	-50.27	252.65
S4 x P2	0.74	-0.01	0.96	0.30	0.28	1.15*	-2.52	1.91	-2.06	-2.88	-0.02	-0.01	21.17	-255.29
S4 x P3	-0.74	1.28	-0.58	0.57	0.10	0.12	-22.22*	-16.64*	-2.20	0.98	-0.02	-0.02	-1272.49*	22.49
S4 x P4	-1.01	-0.62	-2.35	-0.73	-0.29	-0.29	22.60*	24.67**	2.89	-0.29	0.04	-0.24*	279.10	85.98
S4 x P7	4.32*	0.51	1.12	0.21	-0.15	-0.26	3.02	-0.48	-2.65	1.62	0.09	0.03	92.59	-136.24
S4 x P8	-0.79	-0.26	-0.74	0.11	0.10	1.01*	-3.77	1.43	3.98	0.22	-0.04	-0.01	-70.10	30.42
S5 x P1	-0.46	-0.42	-0.21	-0.13	0.10	0.35	5.65	0.54	-0.57	4.07	0.04	-0.09	-8.60	-1534.39*
S5 x P2	-3.94*	0.10	-1.21	3.14*	-0.22	0.11	-20.99*	22.25**	-0.34	-8.10	-0.02	-0.02	-48.28	13.23
S5 x P3	1.45	-0.62	1.38	-0.97	-0.03	-0.42	-0.07	-3.75	1.98	-0.11	0.07	0.00	491.40	235.45
S5 x P4	4.31*	4.36**	0.36	0.48	0.08	0.17	7.26	1.52	0.11	5.30	-0.02	0.03	-1323.68*	-1589.95*
S5 x P7	-0.25	-0.01	-0.17	-0.33	1.10*	-0.30	-5.24	2.20	3.74	-3.63	-0.03	0.21*	-199.08	632.27
S5 x P8	-0.10	0.60	-0.15	0.82	-0.03	0.91*	3.39	-4.76	-4.92	2.47	-0.04	-0.01	-111.77	-256.61
S6 x P1	1.68	-0.46	0.54	-3.86*	-0.30	-1.32**	-0.98	-16.65*	-3.61	-2.04	0.07	0.21*	-54.89	-1664.02*
S6 x P2	-1.05	-0.32	-0.96	-0.59	1.13*	-0.18	6.34	3.65	2.71	1.18	-0.01	0.05	72.09	550.26
S6 x P3	-3.65*	-3.54*	-3.74*	-3.32*	-0.05	0.04	-4.20	1.15	0.53	-0.80	0.02	0.02	-54.89	-283.07
S6 x P4	1.08	0.70	1.49	3.87*	0.43	0.25	2.92	0.30	-2.01	2.73	-0.02	-0.04	-58.86	224.87
S6 x P7	-0.10	0.57	-0.55	0.82	-0.42	0.29	25.21*	16.69*	3.54	4.43	-0.22**	-0.05	1199.08*	1558.20*
S6 x P8	0.04	1.05	0.22	1.09	0.20	-0.07	-24.29*	-17.15*	-1.16	-15.50*	-0.03	-0.27**	-102.52	-386.24
S7 x P1	-5.25*	-4.38**	-4.15**	-0.44	-0.05	-0.05	-1.71	4.58	1.35	-0.03	0.00	-0.03	185.85	-173.28
S7 x P2	0.51	0.14	0.73	-0.08	0.26	-0.16	-0.02	-4.88	-1.46	-0.14	0.00	-0.04	-131.61	-70.11
S7 x P3	-0.47	0.30	-0.56	0.09	-1.05*	-1.07	5.49	-0.08	-0.98	2.05	-0.01	0.01	-369.71	-70.11
S7 x P4	-0.36	0.40	-0.70	0.29	-0.32	-0.91*	-22.40*	-3.43	0.66	-2.54	-0.01	0.01	-12.57	160.05
S7 x P7	-0.54	-0.22	-0.36	-3.14*	0.23	0.07	2.61	-0.71	-1.19	1.45	0.00	-0.02	273.15	104.52
S7 x P8	4.11*	-4.24**	1.06	0.25	-1.06*	0.32	1.05	24.53**	1.62	-0.79	0.22**	0.27**	1254.89*	1548.94*
SE±	1.83	1.62	1.61	1.55	0.52	0.46	11.15	8.42	6.13	7.77	0.07	0.10	595.58	754.38

*, ** Significant at 0.05 and 0.01 probability level, respectively DYTS=Days to 50% tasseling, DYSK=Days to 50% silking, ASI=Anthesis-silking interval, PLHT=Plant height, EHT=Ear height, EPP=Number of ears per plant, GY=Grain yield, S=Stress, NS=non-stress

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