ISSN : 1812-5379 (Print)
ISSN : 1812-5417 (Online)
http://ansijournals.com/ja

JOURNAL OF AGRONOMY

ANSInet
Asian Network for Scientific Information
308 Lasani Town, Sargodha Road, Faisalabad - Pakistan

Journal of Agronomy 13 (3): 89-99, 2014
ISSN 1812-5379 / DOI: 10.3923/ja.2014.89.99

Inheritance of some Root and Grain Quality Traits in Rice under Water Deficiency Conditions

[1]M.S. Sultan, [1]M.A. Abdel-Moneam, [2]A.B. El-Abd and [2]S.A. El-Naem
[1]Department of Agronomy, Faculty of Agriculture, Mansoura University, Mansoura, Egypt
[2]Rice Research Section, Field Crops Research Institute, ARC, Giza, Egypt

Abstract: The present investigation was carried out at the farm of Rice Research and Training Center Sakha, Kafrelsheikh, Egypt during 2010, 2011 and 2012 seasons to estimate heterosis, gene action, heritability, genetic advance and phenotypic correlation coefficient for some root and grain quality traits in rice by using six populations technique, viz., P_1, P_2, F_1, BC_1, BC_2 and F_2 generations of three rice crosses namely Giza 177×Giza 178 (cross I), Sakha 103×WAB 880 SG 33 (cross II) and Sakha 104×IET 1444 (cross III). Two field experiments were layed out in a randomized complete block design with three replicates. First experiment was flashing water irrigation every 10 days intervals (drought conditions) and second experiment was irrigation every 4 days (normal conditions). The results indicated that highly significant and positive heterosis as a deviation from mid and better- parents were obtained for all root (root length, root volume, number of roots/plant and root/shoot ratio) and grain quality traits (grain length, grain shape, hulling%, milling%, head rice % and amylose content), except all crosses in grain shape and cross II in grain length showed highly significant and negative estimates of heterosis as a deviation from mid-parents. In addition, incomplete dominance to over-dominance was operative for most of the studied traits. Additive gene effect (d) and dominance gene effect (h) were more important in the genetic system for all the studied characters, additive×additive gene effects (i), additive×dominance (j) and dominance×dominance (l) were involved in the genetic control of all characters with some exceptions. Heritability in broad sense was high in the three studied crosses for all the studied characters, except crosses I and III for root/shoot ratio under normal conditions and cross I for grain length under normal conditions were moderate, the highest value of heritability estimates (95.95) was recorded for root volume in cross III under normal conditions While narrow sense heritability was moderate to low in most of the crosses. High values of predicted genetic advance were estimated for most of the studied crosses. Significant or highly significant positive phenotypic correlation was found between most of all the studied characters in the three studied crosses especially between each of root and grain quality characters with grain yield/plant, except amylose content trait. From the foregoing results, cross III (Sakha 104×IET1444) could be recommended for growing under water deficiency to obtain the highest root and grain quality characters at the same time.

Key words: Rice, heterosis, gene action, heritability, genetic advance and phenotypic correlation coefficient

INTRODUCTION

In Egypt, it annually, more than one and half million feddans are cultivated with rice, producing about 6.5 million tons of rice, with an average of 4.2 t fed^{-1}, (10 t ha^{-1}) (RRTC, 2006). This average ranked at the first among the rice producing countries in the world. This production satisfies the needs of local consumption and the rest is exported abroad. But, with the expected increase of population, the production should be increased.

Drought is a major abiotic stress limiting rice production in the world. About 30% of the world's rice producing areas suffer from moisture stress and water deficit, in both rainfed and irrigated areas, about 18 million tons of rice valued at US $ 650 million is lost annually due to drought (Pandey *et al*., 2005). For this reason, breeding for drought tolerance become of high priority in rice breeding program, especially in Egypt because of the limited irrigation water available in the River Nile. Some rice planted areas, especially those located at terminal of irrigation of canals in the northern part of the Nile Delta suffer from shortage irrigation water during different growth stages which are considered to be one of the most serious constraints to rice production (Abd Allah, 2009).

Drought affects rice at morphological, physiological and molecular levels such as delayed flowering, reduced dry matter accumulation and partitioning and decreased photosynthetic capacity as a result of stomatal closure, metabolic limitations and oxidative damage to chloroplasts (Farooq *et al*., 2010).

Corresponding Author: M.S. Sultan, Department of Agronomy, Faculty of Agriculture, Mansoura University, Mansoura, Egypt

Heterosis is defined as the phenomenon in which one F_1 hybrid obtained by crossing two genetically dissimilar individuals shows increased values for some characters over the better-parent or over mid-parental value. Moreover, the estimations of the genetic variance, heritabilities in broad and narrow senses, genetic advance and the type of gene action are also important due to their implications in choosing the most effective selection method. In the same time, the knowledge of magnitude and type of association, among different characters, may help the breeders when selection is based on one or more characters.

The present study aimed to determine the heterosis, degree of dominance, genetic variance, heritability, genetic advance and phenotypic correlation coefficient as percent of means among some root and grain quality characters under water deficiency conditions.

MATERIALS AND METHODS

The present investigation was carried out at the Rice Research and Training Center (RRTC, 2006), Sakha, Kafrelsheikh, Egypt during 2010-2012 seasons to study inheritance of some root and grain quality traits in rice under water deficiency conditions i.e., root length (cm), root volume (cm^3), number of roots/plant, root/shoot ratio, grain length (mm), grain shape, hulling %, milling %, head rice % and amylose content.

According to the previous studies the six genotypes were crossed to produce F_1 hybrid seeds of three crosses namely; I-Giza 177 (sensitive)×Giza 178 (moderate). The II-Sakha 103 (sensitive)×WAB 880 SG 33 (tolerant). The III-Sakha 104 (moderate)×IET 1444 (tolerant). Six populations P_1, P_2, F_1, F_2, BC_1 and BC_2 for each cross were utilized in this study.

In 2010 season, the six cultivars were grown at RRTC farm in three successive dates of planting with ten days interval in order to overcome the differences in flowering time between parents. Thirty days old seedlings of each parent were individually transplanted in the permanent field in seven rows. Each row was 5 m long and contained 25 hills. At flowering time, hybridization between parents was carried out following the technique proposed by Jodon (1938) and modified by Butany (1961) and the aforementioned three crosses were produced.

In 2011 season, parents and F_1 hybrid seeds of the three crosses together with their parental lines were planted under normal conditions. At heading, parents were crossed again to produce the F_1 hybrid seeds of three crosses following the same technique. Moreover, some of F_1 plants were left to self pollinated in order to produce F_2 seeds while some other plants were crossed with their own parents to produce BC_1 and BC_2 seeds. At harvest, seeds of different generations were individually harvested to be grown in the next season. Subsequently, in the summer season 2012, seeds of P_1, P_2, F_1, BC_1, BC_2 and F_2 of each cross were sown under drought conditions. Eighteen entries belongs to different generations (6 parents, 3 $F_{1'S}$, 3 $F_{2'S}$, 3 BC_1, 3 BC_2) were included in a randomized complete block design experiment with three replications. Each replicate contained 10 rows of each P_1, P_2 and 5 rows of each F_1, BC_1 and BC_2 and 20 rows of F_2. Rows were 5 m long and 20×20 cm apart. In all growing seasons of the study, all cultural practices such as field preparation, sowing, transplanting and fertilizers were applied as recommended. The six populations in 2012 season were planted under water deficiency conditions (water deficiency was imposed by using flush irrigation every 10 days without staying water after irrigation) and under normal conditions (irrigation every 4 days with staying water after irrigation). Hand weeding was done when it was needed. Sixty plants from each P_1, P_2 and F_1, 90 plants from each BC_1 and BC_2 and 200 plants from each F_2 populations were taken at random. These plants were individually harvested and threshed separately to determine the grain yield/plant and yield components.

Heterosis was estimated according to Falconer and Mackay (1996). Furthermore, appropriate L.S.D values were calculated to test the significance of heterotic effects according to the equation suggested by Wynne *et al.* (1970). The relative of potence ratio (P) was used to determine the degree of dominance and its directions according to the equation given by Mather and Jinks (1971). Estimation of gene effects were suggested by Mather (1949) and Hayman (1958). Expected genetic variance of VBC_1, VBC_2 and VF_2 in terms of additive ($^1/_2D$) and dominance ($^1/_4H$) are derived by Mather (1949). Heritability in both broad and narrow sense were determined by Powers *et al.* (1950) and Warner (1952), respectively. Expected and predicted values of genetic advance (GS and GS%) were calculated according to Johnson *et al.* (1955). The phenotypic correlation coefficient was performed according to the procedure of Dewey and Lu (1959).

RESULTS AND DISCUSSION

Means of the parents and their generations: The best source of information about the question of base on these estimates is that derived by fitting a model to the mean of the basic generation, i.e., P_1, P_2, F_1, F_2, BC_1 and BC_2 which are presented in Table 1 and 2. The results revealed that wide range of means were recorded between the two

Table 1: Means and standard error of the six populations for rice root characters in the three studied crosses under water deficiency (D) and normal (N) conditions

Characters and crosses		Mean performance and standard error					
		P_1	P_2	F_1	BC_1	BC_2	F_2
Root length (cm)							
I	D	19.28±0.18	20.28±0.16	29.41±0.12	21.55±0.12	22.33±0.12	21.57±0.39
	N	24.23±0.13	26.92±0.11	34.96±0.13	29.96±0.12	31.47±0.12	27.33±0.28
II	D	18.87±0.17	21.38±0.17	25.81±0.20	22.22±0.12	22.52±0.14	19.94±0.46
	N	21.97±0.13	26.78±0.12	32.03±0.12	25.92±0.11	27.35±0.13	24.30±0.29
III	D	21.23±0.17	25.22±0.19	28.43±0.23	24.87±0.13	25.90±0.12	22.22±0.53
	N	26.03±0.12	29.83±0.11	38.35±0.11	29.90±0.11	34.37±0.11	27.58±0.35
Root volume (cm^3)							
I	D	21.56±0.20	51.56±0.76	100.80±0.53	48.43±0.73	50.71±0.48	45.13±2.41
	N	35.35±0.26	80.27±0.32	117.96±0.30	56.42±0.45	84.76±0.37	70.50±1.31
II	D	19.40±0.35	23.53±0.36	75.05±0.64	36.15±0.56	39.98±0.61	33.42±1.43
	N	30.13±0.30	34.26±0.42	93.82±0.26	54.71±0.29	71.85±0.30	52.02±0.91
III	D	40.52±0.53	60.42±0.54	106.20±0.72	58.98±0.54	65.50±0.37	49.39±1.49
	N	53.87±0.18	80.87±0.14	119.96±0.31	84.51±0.32	94.98±0.12	68.67±1.11
No. of roots/plant							
I	D	110.60±0.28	115.58±1.00	252.55±1.20	118.50±1.36	154.91±1.20	173.25±3.00
	N	160.05±0.80	232.80±0.38	313.80±0.64	230.80±0.38	240.78±0.21	231.09±2.43
II	D	96.60±1.20	73.28±0.93	192.81±2.00	157.90±2.12	150.25±1.70	132.71±4.47
	N	176.85±0.32	123.40±0.18	259.80±0.24	213.80±0.60	238.32±0.65	205.05±2.10
III	D	125.97±0.76	141.30±1.18	194.50±1.59	150.36±1.20	162.78±1.30	143.41±3.20
	N	174.13±0.63	242.70±0.47	353.20±0.66	244.10±0.60	267.45±0.65	244.02±2.65
Root/shoot ratio (%)							
I	D	0.23±0.01	0.53±0.012	0.82±0.01	0.50±0.012	0.55±0.018	0.37±0.027
	N	0.35±0.01	1.16±0.010	1.50±0.01	0.64±0.010	0.91±0.010	0.83±0.020
II	D	0.34±0.01	0.31±0.010	0.54±0.01	0.51±0.100	0.50±0.010	0.40±0.020
	N	0.49±0.01	0.53±0.010	0.88±0.01	0.57±0.010	0.70±0.010	0.56±0.020
III	D	0.36±0.01	0.43±0.013	0.60±0.01	0.36±0.010	0.48±0.010	0.42±0.020
	N	0.43±0.01	0.78±0.010	0.94±0.01	0.53±0.010	0.71±0.010	0.71±0.020

Crosses I : Giza 177×Giza 178, II : Sakha 103×Wab 880 SG 33, III : Sakha 104×IET 1444

Table 2: Means and standard error of the six populations of grain quality characters for the three studied crosses under water deficiency (D) and normal (N) conditions

Characters and crosses		Mean performance and standard error					
		P_1	P_2	F_1	BC_1	BC_2	F_2
Grain length (mm)							
I	D	7.42±0.016	7.30±0.011	7.82±0.011	7.50±0.013	7.25±0.011	7.54±0.031
	N	7.89±0.010	7.56±0.070	8.15±0.010	7.99±0.010	7.90±0.010	7.85±0.070
II	D	6.98±0.016	9.96±0.015	8.33±0.014	7.55±0.013	8.30±0.011	7.61±0.030
	N	7.90±0.010	10.80±0.010	9.05±0.010	8.55±0.010	8.99±0.010	8.45±0.030
III	D	7.59±0.013	7.74±0.015	7.83±0.010	7.67±0.014	7.70±0.012	7.64±0.025
	N	7.98±0.010	8.49±0.010	8.67±0.010	8.09±0.010	8.60±0.010	8.44±0.030
Grain shape							
I	D	2.19±0.01	2.58±0.018	2.37±0.011	2.23±0.011	2.33±0.011	2.24±0.025
	N	2.17±0.01	2.53±0.010	2.36±0.010	2.24±0.010	2.32±0.010	2.35±0.020
II	D	2.12±0.01	3.30±0.010	2.51±0.011	2.18±0.010	2.48±0.012	2.44±0.026
	N	2.20±0.01	3.32±0.010	2.55±0.010	2.18±0.010	2.66±0.010	2.41±0.020
III	D	2.16±0.01	2.88±0.012	2.39±0.010	2.44±0.014	2.73±0.015	2.27±0.027
	N	2.21±0.01	2.87±0.010	2.38±0.010	2.65±0.010	2.59±0.010	2.28±0.020
Hulling (%)							
I	D	80.22±0.13	79.85±0.15	81.96±0.13	76.80±0.10	79.21±0.20	77.07±0.26
	N	84.10±0.14	81.91±0.13	85.18±0.15	82.65±0.13	82.30±0.14	82.01±0.32
II	D	79.07±0.13	77.87±0.12	80.42±0.13	78.95±0.13	78.36±0.12	77.45±0.29
	N	83.41±0.11	81.78±0.13	84.93±0.14	83.6±20.13	82.28±0.13	82.94±0.33
III	D	80.08±0.12	79.80±0.11	82.31±0.12	78.53±0.13	79.91±0.22	78.39±0.48
	N	83.91±0.14	81.93±0.13	85.01±0.13	83.88±0.14	82.08±0.13	83.29±0.33
Milling (%)							
I	D	69.98±0.13	69.83±0.13	71.02±0.14	66.36±0.19	68.40±0.13	68.00±0.34
	N	72.51±0.12	71.02±0.12	72.91±0.12	70.66±0.12	69.96±0.12	69.75±0.34
II	D	68.95±0.14	67.02±0.12	70.18±0.11	68.58±0.12	68.30±0.12	67.86±0.33
	N	71.13±0.12	69.92±0.11	71.97±0.12	70.01±0.12	70.23±0.14	69.50±0.33
III	D	69.88±0.11	66.87±0.12	71.00±0.13	68.98±0.12	68.33±0.11	67.80±0.33
	N	72.16±0.12	69.76±0.12	72.53±0.11	69.57±0.11	71.00±0.13	70.61±0.35
Head rice (%)							
I	D	60.93±0.03	59.05±0.035	62.12±0.12	57.08±0.12	58.92±0.10	59.35±0.28
	N	63.12±0.12	61.58±0.130	63.53±0.13	62.36±0.15	61.86±0.13	62.31±0.31

Table 2: Continue

Characters and crosses		Mean performance and standard error P$_1$	P$_2$	F$_1$	BC$_1$	BC$_2$	F$_2$
II	D	60.10±0.04	60.90±0.03	62.27±0.12	60.21±0.12	61.02±0.11	59.56±0.29
	N	62.06±0.13	62.28±0.16	63.70±0.15	62.40±0.13	62.95±0.14	62.60±0.37
III	D	62.02±0.10	57.03±0.12	63.05±0.12	59.08±0.12	58.40±0.11	59.77±0.32
	N	62.93±0.12	59.80±0.11	63.40±0.13	61.01±0.13	60.30±0.12	61.97±0.32
Amylose content (%)							
I	D	19.66±0.09	23.95±0.13	26.77±0.12	21.73±0.12	24.48±0.12	23.53±0.29
	N	18.95±0.09	22.18±0.10	23.92±0.12	20.30±0.13	21.45±0.10	22.82±0.29
II	D	20.98±0.12	25.02±0.14	28.72±0.12	22.67±0.12	24.02±0.13	24.60±0.30
	N	19.41±0.13	24.13±0.15	25.05±0.12	22.07±0.12	23.03±0.13	23.55±0.30
III	D	21.02±0.12	25.32±0.14	29.00±0.12	23.37±0.10	25.51±0.11	24.89±0.33
	N	19.67±0.13	24.31±0.13	25.47±0.12	23.81±0.11	24.47±0.12	23.72±0.30

Crosses I : Giza 177×Giza 178, II : Sakha 103×Wab 880 SG 33, III : Sakha 104×IET 1444

parents in most of the studied traits. The F$_1$ mean values were higher than the highest parent for root length, root volume, number of roots/plant, root/shoot ratio, hullin %, milling %, head rice % and amylose content % in all the studied crosses while it was higher than the highest parent for grain length in the crosses I, III. On the contrary, the mean values were intermediated between the two parents for grain shape in all the crosses and grain length in the cross II. On the other hand, the F$_2$ mean values were higher than the highest parent for root length in the cross I, root volume in the cross II, number of roots/plant in the crosses II and III under water deficiency and normal conditions and the cross I under normal conditions, root/shoot ratio in the cross II, grain length in the cross I under water deficiency conditions and head rice % in the cross II under normal conditions and amylose content in the cross I under normal conditions while the other remaining crosses in the same traits were intermediate between the two parents, except hulling% in all the crosses under water deficiency conditions, milling% in the cross I and head rice % in the cross II under water deficiency conditions were lower than the lowest parent. Moreover, BC$_1$ mean values were higher than the highest parent for root length in the crosses I and II under water deficiency conditions and the crosses I and III under normal conditions, root volume in the cross II under water deficiency and the cross III under normal conditions, number of roots/plant in all the crosses under water deficiency and the crosses II and III under normal conditions, root/shoot ratio in the cross II, grain length in the cross I, hulling% and head rice % in the cross II under normal conditions and milling% in the cross II under water deficiency conditions. The BC$_2$ mean values were higher than the highest parent for root length, number of roots/plant, root volume, except cross I under water deficiency conditions, root/shoot ratio, except the crosses I and III under normal conditions were intermediate between the two parents, grain length in the crosses I and III under normal conditions, head rice % in the cross II and amylose content % in the crosses I and III under water deficiency conditions and the cross III under normal conditions.

Estimates of heterosis and degree of dominances: As shown in Table 3 and 4, the degree of dominance was greater than unity (±1.0) for root length, root volume, number of roots/plant, root/shoot ratio, hulling %, milling %, head rice % and amylose content in all the crosses and the crosses I, III for grain length under water deficiency and normal conditions, suggesting the importance of over-dominance in controlling these traits. However, the degree of dominance was less than unity for grain shape in all the crosses and grain length in the cross II under water deficiency and normal conditions. The ratio which was between zero and unity, suggesting partial or incomplete dominance might be played a remarkable role in the inheritance of these traits. The same results were previously obtained by Abd Allah (2000), Abd El-Lattef and Mady (2009) and El-Abd *et al.* (2008).

It is clear in Table 3 and 4 that significant, highly significant and positive estimates of heterosis as a deviation from mid and better parents were obtained for root length, root volume, number of roots/plant, root/shoot ratio, hulling %, amylose content %, milling % and head rice % in the cross II. While, the other remaining crosses were exhibited highly significant negative as a deviation from mid-parents under water deficiency and normal conditions and positive from better parents under water deficiency conditions. Similar results were reported earlier by Abd El-Lattef *et al.* (2008), Ganapathy and Ganesh (2008), Abd Allah (2009) and Hassan *et al.* (2011).

Estimates of genetic components of generation mean: As shown in Table 5 and 6 that mean effect parameters (m) were highly significant for all the studied traits. Additive gene action (d) played an important role in the inheritance of all the studied characters, except root length and root/shoot ratio in the cross II under water deficiency conditions, grain length in the cross III under water deficiency conditions, hulling % in the cross I under

Table 3: Estimates of heterosis as a deviation from mid-parents (MP), better-parent (BP) and degree of dominance of rice root characters, for the three studied crosses under water deficiency (D) and normal (N) conditions

	Heterosis (%)					
	MP		BP		Degree of dominance	
Characters and crosses	D	N	D	N	(D)	(N)
Root length (cm)						
I	48.64**	36.67**	44.97**	29.85**	19.25	6.98
II	28.22**	31.40**	20.68**	19.59**	4.52	3.18
III	22.41**	37.27**	12.73**	28.52**	-14.26	-20.18
Root volume (cm^3)						
I	173.74**	104.04**	94.10**	46.94**	-4.23	-2.67
II	249.57**	191.38**	218.85**	173.84**	-25.90	-29.87
III	110.57**	78.05**	75.89**	48.33**	-5.60	-3.89
No. of roots/plant						
I	123.31**	59.75**	118.49**	34.77**	-55.92	-3.22
II	126.98**	73.08**	99.59**	46.92**	9.25	4.10
III	45.54**	69.50**	37.65**	45.56**	-7.94	-4.22
Root/shoot ratio (%)						
I	116.09**	97.63**	54.66**	28.83**	-2.92	-1.82
II	68.75**	71.79**	58.82**	64.99**	16.03	-17.41
III	51.06**	54.35**	38.77**	20.40**	-5.76	-1.92

*, **Significant and highly significant at 0.05 and 0.01 levels of probability, respectively

Table 4: Estimates of heterosis as a deviation from mid-parents (MP), better-parent (BP) and degree of dominance of rice grain quality characters, for the three studied crosses under water deficiency (D) and normal (N) conditions

	Heterosis (%)					
	MP		BP		Degree of dominance	
Characters and crosses	D	N	D	N	D	N
Grain length (mm)						
I	6.29**	5.48**	7.19**	7.83**	7.51	2.51
II	-1.65**	-3.15**	19.33**	14.59**	0.09	0.20
III	2.22**	5.38**	3.29**	8.75**	-2.14	-1.73
Grain shape (mm)						
I	-0.66**	0.51**	8.17**	8.84**	0.08	-0.06
II	-7.19**	-7.83**	18.58**	15.60**	0.33	0.38
III	-5.20**	-6.54**	10.52**	7.43**	0.36	0.50
Hulling (%)						
I	2.40**	2.62**	2.16**	1.29**	10.26	1.99
II	2.48**	2.82**	1.70**	1.82**	3.25	2.87
III	2.96**	2.51**	2.77**	1.31**	16.47	2.11
Milling (%)						
I	1.59**	1.59**	1.48**	0.55	14.83	1.53
II	3.23**	2.04**	1.79**	1.17**	2.28	2.38
III	3.82**	2.21**	1.59**	0.51	1.73	1.31
Head rice (%)						
I	3.55**	1.89**	1.95**	0.65	2.26	1.53
II	2.90**	2.45**	2.21**	2.26**	-4.26	-13.55
III	5.91**	3.30**	1.65**	0.73	1.41	1.29
Amylose content (%)						
I	22.79**	16.32**	36.16**	26.23**	-2.31	-2.08
II	24.85**	15.04**	36.86**	29.04**	-2.83	-1.38
III	25.13**	15.82**	37.93**	29.47**	-2.70	-1.50

*, **Significant and highly significant at 0.05 and 0.01 levels of probability, respectively

Table 5: Genetic components of generation means of rice root characters for the three studied crosses under water deficiency (D) and normal (N) conditions

		Genetic components of generation mean					
Characters and crosses		m	d	h	i	j	l
Root length (cm)							
I	D	21.57**	-0.78**	11.1**	1.47	-0.28	9.15**
	N	27.33**	-1.51**	22.92**	13.54**	-0.16	-15.32**
II	D	19.94**	-0.30	15.41**	9.73**	0.95**	-7.34**
	N	24.33**	-1.42**	17.00**	9.35**	0.98**	-3.06*
III	D	22.22**	-1.02**	17.85**	12.65**	0.96**	-10.86**
	N	27.58**	-4.47**	28.62**	18.21**	-2.57**	-14.19**
Root volume (cm^3)							
I	D	45.13**	-2.27**	81.29**	17.76	12.72**	57.23**
	N	70.50**	-28.33**	60.52**	0.37	-5.87**	68.80**
II	D	33.42**	-3.83**	72.15**	18.57**	-1.76*	22.18**
	N	52.02**	-17.13**	106.65**	45.02**	-15.07**	-46.10**

Table 5: Continue

Characters and crosses		m	d	h	i	j	l
		Genetic components of generation mean					
III	D	49.39**	-6.51**	107.22**	51.40**	3.43**	13.14
	N	68.67**	-10.47**	136.88**	84.30**	3.02**	-68.62**
No. of roots/plant							
I	D	173.25**	-36.41**	-6.75	-146.20**	-33.91**	330.67**
	N	231.09**	-9.91**	136.35**	18.95	26.50**	58.37**
II	D	132.71**	7.65**	193.31**	85.45**	-4.00	-146.42**
	N	205.05**	-24.52**	193.72**	84.01**	-51.25**	-168.34**
III	D	143.41**	-12.42**	113.49**	52.63**	-4.76*	-22.65
	N	244.02**	-23.27**	192.01**	47.15**	11.00**	53.01**
Root/shoot ratio (%)							
I	D	0.37**	-0.049**	1.05**	0.60**	0.103**	-0.30*
	N	0.83**	-0.26**	0.54**	-0.20*	0.13**	1.60**
II	D	0.40**	0.012	0.62**	0.41**	-0.0002	-0.72**
	N	0.56**	-0.12**	0.67**	0.30**	-0.1**	-0.06
III	D	0.42**	0.11**	0.22*	0.022	-0.08**	0.27
	N	0.71**	-0.17**	-0.02	-0.35	0.004	0.96**

m: Mid-parent value, d and h: Pooled additive and dominance effects, respectively, i, j and l: Pooled additive×additive, additive×dominance and dominance×dominance gene interaction, respectively, *, **Significant and highly significant at 0.05 and 0.01 levels of probability, respectively

Table 6: Genetic components of generation means of rice grain quality characters for the three studied crosses under water deficiency (D) and normal (N) conditions

Characters and crosses		m	d	h	i	j	l
		Genetic components of generation mean					
Grain length (mm)							
I	D	7.54**	0.25**	-0.22	-0.68**	0.19**	1.55**
	N	7.85**	0.09**	0.80**	0.37	-0.07	-0.40
II	D	7.61**	-0.74**	1.13**	1.27**	0.74**	0.62**
	N	8.45**	-0.43**	0.95**	1.24**	1.01**	0.48**
III	D	7.64**	-0.03	0.34**	0.17	0.044*	0.09
	N	8.44**	-0.50**	0.07	-0.37**	-0.25**	0.80**
Grain shape							
I	D	2.24**	-0.10**	0.13	0.15	0.09**	0.25*
	N	2.35**	-0.08**	-0.28**	-0.30**	0.10**	0.60**
II	D	2.44**	-0.29**	-0.61**	-0.41**	0.29**	1.53**
	N	2.41**	-0.48**	-0.18	0.02	0.07**	0.90**
III	D	2.27**	-0.28**	1.14**	1.27**	0.07**	-1.77**
	N	2.28**	0.05**	1.20**	1.30**	0.39**	-2.01**
Hulling (%)							
I	D	77.07**	-2.41**	5.65*	3.72	-2.60**	8.25
	N	82.01**	0.35	4.01**	2.25	-0.74**	4.65**
II	D	77.45**	0.58**	6.77**	4.82**	-0.01	-1.65
	N	82.94**	1.33**	2.39	2.46	0.52*	3.19*
III	D	78.39**	-1.37**	5.70**	3.33	-1.51**	4.27
	N	83.29**	1.80**	0.87	-1.31	0.81**	5.14**
Milling (%)							
I	D	68.00**	-2.03**	-1.36	-2.47	-2.11**	14.82**
	N	69.75**	0.70**	3.39*	2.25	-0.04	5.86**
II	D	67.86**	0.28	4.50**	2.30	-0.67**	0.26
	N	69.50**	-0.22	3.91**	2.46	-0.83**	2.04
III	D	67.80**	0.65**	6.06**	3.45*	-0.85**	0.66
	N	70.61**	-1.42**	0.25	-1.31	-2.62**	7.16**
Head rice (%)							
I	D	59.35**	-1.83**	-3.24**	-5.37**	-2.77**	17.58**
	N	62.00**	0.50*	1.59	0.41	-0.26	2.92
II	D	59.65**	-0.81**	5.63**	3.87**	-0.39*	-0.77
	N	62.60**	-0.55**	1.82	0.30	-0.43	0.75
III	D	59.77**	0.68**	-0.60	-4.12**	-1.80**	14.31**
	N	61.97**	0.71**	-3.24*	-5.27**	-0.85**	12.18**
Amylose content (%)							
I	D	23.53**	-2.75**	3.28**	-1.68	-0.60**	6.39**
	N	22.82**	-1.15**	-4.42**	-7.78**	0.45*	13.25**
II	D	24.60**	-1.35**	0.68	-5.03**	0.66**	15.09**
	N	23.55**	-0.96**	-0.73	-4.00**	1.40**	7.43**
III	D	24.89**	-2.13**	4.03**	-1.79	0.01	8.36**
	N	23.72**	-0.66**	5.15**	1.67	1.65**	-3.31*

m: Mid-parent value, d and h: Pooled additive and dominance effects, respectively, i, j and l: Pooled additive×additive, additive×dominance and dominance×dominance gene interaction, respectively, *, **Significant and highly significant at 0.05 and 0.01 levels of probability, respectively normal conditions and milling% in the cross II under water deficiency and normal conditions. Moreover, dominance gene action (h) played a greater role in all the studied crosses, except number of roots/plant in the cross I under water deficiency conditions, root/shoot ratio in the cross III under normal conditions, grain length in the cross I under water deficiency and the cross III under normal conditions, grain shape in the cross I under water deficiency and cross II under normal conditions, hulling % in the crosses II and III under normal conditions, milling % in the cross I under water deficiency conditions and cross III under normal conditions, hulling % in the crosses I and II under normal conditions and the cross III under water deficiency conditions and amylose content in the cross II under water deficiency and normal conditions. Additive×additive type of gene interaction (i) played an effective role in all the crosses, except root length in the cross I under water deficiency conditions, root volume in the cross I under water deficiency and normal conditions, number of roots/plant in the cross I under normal conditions, root/shoot ratio in the cross III under water deficiency and normal conditions, grain length in the cross I under normal conditions and the cross III under water deficiency conditions, grain shape in the cross I under water deficiency conditions and cross II under normal conditions, hulling % in the cross I and III under water deficiency and normal conditions and the cross II under normal conditions, milling % in the crosses I and II under water deficiency and normal conditions and the cross III under normal conditions, head rice % in the crosses I and II under normal conditions and amylose content in the cross I under water deficiency conditions and the cross III under water deficiency and normal conditions. Additive×dominance type of gene interaction (j) played an important role in the inheritance of all the studied characters, except root length in the cross I under water deficiency and normal conditions, number of roots/plant in the cross II under water deficiency conditions, root/shoot ratio in the cross II under water deficiency conditions and the cross III under normal conditions, grain length and milling % in the cross I under normal conditions, hulling % in the cross II under water deficiency conditions, head rice % in the crosses I and II under normal conditions and amylose content % in the cross III under water deficiency conditions. Dominance×dominance type of gene interaction (l) played an important role in the inheritance of all the studied characters, except root volume and number of roots/plant in the cross III under water deficiency conditions and root/shoot ratio in the cross II under normal conditions and the cross III under water deficiency conditions, grain length in the cross I under normal conditions and the cross III under water deficiency conditions, hulling % in all crosses under water deficiency conditions, milling % in the cross II under water deficiency and normal conditions and the cross III under water deficiency conditions, head rice % in the cross I under normal conditions and the cross II under water deficiency and normal conditions.

These findings suggest that additive gene effects made a significant contribution to the inheritance of the studied characters in these crosses. The three types of gene interaction were important in the inheritance of the studied traits under drought conditions. These results were in agreement with those obtained previously by Shehata *et al*. (2004), Manickavelu *et al*. (2006), Kumar *et al*. (2006), El-Abd *et al*. (2008) and Hassan *et al*. (2011).

Estimates of genetic variance, heritability and genetic advance: Data summarized in Table 7 and 8 revealed

Table 7: Estimates of additive genetic variance ($^1/_2$ D), dominance genetic variance ($^1/_4$ H), broad and narrow-sense heritabilities and genetic advance (G.S %) of rice root characters for the three studied crosses under water deficiency (D) and normal (N) conditions

		Genetic variance		Heritability			
Characters and crosses		$^1/_2$D	$^1/_4$H	Broad-sense	Narrow-sense	G.S	G.S (%)
Root length (cm)							
I	D	0.27	-0.14	82.93	20.30	16.33	75.72
	N	0.12	-0.06	80.23	40.31	23.42	85.69
II	D	0.39	-0.21	83.59	15.89	15.21	76.27
	N	0.13	-0.06	81.15	38.34	23.02	94.75
III	D	0.53	-0.29	85.32	12.20	13.42	60.38
	N	0.22	-0.11	89.01	22.06	16.09	58.35
Root volume (cm^3)							
I	D	10.89	-5.36	94.73	13.35	66.44	147.21
	N	3.11	-1.47	94.60	20.19	54.74	77.65
II	D	3.43	-1.59	89.09	33.68	99.78	298.51
	N	1.50	-0.77	86.41	21.46	40.65	78.14
III	D	4.03	-2.16	83.38	19.50	60.04	121.57
	N	2.38	-1.18	95.95	9.58	22.09	32.17

Table 7: Continue

Characters and crosses		Genetic variance $^1/_2$D	$^1/_4$H	Heritability Broad-sense	Narrow-sense	G.S	G.S (%)
No. of roots/plant							
I	D	14.92	-6.70	90.17	36.23	255.40	130.09
	N	11.65	-6.13	93.15	3.31	16.63	7.19
II	D	32.47	-14.68	88.84	37.79	348.03	262.52
	N	8.05	-3.70	98.48	17.6	76.24	37.18
III	D	18.23	-8.98	85.92	30.69	207.52	144.69
	N	13.28	-6.60	94.91	11.27	61.61	25.24
Root/shoot ratio (%)							
I	D	0.001	-0.0004	83.00	63.85	3.65	969.00
	N	0.0008	-0.0004	66.53	41.78	1.94	233.54
II	D	0.0008	-0.0004	80.36	39.31	1.91	469.39
	N	0.0008	-0.0004	71.49	47.25	2.36	418.65
III	D	0.001	-0.0006	71.20	31.32	1.67	399.12
	N	0.0009	-0.0005	60.46	42.33	2.09	293.84

Crosses I: Giza 177×Giza 178, II: Sakha 103×Wab 880 SG 33, III : Sakha 104×IET 1444

Table 8: Estimates of additive genetic variance ($^1/_2$ D), dominance genetic variance ($^1/_4$ H), broad and narrow-sense heritabilities and genetic advance (G.S %) of rice grain quality characters for the three studied crosses under water deficiency (D) and normal (N) conditions

Characters and crosses		Genetic variance $^1/_2$ D	$^1/_4$ H	Heritability Broad-sense	Narrow-sense	G.S	G.S %
Grain length (mm)							
I	D	0.001	-0.0008	81.81	32.10	2.06	27.31
	N	0.010	-0.007	62.12	7.42	1.14	14.58
II	D	0.001	-0.001	77.91	28.05	1.93	25.38
	N	0.002	-0.001	86.43	27.17	1.98	23.45
III	D	0.0009	-0.0004	72.27	59.18	3.08	40.35
	N	0.002	-0.001	87.36	24.93	1.80	21.37
Grain shape							
I	D	0.001	-0.0005	71.02	39.86	2.11	94.26
	N	0.001	-0.0005	71.85	35.71	1.84	78.39
II	D	0.001	-0.0005	82.90	37.84	2.04	83.69
	N	0.0008	-0.0004	76.03	51.96	2.54	105.11
III	D	0.001	-0.0004	83.31	59.11	3.30	145.51
	N	0.001	-0.0006	80.89	34.63	2.02	88.64
Hulling (%)							
I	D	0.083	-0.034	79.38	71.32	43.08	55.89
	N	0.17	-0.09	80.38	35.73	24.13	29.42
II	D	0.14	-0.07	80.07	36.49	22.15	28.59
	N	0.18	-0.09	84.37	32.99	22.59	27.24
III	D	0.40	-0.18	93.52	29.89	29.91	38.16
	N	0.18	-0.09	83.03	34.23	23.68	28.43
Milling (%)							
I	D	0.17	-0.08	71.32	47.56	33.53	49.31
	N	0.20	-0.10	87.62	27.01	19.08	27.36
II	D	0.18	-0.09	80.07	28.99	19.87	29.29
	N	0.19	-0.09	87.08	31.82	22.12	31.83
III	D	0.19	-0.09	93.52	26.70	18.31	27.00
	N	0.22	-0.11	88.44	25.31	18.68	26.46
Head rice (%)							
I	D	0.13	-0.06	92.73	34.51	20.42	34.41
	N	0.16	-0.07	81.97	41.78	27.44	44.26
II	D	0.14	-0.06	92.56	33.25	20.01	33.55
	N	0.23	-0.11	83.69	29.89	22.79	36.41
III	D	0.18	-0.09	86.20	25.95	17.44	29.19
	N	0.17	-0.08	84.51	33.25	21.97	35.45
Amylose content (%)							
I	D	0.14	-0.07	84.50	34.70	21.27	90.39
	N	0.14	-0.07	86.61	33.38	20.45	89.59
II	D	0.15	-0.07	81.83	36.23	22.69	92.24
	N	0.14	-0.07	78.77	37.45	23.42	99.43
III	D	0.19	-0.1	84.35	22.40	15.32	61.57
	N	0.15	-0.08	80.74	30.15	19.00	80.09

Crosses I : Giza 177×Giza 178, II: Sakha 103×Wab 880 SG 33, III: Sakha 104×IET 1444 that additive genetic variance (½D) was higher than dominance genetic variance (¼H) for all the studied characters under water deficiency and normal conditions, indicating that additive component of genetic variance was predominant in the expression for all the studied characters.

Heritability in broad sense, estimates were larger than their corresponding ones of narrow sense heritability for all the studied crosses. High broad sense heritability was estimated for most of the studied characters under water deficiency and normal conditions. Narrow sense heritability ranged from low to moderate in the three studied crosses. High estimates of expected genetic advance were recorded in all the crosses for root/shoot ratio under water deficiency and normal conditions and most of the crosses for number of roots/plant, root volume and root length under water deficiency conditions. High estimates of expected genetic advance were recorded for grain shape in most of the studied crosses followed by amylose content under water deficiency and normal conditions, indicating that the selection for these traits will be effective in early segregating generations. Similar results were reported by Toorchi *et al.* (2002), Gomez and Kalamani (2003) and Abd El-Lattef *et al.* (2008).

Estimates of phenotypic correlation coefficients: The phenotypic correlation coefficients among all possible pairs of root and grain quality and with grain yield/plant traits are presented in Table 9 and 10. Lucidly, grain yield was positively and strongly correlated with each of root length, root volume, number of roots/plant, root/shoot ratio, grain length, grain shape, hulling%, milling% and head rice % in all the studied crosses under water deficiency and normal conditions. Therefore, any selection based on these traits will bring the desired improvement in grain yield. Amylose content showed insignificant negative or positive correlation with most

Table 9: Phenotypic correlation coefficient among all possible pairs of some root and grain yield/ plant characters in the F_2 generation of the crosses I, II and III under water deficiency (D) and normal (N) conditions

Characters and crosses		1	2	3	4
Root length (cm)					
I	D				
	N				
II	D				
	N				
III	D				
	N				
Root volume (cm^3)					
I	D	0.866**			
	N	0.82**			
II	D	0.775**			
	N	0.81**			
III	D	0.818**			
	N	0.73**			
No.of roots/plant					
I	D	0.859**	0.762**		
	N	0.63**	0.65**		
II	D	0.795**	0.949**		
	N	0.67**	0.84**		
III	D	0.818**	0.943**		
	N	0.82**	0.84**		
Root/ shoot ratio					
I	D	0.759**	0.641**	0.873**	
	N	0.68**	0.79**	0.70**	
II	D	0.409**	0.632**	0.627**	
	N	0.64**	0.79**	0.72**	
III	D	0.943**	0.846**	0.852**	
	N	0.74**	0.73**	0.86**	
Grain yield/plant (g)					
I	D	0.829**	0.721**	0.962**	0.840**
	N	0.66**	0.73**	0.68**	0.79**
II	D	0.674**	0.857**	0.863**	0.724**
	N	0.65**	0.80**	0.75**	0.75**
III	D	0.936**	0.863**	0.879**	0.953**
	N	0.82**	0.82**	0.94**	0.84**

*, **Significant and highly significant at 0.05 and 0.01 levels of probability, respectively

Table 10: Phenotypic correlation coefficient among all possible pairs of grain quality and grain yield/plant characters in the F_2 generation of the crosses I, II and III under water deficiency (D) and normal (N) conditions

Characters and crosses		1	2	3	4	5	6
Grain length (mm)							
I	D						
	N						
II	D						
	N						
III	D						
N							
Grain shape							
I	D	0.675**					
	N	0.68**					
II	D	0.782**					
	N	0.02					
III	D	0.564**					
N		0.62**					
Hulling (%)							
I	D	0.767**	0.642**				
	N		0.63**	0.72**			
II	D	0.841**	0.733**				
	N		0.74**	0.06			
III	D	0.751**	0.537**				
	N		0.92**	0.57**			
Milling (%)							
I	D	0.717**	0.550**	0.621**			
	N		0.69**	0.69**	0.78**		
II	D	0.759**	0.732**	0.748**			
	N		0.82**	0.03	0.78**		
III	D	0.798**	0.567**	0.691**			
	N		0.82**	0.55**	0.83**		
Head rice (%)							
I	D	0.735**	0.672**	0.738**	0.574**		
	N		0.68**	0.74**	0.79**	0.75**	
II	D	0.620**	0.617**	0.675**	0.583**		
	N		0.74**	0.05	0.69**	0.71**	
III	D	0.814**	0.578**	0.672**	0.736**		
	N		0.81**	0.56**	0.85**	0.74**	
Amylose content (%)							
I	D	0.304*	0.252	0.186	0.229	0.265	
	N	0.03	0.07	-0.04	-0.01	-0.06	
II	D	0.114	0.071	-0.015	0.086	-0.038	
	N	-0.27*	0.14	-0.27*	-0.25	-0.35*	
III	D	0.029	-0.125	-0.057	-0.067	0.048	
N		-0.32*	-0.36**	-0.29*	-0.32*	-0.33*	
Grain yield/plant (g)							
I	D	0.963**	0.688**	0.785**	0.718**	0.747**	0.312*
	N	0.75**	0.70**	0.72**	0.78**	0.71**	0.03
II	D	0.948**	0.820**	0.880**	0.779**	677**	0.068
	N	0.84**	0.08	0.74**	0.79**	0.72**	-0.30*
III	D	0.950**	0.581**	0.794**	0.810**	0.846**	-0.002
	N	0.91**	0.59**	0.92**	0.81**	0.83**	-0.29*

*, **Significant and highly significant at 0.05 and 0.01 levels of probability, respectively

other grain quality traits. Root length was highly significant and positive associated with root volume, number of roots/plant and root/shoot ratio in all the studied crosses. However, a highly significant and positive estimate of phenotypic correlation coefficient was recorded between grain length and each of grain shape, hulling%, milling% and head rice %. Present findings coincide with the results of Abd El-Lattef and Mady (2009), Hassan *et al.* (2011) and Haider *et al.* (2012).

REFERENCES

Abd Allah, A.A., 2000. Breeding studies on rice (*Oryza sativa* L.). Ph.D. Thesis, Faculty of Agriculture, Menoufiya University, Shibin El-Kom, Egypt.

Abd Allah, A.A., 2009. Genetic studies on leaf rolling and some root traits under drought conditions in rice (*Oryza sativa* L.). Afr. J. Biotechnol., 8: 6241-6248.

Abd El-Lattef, A.S.M., A.B. El-Abd, A.A. Madyan and W.M.H. El-Khouby, 2008. Inheritance of earliness, grain yield and some grain quality traits in rice (*Oryza sativa* L.) under water deficiency conditions. J. Agric. Res. Kafrelsheikh Univ., 34: 993-1019.

Abd El-Lattef, A.S. and A.A. Mady, 2009. Genetic behavior for some root characters and their relation to some other characters under drought condition in rice (*Oryza sativa* L.). J. Agric. Sci. Mansoura. Univ., 34: 1153-1172.

Butany, W.T., 1961. Mass emasculation in rice. Inster. Rice Comm. Newslett., 9: 9-13.

Dewey, D.R. and K.H. Lu, 1959. A correlation and Path-coefficient analysis of components of crested wheatgrass seed production. Agron. J., 51: 515-518.

El-Abd, A.B., S.E.M. Sedeek, S.A.A. Hammoud and A.A. Abd Allah, 2008. Studies on genetic variability, heritability and genetic advance for grain yield and grain quality traits in some promising genotypes of rice (*Oryza sativa* L.). J. Agric. Res., Kafrelsheikh Univ., 34: 73-97.

Falconer, D.S. and T.F.C. Mackay, 1996. Introduction to Quantitative Genetics. 4th Edn., Longman Group Ltd., London, UK., ISBN-13:9780582243026, Pages: 464.

Farooq, M., N. Kobayashi, O. Ito, A. Wahid and R. Serraj, 2010. Broader leaves result in better performance of indica rice under drought stress. J. Plant Physiol., 167: 1066-1075.

Ganapathy, S. and S.K. Ganesh, 2008. Heterosis analysis for physio-morphological traits in relation to drought tolerance in rice (*Oryza sativa* L.). World J. Agric. Sci., 5: 623-629.

Gomez, S.M. and A. Kalamani, 2003. Scope of landraces for future drought tolerance breeding programme in rice (*Oryza sativa* L.). Plant Arch., 3: 77-79.

Haider, Z., A.S. Khan and S. Zia, 2012. Correlation and path coefficient analysis of yield components in rice (*Oryza sativa* L.) under simulated drought stress condition. Am. Euras. J. Agric. Environ. Sci., 12: 100-104.

Hassan, H.M., A.B. El-Abd and N.M. El-Baghdady, 2011. Combining ability for some root, physiological and grain quality traits in rice (*Oryza sativa* L.) under water deficit conditions. J. Agric. Res. Kafrelsheikh Univ., 37: 239-256.

Hayman, B.I., 1958. The separation of Epistatic from additive and dominance variation in generation means. Heredity, 12: 371-390.

Jodon, N.E., 1938. Experiments on artificial hybridization of rice. J. Am. Soc. Argon., 30: 249-305.

Johnson, H.W., H.F. Robinson and R.E. Comstock, 1955. Estimates of genetic and environmental variability in soybean. Agron. J., 47: 314-318.

Kumar, S., A.S. Gautam and S. Chandel, 2006. Estimates of genetic parameters for quality traits in rice (*Oryza sativa* L.) in Mid Hills of Himachal Pradesh. Crop Res. Hisar, 32: 206-208.

Manickavelu, A., N. Nadarajan, S.K. Ganesh and R.P. Gnanamalar, 2006. Genetic analysis of biparental progenies in rice (*Orzya sativa* L.). Asian J. Plant Sci., 5: 33-36.

Mather, K. and J.L. Jinks, 1971. Biometrical Genetics. Cornell University Press, Ithaca, New York, Pages: 231.

Mather, K., 1949. Biometrical Genetics. Dover Publication Inc., London, UK., Pages: 158.

Pandey, S., H. Bhandari, R. Sharan, D. Naik, S.K. Taunk and A.D. Sastri, 2005. Economic costs of drought and rainfed rice farmers' coping mechanisms in Eastern India. Final Project Report, International Rice Research Institute, Los Banos, Philippines.

Powers, L.R., L.F. Locke and J.C. Garrett, 1950. Partitioning method of genetic analysis applied to quantitative characters of tomato crosses. U.S. Department of Agriculture, Washington, DC., Pages: 56.

RRTC, 2006. The eight national rice research and development program workshop. Rehabilitation Research and Training Centers (RRTC), American Refugee Committee (ARC), Egypt, Cairo, pp: 1-34.

Shehata, S.M., A.E. Draz, A.A. AbdAllah and B.A. Zayed, 2004. Genetic studies on morphological characters as indicators of salt and drought tolerance in rice. Egypt J. Agr. Res., 82: 101-118.

Toorchi, M., H.E. Shashidhar, S. Hittalmani and T.M. Gireesha, 2002. Rice root morphology under contrasting moisture regimes and contribution of molecular marker heterozygosity. Euphytica, 126: 251-257.

Warner, J.N., 1952. A method for estimating heritability. Agron. J., 44: 427-430.

Wynne, J.C., D.A. Emery and P.M. Rice, 1970. Combining ability estimates in *Arachis hypogaea* L. II. Field performance of F_1 hybrids. Crop Sci., 10: 713-715.