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Development of some high yielding rice lines tolerant to drought stress conditions

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In Egypt, water requirement for the rice crop is a problem because of the limited irrigation water available from the River Nile. To solve that problem, a breeding program for drought tolerance, starting from hybridization until yield trials experiments, was designed. Ten promising lines were derived from IET 1444/ Sakha 102, Sakha 101 / IR 65600 and Sakha 101 / Gaori populations. Attentions were paid to the traits more associated with drought tolerance among segregants. The progenies from each cross were advanced from F_2 until F_6 generation. F_7 seeds were collected and bulked to provide the seed source for yield trial experiments. The best selected lines from Fn generation were evaluated under normal and drought conditions (flush irrigation every 12 days) during 2007 and 2008 rice growing seasons. The amount of irrigation water applied was determined by using flow meter. In 2009 season, the lines were evaluated under different irrigation intervals (irrigation every 4, 8 and 12 days). Each experiment was designed in a randomized complete block design, with three replications. These lines were found to be tolerant to drought conditions at different growth stages, that is, seedling stage, early and late vegetative stage, panicle initiation stage and ripening stage. Water saving ranged from 50 to 55% as compared to continuous submergence, with a rice yield of 7-9 tons/ hectare. So, by using such lines the total water requirements might be significantly reduced without significant reduction in the yield. Also, these lines could be used as donor parents at reproductive stage to solve the problem of a lack of the donor parents in breeding rice for drought tolerance.

Key words: Drought stress, rice, high yielding lines, saving irrigation water.

INTRODUCTION

Water productivity can be increased by increasing yield per unit area, that is, better varieties or agronomic practices, or by using suitable irrigation system. In some cases, superior response to vegetative stage stress is associated with better performance under reproductive stage stress, but, in many cases, the strategies that appear to be successful at the reproductive stage may be counterproductive when stress occurs at flowering (Pantuwan et al., 2002).

Because of the increasing needs of water for many other purposes than agriculture, and the susceptibility of rice plant to drought, appropriate line developed under the Egyptian conditions, should be chosen to be grown. These promising lines must possess drought tolerance mechanisms, such as escape, avoidance, tolerance and recovery (Asch et al., 2005). Short growth duration (generally defined by early flowering) constitutes an important attribute of ‘drought escape’, especially for conditions of a late-season drought stress. On the other hand, longer growth duration is often associated with high yield potential. Consequently, using drought escape as a solution should be associated with high yield. Early maturity leads to less evapotranspiration because of the shorter time in the field. However, as growth duration is genetically linked with leaf characters and often with leaf size, early genotypes have a small leaf-area index. Thus, early genotypes show reduced evapotranspiration during most growth stages, up to the point where a full ground cover is achieved (Pantuwan et al., 2002). Rice is sensitive to drought stress during flowering resulting in high floret sterility. It is however clear that increased cuticular resistance of spikelet surfaces would moderate panicle desiccation. Higher rate of osmotic adjustment and the accumulation of protective solutes should protect floral part against desiccation. In conclusion, there are potential traits for improving drought resistance in drought

Table 1. Average of some physical and chemical properties of the soil in the experimental site (during 2007 and 2008 seasons).

Characters	Values
pH	8.3
EC (dS m-1)	2
Soluble Cations (meq. L-1	
Ca^{++}	5.1
Mg^{++}	2.1
K^{+}	0.4
Soluble anions (meq. L-1)	
Na^{+}	12
HCO_3	3.5
Cl^{-}	14.8
Mechanical analysis	
SO_4	1.3
Clay (%)	56.1
Silt (%)	31.3
Sand (%)	12.6
Texture	(Clayey)

tolerant rice, such as root traits, some shoot and physiological traits, cuticular resistance and grain yield. On the other hand, there is a need for further physiological and agronomic research to establish value for other potential traits, such as delayed senescence or stem reserve utilization.

Because the area of the rice cultivation is restricted to the northern half of the Nile Delta; the area of cultivated rice has become limited as well as water resources. We must turn to the cultivation of modern reclaimed land, as well as salt territories light. Also, some rice cultivated areas especially which are located at the end of the terminal in the northern part of the Nile Delta suffer from shortage of irrigation water during different growth stages, which are considered to be one of the most serious constraints to rice production in Egypt. The most practical solution to this problem is by using new rice varieties tolerant to drought to reduce the total water requirements. In an effort to conserve some of the water designated for agriculture, some promising lines can be produced to grow rice under water stress conditions instead of full surface irrigation. If successful, a large percentage of water could potentially be saved.

This study aims to develop new drought tolerant lines to produce more rice with less water, reduce the total water requirement on one hand and also, to tolerate the drought conditions occurring in some rice growing areas due to the shortage of irrigation water on the other hand.

MATERIALS AND METHODS

Genetic components of combining ability estimates of grain yield per plant in rice were investigated using six -parents complete diallel analysis. The parents producing high grain yield per plant under drought conditions were IET 1444, Gaori and IR65600. While those having low grain yield under drought conditions used were Sakha101, Sakha102 and Giza 177 during 2000 season. The hybridization was achieved according to Mather and Jinks model (1982) to produce hybrid F_1 seeds to be grown in 2001. The experiment was conducted in a randomized complete block design with three replications. Grain yield per plant under drought conditions was recorded for combining ability analysis (Griffing, 1956).

The progenies from each cross were advanced from F_2 generation using the pedigree method technique until F_6 generation under drought conditions. Individual plant selection was made under drought conditions based on the traits associated with drought tolerance. Drought stress was imposed by using flush irrigation every 12 days without standing water. Among the crosses, sixty promising lines with early and medium duration were selected for estimating correlation coefficient and path analysis. The promising lines were derived from three populations that is; IET 1444/ Sakha 102, Sakha 101 /IR 65600 and Sakha 101 / Gaori. The best selected entries from F_6 generation (during 2006 rice growing season) were promoted to be grown under yield trials test experiment besides standard check, that is; Giza 177, Sakha 101, Sakha 102, and IET 1444 rice cultivars. Two adjacent experiments were conducted under normal and drought conditions at the farm of the Rice Research and Training Center, Sakha Kafr El-Sheikh, Egypt during 2007 and 2008 rice growing seasons for comparison.

Physiological and shoot characters such as plant height in cm , tiller number per hill , leaf angle , leaf rolling , flag leaf area in c m^2, flag leaf dry weight in gram , nitrogen % ,sugar content, water use efficiency and relative water content were studied. Root characters such as root length, root number per hill, root volume, root/ shoot ratio and root thickness were also studied. Yield (t/ha) and its components such as no. of panicles per plant, sterility % and 100-grain weight were recorded at harvesting and drought index (DI) was used to characterize relative stress resistance of all genotypes.

In 2009 season, the best selected entries were evaluated under different irrigation intervals (flush irrigation every 4 days, every 8 days and every 12 days). Each experiment was designed in a randomized complete block design with three replications. Each plot consisted of seven rows; five meters long with 20 cm between rows and plants allowing a total of 25 plants per row. The other cultural practices of growing rice were practiced as recommended. The details of the soil physical and chemical properties are presented in Table 1. Some soil constants are presented in Table 2.

Statistical analysis

The data were statistically analyzed following Burton (1952) and Chang et al. (1974). Some genetic parameters; that is, phenotypic variance (PV), genotypic variance (GV), heritability in broad sense (Hb) were computed (Johanson et al. 1955; Lush, 1949 and Burton, 1951). Means of the different lines were compared with their respective parents and control, using the least significant differences (L. S.D.) method. The combined analysis was conducted for the date of the two experiments (2007 and 2008 seasons).

Before proceeding with the computations of the combined experiments, it was necessary to determine whether the error variances of the tests are homogeneous. The test described by Bartlett (1937) was used. For comparison between means, Duncan's multiple range test was used (Duncan, 1955). Path coefficient analysis was made between values of grain yield per plant and the most important characters responsible for drought tolerance according to Dewey and Lae (1959).

Soil water relations

Soil moisture content was gravimetrically determined in soil

Table 2. Soil constants determined before each irrigation (2007 and 2008 season).

Soil depth (cm)	Field capacity (%)	Wilting point (%)	Bulk density (g/cm^{3})
0-15	45.68	24.70	1.12
15-70	41.30	22.40	1.18
30-45	38.75	20.28	1.23
45-60	35.16	18.60	1.30
Mean	40.22	21.50	1.21

Table 3. General combining ability, specific combining ability and reciprocal effects of grain yield / plant in 6 x 6 diallel crosses (during 2001 season).

No.	Varieties	1	2	3	4	5	6
1	IET 1444	5.100**	1.80	-6.20	15.30**	-19.70**	12.50**
2	Gaori	-6.00	0.35	-4.20	-7.30	10.15	-3.60
3	Sakha 101	-0.83	1.48	0.75	-4.50	1.18	9.60
4	Sakha 102	-0.43	0.77	-2.18	2.50**	7.25	-8.14
5	IR 65600	13.76**	-25.00**	3.10	-21.00**	-3.400**	-0.20
6	Giza 177	8.00	4.70	-0.51	9.00	5.60	-5.300**

samples taken from consecutive depths of 15 cm down to a depth of 60 cm. Other soil samples were collected just before each irrigation and 48 hrs after irrigation. Field capacity was determined in the field. Wilting point and bulk density were determined according to Klute (1986) to a depth of 60cm. The average values are presented in Table 2.

The amount of irrigation water applied at each irrigation was determined on the basis of raising the soil moisture content to its field capacity plus 10% as a leaching requirements and it was measured by using flow meter. Also, irrigation water applied was calculated according to the equation of Michael (1978). Also, the water use efficiency was estimated. All these measurements together will allow the determination of the real drought tolerant lines rather than identification of lines that have a high yield potential under both normal and drought stress.

RESULTS AND DISCUSSION

Combining ability analysis

Estimates of general combining ability (GCA in bold) and specific combining ability (SCA above diagonal) of grain yield /plant are presented in Table 3. Among the parents tested, highly desirable positive GCA values of LET 1444 and Sakha 102 which make them good combiners were found. These good combiners could produce progenies with high grain yield /plant as crossing with other parents. The largest SCA value was obtained in case of IET 1444 / Sakha 102 and IET 1444 / Giza 177. Then, 60 promising lines with mid-duration genotypes derived from these crosses were selected. Below diagonal values in Table (3) shows the reciprocal effect. Maternal effect was not significantly recognized except IR 6500 in terms of grain yield / plant.

Based on combining ability analysis for the target characters, 60 early and mid-duration lines derived from three populations, that is IET 1444 / Sakha 102, IET 1444 / Giza 177 and Gaori / Sakha 101 were advanced from the F_2 generation by selfing and selection until the F_6 generation. Seeds from the F_6 plants was collected and bulked to provide the seed source for yield trial experiment.

Path analysis and correlation coefficient

Table 4 shows the correlation between field resistance to drought and plant characters. Nitrogen % (0.820), root length (0.558), root volume (0.610), root thickness (0.719) and relative water content (0.580) significantly and positively correlated with drought score. Positive but non-significant association were indicated between drought resistance and each of root /shoot ratio and 100-grain weight. When the correlations were partitioned into its components, flag leaf dry weight, nitrogen %, root thickness, relative water content and 100-grain weight each has a larger direct and positive influence on drought resistance (Table 4). A strong positive influence of tiller number /plant on drought score was reflected via flag leaf area (0.760). Also flag leaf area had a positive effect on drought score via flag leaf dry weight (0.510). Nitrogen % had positive effect on drought resistance via tiller number/ plant (0.770).

Root volume had positive effect on drought resistance via root numbers/plant (o.510), root thickness (0.830), root/shoot ratio (0.620) and relative water content (0.750). Root thickness has positive effect on drought

Table 4. Direct (diagonal) and indirect effect of shoot and some yield characters on drought score of the selected rice lines (during 2006 season).

Characters	Days to heading (day)	Plant height (cm)	No. of tillers/plant	Flag leaf area	Flag leaf dry weight (g)	Nitrogen (%)	Root length (cm)	Correlation with drought resistance
Days to heading (day)	-0.320	-0.015	0.050	-0.081	-0.410	0.019	-0.020	-0.251
Plant height (cm)	-0.015	-0.850	0.218	0.315	-0.110	-0.111	-0.160	0.071
No. of tillers/plant	0.08	0.140	-0.630	0.760	-2.112	0.115	-0.170	-0.370
Flag leaf area	0.030	-0.220	-0.328	-0.740	0.510	0.140	-0.141	-0.040
Flag leaf dry weight	-0.051	-0.350	-0.390	0.450	3.150	0.300	-0.118	-0.081
Nitrogen (%)	-0.030	0.0280	0.770	0.144	0.010	4.180	-0.230	0.820
Root length (cm)	-0.017	-0.275	0.150	0.110	0.031	0.070	-0.380	0.558

Table 5. Direct (diagonal) and indirect effect of root and some yield characters on drought score of the selected rice lines (during 2006 season).

Characters	Root volume	Root number	Root thickness	Root/shoot ratio	Relative water content	100-grain weight	Sterility %	Correlation with drought resistance
Root volume	0.135	0.510	0.830	0.620	0.750	0.230	-0.280	0.610
Root number	0.580	-0.660	-0.140	0.350	0.118	0.242	0.120	-0.370
Root thickness	0.538	0.190	0.560	-0.380	0.550	0.080	0.019	0.719
Root/shoot ratio	0.390	0.170	0.213	-1.810	0.810	0.360	0.269	0.110
Relative water content	0.718	0.112	0.156	0.261	0.480	0.340	0.011	0.580
100-grain weight	0.113	0.198	0.018	0.273	0.013	0.710	-0.070	0.481
Sterility %	0.285	0.135	0.019	0.116	0.081	0.040	-0.115	-0.220

resistance via relative water content (0.555). A strong positive effect of root /shoot ratio on drought score was reflected via relative water content (0.810). Each of plant height, tiller number/plant, flag leaf area, root number/plant and root/shoot ratio had a substantial negative and direct effect on drought resistance (Table 5).

Genetic parameters

The analysis of variance (Table 6) showed significant differences amongst the genotypes for all characters and expressed considerable range of variation. Further, it was also observed that phenotypic and genotypic variance exhibited almost similar trend of variability (Table 6). The maximum range of variation was observed for number of panicles/ plant, relative water content and grain yield / plant indicating better scope for the genetic improvement in these characters. Estimates of heritability ranged from 46.00 (plant height) to 96.00 (days to heading). In general, high estimates of heritability were observed for all the characters studied. However, root thickness expressed maximum heritability (96.00%) followed by days to heading (93.00%) and relative water content (90.00%0 with low genotypic variance. In the present study, it is very interesting to note that all characters having high values of genotypic variance with high heritability except three cases, i.e. plant height, root length and root thickness (Table 6). This implying that heritability was mainly owing to non-additive gene effect and the expected gain would be low. Genetic advance values were higher for 100 grain weight, relative water content and root: shoot ratio and the values were 32.83, 26.88 and 23.40, respectively. This indicated that heritability values were mainly owing to additive gene effect for these traits.

Mean performance

Shoot characters

Means of shoot characters studied of the tested lines under drought conditions are shown in Table 7. The mean values of number of days to heading were lower than the check varieties in most of the tested lines. The earliest lines were GZ 8993-2-1-1-1 and GZ 7684-6-4-2-2 (97 days). While, the latest one was GZ 8743-8-2-1-1 (103 days) comparing with the check varieties Giza 177,

Table 6. Genetic parameters of variation for some characters associated with drought tolerance in the promising lines.

Character	Genotypic variance (%)	Phenotypic variance (%)	Heritability in broad sense (%)	Genetic advance
Days to heading (day)	29.50	31.00	93.00	13.57
Plant height (cm)	96.20	212.00	46.00	14.00
No. of panicles/plant	135.00	230.00	58.00	22.86
100 grain weight (gram)	190.00	226.00	84.00	32.83
Relative water content	120.00	132.00	90.00	26.88
Root length (cm)	0.80	1.16	69.00	1.93
Root thickness (mm)	38.00	39.00	96.00	15.58
Root/shoot ratio	90.00	100.00	90.00	23.40
Grain yield (t/ha)	50.00	65.00	76.00	15.93

Table 7. The mean performance (combined) of the most promising lines under drought conditions for shoot characters studied (2007 and 2008 seasons).

Entries	H.D	P.H	T.no.	L.ang.	L.roll.	F.l.a.	F.l.d.w.	N%
GZ 9333-1-1-1-1	100.00	94.00	20.00	Narrow	1	12.00	2.00	2.10
GZ9333-1-1-2-3	98.00	100.00	22.00	Narrow	3	16.00	1.75	2.20
GZ8993-2-1-1-1	97.00	115.00	22.00	Wide	1	20.00	1.85	1.98
GZ9333-8-1-2-8	100.00	95.00	25.00	Narrow	3	15.00	1.73	2.00
GZ8452-7-6-5-2	102.00	80.00	26.00	Wide	3	16.00	1.89	1.78
GZ8743-4-3-2-1	100.00	93.00	23.00	Narrow	3	21.00	1.63	2.00
GZ8743-5-3-1-1	99.00	99.00	20.00	Narrow	3	16.00	1.46	2.59
GZ8743-8-2-1-1	103.00	107.00	21.00	Narrow	3	18.00	1.63	1.51
GZ8819-1-1-1-1	98.00	83.00	19.00	Wide	3	16.00	1.60	1.68
GZ7684-6-4-2-2	97.00	80.00	22.00	Narrow	1	19.00	1.82	2.058
Giza 177	100.00	82.00	12.00	Wide	7	25.00	1.10	1.22
Sakha101	113.00	87.00	15.00	Wide	5	22.00	1.35	1.30
IET1444	100.00	90.00	19.00	Narrow	3	18.00	1.65	1.42
L.S.D.05	1.88	3.55	1.50	-	1.65	2.50	0.25	0.45

H.D. = Days to heading, P.H = Plant height, T.no = No. of tillers/plant.
L.ang. = Leaf angle, L. roll. = Leaf rolling, F.l.a. = Flag leaf area.
F.l.d.w. = Flag leaf dry weight and N% = Nitrogen percent.

Sakha 101 and IET 1444 (100, 113, 100 days, respectively). With respect to plant height, the values ranged between 80 cm for GZ 8452-7-6-5-2 and 115 cm for GZ8993-2-1-1-1 comparing with the check varieties Giza 177 (82 cm) and IET 1444 (90 cm). The most desirable mean values towards dwarfing were obtained from the lines GZ8452-7-6-5-2 (80 cm), GZ7684-6-4-2-2 (80 cm) and GZ8819-1-1-1-1 (83 cm). Regarding number of tillers/plant, most of the studied lines had number of tillers/plant more than the international check variety IET 1444 and maximized in case of the lines GZ9333-8-1-2-8 (25 tillers/plant) and GZ 8452-7-6-5-2 (26 tillers/plant). The values of the tested lines ranged from 19.00 to 26.00 tillers/plant comparing with the checks (from 12.00 to 19.00 tillers/plant). This result indicates that these lines will be more able to recover after a period of moisture stress.

Five out of the ten tested lines had narrow leaf angle implying that these lines will reduce the areas exposed to solar radiation and therefore reduce evapotranspiration rate. All these lines had drought scores ranged between 1 and 3 based on leaf rolling data as a symptom occurs due to the inability of leaves to sustain the evapo-transpiration demand of the plant. This suggests a close relationship between leaf rolling and drought tolerance. Concerning the flag leaf area, the results showed that it ranged between 12.00 and 25.00. The lines GZ8993-2-1-1-1, GZ8743-4-3-2-1, GZ8743-8-2-1-1 and GZ7684-6-4-2-2 gave the desirable mean values of flag leaf area under. Regarding the flag leaf dry weight, as shown in Table 7, the lines GZ 9333-1-1-1-1, GZ8993-2-1-1-1and GZ 8452-7-6-5-2 gave the highest mean values. Their respective values were 2.00, 1.85 and 1.89, respectively which were more than what the check varieties produced 1.10, 1.35 and 1.65 for Giza 177, Sakha 101 and IET 1444. Nitrogen % of all the tested lines exceeded

Table 8. The mean performance of the most promising lines under drought conditions for some physiological and yield and its components (during 2007 and 2008 seasons).

Entries	No. of pan./pl.	Str. (%)	100-g.w (g)	Sugar (%)	R.W.C	W.U.E	Grain Yield (t/ha.)
GZ 9333-1-1-1-1	18.00	12.00	2.30	8.00	45.00	1.30	7.61
GZ9333-1-1-2-3	17.00	8.00	2.50	6.00	48.00	1.10	7.14
GZ8993-2-1-1-1	19.00	11.00	2.55	13.00	55.00	1.21	8.09
GZ9333-8-1-2-8	21.00	9.00	2.50	14.00	58.00	1.40	8.33
GZ8452-7-6-5-2	25.00	12.00	240	15.00	60.00	1.25	9.04
GZ8743-4-3-2-1	19.00	13.00	2.50	12.00	51.00	0.98	7.37
GZ8743-5-3-1-1	17.00	15.00	250	8.00	55.00	1.15	7.14
GZ8743-8-2-1-1	18.00	11.00	2.40	9.00	58.00	1.35	7.61
GZ8819-1-1-1-1	16.00	9.00	2.50	7.00	50..00	0.97	6.90
Gz7684-6-4-2-2	20.00	10.00	2.50	11.00	68.00	1.25	8.33
Giza 177	10.00	17.00	2.30	3.50	32.00	0.89	3.80
Sakha101	13.00	18.00	2.30	4.20	25.00	0.90	4.28
IET 1444	16.00	12.00	2.40	6.00	38.00	0.98	5.23
L.S.D 0.05	1.90	1.10	0.25	1.50	4.25	0.15	0.65

No. of pan. /pl. = Number of panicles per plant, Str. % = Sterility %, 100-g.w (g) = 100 grain weight, Sugar % = Sugar content, R.W.C = Relative water.

the highest check variety, IET 1444 (1.42). The highest nitrogen % was obtained from GZ 9333-1-1-1-1 (2.10%), GZ 9333-1-1-2-3 (2.20%) and GZ 8743-5-3-1-1 (2.59%). Price et al. (1999) and Toorchi et al. (2003) reported that, shoot characters comprising of plant height, tiller numbers/plant, leaf angle, leaf rolling, flag leaf area, flag leaf dry weight and nitrogen % could be used as selection criteria in selecting drought resistant lines in many crops.

Yield and its component characters

Means of yield and its component characters studied of the tested lines under drought conditions are shown in Table 8. For number of panicles/plant, all the selected lines possess high number of panicles/plant comparing with the check varieties. The mean values of panicles /plant ranged between 16.00 panicle/plant for GZ 8819-1-1-1-1 and 25.00 panicle/plant for GZ 8452 -7-6-5-2 comparing with 10.00 and 13.00 panicles / plant for the check varieties Giza 177 and Sakha 101, respectively.

For sterility %, the most desirable mean values towards this trait were observed by the lines GZ9333-1-1-2-3, GZ9333-8-1-2-8, GZ8819-1-1-1-1, these values ranged from 8.00% to 9.00%. The highest mean values were detected by the lines GZ8743-4-3-2-1(13.00%) and GZ8743-5-3-1-1 (15.00%) which were lower than the check varieties Giza 177(17%) and Sakha 101(18.00%). The same trend was also found for 100-grain weight. It was minimized for GZ 5121-5-2 (2.30 g) and maximized for GZ 8372-5-3-2-1 (2.55 gram), comparing with the two check varieties Giza 177 (2.30 g) and Sakha 101 (2.30 g). For stem sugar at booting stage, most of the selected lines, such as GZ8993-2-1-1-1, GZ9333-8-1-2-8, GZ8452-7-6-5-2, GZ8743-4-3-2-1 and GZ7684-6-4-2-2 were characterized by high stem sugar during the ripening stage, indicating the contribution of stem carbohydrate to grain filling. Regarding relative water content (RWC), all the tested lines had higher RWC than the check varieties. Their respective values ranged from 45.00 for GZ 9333-1-1-1-1 to 68.00 for GZ 7684-6-4-2-2 comparing with the check varieties Giza 177 (32.00), Sakha 101 (25.00) and IET 1444 (38.00). All these lines had high water use efficiency(WUE) due to high productivity, the most desirable mean values for WUE were detected by the lines GZ 9333-1-1-1-1 (1.30), GZ9333-8-1-2-8 (1.40) and GZ8743-8-2-1-1 (1.35). It could be concluded that by using such promising lines, the amount of irrigation water applied could be significantly reduced without significant reduction in rice yield. The mean values of grain yield /plant for the tested lines ranged between 29.00 g in GZ 8819-1-1-1-1 and 36.00 g in GZ 8452-7-6-5-2 which is almost from 7.00 to 8.56 t/ha comparing with the check varieties Giza 177 (16.0 g), Sakha 101 (18.0 g) and IET 1444 (22.00 g) which produced 3.80 , 4.28 and 5.23 t/ha, respectively.

Root characters

Means of root characters studied of the tested lines under drought conditions are shown in Table (9). For root length, most of the tested lines had taller roots than the check varieties. The maximum root length was obtained from GZ 9333-1-1-1-1 (34.00 cm) and the lowest value was obtained from GZ 8819-1-1-1- (25.00 cm). Deep

Table 9. The mean performance of the most promising lines under drought conditions for root characters studied (during 2007 and 2008 seasons).

Entries	Root length (cm)	No. of roots/plant	Root volume (mL)	Root: shoot ratio	Root thickness
GZ 9333-1-1-1-1	34.00	240.00	35.00	1.23	0.60
GZ9333-1-1-2-3	30.00	176.00	37.00	1.10	0.58
GZ8993-2-1-1-1	26.00	200.00	35.00	0.87	0.67
GZ9333-8-1-2-8	30.00	170.00	42.00	1.90	0.62
GZ8452-7-6-5-2	30.00	181.00	45.00	2.20	0.70
GZ8743-4-3-2-1	27.00	230.00	58.00	1.67	0.55
GZ8743-5-3-1-1	32.00	210.00	47.00	0.95	0.54
GZ8743-8-2-1-1	24.00	214.00	53.00	1.20	0.68
GZ8819-1-1-1-1	25.00	250.00	50.00	1.23	0.53
GZ7684-6-4-2-2	27.00	265.00	46.00	0.89	0.75
Giza 177	22.00	135.00	20.00	0.42	0.42
Sakha 101	25.00	156.00	25.00	0.43	0.40
IET 1444	28.00	168.00	35.00	0.88	0.48
L.S.D 0.05	3.30	5.70	3.50	0.35	0.06

Table 10. Grain yield of rice entries as influenced by irrigation intervals (2009 season).

Entries	Grain yield t/ha (continuous flooding))	Grain yield t/ha (irrigation every 4 days)	Grain yield t/ha (irrigation every 8 days)	Grain yield t/ha (irrigation every 12 days)	Drought index (%)
GZ 9333-1-1-1-1	10.50	8.33	7.85	7.61	0.72
GZ9333-1-1-2-3	10.30	7.85	7.61	7.14	0.69
GZ8993-2-1-1-1	10.80	9.52	8.56	8.09	0.74
GZ9333-8-1-2-8	11.00	10.71	9.04	8.33	0.75
GZ8452-7-6-5-2	13.00	10.94	9.52	9.04	0.69
GZ8743-4-3-2-1	10.60	8.33	7.61	7.37	0.69
GZ8743-5-3-1-1	10.30	8.33	7.85	7.14	0.69
GZ8743-8-2-1-1	10.50	9.04	8.33	7.61	0.72
GZ8819-1-1-1-1	10.00	7.61	7.44	6.90	0.69
GZ7684-6-4-2-2	11.00	10.47	9.04	8.33	0.75
(Check)Giza 177	10.00	7.14	4.28	3.80	0.38
(Check)Sakha101	12.00	7.61	5.95	4.28	0.35
(Check)IET 1444	10.00	8.33	6.42	5.23	0.52
Mean	10.80	8.78	8.28	7.80	0.72
Range	10.30 -13.00	7.61- 10.94	7.44 -9.52	6.90 -9.04	0.35-0.75
L.S.D at 0.05	0.35	0.55	0.52	0.62	0.16

rooted plants showed greater drought avoidance than shallow rooted ones.

Most of the tested lines as it is quite clear from the data were superior for number of roots /plant, root volume, root: shoot ratio and root thickness comparing with the check varieties. Data presented in Table 10 showed that, grain yield differed among the lines within each treatment and also between the treatments. The mean values ranged from 10.30-13.00 t/ha for normal condition; from 7.61-10.94 t/ha for irrigation every 4 days; from 7.44-9.52 t/ha for irrigation every 8 days and from 6.90-9.04 t/ha for irrigation every 12 days. These results indicated that the yield increased by decreasing the period of withholding. Regarding drought susceptibility index as a ratio between the yield under drought conditions (irrigation every 12 days) and the yield under normal conditions, all the selected lines had high drought index comparing with the check varieties. The lines GZ8993-2-1-1-1 (0.74), GZ9333-8-1-2-8 (0.75) and GZ7684-6-4-2-2(0.75) gave the highest drought index; it ranged from 0.74 to 0.75.

Conclusion

The promising lines obtained in the current investigation were found to be good candidates for drought tolerance at all stages of growth. They possessed many desirable traits associated with drought tolerance that is root characters, shoot and physiological characters. Also, they produced high grain yield. By using such lines the total water requirements will be significantly reduced without a significant reduction in the yield. Also these lines can be used as a donor parents at reproductive stage to solve the problem of the lack of the donor parents in breeding rice for drought tolerance. These lines produced from 7.00- 9.00 t /ha grain yield under drought conditions with 50- 55% saving of irrigation water applied. These lines will be recommended to be new rice varieties tolerant to drought conditions.

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