



Estimation of genetic variability and frequency distribution in F₂ generation of rice under normal and deficit water supply

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Abstract

The investigation was conducted at the experimental farm of the Rice Research and Training Centre, Kafr el Sheikh, Egypt, during the summer seasons from 2017 to 2019 using the experimental material consisting two populations with their two parents (P₁, P₂, F₁ and F₂) to study the variability in the F₂ population of four crosses: IR 78,936-B-B-B-B (water deficit tolerant) × Giza 177 (water deficit sensitive), FL-496 (moderately water deficit tolerant) × Giza 177, IR 78,936-B-B-B-B (water deficit tolerant) × Giza 178 (moderately water deficit tolerant), FL-496 × Giza 178 under normal (NWS) and deficit water supply (DWS). The experiment was conducted in a randomized complete block design with three replications. The results indicated that the phenotypic values of the measured characters were significantly different between the two parents of all the studied crosses under the two water supply conditions. The means of all the studied characters under DWS were lower than the means under NWS, but the yields and the yield components under DWS varied greatly among the parents due to stress. The averages of the measured traits of the F₁ plants and the F₂ populations in all crosses were near the averages of those of the parents. The results showed no consistent reduction in heritability under DWS compared to NWS. High heritability in a broad sense coupled with high genetic advance (GA) was observed for grain yield in Cross 1 under the two studied conditions offering good scope for selection.

Keywords *Oryza sativa* · Heritability · Segregating generations · Grain yield

Introduction

Rice (*Oryza sativa* L.) is one of the most staple foods and a good source for all generations, and more than one half of the world's population is dependent on it (Bouman 2007). It is also a good source of calories, which provides all humans with about 50–80% of the daily calorific consumption (Seck et al. 2012; Futakuchi et al. 2013). Biotic and abiotic factors adversely limit the productivity of the rice growing areas of the world. It has been estimated that more than 200 million tonnes of rice are lost every year due to environmental stresses (Moonmoon and Islam 2017). Increasing rice production is controlled by different factors, for instance, water deficit, which is an important factor due to the lack of water in many countries of the world (Nirubana et al. 2019). Water deficit affects plant growth, and it is a major constraint for about 50% of the world production area of rice (Khush 2005). Therefore, producing new varieties of rice which are high yielding and tolerant to water deficit through traditional breeding are considered the economical way to avoid the deficit of water, especially at the end of canals.

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Genetic variability is necessary for successful selection of superior breeds from segregating generations for further selection (Priyanka et al. 2019). The success of any crop improvement programme depends not only on the amount of genetic variation present in a crop, but also on the extent of variation that is heritable from the parent to its line (Bello et al. 2012). Trait genes can be better understood by using third- and fourth-degree statistics, kurtosis and skewness in segregation of generations. There is a necessity to beget information on genetic variance, coefficient of genetic variation, heritability, and genetic advance (GA) to estimate the progress of their breeding programme in the future (Savitha and Ushakumara 2015). Heritability is considered to be a character which is important for plant breeders because it provides information on the range to which a particular trait can pass from parent to line. GA is also important because it clarifies the degree of the gain gotten in a character from one selection cycle. High GA combined with high heritability estimates the most favourable conditions for deciding the selection criteria (Syukur and Rosidah 2014). High GA connected with high heritability rating provides the best conditions of selection. It also displays the presence of additive genes in the trait, and furthermore submits reliable crop improvement during the selection of these traits (Nwangburuka and Denton 2012). Frequency distribution pattern based on skewness and kurtosis in F_2 generation and genetic variability parameters is suitable to identify useful segregates with high yield coupled with desirable agronomic traits (Rani et al. 2016). Assessment of heritability with GA is more credible and significant than individual sights of the parameters (Nwangburuka and Denton 2012).

The aims of the present study were: (1) to analyse the statistics and quantify the extent of genetic variation available for grain yield and yield components in the F_2 (segregating) generation of rice under normal and water deficit conditions; (2) to select superior segregants that have water deficit tolerance and high yield; and (3) to assess the genetic gain that can be made by selection when lines are involved in the hybridization.

Materials and methods

The present investigation was conducted at the experimental farm of the Rice Research and Training Centre (RRTC), Sakha, Kafr el Sheikh, Egypt, during three seasons in 2017, 2018, and 2019. The genetic materials used in this investigation involved four genotypes: the water deficit tolerant IR 78,936-B-B-B-B, the moderately water deficit tolerant Giza 178 and FL-496, and the water deficit sensitive Giza 177 varieties (Table 1).

In the growing season of 2017, the four studied parental varieties were sown on three sowing dates in the summer

Table 1 Origin and main characters of the four genotypes used as parents in the studied pair crosses

No	Genotype	Parentage	Origin	Water deficit tolerance
1	IR 78,936-B-B-B-B	Exotic	IRRI	Tolerant
2	FL-496	IR29/Pokkali	IRRI	Moderate
3	Giza 177	Giza 171/Yomji 1/ Pi 4	Egypt	Sensitive
4	Giza 178	Giza 175/Milyang 49	Egypt	Moderate

season with 15-day-intervals to overcome the difference of the heading date among the parental varieties. After 30 days from sowing, seedlings of the parents were transplanted to the experimental field in three rows, 5 m long and 0.2×0.2 m apart between the plants and rows.

The crossing was conducted among the parents in 2017 to produce four crosses. However, the crossing method of Jodon (1938) modified by Butany (1961), the hot water method of gelding, was used. The parental varieties and the F_1 generations of IR 78,936-B-B-B-B (tolerant) x Giza 177 (sensitive), FL-496 (moderate) x Giza 177 (sensitive), IR 78,936-B-B-B-B (tolerant) x Giza 178 (moderate) and FL-496 (moderate) x Giza 178 (moderate) were evaluated and arranged in a randomized complete block design experiment with three replications in 2018. Each replication contained 25 individual plants under normal water supply (NWS) and deficit water supply (DWS). NWS represented normal irrigation as recommended for flooding rice in Egypt with 3–4 days intervals between the irrigation events. DWS represented water deficit stress, in that case, the intervals of irrigation were 12 days starting after transplanting.

In 2019, the parent F_1 and F_2 populations were planted and evaluated under NWS and DWS. Each F_2 population consisted of more than 200 individual plants. All cultural practices such as field preparation, sowing, and fertilizers were applied as recommended in all seasons of the study. The studied characters (quantitative parameters) were recorded for the parents, F_1 and F_2 generations for plant height (cm), number of panicles per plant, panicle length, panicle weight (g), number of filled grains per panicle, sterility %, 100-grain weight (g) and grain yield per plant (g) according to IRRI (1996).

Phenotypic and genotypic coefficient of variation (PCV and GCV) for all the studied characters were calculated by the formula reported by Burton and DeVane (1953). The genetic advance as a percentage of mean (GAM) and broad sense heritability for all the traits as the ratio of GCV to the total PCV were calculated as reported by Johnson et al. (1955). Skewness and kurtosis statistics were estimated according to Snedecor and Cochran (1989) for understanding the nature of distribution of the F_2 population for yield

and its related traits to identify a superior segregant in the F_2 generation of all crosses under study. Skewness and kurtosis mean values as well as correlation analysis were computed using the 'SPSS' software programme. The test of normality of the F_2 populations was carried out by performing 'Shapiro-Wilks' W test (Shapiro et al. 1968) using STATISTICA statistical package R.

Results

Morphological and agronomic characteristics

Mean performance

The mean performance of the parents, F_1 hybrids and F_2 populations was significantly different between the two parents for all crosses under study (Table 2). The results showed that all the mean values of studied characters under DWS were lower than the means in NWS. For Cross 1, all the characters of P_1 showed higher values than those of P_2 under both water supply conditions, even for sterility % (Table 2). On the other hand, for Cross 2, the data showed that the means of P_1 were also higher than those of P_2 for most of

Table 2 Mean values of parents, F_1 plants and F_2 populations of the studied characters in rice Crosses 1 and 2

Cross	Characters	Water supply	Mean P_1	Mean P_2	t-value P_1 - P_2	Mean F_1
Cross 1 IR 78,936-B-B-B- B x Giza 177	Plant height (cm)	NWS	115.75	107.50	5.55**	115.95
		DWS	97.98	93.95	-2.285**	105.4
	Panicles/plant	NWS	25.40	23.00	6.765**	23.00
		DWS	16.80	14.35	2.561*	14.35
	Panicle length (cm)	NWS	26.63	21.35	8.45**	28.35
		DWS	21.55	18.33	4.301*	22.0
	Panicle weight (g)	NWS	4.27	3.3	-46.84**	3.61
		DWS	2.90	2.17	-7.09**	2.39
	Filled grains/panicle	NWS	134.0	131.0	-19.61**	143
		DWS	91.44	87.9	-34.60**	94.0
	Sterility (%)	NWS	18.2	4.06	6.54**	18.22
		DWS	22.43	19.08	12.15**	28.52
	1000-grain weight (g)	NWS	30.76	28.86	11.71**	30.0
		DWS	24.01	23.0	4.141**	24.7
	Grain yield/plant (g)	NWS	65.5	42.42	5.71**	65.0
		DWS	36.65	25.71	-30.48**	40.0
Cross 2 FL-496 x Giza 177	Plant height (cm)	NWS	114.2	107.50	4.92**	117.0
		DWS	87.5	93.95	5.76**	110.0
	Panicles/plant	NWS	20.65	23.00	5.44**	18.75
		DWS	16.65	14.35	3.47**	15.0
	Panicle length (cm)	NWS	25.1	21.35	15.67**	20.95
		DWS	20.05	18.33	3.21**	15.04
	Panicle weight (g)	NWS	4.12	3.3	6.88**	3.75
		DWS	3.03	2.17	3.32*	2.73
	Filled grains/panicle	NWS	131.6	131	-17.26**	105.0
		DWS	100.8	87.9	3.32**	63.3
	Sterility (%)	NWS	10.33	4.06	6.66**	15.04
		DWS	22.17	19.08	7.725*	23.09
	1000-grain weight (g)	NWS	27.05	28.86	2.10*	28.25
		DWS	24.18	23.0	4.35**	23.95
	Grain yield/plant (g)	NWS	62.5	42.42	10.0**	86.0
		DWS	42.5	25.71	7.92*	56.0

t-value was obtained from a paired sample t-test between P_1 and P_2 representing significance at 1% (**) or 5% (*) level

the studied characters except for the number of panicles per plant and 1000-grain weight under NWS and plant height under DWS.

For Cross 3, the results reflected that all studied characters for P_2 were lower than for P_1 except for panicle weight under NWS, plant height and 1000-grain weight under DWS, and the number of filled grains per panicles, sterility % under both water supply conditions (Table 3). In Cross 4, the data indicated that all characters of P_1 were higher than those of P_2 except for the number of panicles under NWS, plant height, 1000-grain weight under DWS, panicle weight and number of filled grains per panicle under both water supply conditions (Table 3). The averages of the measured traits of the F_1 plants and the F_2 populations in all crosses were similar to those of the parents. The F_2 population for Cross 1 gave the highest

yield under water deficit stress, while Cross 2 gave the highest yield under NWS condition (Tables 2, 3, 4).

Range and standard deviation

A range from 60 to 155 g was observed among the studied characters for grain yield per plant under NWS and from 35 to 90 g under DWS in all crosses (Table 4). In Cross 1, the number of filled grains per panicle under DWS and the grain yield per plant under NWS showed the maximum standard deviation of 6.98 and 6.39, respectively, followed by the number of panicles per plant under DWS with its range variation of 29 and standard deviation of 6.32 (Table 4).

In Cross 2, the highest standard deviation (38.8) was observed for the number of filled grains per panicle under

Table 3 Mean values of parents, F_1 plants and F_2 populations of the studied characters in rice Crosses 3 and 4

Cross	Characters	Water supply	Mean P_1	Mean P_2	t -value P_1 - P_2	Mean F_1
Cross 3 IR 78,936-B-B-B- B x Giza 178	Plant height (cm)	NWS	115.75	114.0	3.88**	108.7
		DWS	97.18	97.5	-3.99**	96.25
	Panicles/plant	NWS	28.65	26.40	6.93**	24.25
		DWS	16.65	15.1	2.31**	17.3
	Panicle length (cm)	NWS	25.1	21.95	8.03**	25.08
		DWS	20.05	17.9	3.94**	22.36
	Panicle weight (g)	NWS	4.12	5.30	9.91**	4.78
		DWS	3.03	2.80	8.72**	1.84
	Filled grains/panicle	NWS	134.6	204.25	-15.38**	152.25
		DWS	112.3	162.25	-10.04**	81.6
	Sterility (%)	NWS	10.3	4.4	7.95**	17.92
		DWS	22.17	19.0	4.36**	24.4
	1000-grain weight (g)	NWS	27.05	27.0	6.29**	22.0
		DWS	24.18	26.0	-2.63**	24.04
	Grain yield/plant (g)	NWS	62.5	43.43	8.94**	77.5
		DWS	42.5	27.51	7.06**	35.0
Cross 4 FL 496 x Giza 178	Plant height (cm)	NWS	115.75	114.0	6.94**	127.25
		DWS	93.75	97.5	-2.96**	118.0
	Panicles/plant	NWS	25.4	26.40	-6.42**	26.3
		DWS	16.8	15.1	3.069**	11.1
	Panicle length (cm)	NWS	26.85	21.95	9.38**	26.25
		DWS	21.55	17.9	4.83**	23.93
	Panicle weight (g)	NWS	4.27	5.30	-4.37**	3.88
		DWS	2.17	2.80	6.13**	2.05
	Filled grains/panicle	NWS	134.3	204.25	-8.08**	165.0
		DWS	87.9	162.25	-20.27**	120.75
	Sterility (%)	NWS	10.3	4.4	6.07*	16.63
		DWS	22.43	19.0	7.58**	26.63
	1000-grain weight (g)	NWS	30.76	27.0	3.28**	23.25
		DWS	24.01	26.0	6.44**	21.14
	Grain yield/plant (g)	NWS	65.5	43.43	5.66**	88.75
		DWS	36.65	27.51	4.56**	35.0

t -value was obtained from a paired sample t -test between P_1 and P_2 representing significance at 1% (**) or 5% (*) level

Table 4 Range and standard deviation for the studied characters in the F₂ populations of rice crosses under normal (NWS) and deficit (DWS) water supply conditions

Character	Water supply	Cross 1 (IR 78,936-B-B-B-B x Giza 177)						
		Range	SD	Min	Max	Skewness	Kurtosis	Mean F ₂
Plant height (cm)	NWS	50.0	1.29	100.0	150	0.280	−0.955	129.12
	DWS	53.0	1.08	70.0	123.0	−0.749	−0.045	97.1
Panicles/plant	NWS	29.0	6.09	11.2	40.0	0.929	0.718	22.60
	DWS	29.0	6.32	6.0	35.0	0.280	−0.635	18.62
Panicle length (cm)	NWS	8.0	2.16	22.0	30.0	0.891	0.662	24.79
	DWS	6.0	1.49	20.0	26.14	−0.108	1.21	24.14
Panicle weight (g)	NWS	3.50	2.17	2.4	6.9	0.737	0.662	3.99
	DWS	3.50	1.18	1.7	5.2	−0.052	−1.519	3.34
Filled grains/panicle	NWS	120.0	3.39	90	210	0.780	−0.300	134
	DWS	153.0	6.98	50	203	0.661	−1.86	110.2
Sterility (%)	NWS	33.90	1.01	5.0	38.9	0.445	−0.972	20.15
	DWS	36.70	5.96	21.3	58.0	0.078	−0.393	37.55
1000-grain weight (g)	NWS	8.60	2.51	21.4	32.2	−0.242	−1.33	28.31
	DWS	8.80	2.01	23.6	32.2	−0.370	0.314	26.23
Grain yield/plant (g)	NWS	155.0	6.39	30.0	185.0	2.46	7.69	69.6
	DWS	75.0	3.98	20.0	95.0	0.737	−0.449	46.06
Character	Water supply	Cross 2 (FL-496 x Giza 177)						
		Range	SD	Min	Max	Skewness	Kurtosis	Mean F ₂
Plant height (cm)	NWS	60.0	1.21	105.0	165.0	0.071	0.545	130.76
	DWS	52.0	1.06	80.0	132.0	0.467	0.887	103.46
Panicles/plant	NWS	48.0	1.28	20.0	68.0	0.286	−0.522	22.16
	DWS	25.0	6.13	6.0	31.0	0.607	−0.558	16.54
Panicle length (cm)	NWS	11.0	2.93	20.0	31.0	0.580	−0.578	21.2
	DWS	6.0	1.85	19.0	25.0	0.498	−0.364	17.81
Panicle weight (g)	NWS	4.2	1.12	1.8	6.0	−0.764	0.410	4.29
	DWS	3.0	0.68	1.7	4.7	1.288	1.66	2.94
Filled grains/panicle	NWS	74.0	2.81	100	174	0.543	−1.36	130.1
	DWS	167.0	38.8	59	217	1.95	3.751	89.76
Sterility (%)	NWS	33.9	7.33	5.0	38.9	−0.304	−1.308	17.81
	DWS	36.6	10.3	21.3	58.0	1.147	−0.028	28.48
1000-grain weight (g)	NWS	6.8	2.15	<u>23.8</u>	<u>30.6</u>	0.421	−0.662	26.65
	DWS	13.1	2.73	<u>14.9</u>	<u>28.6</u>	−2.74	8.261	24.68
Grain yield/plant (g)	NWS	60.0	3.2	40.0	135.0	0.307	−1.289	82.3
	DWS	90.0	17.1	15.0	75.0	0.975	−0.118	34.68
Character	Water supply	Cross 3 (IR 78,936-B-B-B-B x Giza 178)						
		Range	SD	Min	Max	Skewness	Kurtosis	Mean F ₂
Plant height (cm)	NWS	65.0	15.7	100.0	165.0	−0.319	−6.275	112.6
	DWS	13.4	22.2	81.0	125.0	−3.69	15.654	98.5
Panicles/plant	NWS	34.0	7.77	12.0	46.0	0.266	−0.552	26.84
	DWS	31.0	6.40	7.0	38.0	0.579	0.491	18.7
Panicle length (cm)	NWS	11.0	2.46	19.0	30.0	−0.181	0.740	24.78
	DWS	8.0	2.07	19.0	27.0	0.349	0.262	22.56
Panicle weight (g)	NWS	4.0	0.98	1.4	5.4	0.965	1.11	3.04
	DWS	4.0	0.97	0.7	4.7	0.713	0.969	2.25
Filled grains/panicle	NWS	158.0	47.3	42.0	200.0	−0.464	−0.776	133.62
	DWS	105.0	27.8	35.0	140.0	0.542	−0.614	76.34

Table 4 (continued)

Character	Water supply	Cross 3 (IR 78,936-B-B-B-B x Giza 178)						
		Range	SD	Min	Max	Skewness	Kurtosis	Mean F ₂
Sterility (%)	NWS	16.0	4.90	19.6	28.4	1.260	0.322	11.31
	DWS	29.40	9.07	20.2	49.6	0.055	− 1.209	21.84
1000-grain weight (g)	NWS	8.80	2.55	19.6	30.1	− 0.339	− 0.560	24.01
	DWS	18.90	6.16	6.0	28.4	− 0.117	− 1.693	19.67
Grain yield/plant (g)	NWS	105.0	33.7	25.0	130.0	0.724	− 0.589	64.4
	DWS	35.0	9.18	15.0	50.0	− 0.189	− 0.472	31.8
Character	Water supply	Cross 4 (FL-496 x Giza 178)						
		Range	SD	Min	Max	Skewness	Kurtosis	Mean F ₂
Plant height (cm)	NWS	65.0	12.2	105.0	170.0	− 0.126	0.574	134.96
	DWS	64.0	12.9	45.0	109.0	− 0.505	1.366	86.84
Panicles/plant	NWS	17.90	10.2	30.0	50.0	− 0.131	0.186	27.48
	DWS	74.0	31.9	6.96	8.0	4.632	2.281	22.48
Panicle length (cm)	NWS	5.0	1.46	20.0	27.0	− 0.432	− 0.703	22.88
	DWS	9.0	2.17	18.0	25.0	− 0.128	− 0.586	22.7
Panicle weight (g)	NWS	3.60	0.79	2.05	5.50	0.759	0.487	3.42
	DWS	2.10	0.58	1.90	4.23	− 0.118	− 0.874	3.27
Filled grains/panicle	NWS	105.0	22.9	77.0	172.0	− 0.724	0.758	127.7
	DWS	92.0	21.8	75.0	167	0.563	0.001	107.4
Sterility (%)	NWS	27.0	7.71	0.08	27.8	0.641	− 0.748	18.63
	DWS	34.20	11.0	2.3	36.5	− 0.431	1.11	29.07
1000-grain weight (g)	NWS	3.30	0.74	24.5	27.8	− 0.397	0.545	26.27
	DWS	0.80	1.53	21.4	28.2	− 0.804	0.449	25.97
Grain yield/plant (g)	NWS	65.0	20.5	35.0	100.0	1.348	0.338	54.9
	DWS	40.0	11.1	20.0	60.0	1.025	0.147	35.04

DWS, then for the grain yield per plant character under DWS (17.1) subsequently with the ranges of 167 and 90, respectively. In Cross 3, the highest standard deviation was observed for the number of filled grains (47.3), then for the grain yield under NWS (33.7) subsequently with the ranges of 158 and 105, respectively. In Cross 4, the highest standard deviation was observed for the number of panicles per plant under DWS, then for the number of filled grains per panicle under NWS (31.9 and 22.9), subsequently with the ranges of 74.0 and 105, respectively (Table 4).

Plant height

In the F₂ population, Cross 4 (FL-496 x Giza 178) under NWS showed the highest mean (134.96) and range (65.0) for plant height. The negative skewness (−0.126) with a positive kurtosis (0.574) under NWS states that a higher frequency of individuals had values at or near to the mean value (Table 4).

Number of panicles per plant

For the number of panicles per plant, Cross 4 (FL-496 x Giza 178) segregant gave the highest mean under both water supply conditions. The negative skewness with a positive kurtosis under NWS states that a higher frequency of individuals had values at or near to the mean value (Table 4).

Panicle length

In the F₂ population, the highest mean value for panicle length was recorded for Cross 1 (IR 78,936-B-B-B-B x Giza 177) segregant under both of the water supply conditions under study. The frequency distribution graph showed highly negative skewness under DWS suggesting the presence of more individuals with plant height higher than the mean value (Table 4).

Panicle weight

The highest mean for the panicle weight was recorded for Cross 2 (FL-496 x Giza 178) segregant under NWS, while

the highest mean of this character was recorded for Cross 1 (IR 78,936-B-B-B x Giza 177) under DWS. The frequency distribution under DWS conditions was fairly negatively skewed (Table 4).

Number of filled grains per panicle

Cross 1 (IR 78,936-B-B-B x Giza 177) gave the highest number of filled grains per panicle under both water supply conditions. The results indicated moderate positive skewness under water deficit stress with a negative kurtosis (Table 4).

Sterility %

Cross 3 (IR 78,936-B-B-B x Giza 178) gave the lowest sterility % under both water supply conditions. A graph shows negative skewness where most of the values are falling on the right side and the tail is longer towards the left (Table 4).

1000-grain weight

For Cross 1 (IR 78,936-B-B-B x Giza 177), it was recorded that the highest value of 1000-grain weight was in both water supply cases. The graphs representing DWS were approximately symmetrical with negative kurtosis (Table 4). This indicates a normal distribution for the population.

Grain yield per plant Cross 1 (IR 78,936-B-B-B x Giza 177) gave the highest grain yield under water deficit and Cross 2 gave the highest value for the same characters. The graph representing the water deficit stress conditions was positively skewed with a negative kurtosis (Table 4). The distribution of the phenotypic variation for the grain yield per plant, which is the main trait, for the four F_2 populations are presented in Figs. 1, 2, 3, 4. The phenotypic variation of this trait displayed a continuous distribution. It also

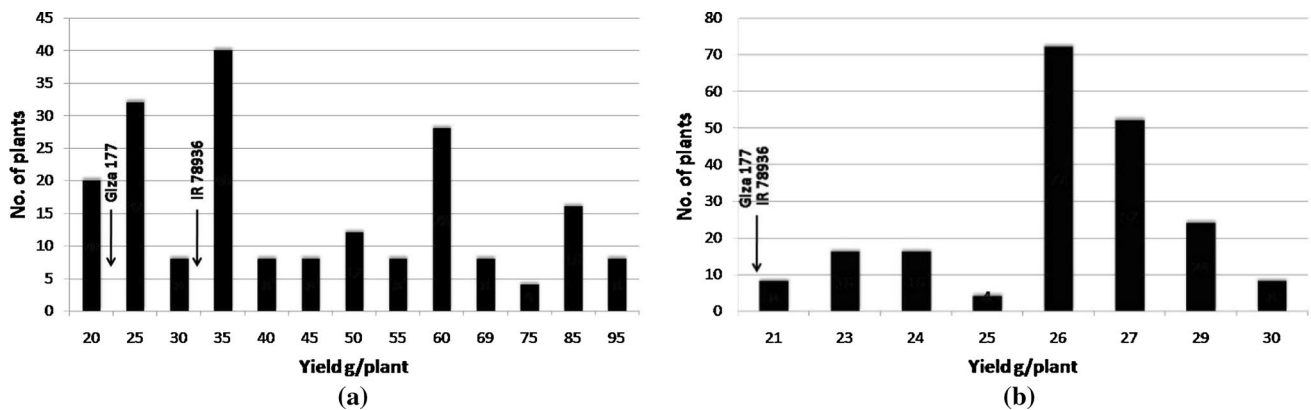


Fig. 1 Frequency distribution of grain yield per plant trait in the F_2 populations of Cross 1 (IR 78,936-B-B-B x Giza 177) under NWS (a) and DWS (b). The positions of the parental trait values are indicated by the arrows

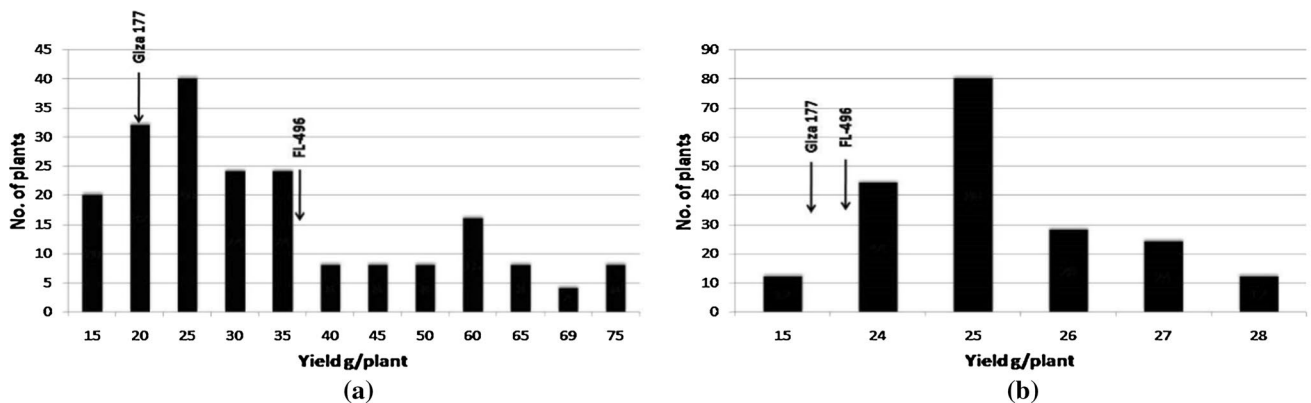


Fig. 2 Frequency distribution of grain yield per plant trait in the F_2 populations of Cross 2 combinations (FL-496 x Giza 177) under NWS (a) and DWS (b). The positions of the parental trait values are indicated by the arrows

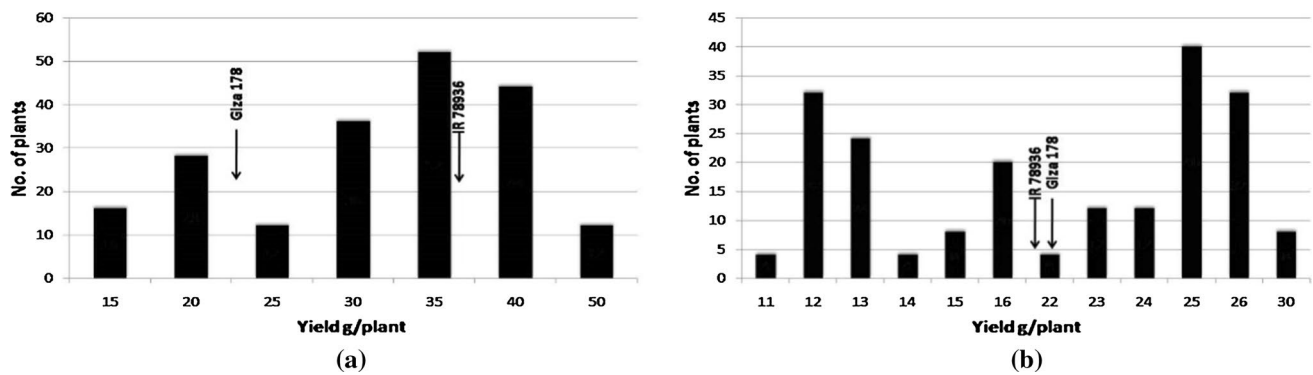


Fig. 3 Frequency distribution of grain yield per plant trait in the F_2 populations of Cross 3 combinations (IR 78,936-B-B-B x Giza 178) under NWS (a) and DWS (b). The positions of the parental trait values are indicated by the arrows

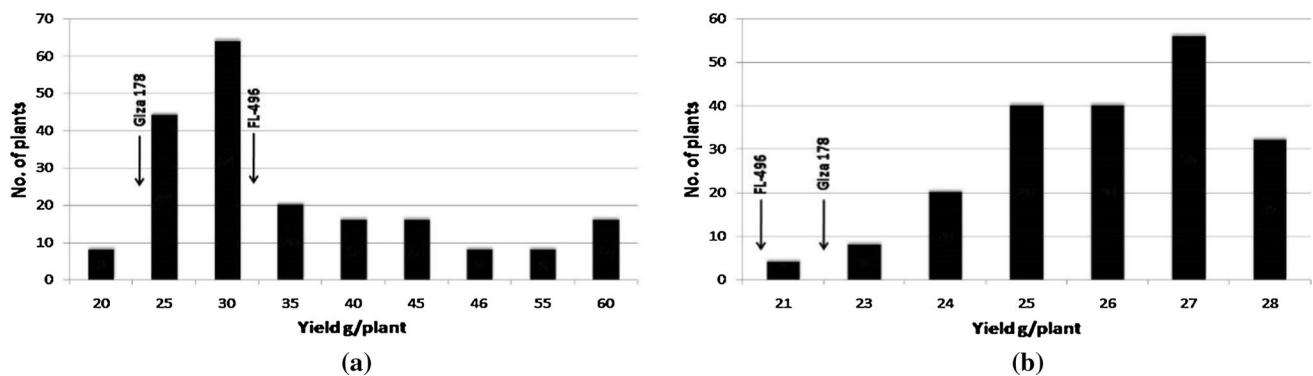


Fig. 4 Frequency distribution of grain yield per plant trait in the F_2 populations of Cross 4 combinations (FL-496 x Giza 178) under NWS (a) and DWS (b). The positions of the parental trait values are indicated by the arrows

illustrated that the frequency distribution varied widely and transgressive segregations indicating polygenic inheritance existed.

Genetic traits

Estimation of variance components and GAM

Data in Table 5 show that PCV of the characters under study was slightly higher than the corresponding GCV in all crosses. The maximum of GCV was found for grain yield in Cross 1 under DWS, while in Cross 3 under NWS. GAM was also calculated and it ranged from 3.70 for panicle length under DWS to 89.33 of panicle weight and grain yield per plant under water deficit for Cross 1.

Heritability

Heritability ($h^2b\%$) of the characters under stress conditions ranged from 42.69 to 92.36, while the range was between 48.49 and 96.57 under NWS in Cross 1 (Table 5). In Cross

2 under DWS, heritability ranged from 42.69 to 87.03, whereas the range was from 48.49 to 95.72 for NSW. The ranges in Cross 3 and Cross 4 were from 43.95 to 98.01 and from 48.44 to 97.37 under DWS, while from 51.98 to 96.18 and from 39.07 to 99.43 under NWS, respectively (Table 5). Heritability values were slightly lower under water deficit stress than in the non-stressed trial for all the characters under study except the number of filled grains per panicle in Cross 1, grain yield per plant in Crosses 1 and 4, number of panicles per plant in Crosses 2, 3 and 4, 1000-grain weight in Crosses 2 and 4, panicle length in Crosses 3, and sterility % in Cross 3 (Table 5). High heritability in a broad sense coupled with high GA was observed for grain yield in Cross 1 under the two studied conditions and hence offered good scope for selection.

W-test results

The results of the Shapiro-Wilks test (W -test) indicate that the F_2 population did not show a normal distribution for all the traits except plant height in Crosses 1, 2 and 4 under

Table 5 Genetic traits for the studied characters in the F₂ populations of rice crosses under normal (NWS) and deficit (DWS) water supply conditions

Character	Water supply	Cross 1				Cross 2			
		PCV%	GCV%	h ² b%	GAM	PCV%	GCV%	h ² b%	GAM
Plant height (cm)	NWS	10.31	9.81	90.29	18.05	9.58	8.55	84.93	14.97
	DWS	12.28	9.50	60.37	15.22	10.32	9.00	76.03	16.17
Panicles/plant	NWS	36.55	33.33	82.91	66.49	30.28	27.66	83.17	51.98
	DWS	35.02	30.92	77.96	56.24	37.09	34.09	87.03	66.50
Panicle length (cm)	NWS	8.75	7.72	69.10	13.04	11.93	10.03	70.66	17.36
	DWS	6.05	4.10	43.80	3.70	8.73	7.06	65.49	9.53
Panicle weight (g)	NWS	20.38	20.03	96.57	40.12	26.31	24.80	88.86	26.31
	DWS	35.4	34.34	92.36	89.33	23.31	17.56	56.73	27.24
Filled grains/panicle	NWS	25.3	19.68	60.46	31.55	21.63	18.24	71.10	31.69
	DWS	36.19	34.52	90.9	67.7	42.45	41.28	47.26	29.18
Sterility (%)	NWS	50.26	35.00	48.49	50.21	50.26	35.00	48.49	50.21
	DWS	23.87	15.6	42.69	20.99	23.87	15.6	42.69	20.99
1000-grain weight (g)	NWS	7.64	4.76	95.83	8.37	8.09	6.66	67.83	<u>9.30</u>
	DWS	7.60	6.64	75.55	11.9	11.10	9.24	69.30	<u>13.19</u>
Grain yield/plant (g)	NWS	57.73	48.51	84.51	91.95	39.10	38.26	95.72	74.69
	DWS	47.19	45.19	92.05	89.33	20.37	17.08	83.88	35.19
Character	Water supply	Cross 3				Cross 4			
		PCV%	GCV%	h ² b%	GAM	PCV%	GCV%	h ² b%	GAM
Plant height (cm)	NWS	13.62	13.30	95.39	26.77	9.01	8.70	93.21	17.30
	DWS	15.66	14.42	84.76	27.34	22.59	14.96	60.01	18.50
Panicles/plant	NWS	28.98	20.79	51.98	31.03	37.16	34.59	88.63	66.32
	DWS	34.12	30.82	81.56	57.34	94.82	93.57	97.37	19.02
Panicle length (cm)	NWS	9.18	5.09	71.84	14.69	6.40	5.93	85.34	10.42
	DWS	24.14	21.16	84.94	5.81	9.59	6.67	48.44	6.66
Panicle weight (g)	NWS	32.52	30.07	85.48	57.27	23.19	22.75	96.18	45.97
	DWS	38.47	32.83	72.86	57.73	17.96	14.85	68.35	25.29
Filled grains/panicle	NWS	35.39	35.35	83.53	66.90	16.0	15.60	83.09	26.69
	DWS	36.40	29.56	53.77	40.30	21.13	18.47	76.42	33.27
Sterility (%)	NWS	25.31	24.84	76.84	38.21	66.85	66.67	99.43	136.5
	DWS	25.31	24.84	93.58	48.79	34.85	31.34	69.07	69.07
1000-grain weight (g)	NWS	10.66	9.83	85.16	17.25	2.81	1.76	39.07	1.41
	DWS	31.6	30.71	98.01	42.20	5.59	4.04	59.25	4.93
Grain yield/plant (g)	NWS	52.28	51.28	96.18	13.59	37.36	29.66	63.01	48.50
	DWS	28.89	19.15	43.95	25.16	31.55	26.24	69.17	44.96

NWS, in Cross 2 under DWS, number of panicles per plant in Crosses 2, 3, 4 under NWS, number of filled grains per panicle in Crosses 3 and 4 under DWS, and 1000-grain weight in Cross 1 under DWS (Table 6).

Correlation analysis results

The estimates of the correlation coefficient among all the studied characters are presented in Table 7. Concerning plant height, data showed that no significant correlation, except for 1000-grain weight under DWS. Regarding the

correlation between the number of panicles and all the other studied traits, the number of panicles significantly and positively correlated with panicle weight and the number of filled grains per panicle under NWS. Panicle length showed highly significant positive correlation with panicle weight, the number of filled grains and grain yield under DWS. Furthermore, the results showed a highly significant positive correlation between panicle weight and sterility % under both water supply conditions as well as between panicle weight and grain yield under DWS. Positive significant and highly significant correlations were found

Table 6 Test of normality of the distribution curve for the studied characters in the F₂ populations of rice crosses under normal (NWS) and deficit (DWS) water supply conditions

Character	Water supply	Cross 1		Cross 2		Cross 3		Cross 4	
		W test	Probability	W test	Probability	W test	Probability	W test	Probability
Plant height (cm)	NWS	0.956	0.061	0.975	0.358	0.893	0.000	0.984	0.738
	DWS	0.952	0.041	0.963	0.118	0.643	0.000	0.957	0.066
Panicles/plant	NWS	0.914	0.001	0.967	0.180	0.987	0.357	0.985	0.771
	DWS	0.939	0.012	0.940	0.014	0.908	0.000	0.357	0.000
Panicle length (cm)	NWS	0.909	0.001	0.818	0.000	0.965	0.005	0.954	0.050
	DWS	0.939	0.012	0.764	0.000	0.934	0.000	0.951	0.038
Panicle weight (g)	NWS	0.738	0.000	0.885	0.000	0.925	0.000	0.734	0.000
	DWS	0.903	0.001	0.872	0.000	0.955	0.001	0.860	0.000
Filled grains/panicle	NWS	0.940	0.013	0.892	0.000	0.909	0.000	0.946	0.024
	DWS	0.905	0.001	0.834	0.000	0.971	0.015	0.962	0.113
Sterility (%)	NWS	0.895	0.000	0.918	0.002	0.962	0.003	0.918	0.002
	DWS	0.854	0.000	0.874	0.000	0.968	0.010	0.951	0.038
1000-grain weight (g)	NWS	0.931	0.006	0.888	0.000	0.917	0.000	0.907	0.001
	DWS	0.967	0.168	0.798	0.000	0.848	0.000	0.901	0.001
Grain yield/plant (g)	NWS	0.921	0.003	0.907	0.001	0.938	0.000	0.943	0.018
	DWS	0.954	0.052	0.651	0.000	0.730	0.000	0.940	0.013

Table 7 Estimates of the phenotypic correlation coefficients for the studied characters in the F₂ populations of rice crosses under normal (NWS) and deficit (DWS) water supply conditions

		Plant height (cm)	Panicles/plant	Panicle length (cm)	Panicle weight (g)	Filled grains/ panicle	Sterility (%)	1000-grain weight (g)	Grain yield/ plant (g)
Plant height (cm)	NWS	1							
	DWS	1							
Panicles/plant	NWS	−0.073	1						
	DWS	−0.131	1						
Panicle length (cm)	NWS	0.068	−0.070	1					
	DWS	0.028	0.011	1					
Panicle weight (g)	NWS	−0.098	0.157*	−0.076	1				
	DWS	−0.003	0.017	0.142*	1				
Filled grains/ panicle	NWS	−0.066	0.143*	−0.037	0.121	1			
	DWS	−0.020	−0.025	0.182**	0.136	1			
Sterility (%)	NWS	−0.063	−0.065	−0.014	0.144*	0.022	1		
	DWS	−0.120	0.076	0.086	0.171*	0.137	1		
1000-grain weight (g)	NWS	−0.160	−0.684	0.016	0.065	−0.136	0.168*	1	
	DWS	0.196**	−0.084	−0.024	0.097	−0.066	0.086	1	
Grain yield/ plant (g)	NWS	−0.380	−0.010	0.016	−0.082	0.192**	−0.035	−0.159*	1
	DWS	−0.118	0.044	0.201**	0.146*	0.303**	0.115	−0.148*	1

t-value was obtained from a paired sample *t*-test between P₁ and P₂ representing significance at 1% (**) or 5% (*) level

between the number of filled grains per panicle and grain yield under both the conditions under study. Positive significant correlation was found between the sterility % and 1000-grain yield under NWS. 1000-grain weight showed

a significant positive correlation with grain yield weight under both water supply conditions.

Discussion

The mean performance of the parents, F_1 hybrids and F_2 populations was significantly different between the two parents for all crosses. These differences between genotypes might be due to their genetic background. The mean values of studied characters under DWS were lower than the means in NWS stating that drought causes serious slowdown of growth (Bassuony et al. 2015). However, the grain yield per plant trait was varying greatly among the parents under water deficit. When drought occurred during panicle development, it was delayed and the number of spikelets per panicle was reduced (Bassuony et al. 2015). Estimating the means of F_1 and F_2 populations, the grain yield character under NWS was higher than the yield under DWS showing that this trait is influenced by the environment. Water deficit stress influences plant growth, and ultimately, it reduced the grain yield of rice as the percentage of spikelet sterility increased under water deficit stress, especially at the panicle initiation stage (Venuprasad et al. 2007).

Selecting the characters (number of filled grains) contributing to the yield together will improve the grain yield in the next segregating population (Ibrahim et al. 2018). The expected response to selection can be measured by determining the parameters like standard deviation (Scossiroli 1977).

Information about the nature of gene action is provided by the study of distribution using skewness and kurtosis (Fisher et al. 1932) and the number of genes controlling the traits (Robson 1956). The sign of skewness assists us to draw the inference about the gene action for a certain trait. The positive skewness showed the existence of epistatic gene action for that trait. The gain is slower with the mild selection and faster with intensive selection for that particular trait. The negative skewness showed the existence of duplicate epistatic gene action and therefore the obtained is faster with moderate selection and slower with strong selection (Snape and Riggs 1975).

The skewed distribution indicated both duplicate and non-additive gene interactions, while the negatively skewed one was connected with additive $\times$ additive duplicate gene interactions. Also, positive skewness indicated the non-additive integral gene interactions. The skewness of the distribution for the F_2 population was found to be platykurtic with a kurtosis coefficient of less than 3, which means they are controlled by a large number of genes. The decrease in the mean of the number of the filled grains under DWS for this population was the lowest compared to others, which shows that water deficit stress had no considerable effect on this character (Rajan and Rani 2019). These transgressive segregants might have been a result of the accumulation of favourable genes derived from the parents. Transgressive

segregation was usually noted in segregating populations for quantitative traits (Tanksley 1993; Xiao et al. 1996). There are many potential reasons of transgression including unmasking of recessive deleterious alleles due to inbreeding. However, it was also supposed that accumulation of complementary alleles of the parents at multiple loci is the basic factor for appearance of such transgressive segregants (Tanksley 1993; Mohammadi et al. 2013).

The PCV of the characters under study was slightly higher than the corresponding GCV in all crosses, but the small difference indicates an environmental effect on the phenotypic. GCV provides information on the genetic variability of the characters in the base population, but it is not possible to determine the heritable amount of the variation only from GCV.

Heritability values were slightly lower under water deficit stress than in the non-stressed trial for all the characters under study except some characters in crosses under study. In those cases, no consistent reduction in heritability appeared under water deficit stress relative to the non-stress conditions. These results confirm with (Lanceras et al. 2004) and support the hypothesis that the assessment of yield under drought stress in rice can be performed with an accuracy equivalent to that obtained for non-stress trials. It indicates that direct phenotypic selection for grain yield under stress will lead to gains if screening trials are well managed (Venuprasad et al. 2007).

The study of the relationships among the morphological characters under study is of great importance. Panicle length showed highly significant positive correlation with panicle weight, the number of filled grains and grain yield under DWS. Similar results were observed in a previous study (Zou et al. 2005). 1000-grain weight showed a significant positive correlation with grain yield weight under both water supply conditions (Bassuony et al. 2015).

The screening of the F_2 populations of the four investigated crosses (IR 78,936-B-B-B-B $\times$ Giza 177, FL-496 $\times$ Giza 177, IR 78,936-B-B-B-B $\times$ Giza 178 and FL-496 $\times$ Giza 178) for water deficit tolerance indicates the complex nature of inheritance and higher heritability estimates. The results indicated high heritability in a broad sense coupled with high GA, which was observed for grain yield in Cross 1 under the two studied water supply conditions and hence offered good scope for selection. We believe that our results have scientific as well as practical significance and can motivate rice breeders to do crosses of various rice varieties with different water deficit tolerance in accordance with the demand of accommodation to the increasing frequency of weather extremes caused by climate change.

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Availability of data and material The data of this study are available from the corresponding author upon request.

Code availability Not applicable.

Declarations

Conflict of interest The authors declare no conflicts of interest.

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