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Determine Physiological Traits Associated with Flowering Stage Drought Tolerance in Lowland Rice (*Oryza sativa* L.) Genotypes

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A B S T R A C T

Drought stress significantly reduced the RWC and LWP of the rice plant. Moreover, Azucena (DT check), NDR-359, NDR-97, DSU-18-6, Vandana, TN-1 and Moroberekan showed less depression. Result revealed that capacity to maintain high LWP is promising traits for selection to improve tolerance against flowering stage drought tolerance. Grain yield under water deficit at the flowering stage is negatively correlated with spikelet sterility and later associated with genotypic variation in maintenance of LWP. Correlation studies between RWC and per cent grain sterility and LWP vs. per cent sterility indicated that maintenance of RWC is necessary but not significant to ensure good yield. These result suggested that other feature are at least as important as RWC in determining response to flowering stage drought tolerance. Grain yield is well correlated with RL and RWD but strong regression coefficient was obtained between root length and RWC. This result indicated that root length did not contribute directly grain yield under drought at flowering stage. But, it indirectly helps to maintained higher plant water status. Assimilate accumulate prior to flowering are of permanent importance when plant experience drought stress at flowering stage. Present study indicated that translocation of soluble sugar for grain growth is supported by ACR and ATR was higher in stress. Grain yield was significantly correlated with ACR and ATR.

Introduction

Breeding rice for drought-prone conditions has had less success than breeding for favorable irrigated environments. There is a lower return on plant breeding for lower yielding upland environments, compounded by a more costly and slower uptake of new varieties. The plant breeding process for drought adaptation can be made more efficient when traits other than yield are added to the selection process. Eastern Uttar Pradesh share only 2.76 m ha area out of total 5.8 ha area under rice which an average yield of 1.42 t ha^{-1} and almost 15 per cent area is planted to rainfed upland. Rainfall pattern of this region is erratic and limited to short period, resulting in drought spells of 1-3 weeks at either seedling/vegetative and anthesis stages depending on the time of rainfall. Terminal drought is recurring feature in this region which is detrimental to rice yield.

Drought is a metrological term involving rainfall deficit and shows variation in intensity, duration and occurrence annually. Drought resistance is the genetic term used to cover a range of mechanisms whereby plants withstand periods of dry weather. It includes drought escape and drought tolerance with high or low tissue water potential. Drought escape is characterized by rapid phenological development and developmental plasticity, which enables the plants to complete its-life cycle before the onset of drought.

A deep root system is considered as important component of drought resistance because it related to the plants ability. A number of physio-morphological characters have been suggested to confer drought resistance in rice.

Low root densities at depth are the main reason for the ineffective use of available moisture in deeper soil layers and well-developed root systems are often associated with dehydration avoidance of cultivars in upland condition (O'Toole and Chang, 1979; Yoshida and Hesegawa, 1982; Ekanayake *et al.,* 1985; Lilley and Fukai, 1994).

Enormous amount of variability is exhibited by traditional cultivars grown under fragile environments indicating that native landraces embody unique tolerance strategies appropriate to specific growing condition. Therefore, present investigation was carried out to estimate the existing variability in population.

Materials and Methods

Experimental sites, genotypes and years of screen

The present investigation was carried out in wet season, during 2007 and 2008 at the Instructional Farm of Department of Crop Physiology, N. D. University of Agriculture & Technology Kumarganj (Faizabad), U.P., India. The genotypes of upland rice (indica and japonica type) from different geographical regions were screened for drought tolerance. These genotypes responded well under severe drought conditions and displayed good drought score, recovery and early vegetative vigour, simultaneously, substantial yield also.

Management of water stress

The experiments were conducted with well defined protocol for water management under natural field conditions during wet season in both the years.

Irrigated control (E1)

The experimental field was left uncovered to receive natural rainfall. In addition to this, experimental plots were irrigated using well laid channels for supplying tube well water, as and when required, to maintain appropriate moisture levels as recommended for irrigated rice.

Reproductive stage drought stress (E2)

The experiment field was covered by constructing temporary rainout shelter at a height of 10-12 feet using polythene sheets to exclude any possibility of natural rainfall falling in the experimental plots with proper drainage channel. Care was taken to check the inflow or seepage of water from the adjoining areas by making adequate bunds around the experiment and covered with polythene in drought condition.

The heading stage drought was created by withholding the irrigation for 15 days up to 80 K Pa at 0-15 cm soil profile and 60 K Pa at 30 cm soil depth. Plants were exposed for two weeks (60-80 KPa). Soil moisture content (SMC) during stress period was monitored through periodical soil sampling at 0-15, 15-30 cm soil depth. Drought was released by irrigation. Recovery was measured at 10th days after released of drought.

Genotypes were scored for leaf rolling and leaf drying at the peak stress period using the IRRI Standard Evaluation System (IRRI, 1996).

Experimental design

The genotypes were seeded and seedling establishment was done in dry beds and transplanting was done 21 days after seeding. Each genotype was transplanted in Randomized Block Design with three replications in a 3 m length row. Row spacing was 20 x 15 cm and one seedling per hill was used. Recommended agronomic practices were followed. Pesticides and bird nets were used to protect the plants against pests. All other crop management practices were at the optimum level.

Observation and evaluation

Observations were recorded on five competitive plants of the middle row of each plot for yield and 18 morpho-physiological traits. The plant height (PH) was measured from the base of stem *i.e.* surface of the ground upto the top of the panicle. Panicle length (PL) of 5 panicles of each replication was randomly measured with the help of meter scale at maturity.

The no. of sterile SG/P and fertile seed FG/P on five panicles, selected randomly from each treatment were counted. Number of Ear Bearing Tillers (EBT) per plant under each treatment was recorded by visual counting. 1000 seeds from each treatment were counted and weighed for assessing test weight (TW) in each treatment.

Harvest index (HI) was calculated as per formula of Beedle (1982). Dry weight of shoot, panicle and root was recorded after drought (TB at flowering). Roots were removed from the PVC pipes after 15 days of drought exposure (60–80 K Pa) and washed the roots with tap water and root lengths (RL) were taken. Roots were removed from the plants and washed with the help of tap water and finally roots volume (RV) was measured by measuring cylinder.

The relative water content (RWC) was determined by the method described by Weatherley (1965). Water potential (WP) of main shoot was measured by the pressure bomb (made in soil moisture equipment corp, santa Barbara, CA, USA) method. Leaf membrane stability index (MTS) is determined by using protocol describe by Saadalla *et al.*, (1990).

The post anthesis decrease in culm dry weight relative to increase in panicle dry weight (ATR) was calculated by the formula of Reyniess *et al.,* (1982). The relative contribution of CHO accumulated before flowering to grain CHO at harvest (ACR) was calculated by the formula of Yoshida and Ahn (1968).

The data of morpho-physiological and grain yield were analyzed by appropriate statistical analysis (Gomez and Gomez, 1984) using CropStat 7.2 (IRRI, 2009) programme. Phenotypic (PCV) and genotypic (GCV) coefficients of variation, heritability (broad sense), genetic advance as percentage of mean (Ga), correlation and path coefficient were computed following Singh and Chaudhury (1985).

Results and Discussion

Correlation coefficients

The correlation coefficient, which provides symmetrical measurement of degree of association between two variables or characters, helps us in understanding the nature and magnitude of associations among yield and yield components. In the present study, genotypic correlation coefficients between different character pairs were generally similar in sign and nature to the corresponding phenotypic correlation coefficients.

However, genotypic correlations were higher in magnitude than respective phenotypic correlations between various characters. Similar observations in rice have also been reported by Bai *et al.,* (1992).

None of the physio-morphological characters exhibited strong positive association at genotypic and phenotypic level in control condition. SG/P resulted into negative and significant association condition. In drought condition, SY, PL, TB at M and TB at F emerged with positive and highly significant phenotypic correlations along with high order positive genotypic correlations with GY/P.

The above results indicated that none of the morpho-physiological traits appeared as strong associates of grain yield in irrigated control condition, whereas four traits, namely, SY, PL and TB at maturity and TB at flowering were found to be strong associates of grain yield in E2.

The strong negative associations at phenotypic as well as phenotypic level of SG/P in both conditions and MTS in E2 were recorded. The above observation appears logical as increase in the number of SG/P are likely to reduce yield, while increasing MTS may have negative effect on yield only under E2.

Strong positive association at genotypic and phenotypic level was also observed between RWC and EBT, WP and TB at maturity, PH and FG/P and SY and PL in E1. In E2, SY showed strong positive association with RWC, PL, HI, TB at maturity and TB at flowering. While, TB at flowering had positive association with TB at maturity and PL. Positive association of MTS with SG/P and RV was observed in E2.

Thus, number of physio-morphological character pairs exhibited strong positive association in control condition, while in E2, thirteen character pairs had strong positive association at phenotypic as well as genotypic level. The number of characters pairs exhibiting strong negative association at both levels in E1 and E2 were two and eleven, respectively.

The above discussion emphatically underlines the existence of markedly high number of strong positive or negative associations in drought stress than control condition.

It is interesting to note that water stress resulted into negative associations among physio- morphological characters and yield in E2 than the E1.

Grain yield exhibited significant and positive correlation with PH, and PL at genotypic as well as phenotypic level. Positive relationship of GY with EBT, FGP, TW and HI was reported by Reddy *et al.,* (1995). Leaf RWC was negatively correlated with leaf rolling and days to heading under stress.

Leaf during scores had negative correlations with yield and harvest index under stress biomass under stress was positively correlated with yield, spike let fertility, G/P per cent stress were positively correlated with relative yield under stress (Babu *et al.,* 2003).

These correlations between plant water status indicators and plant phenology and production traits under stress in this study confirmed the earlier reports in rice (Blum *et al.,* 1999).

Table.1 Estimates of genotypic and phenotypic correlation between physio-morphological characters in rice genotypes in E_1

Character	Correlation	WP	RWC	PL	FG/P	SG/P	EBT	SY	HI	TW	TB at F	TB at M	ATR	ACR	MT	RL	RV	RDW	GY
PH	r_g	0.446	0.223	-0.038	0.671	-0.052	0.400	0.061	-0.207	0.250	0.327	0.360	0.292	0.00	0.064	0.362	-0.119	0.280	0.00
	r_p	0.373	0.188	-0.018	0.550*	-0.048	0.228	0.052	-0.176	0.101	0.230	0.298	0.236	0.002	-0.052	0.302	-0.149	0.233	-0.006
WP	r_g		-0.336	0.028	0.468	0.163	-0.425	0.160	-0.394	0.793	-0.071	0.616	-0.261	0.056	0.119	-0.107	-0.105	0.401	-0.075
	r_p		-0.355	0.026	0.435	0.154	-0.311	0.160	-0.320	0.443	-0.062	0.589**	-0.250	0.057	0.077	-0.109	-0.103	0.398	-0.074
RWC	r_g			-0.296	-0.099	-0.059	0.839	-0.258	-0.253	0.381	-0.163	-0.157	0.101	0.266	0.153	-0.251	0.101	0.113	-0.446
	r_p			-0.294	-0.093	-0.057	0.604**	-0.256	-0.201	0.209	-0.148	-0.151	0.097	0.266	0.092	-0.249	0.099	0.113	-0.445
PL	r_g				-0.146	-0.329	-0.387	0.534	0.330	-0.140	-0.110	-0.055	0.214	-0.228	0.566	0.095	0.073	-0.005	0.205
	r_p				-0.132	-0.315	-0.293	0.526*	0.271	-0.091	-0.094	-0.052	0.197	-0.226	0.362	0.093	0.071	-0.005	0.203
FG/P	r_g					0.097	0.186	0.311	-0.115	0.178	0.167	0.283	0.146	0.233	-0.080	0.063	-0.315	-0.058	-0.088
	r_p					0.097	0.155	0.294	-0.128	0.138	0.152	0.264	0.134	0.218	-0.016	0.058	-0.296	-0.051	-0.082
SG/P	r_g						-0.154	-0.294	-0.162	0.244	-0.285	-0.199	-0.938	0.193	-0.181	0.100	0.039	0.542	-0.576
	r_p						-0.093	-0.286	-0.101	0.118	-0.272	-0.186	-0.873**	0.186	-0.084	0.097	0.040	0.529*	-0.559*
EBT	r_g							-0.494	-0.004	-0.057	0.157	-0.320	0.571	0.111	-0.305	-0.167	-0.016	-0.267	-0.113
	r_p							-0.351	-0.001	0.191	0.045	-0.206	0.405	0.082	-0.110	-0.117	-0.013	-0.193	-0.086
SY	r_g								0.009	-0.169	0.029	0.073	0.114	-0.056	0.459	0.121	-0.373	-0.349	0.430
	r_p								0.002	-0.081	0.019	0.075	0.106	-0.055	0.300	0.120	-0.368	-0.348	0.427
HI	r_g									-0.813	0.298	-0.123	0.267	-0.177	-0.411	0.396	-0.123	-0.022	0.255
	r_p									-0.457	0.168	-0.098	0.206	-0.143	-0.129	0.316	-0.101	-0.018	0.208
TW	r_g										-0.272	0.244	-0.739	0.286	0.226	-0.517	0.325	0.581	-0.373
	r_p										-0.104	0.116	-0.364	0.167	0.236	-0.290	0.172	0.330	-0.206
TB at F	r_g											0.332	0.451	-0.217	-0.591	0.310	0.039	0.040	0.302
	r_p											0.313	0.388	-0.197	-0.296	0.272	0.040	0.034	0.275
TB at M	r_g												0.225	0.250	0.178	-0.032	0.237	0.140	0.109
	r_p												0.188	0.241	0.142	-0.030	0.223	0.134	0.103
ATR	r_g													0.363	0.146	0.072	0.238	-0.285	0.320
	r_p													0.346	0.125	0.070	0.222	-0.271	0.307
ACR	r_g														0.451	-0.224	0.201	0.134	-0.341
	r_p														0.282	-0.223	0.199	0.134	-0.340
MT	r_g															0.036	0.048	0.106	-0.305
	r_p															0.025	0.046	0.060	-0.190
RL	r_g																0.186	0.267	0.305
	r_p																0.183	0.265	0.303
RV	r_g																	0.424	-0.038
	r_p																	0.420	-0.037
RDW	r_g																		-0.465
	r_p																		-0.464

Table.2 Estimates of genotypic and phenotypic correlation between morphological characters in rice genotypes in E_2

Characters	Correlation	WP	RWC	PL	FG/P	SG/P	EBT	SY	HI	TW	TB at F	TB at M	ATR	ACR	MT	RL	RV	RDW	GY
PH	r_g	0.237	0.475	0.024	0.574	-0.221	0.989	0.316	-0.012	0.084	0.259	0.525	0.239	0.112	-0.372	0.247	-0.210	0.301	0.330
	r_p	0.191	0.390	0.018	0.443	-0.177	0.427	0.257	-0.052	0.011	0.171	0.427	0.180	0.089	-0.281	0.200	-0.170	0.246	0.266
	r_g		-0.045	0.015	0.441	0.366	-0.02	-0.044	-0.507	-0.28	-0.025	0.116	-0.436	0.365	0.68	-0.248	-0.412	0.332	-0.202
WP	r_p		-0.045	0.014	0.429	0.357	-0.02	-0.044	-0.415	-0.28	-0.026	0.111	-0.408	0.364	0.067	-0.247	-0.412	0.331	-0.202
	r_g			0.158	0.120	0.190	0.423	0.485	-0.188	0.391	0.308	0.223	0.427	0.340	0.073	-0.088	-0.194	0.420	0.282
RWC	r_p			0.157	0.115	0.183	0.226	0.484*	-0.157	0.290	0.276	0.219	0.400	0.340	0.071	-0.088	-0.194	0.419	0.281
	r_g				0.104	-0.570	-0.14	0.753	0.566	0.228	0.586	0.466	0.077	-0.036	-0.862	-0.142	-0.164	-0.095	0.631
PL	r_p				0.096	-0.59*	-0.070	0.750**	0.457	0.172	0.526*	0.445	0.073	-0.036	-0.833*	-0.141	-0.163	-0.095	0.628**
	r_g					-0.137	-0.016	0.212	-0.082	-0.01	0.231	0.482	-0.305	0.165	-0.310	0.014	-0.212	0.436	-0.149
FG/P	r_p					-0.115	-0.049	0.205	-0.052	0.028	0.191	0.444	-0.277	0.160	-0.293	0.013	-0.205	0.423	-0.144
	r_g						0.128	-0.566	-0.277	-0.19	-0.637	-0.638	0.018	0.052	0.735	0.217	0.068	0.061	-0.623
SG/P	r_p						0.097	-0.551*	-0.255	-0.13	-0.564*	-0.606**	0.018	0.050	0.692**	0.212	0.067	0.062	-0.604*
	r_g							0.388	-0.079	0.278	0.338	0.578	0.487	0.130	-0.111	-0.417	-0.551	0.462	0.393
EBT	r_p							0.213	-0.026	0.107	0.211	0.325	0.255	0.073	-0.119	-0.231	-0.303	0.246	0.213
	r_g								0.657	0.370	0.591	0.572	0.369	0.133	-0.767	-0.122	-0.157	-0.190	0.794
SY	r_p								0.537*	0.271	0.535*	0.552*	0.347	0.133	-0.747*	-0.122	-0.157	-0.189	0.793**
	r_g									0.268	0.382	0.129	0.372	0.053	-0.801	0.348	0.327	-0.453	0.495
HI	r_p									0.216	0.324	0.110	0.327	0.041	-0.655*	0.283	0.267	-0.375	0.399
	r_g										0.433	0.444	0.072	0.189	-0.355	-0.259	0.282	0.292	0.339
TW	r_p										0.331	0.315	0.044	0.139	-0.246	-0.192	0.209	0.217	0.257
	r_g											0.837	0.430	-0.113	-0.919	-0.136	-0.099	0.044	0.645
TB at F	r_p											0.718**	0.393	-0.104	-0.804*	-0.123	-0.092	0.038	0.581*
	r_g												-0.045	0.029	-0.767	-0.321	-0.213	0.268	0.628
TB at M	r_p												-0.038	0.028	-0.732*	-0.310	-0.205	0.258	0.604**
	r_g													-0.261	-0.088	0.224	0.061	-0.382	0.444
ATR	r_p													-0.246	-0.088	0.210	0.057	-0.360	0.416
	r_g														-0.048	-0.096	-0.175	0.374	-0.018
ACR	r_p														-0.046	-0.096	-0.175	0.373	-0.019
	r_g															0.124	0.055	0.188	-0.869
MT	r_p															0.121	0.053	0.184	-0.846*
	r_g																0.651	-0.028	-0.073
RL	r_p																0.650**	-0.028	-0.072
	r_g																	0.039	0.003
RV	r_p																	0.039	0.003
	r_g																		-0.308
RDW	r_p																		-0.307

*, ** Significant at 5% and 1% level of probability.

Table.3 Direct and indirect effects of physio-morphological traits on GY/P at genotypic and phenotypic level in E_1

Character	Env.	PH	WP	RWC	PL	FG/P	SG/P	EBT	SY	HI	TW	TB at F	TB at M	ATR	ACR	MT	RL	RV	RDW
PH	E_1	**-1.47**	1.152	0.121	-0.004	-0.484	-0.031	0.455	0.036	-0.024	-0.049	0.207	-0.112	0.137	0.000	0.004	0.419	-0.037	-0.321
	E_2	**0.647**	0.372	-0.022	0.011	-0.413	-0.007	-0.023	0.036	-0.119	0.013	0.069	-0.202	0.040	0.00	-0.004	0.00	-0.135	-0.270
WP	E_1		**2.581**	-0.193	0.003	-0.338	0.095	-0.483	0.095	-0.045	-0.156	-0.045	-0.191	-0.123	-0.011	0.008	-0.13	-0.033	-0.459
	E_2		**0.999**	0.041	-0.017	-0.327	0.021	0.032	0.112	-0.216	0.057	-0.019	-0.400	-0.042	-0.007	0.006	0.00	-0.093	-0.461
RWC	E_1			**0.541**	-0.033	0.071	-0.035	0.954	-0.154	-0.029	-0.075	-0.103	0.049	0.047	-0.053	0.010	-0.29	0.031	-0.130
	E_2			**-0.116**	0.187	0.070	-0.008	-0.062	-0.180	-0.136	0.027	-0.044	-0.103	0.016	-0.035	0.007	0.00	0.090	-0.131
PL	E_1				**0.112**	0.105	-0.193	-0.440	0.318	0.038	0.028	-0.070	0.017	0.101	0.046	0.037	0.110	0.023	0.005
	E_2				**-0.638**	0.099	-0.043	0.033	0.368	0.183	-0.012	-0.028	0.035	0.033	0.030	0.026	0.00	0.064	0.006
FG/P	E_1					**-0.721**	0.057	0.212	0.185	-0.013	-0.035	0.106	-0.088	-0.069	-0.047	-0.005	0.073	-0.098	0.066
	E_2					**-0.752**	0.013	-0.016	0.206	-0.087	0.018	0.046	-0.179	0.023	-0.028	-0.001	0.00	-0.268	0.059
SG/P	E_1						**0.586**	-0.176	-0.175	-0.019	-0.048	-0.180	0.062	-0.441	-0.039	-0.012	0.115	0.012	-0.622
	E_2						**0.136**	0.010	-0.200	-0.068	0.015	-0.081	0.127	-0.146	-0.024	-0.006	0.00	-0.036	-0.613
EBT	E_1							**1.137**	-0.294	0.000	0.011	0.099	0.099	0.268	-0.022	-0.020	-0.19	-0.005	0.307
	E_2							**-0.103**	-0.246	-0.001	0.025	0.013	0.140	0.068	-0.010	-0.008	0.00	-0.012	0.224
SY	E_1								**0.595**	0.001	0.033	0.018	-0.023	0.054	0.011	0.030	0.140	-0.116	0.400
	E_2								**0.701**	0.001	-0.010	0.006	-0.051	0.018	0.007	0.022	0.00	-0.334	0.403
HI	E_1									**0.114**	0.160	0.188	0.038	1.012	0.036	-0.027	0.458	-0.038	0.025
	E_2									**0.676**	-0.059	0.050	0.067	0.035	0.019	-0.009	0.00	-0.091	0.020
TW	E_1										**-0.197**	-0.172	-0.076	-0.348	-0.058	0.015	-0.60	0.101	-0.667
	E_2										**0.129**	-0.031	-0.079	-0.061	-0.022	0.017	0.00	0.156	-0.383
TB at F	E_1											**0.632**	-0.103	0.212	0.044	-0.038	0.359	0.012	-0.046
	E_2											**0.299**	-0.211	0.064	0.026	-0.021	0.00	0.036	-0.040
TB at M	E_1												**-0.310**	0.106	-0.050	0.011	-0.04	0.074	-0.160
	E_2												**-0.679**	0.032	-0.031	0.010	0.00	0.202	-0.155
ATR	E_1													**0.471**	-0.073	0.009	0.083	0.074	0.327
	E_2													**0.168**	-0.045	0.009	0.00	0.201	0.315
ACR	E_1														**-0.201**	0.029	-0.26	0.062	-0.153
	E_2														**-0.131**	0.020	0.00	0.180	-0.155
MT	E_1															**0.065**	0.042	0.015	-0.122
	E_2															**0.072**	0.00	0.042	-0.070
RL	E_1																**1.158**	0.058	-0.306
	E_2																**0.02**	0.166	-0.308
RV	E_1																	**0.310**	-0.486
	E_2																	**0.906**	-0.487
RDW	E_1																		**-1.147**
	E_2																		**-1.160**

Residual effects = 0.226, Bold figures indicate direct effects.

Table.4 Direct and indirect effects of physio-morphological traits on GY/P at genotypic and phenotypic level in E_2

Character	Env.	PH	WP	RWC	PL	FG/P	SG/P	EBT	SY	HI	TW	TB at F	TB at M	ATR	ACR	MT	RL	RV	RDW
PH	E_1	**0.851**	-0.032	0.406	0.007	-0.317	-0.022	0.029	-0.092	-0.001	-0.085	0.025	0.145	-0.078	0.023	0.231	-0.292	-0.292	-0.178
	E_2	**0.243**	-0.028	-0.025	0.014	-0.041	-0.008	0.079	0.00	0.020	0.00	0.009	0.278	0.039	0.042	-0.071	-0.022	-0.090	-0.173
WP	E_1		**-0.134**	-0.039	0.004	-0.243	0.036	-0.001	0.013	-0.052	0.285	-0.002	0.032	0.142	0.073	-0.042	0.293	-0.574	-0.196
	E_2		**-0.147**	0.003	0.011	-0.040	-0.016	-0.003	0.00	0.156	0.007	-0.001	0.072	-0.089	0.175	0.017	0.027	-0.219	-0.232
RWC	E_1			**0.855**	0.048	-0.066	0.019	0.013	-0.142	-0.119	-0.397	0.030	0.061	-0.139	0.069	-0.046	0.104	-0.270	-0.248
	E_2			**-0.065**	0.119	-0.011	0.008	0.042	0.001	0.059	-0.010	0.014	0.143	0.088	0.163	0.018	0.010	-0.103	-0.294
PL	E_1				**0.307**	-0.057	-0.056	-0.004	-0.220	0.058	-0.232	0.057	0.128	-0.025	-0.007	0.535	0.167	-0.228	0.056
	E_2				**0.758**	-0.009	-0.024	-0.013	0.001	-0.172	-0.006	0.027	0.290	0.016	-0.017	-0.211	0.015	-0.087	0.067
FG/P	E_1					**-0.551**	-0.014	0.00	-0.062	-0.008	0.012	0.022	0.133	0.099	0.033	0.192	-0.017	-0.294	-0.257
	E_2					**-0.093**	-0.005	-0.009	0.00	0.020	-0.001	-0.010	0.289	0.061	0.077	-0.074	-0.001	-0.109	-0.297
SG/P	E_1						**0.099**	0.004	0.166	-0.028	0.198	-0.062	-0.176	-0.006	0.010	-0.457	-0.257	0.095	-0.036
	E_2						**0.044**	0.018	-0.001	0.096	0.005	-0.029	-0.395	0.004	0.024	0.175	-0.023	0.036	-0.044
EBT	E_1							**0.030**	-0.114	-0.008	-0.282	0.033	0.159	-0.159	0.026	0.069	0.493	-0.766	-0.273
	E_2							**0.185**	0.00	0.010	-0.004	0.011	0.212	0.056	0.035	-0.030	0.025	-0.161	-0.173
SY	E_1								**-0.293**	0.067	-0.375	0.057	0.158	-0.120	0.027	0.476	0.144	-0.219	0.112
	E_2								**0.002**	-0.202	-0.009	0.028	0.360	0.076	0.064	-0.189	0.013	-0.084	0.133
HI	E_1									**0.102**	-0.272	0.037	0.036	-0.121	0.011	0.498	-0.412	0.455	0.267
	E_2									**-0.376**	-0.008	0.017	0.071	0.072	0.020	-0.166	-0.031	0.142	0.263
TW	E_1										**-1.014**	0.042	0.122	-0.023	0.038	0.220	0.306	0.392	-0.172
	E_2										**-0.035**	0.017	0.206	0.010	0.067	-0.062	0.021	0.111	-0.152
TB at F	E_1											**0.097**	0.231	-0.140	-0.023	0.571	0.161	-0.138	-0.026
	E_2											**0.052**	0.468	0.086	-0.050	-0.204	0.014	-0.049	-0.027
TB at M	E_1												**0.275**	0.015	0.006	0.477	0.380	-0.296	-0.158
	E_2												**0.652**	-0.008	0.013	-0.185	0.034	-0.109	-0.181
ATR	E_1													**-0.326**	-0.053	0.055	-0.265	0.085	0.225
	E_2													**0.219**	-0.118	-0.022	-0.023	0.030	0.253
ACR	E_1														**0.201**	0.030	0.113	-0.244	-0.221
	E_2														**0.479**	-0.012	0.011	-0.093	-0.262
MT	E_1															**-0.621**	-0.147	0.077	-0.111
	E_2															**0.253**	-0.013	0.028	-0.129
RL	E_1																**-1.183**	0.905	0.017
	E_2																**-0.110**	0.346	0.020
RV	E_1																	**1.392**	-0.023
	E_2																	**0.532**	-0.027
RDW	E_1																		**-0.590**
	E_2																		**-0.702**

Residual effects = -0.147 (genotypic) and 0.0621 (phenotypic), Bold figures indicate direct effects.

Path-coefficient analysis

In present study, path-coefficient analysis was carried out at phenotypic and genotypic level to assess the direct and indirect effects of component characters on GY/P in E1 and E2. In case of physio–morphological traits, WP, SY and RV in E1 emerged as most important direct contributors of GY owing the their high order positive direct effects on grain yield at phenotypic as well as genotypic levels. In addition to these, PH, HI at phenotypic level and RWC, SG/P, EBT, TB at flowering, ATR and RL at genotypic level extended high order positive direct effects on grain yield in irrigated condition to appear as direct components of secondary importance. Similarly, total biomass at re-watering and ACR at phenotypic level were identified as direct contributors of secondary importance. Plant height, fertile grains per panicle, test weight, total biomass at re-watering and root dry weight via water potential; panicle length via straw yield, straw yield and ATR via root dry weight exerted substantial positive indirect effects on grain yield at phenotypic and genotypic levels to appear as important indirect contributors through different characters in the control condition. In stress condition, straw yield, harvest index, total biomass at maturity and total biomass at flowering appeared most important indirect components of grain yield due to their high order positive indirect effects at phenotypic or genotypic levels through more than one character (Tables 1–4).

The estimates of direct and indirect effects of several of physio–morphological traits at genotypic and phenotypic levels in stress condition were strikingly different in sign and magnitude than the corresponding estimates in control condition. The identify characters exhibiting high estimates of direct and indirect effects in either negative or positive direction at phenotypic and genotypic levels was vastly different in the control and stress (drought) condition. This indicated that expression of grain yield requires different balance physio-morphological traits in drought stress condition than the normal control conditions. Therefore, for devising the selection criteria or index for evolving high yielding genotypes for drought stress environments, the inter-relationships and path effects existing in the stress condition should be given due consideration. The substantial differences in correlations and direct and indirect path effects observed at phenotypic and genotypic levels in control and stress environments in case of physio-morphological traits emphasized the importance of genotypic x environment interactions in conditioning the inter-relationship among various physio-morphological characters in rice. The physio-morphological characters identified as important direct and indirect yield contributing traits in normal and stress conditions, as discussed before, should be given due consideration in formulation of selection strategy aimed at developing high yield rice genotypes for respective environments.

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