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Research Article

Revealing genetic variability and character association for yield and yield- attributing traits of rice (*Oryza sativa* L.) under water-limited condition

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Abstract
The present study aims to evaluate the genetic variability, character association and path coefficient for various quantitative traits in fifty rice genotypes comprising of landraces and varieties under water limited conditions. Drought being a major abiotic stress causes severe reduction in grain yield especially during reproductive stages. The results revealed the presence of high genetic variability and significance for all the traits studied. The traits like single plant yield, number of filled spikelets per panicle, number of productive tillers per plant, flag leaf length, leaf rolling and leaf drying showed high variability compared to all other traits. The traits *viz.,* spikelet fertility, number of productive tillers per plant, number of total tillers per plant, plant height, flag leaf breadth, panicle length, number of filled spikelets per panicle and relative water content exhibited a significant and positive correlation and direct effect on single plant yield, suggesting the potential importance of these traits in the improvement and selection of stable and high-yielding rice genotypes.

Keywords: correlation, drought, heritability, rice, path analysis

INTRODUCTION

Rice (*Oryza sativa* L.) thrives under diverse climatic and soil conditions. Drought stress poses a major challenge in rice cultivation bringing about substantial decline in yield and productivity. In India, rice is cultivated in an area of 46.27 million hectares resulting in the overall production of around 129.47 million metric tonnes and an average productivity of 2.7 tonnes per hectare (INDIASTAT 2021-2022). Drought stress at reproductive stage affects the grain yield substantially as flowering is the most critical stage of the crop. Drought tolerant mechanisms include morphological and physiological adaptations that are controlled by genetic factors at various growth stages of the rice. Water deficit conditions results in reduced plant height, leaf rolling and decreased spikelet fertility percentage which results in fewer grains per panicle (Nithya *et al.,* 2020). Root architectural traits such as rooting depth favours adaptation of rice genotypes to water limited conditions which enhances grain yield (Hazman and Brown 2018). Thus, to overcome yield reduction under drought stress condition, breeding objective should be focussed on development of drought tolerant cultivars. The traditional rice varieties and their wild counterparts possess an indispensable reservoir of genes that offers resistance or tolerance to both biotic and abiotic stresses. These genetic resources can be effectively utilised to develop novel rice genotypes possessing resilience to withstand adverse climatic conditions (Manikanta *et al.,* 2020). Heritability of a genetic trait plays a crucial role in predicting its response to selection (Venkateshwarlu *et al.,* 2022). The correlation coefficient reveals the magnitude and direction of association among yield-related characters and path analysis further partition the relationship between grain yield and yield contributing characters into distinct direct and indirect path coefficients that offers valuable criteria for selection that can enhance grain yield (Beena *et al.,* 2021). With this background, the present study has been carried out to estimate the variability, heritability, genetic advance as percent of mean, correlation, and path analysis to determine contribution of each trait to overall yield, which could serve as selection criteria for the development of high-yielding rice varieties.

MATERIALS AND METHODS

The field experiment was conducted at Agricultural Research Station, Paramakudi during November 2022 to April 2023 using fifty rice genotypes comprising of land races and varieties **(Table 1**). The 50 rice genotypes were staggered sown thrice in nursery bed and transplanted under main field conditions. The experiment was laid out in Randomised Block Design (RBD) with three replications consisting of three rows, each measuring three metres in length at a spacing of 20 x 15 cm and followed the recommended agronomic practices. The field was maintained under well-watered conditions until 45 days from transplanting and irrigation was withheld to impose reproductive stage drought stress. The stress was continued for about 15 days until severe leaf rolling and leaf drying were seen in atleast 75% of the examined genotypes and the plants were re-watered and drained after a day to impose second cycle of drought stress (Venkateshwarlu *et al.,* 2022). The stress cycles were repeated to make sure all the genotypes with different durations experienced water stress both 15 days prior to and after the flowering stage. (Lafitte *et al*., 2004). The drought scores on leaf rolling and leaf drying were taken following SES, (IRRI, 2013) and physiological trait *viz.,* relative water content was measured after 15 days of with-holding irrigation by following Weatherley (1950). Five representative plants were selected for the measurement of agronomic traits such as plant height(cm), panicle length(cm), number of total tillers per plant per plant, number of productive tillers per plant, flag leaf length(cm), flag leaf breadth(cm), number of filled spikelets per panicle, root length(cm), kernel length(cm), kernel breadth(cm), spikelet fertility (%), hundred seed weight(g) and single plant yield(g). The data on days to fifty percent flowering and days to maturity was observed at the plot level. The collected data was analysed using R, a statistical software package. By following Burton's method (1952), the genotypic coefficient of variation (GCV) and phenotypic coefficient of variation (PCV) were computed. Broad-sense heritability was estimated using Lush's approach (1940) and genetic advance was assessed by employing Johnson's method (1955). The correlation coefficient was calculated and path analysis was estimated using Wright (1921) and Dewey and Lu (1959).

Table 1. List of rice genotypes used in the study

S. No.	Genotypes	S. No.	Genotypes	S. No.	Genotypes
1	CO 48	18	Kattanur	35	IC 458608
2	CO 49	19	Kallurundaikar	36	IC 386358
3	CO 50	20	Kuzhiyadichan	37	IC 458005
4	CO 51	21	IC 205988	38	IC 464685
5	CO 52	22	IC 208155	39	IC 461349
6	CO 53	23	IC 67496	40	IC 214151
7	CO 54	24	IC 555090	41	IC 460367X
8	CO 55	25	IC 467267	42	IC 115406
9	GEB 24	26	IC 207562	43	IC 125403
10	CR 1009	27	IC 216378	44	IC 458581
11	Arubadham kuruvai	28	IC 378202	45	IC 213773
12	Kuruvai kalanjiyam	29	IC 206999	46	IC 248033
13	Nootripathu	30	IC 457996	47	IC 206282
14	Norungan	31	IC 126468	48	IC 458210X
15	Poongar	32	IC 378553	49	IC 465008
16	Chithiraikar	33	IC 378408	50	IC350740
17	Chandikar	34	IC 126331		

*IC- Indigenous collection

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RESULTS AND DISCUSSION

The analysis of variance showed the presence of considerable variations between fifty rice genotypes, signifying the existence of variability among all the examined traits (**Table 2).** Comparatively, magnitude of PCV was slightly greater than GCV for all the traits studied, suggesting that the environmental factors have relatively lesser control on phenotypic appearance of these characteristics. Consistent results were previously reported by Katral *et al.* (2022), provides adequate scope for the selection of superior plants. The results of estimates of genetic variability (PCV and GCV), heritability in broad sense and GAM are presented in **Table 3**. Single plant yield recorded high variation in phenotypic and genotypic coefficients, which is akin to the results of Renuprasath *et al.* (2023). High estimates of variability were recorded for number of productive tillers per plant, number of filled spikelets per panicle and flag leaf length, which aligned with the conclusions of Singh *et al.* (2022) and Manohar *et al.* (2022) for flag leaf length. The traits, leaf rolling and leaf drying exhibited high values for the coefficients of variation which is analogous to the results of Acharjee *et al.* (2021). This showed that yield improvement could be achieved by considering these traits at the time of selection. The low genotypic and phenotypic coefficients of variation was noted for the characters namely days to maturity, kernel length, spikelet fertility and relative water content which is consistent with the findings in the order of Demeke *et al.* (2023), Singh *et al.* (2020), Renuprasath *et al.* (2023) and Singh *et al.* (2022) for the above traits. Moderate PCV and GCV was observed for days to fifty percent flowering, root length, flag leaf breadth and kernel breadth which is in line to the results of Ahmed *et al.* (2021) for days to fifty per cent flowering; Ali *et al.* (2021) for flag leaf breadth, Singh *et al.* (2020) for kernel breadth. Similarily, the traits *viz.,* plant height, panicle length, and hundred seed weight exhibited the moderate values and the similar trend was observed by Acharjee *et al.* (2021).

The heritability concept explains about the significant difference among the rice genotypes arises from variation in genetic factors or due to environmental influences. In the present study, sixteen out of eighteen characters recorded high heritability, which indicates the least environmental influence. Since broad sense heritability is based on total genetic variance, heritability along with genetic advance will be useful for selection. High heritability was noticed for the traits, days to fifty percent flowering (99.27%), days to maturity (98.49%), plant height (87.04%), number of productive tillers per plant (73.93%), flag leaf length (94.61%), flag leaf breadth (68.39%), leaf rolling (80.91%), leaf drying (72.38%), number of filled spikelets per panicle (98.15%), spikelet fertility (93.19%), root length (88.68%), kernel length (97.16%), kernel breadth (93.74%) and single plant yield (93.50%). The results were found in accordance with the earlier reports of Aswin *et al.* (2021) for days to fifty percent

Table 2. ANOVA for eighteen characters in rice

Characters	Mean Sum of Squares		
	Replication	**Treatment**	**Error**
Days to 50% flowering	3.247	486.705**	1.192
Days to maturity	4.247	406.615**	2.070
Plant height(cm)	9.102	826.315**	39.072
Panicle length (cm)	4.943	17.980**	3.352
Number of total tillers/plant	2.927	13.762**	3.192
Number of productive tillers/plant	1.727	10.401**	1.094
Flag leaf length (cm)	7.288	219.206**	4.083
Flag leaf breadth (cm)	0.023	0.081**	0.011
Relative water content (%)	5.053	38.162**	3.959
Leaf rolling	0.487	10.436**	0.759
Leaf drying	2.101	5.889**	0.665
Number of filled spikelets /panicle	12.860	1708.853**	10.663
Spikelet fertility%	2.684	57.688**	1.372
Root length(cm)	0.240	44.895**	1.832
Hundred seed weight(g)	0.005	0.708**	0.002
Kernel length(mm)	0.018	0.701**	0.007
Kernel breadth(mm)	0.002	0.309**	0.007
Single plant yield (g)	6.318	93.978**	2.128

** significance at 1% level

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Table 3. Genetic variability parameters for eighteen characters in 50 rice genotypes

Characters	Range		PCV (%)	GCV (%)	h^2b (%)	GAM (%)
	Minimum	Maximum				
Days to 50% flowering	58.33	114.00	17.04	16.98	99.27	34.85
Days to maturity	87.67	148.00	9.76	9.69	98.49	19.81
Plant height(cm)	72.00	134.93	16.83	15.70	87.04	30.18
Panicle length (cm)	15.30	25.47	13.68	10.53	59.26	16.71
Number of total tillers/plant	7.00	18.00	21.61	15.65	52.47	23.35
Number of productive tillers/plant	4.67	12.33	24.90	21.41	73.93	37.92
Flag leaf length (cm)	15.77	53.07	24.04	23.39	94.61	46.86
Flag leaf breadth(cm)	0.83	1.50	17.37	14.37	68.39	24.47
Relative water content (%)	69.00	84.50	5.16	4.45	74.22	9.89
Leaf rolling	0.00	7.00	48.77	43.88	80.91	81.33
Leaf drying	0.00	7.00	50.25	42.75	72.38	74.93
Number of filled spikelets /panicle	42.00	134.67	27.94	27.69	98.15	56.50
Spikelet fertility%	69.00	82.5	5.88	5.68	93.19	11.29
Root length(cm)	18.07	36.33	16.49	15.53	88.68	30.13
Hundred seed weight (g)	1.49	3.24	19.95	19.87	99.15	40.75
Kernel length(mm)	4.70	7.27	8.03	7.91	97.16	16.06
Kernel breadth(mm)	1.53	2.83	14.06	13.61	93.74	27.15
Single plant yield (g)	8.30	27.67	36.17	34.97	93.50	69.66

flowering, plant height, number of productive tillers per plant and single plant yield; Palaniyappan *et al.* (2020) for flag leaf length and flag leaf breadth; Ahmed *et al.* (2021) for number of filled spikelets per panicle and root length; Dinesh *et al.* (2023) for days to maturity, spikelet fertility, kernel length, and kernel breadth and Manickavelu *et al.* (2006) for leaf rolling and leaf drying. Moderate heritability was observed for panicle length (59.26%) and number of total tillers per plant per plant (52.47%), which is similar to the results of Faysal *et al.* (2022) for panicle length.

The GAM values were observed from 9.89% to 81.33%. Moderate GAM was observed for days to maturity (19.81%), panicle length (16.71%), spikelet fertility (11.29%), and kernel length (16.06%). Such GAM values were found out by Demeke *et al.* (2023) for days to maturity and panicle length; Nithya *et al.* (2020) for spikelet fertility. Leaf rolling (81.33%) and leaf drying (74.93%) exhibited high GAM and comparable results were obtained by Manickavelu *et al.* (2006). High GAM was reported for days to fifty percent flowering (34.85%), plant height (30.18%), number of total tillers per plant per plant (23.35%), number of productive tillers per plant (37.92%), flag leaf length (46.86%), flag leaf breadth (24.47%), number of filled spikelets per panicle (56.50%), hundred seed weight (40.75%), kernel breadth (27.15%) and single plant yield (69.66%). Shanmugam *et al.* (2023) reported similar results for such traits.

Days to fifty percent flowering, plant height, number of productive tillers per plant, flag leaf length, flag leaf breadth, leaf rolling, leaf drying, number of filled spikelets per panicle, root length, hundred seed weight, kernel breadth and single plant yield showed high heritability in conjunction with high genetic advance indicates the additive gene action on expression of these traits and phenotypic selection will bring more yield effective outcomes.

Correlation coefficient analysis helps in understanding the connection between yield and its contributing traits and aids in discerning the roles played by genetic and non-genetic factors in the process of improvement via selection. Estimates of genotypic correlation coefficient between yield and its attributes for eighteen characters in fifty rice genotypes were presented in (**Table 4**). The correlation analysis revealed that the single plant yield exhibited a significant and positive correlation with plant height (0.448), panicle length (0.384), number of total tillers per plant per plant (0.740), number of productive tillers per plant (0.706), flag leaf breadth (0.317), relative water content (0.369), number of filled spikelets per panicle (0.789), spikelet fertility (0.817), and root length (0.350). Similar results were reported by Faysal *et al.* (2022) for plant height and panicle length; Sanku *et al.* (2022) for number of total tillers per plant per plant, number of productive tillers per plant, flag leaf breadth, and number of filled spikelets per panicle, Lohiteswararao *et al.* (2021) for number of filled spikelets per panicle and spikelet fertility and Navya *et al.* (2019) for relative water content.

Table 4. Genotypic correlation coefficient between yield and its attributes in 50 rice genotypes

Traits	DFF	DM	PH	PL	TT	PT	FLL	FLB	RWC	LR	LD	FSP	SF	RL	HSW	KL	KB	SPY
DFF	1.00	0.845**	-0.119	0.151	-0.023	-0.084	0.187	0.052	-0.032	0.038	0.292*	-0.303*	-0.274	0.215	-0.145	0.013	0.127	-0.259
DM		1.00	-0.091	0.183	0.056	-0.086	0.351*	0.242	0.061	0.088	0.267	-0.154	-0.210	0.179	-0.259	-0.031	0.027	-0.161
PH			1.00	0.537**	0.183	0.081	-0.011	-0.016	0.169	-0.126	-0.153	0.333*	0.455**	0.292*	0.437**	0.186	0.233	0.448**
PL				1.00	0.415**	0.328*	-0.169	0.116	0.053	0.079	-0.226	0.264	0.126	0.059	0.098	0.037	0.109	0.384**
PT					1.00	0.912**	-0.256	0.118	0.084	-0.200	-0.056	0.527**	0.492**	0.210	-0.299*	-0.127	-0.352*	0.740**
ET						1.00	-0.297*	-0.010	0.014	-0.146	-0.086	0.537**	0.440**	0.174	-0.325*	-0.338*	-0.301*	0.706**
FLL							1.00	0.286*	0.071	0.215	0.141	0.051	-0.033	0.185	0.100	-0.032	0.296*	-0.111
FLB								1.00	0.413**	-0.040	-0.211	0.383**	0.238	0.400**	-0.111	0.132	-0.161	0.317*
RWC									1.00	-0.427**	-0.344*	0.299*	0.469**	0.200	0.151	0.082	0.084	0.369*
LR										1.00	0.383**	-0.146	-0.234	0.058	-0.176	-0.005	-0.149	-0.275
LD											1.00	-0.421**	-0.443**	0.045	-0.380**	0.112	-0.307*	-0.368**
FSP												1.00	0.771**	0.413**	0.107	-0.116	-0.008	0.789**
SF													1.00	0.419**	0.209	-0.092	0.073	0.817**
RL														1.00	0.054	0.095	0.058	0.350*
HSW															1.00	0.455**	0.733**	0.060
KL																1.00	0.049	-0.174
KB																	1.00	-0.074
SPY																		1.00

DFF- Days to fifty percent flowering, DM- Days to Maturity, PH- Plant Height, PL-Panicle length, NT-Number of total tillers per plant per plant, PT- Number of productive tillers per plant, FLL- Flag leaf length, FLB- Flag leaf breadth, RWC- Relative water content, LR- Leaf rolling, LD- Leaf drying, FSP-Number of filled spikelets per panicle, SF- Spikelet fertility, RL- Root length, HSW- Hundred Seed Weight KL- kernel length. KB- Kernel breadth, SPY- Single plant yield

'*' Significance at 5% level, '**' Significance at 1% level

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Table 5. Path analysis representing both the effects of 18 traits on single plant yield in rice.

Traits	DFF	DM	PH	PL	TT	PT	FLL	FLB	RWC	LR	LD	FSP	SF	RL	HSW	KL	KB	SPY
DFF	**-0.080**	-0.049	-0.018	0.014	-0.003	-0.025	0.002	0.011	-0.001	-0.003	0.015	-0.020	-0.115	-0.009	0.010	-0.001	0.012	-0.259
DM	-0.068	**-0.058**	-0.014	0.018	0.008	-0.026	0.003	0.052	0.001	-0.007	0.013	-0.010	-0.088	-0.007	0.018	0.001	0.003	-0.161
PH	0.010	0.005	**0.149**	0.051	0.025	0.024	0.000	-0.003	0.003	0.010	-0.008	0.022	0.190	-0.012	-0.031	-0.008	0.022	0.448**
PL	-0.012	-0.011	0.080	**0.095**	0.057	0.099	-0.002	0.025	0.001	-0.006	-0.011	0.018	0.052	-0.003	-0.007	-0.002	0.010	0.384**
TT	0.002	-0.003	0.027	0.040	**0.137**	0.275	-0.003	0.026	0.002	0.016	-0.003	0.035	0.206	-0.009	0.021	0.006	-0.032	0.740**
PT	0.007	0.005	0.012	0.031	0.125	**0.301**	-0.003	-0.002	0.000	0.011	-0.004	0.036	0.184	-0.007	0.023	0.015	-0.028	0.706**
FLL	-0.015	-0.021	-0.002	-0.016	-0.035	-0.089	**0.010**	0.062	0.001	-0.017	0.007	0.003	-0.014	-0.008	-0.007	0.001	0.027	-0.111
FLB	-0.004	-0.014	-0.002	0.011	0.016	-0.003	0.003	**0.216**	0.007	0.003	-0.011	0.025	0.099	-0.017	0.008	-0.006	-0.015	0.317*
RWC	0.003	-0.004	0.025	0.005	0.012	0.004	0.001	0.089	**0.018**	0.033	-0.017	0.020	0.196	-0.008	-0.011	-0.004	0.008	0.369*
LR	-0.003	-0.005	-0.019	0.008	-0.027	-0.044	0.002	-0.009	-0.008	**-0.078**	0.019	-0.010	-0.098	-0.002	0.012	0.000	-0.014	-0.275
LD	-0.024	-0.016	-0.023	-0.022	-0.008	-0.026	0.001	-0.045	-0.006	-0.030	**0.050**	-0.028	-0.185	-0.002	0.027	-0.005	-0.028	-0.368**
FSP	0.024	0.009	0.049	0.025	0.072	0.162	0.001	0.083	0.005	0.011	-0.021	**0.066**	0.322	-0.017	-0.008	0.005	-0.001	0.789**
SF	0.022	0.012	0.068	0.012	0.067	0.133	0.000	0.051	0.008	0.018	-0.022	0.051	**0.418**	-0.018	-0.015	0.004	0.007	0.817**
RL	-0.017	-0.010	0.043	0.006	0.029	0.053	0.002	0.086	0.004	-0.005	0.002	0.027	0.175	**-0.042**	-0.004	-0.004	0.005	0.350*
HSW	0.012	0.015	0.065	0.009	-0.041	-0.098	0.001	-0.024	0.003	0.014	-0.019	0.007	0.087	-0.002	**0.070**	-0.020	0.067	0.060
KL	-0.001	0.002	0.028	0.004	-0.017	-0.102	0.000	0.029	0.001	0.000	0.006	-0.008	-0.039	-0.004	-0.032	**-0.045**	0.005	-0.174
KB	-0.010	-0.002	0.035	0.010	-0.048	-0.091	0.003	-0.035	0.002	0.012	-0.015	-0.001	0.030	-0.002	-0.052	-0.002	**0.092**	-0.074

DFF- Days to fifty percent flowering, DM- Days to Maturity, PH- Plant Height, PL- panicle length, NT-Number of total tillers per plant per plant, PT- Number of productive tillers per plant, FLL- Flag leaf length, FLB- Flag leaf breadth, RWC- Relative water content, LR- Leaf rolling, LD- Leaf drying, FSP-Number of filled spikelets per panicle, SF- Spikelet fertility, RL- Root length, HSW- Hundred Seed Weight KL- kernel length. KB- Kernel breadth, SPY- Single plant yield

Residual effect: 0.0967, '*' Significance at 5% level, '**' Significance at 1% level

Days to fifty percent flowering exhibited a notable positive inter-relatedness with days to maturity (0.845), which is consistent with the results of Ali *et al.* (2019). A positive and significant inter correlation was noticed between plant height with panicle length (0.537), number of filled spikelets per panicle (0.333), spikelet fertility (0.455), root length (0.292), and hundred seed weight (0.437). The outcomes were in corroboration with the report of Dinesh *et al.* (2023) for panicle length and spikelet fertility. Panicle length showed a positive and significant inter connectedness with number of total tillers per plant per plant (0.415) and number of productive tillers per plant (0.328), which is comparable to the report of Sathishkumar *et al.* (2020) for number of productive tillers per plant. Number of total tillers per plant per plant is positively and significantly inter correlated with number of productive tillers per plant (0.912), number of filled spikelets per panicle (0.527) and spikelet fertility (0.492), similar result was obtained by Muthuramu and Ragavan, (2020) for spikelet fertility. Leaf rolling showed significant inter correlation with leaf drying (0.383) which is similar to the results of Sellammal *et al.* (2014). Number of filled spikelets per panicle had a strong positive inter-association with spikelet fertility (0.771) and root length (0.413). Mukherjee *et al.* (2018) observed the same positive inter relationship between number of filled spikelets per panicle and spikelet fertility. Positive and significant inter association were noticed for hundred seed weight with kernel length (0.455), kernel breadth (0.733) and the results were in relation to the reports of Manivelan *et al.* (2022) for kernel length and Singh *et al.* (2020) for kernel breadth.

Path analysis was done by considering single plant yield as dependent variable and all other yield contributing traits as independent variables. The path coefficient analysis of eighteen characters on yield per plant is represented in the **Table 5.** Evaluation of the path coefficient for various traits contributing to the grain yield per plant under water stress conditions indicated that the examined yield attributes hardly exerted a very high or high direct effect on single plant yield (Beena *et al.* 2021). The traits such as spikelet fertility (0.418), number of productive tillers per plant (0.301), flag leaf breadth (0.216), plant height (0.149) and Number of total tillers per plant per plant (0.137) recorded direct effect on single plant yield. The positive indirect effect on single plant yield were from number of productive tillers per plant via number of total tillers per plant per plant (0.275), number of filled spikelets per panicle (0.162) and spikelet fertility (0.133) which is in line with the results of Fathima *et al.* (2021). Spikelet fertility indirectly influences the single plant yield in a positive manner through number of filled spikelets per panicle (0.322), followed by number of total tillers per plant per plant (0.206), relative water content (0.196), plant height (0.190), number of productive tillers per plant (0.184), and root length (0.175). Bhor *et al.* (2020) obtained similar outcomes for spikelet fertility with plant height and number of productive tillers per plant.

On the basis of above results, it can be inferred that the characters *viz.,* number of productive tillers per plant, flag leaf length, leaf rolling, leaf drying, number of filled spikelets per panicle, and single plant yield exhibited high phenotypic and genotypic coefficient of variation together with high heritability and genetic advance as per cent of mean, which signifies the predominance of additive gene action indicating the potential for improving these traits through selection. Based on the correlation and path analysis, the traits such as spikelet fertility, number of productive tillers per plant, number of total tillers per plant, plant height, panicle length, flag leaf breadth, relative water content and number of filled spikelets per panicle showed positive significant correlation and direct effect in association with single plant yield and are responsible for grain yield improvement in rice under water limited condition.

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