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Genetic Parameters and Association Studies for Morphological, Physiological and Grain Quality Parameters in Rice (*Oryza sativa* L.)

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Abstract

The present investigation was undertaken to study the extent of variability and correlation coefficients of 19 morphological traits, yield components, physiological and physico-chemical grain quality traits in a set of 30 high yielding diverse rice genotypes. Phenotypic and genotypic coefficients of variations were high for net assimilation rate at 60-90 DAT followed by grain yield/plant and volume expansion ratio. Moderate to high heritability estimates were recorded for all parameters under study except for productive tillers/plant. The perusal of results on association and path coefficient analysis revealed that significant and positive correlation coupled with positive direct effects were manifested by test weight, RWC at 60 DAT and harvest index indicating simultaneous improvement of grain yield along with the improvement of these characters.

Keywords: Rice, physiological parameters, Net assimilation rate, relative water content

Introduction

Rice (*Oryza sativa* L.), as a staple food crop for more than half of the world's population is playing a pivotal role in providing human nutrition, energy supply and food security to Asian countries. India is one of the largest countries in terms of energy consumption from agriculture and rice comprises a major part of it (Kennedy *et al*., 2019). Assessment of genetic variability in any crop is essential for making the progress in crop improvement. Information on the nature of inheritance and association of grain yield with morphological, physiological and grain quality traits will help in formulation of effective breeding programme

Materials and Methods

The experimental material consisted of 30 rice genotypes which includes four released varieties, one pre released culture and 25 advanced breeding lines. Thirty days old seedlings of these genotypes were transplanted in Randomized Block Design (RBD) in 5 rows of 3 m length with three replications by adopting 20 x 15 cm spacing between and within the rows. All recommended package of practices were adopted to raise a healthy crop. At different stages of plant growth, data was recorded on various growth parameters and physiological traits *viz.,* root length and shoot length at harvesting, leaf area index at flowering (LAI), relative water content (RWC), net assimilation rate (NAR), harvest index (HI) and grain yield/plant. Five hills from each replication of all genotypes were uprooted from different rows and washed to remove the soil. Root length was measured from base of the stem to tip of the root using scale while the shoot length or culm length was measured in centimetres from ground base to the base of the panicle. Samples were taken at tillering, panicle initiation, flowering, grain filling and harvesting stages. For measurement of leaf area index, leaves were collected from five adjacent plants from each genotype in three replications. Leaf Area Meter (Model No. LP-80) was used for measurement of LAI and the average was expressed as leaf area plant^{-1} in cm^2. Relative water content of leaf samples collected from different treatments was determined by following the method described by Slatyer and Mc Liroy (1967), while net assimilation rate was calculated as per the formula suggested by Gregory (1926). The dry matter accumulation of root, stem, leaf, panicle and total plant was calculated by collecting the samples from five adjacent plants from each treatment in three replications. Five hills were uprooted from different rows and washed to remove soil and were dried first in shade and then the plants were separated into root, stem, leaves and reproductive parts and then dried in hot air oven at 80 °C till a constant weight is obtained. The weights of respected parts were recorded and expressed as g plant^{-1}. Samples were taken at tillering, panicle initiation, flowering, grain filling and at harvesting stages. The harvest index (HI) is the ratio of economic yield to total biological yield and is expressed in percentage. The harvest index of rice of different genotypes was calculated using the following formula.

$$\text{Harvest index (HI) in \%} = \frac{\text{Economic yield (g plant}^{-1}\text{)}}{\text{Total biological yield (g plant}^{-1}\text{)}} \text{X } 100$$

The mean data calculated for all characters under study was utilized for estimating genetic parameters were computed according to Burton and Devane (1953). Genotypic and phenotypic correlation coefficients were estimated using the method given by Johnson *et al.*, (1955). Path coefficient analysis was carried out by the procedure originally proposed by Wright (1921) which was subsequently elaborated by Dewey and Lu (1959) to estimate the direct effects as well as the indirect effects of the individual characters on yield.

Results and Discussion

The results of analysis of variance for 19 characters studied in rice genotypes indicated the existence of significant differences among all the genotypes studied. The general mean, maximum and minimum range, genotypic and phenotypic coefficient of variation, heritability and genetic advance as per cent of mean values obtained for various yield components, grain quality traits and physiological parameters were presented in **Table 1.** Wide range of variation was observed for plant height (94.8-134.8 cm) and water uptake (145.3-301.7 ml) among the nineteen characters studied. LAI at flowering stage varied from 4.3 to 7.2 with a mean value of 5.9 while RWC at 60 DAT ranged from 61.0 to 90.7 among the genotypes under study. Highest phenotypic and genotypic coefficients of variation was observed for net assimilation rate at 60-90 DAT (39.57 and 40.0 respectively) while days to 50% flowering manifested the least values (6.76 and 7.13 respectively). Knowledge of genetic parameters will help in understanding the nature of gene action for the characters under study. In the present investigation, the results of variability parameters revealed that low estimates of genotypic and phenotypic coefficients of variation were recorded for plant height (8.11, 9.40), days to 50 per cent flowering (6.76, 7.13), panicle length (6.19, 7.47), spikelet fertility percentage 6.4, 7.57), kernel length (7.95, 9.96), protein content (7.63, 7.77), root length and shoot length at harvesting and relative water content at 60 DAT indicating less variation among the genotypes for these characters under study. The estimates of heritability ranged from 22.36 (productive tillers/plant) to 99.67 (water uptake). Maximum genetic advance as per cent of mean was manifested by NAR at 60-90 DAT (80.51) followed by volume expansion ratio (48.72) while productive tillers/plant (6.99) manifested minimum value for genetic advance as per cent of mean.

Table 1: Variability, heritability and genetic advance as per cent of mean for morphological, physiological and grain quality traits in rice

S. No.	Character	Mean	Range		Coefficient of variation		Heritability (%)	Genetic advance as per cent of mean
			Minimum	Maximum	GCV (%)	PCV (%)		
1	Plant height (cm)	112.7	94.8	134.8	8.11	9.40	74.50	14.42
2	Days to 50 per cent flowering	109.5	98.0	118.3	6.76	7.13	89.79	13.20
3	Productive tillers per plant	6.9	5.9	9.20	7.18	8.18	22.36	6.99
4	Panicle length (cm)	25.6	21.5	29.1	6.19	7.47	68.68	10.56
5	Spikelet fertility (%)	86.2	68.1	94.9	6.54	7.57	74.61	11.63
6	Test weight (g)	17.3	12.7	23.2	11.15	12.45	45.95	15.57
7	Grain yield per plant (g)	30.8	21.9	58.6	22.32	24.41	83.60	42.04
8	Kernel length (mm)	5.9	5.2	7.5	7.95	9.96	63.64	13.06
9	Kernel breadth (mm)	1.9	1.4	2.8	17.70	18.69	55.80	27.24
10	L/ B ratio	3.1	2.2	4.2	14.54	15.85	44.29	19.93
11	Water uptake (ml)	210.9	145.3	301.7	17.71	17.74	99.67	36.42
12	Volume expansion ratio	4.9	3.4	7.6	23.73	23.82	99.31	48.72
13	Amylose content (%)	22.5	17.3	27.9	12.13	12.39	95.88	24.47
14	Protein content (%)	7.3	6.0	8.4	7.63	7.77	96.64	15.46
15	LAI at Flowering	5.9	4.3	7.2	14.04	15.58	81.26	26.07
16	RWC at 60 DAT	73.5	61.0	90.7	9.16	9.95	84.60	17.35
17	NAR (mg cm^{-2} d^{-1}) at 60-90 DAT	0.32	0.13	0.63	39.54	40.00	97.70	80.51
18	Root length (cm) at harvesting	30.4	26.2	35.2	8.25	9.70	72.25	14.44
19	Shoot length (cm) at harvesting	121.3	103.1	135.2	7.60	8.85	73.79	13.45

Low to moderate heritability and genetic advance as per cent of mean was noticed by number of productive tillers/ plant, test weight and L/B ratio indicating that these traits might not be improved by simple selection. Similar results were reported by Bandi *et al.*, (2018), Dhavaleshvar *et al.*, (2019), Sudeepthi *et al.,* (2020) and Rao *et al.*, (2017). Moderate to high estimates of genotypic as well as the phenotypic coefficient of variation coupled with high heritability and high genetic advance as per cent of mean were recorded for grain yield per plant, water uptake, volume expansion ratio and amylose content among yield components and quality parameters. Singh *et al.*, (2020),Veni *et al.*, (2013) and Devi *et al.*, (2020) also reported similar findings. Among physiological traits under study, root length and shoot length at harvest, leaf area index at flowering and net assimilation rate at 60-90 DAT manifested moderate to high heritability coupled with genetic advance as per cent of mean indicating the preponderance of additive gene action, thus, direct selection for these traits may be effective for improvement of these characters. Remaining all other traits under study recorded either low to moderate genotypic and phenotypic coefficient of variation or low to moderate heritability and genetic advance as per cent of mean suggesting that both additive and non-additive gene actions are involved in the inheritance of these traits. Similar results were reported by Srivastava *et al.*, (2017), Akshitha *et al.*, (2020) and Sudeepthi *et al.*, (2020).

The perusal of association studies between yield components, physical grain quality and physiological traits revealed that significant and positive association of grain yield/plant with test weight, root length at harvesting, harvest index, relative water content at 60 DAT indicating simultaneous improvement of grain yield with improvement of these characters **(Tables 2 and 3).** Hence, priority should be given to these traits while making selection for improvement of grain yield. These results are in confirmation with the

Table 2: Phenotypic and genotypic correlation coefficients of grain yield with morphological and grain quality traits in rice

Character		PH	DFF	PTPP	PL	SFP	TW	KL	KB	L/B	WU	VER	AC	PC	GYPP
PH	r_p	1.0000	-0.1688	-0.1055	0.532**	0.0651	0.330**	0.1537	0.0195	0.0853	-0.1720	0.0682	-0.0271	-0.272**	0.0548
	r_g	1.0000	-0.1834	-0.377**	0.610**	0.1794	0.527**	0.1376	0.0335	0.0921	-0.2049	0.0882	-0.0098	-0.322**	0.0679
DFF	r_p		1.0000	-0.1218	-0.1983	0.220*	-0.2070	-0.1410	-0.1825	0.1167	0.1497	-0.1411	-0.234*	-0.1132	-0.1346
	r_g		1.0000	-0.1876	-0.289**	0.228*	-0.291**	-0.2049	-0.253*	0.1699	0.1567	-0.1592	-0.267*	-0.1351	-0.1404
PTPP	r_p			1.0000	-0.0554	-0.1336	-0.0420	0.0276	0.0042	-0.0355	-0.0032	0.1970	0.0145	-0.1611	0.1739
	r_g			1.0000	-0.253*	-0.1462	0.0337	0.347**	0.0168	0.0200	-0.0307	0.390**	0.0077	-0.308**	0.1915
PL	r_p				1.0000	-0.1559	0.346**	0.292**	0.265*	-0.0910	-0.1095	-0.0910	0.1468	-0.1727	-0.0661
	r_g				1.0000	-0.239*	0.632**	0.410**	0.373**	-0.1087	-0.1313	-0.1215	0.1623	-0.212*	-0.1447
SFP	r_p					1.0000	0.224*	-0.258*	0.0369	-0.0976	-0.473**	-0.407**	-0.237*	-0.281**	-0.0483
	r_g					1.0000	0.211*	-0.408**	0.1340	-0.308**	-0.544**	-0.471**	-0.281**	-0.335**	-0.0407
TW	r_p						1.0000	0.340**	0.441**	-0.247*	-0.358**	-0.295**	-0.270*	-0.1417	0.1758
	r_g						1.0000	0.398**	0.925**	-0.880**	-0.523**	-0.416**	-0.401**	-0.210*	0.296**
KL	r_p							1.0000	0.257*	0.1735	-0.1231	-0.0004	-0.1562	0.0881	-0.1308
	r_g							1.0000	0.366**	0.0976	-0.1542	0.0145	-0.1912	0.1105	-0.1613
KB	r_p								1.0000	-0.891**	-0.265*	-0.1751	-0.1157	-0.1154	0.1107
	r_g								1.0000	-0.881**	-0.373**	-0.239*	-0.1805	-0.1866	0.1693
L/B	r_p									1.0000	0.1686	0.1094	0.0325	0.1533	-0.1794
	r_g									1.0000	0.273**	0.1774	0.0794	0.262*	-0.261*
WU	r_p										1.0000	0.707**	0.1837	0.0186	0.0968
	r_g										1.0000	0.710**	0.1872	0.0185	0.1056
VER	r_p											1.0000	0.245*	-0.1885	0.1630
	r_g											1.0000	0.247*	-0.1950	0.1744
AC	r_p												1.0000	-0.2023	-0.1588
	r_g												1.0000	-0.222*	-0.1865
PC	r_p													1.0000	-0.334**
	r_g													1.0000	-0.362**

* Significant at 5% and ** Significant at % levels

PH= Plant height (cm),DFF= Days to 50 per cent flowering,PTPP= Productive tillers per plant,PL= Panicle length (cm),SFP= Spikelet fertility percentage, TW= Test weight (g),KL= Kernel length (mm),KB= Kernel breadth (mm),L/B= Length/Breadth ratio,WU= Water uptake (ml),VER= Volume expansion ratio,AC= Amylose content (%), PC=Protein content (%), GYPP= Grain yield per plant (g).

Table 3: Phenotypic and genotypic correlation coefficients of grain yield with physiological parameters in rice

Character		RLH	SLH	LAIF	RWC (60 DAT)	NAR (60-90 DAT)	HI	GYPP
RLH	r_p	1.0000	-0.351**	0.0312	0.1959	0.1869	0.1638	0.260*
	r_g	1.0000	-0.506**	-0.0188	0.236*	0.2041	0.1044	0.332**
SLH	r_p		1.0000	0.359**	-0.1168	-0.334**	-0.302**	-0.0776
	r_g		1.0000	0.492**	-0.1219	-0.393**	-0.466**	-0.1086
LAIF	r_p			1.0000	-0.2037	-0.402**	-0.271**	-0.0639
	r_g			1.0000	-0.230*	-0.441**	-0.483**	-0.0812
RWC (60 DAT)	r_p				1.0000	0.329**	0.0238	0.1703
	r_g				1.0000	0.366**	0.0785	0.218*
NAR (60-90 DAT)	r_p					1.0000	0.236*	-0.0273
	r_g					1.0000	0.327**	-0.0380
HI	r_p						1.0000	0.265*
	r_g						1.0000	0.214*

**Significant at 5% level and ** Significant at 1% level*

RLH=Root length at harvesting (cm), SLH=Shoot length at harvesting (cm),LAIF=Leaf area index at flowering; RWC= Relative Water Content (%), NAR=Net assimilation rate (mg cm^{-2} d^{-1}), HI=Harvest index (%), GYPP=Grain yield per plant (g)

findings of Haider *et al.*, (2012) and Hossain *et al.*, (2015), Gunasekaran *et al.*, (2017) and Manickavelu *et al.*, (2006), Among yield components, significant and positive correlations were noticed for plant height with panicle length (0.532**, 0.610**) and test weight (0.330**,0.527**) at both phenotypic and genotypic levels, days to 50 per cent flowering with spikelet fertility percentage (0.220*, 0.228*) suggesting that the genotypes with tall plant stature possessed longer panicles with bold grains and long duration genotypes used in the study had more fertile spikelets when compared with medium duration genotypes. When both yield components and grain quality parameters are considered, panicle length manifested significantly positive correlation with test weight (0.346**, 0.632**) kernel length (0.292**, 0.410**) and kernel breadth (0.265**, 0.373**) suggesting that the genotypes with longer panicles had long bold grain resulting in high test weight. These results were in agreement with previous findings of Tejaswini (2016), Premkumar *et al.*, (2016) and Gunasekaran *et al.,* (2017). Among quality parameters, L/B ratio exhibited significant and positive correlation with water uptake (0.273**) and protein content (0.262*) at genotypic level. Further, water uptake had positive relationship with volume expansion ratio (0.707**, 0.710**) and amylose content (0.184, 0.187) indicating that the genotypes which absorb more water during cooking produced high volume of cooked rice and possessed high amylose content. These results were in accordance with the findings of Premkumar *et al.,* (2016), Gunasekaran *et al.,* (2017) and Singh *et al.,* (2020).

Among physiological parameters, significant and positive association of root length at harvesting was observed with relative water content at 60 DAT (0.236*) at genotypic level and grain yield/plant (0.260*, 0.332**) suggesting that the genotypes with deeper root system will efficiently maintain the water balance thus, high grain yield is anticipated. Similar results were reported by Mishra *et al.,* (2019). Shoot length at harvesting also manifested significantly positive relationship with leaf area index at flowering (0.359**, 0.492**) and negative and significant correlation with NAR at 60-90 DAT (-0.334**, -0.393**), harvest index (-0.302**, -0.466**) suggesting that the genotypes with tall plant stature possess more leaf area index resulting in the production of more photosynthates, more leaf and total dry matter at harvesting. Further strong associations were observed between net assimilation rate at 60-90 DAT with harvest index (0.236*, 0.327**) indicating the scope for simultaneous improvement of these characters. Significant and positive relationship was manifested between relative water content at 60 DAT and harvest index (0.236*,0.327**) & harvest index also exhibited similar association with grain yield/plant (0.265*, 0.214*) suggesting simultaneous improvement of these traits. Manickavelu *et al.,* (2006), Rahman *et al.,* (2012) and Haider *et al.,* (2012) also reported similar findings in their studies.

In contrast, significant and negative association was observed between plant height and protein content (-0.272**,-0.322**), plant height and productive tillers per plant (-0.377**) indicating that the genotypes with tall plant stature used in the study possessed less productive tillers and low protein content. These results are in agreement with the findings of Devi *et al.*, (2019), Parimala *et al.*, (2020) Gunasekaran *et al.*, (2017), Singh *et al.,* (2020) for test weight and Sameera *et al.*, (2016) for kernel breadth. Significantly negative relationship was observed between test weight with L/B ratio (-0.247*,-0.880**), water uptake (-0.358**,-0.523**), volume expansion ratio (-0.295**,-0.416**) and amylose content (-0.270*,-0.401**) both at phenotypic and genotypic levels suggesting that the genotypes with less test weight had slender grain, high water absorption capacity thus, producing more cooked rice. Similar results were reported by Gunasekaran *et al.,* (2017) for grain yield per plant at genotypic level; Mohanty *et al.*, (2012) for kernel length (KL), kernel breadth (KB)and L/B ratio at phenotypic level and Singh *et al.,* (2020) for KB and L/B ratio at genotypic level. Likewise, genotypes with less KB manifested more L/B ratio, high water uptake and VER which is evident from significant and negative association of kernel breadth with L/B ratio (-0.891**, -0.881**), water uptake (-0.265*, -0.373**) at both phenotypic and genotypic levels and VER (-0.239*) at genotypic level. L/B ratio (-0.261*) and protein content (-0.334**,-0.362**) exhibited significant and negative relationship with grain yield/plant revealing that the genotypes with low grain yield had slender grain type and recorded high protein content. These results were in agreement with previous findings of Tejaswini (2016) for grain yield per plant at phenotypic level and Premkumar *et al.,* (2016) and Gunasekaran *et al.,* (2017) for grain yield per plant at genotypic level.

The direct effects as well as indirect effects of various morphological, yield components, physiological and quality traits were presented in **Tables 4 and 5.** Among yield component traits, test weight manifested positive correlation coupled with positive direct effect (0.1980, 0.1356) both at phenotypic and genotypic levels. These results are in agreement with Lakshmi *et al.,* (2020) at phenotypic level and Singh *et al.*, (2020) at genotypic level. In contrast, amylose content exhibited significantly negative correlation (-0.261*) along with negative direct effect (-0.0116,-2.1068). Similar results were reported by Premkumar *et al.*, (2016) at genotypic level. Among physiological traits under study, positive correlations coupled with positive direct effects were observed with RWC at 60 DAT (0.2300,0.4292) & harvest index (0.2818, 0.2039). At phenotypic level, similar results were reported by Manickavelu *et al.*, (2006) and Katiyar *et al.*, (2019) at phenotypic level and Roy *et al.*, (2015) at genotypic level. Hence, the traits *viz.,* test weight, relative water content at 60 DAT and harvest index may be given importance while making selection for improvement of grain yield in rice.

Table 4: Direct and indirect effects of morphological and grain quality traits on grain yield in rice

Character		PH	DFF	PTPP	PL	SFP	TW	KL	KB	L/B	WU	VER	AC	PC
PH	P	**0.0179**	0.0030	0.0019	-0.0095	-0.0012	-0.0059	-0.0027	-0.0003	-0.0015	0.0031	-0.0012	0.0005	0.0049
	G	**0.2921**	-0.0536	-0.1100	0.1781	0.0524	0.1539	0.0402	0.0098	0.0269	-0.0598	0.0258	-0.0028	-0.0941
DFF	P	0.0445	**-0.2637**	0.0321	0.0523	-0.0581	0.0546	0.0372	0.0481	-0.0308	-0.0395	0.0372	0.0617	0.0298
	G	0.1525	**-0.8314**	0.1560	0.2404	-0.1894	0.2422	0.1704	0.2103	-0.1412	-0.1303	0.1324	0.2217	0.1123
PTPP	P	-0.0038	-0.0043	**0.0356**	-0.0020	-0.0048	-0.0015	0.0010	0.0001	-0.0013	-0.0001	0.0070	0.0005	-0.0057
	G	0.2940	0.1465	**0.7806**	0.1974	0.1141	-0.0263	-0.2706	-0.0131	-0.0156	0.0240	-0.3041	-0.0060	0.2405
PL	P	-0.0967	0.0361	0.0101	**-0.1818**	0.0283	-0.0629	-0.0531	-0.0482	0.0165	0.0199	0.0166	-0.0267	0.0314
	G	-0.6779	0.3216	0.2812	**-1.1119**	0.2654	-0.7030	-0.4554	-0.4152	0.1208	0.1460	0.1351	-0.1805	0.2362
SFP	P	-0.0213	-0.0722	0.0438	0.0511	**-0.3279**	-0.0736	0.0845	-0.0121	0.0320	0.1552	0.1335	0.0778	0.0920
	G	-0.2956	-0.3754	0.2409	0.3934	**-1.6481**	-0.3471	0.6724	-0.2208	0.5083	0.8960	0.7766	0.4635	0.5523
TW	P	0.0652	-0.0410	-0.0083	0.0685	0.0444	**0.1980**	0.0673	0.0874	-0.0489	-0.0710	-0.0583	-0.0534	-0.0281
	G	-0.0715	0.0395	-0.0046	-0.0858	-0.0286	**0.1356**	-0.0540	-0.1397	0.1194	0.0709	0.0564	0.0544	0.0285
KL	P	-0.0403	0.0370	-0.0072	-0.0766	0.0677	-0.0892	**0.2625**	-0.0674	-0.0455	0.0323	0.0001	0.0410	-0.0231
	G	0.0963	-0.1435	0.2427	0.2868	-0.2857	0.2787	**0.7002**	0.2565	0.0683	-0.1080	0.0102	-0.1339	0.0774
KB	P	0.0002	-0.0021	0.0000	0.0031	0.0004	0.0051	0.0030	**0.0115**	-0.0103	-0.0031	-0.0020	-0.0013	-0.0013
	G	-0.0714	0.5388	-0.0358	-0.7952	-0.2853	-1.8520	-0.7802	**2.1297**	1.8770	0.7952	0.5094	0.3843	0.3975
L/B	P	-0.0010	-0.0013	0.0004	0.0011	0.0011	0.0029	-0.0020	0.0103	**-0.0116**	-0.0020	-0.0013	-0.0004	-0.0018
	G	-0.1941	-0.3579	-0.0422	0.2289	0.6497	1.8541	-0.2055	1.8568	**-2.1068**	-0.5742	-0.3738	-0.1672	-0.5525
WU	P	-0.0217	0.0189	-0.0004	-0.0138	-0.0596	-0.0451	-0.0155	-0.0334	0.0212	**0.1260**	0.0890	0.0231	0.0023
	G	0.0453	-0.0346	0.0068	0.0290	0.1201	0.1156	0.0341	0.0825	-0.0602	**0.2210**	-0.1569	-0.0414	-0.0041
VER	P	-0.0044	0.0092	-0.0128	0.0059	0.0265	0.0192	0.0000	0.0114	-0.0071	-0.0461	**-0.0652**	-0.0159	0.0123
	G	-0.0644	0.1162	-0.2842	0.0887	0.3438	0.3031	-0.0106	0.1745	-0.1294	-0.5179	**-0.7295**	-0.1799	0.1423
AC	P	0.0101	0.0869	-0.0054	-0.0545	0.0881	0.1002	0.0580	0.0430	-0.0121	-0.0682	-0.0908	**-0.3714**	0.0752
	G	0.0096	0.2614	-0.0076	-0.1591	0.2757	0.3932	0.1874	0.1769	-0.0778	-0.1836	-0.2418	**-0.9804**	0.2180
PC	P	0.1419	0.0591	0.0841	0.0902	0.1466	0.0740	-0.0460	0.0603	-0.0800	-0.0097	0.0984	0.1057	**-0.5222**
	G	0.5532	0.2319	0.5289	0.3646	0.5751	0.3608	-0.1897	0.3203	-0.4501	-0.0318	0.3348	0.3817	**-1.7164**
GYPP	P	0.0548	-0.1346	0.1739	-0.0661	-0.0483	0.1758	-0.1308	0.1107	-0.1794	0.0968	0.1630	-0.1588	-0.334**
	G	0.0679	-0.1404	0.1915	-0.1447	-0.0407	0.296**	-0.1613	0.1693	-0.261*	0.1056	0.1744	-0.1865	-0.362**

*Residual Effect = 0.279 (P), 0.231 (G) ; * Significant at 5% level and ** Significant at 1% level; Diagonal bold values indicate direct effects*

PH= Plant height (cm), DFF= Days to 50 per cent flowering, PTPP= Productive tillers per plant, PL= Panicle length (cm), SFP= Spikelet fertility percentage, TW= Test weight (g), KL= Kernel length (mm), KB= Kernel breadth (mm), L/B= Length/Breadth ratio, WU= Water uptake (ml), VER= Volume expansion ratio, AC= Amylose content (%), PC=Protein content (%), GYPP= Grain yield per plant (g).

Table 5: Direct and indirect effects of physiological traits on grain yield in rice

Character		RLH	SLH	LAIF	RWC (60 DAT)	NAR (60-90 DAT)	HI
RLH	P	**0.0186**	-0.0065	0.0006	0.0036	0.0035	0.0030
	G	**0.0495**	0.0251	0.0009	-0.0117	-0.0101	-0.0052
SLH	P	0.0158	**-0.0450**	-0.0161	0.0053	0.0150	0.0136
	G	0.0927	**-0.1832**	-0.0901	0.0223	0.0720	0.0854
LAIF	P	-0.0054	-0.0624	**-0.1740**	0.0354	0.0700	0.0472
	G	0.0034	-0.0896	**-0.1823**	0.0419	0.0803	0.0880
RWC (60 DAT)	P	0.0451	-0.0269	-0.0468	**0.2300**	0.0756	0.0055
	G	0.1014	-0.0523	-0.0987	**0.4292**	0.1570	0.0337
NAR (60-90 DAT)	P	-0.0346	0.0618	0.0744	-0.0608	**-0.1851**	-0.0437
	G	-0.0527	0.1016	0.1139	-0.0945	**-0.2584**	-0.0844
HI	P	0.0462	-0.0850	-0.0764	0.0067	0.0666	**0.2818**
	G	0.0213	-0.0950	-0.0985	0.0160	0.0666	**0.2039**
GYPP	P	0.260*	-0.0776	-0.0639	0.1703	-0.0273	0.265*
	G	0.332**	-0.1086	-0.0812	0.218*	-0.0380	0.214*

*Significant at 5% level and ** Significant at 1% level

Diagonal bold values indicate direct effects

RLH=Root length at harvesting (cm), SLH=Shoot length at harvesting (cm),LAIF=Leaf area index at flowering; RWC= Relative Water Content (%), NAR=Net assimilation rate (mg cm^{-2} d^{-1}), HI=Harvest index (%), GYPP=Grain yield per plant (g)

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