Current Journal of Applied Science and Technology

40(2): 33-45, 2021; Article no.CJAST.65381
ISSN: 2457-1024
(Past name: British Journal of Applied Science & Technology, Past ISSN: 2231-0843, NLM ID: 101664541)

Multiple Regression, Correlation and Path Analysis of Gall Midge Incidence, Yield and Yield Components in Rice (*Oryza sativa* L.) Hybrids

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Authors' contributions

This work was carried out in collaboration among all authors. Author SB performed the study, done statistical analysis and wrote the first draft of the manuscript. Authors BS and VRR designed the study and monitored the research. Author AK managed literature searches and corrections of the manuscript. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/CJAST/2021/v40i231250
Editor(s):
(1) Dr. Rita Andini, Syiah Kuala University, Indonesia.
Reviewers:
(1) Rindu Rika Gamayuni, SE. MSi, University of Lampung, Indonesia.
(2) Yashik Singh, University of KwaZulu Natal, South Africa.
Complete Peer review History: http://www.sdiarticle4.com/review-history/65381

Original Research Article

Received 10 December 2020
Accepted 17 February 2021
Published 08 March 2021

ABSTRACT

The present investigation was carried out to understand the interrelationship and degree of dependence of grain yield on its components and gall midge incidence and to elucidate their relative importance. The experiment was conducted using 42 rice hybrids developed by crossing 6 CMS lines and seven testers in Line X Tester mating design, their parents and four checks. Observations were recorded on gall midge incidence, grain yield and fourteen component characters. Correlation coefficient analysis suggested that grain yield per plant had highly significant and positive association with panicle length (rp = 0.4600**, rg = 0.5545**) followed by number of grains per panicle (rp = 0.4219**, rg = 0.5125**) and number of productive tillers per plant (rp = 0.4006**, rg = 0.4942**) and negative non significant association with gall midge incidence (rp =-0.1154, rg =-0.1430). Panicle length had the highest positive direct effect (0.9688) followed by the number of grains per panicle (0.5748**).** Gall midge incidence showed a negative direct effect at the phenotypic level and a positive direct effect at the genotypic level on the grain yield per plant. Further, it showed indirect negative effects via plant height, number of productive tillers per plant, number of grains per panicle, spikelet fertility, hulling percentage, milling percentage, kernel length and kernel breadth as

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revealed from path analysis. The result of multiple linear regression exhibited that only the number of productive tillers per plant and the number of grains per panicle contributed significantly towards grain yield per plant. The step-wise regression analysis revealed that the panicle length, number of grains per panicle and number of productive tillers per plant were the most important characters having R=0.6505 and thus, could explain 42.31% of the total variation of grain yield. Gall midge incidence contributed to only 0.95% of the variation for grain yield, which might be due to the low incidence or resistance of the hybrids to the gall midge.

Keywords: Rice hybrids; gall midge; grain yield; correlation; path analysis; multiple regression.

1. INTRODUCTION

Rice (*Oryza sativa* L.) is one of the pivotal staple cereal crops feeding more than half of the world population. In view of the growing population, the basic objective of the plant breeders would always be towards yield improvement in staple food crops. It has been estimated that the world will have to produce 60% more rice by 2030 than what is produced in 1995. However, the increasing frequency of temperature extremes, pest and disease incidence, onset of droughts, storms and floods, a rapidly growing population and urbanization are still major constraints against ensuring food security [1]. Therefore, it is essential to develop high-yielding, climate-resilient, disease and insect resistant rice varieties and hybrids. The development of semi-dwarf varieties through heterosis has substantially increased rice yield in the past 50 years [2]. However, hybrid rice technology has proved to be one of the most feasible and readily adaptable approaches to break the yield barrier, as they yield about 15-20 per cent more than the best of the improved or High Yielding Varieties. Yield is a complex character [3] influenced by several other characters that could regulate yield jointly may be directly and/or even indirectly through other related characters. As a result, screening of segregating breeding lines based on only yield may misguide selection in the breeding programs. Information on plant traits association, direct influence and indirect influence via different other traits contributed towards yield would generate valuable messages to perform the successful selection. The study of trait association among component characters along with yield is very important [4]. Correlation estimates are useful in determining the components that influence a trait either positively or negatively. Path coefficient analysis is a standardized partial regression coefficient that permits the partitioning of the correlation coefficient into components of direct and indirect effects of various traits towards the dependent variable [5]. The measurement of direct influence on yield and also indirect effects via different characters on yield estimated through path coefficient analyses enables the breeders to select better plants by accommodating the most suitable component characters [6]. There have been several researches and investigations about the correlation between traits and path analysis in rice varieties [7]. But, the relationship between yield and its main economic components in the segregating population of rice has been studied by a few researchers [8]. Multiple linear and stepwise regression analyses predict yield and identify few predominantly responsible secondary traits having considerable influence on yield to be used in the selection process to boost the yield of rice [9]. Therefore, this study aimed to use stepwise regression, multiple regression, correlation and path analysis to evaluate the relationship among yield, its components and gall midge incidence in rice hybrids to elucidate the best selection index for yield improvement in rice breeding.

2. MATERIALS AND METHODS

2.1 Experimental Site

The study was conducted at Regional Agricultural Research Station, Polasa, Jagtial in Northern Telangana. It is situated at an altitude of 243.4 m above mean sea level on 18º49’40” N latitude and 78º56’45” E longitudes in the Northern zone of Telangana state. The fields were homogeneously fertile with even topography and uniform textural makeup. Further, the fields were located adjoining the main irrigation channel connecting the farm tube well for quick, regular and timely irrigation. The experimental soil was loamy clay, proper drainage facility was also provided to remove excess water during the experimental period.

2.2 Genetic Materials and Experimental Design

Fifty-nine genotypes, including six cytoplasmic male sterile lines viz., CMS 64A, JMS 11A, JMS

19A, CMS 52A, JMS 21A and JMS 20A, seven restorer lines viz., JR 83, JR 85, JR 80, JMBR 44, JMBR 31, JR 67 and JBR 6, their 42 hybrids and four checks (US 312, HRI 174, MTU 1010 and JGL 384) were used in the study. During *rabi* 2016-17 parents (six lines and seven testers) were planted in a crossing block with a spacing of 15 x 15 cm and crosses were effected in a 6 x 7, Line x Tester mating design to produce 42 hybrids. During *kharif*, 2017, 30 days old seedlings of 59 entries (6 lines, 7 testers, 42 hybrids and 4 checks) were transplanted in the main field in randomized block design. Each entry was planted in two rows of four meters length with a spacing of 20 x 15 cm in two replications. The experiment was allowed natural infestation as no protection measures were undertaken, but all the agronomic practices were applied to ensure good crop growth.

2.3 Data Collection

Observations were recorded on ten random plants in each entry on fifteen quantitative characters namely, days to 50 per cent flowering, plant height (cm), panicle length (cm), number of productive tillers per plant, number of grains per panicle, spikelet fertility percentage (%),1000-grain weight (g), the incidence of gall midge (%), hulling (%), milling (%), head rice recovery (HRR)%, kernel length (mm), kernel breadth (mm), kernel L/B ratio and grain yield per plant (g).

3. STATISTICAL ANALYSES

3.1 Simple Correlation Coefficients

Pearson simple correlation coefficients were calculated, and the matrix of these correlations was studied [10].

3.2 Path Analysis

Path coefficient analysis was performed using simple Pearson correlation coefficients with grain yield per plant as the dependent variable and the other characters as influential variables. The direct and indirect effects of influential variables on grain yield were calculated according to the proposed method [5].

3.3 Multiple Linear Regressions

A multiple linear regression model was used for determining the relative contribution of related components to the grain yield (Y) variations by applying the following equation [10]:

$$y=a+b_1x_1+ b_2x_2+ b_3x_3+\ldots\ldots\ldots\ldots +b_ix_i$$

Where y is the dependent variable (yield), the x's are independent variables (measured traits) affecting the dependent one, a is the intercept coefficient and the b's are the related coefficients of independent variables in predicting the dependent variable.

3.4 Stepwise Regression

Stepwise regression [11] was used to determine the most important variables that significantly contributed to total yield variability.

4. RESULTS AND DISCUSSION

The estimated variance analysis revealed significant variations for the studied traits indicating the considerable genetic variability existed among the genotypes of this study.

4.1 Phenotypic and Genotypic Correlation

The association analyses among different traits of the genotypes help the plant breeder to determine priority component traits on which selection needs to proceed for genetic advancement leading to genetic gain. Trait association reveals the strength of relationships in determining traits on which selection could be executed for enhancing rice genotypes. The traits association of 15 selective traits in 59 genotypes is presented in Table 1. Out of 210 phenotypic and genotypic associations, 151 associations were positive and the rests of the associations were negative. The associations that are statistically significant and nonsignificant with grain yield per plant were 19 and 9, respectively. All the statistically significant associations were positive so, possibly less affected by the environment. Nine traits showed positive and significant association with grain yield per plant in genotypic and phenotypic situations. In contrast, two traits had negative and non- significant associations both at the genotypic and phenotypic level (Fig. 1 and 2). The results revealed that the estimates of genotypic coefficients were higher than phenotypic correlation coefficients for most of the characters under study which indicated a strong inherent association between the characters which might be due to masking or modifying effects of the environment as Singh [12] reported in rice.

Plant traits association analyses among yield and yield influencing traits of rice genotypes depicted that days to 50 per cent flowering was significantly and positively correlated with grain yield per plant at both phenotypic and genotypic level (rp = 0.1818*, rg = 0.2032*).These results are in the agreement with the earlier findings [13] suggesting that late flowering types may have more chance of vegetative growth, increasing source and sink relationship paving way for more number of grains and yield. Plant height recorded positive and significant phenotypic and genotypic correlation with grain yield per plant (rp = 0.3211**, rg = 0.3487**). Plant height is an important morphological trait affecting yield performance [14]. Though, the introduction of semi-dwarf cultivars improves the harvest index and increases the grain yield by enhancing lodging resistance, if the plants are too short, the yield potential will be negatively affected. Based on their experience in super-hybrid rice breeding, Yuan (2017) [15] suggested that increasing plant height is an effective way to increase grain yield. Therefore, in the absence of lodging, it is essential to increase plant height to increase yield [3]. The increase in plant height will increase the number of tillers per plant and the number of productive tillers per plant, but it will decrease the panicle length. The number of productive tillers per plant showed a significant and positive correlation with grain yield per plant at both genotypic and phenotypic level (rp = 0.4006**, rg = 0.4942**) indicating that grain yield per plant will increase with the increase in the number of productive tillers per plant as reported in previous studies [16]. Panicle length exhibited positive and significant phenotypic as well as genotypic correlation with grain yield per plant (rp = 0.4600**, rg = 0.5545**). Laxuman et al. [6] also found a significant positive correlation between panicle length and grain yield per plant. Besides, a positive and significant relationship was found between panicle length and the number of grains per panicle showing that the maximum number of grains per panicle were due to maximum panicle length.

Further, correlation coefficient of studied traits showed that 1000-grain weight (rp = 0.1970*, rg = 0.1890*), number of grains per panicle (rp = 0.4219**, rg = 0.5125**), hulling percentage (rp = 0.2119*, rg = 0.2318*), kernel length (rp = 0.2040*, rg = 0.2207*) and kernel breadth (rp = 0.1901*, rg = 0.2458**) had high significant and positive correlation with grain yield per plant at phenotypic and genotypic level. A strong correlation of grain yield with these traits indicated that the simultaneous improvement of these traits is possible. The quantitative trait of 1000-grain weight is determined by both grain size and grain filling rate, which is characterized by the three dimensions of grain length, width and height. Grain weight is mainly governed by genetic factors, whereas grain filling rate is affected by external environmental conditions. In this study, we found that the 1000-grain weight influences yield greatly. Additionally, the kernel length and breadth showed a significant positive correlation with the grain yield, a greater width may contribute to a higher 1000-grain weight and thus a higher yield. These results are consistent with the opinion that the grain length and width are important factors influencing the yield [17]. It is worth noting that an increased 1000-grain weight may decrease the number of grain per panicle decreasing overall yield. The tradeoff between 1000-grain weight and the number of grain per panicle should be carefully considered in rice breeding. Spikelet fertility had a significant and positive genotypic association with grain yield per plant (rg =0.2289**).

But, gall midge incidence had a negative and non-significant correlation with grain yield per plant. Ukwungwu et al. [18] reported that only a severe larval infestation or high density of midge adults and 80% level of gall midge infested tillers causes a yield loss of 100%. It was found that the nature and importance of yield loss is dependent on a complex of reactions between the plant and the pest. Thus, the physiological state of the plant, its phonological stage at the time of attack, the part of the plant attacked, soil fertility, the presence of other biotic and abiotic stresses [19] and the species of the pest all can be factors determining the yield loss caused by the pest.

4.2 Path Analysis

As simple correlation does not provide the true contribution of the characters towards the yield, these genotypic correlations were partitioned into direct and indirect effects through path coefficient analysis. It allows separating the direct effect and their indirect effects through other attributes by apportioning the correlations for better interpretation of cause and effect relationship. The estimates of path coefficient analysis are furnished for yield and yield component characters in Table 2 and Fig. 3. The results revealed that panicle length (0.9688) had the highest direct effect on the grain yield per plant followed by the number of grains per panicle

(0.5748). This was supported by Seyoum et al. [20] who have stated that cultivars with higher grains per panicle showed higher grain yield in rice. Although the number of grains per panicle depends on tillers per hill and panicle per hill, its suitability as selection criteria in a crop improvement program is mainly dependent on the percentage of filled grains.

At the genotypic level, days to 50% flowering, 1000 grain weight, spikelet fertility and head rice recovery percentage had a direct positive effect on yield per plant. The direct positive effect of the aforesaid characters on grain yield indicated that the selection of these traits is directly helpful for the improvement of yield. These results are in line with the earlier reports [21,22,23]. Singh and Choudhury [24] suggested that if the correlation coefficient between a causal factor and the effect is almost equal to its direct effect, the correlation explains the true relationship and the direct selection based on these traits is effective.

In this study, plant height and milling percentage had a direct negative effect on yield per plant. The negative direct effect of plant height on grain yield per plant indicated that tallness in rice lowers the yield due to the high accumulation of photosynthates in vegetative parts as compared to reproductive parts (i.e. seed formation and grain filling) and lodging susceptibility. Therefore, the indirect effects appeared to be the cause of a significant positive correlation between plant height and grain yield per plant. Gall midge incidence showed a negative direct effect at the phenotypic level and a positive direct effect at the genotypic level on the grain yield per plant, while its correlation was negative and non-significant with grain yield per plant. The direct effect of gall midge incidence was seemed to be neutralized by its considerable indirect negative effects via plant height, number of productive tillers per plant, number of grains per panicle, spikelet fertility, hulling percentage, milling percentage, kernel length and kernel breadth. If the correlation of a character with yield is negative but its direct effect is positive and high, a restricted simultaneous selection model should be followed, i.e. restrictions are to be imposed to nullify the unwanted indirect effects in order to make use of the direct effect.

The residual effect determines how best the causal factors account for the variability of the resultant factor, the grain yield per plant. In the present study, the residual effect was 0.696 and 0.528 at the phenotypic and genotypic levels, respectively (Table 2). Residual effect indicated that characters included in the path analysis explained 31% and 48% of the variability in grain yield at genetic and phenotypic levels.

4.3 Multiple Linear Regressions

The result of multiple linear regression (Table 3) revealed that only the number of productive tillers per plant and number of grains per panicle contributed significantly towards grain yield, whereas contribution of other traits was negligible. So, the number of productive tillers per plant and the number of grains per panicle were determined as the most effective variables contributing to the grain yield by this statistical method. Several researchers reported that the number of productive tillers per plant contributes significantly towards grain yield [25].

4.4 Stepwise Multiple Regression Analysis

The step-wise multiple regression analysis is a statistical tool to pinpoint the most important characters from a group of independent characters that influence the dependent character and hence, could precisely be included in the construction of selection indices. The path analysis though helps in selecting the most important characters, has limited application in the selection of the characters when compared with regression analysis. From Table 4 it is clear that the multiple correlation coefficient between grain yield and all fourteen characters in the equation was high in magnitude and statistically significant at 5% level (R=0.7131). This indicated that about 50.85% of total variation (coefficient of determination, R^2 = 50.85) for grain yield could be accounted for by these fourteen characters. The step-wise regression analysis revealed that the panicle length, number of grains per panicle and number of productive tillers per plant were the most important character having R=0.6505 and, thus, could explain 42.31% of the total variation of grain yield. All the yield traits together explained the 49.90% of the variation (coefficient of determination, R^2=0.4990) for grain yield. On the other hand, gall midge incidence contributed to only 0.95% of the variation for grain yield. It might be due to the low incidence or resistance of the hybrids to the gall midge. The remaining 49.15% of variation was not being able to explain. This shows that this amount of variation may disseminate within other components.

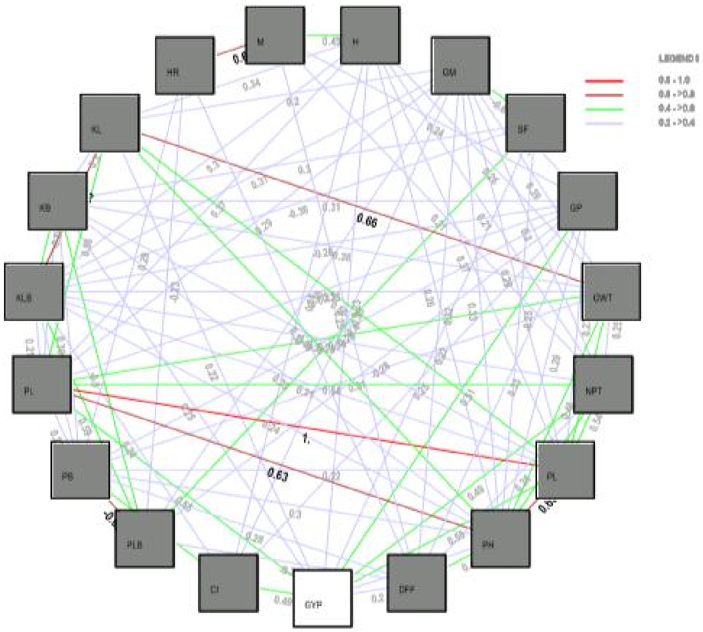

Fig. 1. Genotypic correlations between yield and yield components

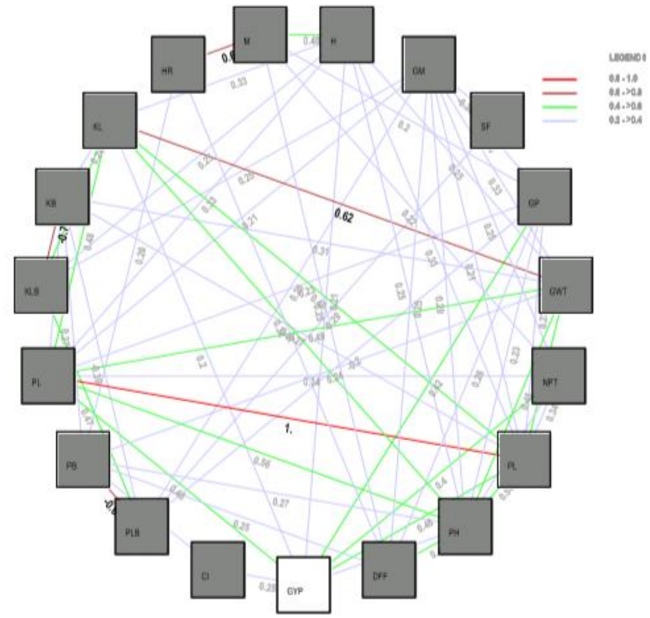

Fig. 2. Phenotypic correlations between yield and yield components

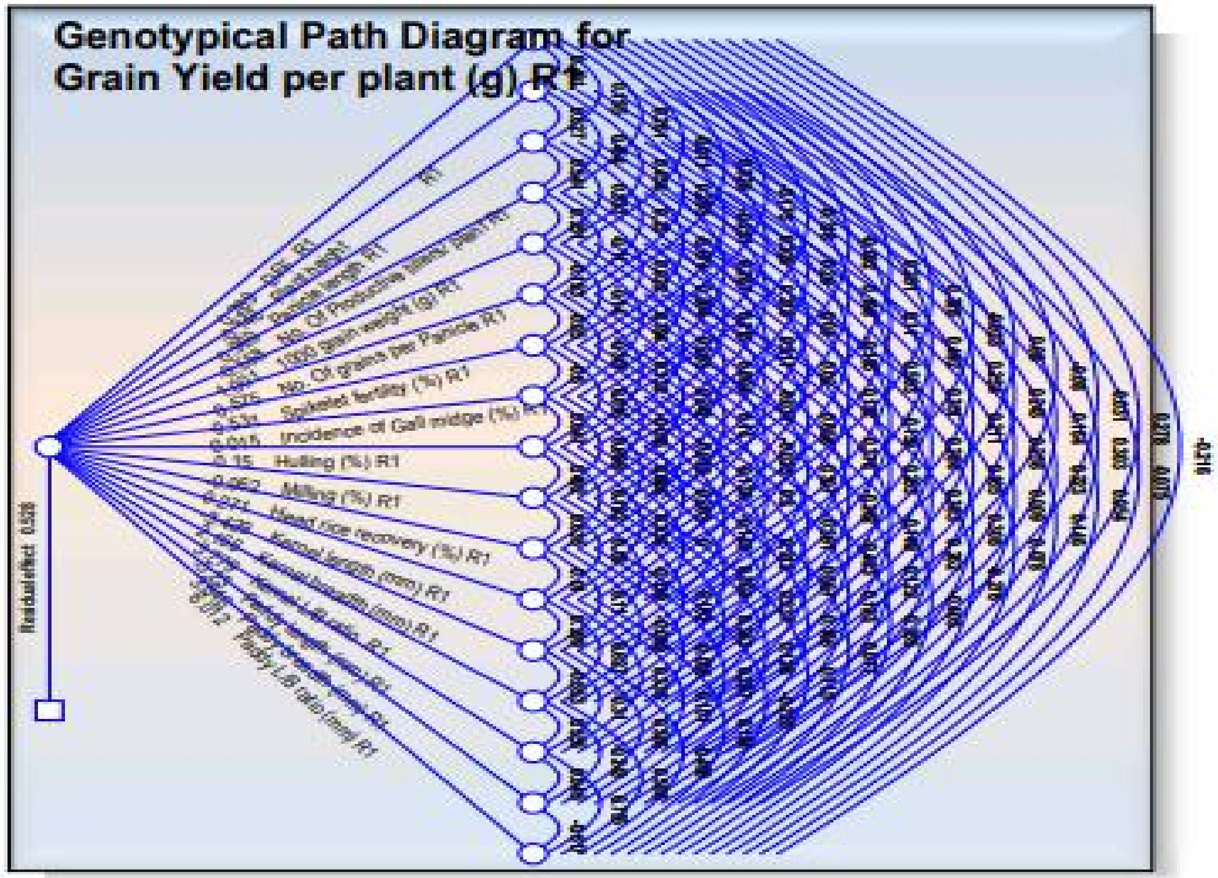

Fig.3. Genotypic path diagram for grain yield per plant in rice

Table 1. Phenotypic (P) and genotypic (G) correlation coefficients of yield and its traits in rice hybrids (*Oryza sativa* L.)

Source		DF	PTH	PL	No. PTP	1000 GW	No. GPP	SF	GM	HUL	MIL	HRR	KL	KB	KL/B	GYP
DF	P	1.0000	0.4788**	0.1424	0.1662	-0.0106	0.2586*	-0.1258	0.2544*	-0.0584	0.2495*	0.3249**	-0.0241	0.0739	-0.0790	0.1818*
	G	1.0000	0.4915**	0.1549	0.2614**	-0.0112	0.3279**	-0.1733	0.3183**	-0.0617	0.2509**	0.3275**	-0.0231	0.0798	-0.0802	0.2032*
PH	P		1.0000	0.5604**	0.3058**	0.4500**	0.2309*	-0.1725	0.2940**	0.2546**	0.1927*	0.1083	0.4750**	0.1937*	0.1816*	0.3211**
	G		1.0000	0.6273**	0.4544**	0.4579**	0.2934**	-0.2506**	0.3254**	0.2601**	0.1980*	0.1102	0.4921**	0.2337*	0.2433**	0.3487**
PL	P			1.0000	0.3417**	0.4926**	0.2254*	-0.0774	0.2131*	0.3334**	0.0431	-0.1569	0.4831**	0.2707*	0.1220	0.4600**
	G			1.0000	0.5411**	0.5367**	0.2300*	-0.0737	0.2872**	0.3748**	0.0295	-0.1947*	0.5632**	0.3512**	0.2113*	0.5545**
No. PTP	P				1.0000	0.1627	-0.0253	-0.0315	0.2466**	0.1605	0.2205*	-0.0028	0.0961	0.0481	0.0525	0.4006**
	G				1.0000	0.2515**	-0.1097	0.0221	0.3042**	0.2146*	0.3113**	0.0202	0.1325	-0.1387	0.2836**	0.4942**
1000 GW	P					1.0000	-0.1705	-0.1437	0.3339**	0.2510*	0.0114	-0.0335	0.6195**	0.3077**	0.1780	0.1970*
	G					1.0000	-0.1932*	-0.1401	0.3942**	0.2627**	0.0040	-0.0374	0.6579**	0.3784**	0.2525**	0.1890*
No. GPP	P						1.0000	0.1754	-0.2236*	0.1112	0.2023*	0.1248	-0.0080	0.1035	-0.0928	0.4219**
	G						1.0000	-0.0495	-0.3065**	0.1323	0.2423**	0.1400	-0.0233	0.3066**	-0.2615**	0.5125**
SF	P							1.0000	-0.3611**	0.0143	-0.0503	-0.0074	-0.1068	0.0367	-0.1152	0.1766
	G							1.0000	-0.5996	0.0164	-0.0783	-0.0316	-0.1359	0.3003	-0.3612**	0.2289*
GM	P								1.0000	0.0407	0.0607	0.0472	0.1845*	-0.1250	0.2544*	-0.1154
	G								1.0000	0.0466	0.0885	0.0458	0.2026*	-0.1422	0.3131**	-0.1430
HUL	P									1.0000	0.4836**	0.1795	0.3287**	-0.0060	0.2524**	0.2119*
	G									1.0000	0.4919**	0.1815*	0.3363**	0.0004	0.3043**	0.2318*
MIL	P										1.0000	0.6185**	0.0323	-0.1036	0.1314	0.1342
	G										1.0000	0.6354**	0.0300	-0.1386	0.1621	0.1341
HRR	P											1.0000	-0.0099	0.0698	-0.0579	0.0156
	G											1.0000	-0.0102	0.1098	-0.0886	0.0121
	P												1.0000	0.2364*	0.5248**	0.2040*
KL	G												1.0000	0.2986**	0.6266**	0.2207*
KB	P													1.0000	-0.6967**	0.1901*
	G													1.0000	-0.5528**	0.2458**
KL/B	P														1.0000	-0.0087
	G														1.0000	-0.0037
GYP	P															1.0000
	G															1.0000

** Significant at 5 per cent level; ** Significant at 1 per cent level DF: Days to 50% flowering, PTH: Plant height (cm), PL: Panicle length (cm), No. PTP: Number of tillers per plant, 1000 GW: 1000-grain weight No. GPP: Number of grains per panicle, SF: Spikelet fertility (%), GM: Incidence of Gall Midge, HUL: Hulling%, MIL: Milling %, HRR: Head rice recovery %, KL: Kernel length (mm), KB: Kernel breadth (mm), K L/B: Kernel L/B Ratio and GYP: Grain yield per plant (g)*

Table.2. Phenotypic (P) and genotypic (G) path coefficients of yield and its traits in rice hybrids (*Oryza sativa* L.)

Source		DF	PTH	PL	No.PTP	1000 GW	No. GPP	SF	GM	HUL	MIL	HRR	KL	KB	KL/B	GYP
DF	P	0.1617	-0.0423	0.0340	0.0501	-0.0030	0.0896	-0.0117	-0.0414	-0.0037	-0.0112	0.0066	-0.0056	-0.0207	0.0202	0.1818
	G	0.2687	-0.0718	0.1501	0.1501	-0.0112	0.1885	-0.0920	0.0047	0.0092	-0.0156	0.0889	0.0793	0.1729	-0.3032	0.2032*
PH	P	0.0774	-0.0884	0.1338	0.0923	0.1264	0.0800	-0.0160	-0.0478	0.0163	-0.0086	0.0022	0.1104	-0.0542	-0.0465	0.3211**
	G	0.1321	-0.1461	0.6078	-0.2537	0.4584	0.1686	-0.1330	0.0048	-0.0389	-0.0123	0.0299	-1.6874	0.5062	0.9194	0.3487**
PL	P	0.0230	-0.0495	0.2388	0.1031	0.1384	0.0781	-0.0072	-0.0347	0.0213	-0.0019	-0.0032	0.1123	-0.0757	-0.0313	0.4600**
	G	0.0416	-0.0916	0.9688	-0.3020	0.5373	0.1322	-0.0391	0.0042	-0.0561	-0.0018	-0.0528	-1.9314	0.7609	0.7986	0.5545**
No. PTP	P	0.0269	-0.0270	0.0816	0.3017	0.0457	-0.0088	-0.0029	-0.0401	0.0103	-0.0099	-0.0001	0.0223	-0.0135	-0.0135	0.4006**
	G	0.0702	-0.0664	0.5242	-0.5582	0.2518	-0.0631	0.0117	0.0045	-0.0321	-0.0194	0.0055	-0.4542	-0.3005	1.0715	0.4942**
1000 GW	P	-0.0017	-0.0398	0.1176	0.0491	0.2809	-0.0591	-0.0133	-0.0543	0.0160	-0.0005	-0.0007	0.1440	-0.0861	-0.0456	0.1970*
	G	-0.0030	-0.0669	0.5199	-0.1404	1.0011	-0.1110	-0.0744	0.0058	-0.0393	-0.0002	-0.0102	-2.2560	0.8198	0.9542	0.1890*
No. GPP	P	0.0418	-0.0204	0.0538	-0.0076	-0.0479	0.3464	0.0163	0.0364	0.0071	-0.0091	0.0025	-0.0091	-0.0290	0.0238	0.4219**
	G	0.0881	-0.0428	0.2228	0.0612	-0.1934	0.5748	-0.0263	-0.0045	-0.0198	-0.0151	0.0380	0.0800	0.6642	-0.9882	0.5125**
SF	P	-0.0203	0.0152	-0.0185	-0.0095	-0.0404	0.0608	0.0929	0.0588	0.0009	0.0023	-0.0001	-0.0248	-0.0103	0.0295	0.1766
	G	-0.0466	0.0366	-0.0714	-0.0123	-0.1403	-0.0285	0.5309	-0.0089	-0.0024	0.0049	-0.0086	0.4658	0.6505	-1.3648	0.2289**
GM	P	0.0412	-0.0260	0.0509	0.0744	0.0938	-0.0775	-0.0335	-0.1627	0.0026	-0.0027	0.0010	0.0429	0.0350	-0.0652	-0.1154
	G	0.0855	-0.0475	0.2782	-0.1698	0.3946	-0.1762	-0.3183	0.0148	-0.0070	-0.0055	0.0124	-0.6948	-0.3082	1.1830	-0.1430
HUL	P	-0.0094	-0.0225	0.0796	0.0484	0.0705	0.0385	0.0013	-0.0066	0.0639	-0.0217	0.0036	0.0764	0.0017	-0.0647	0.2119*
	G	-0.0166	-0.0380	0.3631	-0.1198	0.2630	0.0760	0.0087	0.0007	-0.1497	-0.0307	0.0493	-1.1532	0.0010	1.1500	0.2318*
MIL	P	0.0404	-0.0170	0.0103	0.0665	0.0032	0.0701	-0.0047	-0.0099	0.0309	-0.0448	0.0126	0.0075	0.0290	-0.0336	0.1342
	G	0.0674	-0.0289	0.0286	-0.1738	0.0040	0.1393	-0.0416	0.0013	-0.0737	-0.0623	0.1725	-0.1028	-0.3003	0.6127	0.1341
HRR	P	0.0525	-0.0096	-0.0375	-0.0008	-0.0094	0.0432	-0.0007	0.0077	0.0115	-0.0277	0.0203	-0.0023	-0.0195	0.0148	0.0156
	G	0.0880	-0.0161	-0.1886	-0.0113	-0.0374	0.0865	-0.0168	0.0007	-0.0272	-0.0396	0.2715	0.0349	0.2379	-0.3346	0.0121
KL	P	-0.0039	-0.0420	0.1154	0.0290	0.1740	-0.0028	-0.0099	-0.0300	0.0210	-0.0014	-0.0002	0.2325	-0.0662	-0.1344	0.2040*
	G	-0.0062	-0.0719	0.5457	-0.0739	0.6587	-0.0134	-0.0721	0.0030	-0.0504	-0.0019	-0.0028	-3.429	0.6469	2.3677	0.2207*
KB	P	0.0120	-0.0171	0.0646	0.0145	0.0864	0.0359	0.0034	0.0203	-0.0004	0.0046	0.0014	0.0550	-0.2798	0.1784	0.1901*
	G	0.0214	-0.0341	0.3403	0.0774	0.3788	0.1762	0.1594	-0.0021	-0.0001	0.0086	0.0298	-1.0239	2.1664	-2.0887	0.2458**
KL/B	P	-0.0128	-0.0160	0.0291	0.0158	0.0500	-0.0321	-0.0107	-0.0414	0.0161	-0.0059	-0.0012	0.1220	0.1950	-0.2561	-0.0087
	G	-0.0216	-0.0355	0.2047	-0.1583	0.2528	-0.1503	-0.1918	0.0046	-0.0456	-0.0101	-0.0240	-2.1486	-1.1975	3.7787	-0.0037

** Significant at 5 per cent level; ** Significant at 1 per cent levelDF: Days to 50% flowering , PTH: Plant height (cm), PL: Panicle length (cm), No. PTP: Number of tillers per plant, 1000 GW: 1000-grain weight No. GPP: Number of grains per panicle, SF: Spikelet fertility (%), GM: Incidence of Gall Midge, HUL: Hulling%, MIL: Milling %, HRR: Head rice recovery %, KL: Kernel length (mm), KB: Kernel breadth (mm), KL/B: L/B Ratio and GYP: Grain yield per plant (g)*

Genotypic residual effect = 0.5281 Phenotypic residual effect =0.6968 Bold values are direct effects

Table 3. Multiple linear regressions between yield and its traits in rice hybrids (*Oryza sativa* L.)

	Coefficients	Standard error	T Stat	P-value
Intercepts	16.8112	112.0237	0.1501	0.8814
DFF	0.1115	0.1705	0.6539	0.5166
Plant height	-0.1043	0.1269	-0.8213	0.4159
Panicle length	1.0249	0.6869	1.4921	0.1428
No. of productive tillers/ plant	2.8345	0.8542	3.3182	0.0018
1000 grain weight (g)	0.5147	0.4530	1.1361	0.2620
No. of grains per panicle	0.0759	0.0232	3.2687	0.0021
Spikelet fertility (%)	0.1084	0.1196	0.9063	0.3697
Incidence of Gall midge (%)	-0.2543	0.1785	-1.4250	0.1612
Hulling (%)	0.1099	0.4362	0.2519	0.8023
Milling (%)	-0.2689	0.3600	-0.7471	0.4590
Head rice recovery (%)	0.1008	0.1841	0.5474	0.5869
Kernel length (mm)	11.7870	18.5515	0.6354	0.5285
Kernel breadth (mm)	-37.5970	57.4460	-0.6545	0.5162
Kernel L/B ratio	-20.4631	34.0193	-0.6015	0.5506

Table 4. Equations of stepwise multiple regression of grain yield and fourteen traits in rice hybrids (*Oryza sativa* L.)

Regression equation	R	R^2
GYP= -25.0577 + 2.0787 PL	0.5018	0.2518
GYP= -13.1270+ 2.9226PL+ 0.0853 No. GPP	0.6505	0.4231
GYP= -13.1270+ 2.9226PL+ 0.0853 No. GPP + 2.8344 No. PTP	0.6505	0.4231
GYP= -31.6867 + 2.8046 PL+ 0.0855 No. GPP + 2.8344 No. PTP + 3.2801 KL	0.6722	0.4519
GYP= -46.8502 + 2.8001 PL+ 0.08267 No. GPP + 2.8344 No. PTP + 3.6824 KL+ 0.1867 SF	0.6955	0.4837
GYP= -51.0474 + 2.8166 PL+ 0.0805 No. GPP + 2.8344 No. PTP + 3.3008 KL+ 0.1761 SF+ 3.9986 KB	0.6985	0.4880
GYP= -58.1532 + 2.7865 PL+ 0.0797 No. GPP + 2.8344 No. PTP + 3.0786 KL+ 0.1740 SF+ 4.2399 KB+ 0.1046 HUL	0.6991	0.4888
GYP= -57.5759 + 2.7936 PL+ 0.0799 No. GPP + 2.8344 No. PTP + 3.0752 KL+ 0.1732 SF+ 4.2539 KB+ 0.1027 HUL -0.0054 DF	0.6992	0.4888
GYP= -58.3039 + 2.8191 PL+ 0.0804 No. GPP + 2.8344 No. PTP + 3.2125 KL+ 0.1710 SF+ 4.3187 KB+ 0.1076 HUL +0.0026 DF -0.0136 PTH	0.6992	0.4890
GYP= -60.9866 + 2.8191 PL+ 0.0803 No. GPP + 2.8344 No. PTP + 3.1563 KL+ 0.1706 SF+ 4.6949 KB+ 0.1670 HUL + 0.0368 DF -0.0207 PTH -0.0847HRR	0.7020	0.4928
GYP= -57.5277 + 2.9539 PL+ 0.0837 No. GPP + 2.8344 No. PTP + 3.0366 KL+ 0.1631 SF+ 3.4923 KB+ 0.3189 HUL + 0.0417 DF - 0.0246 PTH +0.0031 HRR -0.2811 MIL	0.7064	0.4990
GYP= -57.1832 + 3.0715 PL+ 0.0771 No. GPP + 2.8344 No. PTP + 3.3001 KL+ 0.1182 SF+ 2.7090 KB+ 0.3241 HUL + 0.0806 DF -0.0139 PTH + 0.0053 HRR -0.2941 MIL -0.1605GM	0.7131	0.5085

DF: Days to 50% flowering, PTH: Plant height (cm), PL: Panicle length (cm), No. PTP: Number of tillers per plant, 1000 GW: 1000-grain weight No. GPP: Number of grains per panicle, SF: Spikelet fertility (%), GM: Incidence of Gall Midge, HUL: Hulling %, MIL: Milling%, HRR: Head rice recovery %, KL: Kernel length (mm), KB: Kernel breadth (mm), KL/B: L/B Ratio and GYP: Grain yield per plant (g)

The relative importance of the characters for grain yield per plant of rice could be in the order of panicle length> number of grains per panicle> number of productive tillers per plant> 1000-seed weight> kernel length> spikelet fertility> kernel breadth > hulling percentage> days to 50% flowering> plant height> head rice recovery percentage > milling percentage.

5. CONCLUSIONS

Yield, the ultimate desire of breeders as well as growers, is a complex trait affected by yield influential traits and biotic or abiotic stresses directly or indirectly and the perfect selection of breeding lines through plant breeders becomes more accurate by considering yield influential traits. Our research findings suggested that panicle length, number of grains per panicle and number of productive tillers per plant could be considered as valuable traits for selecting better genotypes. Breeders in this area should, therefore, develop gall midge resistant rice hybrids focusing on panicle length, number of grains per panicle and number of productive tillers per plant for improving the grain yield per plant.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/65381