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Genetic Variability and Character Association Studies on Yield Attributing and Grain Quality Traits in Rice (*Oryza sativa* L.)

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aim: The present investigation was undertaken with 49 genotypes to study variability and genetic parameters in addition to character association and path effects of yield, yield attributing and quality traits.

Design: Simple lattice design with two replications.

Place of study: Forty-nine genotypes were sown at IIRR Farm at ICRISAT, Hyderabad during Kharif season 2023.

Methodology: The data was collected for all the genotypes and evaluated for variability, correlation and path coefficient studies.

Results: High range of variation and high heritability coupled with high genetic advance as percent mean was recorded for days to 50 per cent flowering, plant height, productive tillers plant-1, test weight, LB ratio, water uptake, kernel length after cooking, zinc content and iron content. Correlation revealed that the grain yield was positively correlated with days to 50% flowering, productive tillers plant-1, LB ratio and iron content, meanwhile plant height, test weight, head rice recovery, kernel length, kernel breadth, water uptake, volume expansion ratio, amylose content, kernel length after cooking, elongation ratio and zinc content were found to be negatively correlated. Path analysis identified that iron content exerted the highest direct positive effect on grain yield plant-1 followed by kernel length and productive tillers plant-1, indicating that selection for these characters is likely to bring about on overall improvement in grain yield directly.

Conclusion: The study found adequate genetic variability, with high heritability and additive gene action in certain traits. The prime selection indices include days to 50% flowering, productive tillers plant-1, LB ratio, kernel length, and iron content. These parameters should be given priority in rice breeding programs for high grain yield and quality traits.

Keywords: PCV; GCV; heritability; genetic advance as percent mean; correlation; path.

1. INTRODUCTION

Rice is the principal source of nutrition for about 3 billion people in the world. Seven Asian countries account for more than 80% of the global rice production which is 540.62 million tonnes from 138.56 million hectares. In India it is grown in an area of 43.79 m ha with a production of 116.42 mt and productivity of 2659 kg/ha which contributes 41 per cent of total food grain production [1]. By 2050, it is predicted that 160 million tons of rice is needed to feed the ever growing Indian population [2].

To feed the accelerating population with diminishing natural resources and environmental fluctuations on one-hand and varieties that have grain quality that the consumer demands, on the other became a challenging factor. The economic value and the consumer acceptance of a rice variety depend on rice grain quality. Rice grain quality is a complex trait, it comes from a polygenic group of traits that are affected by environmental factors, crop management and the resulting interactions among these. Grain quality in rice is mainly determined based on physical properties (such as head rice recovery, grain size and shape, and grain color), biochemical composition (such as amylose content, aroma, and others), and nutritional properties (such as micronutrients, and others) [3].

The ultimate goal of a plant breeder is to create versatile and high-yielding cultivars with good grain quality that are adaptable to a wide range of conditions. Presence of variability among the genotypes and the relationship between yield and its attributing traits is crucial for selection, which may be described using correlation and path coefficient analysis. The correlation coefficient evaluates the impact of individual traits on seed yield. Path analysis determines whether independent characters have a direct or indirect effect on the dependent variable.

2. MATERIALS AND METHODS

2.1 Plant Material and Experimental Design and Layout

The present investigation consists of 49 genotypes obtained from Indian Institute of Rice Research, Rajendranagar, Hyderabad out of which four were checks namely, Gontrobidhan-3, BPT-5204, Zincorice and Protozinc that are superior in yield, quality and micronutrient content respectively. The layout of the experiment is Simple lattice design with two replications. The lines were sown at IIRR Farm at ICRISAT, Hyderabad during Kharif 2023 on a raised nursery. All suggested measures were followed to get a good crop. The 35 days old seedlings were transplanted in the main field, each line is transplanted in five rows of 4.5m with 20×15cm of spacing. All the recommended package of practices were followed throughout the crop period to ensure a healthy crop. The data for quantitative traits, namely, plant height (cm), productive tillers plant^{-1}, test weight (g) and yield plant^{-1} (g) were recorded from five randomly selected plants; and qualitative traits, namely, head rice recovery (%), kernel length (mm), kernel breadth (mm), lb ratio, water uptake (ml), volume expansion ratio, amylose content (%), kernel length after cooking (mm), elongation ratio, zinc content (ppm) and iron content (ppm) were obtained from random grain sample taken from each plot in each replication. Days to 50% flowering is however, recorded on plot basis.

2.2 Statistical Methods

The data collected was subjected to statistical analysis using SAS software to obtain phenotypic and genotypic coefficient of variation, correlation coefficients and path coefficients. Phenotypic and genotypic coefficients of variation (PCV and GCV) were as per Burton (1952) and were categorized as low (0-10%), moderate (10-20%) and high (>20%) as indicated by Sivasubramanian and Madhavamenon (1973). Heritability in broad sense was estimated as the ratio of genotypic variance to the phenotypic variance as suggested by Hanson et al*.* (1956) and it was categorized as low (0-30%), moderate (30- 60%) and high (>60%) as indicated by Johnson et al. (1955). Genetic advance (GA) and genetic advance as percent of the mean (GAM) were calculated by using the formulae given by Johnson et al*.* (1955). The Genetic advance as percent of the mean was categorized as low (0-10%), moderate (10- 20%) and high (>20%) according to Johnson et al*.* (1955). Correlation coefficients were calculated by using the formulae given by Johnson et al*.* (1955). The direct and indirect effects for genotypes were estimated by using path coefficient analysis suggested by Wright (1921) and Dewey and Lu (1959).

3. RESULTS AND DISCUSSION

Forty-nine accessions consists of four checks namely BPT 5204, Gontrobhidan-3, Protozinc and Zincorice were evaluated for yield, yield attributing and quality traits and the means of the entries in two replications was also analyzed for the estimation of components of genetic variance.

Days to 50 percent flowering recorded a general mean of 66 days (Table 1) (Fig. 1) ranging from 55 days (JAK-126) to 97 days (WGL14). The Genotypic coefficient of variation and phenotypic coefficient of variation (Table 2) (Fig 2) for this character are moderate (12.37%, 12.57% respectively). Heritability estimate for the character is 96.9% coupled with high genetic advance as percent of mean (25%) indicating the preponderance of high additive variance. Hence, this trait can be improved by simple selection. Similar results were reported by Bhargavi et al. [4] and Nath and Kole [5] for GCV, PCV, Heritability and Genetic advance as percent of mean.

Plant height recorded a general mean of 100.8 cm ranging from 71.7 cm (JAK-152) to 154.8 cm (JAK-320). It exhibited moderate variability with GCV (19.8%), PCV (19.8%) and high heritability 99% with high genetic advance as percent of mean 40.7% indicating that the selection is effective. Similar findings were reported by Singh et al. [6] and Sudeepthi et al. [7] for GCV, PCV, heritability and genetic advance as percent mean.

Number of productive tillers plant^{-1} ranged from 5 (JAK-34, JAK-94 and JAK-208) to 20 (JAK-153) with a general mean of 10. High GCV and PCV was recorded for this character (28.8%, 30.1% respectively) with high heritability estimate (91.7%) and high genetic advance as percent of mean 56.9% indicating a good scope for selection. These were in accordance with Rao et al. [8] and Bhusan et al. [9] for GCV, PCV, heritability and genetic advance as percent mean.

In the present investigation the test weight ranged from 14.16 g (JAK-117) to 31.96 g (JAK-210) with a general mean of 23.12 g. Moderate GCV and PCV (17.2%, 17.4% respectively) with high heritability estimate (91.7%) and high genetic advance as percent of mean 35.24% indicating that the selection will be effective. These are similar with Singh et al. (2020) and Sudeepthi et al. (2020) for GCV, PCV, heritability and genetic advance as percent of mean.

The mean values for yield plant^{-1} ranged from 6.95g (JAK-208) to 31.8g (WGL14) with an average of 12.59 g. High GCV and PCV was recorded for this trait (39.8%, 40.6% respectively) with the heritability estimate of the character is 95.6% with genetic advance 10 and genetic advance as percent of mean 80% indicating predominance of additive variance. Hence, further improvement by simple selection can be performed for this trait. Similar results were reported by Nath and Kole (2021) and Singh et al. (2020) for all the parameters.

Head rice recovery observed from 39.9% (JAK-60) to 70.3% (JAK-284-2) with a mean value of 60.39 %. Low GCV (8.7%) and moderate PCV (10.9%) showing variability was influenced by environmental factors. The heritability estimate of the character is 63% coupled with moderate genetic advance as percent of mean (14.4%) and low genetic advance (8.7), showing the presence of non-additive gene action governing the trait. The findings are in accordance with Edukondalu et al. (2017) for GCV and Singh et al. (2020) for heritability and genetic advance as percent of mean.

The present investigation observed kernel length ranging from 4.47 mm (JAK-77) to 7.91 mm (JAK-26) with a general mean of 5.87 mm. Low GCV (9.7%) and moderate PCV (11.1%) was recorded indicating the effect of external factors on variability. High heritability 75.4%, low genetic advance 1.02 and moderate genetic advance as percent of mean 17.34, showing the presence of non-additive gene action governing the trait. These results are in conformity with Bandi et al. (2018) for GCV, Lingaiah (2018) for PCV and Singh et al. (2020) for heritability and genetic advance as percent mean.

Kernel breadth recorded a general mean of 2.23 mm ranging from 1.77 mm (JAK-117) to 2.69 mm (JAK-472). GCV and PCV shown moderate values (10.6%, 11.3% respectively). High heritability (87%) coupled with genetic advance 0.45 and genetic advance as percent of mean 20.4% indicating that the direct selection is not effective. Similar results were reported by Kumar et al. [10] for GCV and PCV and Devi et al. [11] for heritability and genetic advance as percent of mean.

The LB ratio is ranging from 1.66 (JAK-77) to 4.21 (JAK-26) with a general mean value of 2.66. The genotypes with high LB ratio were more slender and were more preferred by consumers. Moderate GCV and PCV was recorded (16.5%, 18.5% respectively). High heritability (80%) coupled with high genetic advance as percent of mean (30.6%) and genetic advance 0.81 indicated that presence of additive variance. Hence, simple selection can be practiced for further crop improvement programmes.

The general mean of water uptake is 221.3 ml ranged from 145 ml (JAK-10) to 292.5 ml (JAK-32). The GCV and PCV were moderate (14.5%, 17.2% respectively) with high heritability estimate (71.3%), high genetic advance as percent of mean 25.3% and genetic advance 55.9 indicating that direct selection if effective for the character. The results are in accordance with Devi et al. [11] for GCV and PCV, Devi et al. [12] for heritability and genetic advance as percent of mean.

Volume expansion ratio ranged between 4.35 (BPT-5204 and JAK-320) to 5.63 with a general mean of 4.91. Low GCV and PCV was recorded (0%, 8.5% respectively) with heritability, genetic advance and genetic advance as percent of mean of the character are low (0%, 0, 0%). These findings are reported earlier by Lakshmi et al. [13] for PCV.

Amylose content recorded a general mean of 23.92% ranging from 7.18% (JAK-320) to 28.25% (JAK-286). Moderate GCV and PCV (14.2%, 14.9% respectively) was recorded. High heritability estimate (90.5%) coupled with high genetic advance as percent of mean (27.8%) and genetic advance 6.6 indicating that the selection is effective for the character. The results are in accordance with Singh et al. (2020) and Bandi et al. [14] for all the parameters.

The average value of kernel length after cooking 9.38 mm ranging from 7.01 mm (JAK-60) to 12.4 mm (JAK-494). Moderate GCV and PCV was recorded (13.3%, 15.5% respectively). The heritability estimate of the character was 73.9% with genetic advance as percent of mean 23.7% and genetic advance 2.2 showing that the selection is effective. The results are reported by Devi et al. [15] for heritability.

Elongation ratio ranging from 1.21 (JAK-320) to 2.08 (JAK-271) with a general mean of 1.62. It noticed moderate GCV and PCV (10.8%, 12.6% respectively). The heritability estimate is high (72.8%) with genetic advance 0.3 and genetic advance as percent mean 19% was recorded indicating the presence of non-additive gene action. Hence, selection for the trait cannot be effective.

Table 1. Mean performance of the 49 genotypes with respect to yield, yield component and quality related traits

S.No.	Genotype	DFF	PH	PP	TW	YP	HRR	KL	KB	LB	WU	VER	AC	KLAC	ER	Zn	Fe
1	JAK-10	59	77.18	12	22.34	12.60	55.70	5.71	2.13	2.67	145.00	4.55	23.34	9.50	1.65	17.00	1.95
2	JAK-20	70	124.31	11	28.41	15.49	58.45	5.55	2.02	2.74	202.50	4.50	23.78	8.00	1.43	16.65	3.60
3	JAK-25	63	106.98	10	24.50	11.44	65.70	6.06	2.28	2.64	202.50	4.40	25.83	9.45	1.55	19.25	2.05
4	JAK-26	58	98.31	8	26.53	12.66	61.60	7.91	1.87	4.21	261.00	5.00	22.72	12.65	1.59	20.40	2.90
5	JAK-32	69	83.96	7	27.45	9.46	50.20	7.62	1.96	3.88	292.50	4.70	25.00	13.50	1.77	15.65	3.85
6	JAK-34	62	91.20	5	22.87	7.69	59.95	5.50	2.29	2.39	235.00	5.30	24.54	8.75	1.58	17.10	3.05
7	JAK-58	64	126.18	7	29.81	10.72	55.35	5.64	2.59	2.17	217.50	5.15	24.81	9.85	1.74	19.70	3.60
8	JAK-60	66	111.68	8	21.63	12.87	39.92	5.21	2.53	2.06	228.00	4.85	25.25	7.01	1.42	20.70	4.80
9	JAK-77	59	99.28	8	21.9	8.88	69.45	4.47	2.68	1.66	207.50	5.15	26.09	9.15	2.04	20.00	2.20
10	JAK-94	57	114.43	5	19.37	7.79	67.12	6.30	2.38	2.64	147.50	4.80	25.19	10.05	1.71	20.50	4.85
11	JAK-99	59	95.26	10	26.72	11.94	65.61	6.12	2.34	2.60	268.00	5.10	27.94	9.90	1.65	19.20	1.95
12	JAK-117	56	104.00	13	14.16	11.93	63.15	5.47	1.77	3.09	275.00	5.05	26.55	9.95	1.81	18.70	1.50
13	JAK-126	55	128.71	10	25.00	15.69	59.20	5.87	2.11	2.77	207.50	5.00	22.92	9.45	1.61	17.65	2.20
14	JAK-152	74	71.75	11	22.99	13.36	55.00	5.95	2.10	2.66	177.50	4.95	27.81	9.05	1.51	17.35	3.10
15	JAK-153	68	85.60	20	22.45	7.75	57.85	5.37	2.70	1.99	178.00	5.00	27.40	7.57	1.45	20.70	4.00
16	JAK-172	65	83.50	9	25.95	9.97	62.60	6.61	2.11	3.12	216.50	4.85	23.00	8.93	1.44	21.55	3.70
17	JAK-208	63	96.33	5	28.21	6.95	61.30	5.67	2.49	2.27	196.50	5.15	26.98	9.80	1.79	17.55	3.50
18	JAK-210	66	101.33	6	31.96	12.38	69.50	6.34	2.42	2.61	205.00	4.65	22.40	10.15	1.63	15.40	3.00
19	JAK-216	69	120.85	14	21.43	17.18	61.75	5.94	2.42	2.45	170.00	4.50	26.32	8.25	1.38	14.15	2.80
20	JAK-221	70	119.63	10	26.91	10.19	50.00	5.92	2.49	2.37	259.00	4.70	24.71	9.75	1.60	13.20	2.35
21	JAK-271	78	73.98	13	25.13	7.51	64.95	5.13	1.89	2.70	228.00	5.30	25.37	10.10	2.08	14.75	2.65
22	JAK-273	65	112.83	10	23.81	10.05	53.70	5.64	2.33	2.41	187.50	4.95	24.87	8.35	1.47	17.80	1.55
23	JAK-274	64	120.83	13	21.16	7.95	53.65	6.47	2.00	3.30	242.50	4.75	24.66	12.30	1.87	21.45	1.60
24	JAK-286	57	81.68	10	24.66	12.34	57.40	6.58	2.02	3.25	288.50	4.90	28.25	8.95	1.35	23.45	1.95
25	JAK-320	69	154.83	6	29.05	10.65	63.30	6.08	2.60	2.33	252.50	4.40	7.18	7.30	1.21	21.35	2.20
26	JAK-410	58	82.33	11	19.50	18.99	63.10	6.29	1.90	3.24	227.50	5.15	25.63	9.40	1.49	12.30	2.55
27	JAK-411	60	77.73	15	30.27	17.65	64.45	5.90	2.08	2.83	222.50	4.65	26.31	9.70	1.65	14.55	2.50
28	JAK-416	57	87.15	12	19.48	16.59	62.90	5.96	1.99	2.98	222.50	5.10	27.14	9.65	1.61	17.60	2.10
29	JAK-424	69	140.90	10	20.65	9.62	63.50	6.04	2.19	2.75	260.00	5.45	23.06	10.60	1.75	22.30	3.05
30	JAK-467	70	73.18	7	15.34	8.47	65.00	5.57	2.01	2.76	218.00	4.93	24.99	8.45	1.67	22.45	3.45
31	JAK-468	67	72.66	10	18.79	10.59	52.70	5.73	2.21	2.59	237.50	4.45	21.32	10.75	1.89	22.45	3.60
32	JAK-469	59	123.28	10	25.56	14.19	57.30	5.44	2.62	2.07	288.50	4.64	24.14	7.79	1.59	18.55	3.70
33	JAK-472	63	130.83	8	24.22	10.93	61.50	5.40	2.69	2.00	257.50	4.90	24.58	8.85	1.64	16.65	4.95
34	JAK-474	72	110.35	12	17.54	11.79	59.70	5.24	2.34	2.25	215.00	5.40	25.38	8.35	1.58	17.30	3.40
35	JAK-494	77	105.76	7	19.98	7.56	56.60	6.41	2.10	3.04	229.50	4.70	25.32	12.80	2.21	17.40	4.35
36	JAK-542	77	104.98	7	24.03	8.52	64.10	6.68	2.09	3.18	247.50	4.85	25.03	9.60	1.43	16.00	4.10
37	JAK-595	69	90.03	10	21.11	7.65	54.55	5.70	2.21	2.58	192.50	4.75	22.89	9.05	1.58	17.05	4.95
38	JAK-622	67	84.81	9	23.62	12.73	65.30	5.61	2.49	2.25	195.00	4.90	24.34	8.10	1.44	21.50	2.95
39	JAK-659	64	125.00	10	23.17	9.83	64.55	5.42	2.49	2.17	245.00	5.10	14.19	9.30	1.71	19.85	2.10
40	JAK-284-2	63	93.31	9	25.66	10.58	70.30	6.52	2.16	3.01	190.00	4.65	22.04	10.30	1.57	15.50	1.95
41	JAK-377-3	66	72.08	15	22.98	12.80	67.70	6.50	2.17	2.98	187.50	4.65	20.12	10.00	1.53	16.30	2.60
42	JAK-420-2	65	78.56	9	23.90	11.18	54.75	5.61	2.39	2.34	278.00	5.05	17.99	9.10	1.71	20.50	2.40
43	JAK-625	71	122.50	15	22.57	12.94	64.65	5.49	2.31	2.36	238.00	5.20	24.48	8.95	1.75	19.65	2.80
44	JAK-595-1	73	112.00	6	24.01	7.66	63.95	5.57	2.22	2.50	192.50	5.00	24.16	9.20	1.64	18.50	2.65
45	WGL14	97	107.70	10	16.35	31.80	64.25	5.26	1.82	2.88	205.00	5.63	24.59	7.75	1.46	13.50	19.10
46	Gontrobidhan-3	64	94.26	10	16.82	23.50	50.90	5.18	2.15	2.40	197.50	4.95	23.46	8.10	1.56	16.65	2.95
47	Zincorice	66	84.71	10	22.06	18.59	56.25	5.67	2.10	2.69	220.00	5.35	22.25	7.40	1.30	23.70	3.10

S.No.	Genotype	DFF	PH	PP	TW	YP	HRR	KL	KB	LB	WU	VER	AC	KLAC	ER	Zn	Fe
48	Protozinc	69	89.78	11	25.48	25.09	64.35	6.29	2.17	2.89	197.50	5.00	20.88	9.75	1.54	23.45	3.00
49	BPT-5204	96	91.95	9	15.25	21.99	64.45	5.05	1.87	2.69	188.00	4.35	24.83	9.00	1.71	15.70	22.48
	General mean	66	100.8	10	23.12	12.59	60.39	5.87	2.69	2.66	221.3	4.9	23.92	9.38	1.62	18.38	3.71

DFF=Days to 50% flowering, PP=Productive tillers plant^{-1}, PH=Plant height, TW=Test weight. HRR=Head rice recovery, KL=kernel length, KB=Kernel breadth, LB=LB ratio, WU=water uptake, VER=Volume expansion ratio, KLAC=Kernel length after cooking, ER=elongation ratio, Zn=Zinc content, Fe=Iron content, YP=Yield plant^{-1}

Table 2. Estimation of variability, heritability and genetic advance for yield and yield contributing and quality traits

Characters	Coefficient of variance		Heritability (%)	Genetic advance	Genetic advance as percent mean (%)
	GCV(%)	PCV(%)			
DFF	12.37	12.57	96.90	16.79	25.09
PH(cm)	19.83	19.88	99.40	41.07	40.73
PP	28.85	30.12	91.70	5.71	56.93
TW(g)	17.28	17.46	97.90	8.14	35.24
YP(g)	39.80	40.69	95.66	10.09	80.19
HRR(%)	8.78	10.99	63.80	8.73	14.46
KL(mm)	9.71	11.18	75.40	1.02	17.37
KB(mm)	10.62	11.37	87.00	0.45	20.42
LB	16.58	18.51	80.00	0.81	30.61
WU(ml)	14.53	17.21	71.30	55.99	25.30
VER	0	8.55	0	0	0
AC(%)	14.23	14.95	90.50	6.67	27.89
KLAC	13.39	15.57	73.90	2.22	23.72
ER	10.82	12.68	72.80	0.30	19.03
FE(ppm)	99.34	99.59	99.70	7.58	60.27
ZN(ppm)	15.53	15.66	98.30	5.83	31.74

DFF=Days to 50% flowering, PP=Productive tillers plant^{-1}, PH=Plant height, TW=Test weight. HRR=Head rice recovery, KL=kernel length, KB=Kernel breadth, LB=LB ratio, WU=water uptake, VER=Volume expansion ratio, KLAC=Kernel length after cooking, ER=elongation ratio, Zn=Zinc content, Fe=Iron content, YP=Yield plant^{-1}

Zinc content varied from 13.2 ppm (JAK-221) to 23.45 ppm (JAK-286) with a mean of 18.38 ppm. High GCV and PCV was recorded (99.3%, 99.5% respectively) for the trait. High heritability (99.7%) with high genetic advance as percent of mean (60.2%) and genetic advance 7.5 indicating the presence of additive variance. Hence, selection is effective for further crop improvement. The results are in conformity of Singh et al. (2020) for GCV and PCV and Ullah et al. [16] for heritability and genetic advance as percent of mean.

In the present study, iron content recorded from 1.5 ppm (JAK-117) to 22.485 ppm (BPT-5204) with a mean of 3.71 ppm. Moderate GCV and PCV was recorded for the character (15.5%, 15.6% respectively). High heritability (98.3%) coupled with high genetic advance as percent mean 31.7 and genetic advance 5.8 indicating that the selective is effective. These findings are reported by Sudeepti et al. [7] for GCV and Ullah et al. [16] for heritability and genetic advance as percent of mean.

Character association is driven by the correlation coefficient, aids in the evaluation of the relative influence of various yield attributing and quality traits on grain yield. In the present investigation, correlation analysis among yield and its attributing traits (Table 3) revealed the grain yield was positively correlated with days to 50% flowering (0.0555), productive tillers plant^{-1} (0.2827), LB ratio (0.1188) and iron content (0.2683) indicating that these traits could be considered as a criteria of selection for higher grain yield, since they were mutually and directly associated with grain yield. The observed positive correlation of grain yield with these traits was supported by Jasmine et al. [17], Kiran et al. [18] in rice. However, plant height (-0.1471), test weight (-0.1207), head rice recovery (-0.0386), kernel length (-0.0387), kernel breadth (-0.2787), water uptake (-0.1334), volume expansion ratio (-0.1538), amylose content (-0.0276), kernel length after cooking (-0.2349), elongation ratio (-0.3381) and zinc content (-0.092) were found to be negatively correlated with a yield that would hinder the expression of the plant yield as reported by Vennela et al. [19] and Lakshmi et al. [20]. Hence, selecting the accessions with late maturity producing more no of productive tillers plant^{-1}, reduced plant height, and less kernel breadth would be rewarding [21].

Pearson correlation plot (Fig. 3) depicting the strong correlation between kernel length and LB ratio while, no correlation between days to 50% flowering and Productive tillers plant^{-1}, Productive tillers plant^{-1} and LB ratio; and kernel length and zinc content. The yield plant^{-1} had a moderate correlation with productive tillers plant^{-1} [22].

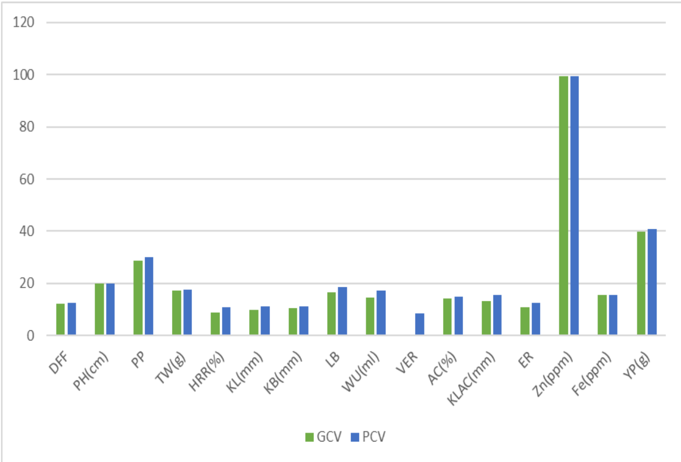

Fig. 1. Coefficient of variations for yield, yield attributing and quality traits

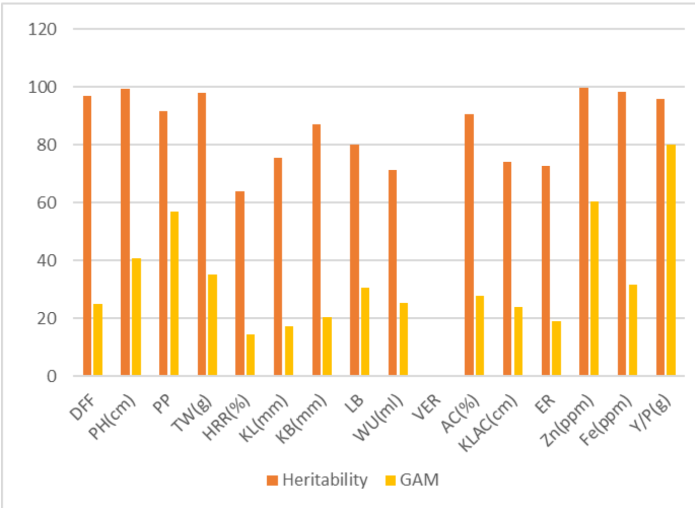

Fig. 2. Heritability and genetic advance as percent mean for yield, yield attributing and quality traits

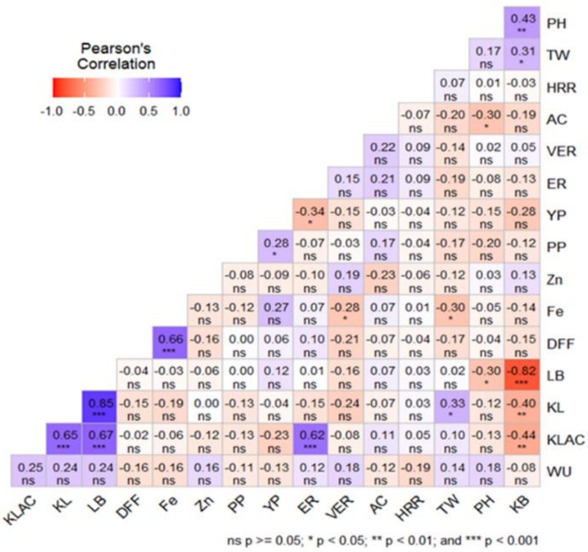

Fig. 3. Pearson's correlation plot for yield, yield component and quality traits

Table 3. Correlation coefficient for yield, yield component and quality traits

	DFF	PH	PP	TW	HRR	KL	KB	LB	WU	VER	AC	KLAC	ER	Zn	Fe	YP
DFF	1	-0.0413	-0.002811	-0.1685	-0.04264	-0.15233	-0.1478	-0.038413	-0.1566	-0.213	-0.071	-0.0249	0.1037	-0.15997	0.6631***	0.0555
PH		1	-0.20155	0.1731	0.00785	-0.11881	0.4329**	-0.303934*	0.1752	0.0156	-0.298*	-0.1266	-0.0793	0.03437	-0.0535	-0.1471
PP			1	-0.1717	-0.04068	-0.12929	-0.1248	-0.000579	-0.1082	-0.0275	0.1671	-0.1283	-0.0718	-0.08248	-0.1247	0.2827*
TW				1	0.07374	0.33119*	0.3075*	0.018129	0.141	-0.1402	-0.199	0.0952	-0.1916	-0.11719	-0.2987*	-0.1207
HRR					1	0.02865	-0.0304	0.027965	-0.186	0.0934	-0.072	0.0471	0.0886	-0.06094	0.0147	-0.0386
KL						1	-0.4035**	0.846772***	0.2355	-0.2407	-0.074	0.6502***	-0.1495	0.00392	-0.1867	-0.0387
KB							1	-0.815004***	-0.0767	0.0468	-0.191	-0.4358**	-0.1271	0.13303	-0.1397	-0.2787
LB								1	0.2359	-0.1607	0.0717	0.6745***	0.0102	-0.0573	-0.03	0.1188
WU									1	0.1765	-0.123	0.252	0.1188	0.15789	-0.161	-0.1334
VER										1	0.2169	-0.0794	0.151	0.19207	-0.2842*	-0.1538
AC											1	0.1095	0.207	-0.228	0.0722	-0.0276
KLAC												1	0.6185***	-0.12321	-0.061	-0.2349
ER													1	-0.0967	0.0652	-0.3381*
Zn														1	-0.1297	-0.092
Fe															1	0.2683
YP																1

** ,**,*** Significant at 5 % , 1 % and 0.1% levels, respectively DFF=Days to 50% flowering, PP=Productive tillers plant^{-1}, PH=Plant height, TW=Test weight. HRR=Head rice recovery, KL=kernel length, KB=Kernel breadth, LB=LB ratio, WU=water uptake, VER=Volume expansion ratio, KLAC=Kernel length after cooking, ER=elongation ratio, Zn=Zinc content, Fe=Iron content, YP=Yield plant^{-1}*

Table 4. Direct and indirect effects of independent variables on dependent variable

	DFF	PH(cm)	PP	TW(gm)	HRR(%)	KL(cm)	KB(cm)	L/B	WU(ml)	VER	AC(%)	KLAC(cm)	ER	Zn(ppm)	Fe(ppm)
DFF	**-0.3497**	-0.002	0.0015	0.0927	-0.0025	0.0679	0.0819	0.0013	0.051	-0.0028	0.0133	0.039	-0.0061	0.0917	-0.2641
PH(cm)	0.0002	**0.0396**	-0.007	0.0063	-0.0005	-0.0037	0.0151	-0.0105	0.0067	0.0002	-0.0122	-0.0045	-0.0032	0.0012	-0.0004
PP	-0.0011	-0.0465	**0.2615**	-0.0459	0.0024	-0.0397	-0.0248	-0.0087	-0.0305	0.0071	0.0441	-0.0358	-0.0176	-0.0234	-0.0222
TW(gm)	-0.0184	0.011	-0.0122	**0.0694**	0.0036	0.0229	0.0234	-0.0001	0.01	-0.0106	-0.0133	0.0079	-0.0104	-0.0035	-0.0261
HRR(%)	-0.0001	0.0002	-0.0002	-0.001	**-0.02**	-0.0006	0.0012	-0.0009	0.0035	-0.0015	0.0008	-0.0007	-0.0015	0.0015	-0.0013
KL(cm)	-0.065	-0.0315	-0.0508	0.1102	0.0096	**0.3345**	-0.1096	0.2763	0.0863	-0.0708	-0.0153	0.2139	-0.0417	0.0099	-0.0747
KB(cm)	0.1752	-0.2853	0.0709	-0.2524	0.0448	0.245	**-0.7478**	0.5889	0.0521	0.0026	0.1363	0.2652	0.0489	-0.1392	0.1838
L/B	0.0027	0.1943	0.0243	0.0007	-0.0342	-0.6069	0.5788	**-0.7349**	-0.1831	0.0922	-0.0631	-0.4688	0.0112	0.0554	-0.0101
WU(ml)	0.0027	-0.0031	0.0022	-0.0027	0.0033	-0.0048	0.0013	-0.0046	**-0.0186**	-0.0017	0.0017	-0.0044	-0.0019	-0.0029	0.0029
VER	0.0008	0.0005	0.0026	-0.0147	0.0071	-0.0203	-0.0003	-0.012	0.0088	**0.096**	0.0166	-0.0178	0.0011	0.0069	0.0003
AC(%)	0.0047	0.0381	-0.0208	0.0237	0.005	0.0057	0.0225	-0.0106	0.0115	-0.0213	**-0.1236**	-0.0109	-0.0229	0.0276	-0.0091
KLAC(mm)	-0.0003	-0.0003	-0.0004	0.0003	0.0001	0.0019	-0.0011	0.0019	0.0007	-0.0006	0.0003	**0.003**	0.0019	-0.0002	-0.0004
ER	-0.0048	0.0223	0.0188	0.0418	-0.021	0.0348	0.0183	0.0042	-0.0281	-0.0032	-0.0517	-0.1732	**-0.2792**	0.017	0.005
Zn(ppm)	0.0212	-0.0024	0.0072	0.0041	0.0061	-0.0024	-0.015	0.0061	-0.0125	-0.0058	0.018	0.0057	0.0049	**-0.0807**	0.0202
Fe(ppm)	0.5324	-0.0073	-0.0597	-0.2658	0.0455	-0.1575	-0.1733	0.0097	-0.1096	0.0021	0.052	-0.1013	-0.0125	-0.1761	**0.7051**

Diagonal bold values indicate direct effects, Residual Effect =0.677, DFF=Days to 50% flowering, PP=Productive tillers plant`1, PH=Plant height, TW=Test weight. HRR=Head rice recovery, KL=kernel length, KB=Kernel breadth, LB=LB ratio, WU=water uptake, VER=Volume expansion ratio, KLAC=Kernel length after cooking, ER=elongation ratio, Zn=Zinc content, Fe=Iron content

Path coefficient analysis allows the separation of the correlation coefficients into direct as well as indirect effects (Table 4). Iron content (0.7051) exerted the highest direct positive effect on grain yield per plant followed by kernel length (0.3345) and productive tillers plant^{-1} (0.2615), indicating that selection for these characters is likely to bring about on overall improvement in grain yield directly. These findings were also reported by Singh et al. (2020) and Sudeepthi et al. (2020). The direct effects of other twelve characters were too low to be considered of any consequence. Although LB ratio (-0.7349) had negative direct effect, its indirect effect through kernel breadth (0.5889), kernel length (0.2763) was positive. In the present investigation, high positive indirect effects on grain yield per plant were of LB ratio via, kernel breadth (0.5889). Thus, indirect selection for this trait would be beneficial in enhancing the yield potential of rice varieties.

4. CONCLUSION

The present study revealed a high range of variation and high heritability coupled with high genetic advance was recorded for days to 50 per cent flowering, plant height, productive tillers plant^{-1}, test weight, LB ratio, water uptake, kernel length after cooking, zinc content and iron content. The overall study reveals the presence of a broad genetic base, less environmental influence and additive gene action for the traits studied. Hence, simple and early generation selection of promising lines from present gene pool would be effective for future gene introgression programs. correlation revealed that the grain yield was positively correlated with days to 50% flowering, productive tillers plant^{-1}, LB ratio and iron content indicating that these traits could be considered as a criteria of selection for higher grain yield. Direct positive associations between yield per plant and iron content, kernel length and productive tillers plant^{-1}, selection for which would be effective to enhance the yield potential. Also, L/B ratio via kernel breadth exhibited high positive indirect effects. Therefore, these characters would be most suitable for indirect selection of yield in rice improvement programs.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

I hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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