



Morphological characterization, Genetic Variability and Trait Association of Basmati, Red and White Rice Lines under North Hill Zone of India

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ABSTRACT: During the *Kharif* 2023, an experiment involving 14 rice lines, including 8 red rice landraces, a Basmati genotype and 5 white rice lines, was conducted to investigate the genetic variability, correlation, path coefficient analysis and principal component analysis for yield and its contributing traits. Analysis of variance revealed significant differences among all studied genotypes. Phenotypic coefficient of variation exceeded genotypic coefficient of variation for all traits. Traits such as plant height, flag leaf area, total tillers, effective tillers, spikelets per panicle, spikelet fertility, harvest index, and grain length to breadth ratio exhibited high heritability coupled with high genetic advance. Correlation studies indicated significant positive correlations between grain yield and total tillers, effective tillers, grain length, biological yield per plant, and panicle length. Path analysis revealed that effective tillers per plant, number of grains per panicle, biological yield per plant, days to 75% maturity, and grain length to breadth ratio exerted high direct effects on yield. Principal component analysis (PCA) demonstrated that the first four principal components accounted for 84.33% of the total variability across seventeen traits. PC1 contributed the most to variability (39.06%), followed by PC2 (22.15%), PC3 (14.84%), and PC4 (8.28%). The observed variation in genotypes based on variability parameters, principal component analysis, correlation, and path analysis offers valuable insights for researchers in devising breeding programs for rice crop improvement.

Keywords: Red rice, Genetic variability, Principal component analysis, correlation and path analysis.

INTRODUCTION

Alarming rise in population, increasing urbanization, modern technology and climate change have paced up the demand for good quality as well as quantity of food. The question of how to eradicate global hunger and feed the future world population is a burning global societal challenge. Green revolution and other related movements have eradicated the hunger from the country by providing enough food grains but unfortunately have failed in providing enough nutrients needed for a balanced diet which resulted in the eventful problem of hidden hunger. More than 50% of global population suffer from Fe, Zn and Vitamin A deficiency. We cannot deny the fact that more than half of the world's population depends upon rice as their dietary staple food. Rice is grown in more than 100 countries where 90% of the total global production is from Asia (Samal *et al.*, 2022). Globally, a half billion metric tonnes of rice is consumed every year. Maintaining price stability and justifiable success and self-sufficiency in the rice production are important political objectives in countries like India where rice provides food security and creates job and income for people. India holds 26% of global rice production,

consumes 22% of global rice stocks while contributing around 40 % of world's rice exports. India exported 22.2 million tons rice in 2022, more than ever before. Rice is the most cheap, common, and reliable source of human nutrition and calorie intake amongst the Asian populace. There are numerous types of rice, like red rice, white rice, brown rice, black rice, white rice and depending on the strain of rice, it can contain decent amount of fibre, protein, vitamin B, iron and manganese which makes rice crop as a boon to fight hidden hunger. But considering nutritional components, red, white and basmati rice are studied in this research work. Red rice and basmati rice possesses an impressive amount of nutrients when compared to white rice. Red rice and basmati rice, both are high in protein, fibre, and antioxidants, like anthocyanins, apigenin, myricetin, and quercetin which makes them more suitable to lower blood glucose, fight against lung disorders, build bone health, supports digestion, trigger weight loss and maintain heart health. Himachal Pradesh is bestowed with biodiversity of red rice which is also known as red pearls of Himalayas. Many rice landraces with exceptional quality are grown in agroclimatic zones at different altitudes. RWRC, Malan has collection of these specialty rice collected from

distinct parts of the state and out of these, high yielding and nutritionally rich lines have been identified which could be used in breeding program for boosting the nutrient content of rice.

Though Indian is self-sufficient in the production of food crops but there is still a massive gap between the production and the demand of food. More rice per unit area needs to be produced to fulfil the increasing food demand. Grain yield is a complex quantitative trait of any crop and is contributed by various morphological and physiological traits. These yield contributing traits are interrelated with each other and shows a complex chain of relationship among each other and are highly influenced by the environmental factors (Prasad *et al.*, 2001). The strategy of crop breeding depends on the degree of associated traits as well as its magnitude and nature of variation present (Zahid *et al.*, 2006; Prasad *et al.*, 2001), thus making it evident to opt for the breeding strategy of any crop advertently for best results. It is important to understand the inter-relationship among the characters to accumulate a combination of yield contributing characters in a single genotype. Thus, it is necessary to associate such traits when rational improvement is done through selection. Path coefficient analysis is a standardized partial regression coefficient which hews the correlation coefficient into the measures of direct and indirect effects. The concept of path analysis was first used by Dewey and Lu in 1959 for plant selection. The present research was conducted to study the genetic variability among various traits of rice, their direct and indirect contribution towards yield and to find out the best combinations for selection for developing high yielding rice genotypes.

MATERIAL AND METHODS

A total of 14 rice genotypes, including 8 red rice lines (*Bongal Dhan, Totu, Shimla Collection, Kalizhini, Gosha, Lal Nakanda, Jattoo and Sukara Red*), one basmati line (*Pusa Basmati 1637*), 5 white rice lines (*DHR 9, RB 13, HPR 2880, HPR 3106, HPR 2143*) were grown in the *Kharif, 2023* at Rice and Wheat Research Centre, Malan, Palampur, Himachal Pradesh

to study the genetic variability, correlation, path coefficient analysis and principle component analysis for yield and its contributing traits. The design was laid out in randomized block design with 3 replications. Each entry was grown in two rows of three metre each, spaced 20 cm between rows and 15 cm between plants. Recommended package of practice was maintained throughout the crop growth period. At maturity, five competitive plants from the central two rows of each plot in each replication were randomly selected to obtain data on plant height (cm), Flag leaf area (cm²), Total tillers per plant, effective tillers per plant, panicle length, number of spikelets per panicle, number of grains per panicle, harvest index, grain length, grain breadth, grain L:B ratio, biological yield per plant and grain yield per plant. Days to flowering, and days to 75 %maturity were taken on plot basis.

Statistical analysis. Using SPSS software, the replicated data were subjected to analysis of variation as per Panse and Sukhatme (1984). According to Burton and De Vane (1953), estimates of variability, including phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability (h²bs) in a broad sense, and expected genetic advance (GA), expressed as a percentage of mean, were calculated in TNAUSTAT software, and correlation (Al-Tabbal *et al.*, 1958) and path analysis (Dewey and Lu 1959) were done using OPSTAT. Principal Component Analysis was computed using the statistical software GRAPES (Gopinath *et al.*, 2020).

RESULTS AND DISCUSSION

Analysis of variance and mean performance. The results obtained from analysis of variance indicated that there were notable differences among the genotypes for all the characters taken for investigation (Table). The presence of a high degree of variability may result from the different region of origin as well as environmental influences on phenotypes. This result also suggested that this population of would respond favorably to selection (Table 1).

Table 1: Analysis of variance for yield and contributing traits.

Sr. No.	Sources	Replication	Treatment	Error
	Degrees of freedom	2	13	26
1.	Days to flowering	19.50	159.22*	6.91
2.	Days to 75% maturity	38.73	178.63*	9.35
3.	Plant height	284.29	1959.24*	62.59
4.	Flag leaf area	7.57	944.38*	37.71
5.	Total tillers per plant	0.47	51.99*	2.27
6.	Effective tillers per plant	0.87	35.51*	1.45
7.	Panicle length	7.15	17.64*	6.31
8.	Number of spikelets per panicle	304.72	1539.56*	120.09
9.	Number of grains per panicle	92.07	1734.04*	189.63
10.	Spikelet fertility	333.08	858.21*	47.01
11.	Harvest index	0.001	0.008*	0.001
12.	Thousand grain weight	0.25	18.65*	1.43
13.	Grain length	0.05	1.033*	0.04
14.	Grain breadth	0.01	0.092*	0.02
15.	Grain L:B ratio	0.02	1.065*	0.02
16.	biological yield per plant	9.50	168.33*	41.15
17.	grain yield per plant	5.95	44.10*	9.18

*Significant at $p \leq 0.05$

Table 2: Mean performance of yield and contributing traits.

Genotypes	DDF	DSM	PH	FLA	TTPP	ETPP	PL	NSPP	NGPP	SF	HI	TGW	GL	GB	LBR	BYPP	GYPP
Bongal dhan	80.00	108.00	96.40	36.12	7.93	6.67	22.96	125.07	105.53	84.63	0.44	21.36	6.13	2.04	3.00	35.54	15.51
Totu	94.67	123.67	124.50	59.95	5.87	4.87	28.27	168.27*	140.27*	83.46	0.38	19.23	5.20	1.90	2.74	38.26	16.97
Shimla collection	81.67	116.67	158.77	86.73*	4.93	4.33	23.89	182.27*	159.73*	87.76	0.34	26.98*	6.22	2.04	3.05	50.14	19.21
Kalizhini	77.67*	102.67*	135.42	83.34*	7.33	6.47	24.20	122.13	103.27	84.54	0.38	20.41	5.94	1.81	3.27	40.15	13.52
Gosha	79.67	113.67	138.75	59.02	9.13	8.00	21.91	140.27	104.33	74.54	0.33	20.41	5.53	1.97	2.81	40.67	15.56
Lal nakanda	84.33	117.67	168.25	73.23	7.13	5.87	26.77	161.27*	149.13*	92.06	0.46	24.19	5.98	1.80	3.32	54.87	17.88
Jattoo	94.67	123.00	123.25	57.19	11.80	10.87	20.13	111.27	86.47	77.62	0.38	20.16	5.40	1.78	3.03	31.27	14.50
Sukara red	93.33	123.67	140.92	74.94	5.73	4.73	25.84	168.67*	145.67*	86.49	0.47	26.55	6.18	1.97	3.13	39.57	15.21
Pusa Basmati 1637	103.33	130.67	84.27*	29.41	20.87*	16.47*	29.33*	137.60	84.53	61.36	0.48	23.70	7.36*	1.78	4.14*	56.24	26.40
DHR 9	82.33	109.00	82.31*	50.33	14.47*	13.20*	25.50	127.67	98.33	77.06	0.43	20.32	5.84	1.85	3.15	46.24	22.24
RB-13	86.67	109.67	104.64	37.27	10.07	8.60	26.20	125.73	110.47	88.46	0.48	24.57	6.92	2.34	2.96	51.28	21.80
HPR 2880	87.67	114.67	125.38	51.76	11.07	10.13	24.22	115.40	106.87	92.49	0.45	23.54	6.31	2.27	2.78	46.77	21.48
HPR 3106	83.33	111.33	107.63	43.18	11.20	9.20	23.71	122.13	102.73	84.85	0.44	24.67	6.43	1.89	3.41	51.12	23.22
HPR 2143	84.67	110.00	121.53	65.63	9.00	7.93	24.26	125.53	101.60	81.37	0.44	22.67	6.68	1.84	3.64	42.92	19.69
CD at P<0.05	4.42	5.14	13.30	10.32	2.53	2.03	4.22	18.43	13.16	11.53	0.04	2.01	0.36	0.25	0.26	10.78	5.09
CV (%)	3.03	2.65	6.46	10.63	15.44	14.40	10.13	7.93	12.05	9.23	5.79	5.26	3.53	7.71	5.43	14.36	16.12

*Significant at $p \leq 0.05$

DDF - Days to flowering	TTPP - Total tillers per plant	NGPP - Number of grains per panicle	GL - Grain length (mm)	GYPP - Grain yield per plant (g)
DSM - Days to 75% maturity	ETPP - effective tillers per plant	SF - Spikelets fertility (%)	GB - Grain breadth (mm)	
PH - Plant height (cm)	PL - Panicle length (cm)	HI - Harvest index	LBR - Grain L:B ratio	
FLA - Flag leaf area (cm ²)	NSPP - Number of spikelets per panicle	TGW - Thousand grain weight (g)	BYPP - Biological yield per plant (g)	

Days to 50% flowering ranged from 77.67 – 103.33 days and days to 75% maturity ranged from 102.67 – 130.67 days. Genotype *Kalizhini* was found to be early in maturity whereas, Pusa Basmati 1637 was found to be late in maturity. Two genotypes *viz.*, Pusa Basmati 1637 and DHR 9 were found to be less in height compared to the best check HPR 3106.

Pusa Basmati 1637, derived from Pusa Basmati 1 through MAS was carrying *sd1* gene which is responsible for its reduced height. Wide range of variation was observed in terms of flag leaf area. Two genotypes *viz.*, *Shimla collection* and *Kalizhini* were found to have maximum flag leaf area compared to best check HPR 2143. For total tillers and effective tillers per plant Pusa Basmati and DHR 9 were found to be significant superiority over best checks. Highest panicle length was observed in Pusa Basmati 1637 (29.33 cm). Four genotypes *viz.*, *Totu*, *Shimla collection*, *Lal Nakanda* and *Sukara red* was found to be significant superior with the check HPR 2143 for spikelets per plant and HPR 2880 for grains per panicle, respectively. None of the genotype were found significant for spikelets fertility and harvest index. Highest thousand grain weight was recorded for *Shimla collection* with the range of 19.23-26.98 among all the fourteen genotypes studied. In terms of grain size and shape, narrow slender grain is preferred by consumers. Only one genotype Pusa basmati 1637 was found to have significant in terms of grain length size and shape. None of the genotypes were found to be superior in terms of biological yield and grain yield. Six genotypes were found significantly at par with best check HPR 3106 for BYPP. Among red rice lines, *Shimla collection* and among white rice genotypes all genotypes were found to be significantly at par with best check HPR 3106 (Table 2).

Genetic Variability. Variability is crucial for broad adaptation and resistance to both biotic and abiotic

factors; as a result, a plant breeder's understanding of the level of genetic variability present in a population is necessary for beginning an effective breeding programme. The results are provided in Table 3, which includes the mean, range, phenotypic coefficient of variation (PCV), genotypic coefficient of variation (GCV), heritability in the broadest sense (h^2_{bs}), and expected genetic advance as a percentage of mean (GAM) for each character under study. When choosing better cultivars and launching a breeding programme, a species' genotypic and phenotypic variability is of paramount significance. Coefficients of variation for both genotypes and phenotypes are used to quantify the variability within a given genotype.

Phenotypic coefficient of variation was found to be slightly higher than that of genotypic coefficient of variation for all the 17 characters studied. Most of the lines included in our current investigation were having stable performance in low hills zones of Himachal Pradesh due to less influence of environment. The estimates of coefficient of variation have been classified into three categories *viz.*, high (> 20%), medium (10-20%) and low (<10%). High PCV and GCV were found for traits *viz.*, plant height, flag leaf area, total tillers per plant, effective tillers per plant, number of grains per panicle, spikelet fertility, and grain L:B ratio. Whereas, medium PCV and GCV were found for panicle length, spikelets per panicle, harvest index, thousand grain weight, biological yield per plant and grain yield per plant. Remaining 4 traits were found to have low phenotypic and genotypic coefficient of variation. Yadav (2000) and Iftekharuddeula *et al.* (2001) documented moderate to low genotypic and phenotypic coefficients of variation for days to 50% flowering, days to maturity, panicle length, biological yield, and grain yield.

Table 3: Estimates of parameters of variability for various traits in rice genotypes.

	Mean± SE	Range	PCV (%)	GCV (%)	Heritability (%) h ² (bs)	Genetic advance (%)
DFD	8.72 ± 1.51	77.67-103.33	8.75	8.21	88.01	15.88
DSM	115.31 ± 1.76	102.67-130.67	7.03	6.51	85.78	12.42
PH	122.29 ± 4.56	82.31-168.25	21.55	20.56	90.99	40.4
FLA	57.72 ± 3.54	29.41-86.73	31.94	30.11	88.90	58.49
TTPP	9.75 ± 0.86	4.93-20.87	44.51	41.74	87.95	80.65
ETPP	8.38 ± 0.69	4.33-16.47	42.7	40.2	88.62	77.96
PL	24.80 ± 1.45	20.13-19.33	12.8	7.83	37.42	9.87
NSPP	138.09 ± 6.32	111.27-182.27	17.63	15.75	79.75	28.97
NGPP	114.21 ± 7.95	84.53-159.73	23.23	20.86	73.07	34.98
SF	82.62 ± 3.95	61.36-92.49	23.99	22.14	85.18	42.11
HI	0.42 ± 0.01	0.33-0.48	13.07	11.71	80.32	21.62
TGW	22.77 ± 0.69	19.23-26.98	11.76	10.52	79.98	19.38
GL	6.15 ± 0.12	5.2-7.36	9.96	9.31	87.38	17.94
GB	1.95 ± 0.08	1.78-2.34	10.95	7.78	50.47	11.39
LBR	3.17 ± 0.09	2.74-4.14	21.01	20.3	93.32	40.40
BYPP	44.65 ± 3.70	31.27-56.24	20.47	14.58	47.74	21.40
GYPP	18.80 ± 1.74	13.52-26.40	24.27	18.14	48.89	27.95

DFD - Days to flowering

DSM - Days to 75% maturity

PH - Plant height (cm)

FLA - Flag leaf area (cm²)

TTPP - Total tillers per plant

ETPP - effective tillers per plant

PL - Panicle length (cm)

NSPP - Number of spikelets per panicle

NGPP - Number of grains per panicle

SF - Spikelets fertility (%)

HI - Harvest index

TGW - Thousand grain weight (g)

HI - Harvest index

GL - Grain length (mm)

GB - Grain breadth (mm)

LBR - Grain L:B ratio

BYPP - Biological yield per plant (g)

LBR - Grain L:B ratio

GYPP - Grain yield per plant (g)

Heritability is a helpful quantitative parameter that takes into account how both environment and heredity affect a trait that manifests itself (Allard, 1960). Selection will be effective only when additive effects are significant and environmental effects are minimal. The estimates of heritability in broad sense (h²bs) have been classified by Robinson (1966) into three categories viz., high (> 75%), medium (50-75%) and low (<50%). Almost all the traits showed high heritability except panicle length, grains per panicle, grain breadth, biological yield per plant and grain yield per plant reveals that the variation was largely under genetic control rather than environmental effects (Table 3). These outcomes are consistent with the findings of Babu *et al.* (2011); Idris *et al.* (2012). They suggest that the heritable component has a major role in the variance, which in turn affects how certain characteristics are selected and determined. The low broad-sense heritability reported for panicle length indicates that the environment has a significant influence on the expression of these characteristics. The low heritability values linked to these qualities suggest that direct selection for them is not successful. While high heritability does not always indicate substantial genetic gain, it is crucial to take into account both heredity and genetic progress when generating estimates. Genetic advance was found to be high in most of the traits except days to 50 % flowering and 75% maturity, panicle length, thousand grain weight, grain length and grain breadth.

High heritability coupled with high genetic advance was found for plant height, flag leaf area, total tillers, effective tillers, spikelets per panicle, spikelet fertility, harvest index and grain L:B ratio suggests that variation in these traits was arise due to additive genetic effects (Table 3).The high estimates of heritability and genetic

advance observed for the above characters are broadly in agreement with earlier reports in rice. These findings were also reported by Sharma and Sharma (2005); Singh *et al.* 2008; Bughio *et al.* (2009); Sarangi *et al.* 2009; Akinwale *et al.* (2011); Garg *et al.* (2011).

Correlation analysis. Understanding the nature and magnitude of associations among traits that make up a complex trait like GY is essential for breeders who would like to improve those traits. Grain yield is the result of the accumulative relationships of a number of yield component characters. The balance or overall net effect that various yield components directly or indirectly produce by interacting with one another forms the foundation for genetic architecture of grain yield in all the crops.

Among all the traits studied, characters viz., total tillers per plant, effective tillers per plant, grain length, biological yield per plant showed significant positive correlation with grain yield per plant. Whereas, flag leaf area showed significant negative correlation with grain yield (Table 4). On the other hand, significant positive correlation was also found for traits viz., plant height with flag leaf area and grains per panicle, grain length with biological yield, thousand grain weight with biological yield and flag leaf area with grains per panicle. Plant height and flag leaf area showed significant negative correlation with total tillers per plant. These observations indicating the importance of these characters for yield improvement. Henceforth, deliberate selection of these traits would be conducted to enhance grain yield within this population of red rice ecotypes amidst temperate climates. Prior investigations by Eradasappa *et al.* (2007); Sanghera and Kashyap (2012), have substantiated a noteworthy positive correlation between these characteristics and grain yield in rice.

Table 4: Estimates of correlation coefficient among various yield and morphological traits in rice.

	DFD	DSM	PH	FLA	TPPP	ETPP	PL	NSPP	NGPP	SF	HI	TGW	GL	GB	LBR	BYPP	GYPP
DFD	1.000	0.892*	-0.251	-0.334	0.481	0.425	0.486	0.122	-0.112	0.131	0.362	0.082	0.229	-0.174	0.345	0.079	0.322
DSM		1.000	0.064	-0.104	0.283	0.219	0.393	0.432	0.170	0.027	0.110	0.188	0.039	0.243	0.396	0.100	0.182
PH			1.000	0.837*	0.727*	0.729*	0.171	0.568*	0.724*	0.315	0.399	0.303	-0.365	0.029	-0.093	-0.019	-0.531
FLA				1.000	0.701*	-0.675	0.168	0.523	0.634*	0.287	0.507	0.159	-0.414	0.222	-0.049	-0.171	0.576*
TPPP					1.000	0.988*	0.234	-0.497	0.745*	0.428	0.381	-0.132	0.489	0.205	0.324	0.361	0.697*
ETPP						1.000	0.139	0.565*	0.782*	0.446	0.331	-0.193	0.416	0.180	0.261	0.293	0.659*
PL							1.000	0.427	0.269	0.083	0.499	0.205	0.403	0.045	0.399	0.578*	0.500
NSPP								1.000	0.891*	0.486	0.232	0.415	-0.159	0.062	0.285	0.198	-0.134
NGPP									1.000	0.513	0.152	0.487	-0.228	0.154	0.026	0.152	-0.258
SF										1.000	0.207	0.005	-0.386	0.045	0.597*	-0.128	-0.480
HI											1.000	0.386	0.657*	0.173	0.053	0.437	0.514
TGW												1.000	0.598*	0.345	-0.002	0.583*	0.351
GL													1.000	0.239	0.116	0.667*	0.713*
GB														1.000	-0.323	0.121	0.147
LBR															1.000	0.182	0.001
BYPP																1.000	0.785*
GYPP																	1.000

*Significant at $p \leq 0.05$

DFD - Days to flowering
 DSM - Days to 75% maturity
 PH - Plant height (cm)
 FLA - Flag leaf area (cm²)
 TTPP - Total tillers per plant
 ETPP - effective tillers per plant
 PL - Panicle length (cm)
 NSPP - Number of spikelets per panicle
 NGPP - Number of grains per panicle
 SF - Spikelets fertility (%)
 HI - Harvest index
 TGW - Thousand grain weight (g)
 GL - Grain length (mm)
 GB - Grain breadth (mm)
 LBR - Grain L:B ratio
 BYPP - Biological yield per plant (g)
 GYPP - Grain yield per plant (g)

Path analysis. Path coefficient analysis was used to thoroughly examine the relationship between characters that contribute to yield. Path coefficient analysis was used to reveal the logic beneath the series of interactions between the various characters that contribute to yield as well as their effects. According to correlations, estimates of the direct and indirect effects

of yield-contributing traits on grain yield per plant were shown in Table 5.

Residual effect at genotypic and phenotypic path coefficient was -0.1846. Effective tillers per plant, number grains per panicle, biological yield per plant, days to 75% maturity and grain L:B ratio exhibited positive direct effect and strong association with grain yield.

Table 5: Path coefficient analysis among various yield and morphological traits in rice.

	DFD	DSM	PH	FLA	TPPP	ETPP	PL	NSPP	NGPP	SF	HI	TGW	GL	GB	LBR	BYPP	GYPP
DFD	-0.03	0.48	0.28	0.14	-1.98	1.57	-0.20	-0.14	-0.20	0.11	-0.15	-0.02	0.04	0.21	0.06	0.38	0.322
DSM	-0.02	0.53	-0.03	0.04	-1.25	0.88	-0.17	-0.44	0.43	-0.03	-0.06	-0.08	0.07	0.24	0.09	0.25	0.182
PH	0.01	0.02	-1.01	-0.38	2.84	-2.53	0.06	-0.57	1.60	-0.25	0.14	-0.15	0.01	-0.05	-0.01	-0.58	-0.531
FLA	0.01	-0.05	-0.88	-0.44	2.86	-2.45	0.08	-0.54	1.35	-0.23	0.20	-0.09	0.06	-0.04	-0.15	-0.67	-0.576*
TPPP	-0.01	0.17	0.75	0.33	-3.84	3.40	-0.07	0.52	-1.72	0.35	-0.13	0.06	0.04	0.19	0.28	0.75	0.697*
ETPP	-0.01	0.14	0.75	0.32	-3.83	3.41	-0.01	0.58	-1.74	0.35	-0.11	0.09	0.04	0.15	0.23	0.71	0.659*
PL	-0.02	0.29	0.20	0.12	-0.79	0.16	-0.32	-0.59	0.78	-0.09	-0.21	-0.14	-0.02	0.27	0.54	0.60	0.500
NSPP	0.00	0.24	-0.59	-0.24	2.03	-0.03	-0.19	-0.98	1.86	-0.39	0.09	-0.24	0.04	0.18	0.19	-0.12	-0.134
NGPP	0.00	0.11	-0.80	-0.29	3.25	-2.93	-0.12	-0.90	2.03	-0.38	0.08	-0.28	-0.04	0.02	0.15	-0.29	-0.258
SF	0.00	0.02	-0.35	-0.14	1.83	-1.63	-0.04	-0.52	1.04	-0.74	0.09	0.00	-0.03	0.36	-0.11	-0.56	-0.480
HI	-0.01	0.09	0.40	0.25	-1.43	1.11	-0.20	0.26	-0.45	0.18	-0.35	-0.23	-0.05	0.03	0.37	0.57	0.514
TGW	0.00	0.09	-0.31	-0.08	0.51	-0.65	-0.09	-0.48	1.17	0.01	-0.16	-0.49	-0.12	0.00	0.52	0.43	0.351
GL	-0.01	0.03	0.37	0.19	-1.89	1.44	-0.15	0.13	-0.48	0.31	-0.24	-0.30	-0.08	0.06	0.52	0.75	0.713*
GB	0.00	-0.16	0.05	0.12	0.73	-0.58	-0.02	0.17	0.32	-0.09	-0.07	-0.25	-0.23	-0.19	0.15	0.24	0.147
LBR	-0.01	0.23	0.09	0.03	-1.26	0.89	-0.15	-0.31	0.07	-0.46	-0.02	0.00	0.08	0.57	0.15	-0.01	-0.001*
BYPP	0.00	0.07	0.02	0.09	-1.44	1.07	-0.23	-0.25	0.42	0.11	-0.18	-0.34	-0.05	0.12	0.73	0.73	0.785

DFD - Days to flowering
 DSM - Days to 75% maturity
 PH - Plant height (cm)
 FLA - Flag leaf area (cm²)
 TTPP - Total tillers per plant
 ETPP - effective tillers per plant
 PL - Panicle length (cm)
 NSPP - Number of spikelets per panicle
 NGPP - Number of grains per panicle
 SF - Spikelets fertility (%)
 HI - Harvest index
 TGW - Thousand grain weight (g)
 GL - Grain length (mm)
 GB - Grain breadth (mm)
 LBR - Grain L:B ratio
 BYPP - Biological yield per plant (g)
 GYPP - Grain yield per plant (g)

This indicates that improvement in these above mentioned traits will perfectly reflects in the improvement of grain yield. Whereas, remaining traits showed negative direct effect on grain yield.

Positive indirect effects on grain yield was attributed by days to flowering through days to 75% maturity and effective tillers per plant, Days to 75% maturity through effective tillers per plant, plant height through number of grains per panicle, total tillers through effective

tillers, panicle length through number of grains per panicle, spikelet per plant with total tillers and grains per panicle, grains per panicle through total tillers, grain length through effective tillers, grain L:B ratio through biological yield. High negative indirect on grain yield was revealed by Days to flowering through effective tillers, plant height through effective tillers, flag leaf area through effective tillers, total tillers through grains per panicle, grains per panicle through effective tillers, harvest index through total tillers, grain L:B ratio and biological yield through total tillers per plant. These results suggests that the consideration of above-

mentioned traits on improvement in grain yield. These conclusions find support from Meenakshi *et al.* (1999); Nayak *et al.* (2001); Khedikar *et al.* (2004). Conversely, negative direct impacts on grain yield were observed for the days to flowering, effective tillers, grains per panicle as indicated by Ganesan *et al.* (1997); Nayak *et al.* (2001).

Principle component analysis. Principal component analysis (PCA) showed that the first four Eigen vectors are the most important as they have Eigen values more than one.

Table 6: Eigenvectors for the ten components of quantitatively measured traits.

	Eigen variables							
	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
Eigenvalue	6.64	3.77	2.52	1.41	0.83	0.78	0.44	0.26
Variability (%)	39.06	22.15	14.84	8.28	4.86	4.61	2.60	1.55
CUM. (%)	39.06	61.21	76.05	84.33	89.19	93.80	96.40	97.95
DFP	4.19	1.78	13.20	15.26	8.28	0.23	1.20	5.14
DSM	1.15	3.82	21.24	10.89	5.70	3.77	1.39	0.85
PH	9.14	3.62	1.20	3.06	3.99	3.27	14.11	7.91
FLA	9.01	1.24	2.41	11.60	0.81	0.10	2.48	17.04
TTPP	13.56	0.78	0.41	0.10	0.14	3.42	3.60	0.07
ETPP	12.42	1.82	0.16	0.06	0.12	4.82	7.78	0.14
PL	2.30	11.09	1.73	1.46	21.97	17.89	0.01	15.66
NSPP	2.97	12.86	7.52	0.24	6.73	0.76	10.09	4.29
NGPP	6.79	12.91	0.57	0.60	2.28	0.08	0.06	5.32
SF	6.62	2.34	11.84	1.30	1.04	4.42	20.37	0.76
HI	5.27	4.26	4.49	1.54	7.11	31.33	3.93	3.89
TGW	0.01	18.13	2.95	0.67	16.13	6.65	2.61	7.22
GL	6.83	5.96	5.59	2.71	5.42	0.02	14.04	11.43
GB	0.21	1.02	20.44	21.68	0.01	8.48	3.18	16.64
LBR	7.13	1.79	2.00	23.28	3.84	3.77	2.64	0.06
BYPP	3.04	12.77	2.20	5.55	9.45	4.90	10.16	0.01
GYPP	9.39	3.83	2.05	0.02	7.02	6.09	2.37	3.59

DFP - Days to flowering	ETPP – effective tillers per plant	HI – Harvest index	LBR – Grain L:B ratio
DSM – Days to 75% maturity	PL - Panicle length (cm)	TGW – Thousand grain weight (g)	BYPP – Biological yield per plant (g)
PH – Plant height (cm)	NSPP – Number of spikelets per panicle	HI – Harvest index	LBR – Grain L:B ratio
FLA – Flag leaf area (cm ²)	NGPP – Number of grains per panicle	GL – Grain length (mm)	GYPP – Grain yield per plant (g)
TTPP – Total tillers per plant	SF – Spikelets fertility (%)	GB – Grain breadth (mm)	

First principal component (PC1) explained 39.06 per cent of the total variation, which was mainly contributed by plant height, total tillers, effective tillers, grain length and grain yield per plant. PC2 accounted for 22.15 per cent variation and was highly attributed by panicle length, spikelets per panicle, grains per panicle and biological yield per plant. PC3 contributed 14.84 per cent of the total variance through days to 50 % flowering, days to 75% maturity and spikelets fertility. PC4 contributed 8.28 per cent to the total variability and was accounted by days to 50% flowering and 75% maturity, flag leaf area, grain breadth and grain L:B ratio(Fig. 1). Eigenvalues and proportion of accounted variance for each variable have been shown in Table 6. These results were also reflected in Fig. 2,

which depicts the correlation between traits and components. The first two principal components biplot including loadings of the various characters along with the genotypes is presented in Fig. 3. This figure indicates that the PCA showed a clear differentiation between fourteen rice genotypes from each other in terms of morphological traits and grain pericarp colour. Sudeepthi *et al.* (2020a), in their investigation utilizing principal component analysis in rice, identified days to 50% flowering as one of the major contributors to variability. Similarly, Ratnam *et al.* (2022) also reported the importance of yield contributing traits in zinc rich rice landraces which were correlated with our current investigation in red rice landraces.

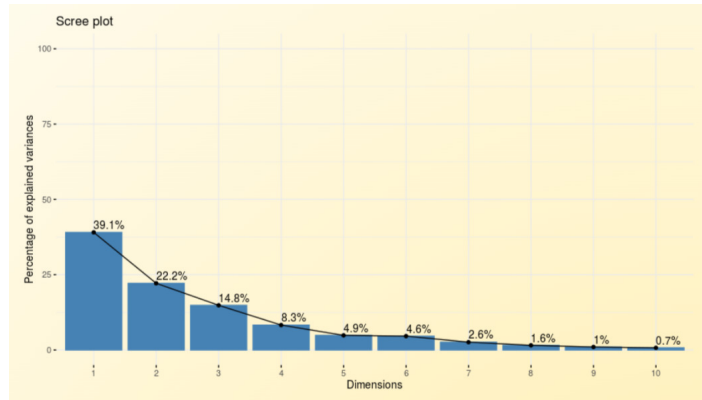


Fig. 1. Scree plot of different 10 components.

Correlation Plot of variables VS PCs

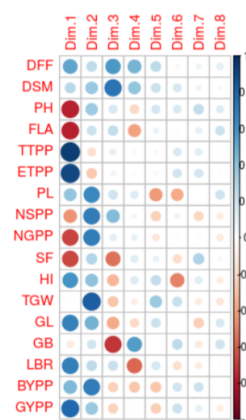


Fig. 2. Correlation between traits and components.

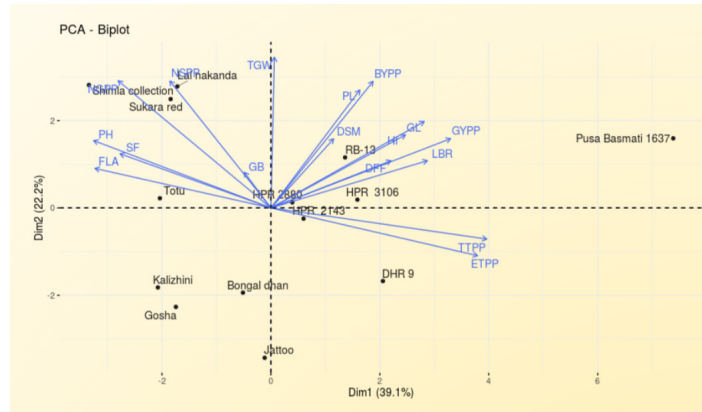


Fig. 3. Biplot of different variables with 14 observations on PC1 and PC2.

CONCLUSIONS

In summary, the findings demonstrated substantial genotypic and phenotypic variability, along with high heritability and genetic advance as a percentage of the mean. Additionally, notable positive associations and significant direct effects were observed for grains per panicle, protein content, and zinc content, underscoring their significance as valuable selection criteria for enhancing grain yield per plant in the development of high-yielding coloured rice varieties with enhanced nutritional attributes. Hybridization of these diverse genotypes is recommended to yield favourable coloured transgressive segregants, facilitating the development of

coloured rice cultivars with elevated yield potential, as well as improved grain characteristics, and nutritional composition.

FUTURE SCOPE

Genotypes which were investigated in the present study represented genetic differentiation among them in terms of morphological traits, quality traits and grain colour. Hence, can be further utilized in various breeding programs to enhance yield and quality traits for North hill zone of India.

Author contributions. NB & VN designed research. NB collected samples. NB&VN analysed data.

NB&VN wrote the paper and original draft. KB, VS, C, KB contributed in writing and editing. All the authors revised and agreed to the published version of the manuscript.

Conflict of interest. None.

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