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RESEARCH ARTICLE

Identification of superior and consistent rice (*Oryza sativa* L.) genotypes suitable for wet and dry seasons of the Northern Telangana region, India

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Abstract

The main objective of the study was to identify the high-yielding rice genotypes with promising head rice recovery suitable for both kharif (wet) and rabi (dry) seasons. Twenty-one rice genotypes were evaluated in a randomised block design (RBD) with three replications during kharif, 2022 and rabi, 2022-23 at the Regional Agricultural Research Station, Professor Jayashankar Telangana Agricultural University (PJTAU), Polasa, Jagtial, Telangana. The data was subjected to principal component analysis (PCA) and Duncan's Multiple Range Test (DMRT) to identify the traits with maximum contribution towards total genetic variation present in the genotypes and rank them based on their performance specific to season and across the seasons. The mean days to reach 50 % flowering during the dry season (103 days) were significantly higher than the wet season (93 days). The other traits, viz. effective bearing tillers/m^2, plant height, panicle length, test weight and head rice recovery were higher during the wet season than in the dry season. Yield in the dry season (7494 kg/ha) was significantly higher than in the wet season (7188 kg/ha). High temperatures during the grain development stage resulted in low head rice recovery in the dry season (31 %) compared to the wet season (53 %). Principal component analysis revealed that the first two PCs captured 72.5 % and 79.6 % of total variance during wet and dry seasons, respectively. Panicle length, effective bearing tillers/m^2 and test weight were identified as primary drivers of genotypic divergence in both seasons. The genotypes, G_4, G_3, G_2 and G_1 for yield and G_{13}, G_{16}, G_{18} and G_{19} for head rice recovery were identified as best genotypes for both wet and dry seasons.

Keywords: biplot analysis; dry season; genetic variance; grain yield; principal components; rice; wet season

Introduction

Rice, one of the major food crops of the world, plays a crucial role in the social and economic development of the Asian continent. The major rice cultivating countries of this continent include China, India, Pakistan, Bangladesh, the Philippines, Indonesia, Vietnam, Thailand and Myanmar. Of these, China and India are the global leaders in terms of area of cultivation and production. In India, rice occupies a major cultivable area of 477.3 lakh ha with production of 1364.37 lakh tonnes and productivity of 2859 kg/ha. Telangana, the eleventh largest state of the country, occupied second position in the area of rice cultivation with 47.04 lakh ha after Uttar Pradesh (72.25 lakh ha) (1). The rice crop can be cultivated during both the wet season (kharif) and the dry season (rabi) in Telangana, occupying its major area under kharif. For the past five years, the area under rabi increased enormously in Telangana due to increased irrigation facilities and stood first in position in the country with an area of 22.17 lakh ha. The climate conditions during the crop period are completely different for both seasons in Telangana, especially in the northern part of the state. During kharif (June to October), the crop experiences cloudy weather conditions, frequent rainfall and average normal temperatures. In contrast, rabi (November to April) records a varying range of temperature like low (10 to 18 °C) at the nursery/seedling stage to high (38 to 45 °C) during harvesting time. There is a large diurnal variation in rabi in the Telangana region, with colder nights and bright sunny days and the temperature gradually increases from March onwards, with very low relative humidity, which is very favourable for higher yields (2). The rice cultivation during rabi is facing some major challenges like increased crop duration, seedling cold injury, zinc deficiency, incidence of blast and stem borer, occurrence of hail storms at the time of harvest and low head rice recovery, etc. One of the major causes for increased crop duration (10 to 20 days) during rabi is the recording of low temperatures (10 to 15 °C) during the nursery and seedling stage of the crop. Cold stress in rice leads to stunted growth of seedlings, delays flowering, lengthens the growth cycle, reduces tillering, increases plant mortality and causes significant yield loss in rice production (3, 4). Another important bottleneck of rabi rice cultivation is low head rice recovery from the harvested produce. Occurrence of high temperatures (36 to 42 °C) during the grain development stage is the main cause of obtaining more brokens during the milling process. Hence, head rice recovery has been considered as one of the important criteria for selecting new varieties for release (5). To overcome the low head rice recovery problem during rabi, harvesting the crop by the end of March serves as the best measure that avoids the grain development stage being exposed to high temperatures. Cultivation of short-duration varieties (130-135 days duration), ensuring completion of their sowings by the 1st week of December, could result in early harvestings (end of March or during the 1st fortnight of April). These early harvestings could also save the crop from hailstorms occurring from the 2nd fortnight of April. In addition, testing and identification of genotypes exhibiting good head rice recovery during the rabi season will benefit the farmers who sow the paddy beyond the sowing window and harvest the produce during the peak hot summer.

Principal component analysis (PCA) is used to identify the traits with maximum contribution towards total genetic variation present in the experimental material. This technique helps in the identification of traits that help in distinguishing selected genotypes based on similarities in one or more traits and classifying the genotypes into separate groups (6, 7). In the present study, PCA was employed to determine the trait correlation and genetic diversity among the genotypes studied under two different weather conditions. Duncan's multiple range test (DMRT) was used to identify the superior genotypes specific to each season and also to identify consistent genotypes for both kharif and rabi. As the northern part of Telangana experiences major climatic challenges like severe cold during the seedling stage and high temperatures, as well as risks of hailstorms during harvest in rabi, the present study provides insight into identifying high-yielding genotypes showing reduced prolonged duration and good head rice recovery, especially for the rabi season, with reliable performance during kharif.

Materials and Methods

Experimental site

The present investigation was carried out at the Regional Agricultural Research Station, Jagtial, PJTAU, located at Northern part of the Telangana state, India, with GPS coordinates of 18° 50'20.24" N latitude, 78° 56'54.20" E longitude and 249 m above mean sea level.

Experimental material, layout and season of investigation

The experiment was carried out during kharif 2022 and rabi 2022-23 with 21 elite rice genotypes (Table 1). The main aim of choosing these genotypes for the present study was to find out their suitability for cultivation during both kharif and rabi seasons in Telangana. The spacing and number of replications adapted were the same for both seasons. The material was laid out in RBD with three replications, adapting the spacing of 15 cm between the rows and within the rows. During kharif, each entry was planted in the area of 9.65 m^2 plot with the application of N, P and K fertiliser at 100, 50 and 40 kg/ha, respectively. The material was sown on 26th June, 2022 and was transplanted on 17th July, 2022. During rabi, each entry was planted in the area of 9.65 m^2 plot size with the application of N, P and K fertiliser at 120, 60 and 40 kg/ha, respectively. The material was sown on 1st December, 2022 and was transplanted on 29th December, 2022. The weather particulars during crop grown period are presented in Table 2. The recommended doses of nitrogen and phosphorus were higher during rabi than kharif. Losses due to leaching and denitrification are more in rabi, hence an excess dose of nitrogen was recommended to compensate for these losses. Similarly, environmental conditions during rabi accelerates conversion of a larger proportion of applied phosphorus into insoluble fixed form and a low amount (20-30 %) of phosphorous only was available to the plants in soluble form. All required plant protection measures and management practices were adapted uniformly for both kharif and rabi to raise a healthy crop. In both seasons, the gross plot area was taken as the net plot area for recording the traits, grain yield and days to 50 % flowering.

Data recording parameters and statistical analysis

Data were recorded at maturity on 10 random plants for each entry from each replication for effective bearing tillers/m^2 and

Table 1. List of 21 rice genotypes studied in the present investigation

Entry No	Entry name	Grain type	Duration	Developed by
G_1	JGL 38917	Long slender	Short	RARS, Jagtial, PJTAU
G_2	WGL 1533	Long slender	Short	RARS, Warangal, PJTAU
G_3	RNR 35008	Long slender	Short	RRU, ARI, Hyderabad, PJTAU
G_4	JGL 38053	Long slender	Short	RARS, Jagtial, PJTAU
G_5	RDR 2747	Long slender	Short	RS&RRS, Rudrur, PJTAU
G_6	KNM 118	Long slender	Short	ARS, Kunaram, PJTAU
G_7	WGL 1537	Long slender	Short	RARS, Warangal, PJTAU
G_8	RNR 35131	Long slender	Short	RRU, ARI, Hyderabad, PJTAU
G_9	JGL 18047	Long slender	Short	RARS, Jagtial, PJTAU
G_{10}	KNM 11505	Long slender	Short	ARS, Kunaram, PJTAU
G_{11}	RNR 35105	Long slender	Short	RRU, ARI, Hyderabad, PJTAU
G_{12}	RDR 2742	Medium slender	Short	RS&RRS, Rudrur, PJTAU
G_{13}	KNM 1638	Medium slender	Mid early	ARS, Kunaram, PJTAU
G_{14}	KNM 11601	Medium slender	Medium	ARS, Kunaram, PJTAU
G_{15}	RDR 2751	Medium slender	Short	RS&RRS, Rudrur, PJTAU
G_{16}	RNR 15048	Short slender	Mid early	RRU, ARI, Hyderabad, PJTAU
G_{17}	WGL 1560	Long slender	Short	RARS, Warangal, PJTAU
G_{18}	KNM 12368	Short slender	Short	ARS, Kunaram, PJTAU
G_{19}	KNM 12445	Short slender	Mid early	ARS, Kunaram, PJTAU
G_{20}	RNR 31451	Short slender	Mid early	RRU, ARI, Hyderabad, PJTAU
G_{21}	POOJA	Short slender	Medium	Private seed industry

Table 2. Mean weather data of the *kharif* and *rabi* seasons during crop grown period

Stage of the crop	Max. Temp		Min. Temp		Bright sunshine hours		No. of rainy days	
	Kharif	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*	*Kharif*	*Rabi*
Sowing to flowering	30.9	32.3	23.2	17.0	4.12	7.41	44	1
Flowering to maturity	31.5	37.6	19.0	22.5	7.15	8.0	4	1

plant height (cm). Panicle length was recorded from 10 random panicles from each entry and threshed seed from these 10 panicles was used to count the number of grains per panicle, whereas a random sample from each entry was used to record 1000 grain weight (test weight). Days to 50 % flowering and grain yield (kg/ha) were recorded on whole plot basis. 100 g of a random seed sample from each entry was used to record the head rice recovery.

Principal component analysis was conducted to reduce the larger data sets into smaller variables known as principal components, which capture maximum variance and to identify the proportional contribution of each trait to the total variation present among the genotypes. Correlations between original variables and the respective PCs were calculated and PCs with eigenvalues greater than one were selected (8). Using R software version RStudio/2025.09.0+387, the mean values of all the traits were compared season-wise, genotype-wise and interaction-wise by Duncan's new multiple range test (DMRT) at 5 % level of significance to identify superior genotypes specific to each season and for both kharif and rabi. Before analysis, the assumptions of analysis of variance (ANOVA) were examined (9). Normality of residuals was tested using the Shapiro–Wilk test and homogeneity of variances was assessed using Levene's test. Since the assumptions were satisfied, ANOVA was performed.

Results and Discussions

Comparison of trait means between kharif and rabi seasons

The mean data of 21 rice genotypes for eight characters were presented for both kharif (Table 3) and rabi (Table 4). Days to 50 % flowering is one of the important traits in rice, based on which the cultures are grouped into short, medium and long duration varieties. The mean days to flower 50 % during kharif (93 days) were less and significantly differed with rabi (107 days). Low temperatures at active growth stages during rabi (Fig. 1) resulted in a prolonged vegetative phase, which eventually delayed flowering (10). Compared to the kharif season (23.2 °C), the mean minimum temperatures recorded during the rabi season were very low (17 °C) (Table 2) during the active crop growth period. The growth rate at each stage is influenced by various environmental factors, with temperature being one of the most significant factors affecting rice growth (11). Short-duration varieties with high yield potential are gaining much importance in rice cultivation as they require less water during their crop period compared to medium and long-duration varieties. The long maturity varieties demand significant amounts of irrigation, especially in areas dependent on seasonal rainfall or with erratic monsoons (12). Moreover, on average, producing one kilogram of rice requires between 3000 and 5000 L of water, making it one of the most water-demanding crops globally (13).

The mean values for effective bearing tillers/m^2, one of the important yield attributing characters, varied significantly between kharif (392) and rabi (379). Plant height, which directly correlated to biomass, was low during rabi (89.8 cm) compared to kharif (112.8 cm). Plant height is not only a decisive factor in plant architecture, but also an important agronomic trait that is directly linked to the harvest index and yield potential (14). Closely related to biomass production, plant height is an important morphological trait affecting yield performance (15). Adequate rainfall during kharif promoted higher crop growth, whereas low temperatures and a negligible amount of rainfall during the active growth stage of the crop are the major causes for biomass reduction during rabi (Fig. 1). Panicle length also contributes much towards higher yields in rice, as the varieties with greater panicle length have chances of accommodating a larger number of grains. This trait recorded a mean value of 24 cm during kharif and 22.60 cm during rabi. Test weight plays a major role in yield enhancement. The mean test weight values recorded during rabi (18.05 g) were significantly lower than kharif (20.64 g). High

Table 3. Mean performance of 21 rice genotypes for yield and yield attributing traits evaluated during the kharif season

Genotype	DFF	EBTSM	PH (cm)	PL (cm)	TW (g)	NGP	SY (kg/ha)	HRR (%)
G_1	88^{gh}	340^{gh}	130.3^{b}	26^{a-c}	26.23^{b}	213^{c-e}	8089^{ac}	61^{a-e}
G_2	91^{e-h}	333^{h}	118.4^{cd}	25^{cd}	23.93^{d}	189^{d-g}	8011^{a-c}	62^{ab}
G_3	91^{e-h}	369^{d-h}	109.4^{fg}	24^{d}	27.67^{a}	174^{e-h}	8558^{a}	56^{d-g}
G_4	90^{e-h}	339^{gh}	112.9^{e-g}	26^{a-c}	25.77^{b}	218^{c-e}	8615^{a}	56^{d-g}
G_5	92^{ef}	402^{b-f}	118.5^{cd}	26^{a-c}	25.27^{bc}	123^{i}	7181^{a-d}	34^{k}
G_6	88^{gh}	398^{b-f}	110.8^{e-g}	25^{b-d}	25.53^{b}	120^{i}	6879^{b-e}	47^{ij}
G_7	88^{h}	370^{d-h}	118.1^{cd}	27^{ab}	25.93^{b}	193^{d-g}	7405^{a-d}	45^{j}
G_8	88^{h}	411^{b-d}	112.1^{e-g}	25^{b-d}	25.73^{b}	141^{hi}	8027^{a-c}	52^{g-i}
G_9	90^{e-h}	395^{b-f}	107.7^{gh}	24^{d}	25.08^{b-d}	127^{i}	6846^{b-e}	58^{a-f}
G_{10}	92^{e-g}	434^{ab}	118.5^{cd}	24^{d}	24.2^{cd}	148^{g-i}	7620^{a-d}	55^{f-h}
G_{11}	88^{gh}	382^{c-g}	122.7^{c}	27^{a}	25.6^{b}	175^{e-h}	8426^{a}	47^{ij}
G_{12}	91^{e-h}	411^{b-d}	103.9^{hi}	22^{e}	15.43^{f}	214^{c-e}	6718^{c-e}	55^{e-g}
G_{13}	97^{cd}	362^{e-h}	113.7^{d-f}	24^{d}	15.93^{f}	262^{ab}	8565^{a}	49^{h-j}
G_{14}	101^{ab}	456^{a}	107.9^{gh}	22^{e}	16^{f}	189^{d-g}	8227^{ab}	61^{a-d}
G_{15}	88^{f-h}	459^{a}	83.3^{k}	21^{ef}	17.4^{e}	136^{hi}	3944^{h}	27^{l}
G_{16}	97^{cd}	403^{b-f}	141.9^{a}	26^{a-c}	12.83^{gh}	280^{a}	5704^{e-g}	64^{a}
G_{17}	94^{de}	364^{e-h}	122.2^{c}	26^{a-d}	23.93^{d}	205^{d-f}	7988^{a-c}	56^{c-g}
G_{18}	93^{de}	358^{f-h}	101.9^{ij}	22^{e}	11.57^{h}	256^{a-c}	7889^{a-c}	62^{a-c}
G_{19}	97^{cd}	420^{a-c}	115.6^{de}	25^{b-d}	12.77^{gh}	160^{f-i}	6406^{d-f}	57^{b-g}
G_{20}	98^{bc}	420^{a-c}	98.7^{j}	20^{f}	13.1^{g}	224^{b-d}	5126^{f-h}	49^{h-j}
G_{21}	104^{a}	405^{b-e}	100.8^{ij}	19^{f}	13.5^{g}	204^{d-f}	4729^{gh}	53^{f-h}
Mean	93	392	112.8	24	20.64	188	7188	53
SEM (±)	1.16	13.78	1.62	0.59	0.42	13.93	436.96	1.71
$LSD_{0.05}$	3.31	39.40	4.63	1.69	1.22	39.82	1248.94	4.89
CV (%)	2.17	6.09	2.49	4.28	3.58	12.82	10.52	5.63

Superscript letters in the table represent the results of Duncan's multiple range test (DMRT) at a 5 % significance level. Means that share the same letter are not significantly different from each other, indicating statistical similarity among those treatments or groups. DFF – Days to 50 % flowering, EBTSM – Effective bearing tillers per square meter, PH – Plant height, PL – Panicle length, TW – Test weight, NGP – Number of grains per panicle, SY – Seed yield, HRR (%) – Head rice recovery (percentage).

Table 4. Mean performance of 21 rice genotypes for yield and yield attributing traits evaluated during rabi season

Genotype	DFF	EBTSM	PH (cm)	PL (cm)	TW (g)	NGP	SY (kg/ha)	HRR (%)
G_1	104^{ij}	327^{f}	105.7^{a}	23.93^{b-e}	21.94^{c-f}	152^{c-f}	8657^{b-d}	18^{jk}
G_2	105^{g-i}	333^{ef}	101^{b}	26.33^{a}	20.22^{g}	156^{c-f}	8933^{ab}	21^{ij}
G_3	105^{g-i}	377^{a-c}	92.3^{d-f}	22.6^{d-f}	23.18^{bc}	118^{f-j}	8981^{ab}	28^{gh}
G_4	106^{e}	334^{d-f}	94.4^{c-e}	26.33^{a}	21.31^{e-g}	203^{ab}	9848^{a}	21^{i-k}
G_5	104^{hi}	383^{a-c}	90.2^{e-g}	23.93^{b-e}	21.32^{e-g}	100^{h-j}	7814^{c-e}	21^{ij}
G_6	105^{f-h}	393^{a-c}	92.7^{d-f}	22.53^{ef}	24.08^{ab}	104^{g-j}	7931^{b-e}	36^{ef}
G_7	108^{d}	364^{c-f}	105.5^{a}	25.03^{ab}	21.87^{d-f}	139^{e-h}	8874^{a-c}	24^{hi}
G_8	106^{ef}	372^{b-e}	88.9^{f-h}	24.07^{b-d}	22.58^{c-e}	111^{f-j}	8059^{b-e}	17^{j-l}
G_9	105^{g-i}	402^{a-c}	88.3^{f-h}	22.53^{ef}	24.46^{a}	82^{j}	7036^{e-i}	31^{fg}
G_{10}	105^{g-i}	381^{a-c}	94.7^{cd}	23.2^{c-f}	20.94^{fg}	126^{f-j}	6694^{f-i}	30^{g}
G_{11}	103^{j}	383^{a-c}	88.8^{f-h}	23.53^{c-e}	22.86^{b-d}	135^{e-h}	7651^{d-f}	12^{l}
G_{12}	105^{fg}	377^{a-d}	78.1^{jk}	20.07^{g}	13.27^{hi}	147^{d-g}	7565^{e-g}	28^{gh}
G_{13}	115^{a}	381^{a-c}	86.1^{gh}	21.73^{f}	13.32^{hi}	173^{b-e}	7019^{e-i}	48^{bc}
G_{14}	114^{ab}	397^{a-c}	81.5^{ij}	19.6^{g}	12.59^{ij}	136^{e-h}	7420^{e-g}	44^{cd}
G_{15}	108^{d}	409^{ab}	69.1^{l}	18.93^{gh}	14.22^{h}	87^{ij}	4853^{j}	16^{kl}
G_{16}	104^{hi}	365^{c-f}	97.3^{bc}	24.6^{bc}	10.25^{k}	196^{a-c}	6028^{i}	51^{ab}
G_{17}	105^{g-i}	381^{a-c}	100.7^{b}	24.2^{bc}	22.8^{cd}	138^{e-h}	7924^{b-e}	20^{i-k}
G_{18}	114^{b}	399^{a-c}	84.7^{hi}	21.93^{f}	10.37^{k}	218^{a}	6549^{g-i}	54^{a}
G_{19}	110^{c}	362^{c-f}	95.7^{cd}	24.4^{bc}	11.39^{jk}	189^{a-d}	6138^{hi}	52^{ab}
G_{20}	108^{d}	418^{a}	75.1^{k}	17.53^{h}	12.71^{i}	132^{e-i}	7119^{e-h}	31^{g}
G_{21}	108^{d}	418^{a}	76.7^{k}	17.6^{h}	13.53^{hi}	135^{e-h}	6273^{hi}	40^{de}
Mean	107	379	89.8	23	18.05	142	7494	31
SEM (±)	0.32	15.01	1.51	0.52	0.44	15.94	377.57	1.80
$LSD_{0.05}$	0.92	42.91	4.40	1.48	1.27	45.58	1079.19	5.15
CV (%)	0.52	6.86	2.96	3.99	4.26	19.50	8.82	10.15

Superscript letters in the table represent the results of Duncan's multiple range test (DMRT) at a 5 % significance level. Means that share the same letter are not significantly different from each other, indicating statistical similarity among those treatments or groups. DFF – Days to 50 % flowering, EBTSM – Effective bearing tillers per square meter, PH – Plant height, PL – Panicle length, TW – Test weight, NGP – Number of grains per panicle, SY – Seed yield, HRR (%) – Head rice recovery (percentage).

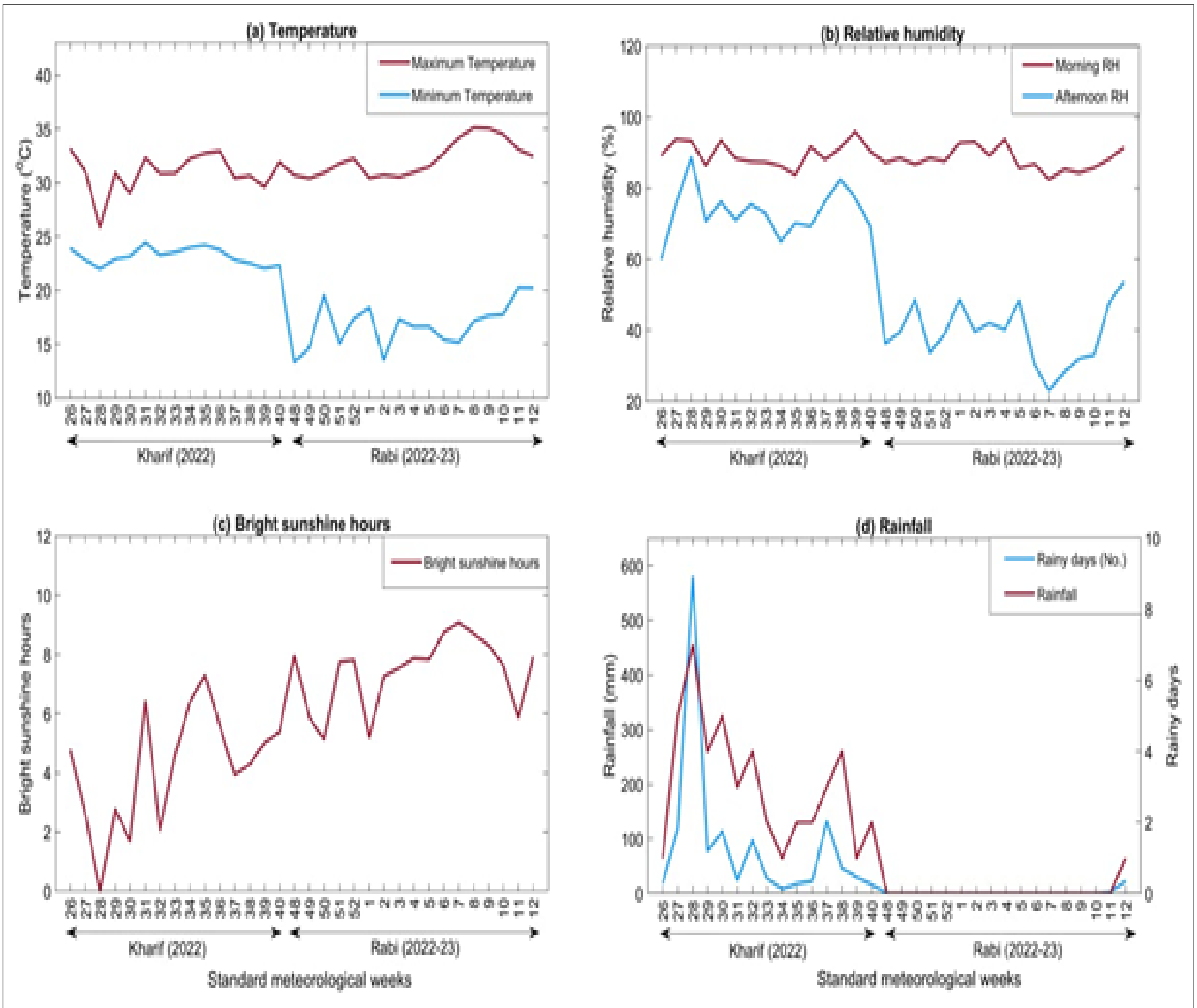

Fig. 1. Graphs showing the mean temperatures (max. and min.), relative humidity, bright sunshine hours and rainfall of standard meteorological weeks during the sowing to flowering stage of rice crop in kharif and rabi seasons.

maximum temperatures recorded during rabi at the grain development stage could shorten the grain development period and reduce the final grain weight. Both high night temperature (22/34 °C day/night) and high day temperature (34/22 °C day/night) significantly reduced the grain weight as well as the growth duration in rice, as shown in Fig. 2 (16). The trait number of grains per panicle also exhibited a significant difference between kharif (188) and rabi (142). In rice, yield is determined by indirect traits like plant height and panicle length as well as direct traits like panicle number per plant, filled grains per panicle and 1000 grain weight (17, 18). Head rice recovery is the trait that fluctuates most depending on the season of cultivation. Post-harvest handling of paddy plays a key role in obtaining less broken rice during the milling process. Generally, rice grain holds around 22–24 % moisture at the time of harvest. But the optimum grain moisture content for effective milling is around 12-13 %. This needs proper drying of paddy after harvest to bring the grain moisture content to the optimum level. In the present study, this trait recorded a high mean value of 53 % in kharif as compared to 31 % of rabi. The highest head rice recovery recorded during kharif was 64, whereas it was limited to 54 % during rabi. The low mean values exhibited during rabi could be due to recording of high mean maximum temperatures (37.6 °C) compared to kharif (31.5 °C) at grain development stage (Table 2 & Fig. 2). High temperatures for prolonged duration at the early grain filling stage increases the chalkiness rate and decreases the brown rice rate, milled rice rate and head rice rate (19). Yield, the complex dependent variable, exhibited a significant difference between the seasons, with high mean values recorded during rabi (7494 kg/ha) compared to kharif (7188 kg/ha). The higher yields in rabi are due to increased solar radiation and less cloudiness, which enhances photosynthesis. Similar findings were reported by earlier studies in rice (20, 21).

Superior genotypes suitable for both seasons and specific to the season

Most of the rice varieties released till today are specific to cultivate either in kharif or in rabi. In Telangana, rice cultivation during kharif starts in the end of May and ends in October. Due to a long sowing window (end of May to the 1st week of August), varieties belonging to all maturity groups, like long, medium and short duration can be cultivated during this season. But, except for short-duration cultures, medium and long-duration varieties are not suitable to cultivate during rabi as long-duration varieties could face the problems of hailstorms at the time of harvest and high temperatures during the grain development stage, which results in low head rice recovery. Hence, identification of short-duration varieties that exhibit less difference in flowering duration between kharif and rabi, having good yield potential along with good head rice recovery, is gaining much attention among the rice breeders. In the present investigation, three characters, viz. days to 50 % flowering, grain yield and head rice recovery, were taken into consideration for the identification of superior genotypes specific to kharif and rabi and suitable for both seasons. The remaining traits, viz. plant height, effective bearing tillers/m^2, test weight and number of grains/panicle, however, contribute directly or indirectly to the final yield.

During kharif, the genotypes G_4, G_{13}, G_3, G_{11}, G_{14}, G_1, G_8, G_2, G_{17} and G_{18} performed well for seed yield. When high yield along with good head rice recovery were considered, G_4 (8615 kg/ha,

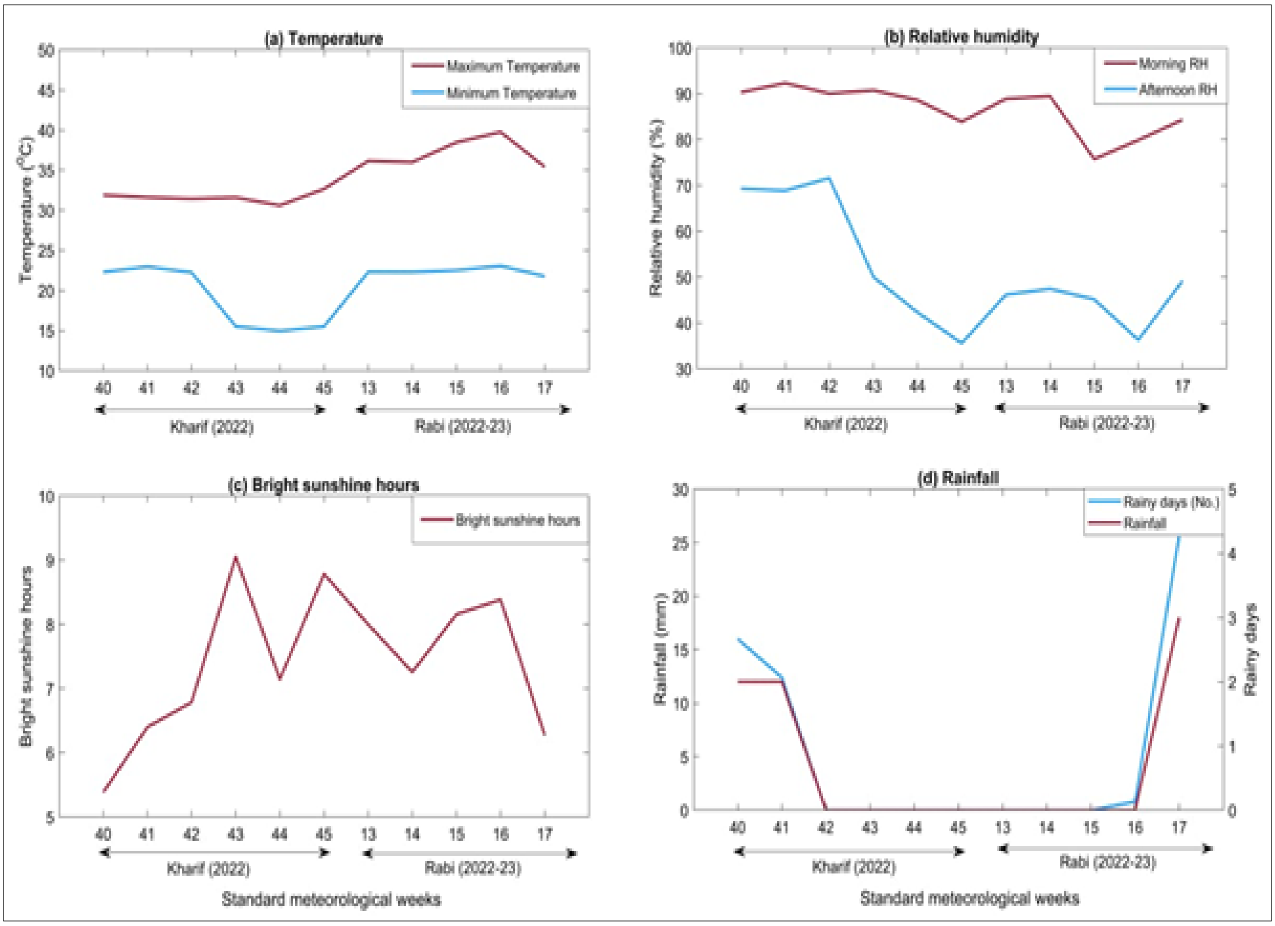

Fig. 2. Graphs showing the mean temperatures (max. and min.), relative humidity, bright sunshine hours and rainfall of standard meteorological weeks during the flowering to maturity stage of rice crop in kharif and rabi seasons.

56 %), G_3 (8558 kg/ha, 56 %), G_{14}(8227 kg/ha, 61 %), G_1 (8089 kg/ha, 61 %), G_2 (8011 kg/ha, 62 %), G_{17} (7988 kg/ha, 56 %) and G_{18} (7889 kg/ha, 62 %) were identified as promising cultures (Table 3). These genotypes even completed the crop cycle between 120-130 days and are considered as short duration varieties. Hence, these varieties are said to be promising for kharif cultivation as they exhibited good yield potential, short duration nature, along with high head rice recovery. The genotypes G_9 and $G_{16,}$ even though posses high head rice recovery and exhibited a short duration nature, were considered as inferior due to low yield potential. For rabi, the genotypes G_4, G_3, G_2, G_7, G_1, G_8, G_8 and G_{17} were found promising for grain yield, but none of these performed well in terms of head rice recovery and most of these genotypes recorded low mean values for days to 50 % flowering and completed the crop cycle within 135 days (Table 4). However, G18, G19 and G16 registered good means values for the trait head rice recovery.

Two-way ANOVA revealed that season, genotype and their interaction (genotype × season) had a significant effect (*$p \leq 0.05$*) on days to 50 % flowering, head rice recovery and seed yield. G_1, G_6, G_8, G_9 and G_{11} were identified as early maturing genotypes (Table 5). High head rice recovery was recorded by G_{18} (58 %), G_{16} (57 %) and G_{19} (55 %), where G_{15} recorded the least (21 %). The mean yield varied from 4398 kg/ha (G_{15}) to 9232 kg/ha (G_4) indicated substantial genetic diversity among genotypes. Based on yield potential and flowering period, G_4, G_3, G_2 and G_1 were identified as the most favourable genotypes for both seasons. The genotypes, G_{21}, G_{16}, G_{20} and G_{17}recorded the least difference in flowering duration between the seasons, which could be due to their early vigour and seedling cold tolerance nature. Further, these genotypes could be used as donors for the development of short-duration varieties suitable for both seasons. For head rice recovery, an important grain physical quality parameter that actually determines the price in the market, G_{19} was identified as a stable performer for both kharif and rabi. Similarly, G_{16} and G_{18} registered high values in both seasons. Four genotypes, namely, G_{13}, G_{16}, G_{18} and $G_{19,}$ could serve as the best source for the development of rice varieties with high head rice recovery for both kharif and rabi.

Table 5. Combined analysis of both kharif and rabi seasons for Days to 50 % flowering, Head rice recovery and seed yield

Genotypes	DFF			HRR (%)			Yield (kg/ha)		
	Kharif	*Rabi*	Pooled mean	*Kharif*	*Rabi*	Pooled mean	*Kharif*	*Rabi*	Pooled mean
G_1	88^{k}	104^{ef}	96^{gh}	61^{a-d}	18^{r}	39^{f}	8089^{b-g}	8657^{a-c}	8373^{a-d}
G_2	91^{ij}	105^{ef}	98^{e-g}	62^{ab}	21^{p-r}	42^{ef}	8011^{b-g}	8933^{ab}	8472^{a-c}
G_3	91^{ij}	105^{ef}	98^{ef}	56^{c-f}	28^{m-o}	42^{ef}	8558^{a-d}	8981^{ab}	8770^{ab}
G_4	90^{jk}	106^{c-e}	98^{ef}	56^{c-f}	21^{p-r}	39^{f}	8615^{a-c}	9848^{a}	9232^{a}
G_5	92^{ij}	104^{ef}	98^{ef}	34^{lm}	21^{p-r}	28^{h}	7181^{d-k}	7814^{b-i}	7498^{d-g}
G_6	88^{k}	105^{d-f}	97^{f--h}	47^{hi}	36^{kl}	42^{ef}	6879^{f-l}	7931^{b-h}	7405^{e-g}
G_7	88^{k}	108^{b-d}	98^{e-g}	45^{ij}	24^{o-q}	35^{g}	7405^{c-k}	8874^{ab}	8139^{b-e}
G_8	88^{k}	106^{c-f}	97^{f-h}	52^{e-h}	17^{rs}	35^{g}	8027^{b-g}	8059^{b-g}	8043^{b-f}
G_9	90^{jk}	105^{ef}	97^{e-h}	58^{a-e}	31^{l-n}	45^{de}	6846^{f-l}	7036^{e-l}	6941^{g-i}
G_{10}	92^{ij}	105^{ef}	98^{ef}	55^{e-g}	30^{mn}	42^{ef}	7620^{b-j}	6694^{g-l}	7157^{f-h}
G_{11}	88^{k}	103^{f}	96^{h}	47^{hi}	12^{s}	30^{h}	8426^{b-e}	7651^{b-j}	8039^{b-f}
G_{12}	91^{ij}	105^{d-f}	98^{ef}	55^{d-f}	28^{m-o}	42^{ef}	6718^{g-l}	7565^{b-j}	7142^{f-h}
G_{13}	97^{h}	115^{a}	106^{b}	49^{g-i}	48^{hi}	49^{c}	8565^{a-d}	7019^{e-l}	7792^{c-g}
G_{14}	101^{g}	114^{a}	108^{a}	61^{a-d}	44^{ij}	52^{b}	8227^{b-f}	7420^{c-k}	7823^{b-g}
G_{15}	88^{k}	108^{b-d}	98^{ef}	27^{n-p}	16^{rs}	21^{i}	3944^{p}	4853^{n-p}	4398^{k}
G_{16}	97^{h}	104^{ef}	101^{d}	64^{a}	51^{f-h}	57^{a}	5704^{l-o}	6028^{k-n}	5866^{j}
G_{17}	94^{i}	105^{ef}	99^{de}	56^{c-f}	20^{qr}	38^{f}	7988^{b-g}	7924^{b-h}	7956^{b-f}
G_{18}	93^{i}	114^{a}	104^{c}	62^{a-c}	54^{e-g}	58^{a}	7889^{b-h}	6549^{h-l}	7219^{e-g}
G_{19}	97^{h}	110^{b}	103^{c}	57^{b-f}	52^{f-h}	55^{ab}	6406^{i-m}	6138^{k-n}	6272^{h-j}
G_{20}	98^{h}	108^{b-d}	103^{c}	49^{g-i}	31^{l-n}	40^{f}	5126^{m-p}	7119^{e-k}	6123^{ij}
G_{21}	104^{ef}	108^{bc}	106^{ab}	53^{e-h}	40^{jk}	46^{cd}	4729^{op}	6273^{j-m}	5501^{j}
Mean	93	107	100	53	31	42	7188	7494	7341
SEM (±) (Seasons vs Genotypes)		0.85			1.83			411.68	
$LSD_{0.05}$ (Seasons)		0.52			1.12			252.73	
$LSD_{0.05}$ (Genotypes)		1.68			3.63			818.97	
$LSD_{0.05}$ (Seasons Vs Genotypes)		2.38			5.13			1158.20	
CV (%)		1.47			7.57			9.71	

Superscript letters in the table represent the results of Duncan's multiple range test (DMRT) at a 5 % significance level. Means that share the same letter are not significantly different from each other, indicating statistical similarity among those treatments or groups. DFF – Days to 50 % flowering, HRR (%) – Head rice recovery (percentage).

Table 6. Eigen values, percentage of variance and cumulative variance of the first two principal components of rice for the kharif and rabi seasons

	Kharif		Rabi	
Principal components	**PC1**	**PC2**	**PC1**	**PC2**
Eigen value	3.443	2.356	4.076	2.292
percentage of variance	43.047	29.454	50.952	28.652
Cumulative percentage	43.047	72.501	50.952	79.605
Individual characters' PC score				
Days to 50 % flowering	0.328	0.396	0.333	0.302
Effective bearing tillers/m^2	0.378	-0.236	0.387	-0.329
Plant height	-0.379	0.257	-0.403	0.271
Panicle length	-0.479	-0.053	-0.413	0.271
Test weight	-0.416	-0.342	-0.397	-0.315
Number of grains/panicle	0.027	0.571	0.025	0.615
Seed yield	-0.423	0.128	0.392	-0.048
Head rice recovery	-0.143	0.506	0.304	0.415

Principal component analysis

Eigenvalues and proportion of total genetic variance

Principal component analysis was carried out for each season. Eigenvalues, percentage of variance and PC scores for individual variables were presented in Table 6. In the present investigation, principal components possessing eigenvalues of more than 1 only were considered as they capture the major portion of genetic variation present in the experimental material. If the eigenvalue is less than one, it indicates that the explanatory efficacy of the principal components is inferior to the average explanatory efficacy of the original variables (22). Out of eight, two components, PC1 and PC2, explained the highest proportion of total variation. The cumulative percentage of variance explained by these two components was 72.5 % and 79.6 % during kharif and rabi, respectively. Hence, these two PCs are said to accommodate a substantial amount of total genetic variance present in genotypes and the remaining components hold a relatively small proportion of total variance. 73.19 %, 70.34 % and 64.81 % of the total genetic variation captured by the first three PCs in seasons 1, 2 and 3, respectively was reported in previous studies in rice (23).

The contribution of each trait towards the concerned PC is denoted by the factor loading of that trait on the respective principal component. Factor loadings of each variable to the respective PC for two seasons were illustrated in Table 6, which demonstrated how differently the traits contributed to genetic diversity in kharif and rabi. The value and sign of the factor loading of each trait explain the relation of that trait with the concerned PC and the proportion of variability expressed by that trait towards the principal component. In the present study, most of the traits showed positive loading towards either of the principal components; however, the number of grains per panicle exhibited more than 0.5 loading in PC2 for both kharif (0.571) and rabi (0.615).

PCA results revealed differential expression of the traits between the seasons. In kharif, days to 50 % flowering and effective bearing tillers/m^2 contributed more towards the total variability captured by PC1 and had a positive correlation with it. The traits, panicle length, seed yield, test weight and plant height showed negative correlation with PC1, whereas number of grains/panicle and head rice recovery exhibited negligible proportion of contribution towards total variance. In PC2, the number of grains/panicle, head rice recovery and days to 50 % flowering recorded a strong positive influence for total genetic variation. In PC1, all the variables except seed yield and head rice recovery exhibited a similar trend for both kharif and rabi. These two traits had a positive correlation in rabi and a negative influence in kharif with PC1. The differential expression of these traits between the seasons could be due to the varied environmental conditions, like most cloudy weather and fewer sunshine hours during kharif and clear weather, more sunshine hours and high temperatures at the time of grain development during rabi. The trait association with respect to principal component revealed that days to 50 % flowering, effective bearing tillers/m^2, plant height, test weight and number of grains/panicle exhibited a similar type of response in both seasons. Similar results were reported from previous studies (24).

Scree plot and biplot analysis

The percentage of total variation explained by each principal component for two seasons was illustrated in Fig. 3 and 4. In kharif, PC1 contributed 43.04 % of the total variation, followed by PC2 with 29.45 %, exhibiting eigenvalues of 3.44 and 2.35, respectively. Similarly, during rabi, PC1 contributed 50.95 % and PC2 contributed 28.65 % with eigenvalues of 4.07 and 2.29, respectively. Previous studies on PCA in rice reported similar research findings (25, 26).

A biplot demonstrated the first two principal components, PC1 and PC2, on the X-axis and Y-axis, respectively.

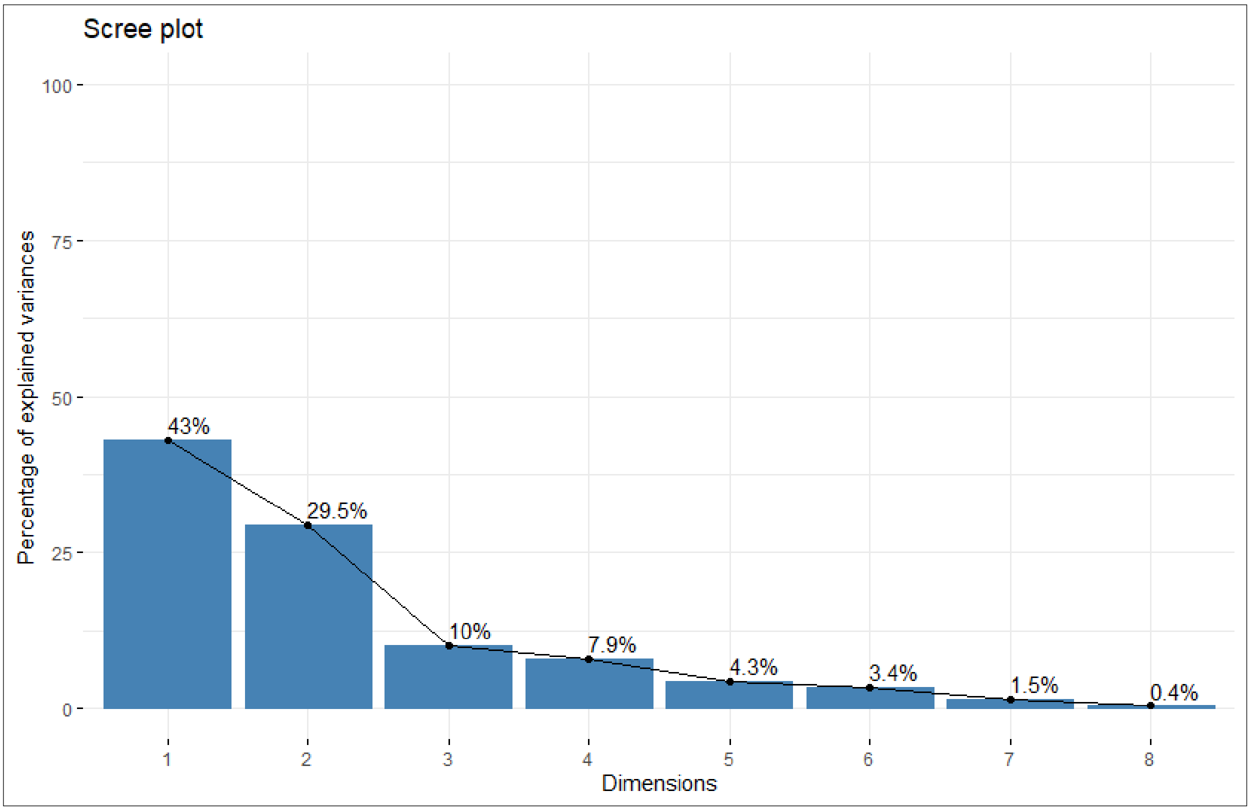

Fig. 3. Scree plot illustrating the percentage of variance explained by 8 principal components during kharif.

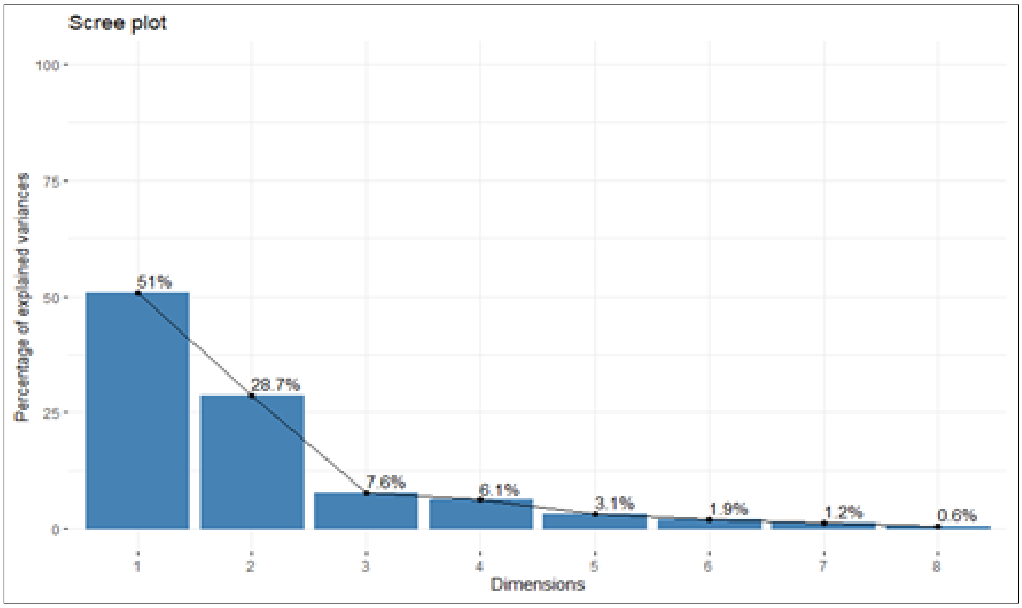

Fig. 4. Scree plot illustrating the percentage of variance explained by 8 principal components during rabi.

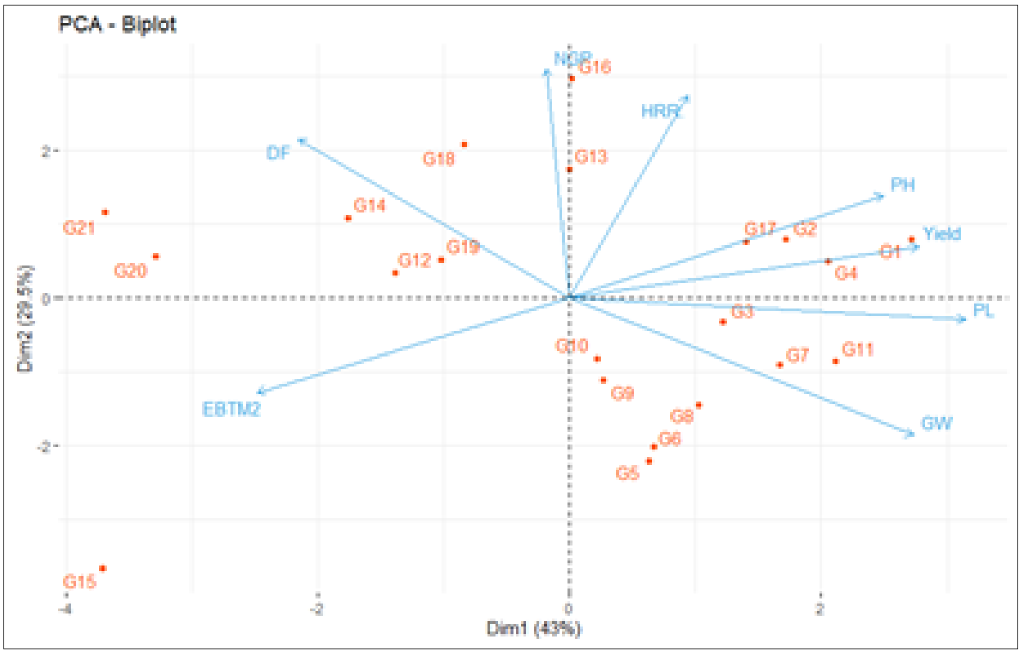

Fig. 5. Biplot showing the distribution of 21 rice genotypes and the contribution of 8 variables in the first two principal components during the kharif season.

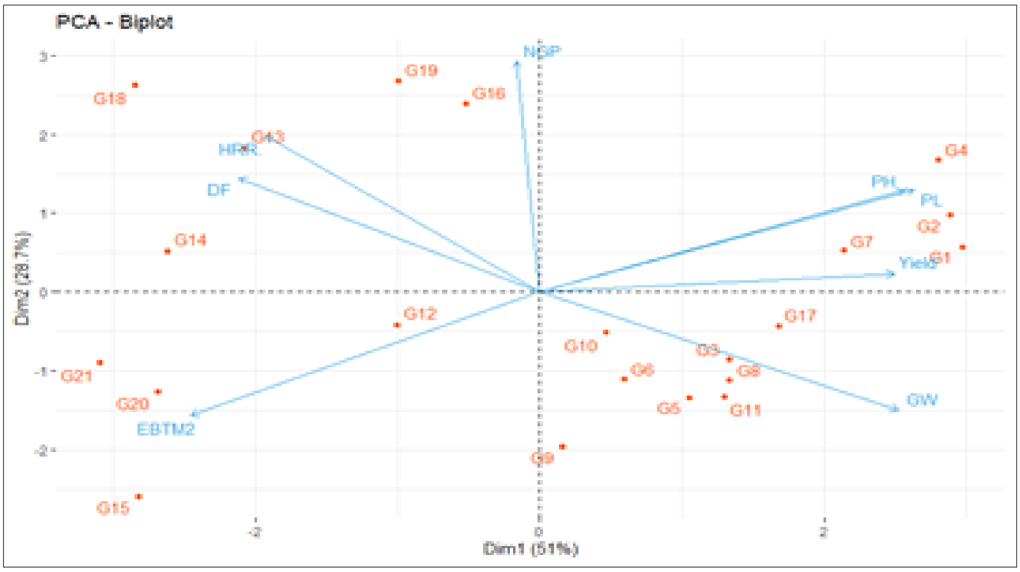

Fig. 6. Biplot showing the distribution of 21 rice genotypes and the contribution of 8 variables in the first two principal components during rabi season.

The season-wise biplots (Fig. 5 and 6) illustrated the distribution and nature of diversity concerning the first two principal components based on the performance of variables as well as genotypes. The length of the trait vector denotes the strength of the contribution of that particular character to the concerned principal component. The variable vectors with greater length are said to be the major contributors to the variation represented by respective PCs. In kharif, panicle length displayed the longest vector, indicating its major role in identifying the diversity in the studied genotypes. The other major contributing traits include test weight, seed yield, days to 50 % flowering and effective bearing tillers/m^2. During rabi, effective bearing tillers/m^2, test weight, plant height, panicle length and head rice recovery were identified as source traits that explain the existing diversity among the genotypes. Changing of environmental factors and management practices during kharif and rabi could result in the shifting of variables as a source for identifying diversity in genotypes. However, the traits like panicle length, effective bearing tillers/m^2 and test weight acted as primary drivers of genotypic divergence in both seasons. Several workers reported the importance of these yield-attributing characters in identifying the diversity among groups of rice genotypes (27, 28).

Biplot also revealed how the association of seed yield with other traits and the association among the traits differed in both seasons (Fig. 5 and 6). The angle between the variables decides the type of correlation existing between those traits. An acute angle between two traits indicates the positive correlation between those traits, whereas an obtuse angle between the traits reveals negative correlation (29). During kharif, seed yield exhibited positive correlation with important yield contributing traits like panicle length, plant height, test weight and number of grains/ panicle and it also showed positive association with head rice recovery, whereas days to 50 % flowering and effective bearing tillers/m^2 registered negative correlation. Test weight showed non significant association with head rice recovery, whereas the number of grains/panicle had a strong positive correlation with head rice recovery. In rabi, a similar trend was observed for the traits panicle length, plant height, test weight, days to 50 % flowering and effective bearing tillers/m^2 with seed yield, whereas the number of grains/panicle registered non significant association. In contrast to kharif, yield and test weight exhibited a high negative correlation with head rice recovery during rabi. Strong negative correlation of test weight with head rice recovery implies that coarse or long slender grain genotypes had low head rice recovery, while fine or medium slender grain cultures exhibited comparatively high head rice recovery in the rabi season. Slender or very long grains generally tend to break more easily than medium or short grains during the milling process, leading to a low head rice recovery (30).

PCA biplot facilitates the identification of superior genotypes associated with favourable traits or trait combinations. In the present investigation, during kharif (Fig. 5), genotypes, namely G_1, G_2 and G_4, were located far from the origin of the biplot in the direction of the yield vector and in the same quadrant, indicating their superior performance for grain yield. As yield exhibited positive correlation with panicle length, test weight and plant height, these genotypes are said to acquire important yield contributing traits in a desirable direction. Similarly, G_{13}, G_{16} and G_{18} were identified as superior performers for the traits number of grains/panicle and head rice recovery, having a strong positive correlation between them. During rabi (Fig. 6), G_1, G_2, G_4 and G_7 performed well for seed yield. The PCA biplots of both seasons revealed the superior and stable performance of G_1, G_2 and G_4 for seed yield and G_{13} and G_{18} for head rice recovery for both kharif and rabi.

Conclusion

The expression of the traits was significantly different between the seasons. Days to reach 50 % flowering during rabi were increased due to a prolonged vegetative period and favourable weather conditions prevaling during this season, which increased the yields when compared to kharif. High temperatures during the grain development stage in rabi resulted in the recording of low mean values for the important physical grain quality parameter, head rice recovery. Panicle length, effective bearing tillers/m^2 and test weight were identified as key traits in categorising the large number of rice genotypes into different groups. Genotypes G_1, G_2 and G_4 for yield and G_{13} and G_{18} for head rice recovery were the best performers in both seasons and could be potential sources for the development of high-yielding rice varieties with good head rice recovery suitable for both kharif and rabi.

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Authors' contributions

BS[1] has done the research and written the original draft. PM, PGN and BLP are associated with the original research. AS has been involved in the statistical analysis of the data. BS[2] performed weather analysis and prepared graphs. DS and GS has improvised the content of the manuscript. All the authors read and approved the manuscript. [BS[1] stands for B. Srinivas and BS[2] stands for B. Srilaxmi].

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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