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Varietal Variations in Basmati Rice for Yield and Quality Traits in Response to Temperature during the Ripening Phase under Staggered Transplantation

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Abstract

High ripening-stage temperatures strongly influence basmati rice yield, quality, and commercial value. This study investigated how different basmati varieties perform in yield and quality traits when exposed to varying temperatures by shifting the transplanting date. The response of four basmati varieties to early transplanting (5 July) and late transplanting (25 July) was evaluated under field conditions for two consecutive years. Across the varieties, basmati rice yield decreased for late transplanting (2.8 t /ha) as compared to early transplanting (3.5 t /ha), and the variety Pusa basmati-1509 (3.5 t /ha) produced higher grain yield than other tested varieties (2.9-3.1 t /ha). A wide variation in chalkiness (2–32%) was observed among the evaluated basmati rice varieties. Punjab basmati-3 and RYT-3390 exhibited markedly lower chalkiness than Pusa basmati-1121 and Pusa basmati-1509. Chalkiness showed a positive correlation with temperature during the ripening phase. Maximum temperatures ranged from 31.1 to 32.8°C in the 5 July transplanting and 29.8 to 32.9°C in the 25 July transplanting. Minimum temperature declined from 24.5 to 19.1°C in the early transplanting and 23.9 to 16.7 °C in the late transplanting. The greatest reduction in temperature was observed under late transplanting during the later stages of grain filling, indicating a cooler thermal environment during grain development. Head rice recovery (HRR) was comparatively higher in Punjab basmati-3 (52–54%) and RYT-3390 (~57%) than in Pusa basmati-1121 (~49%) and Pusa basmati-1509(44–51%). In early-transplanted basmati, HRR was negatively associated with ripening-stage temperature. Varieties exhibiting high HRR together with low and stable chalkiness—such as Punjab basmati-3 and RYT-3390—may therefore serve as promising parental lines in breeding programs aimed at developing basmati varieties with improved grain appearance, quality, and HRR, particularly under warming climatic conditions.

Keywords: Transplanting time; Temperature; Head rice recovery; Chalkiness; Varieties; Basmati rice

Introduction

The availability of high-yielding basmati varieties, reduced production costs (e.g., lower water and fertilizer requirements), and premium export pricing have increased interest in basmati cultivation in northwest India (APEDA, 2022; Mishra et al., 2021). Owing to its unique cooking properties and pleasant aroma, basmati rice enjoys special significance in rice agriculture and commands a high price in international markets (Anonymous, 2021). Early transplanting of basmati rice leads to earlier crop maturity. However, exposure to elevated temperatures during grain filling can deteriorate grain quality and increase water requirements (Fayaz et al., 2023; Sharma et al., 2022). Delayed transplanting can reduce water use and it also enhances grain quality (Pandey et al., 2020).

The crop's potential yield and quality depend on three climatic parameters: temperature, rainfall, and light (Indiarto and Nurannisa, 2021). Among these, temperature plays the most critical role in almost all biological processes of crop plants (Singh et al., 2021). An increase in atmospheric temperature (heliothermal stress) negatively affects rice growth, yield, and grain quality by altering phenology, physiological processes, and key yield components (Sindhu et al., 2022). Growing degree days (GDD) are used to assess the suitability of a region for a particular crop genotype and determine the growth stage and heliothermal stress on the crop. Crop development and yield are both influenced by temperature and photoperiod (Priyadarshi et al., 2018). Therefore, in addition to GDD, the study of photothermal units (PTU) and heliothermal units (HTU) is also essential. As planting is delayed beyond the optimum time, rice yield declines and the extent of decline depends on the variety (Sharma et al., 2022; Hossain et al., 2024).

Sowing basmati rice in northwest India is generally done at the onset of monsoon rains. The early sown basmati rice experiences extremely high temperatures and low humidity during flowering time that may result in the desiccation of pollen leading to poor grain formation (Patel et al., 2019). Thus, grain quality characteristics and rate of development in basmati rice are a function of temperature rather than photosynthesis (Mishra et al., 2026). It was hypothesized that quality characteristics and yield of basmati genotypes might be influenced by GDD, heliothermal use efficiency (HTUE), and HTU (Prodhan et al., 2024). Hence, to evaluate the effect of GDD on dry matter production and HTUE and to assess the yield and quality response, especially chalkiness, of basmati genotypes to HTU, a present study was conducted.

Materials and Methods

Description of experimental site

The study was conducted during the *Kharif* season at the Punjab Agricultural University (PAU) research farm, Ludhiana (30°56/N, 75°52/E, 247m above sea level), Punjab, India. The field had been under a rice–wheat rotation for the previous ten years. The region has a semiarid climate with an average annual rainfall of 400–700 mm. The surface soil (0–15 cm) is sandy loam with a pH of 7.3, organic carbon content of 0.34%, and Olsen P concentration of 8.1 mg/kg. Rainfall during the cropping season (June–October) was 448 mm and 541 mm during first and second year respectively. The weather observed over the 2-year study period was consistent with long-term climatic trends and is considered representative of the region (Fig. 1). Variation in minimum and maximum temperature recorded during flowering and grain filling stages has been presented in Fig. 2.

Experimental treatments and observations

The experiment was conducted in a split-plot design with three replications. The main-plot treatments consisted of two transplanting dates (5 July and 25 July) and subplot treatments comprised four basmati rice varieties: Pusa basmati-1121, Pusa basmati-1509, Punjab basmati-3, and RYT-3390. Thirty-day-old seedlings of each variety were transplanted into puddled soil at 20-cm row and 15-cm plant spacing. The crop was raised as per package of practices for *Kharif* crops given by PAU, Ludhiana. Days to 50% flowering were recorded when half the plants in each plot had flowered. Grain yield was measured at harvest and adjusted to 14% moisture content. Additionally, five plant hills were randomly selected from each plot to determine agronomic traits.
Growing degree days (GDD) were determined (Gill et al., 2023):

$$\mathbf{GDD = T_{mean} - T_b}$$

Where, Tmean = mean of maximum and minimum temperatures (°C) during a day; and Tb = base temperature (10.0°C). PTU was computed by taking the product of GDD and day length. HTU was calculated as the product of GDD and corresponding actual sunshine hours for that particular day. Helio-thermal use efficiency (HTUE) was calculated by dividing the yield by HTU.

Quality analysis

For quality analysis, a composite representative sample (125 g) from each plot was dehulled using a laboratory dehuller. The resulting brown rice and head rice recovery (HRR) was calculated according to Gill et al. (2023). Kernel length and width were measured using a dial micrometre. Amylose content was determined using the simplified method (Hebishy et al., 2024). Kernel length after cooking (KLAC) and grain elongation ratio were calculated as described by Gill et al. (2023). Chalky kernels were manually separated and weighed from a 20-g sample of head rice. Kernels exhibiting more than 50% chalkiness were classified as chalky.

Statistical Analysis

In the combined analysis of variance, year effects and year x treatment interactions were tested for variance and then data from both years were pooled (six total replications). Treatment means were compared using the least significant difference (LSD) test at p = 0.05. Relationships between grain yield and selected traits were examined through linear regression analysis using Sigma Plot 10.0.

Results and Discussion

Crop development stages

Average data revealed that the vegetative stage (before anthesis) in basmati varieties varied from 82-109 days. Anthesis and grain development stages varied from 12-17 days and 21-25 days, respectively (Fig. 3). Plant height of all the tested genotypes decreased with late as compared to early transplanting. RYT-3390 had the lowest plant height, while Pusa basmati-1121 attained the highest. For both transplanting dates, Pusa basmati-1509 took the least days to reach 50% flowering (Table 1). Except for Pusa basmati-1509, all the varieties took less time to reach 50% flowering for late transplanting compared to early transplanting. Pusa basmati-1509 took a similar number of days to reach 50% flowering from each transplanting date. The late transplanting of Punjab basmati-3 reduced the time to 50% flowering by 15 days. However, late transplanting reduced the time to 50%flowering by five days for RYT-3390 and 6 days for Pusa basmati-1121. Punjab basmati-3 and Pusa basmati-1121 took a similar number of days to reach 50% flowering for late transplanting, while for early transplanting, Punjab basmati-3 took eight days more than Pusa basmati-1121.

Table 1. Interaction effect of transplanting date and varieties on plant height, number of days taken for attaining 50% flowering, GDD and HTU

	Basmati varieties			
Date of transplanting↓	**RYT 3390**	**Pusa Basmati 1121**	**Pusa Basmati 1509**	**Punjab Basmati 3**
Plant height (cm)				
5 July	92.7	125.2	108.0	108.6
25July	83.0	105.4	96.4	94.0
s.e.d.	2.8			
l.s.d. (p=0.05)	4.9			
No. of days taken for 50 % flowering				
5 July	116	109	91	117
25 July	111	103	89	102
s.e.d.	0.9			
l.s.d. (p=0.05)	1.6			
GDD at maturity (°C days)				
5 July	2860	2762	2484	2878
25 July	2556	2469	2292	2458
s.e.d.	18.0			
l.s.d. (p=0.05)	32.1			
HTU at maturity (°C days hrs)				
5 July	20736	20251	18035	20885
25 July	17203	16861	15891	16836
s.e.d.	189.7			
l.s.d. (p=0.05)	337.6			

Yield response

Amongst the transplanting time, 5 July transplanting (early transplanting) resulted in a 26.7% increase in grain yield as compared to 25 July transplanting (late transplanting) (Table 2). The difference in grain yield was mainly due to higher numbers of filled grains/panicles. Filled grains/panicle in the early transplanting was 14% higher than for late transplanting (Table 2). Pusa basmati-1509 (5.2 t/ha) produced the highest grain yield, followed by Pusa basmati-1121 (4.6 t/ha). The grain yield of RYT-3390, Pusa basmati-1121, and Punjab basmati-3 was similar but lower than Pusa basmati-1509 (Fig. 4). All varieties took less GDD for late transplanting than the early transplanting date (Table 1). Punjab basmati-3 and RYT-3390 took similar GDD to maturity for 5 July transplanting. However, under late transplanting, Punjab basmati-3 took less GDD than RYT-3390. Pusa basmati-1509 took the least GDD to reach maturity for each transplanting date.

Table 2. Yield attributes, grain yield and heliothermal use efficiency of varieties as affected by transplanting date

	No. of Panicles/m²	**Filled grains/Panicle**	**Paddy yield (t/ha)**	**1000 grain weight (g)**	**Rice yield (t/ha)**	**HTUE (kg/ha/°C/days)**	**Kernel elongation ratio**
Date of transplanting							
5 July	371	65	5.26	28.18	3.48	1.93	1.67
25 July	361	57	4.15	26.98	2.77	1.71	1.85
s.e.d.	-	1.3	0.18	-	0.11	-	0.01
l.s.d (p=0.05)	n.s.	3.8	0.54	n.s.	0.32	n.s.	0.03
Basmati varieties							
RYT-3390	399	50	4.58	26.45	3.04	1.68	1.69

Pusa Basmati-1121	360	57	4.65	27.50	3.07	1.77	2.04
Pusa Basmati-1509	318	73	5.22	30.35	3.52	2.19	1.70
Punjab Basmati-3	388	65	4.38	26.00	2.87	1.64	1.60
s.e.d.	17.4	3.76	0.17	0.62	0.11	0.07	0.07
l.s.d (p=0.05)	31	6.7	0.31	1.1	0.20	0.12	0.12

Table 3. Interaction effect of transplanting date and varieties on brown rice, milled rice, head rice recovery (%)

	Basmati varieties			
Date of transplanting↓	**RYT 3390**	**Pusa Basmati 1121**	**Pusa Basmati 1509**	**Punjab Basmati 3**
Brown rice (%)				
5 July	73.5	75.8	74.8	73.7
25 July	74.3	74.3	74.9	73.6
s.e.d.	0.51			
l.s.d. (p=0.05)	0.9			
Milled rice (%)				
5 July	66.0	65.5	67.4	65.8
25 July	66.8	66.7	67.6	65.4
s.e.d.	0.39			
l.s.d. (p=0.05)	0.7			
Head Rice (%)				
5 July	56.7	48.8	43.8	53.9
25 July	56.7	48.8	50.9	52.3
s.e.d.	1.97			
l.s.d. (p=0.05)	3.5			

Punjab basmati-3 and Pusa basmati-1121 required a similar amount of GDD to reach maturity under late transplanting, comparable to the GDD requirement of Pusa basmati-1509 under 5 July transplanting. HTU of all varieties decreased under late compared with early transplanting (Table 1). Among the varieties, Pusa basmati-1509 consistently recorded the lowest HTU to reach maturity for both transplanting dates. HTU values for RYT-3390 and Punjab basmati-3 remained comparable across transplanting dates. Under early transplanting, Punjab basmati-3 had higher HTU than Pusa basmati-1121, whereas both varieties accumulated similar HTU under late transplanting. HTUE did not differ between transplanting dates (Table 2). Among the varieties, Pusa basmati-1509 exhibited the highest HTUE, while Punjab basmati-3 showed the lowest. HTUE values of Punjab basmati-3 and RYT-3390 were similar. Punjab basmati-3 had lower HTUE than both Pusa basmati-1121 and Pusa basmati-1509. It has been observed that high nighttime temperature, especially during the reproductive period, is known to cause decreased yields (Hossain et al., 2024).

Table 4. Interaction effect of transplanting date and varieties on Length-breadth ratio, kernel length after cooking, amylase and chalkiness

	Basmati varieties			
Date of transplanting↓	**RYT 3390**	**Pusa Basmati 1121**	**Pusa Basmati 1509**	**Punjab Basmati 3**
L:B				
5 July	4.75	5.04	5.29	5.23
25 July	4.51	4.75	5.13	5.14
s.e.d.	0.04			
l.s.d. (p=0.05)	0.08			
kernel length after cooking				
5 July	12.9	17.4	15.9	12.8
25 July	14.8	18.6	17.3	13.5
s.e.d.	0.22			
l.s.d. (p=0.05)	0.4			
Amylose (%)				
5 July	20.2	20.5	20.8	21.6
25 July	21.6	22.3	23.3	23.7
s.e.d.	0.22			
l.s.d. (p=0.05)	0.4			
Chalkiness (%)				
5 July	15.7	22.3	32.3	2.43
25 July	2.5	15.8	26.6	2.00
s.e.d.	4.16			
l.s.d. (p=0.05)	7.4			

For the July 5 transplanting, the highest brown rice recovery (BRR) was observed in Pusa basmati-1121 (75.8%), followed closely by Pusa Basmati-1509 (74.8%) (Table 3). RYT-3390 and Punjab basmati-3 recorded lower BRR than Pusa Basmati-1121 and Pusa basmati-1509 under early transplanting. Under the 25 July transplanting, BRR values of RYT-3390, Pusa basmati-1509, and Pusa basmati-1121 were statistically similar, while Punjab basmati-3 had a lower BRR than Pusa basmati-1509. BRR of RYT-3390, Pusa basmati-1509, and Punjab basmati-3 did not vary with transplanting date; however, Pusa basmati-1121 exhibited higher BRR under early compared with late transplanting. Milled rice recovery for RYT-3390 and Pusa basmati-1121 increased for late transplanting compared to early transplanting (Table 3).

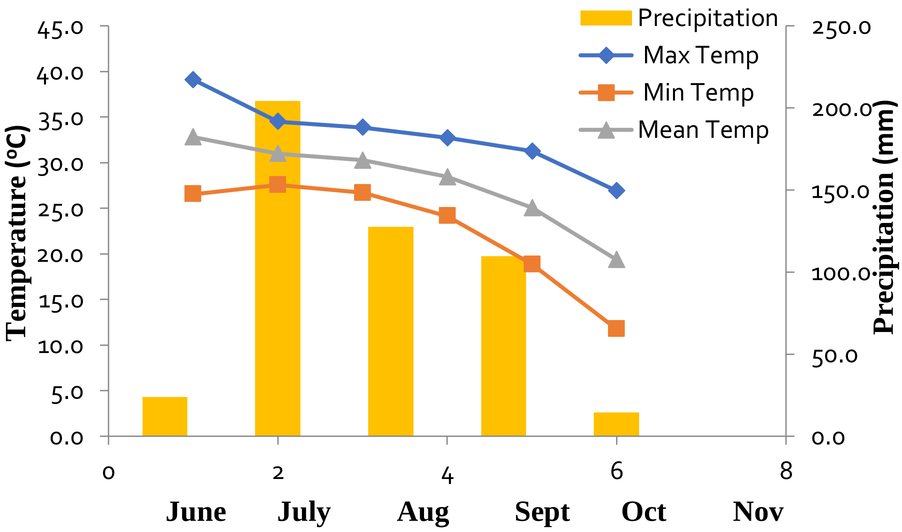

Fig. 1. Weather during the crop season (average of both years) measured from Punjab Agricultural University meteorological station.

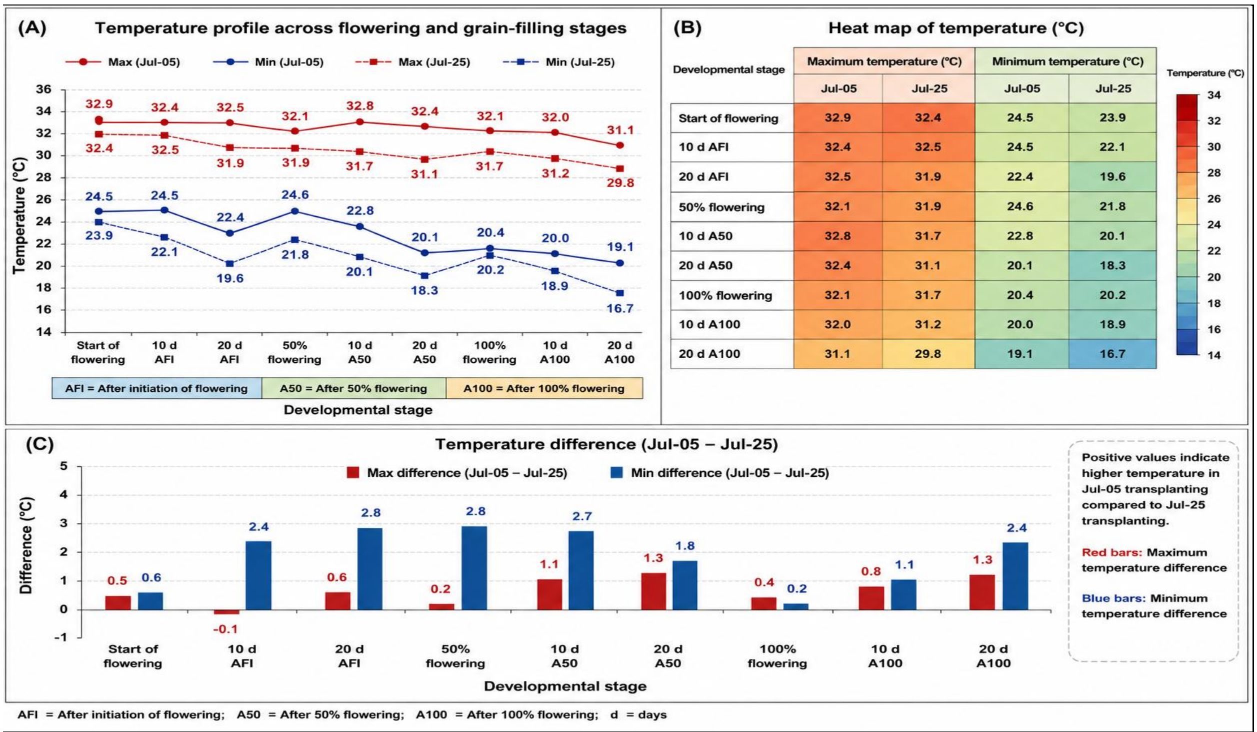

Fig. 2. Variation in maximum and minimum temperatures during flowering and grain filling stages under dates of transplanting

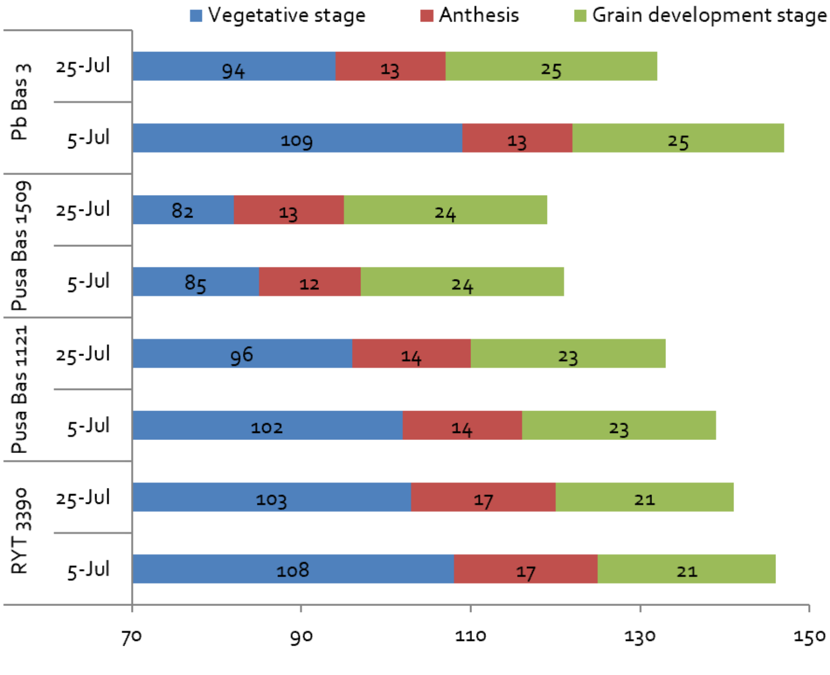

Fig. 3. Crop developmental stages (days) of basmati varieties (average of 2 years)

Transplanting dates did not affect the milled rice recovery of Pusa basmati-1509 or Punjab basmati-3. Under the 5 July transplanting, milled rice recovery was highest in Pusa basmati-1509 and lowest in Pusa basmati-1121. For the 25 July transplanting, milled rice recovery of RYT-3390 and Pusa basmati-1121 was similar, and both varieties recorded higher recovery than Punjab basmati-3. Transplanting date had no effect on head rice recovery (HRR) for RYT-3390, Pusa basmati-1121, or Punjab basmati-3 (Table 3). However, the HRR of Pusa basmati-1509 significantly increased under late transplanting. Under early transplanting, HRR values for RYT-3390 and Punjab basmati-3 were similar, and both were higher than those of Pusa basmati-1509 and Pusa basmati-1121. Under late transplanting, HRR for Pusa basmati-1121 and Pusa basmati-1509 did not differ, but both exhibited lower HRR than RYT-3390 and Punjab basmati-3. Across both transplanting dates, RYT-3390 had the highest HRR. HRR of Pusa basmati-1509 under 25 July transplanting was comparable to that of Punjab basmati-3 under both transplanting dates.

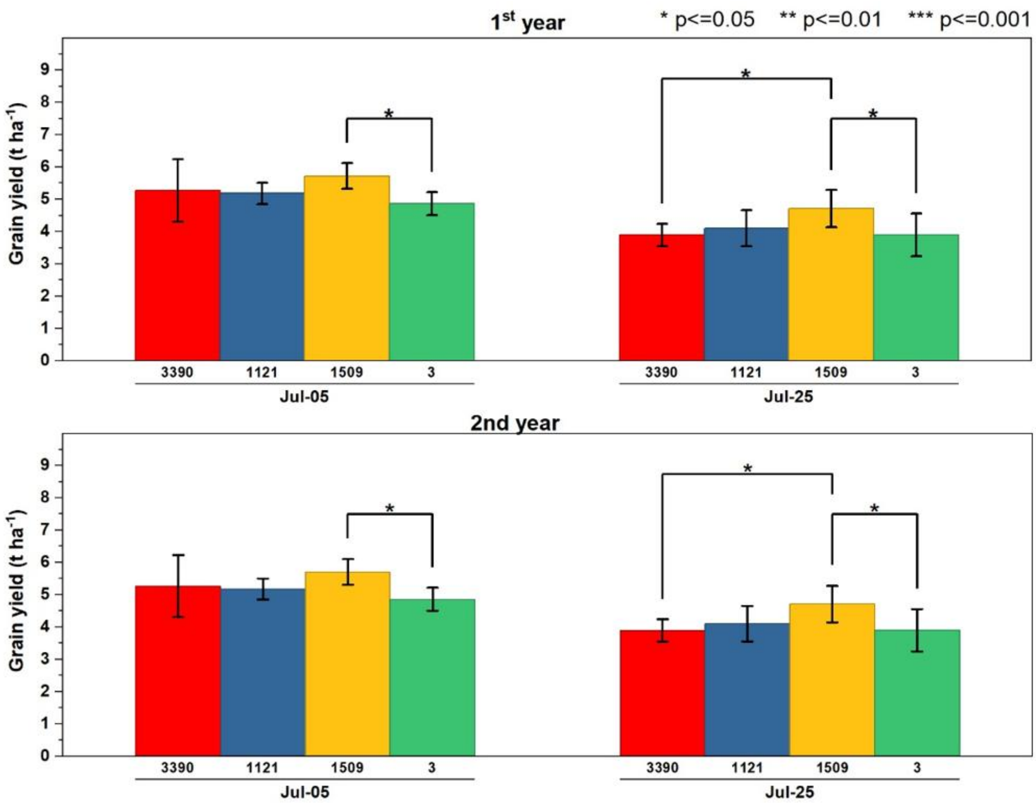

Fig. 4. Grain yield (t/ha) of basmati varieties as affected by time of transplanting during two years of study

For each transplanting date, the length-breadth ratio (L: B) of Punjab basmati-3 and Pusa basmati-1509 remained similar but was higher than RYT-3390 and Pusa basmati-1121(Table 4). For each transplanting date, the L: B of RYT-3390 was lower than that of the other varieties. The L: B of each variety was higher for early transplanting (5 July) than for late transplanting (25 July). Pusa basmati-1121 exhibited the greatest kernel length after cooking (KLAC) across both transplanting dates, followed closely by Pusa basmati-1509 (Table 4). For each transplanting date, RYT-3390 and Punjab basmati-3 recorded lower KLAC values than Pusa basmati-1509 and Pusa basmati-1121. KLAC increased for all varieties under the 25 July transplanting. Notably, the KLAC of Pusa basmati-1121 and Pusa basmati-1509 under early transplanting remained higher than that of late-transplanted RYT-3390 and Punjab basmati-3. For both transplanting dates, Punjab basmati-3 had higher amylose content than the other genotypes (Table 4). Amylose content increased for all varieties under late compared with early transplanting. Chalkiness (%) was highest in Pusa basmati-1509 and lowest in Punjab basmati-3 across both transplanting dates (Table 4). Only RYT-3390 exhibited a significant change in chalkiness with transplanting time, showing reduced chalkiness under late transplanting. Under 5 July transplanting, RYT-3390 showed higher chalkiness than Punjab basmati-3, whereas under late transplanting both varieties had comparable chalkiness. Chalkiness in Punjab basmati-3 remained unaffected by transplanting date. Wang et al. (2012) demonstrated that varietal differences in chalkiness lead to differential head rice percentages. The elongation ratio increased under late compared with early transplanting (Table 3). Pusa basmati-1121 recorded the highest elongation ratio, while other varieties exhibited similar elongation ratios.

(A) CORRELATION HEATMAP

	GY	GDD	HTU	HUE	FG	GW	Ch	Ac	HRR	E ratio	L:B	KLAC	Temp at flowering	Temp at ripening
GY	1.00	.37	.57*	.83*	.63*	.72*	.48	-.70*	-.43	-.39	.49	-.02	.85*	.76*
GDD	.37	1.00	.97*	-.21	-.14	-.32	-.48	-.71*	.40	-.40	-.08	-.54	.12	-.12
HTU	.57*	.97*	1.00	.01	.07	-.12	-.32	.76*	.23	-.44	.10	-.47	.32	.11
HUE	.83*	-.21	.01	1.00	.76*	.96*	.79*	-.31	-.69*	-.19	.57*	.29	.83*	.87*
FG	.63*	-.14	.07	.76*	1.00	.70*	.42	.05	-.63*	-.42	.95*	.03	.67*	.87*
GW	.72*	-.32	-.12	.96*	.70*	1.00	.83*	-.26	-.75*	-.04	.48	.45	.79*	.75*
Ch	.48	-.48	-.32	.79*	.42	.83*	1.00	-.05	-.62*	.24	.22	.69*	.76*	.60*
Ac	-.70*	-.71*	.76*	-.31	.05	-.26	-.05	1.00	.02	.14	.17	.11	-.40	-.10
HRR	-.43	.40	.23	-.69*	-.63*	-.75*	-.62*	.02	1.00	-.36	-.58	-.62*	-.51	-.75*
E ratio	-.39	-.40	-.44	-.19	-.42	-.04	.24	.14	-.36	1.00	-.40	.82*	-.18	-.16
L:B	.49	-.08	.10	.57*	.95*	.48	.22	.17	-.58	-.40	1.00	-.06	.50	.82*
KLAC	-.02	-.54	-.47	.29	.03	.45	.69*	.11	-.62*	.82*	-.06	1.00	.32	.24
Temp at flowering	.85*	.12	.32	.83*	.67*	.79*	.76*	-.40	-.51	-.18	.50	.32	1.00	.77*
Temp at ripening	.76*	-.12	.11	.87*	.87*	.75*	.60*	-.10	-.75*	-.16	.82*	.24	.77*	1.00

−1.0 −0.5 0 0.5 1.0

Correlation coefficient (r)

* Significant at 5% level (r critical = 0.71)

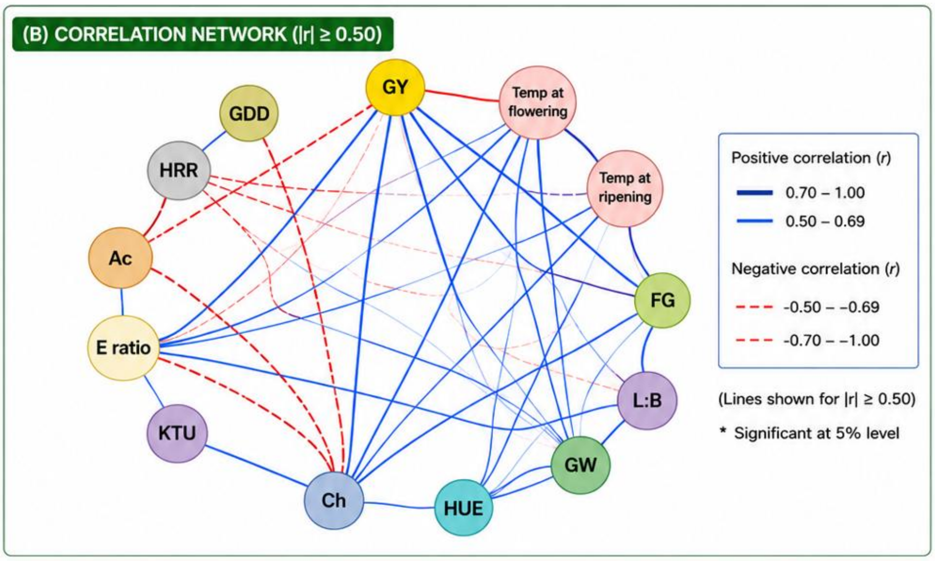

Fig. 5. Correlation among different traits for combination treatments.

Correlation studies

Correlation studies revealed that grain yield positively correlated with HTUE and 1000-grain weight (Fig. 5). The relatively high yield and HTUE of Pusa basmati-1509 despite its shorter growth duration compared to others was evident from relatively high filled grains/panicle (r=0.76) and 1000-grain weight (r=0.96), and their positive relationship. For late transplanting, the relationship of HTU with grain yield was negative (r=-0.96). GDD had a positive correlation with HTU, and HTU also had a positive correlation with amylose content. The 1000-grain weight had a positive correlation with chalkiness (%) but a negative correlation with HRR (%). Chalkiness is directly correlated with minimum temperature at flowering and ripening. HRR (%) had an inverse relationship with minimum temperature 20 days after 50% flowering. The elongation ratio was directly correlated with KLAC. The minimum temperature 20 days after 50% flowering had a positive correlation with grain yield, HTUE, filled grains/panicle, 1000-grain weight, KLAC, and L: B; however, it had a negative correlation with HRR (%). The negative relationship between minimum temperature at ripening (up to 20 days after 50% flowering) and HRR percent (r = -0.98) for the early transplanted crop indicated that night temperature played a significant role in influencing HRR (Mondal et al., 2025).

Temperature is generally known to be negatively correlated with amylose content (Liu et al., 2021; Mondal et al., 2025), and our results follow this trend, with higher amylose values recorded under late transplanting (Table 4). The relationship of amylose content with L: B was positive (r= 0.98) in the late transplanted crop. This was because early transplanted Pusa basmati-1509 and Punjab basmati-3 had higher L: B than RYT-3390 and Pusa basmati-1121. The relationship between KLAC and elongation ratio was positive (r = 0.82). Correlation heatmaps indicated a strong positive association of grain yield with HUE, 1000-grain weight, temperature at flowering and ripening, whereas it had a negative association with amylose content. Similarly, the correlation network showed that grain yield was strongly associated with temperature, HUE, grain filling and grain weight, and these are the major contributors to productivity. These parameters strongly influence grain yield and quality traits in Basmati rice.

Conclusion

The present investigation revealed that the high minimum temperature at ripening played an important role in reducing HRR. Higher minimum temperatures at ripening increased chalkiness in basmati grains. Punjab basmati-3 and RYT-3390 had relatively low chalkiness. L: B also significantly influenced chalkiness and HRR. Chalkiness increased, and HRR decreased with high L: B. These results suggest that air temperature (minimum) at ripening has a significant influence on KLAC and amylose, which is why the KLAC and amylose content of all varieties was improved with late transplanting. This study suggests that more emphasis should be placed on choosing basmati varieties with a high elongation ratio and high HRR percent. Changing these dates in response to climate change could result in yield penalties and altered grain quality.

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