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Grain Yield, Water Productivity and Quality Characteristics of Basmati Rice in Response to Cultivars and Transplanting Dates

Gulshan Mahajan* • Neerja Sharma • T. S. Bharaj

Rice Section, Department of Plant Breeding and Genetics, Punjab Agricultural University, Ludhiana 141 004, India

Corresponding author: * **mahajangulshan@rediffmail.com**

ABSTRACT

A field experiment was conducted to study the grain yield, water productivity and quality of basmati rice cultivars in relation to transplanting dates in an irrigated agro-eco system of Punjab during the 2006 and 2007 *kharif* season. Cultivars 'Pusa Basmati 1' and 'Superbasmati' were superior in terms of water productivity than highly photoperiod-sensitive cultivars 'Basmati 386' and 'Punjab Basmati 2. The water productivity of 'Pusa Basmati 1' and Superbasmati was similar even when transplanted up to the 20th of July, but it decreased significantly in 'Basmati 386' and 'Punjab Basmati 2' with a shift in transplanting date from the 10th of July. Significantly more grains/panicle, higher test weight and grain yield were recorded when transplanting took place on the 10th July. A subsequent delay in transplanting, i.e., 20th and 30th July, resulted in reduced grain yield by 8.4 and 27.1%, respectively, compared to the 10th July transplanting values. Among the basmati cultivars, 'Pusa Basmati 1' registered the highest mean grain yield (4.7 t/ha) and it resulted in 73.6, 19.4 and 41.4% higher yield than 'Basmati 386', 'Superbasmati' and 'Punjab Basmati 2', respectively. Under late transplanting conditions (30th July), 'Punjab Basmati 2' and 'Superbasmati' performed significantly better than 'Basmati 386' with respect to grain yield and crop water productivity. The grain yield of 'Pusa Basmati 1' was drastically reduced under late transplanting conditions (30th July). The quality traits of 'Basmati 386' and 'Punjab Basmati 2' were very similar to each other and superior to those of 'Pusa Basmati 1'. Of interest, the quality traits of 'Basmati 386' and 'Punjab Basmati 2' improved significantly with delayed transplanting from the 10th to 30th July.

Keywords: basmati quality, crop water productivity, days to 50% flowering, rice cultivars, transplanting dates, water use

INTRODUCTION

In the Indian Punjab, as well as in many other parts of Asia, water is becoming increasingly scarce. Per capita availability of water has declined in many Asian countries (Gleik 1993; Rijsberman 2006). Agriculture's share of freshwater supplies is likely to decline by 8 to 10% because of increasing competition from the urban and industrial sectors (Seckler *et al*. 1998; Toung and Bouman 2003). Poor-quality irrigation systems and greater reliance on groundwater have led to water table decline of 0.1 to 1.0 m yr^{-1} in parts of the IGP, resulting in scarcity and higher cost of pumping water (Harrington *et al*. 1993; Gill 1994; Sharma *et al*. 1994; Sondhi *et al*. 1994). But evidence is now appearing that rice productivity is plateauing and further growing water shortages are likely to adversely affect the productivity of the rice–wheat system (Ladha *et al*. 2003).

In this direction, basmati rice cultivation may play a vital role because of less water requirement and greater returns due to its higher price in the market. Basmati rice is prized for its intriguing, perfumed, almost popcorn-like aroma and nut-like flavour. When cooked, the rice only swells and plumps up lengthwise, resulting in long, thin grains that are dry and separate. So, due to these unique cooking quality features and pleasant aroma it occupies a special status in rice cultivation. Due to its low yield potential and problem of declining water table in Punjab, efforts are being made to increase its crop and water productivity.

There is an urgent need, therefore, to develop suitable rice cultivation technology capable of producing more grains while using less water in Punjab. Many technologies appear to be promising in saving substantial amounts of water through reduced irrigation but whether these are true water saving is uncertain (Humphreys *et al*. 2006). One of the approaches could be maximization of WP_1, WP_{I+R} and WP_{ET} by growing crops in the period of least evaporation demand by altering the date of transplanting without any loss in crop productivity. Very early transplanted crop may increase the water requirement of rice because of high evapotranspiration demand (Mahajan *et al*. 2009). On the other hand, delayed rice planting, despite being able to save water, could also result in delayed planting of wheat in the predominant rice–wheat system of this region beyond the optimum time of wheat sowing (25th October – 15th November), causing yield losses of about 1-1.5% per day due to poor grain filling at higher temperatures (Ortiz-Mont *et al*. 1994). Therefore, optimum date of transplanting of basmati rice cultivars may influence the water need as well as crop productivity of rice because of varying duration in response to transplanting dates due to photo-period sensitive nature. Another disadvantage of early transplanted crop (in June) is the high spikelet sterility induced by high temperature during the reproductive period (Hassan *et al*. 2003). Early transplanting also resulted in low quality rice from a milling point of view (Hassan *et al.* 2003). Further, quality traits of aromatic rice are known to be highly influenced by temperature particularly at the time of flowering, grain filling and maturity. Therefore, the optimum time of transplanting and selection of suitable varieties play an important role in boosting the yield and quality of basmati rice. Late planting coinciding with the flowering and maturity in cooler days has been reported to enhance the grain quality but reduction in grain yield in all the aromatic rices tested by Singh *et al*. (1996) and Asghar *et al*. (2001).

Vandana *et al*. (1994) reported that dry matter accumulation in leaves decreased in test cultivars (PR-106, PR-109 and Basmati-370) with later transplanting dates. They further observed that delayed transplanting reduced seedling dry matter in PR-106 and PR-109, but an increase was observed in Basmati-370 with least accumulation of dry

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matter in leaves. Bali and Uppal (1995) concluded that rice crop transplanted on 10th July gave 9.4 to 17.9% higher grain yield than that transplanted on 30th July due to higher root density, NPK uptake and head rice recovery. Gangwar and Sharma (1997) obtained maximum grain yield by transplanting on 1st to 16th July as compared to 31st July and 16th August. Maximum panicles were observed in early planting (1st July) but panicle weight was not affected up to 16th July. Katyal (1996) observed 10.1, 4.1 and 57.1% increase in grain yield for 25th June planting as compared with 15th June, 25th July and 25th August planting, respectively. Hence the final grain yield and water productivity of a crop mainly depends on the genetic constitution and the weather conditions which it encounters during growth and development.

Therefore, this study was planned to determine the optimum time of transplanting for basmati rice cultivars for higher crop, water productivity and superior quality.

MATERIALS AND METHODS

Experimental site

An experiment was conducted on loamy sand soil at the research farm of rice section, Department of Plant Breeding, Genetics and Biotechnology, Punjab Agricultural University (PAU), Ludhiana (30° 56′ N, 75° 52′ E and 247 m a.s.l.), in India during 2006 and 2007. The field had a history of rice-wheat rotation for more than 20 years and had a hard pan below 25 cm. The climate of the area is semi-arid with an average annual rainfall of 400-700 mm, of which 75-80% is received during July to September, the lowest minimum temperature of 0 to 4°C in January and the highest maximum temperature of 41 to 45°C in June. The soil (0-15 cm) of the experimental site is loamy sand with a bulk density of 1.42 Mg m^{-3}, pH 7.6, EC (saturation extract) 0.16 dS m^{-1}, organic nitrogen 0.22%, organic matter 0.28% and Olsen P 8 mg kg^{-1}. The climatic parameters were recorded at a meteorological observatory located at a distance of 500 m from the experimental site. The mean monthly air temperature, rainfall, sunshine hours and relative humidity during the cropping seasons (for 2006 and 2007) are presented in **Table 1**.

Experimental treatments and observations

The experiment was arranged in a split-plot design with three replications. The treatments included three transplanting dates (D_1: 10th July, D_2: 20th July and D_3: 30th July) as main plots and four cultivars ('Basmati 386', 'Punjab Basmati 2', 'Pusa Basmati 1' and 'Superbasmati') as subplots. Thirty-days-old nursery seedlings of each variety were transplanted on the three dates of transplanting with a row-to-row spacing of 20 cm and a hill-to-hill spacing of 15 cm on puddled soil. Puddling was done by running a cultivator in standing water (75 mm) followed by planking. At each date of transplanting, 20 kg N/ha was applied 5 days after transplanting. A second dose of nitrogen (20 kg/ha) was applied at 30 days after transplanting on D_1, D_2 and D_3. Irrigation comprised of continuous flooding for 15 days after transplanting followed by intermittent irrigation at 3 days interval up to 14 days before harvest. The depth of irrigation water was computed by monitoring the water level before and after irrigation using fixed scales in the field plots. To control weeds, herbicide Rifit at 1.5 kg/ha (Pretilachlor) was applied two days after transplanting. Chlorpyriphos (2.5 l/ha) and Tilt 25 EC (250 ml/ha) were used to control insect-pests and diseases. At harvest stage of the crop, five hills were selected randomly from each plot for measuring agronomic parameters, including plant height, number of productive tillers/m^2, number of filled grains/panicle, and sterility (%). Grain yield of rice was measured at 14% grain moisture content and all the observations were recorded by following the standard protocol of IRRI (Anonymous 1996). For quality characteristics, a composite representative sample (125 g) for each plot was hulled and brown rice was milled for 20 sec for obtaining 6% milling. Head rice recovery was computed by Govidaswamy and Ghosh (1969). Lengths and breadths were recorded using dial micrometer. The simplified procedure of Juliano (1971) was used for estimating the amylose content.The alkali digestion technique was used for estimating the gelatinization temperature and the appearance and disintegration of kernel in 1.7% KOH was rated visually based on the 7 point numerical spreading value (Little *et al.* 1958). Grain elongation ratio was estimated as the ration of the average length of cooked rice grain to the average length of raw rice grain (Azeez and Shafi 1966).

Statistical analysis

The data were analyzed statistically by analysis of variance. For significant main effects, means were separated using least significance difference test (LSD) (Gomez and Gomez 1984). Since the data for the individual years showed no significant differences, the data for two years were pooled and analysed jointly. Since the data for two years for three transplanting dates (differing in growing environment) were pooled separately, environmental effect of transplanting dates was still retained in the pooled or joint analysis.

RESULTS AND DISCUSSION

The mean air temperature during 2006 varied from 19.6 to 31.5°C, while in the following year, i.e. 2007, it varied from 17.8 to 32.3°C (**Table 1**). During 2007, October and November received less mean air temperature in comparison to 2006. The total rainfall was higher in 2006 than in 2007. During 2006, the crop received more rainfall in October and November (the period matching with the reproductive stage of the crop) while in 2007 the crop matured in the rain-free period. During 2007, August and September received less sunshine hours in comparison to 2006. Relative humidity was comparatively higher during 2006 than 2007 except for September when it was higher in 2007.

Yield response

Growth and yield attributes of the crop were significantly influenced by transplanting dates (**Tables 2, 3**). These parameters, viz., plant height, filled grains/panicle and test weight, attained their significantly highest values when the crop was transplanted on the 10th July. The performance of the crop in reference to these attributes was notably poor when transplanting was done after the 20th July. Improvement in these parameters can be better explained by the fact that the crop transplanted on the 10th July received optimum environmental conditions required for better growth and development. Due to the photoperiod sensitivity nature of the basmati rice cultivars ('Basmati 386', 'Punjab Basmati 2', 'Superbasmati'), delay in transplanting after the 20th July could not provide sufficient time to complete the vegetative phase of the crop. Bhattacharjee (2002) reported re-

Table 1 Mean air temperature, rainfall, sunshine hours and relative humidity during 2006 and 2007.

Month	Mean air temperature (Mean of max. and min. temperature °C)		Rainfall (mm)		Sunshine hours		Relative humidity (%)	
	2006	2007	2006	2007	2006	2007	2006	2007
July	31.5	32.3	209.2	150.7	5.9	7.7	77.0	62.0
August	30.0	30.4	142.7	110.6	7.3	6.5	77.0	77.0
September	28.0	28.4	103.6	56.8	8.0	6.5	76.0	80.0
October	25.3	23.8	6.8	0.0	7.4	8.9	68.0	80.0
November	19.6	17.8	14.0	1.3	5.8	4.9	69.0	72.0

Table 2 Plant height, Days to 50% flowering and panicles/m^2 of basmati rice cultivars as influenced by transplanting dates (pooled mean).

		Basmati 386	Punjab Basmati 2	Pusa Basmati 1	Superbasmati	Mean
Plant height (cm)	10th July	140.6	120.4	107.5	108.1	119.1
	20th July	138.7	110.4	101.5	102.2	113.2
	30th July	122.0	98.9	86.9	90.3	99.5
	Mean	133.8	109.9	98.6	100.2	
	LSD (0.05)	Transplanting Dates: 3.9		Cultivars: 5.2	Transplanting dates x Cultivar: NS	
Days to 50% flowering	10th July	94	93	77	89	88
	20th July	85	84	74	81	81
	30th July	76	76	72	72	74
	Mean	85	84	74	81	
	LSD (0.05)	Transplanting Dates: 3.1		Cultivars: 2.5	Transplanting dates x Cultivar:4.3	
Panicles/sqm. (No.)	10th July	357	444	356	375	383
	20th July	368	413	383	410	393
	30th July	399	427	402	428	414
	Mean	375	428	380	404	
	LSD (0.05)	Transplanting Dates: NS		Cultivars: 27.6	Transplanting dates x Cultivar: NS	

Table 3 Grains/panicle, Test weight and Sterility (%) of basmati rice cultivars as influenced by transplanting dates (pooled mean).

		Basmati 386	Punjab Basmati 2	Pusa Basmati 1	Superbasmati	Mean
Filled grains/panicle (No.)	10th July	57	75	101	82	78
	20th July	52	54	93	69	67
	30th July	55	54	85	79	68
	Mean	55	61	93	77	
	LSD (0.05)	Transplanting Dates: 6.6		Cultivars: 10.4	Transplanting dates x Cultivar: NS	
Test weight (g)	10th July	22.9	21.1	21.4	19.9	21.3
	20th July	22.6	19.0	20.4	20.0	20.5
	30th July	21.3	20.1	20.1	19.2	20.2
	Mean	22.2	20.1	20.6	19.7	
	LSD (0.05)	Transplanting Dates: 0.45		Cultivars: 0.55	Transplanting dates x Cultivar: 0.95	
Sterility (%)	10th July	16.4	21.9	25.0	28.2	22.9
	20th July	21	23.9	21.5	26.2	23.1
	30th July	28.5	26.0	33.0	25.5	28.2
	Mean	22.0	23.9	26.5	26.6	
	LSD (0.05)	Transplanting Dates: NS		Cultivars: NS	Transplanting dates x Cultivar: NS	

duction in grain yield with delayed transplanting (in the second fortnight of July) of photoperiod-sensitive basmati rice cultivars. This was evident from the data pertaining to days to 50% flowering (**Table 2**), which clearly indicate that this parameter reduced with delayed transplanting from the 10th July in the photoperiod-sensitive cultivars. Dingkhun and Asch (1999) reported that the photoperiod sensitivity is the growth stage indicative of rice plant's capability to accept flowering stimulus so usually determined by difference in growth duration under varied transplanting dates. Sarkar and Reddy (2006) also studied the photoperiod sensitivity of many varieties by comparing the difference in the flowering period of rice cultivars under varied transplanting dates. So, the crop could not accumulate sufficient dry matter and photosynthesizing area (source) that could have been very useful in partitioning assimilates towards the sink (Dingkhun and Asch 1999). These results are in accordance with those of Bhattacharjee (2002) and Akram *et al*. (2007), who reported that grain yield of basmati rice cultivars decreased with delaying transplanting from 20th July. The grain yield of 'Pusa Basmati 1' reduced with delayed transplanting from 20th July due to prevailing low temperature at the grain filling stage caused less number of filled grains/panicle with delayed transplanting (**Table 3**). For late transplanting, poor pollen germination may be another reason for decline in grain yield. The optimum temperature required for the germination of pollen is 31-33°C (Grist 1986). For late transplanting, low temperature at the pollen development stage may cause a sharp decline in fertile or filled spikelets particularly in the photoinsensitive cultivars (Mahajan and Bharaj 2008).

The crop transplanted on the 10th July produced the maximum mean grain yield of 4.2 t/ha, though it remained at par with that on the 20th July transplanting (**Table 4**). Delay in transplanting after the 20th July resulted in a significant reduction in grain yield with a minimum of 3.05 t/ha when transplanted on the 30th July. The improvement in grain yield in relation to early transplanting can mainly be attributed to the corresponding improvement in crop growth and yield parameter of the crop. The results are in close conformity with those reported by many workers (Mahmood 1995; Paliwal *et al*. 1996), who reported in their studies that grain yield of basmati varieties decreased when transplanted in the second fortnight of July.

The varieties showed significant variation in growth and yield parameters of the crop (**Tables 2, 3**). 'Basmati 386' attained maximum plant height up to 133.8 cm followed by 'Punjab Basmati 2'. The varieties 'Pusa Basmati 1' and 'Superbasmati' had statistically the same plant height. The number of panicles/m^2 was highest in 'Punjab Basmati 2' (428) followed by 'Superbasmati'. The highest percentage sterility was found in 'Superbasmati' followed by 'Pusa Basmati', while the highest test weight was registered in 'Basmati 386' (22.4 g) among all other varieties. The mean grain yield data pertaining to varietal performance (**Table 4**) revealed that 'Pusa Basmati 1', which had a grain yield of 4.7 t/ha, performed significantly superior than the rest of the cultivars and accounted for a 73.6, 41.4 and 19.4% increase over 'Basmati 386', 'Punjab Basmati 2' and 'Superbasmati', respectively. 'Basmati 386' recorded the lowest grain yield of 2.7 t/ha among all the tested varieties. The significant variation in grain yield was mainly due to their genetic constitution. Moreover, a significant improvement in yield attributes might have also increased the grain yield of these varieties.

An interactive effect of transplanting date with varieties was also found to significantly influence the grain yield of basmati rice varieties (**Table 4**). It was observed that Punjab Basmati 2 even on the 20th July transplanted conditions gave statistically the same yield as 'Basmati 386' when transplanted on the 10th July. So, under delayed transplan-

Table 4 Impact of transplanting dates and cultivars on the grain yield (q/ha) and water productivity (Kg/ha-cm) of basmati rice.

	Basmati 386	Punjab Basmati 2	Pusa Basmati 1	Superbasmati	Mean
Grain yield					
10th July	31.61	39.36	55.44	40.95	41.84
20th July	25.27	33.93	52.49	41.59	38.32
30th July	24.83	27.0	33.90	36.22	30.49
Mean	27.24	33.43	47.28	39.59	
LSD (0.05)	Dates: 4.92	Var: 3.31	Dates x Var.: 5.74		
Irrigation water productivity					
10th July	22.83 (138.45)	28.43 (138.45)	47.69 (116.25)	29.57 (138.45)	32.13 (132.9)
20th July	21.74 (116.25)	29.18 (116.25)	53.84 (97.5)	35.78 (116.25)	35.13 (111.56)
30th July	24.52 (101.25)	26.67 (101.25)	36.16 (93.75)	35.77 (101.25)	30.78 (99.37)
Mean	23.03 (118.65)	28.09 (118.65)	45.89 (102.5)	33.71 (118.65)	
LSD (0.05)	Dates: NS	Var: 2.86	Dates x Var.: 4.96		

Figures in parentheses are the irrigation water applied (cm); q/ha = quintals/hectare; 1 t/ha = 10 q/ha

Table 5 Effect of different treatments on the milling characteristics of basmati rice.

		Basmati 386	Superbasmati	Pusa Basmati 1	Punjab Basmati 2	Mean
Milled rice recovery (%)	10th July	68.6	68.4	67.6	70.08	68.7
	20th July	69.6	68.6	67.4	69.6	68.8
	30th July	69.7	69.0	66.8	70.0	68.9
	Mean	69.3	68.7	67.3	69.9	
	LSD (0.05)	Dates: NS	Var: 0.3	Dates x Var.: 0.5		
Head rice recovery (%)	10th July	50.8	52.0	45.2	53.6	50.4
	20th July	51.4	48.9	34.0	53.9	47.0
	30th July	48.0	48.3	39.2	51.4	46.7
	Mean	50.1	49.7	39.5		53.0
	LSD (0.05)	Dates: 0.13	Var: 0.44	Dates x Var.: 0.76		
L: B ratio	10th July	4.27	4.37	4.41	4.44	4.37
	20th July	4.25	4.42	4.47	4.36	4.37
	30th July	4.30	4.34	4.42	4.37	4.36
	Mean	4.27	4.38	4.43		4.39
	LSD (0.05)	Dates: NS	Var: 0.04	Dates x Var.:0.07		

ting conditions, 'Punjab Basmati 2' performed better than 'Basmati 386'. However, 'Superbasmati' outyielded all the varieties under late transplanting (30th July) with an increase in yield of approximately 45.9, 34.1 and 6.8% more than 'Basmati 386', 'Punjab Basmati 2' and 'Pusa Basmati 1', respectively. There was a drastic reduction in grain yield of 'Pusa Basmati 1' found when transplanted after the 20th July.

Irrigation water productivity

The mean data in **Table 4** revealed that water use by the crop varied from 93.75 to 138.45 cm for rice crop transplanted from July 10 to July 30. The decreased water use with late transplanting conditions was associated with lower potential evapotranspiration demand by the atmosphere. Hira and Khera (2000) reported that the evapotranspiration requirement of rice declined from around 800 to 500 mm as the date of transplanting was delayed from 1st May to 30th June. The data in **Table 4** revealed that by shifting the transplanting dates of rice from the 10th July to the 20th July, as much as 16.0% water was saved with a maximum mean crop water productivity of 35.13 kg/ha-cm. These findings are in conformity with those of Chahal *et al.* (2007), who were also of the same opinion that shifting rice transplanting dates resulted in a saving of 192 mm as wet (evapotranspiration) and 590 mm as dry water (irrigation). 'Pusa Basmati 1' registered the highest water productivity (47.28 kg/ha-cm) among all the tested cultivars followed by 'Superbasmati'. This was due to less duration of 'Pusa Basmati' as reflected from days to 50% flowering (**Table 2**) compared with other Basmati cultivars coupled with highest grain yield among all the cultivars. Pusa Basmati 1 matured earlier so required few irrigations as compared to other Basmati cultivars. The interaction effect of transplanting date and cultivars was significant with respect to water productivity (**Table 4**). The water productivity of 'Basmati 386' and 'Punjab Basmati 2' remained statistically the same at all transplanting dates. 'Pusa Basmati 1' had highest water productivity when transplanted on the 20th July and thereafter it declined, while 'Superbasmati' had higher water productivity under late transplanting conditions. 'Superbasmati' also resulted in higher water productivity under all transplanting dates compared with 'Basmati 386' and 'Punjab Basmati 2'. These findings confirmed the view of Bennett *et al.* (2003) and Mahajan *et al.* (2009), who pointed out that water productivity may increase through short duration cultivars or photoperiod-sensitive rice cultivars by reducing transpiration without compromising grain yield.

Quality characteristics

The grain quality characteristics viz. head rice recovery, amylose content (AC), kernel length after cooking (KLAC), and elongation ratio (ER) were influenced significantly with regard to transplanting dates and cultivars, while milled rice recovery, length: breadth (L: B) ratio and alkali spreading value (ASV), were not affected significantly (**Tables 5, 6**). The data in **Table 5** revealed that delaying transplanting from 10 to 30 July did not affect the milled rice recovery sig-nificantly. Among the cultivars, 'Punjab Basmati 2' gave the highest milled rice recovery (69.9%) followed by Basmati 386 (69.3%). 'Pusa Basmati 1' gave the lowest milled rice recovery of 67.3%. Head rice recovery decreased significantly with a delay in transplanting from 10 to 30 July (**Table 5**). Among the cultivars, highest head rice recovery was obtained in 'Punjab Basmati 2' (53.0%), followed by 'Basmati 386' (50.1%) and 'Superbasmati' (49.7%). 'Pusa Basmati 1' gave the lowest head rice recovery of 39.5%. It was further revealed that the head rice recovery in case of 'Punjab Basmati 2' and 'Basmati 386' was not affected significantly with delay in transplanting from 10 to 30 July while it decreased significantly in 'Superbasmati' and 'Pusa Basmati 1' (**Table 5**). The L: B

Table 6 Effect of different treatments on physico-chemical and cooking characteristics of basmati rice.

		Basmati 386	Superbasmati	Pusa Basmati 1	Punjab Basmati 2	Mean
Amylose content (%)	10th July	19.4	18.5	21.5	19.8	19.8
	20th July	19.9	19.8	21.8	20.7	20.6
	30th July	23.4	22.4	26.1	20.7	23.2
	Mean	20.9	20.2	23.1	20.4	
	LSD (0.05)	Dates: 0.16	Var: 0.29	Dates x Var.: 0.51		
KLAC (mm)	10th July	14.2	13.8	15.1	14.1	14.3
	20th July	14.7	13.7	15.3	14.7	14.6
	30th July	14.6	13.4	14.5	14.4	14.2
	Mean	14.5	13.6	15.0	14.4	
	LSD (0.05)	Dates: 0.12	Var: 0.09	Dates x Var.: 0.16		
ASV score	10th July	6.5	6.5	7.0	7.0	6.75
	20th July	6.5	6.5	7.0	7.0	6.75
	30th July	6.5	6.5	7.0	7.0	6.75
	Mean	6.5	6.5	7.0	7.0	
	LSD (0.05)	Dates: NS	Var: 0.3	Dates x Var. : NS		
Elongation ratio	10th July	1.75	1.72	1.83	1.73	1.76
	20th July	1.79	1.79	1.72	1.79	1.77
	30th July	1.79	1.69	1.78	1.77	1.76
	Mean	1.78	1.73	1.78	1.76	
	LSD (0.05)	Dates: 0.005	Var: 0.01	Dates x Var.:0.02		

ratio was not affected by transplanting date. Environmental factors like temperature, photoperiod and relative humidity have been documented to have little effect on the length, breadth and L: B ratio of rice grains compared with that on chalkiness, gelatinization temperature, amylose content and gel consistency (Li *et al*. 1989; Kibanda and Luzi-Kihupi 2007). KLAC and ER were statistically the same during transplanting on the 10th and 30th July but increased significantly when the crop was transplanted on the 20th July (**Table 6**). ER increased significantly in 'Basmati 386' and 'Punjab Basmati 2' when the crop was transplanted on the 30th July but decreased in 'Superbasmati' and 'Pusa Basmati 1'. de la Cruz *et al*. (1989) reported that grain elongation was also influenced by environmental factors, especially temperature, at the time of ripening. Maximum grain elongation was observed at 25/21°C day/night temperature during ripening.

AC increased significantly with a delay in transplanting (**Table 6**). This may be because the late transplanted crop encounters cooler temperatures during grain filling and maturity. Our observations revealed that late transplanted crop experienced lower mean temperature (by 6^0C) in the month of November (**Table 1**) as compared to October. It has been reported that quality traits of aromatic rice are highly influenced by temperature at the time of flowering, grain filling and maturity (He *et al*. 1990; Lee *et al*. 1996; Meng and Zhou 1997). In general, temperature correlates negatively with AC (Lee *et al*. 1996) and positively with GT (Resurrecion *et al*. 1977; Li *et al*. 1989; He *et al*. 1990). In the present study, the highest AC was found in 'Pusa Basmati 1' (23.1%) followed by 'Basmati 386' (20.9%), 'Punjab Basmati 2' (20.4%) and 'Superbasmati' (20.2%). Amylose is a factor responsible for cooked rice hardness, stickiness, colour, gloss and general acceptability (Mackill *et al*. 1996). Low ambient temperatures during ripening increase AC (Juliano 1972). ASV did not change with the delay in transplanting dates (**Table 6**). de la Cruz *et al*. (1989) stated that AC decreases with increase in temperature whereas gel consistency and GT did not show any interaction with temperature. In our study also, relatively cooler temperature encountered by the crop transplanted on the 30th July during grain filling and maturity resulted in higher AC but the ASV and hence the GT was not affected. All the varieties under study fell into the low GT group with an ASV of 6-7. Rice with high GT values tend to require more water and time to cook than those possessing either low or intermediate GT (Chatterjee and Maiti 1985). Late planting, coinciding with flowering and maturity in cooler days, has been reported to enhance grain quality but reduce grain yield in all aromatic rice tested by Singh *et al*. (1996), Thakur *et al*. (1996) and Chandra *et al*. (1997).

CONCLUDING REMARKS

The transplanting of 'Basmati 386' and 'Punjab Basmati 2' during 10-20th July ensures higher yield along with higher crop water productivity due to their strong photoperiod-sensitive nature. Pusa Basmati recorded the highest yield of 4.7 t/ha and the grain yield increased to about 73.6, 41.4 and 19.4% over 'Basmati 386', 'Punjab Basmati 2' and 'Superbasmati', respectively. Under late transplanting conditions (30th July), 'Superbasmati' was superior in performance among all the cultivars both in yield and crop water productivity due to its weak photoperiod-sensitive nature. The grain yield and water productivity of 'Pusa Basmati 1' was drastically reduced when transplanted after the 20th July due to prevailing low temperature during flowering, which caused a reduction in yield. The quality traits of Basmati 386 and Punjab Basmati 2 found very much similar and superior than Pusa Basmati 1. It was interesting that quality traits of Basmati 386 and Punjab Basmati 2 improved significantly with delaying transplanting from 10 to 30 July. Thus, the present study emphasizes the importance of transplanting the crop at an appropriate time for a better performance of in terms of yield, water productivity and quality traits in basmati rice.

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