ORIGINAL ARTICLE

ISSN (Print): 2517-9675
ISSN (Online): 2518-2625

ADAPTABILITY OF FINE GRAIN RICE GENOTYPES UNDER DIRECT SOWN GROWING CONDITIONS

Tahir Hussain Awan[1] • Muhammad Ehsan Safdar[2*] • Sharif Ahmed[3]

AUTHOR'S AFFILIATION

[1]Department of Agronomy, Rice Research Institute, Kala shah Kaku, Lahore, Punjab, Pakistan
[2]Department of Agronomy, University College of Agriculture, University of Sargodha, Sargodha-40100, Punjab, Pakistan
[3]Agronomy Division, Bangladesh Agricultural University, Mymensingh, Bangladesh
*Corresponding author's email: ehsan_safdar2002@yahoo.com

Key words:
Cooking quality; dry-seedling; grain yield; grain quality; milling recovery

ABSTRACT

Background Traditional method of rice transplanting under puddled conditions is going to become difficult for farmers of Pakistan due to current scenario of water and labor shortage. Therefore, there is an urge to develop rice varieties that are suitable for direct sowing under dry conditions.

Methodology Ten fine rice genotypes were evaluated under dry-seeding field conditions for two consecutive summer seasons of years 2009 and 2010 at Rice Research Institute, Kala Shah Kaku, Haji Sons Farm Chinute and Adaptive Research Farm, Gujranwala, Pakistan to identify the plant traits of rice that contribute positively to its yield performance. Moreover, their milling recovery and grain quality characteristics were also studied.

Results All the rice genotypes, except 7392 and 7909-4-1-1 gave better yield performance. A higher head rice recovery from rice genotypes Basmati 5151 (55.5%), Basmati 2000 (52.2%), LH1 (55%), and 7909-4-1-1 (52.8%) while higher cooked grain length (17.23 mm) and elongation ratio (2.14) from rice genotype PS2 were observed as compared to 7392 and 7909-4-1-1. Grain yield showed a positive relationship with number of tillers m^{-2} ($r = 0.375$ and $R^2 = 0.75$) while negative relationship with plant height ($r = -0.529$ and $R^2 = 0.77$) as revealed from their correlation and regression.

Conclusion It can be concluded that rice genotypes Basmati 5151, Basmati 2000 and LH1 can perform better under dry-seeding conditions.

INTRODUCTION

Rice is among the most important cereals as it fulfills dietary requirements of about 4 billion people, and is staple food of more than half of the world population (Vijayakumar et al. 2006). In Pakistan, rice is ranked as second staple food crop after wheat, important cash crop and has earned US$ 1.7 billion foreign exchange in 2013 (Government of Pakistan 2014). Rice is grown on an area of 2.7 million hectares with annual production of 6.8 million tons (Government of Pakistan 2014).

Rice is a water loving crop and its plant is adapted to grow in standing water conditions throughout its growing season. Its hydroponic adaptability is therefore utilized by growing it in puddled soil with flooded conditions by transplanting nursery seedlings as a conventional practice from years. Besides eliminating the chance of water stress to rice crop, this practice also creates adverse conditions for most of the weed species to grow. However, puddling process requires high input of water and excessive costly and time consuming land preparation operations in standing water. Further, nursery transplanting is highly laborious practice and involves high man power in uprooting and transplanting operations.

However, human population is increasing at an alarming rate and water resources are depleting. Now a days, water scarcity is a major concern in many regions of the world, as competition between agricultural and industrial consumption of water resources intensifies and climatic unpredictability increases (Hanjar and Quereshi 2010; Mahajan et al. 2011, 2012). There is a threat that Asian rice growers will probably have inadequate access to irrigation water in the future (Tuong and Bouman 2003; Mahajan et al. 2013). The scarcity of irrigation water, therefore, threatens the sustainability of rice production in irrigated environments (Chauhan et al. 2012, 2014). In addition, the migration of rural labor to urban areas, because of industrialization, causes a shortage of labor during the peak season of transplanting in many regions of Asia (Mahajan et al. 2013; Pandey and Velasco 2005). This result delayed transplanting, lower grain yield and

Cite As: Awan TH, ME Safdar, S Ahmed (2016) Adaptability of fine grain rice genotypes under direct sown growing conditions. *J. Environ. Agric.*, (1): 22-29.

late in planting of the next crop. Puddling also has deteriorating effects on soil structure, which adversely affects the subsequent non-rice crop also (Timsina and Connor 2001).

Several studies in China (Yan et al. 2010), South Asia (Gupta et al. 2002; Malik and Yadav 2008), and Australia (Beecher et al. 2006) have revealed that rice can be successfully grown using dry seeding in dry conditions. Direct seeding of rice in dry soil conditions has been developed as an alternative method of rice establishment that reduces labor requirements and other inputs while increasing or maintaining economic productivity and alleviating soil degradation problems (Ladha et al. 2009; Farooq et al. 2011). However, some studies reported a reduction in yield when shifting from puddled transplanted rice to dry seeded rice (DSR) using alternate wetting and drying water management (Bhushan et al. 2007; Choudhury et al. 2007). The yield reductions were related to the management practices applied and the climatic conditions at the planting site (Belder et al. 2004; Gathala et al. 2006; Kato et al. 2009; Singh et al. 2011).

Due to current water crises, higher labor costs and acute labor shortage, rice growers are being diverting from traditional transplanting system to DSR technique in several Southeast Asian countries (Pandey and Velasco 2002). Dry seeding is the practice of growing rice directly from seed instead of transplanting its nursery in the field. The rice cultivation in Punjab province has recently been extended to over 0.65 million hectares of non-traditional rice areas, where puddling is not possible due to severe water shortage and soil texture that do not permit true puddling (Mann 2006). The DSR technique is only the viable approach for growing rice in those areas.

In spite of several advantages of DSR over transplanted rice, rice yields could not be attained to levels as gained by puddled transplanting technique. Various constraints confronting higher productivity in DSR system are poor stand establishment and high weed infestation (Moody, 1993; Du and Tuong 2002). Moreover, grain quality and milling recovery are deteriorated under DSR conditions to more or less extent depending upon crop variety and agronomic conditions (Chen et al. 2011). This is especially true for basmati rice which is preferred by rice eaters for its best quality, taste and aroma.

All the existing cultivars of rice in Asian countries have been developed for puddled conditions and no breeding effort has been made keeping in view the un-puddled dry-seeding environment (Weerakoon et al. 2011; Lafitte et al. 2002). That is why, dry-seeding technique of rice have not become so successful. In fact, comparisons of rice yields between dry-seeded and puddled rice with the current rice cultivars that are adapted only to puddled conditions seem totally biased. Therefore, first step towards the successful dry-seeding production plan should be identification of rice plant traits that can give optimum yield under DSR conditions. Selection of rice variety for DSR is an important task of both the breeders and agronomist. The plant type should have certain traits that would enable it to withstand DSR conditions that are usually more adverse compared with puddled rice. The variety should be adapted to more competitive and water stressed environment. The plant stature, tillering capacity, and yield components may play role in achievement of higher grain yields of rice under DSR conditions.

Studies have been carried out to optimize production technology of rice under DSR conditions. However, very little is known about set of plant characteristics that enable rice to attain good yield under these conditions. The knowledge about the dependence of rice grain yield on various plant traits may serve as a tool for plant breeders and guide for farmers to develop and choose suitable rice variety for DSR conditions. The present study therefore was planned to see the grain yield and grain quality performance of different fine grain rice genotypes and find out plant traits responsible for higher grain yield under DSR conditions.

MATERIALS AND METHODS

Experimental site

Experiments were conducted at three different locations of Punjab, Pakistan viz., farm of Rice Research Institute Kala Shah Kaku, Haji Sons Farm Chinute, and Adaptive Research Farm, Gujranwala respectively, during the summer seasons of 2009 and 2010.

Plant material

Ten fine grain rice genotypes viz., Super Basmati, Basmati 2000, Basmati 5151, 98316, 99404, 7429, 7392, 7909-4-1-1, LH1 and PS2 were used in the experiments.

Crop husbandry

Before direct-seeding, the field was prepared by two disc ploughings, two cultivations and leveling. Rice was sown on 5^{th}, 6^{th} and 7^{th} June of 2009 and 7^{th}, 8^{th} and 9^{th} of 2010 at the research area of Rice Research Institute, Haji Sons Farm Chinute, and Adaptive Research Farm Gujranwala, respectively. The seed was soaked in water for 24 hours and then air dried before planting. Soaked rice seed was sown by hand drill at soil depth of 2-3 cm and row to row spacing of 9 inches (22.5 cm).

At the time of sowing 45 kg ha^{-1} N, 84 kg ha^{-1} P_2O_5 and 31 kg ha^{-1} K_2O were applied in the form of urea, di-ammonium phosphate and potassium sulfate, respectively. Same amount of urea was applied at 35 days (maximum tillering stage) and 60 days (panicle initiation) after seeding. Bispyribac sodium herbicide at its recommended dose was sprayed at 21 days after sowing to control the weeds. Later on hand weeding was done when where it was needed to control the later germinated weeds. Other agronomic and cultural practices were kept standard and uniform for all treatments for both years (2009 and 2010). The field was irrigated approximately one week after sowing when all seedlings emerged out from the soil. Urea was applied on moist soil, and then, irrigation was applied. The soil was kept moist near field capacity and irrigation was applied whenever needed. No water stress was observed during the whole study period.

Observations and measurements

Three samples of one m^2 area were selected at random from each plot. Data regarding growth and yield components i.e. plant height, productive tillers per m^2, grains per panicle and 1000-grain weight were recorded by taking the average of three samples taken randomly from each plot. However, rice paddy yield was determined from a harvested area of 9 m^2. After threshing and cleaning, the paddy yield and its moisture contents were measured with a moisture meter. Randomly 1000 grains were sub sampled, counted, and weighed. Grain yield was adjusted at 14% moisture content.

Milling and cooking characteristics

Milling and cooking characteristics were determined in Grain Quality Laboratory of Rice Research Institute, Kala Shah Kaku, Lahore, Pakistan. Grain samples of each rice genotype were cleaned with a seed blower and then dried to less than 12% moisture with electric forced air drier. The moisture content of each sample was predetermined using a Steinlite Model 500 RC Electronic moisture tester. One kg of dried paddy sample of each rice genotype was hulled with a testing husker (THU, 35H, Satake Engineering Co. Ltd., Japan) to get brown rice. Then 500 g of brown rice of each sample obtained was whitened in a single pass friction rice pearler (BS08A, Satake Engineering Co. Ltd., Japan) with the degree of whiteness set between 'Low' and 'Medium' on the equipment. After milling, rice bran was removed with a 1.7 mm sieve. A cleaned sample of milled rice was weighed and used to determine milling recovery parameters, such as, total milling recovery percentage (TMR %), head rice recovery (HRR) and percentage of brokens. Head rice recovery (HRR %) was calculated as percentage of whole milled grains with respect to the brown rice, then the average value was calculated (Bello et. al. 2004).

Ten grains of head rice were measured with the help of scale for their average length, width and breadth. Head rice of each genotype was cooked in excess water. Twenty grains of each sample were cooked with a colander in a boiler placed on an electric heater (98°C) at cooking time of the respective rice genotype. Then cooking quality parameters, such as, cooked grain length (CGL in millimeters), bursting percentage and elongation ratio of samples of each rice genotype were measured.

Experimental design and statistical analysis

The experiment was laid out in a Randomized Complete Block Design (RCBD) and replicated three times having a net plot size of 5 m x 10 m (50 m^2) at each location. Data collected were analyzed statistically using Statistix 8.1 (Analytical Software, 2005) computer software and means were compared using Turkey's Honestly Significant Difference (HSD) test at 5% probability. Regression analyses were performed on MS Office Excel software.

RESULTS AND DISCUSSION

Yield and yield related traits

Data related to various yield and yield contributing traits have been presented in Table 1. An overview of data revealed that significant difference lies among rice genotypes with respect to plant height, number of grains panicle^{-1}, 1000-grain weight and grain yield. However, number of tillers m^{-2} and panicle length did not differ significantly among genotypes under study. Significantly the highest plant height (169.2 cm) was attained by the rice genotype 7392 that remained statistically at par with that recorded with 7909-4-1-1, 7429 and Basmati 2000. In contrast, the lowest plant height was gained by Super Basmati. Rice genotypes 7429, 7909-4-1-1, 99404, 98316 and Super Basmati produced the highest number of grains panicle^{-1} whereas the lowest number of grains panicle^{-1} was counted with PS2 rice genotype. Regarding 1000-grain weight, all the rice genotypes remained superior over Basmati 2000. Grain yield performance under dry-seeding conditions was better by all the rice genotypes except 7392 and 7909-4-1-1.

Regression analysis indicated a significant positive relationship of grain yield with number of tillers m^{-2} (R^2 = 0.75) while negative relationship with plant height (R^2 = 0.77) (Figure 1). However, grain yield showed a non-significant relationship with panicle length, number of grains panicle^{-1} and 1000-grain weight. The correlation matrix was presented in Table 2. The data revealed that significant positive correlation (r = 0.375) exists between grain yield and number of tillers m^{-2}.

Table 1 Grain yield and yield related traits of fine grain rice genotypes as influenced by direct seeding

Genotypes	Number of tillers m^{-2}	Plant height (cm)	Panicle length (cm)	Number of grains panicle^{-1}	1000-grain weight (g)	Grain yield (t ha^{-1})
Super Basmati	330	124.7 d	28.9	86.7 ab	22.2 ab	4.3 a
Basmati 2000	288	145.8 a-d	28.7	77.3 b	21.6 b	3.8 ab
Basmati 5151	280	142.2 bcd	28.5	91.3 ab	22.0 ab	3.8 ab
98316	268	134.8 cd	28.9	79.7 b	20.7 b	3.7 abc
99404	274	127.3 d	27.5	91.3 ab	22.7 ab	3.8 ab
7429	258	158.3 abc	28.3	105.0 a	23.5 ab	3.4 abc
7392	236	169.2 a	28.4	80.0 b	22.6 ab	2.7 c
7909-4-1-1	230	163.1 ab	26.6	84.0 ab	23.3 ab	3.0 bc
LH 1	245	136.3 cd	29.0	78.0 b	22.7 ab	3.7 abc
PS2	292	126.4 d	27.8	71.7 b	26.1 a	3.8 ab
LSD	NS	24.67	NS	24.35	4.10	0.99
SE	-	6.88	-	6.79	1.14	0.28

While a significant negative correlation (r = -0.5285) lies between grain yield and plant height of rice under dry-seeding conditions. Regression and correlation analyses revealed that rice plant with less plant height and greater number of tillers is suitable ideotype under direct sown un-puddled growing conditions. Number of tillers is an important yield component of rice that always contribute positively to grain yield (Devic et al. 2012) either sown under dry-seeding or puddled transplanting conditions. The grain yield reduction by increase in plant height of rice under dry-seeding conditions could be the result of increased lodging as long statured crop varieties are more prone to lodging (Mackill et al. 1996). Lodging is more prevalent in direct seeded rice compared with conventional puddled rice (Setter et al. 1997; Farooq et al. 2011). Lodging caused grain yield to reduce drastically on account of reduced photosynthetic activity of plant by self-shading effect (Setter et al. 1997).

Grain quality traits

The grain quality attributes determining milling recovery, grain measurement, and cooking quality were significantly different among various rice genotypes sown under direct seedling conditions (Table 3). However, total milling recovery (%) did not differ significantly among rice genotypes. The brown rice (BR) percentage of all genotypes was statistically at par with each other except that recorded with PS2 which gave the lowest BR percentage. The head rice is the ultimate finished product of rice milling acquired after polishing, and is eaten by the consumers and head rice recovery (HRR) is the percentage of polished whole grain obtained from paddy. The highest HRR was obtained from rice genotypes Basmati 5151 (55.5%), Basmati 2000 (52.2%), LH1 (55%), and 7909-4-1-1 (52.8%). Contrastingly, PS2 gave the lowest (42.8%) HRR (Table 3). The minimum HRR of rice genotype PS2 among ten rice genotypes grown under puddled conditions was also reported by Akhter et al. (2014) which proved that genotype to be poor in milling recovery both under puddled as well as DSR conditions. Regarding grain measurement, the maximum grain length (8.06 mm), grain width (1.72 mm), and grain thickness (1.52 mm) was measured with rice genotype PS2 (Table 3). However, statistically similar grain widths were recorded with rice genotypes Basmati 5151, 7429, 7392, 7909-4-1-1, and LH1 while grain thicknesses with all genotypes except 98316 and 99404. Among all genotypes sown under dry-seeding conditions, rice genotype PS2 showed the highest cooked grain length (17.23 mm) and elongation ratio (2.14) (Table 3). However, bursting percentage upon cooking was also greater (14%) in grains of PS2 rice genotype which was statistically at par with that observed in 7909-4-1-1. The highest CGL and bursting percentage of rice genotype PS2 was probably due to its greater uncooked grain length. Akhter et al. (2014) also found that PS2 gave the highest CGL and bursting percentage among ten rice genotypes grown under puddled conditions.

CONCLUSION

Rice genotypes with less plant height and larger number of tillers such as Basmati 5151 (55.5%), Basmati 2000 (52.2%), LH1 (55%) and PS2 perform better under dry direct seeding conditions without deteriorating their grain quality and cooking attributes.

REFERENCES

Akhter M, MA Ali, Z Haider, S Muzammil (2014) Efficacy of parboiling on physicochemical properties of some promising line/varieties of rice (*Oryza sativa* L.). *Science, Technology and Development*, **33:** 115–122.

Analytical Software (2005) Statistix 8.1 for Windows. Analytical Software, Tallahassee, Florida.

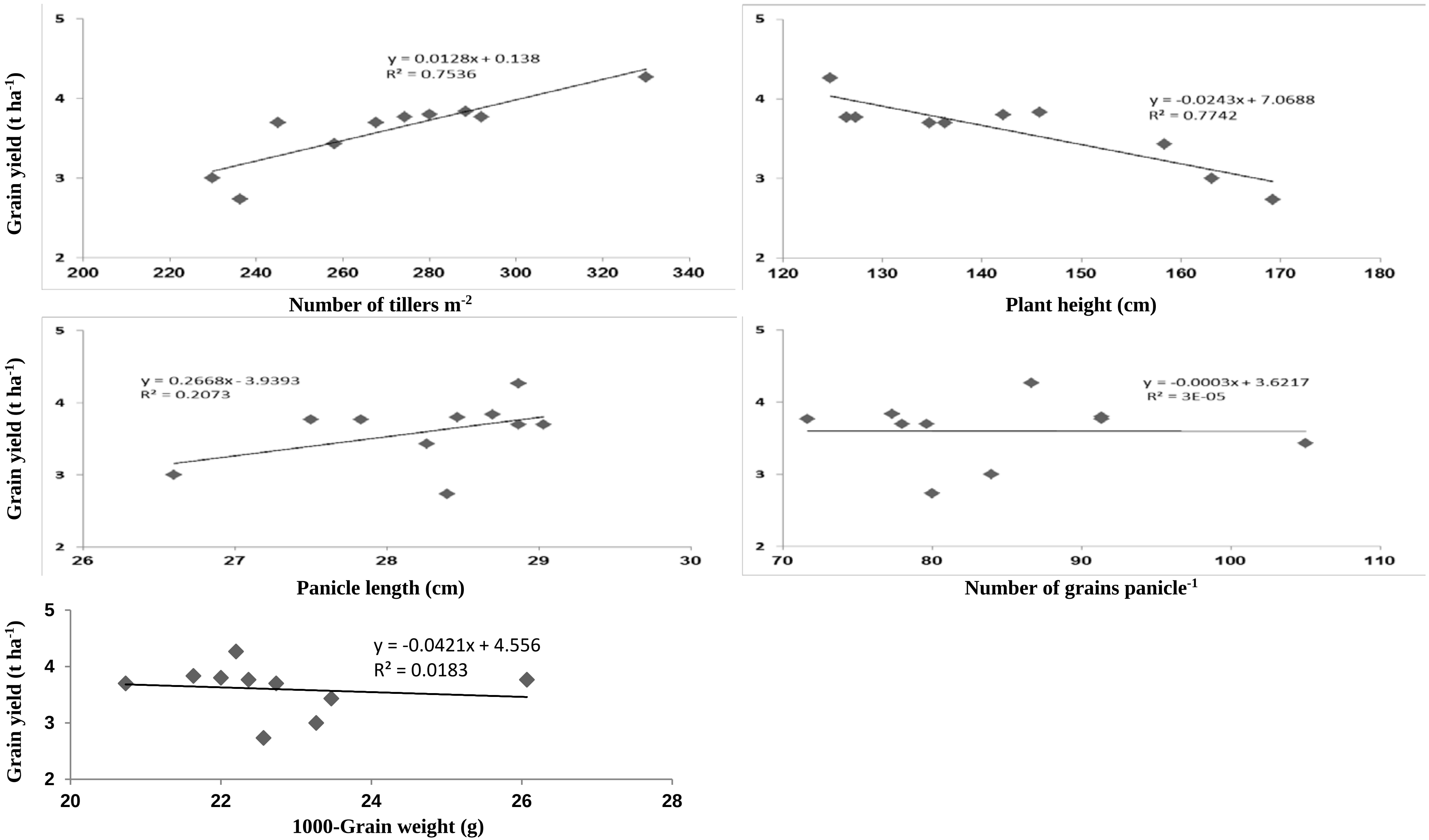

Figure 1 Relationship of grain yield and yield contributing attributes as influenced by direct seeding rice

Table 2 Correlation matrix among grain yield and yield related traits of rice genotypes as influenced by direct seeding

Yield related traits	Number of tiller m^{-2}	Plant height (cm)	Panicle length (cm)	Number of grains $panicle^{-1}$	1000-grain weight (g)
Plant height (cm)	-0.3439^{NS}	-	-	-	-
Panicle length (cm)	0.1761^{NS}	-0.1695^{NS}	-	-	-
Number of grains $panicle^{-1}$	-0.3104^{NS}	0.2926^{NS}	-0.2635^{NS}	-	-
1000-grain weight (g)	-0.0631^{NS}	0.1168^{NS}	0.0667^{NS}	-0.0418^{NS}	-
Grain yield (t ha^{-1})	0.3746*	-0.5285**	0.1321^{NS}	0.1479^{NS}	0.0378^{NS}

Table 3 Grain quality attributes of fine grain rice genotypes as influenced by direct seeding

Genotypes	Milling Recovery			Grain Measurements			Cooking Data		
	BR %	TMR %	HRR %	L (mm)	W (mm)	T (mm)	CGL (mm)	Bursting %	E/R
Super Basmati	80.2 ab	70.2	51.5 bc	7.24 d	1.57 b-e	1.44 ab	13.83 bc	3.67 c	1.91 b
Basmati 2000	80.0 ab	70.0	52.2 abc	7.22 d	1.56 cde	1.40 ab	13.67 bc	6.00 bc	1.89 b
Basmati 5151	80.5 a	71.2	55.5 a	7.33 d	1.59 a-e	1.42 ab	14.03 bc	4.67 c	1.91 b
98316	79.5 ab	69.0	51.2 bc	7.23 d	1.46 e	1.34 b	13.87 bc	6.67 bc	1.92 b
99404	80.2 ab	70.5	51.3 bc	7.20 d	1.50 de	1.36 b	13.43 c	6.00 bc	1.86 b
7429	80.2 ab	70.0	50.7 c	7.61 c	1.70 abc	1.43 ab	13.93 bc	5.33 c	1.84 b
7392	80.2 ab	70.2	50.5 c	7.63 c	1.64 a-d	1.44 ab	14.07 bc	6.00 bc	1.84 b
7909-4-1-1	79.5 ab	69.5	52.8 abc	7.80 b	1.72 ab	1.51 a	14.23 b	10.67 ab	1.82 b
LH1	80.5 a	69.8	55.0 ab	7.24 d	1.60 a-e	1.41 ab	13.73 bc	6.00 bc	1.89 b
PS2	78.8 b	69.3	42.8 d	8.06 a	1.72 a	1.52 a	17.23 a	14.00 a	2.14 a
LSD	1.5854	NS	3.9386	0.1458	0.1482	0.1279	0.6723	5.3219	0.0948
SE	0.4424	-	1.0989	0.0407	0.0414	0.0357	0.1876	1.4849	0.0265

BR = Brown rice, TMR = Total milling recovery, HR = Head rice recovery, L = Grain length, W = Grain width, T = Grain thickness, CGL = Cooked grain length, E/R = Elongation ratio

Beecher G, B Dunn, S Mathews, J Thompson, RP Singh, L Humphreys, J Timsina, K O'Keefe, D Johnston (2006) Permanent beds for sustainable cropping. *IREC Farmers' Newsletter*, **171:** 24–27.

Belder P, BAM Bouman, RLC Guoan, EJP Quilang, Y Li, JHJ Spiertz, TP Tuong (2004) Effect of water-saving irrigation on rice yield and water use in typical lowland conditions in Asia. *Agricultural Water Management*, **65:** 193–210.

Bello M, R Baeza, MP Tolaba (2004) Quality characters of milled and cooked rice affected by hydrothermal treatment. *Journal of Food Engineering*, **72:** 124–133.

Bhushan L, JK Ladha, RK Gupta, S Singh, A Tirol-Padre, YS Saharawat, M Gathala, H Pathak (2007) Saving of water and labor in a rice–wheat system with no-tillage direct seeding technologies. *Agronomy Journal*, **99:** 1288–1296.

Chauhan BS, G Mahajan, V Sardana, J Timsina, ML Jat (2012) Productivity and sustainability of the rice–wheat cropping system in the Indo-Gangetic Plains of the Indian subcontinent: problems, opportunities, and strategies. *Advanced Agronomy*, **117:** 315–369.

Chauhan BS, Prabhjyot-Kaur, G Mahajan, RK Randhawa, H Singh, MS Kang (2014) Global warming and its possible impact on agriculture in India. *Advanced Agronomy*, **123:** 65–121.

Chen S, W Zhou, F Zeng, G Zhang (2011) Effect of Planting Method on Grain Quality and Nutrient Utilization for No-Tillage Rice. *Communications in Soil Science and Plant Analysis*, **42:** 1324–1335

Choudhury BU, BAM Bouman, AK Singh (2007) Yield and water productivity of rice–wheat on raised beds at New Delhi, India. *Field Crops Research*, **100:** 229–239.

Devic B, GM Lal, CM Singh, P Yadav (2012) Genetic architecture, interrelationship and path analysis for yield improvement in exotic rice (*Oryza sativa* L.). *International Journal of Agriculture, Environment and Biotechnology*, **5:** 387–392.

Du LV, TP Tuong (2002) Enhancing the performance of dry seeded rice: Effects of seed priming, seedling rate and time of seedling. In Direct Seeding: Research strategies and opportunities. In: Pandey S, M Mortimer, L Wade, T Tuong, K Lopes, B Hardy (Eds.). Manila, Philippines: International Research Institute, pp 241–256.

Farooq M, KHM Siddique, H Rehman, T Aziz, DJ Lee, A Wahid (2011) Rice direct seeding: experiences, challenges and opportunities. *Soil and Tillage Research,* **116:** 260–267.

Farooq M, KHM Siddique, H Rehman, T Aziz, Dong-Jin Lee, A Wahid (2011) Rice direct seeding: Experiences, challenges and opportunities. *Soil and Tillage Research,* **111:** 87–98.

Gathala MK, JK Ladha, YS Saharawat, H Pathak, RK Gupta, MP Yadav (2006) Performance of no-till rice–wheat system in the Indo-Gangetic Plains. In: Proceedings of the 2nd International Rice Congress, New Delhi, India, P 474.

Government of Pakistan (2014) Economic Survey of Pakistan. Government of Pakistan, Finance Division, Economic Advisors Wing, Islamabad, Pakistan, P 27.

Gupta RK, RK Naresh, PR Hobbs, JK Ladha (2002) Adopting conservation agriculture in the rice–wheat system of the Indo-Gangetic Plains: new opportunities for saving water. In: Bouman BAM, H Hengsdijk, B Hardy, PS Bindraban, TP Tuong, JK Ladha (Eds.). Water-Wise Rice Production. Proceedings of the International Workshop on Water-Wise Rice Production, April 8–11, 2002, Los Baños, Philippines, pp 207–222.

Hanjar MA, ME Quereshi (2010) Global water crisis and food security in an era of climate change. *Food Policy,* **35:** 365–377.

Kato Y, M Okami, K Katsura (2009) Yield potential and water use efficiency of aerobic rice (*Oryza sativa* L.) in Japan. *Field Crops Resarch,* **113:** 328–334.

Ladha JK, V Kumar, MM Alam, S Sharma, MK Gathala, P Chandna, YS Saharawat, V Balasubramanian (2009) Integrating crop and resource management for enhanced productivity, profitability and sustainability of the rice–wheat system in South Asia. In: Ladha JK, Y Singh, O Erenstein, B Hardy (Eds.). International Rice Research Institute, Los Baños, Philippines, pp 69–108.

Lafitte HR, B Courtois, M Arradeau (2002) Genetic improvement of rice in aerobic systems: Progress from yield to genes. *Field Crops Research,* **75:** 171–190.

Mackill DJ, WR Coffman, DP Garrity (1996) Rainfed Lowland Rice Improvement. International Rice Research Institute, Manila, Philippines, P 242.

Mahajan G, BS Chauhan, J Timsina, PP Singh, K Singh (2012) Crop performance and water- and nitrogen-use efficiencies in dry-seeded rice in response to irrigation and fertilizer amounts in northwest India. *Field Crops Reserch,* **134:** 59–70.

Mahajan G, BS Chauhan, MS Gill (2011) Optimal nitrogen fertilization timing and rate in dry-seeded rice in northwest India. *Agronomy Journal,* **103:** 1676–1682.

Mahajan G, BS Chauhan, MS Gill (2013) Dry-seeded rice culture in Punjab state of India: lessons learned from farmers. *Field Crops Research,* **144:** 89–99.

Malik RK, A Yadav (2008) Direct-seeded rice in the Indo-Gangetic Plain: progress, problems and opportunities. In: Humphreys E, CH Roth (Eds.). Proceedings of permanent beds and rice residue management for rice–wheat systems in the Indo-Gangetic Plains. ACIAR Workshop Proceedings No. 127, ACIAR. Canberra, Australia, pp 124–132.

Mann RA (2006) Semi-annual Progress Report of the IRRI-ADB project (ReTA # 6267) on Development and Dissemination of Water-Saving Rice Technologies in South Asia. Pakistan Agricultural Research Council, Islamabad.

Moody K (1993) Weed control in wet-seeded rice. *Experimental Agriculture,* **29:** 393–403.

Pandey S, L Velasco (2002) Economics of direct seeding in Asia: patterns of adoption and research priorities. In: Pandey S, M. Mortimer, L Wade, TP Tuong, K Lopes, B Hardy (Eds.), Direct Seeding: Research Strategies and Opportunities. International Rice Research Institute, Los Ban˜ os, Philippines.

Pandey S, L Velasco (2005) Trends in crop establishment methods in Asia and research issues. In: Toriyama, K, KL Heong, B Hardy (Eds.), Rice is Life: Scientific Perspectives for the 21st Century. International Rice Research Institute and Tsukuba, Japan: Japan International Research Center for Agricultural Sciences, Los Baños, Philippines, pp 178–181.

Setter TI, EV Laureles, AM Mazaredo (1997) Lodging reduces yield of rice by self-shading and reduction of photosynthesis. *Field Crops Research,* **49:** 95–106

Singh Y, VP Singh, G Singh, DS Yadav, RKP Sinha, DE Johnson, AM Mortimer (2011) The implications of land preparation, crop establishment method and weed management on rice yield variation in the rice–wheat system in the Indo-Gangetic plains. *Field Crops Res.,* **121:** 64–74.

Timsina J, DL Connor (2001) The productivity and sustainability of the rice–wheat cropping systems: issues and challenges. *Field Crops Research,* **69:** 93–132.

Tuong TP, BAM Bouman (2003) Rice production in water-scarce environments. In: Proceedings of the Water Productivity Workshop. International Water Management Institute, Colombo, Sri Lanka.

Vijayakumar M, S Ramesh, B Chandrasekaran, TM Thiyagarajan (2006) Effect of system of rice intensification (SRI) practices on yield attributes, yield and water productivity of rice (*Oryza sativa* L.). *Research Journal of Agriculture and Biological Sciences*, **2:** 236–242.

Weerakoon WMW, MMP Mutunayake, C Bandara, AN Rao, DC Bhandari, JK Ladha (2011) Direct-seeded rice culture in Sri Lanka. *Field Crops Research*, **121:** 53–63.

Yan J, J Yua, GC Taoa, J Vosb, BAM Boumanc, GH Xiea, H Meinke (2010) Yield formation and tillering dynamics of direct-seeded rice in flooded and non-flooded soils in the Huai River Basin of China. *Field Crops Research*, **116:** 252–259