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Evaluation of different duration rice (*Oryza sativa*) cultivars for yield and water use efficiency under direct seeded conditions

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ABSTRACT

A field experiment was conducted during rainy (*kharif*) seasons of 2019 and 2020 at Rice Research Station Kaul (Kaithal), Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana to evaluate seven rice (*Oryza sativa* L.) cultivars [(HKR 09-93 (medium), HKR 127 (medium), HKR 14-30 (mid early), HKR 47 (mid early), IR 99-784-255-91-1-5 (early), HKR 49 (early) and HKR 48 (early)], for yield and water use efficiency under the direct seeded (aerobic) conditions relative to puddled transplanted control. Grain yield of all the short duration cultivars was at par both under the aerobic and transplanted conditions. However, the yield of longer duration (mid-early and medium) cultivars reduced significantly under aerobic conditions compared to that under the transplanted conditions with comparatively more yield reduction in medium duration cultivars (26.3%) than in mid early cultivars (21.7 22.0%). The short duration cultivars, except HKR 48, were found significantly superior to longer duration cultivars under the direct seeded conditions. The highest water use efficiency (7.74 kg/ha/mm) was achieved with HKR 49. Net income obtained from short duration cultivars under direct seeded conditions was comparable to that under transplanted conditions but the income from medium and mid-early duration cultivars reduced significantly (by ₹20,077/ha – ₹2,8918/ha) under direct seeding. The short duration cultivars, except HKR 48, were more profitable than the longer duration varieties under the aerobic conditions with HKR 49 fetching the highest net returns (₹84,963/ha). It can be concluded from the results that short duration rice cultivars may be developed, identified and recommended for the success of water saving direct seeding technology of rice cultivation.

Keywords: Aerobic, Cultivars, Direct seeded rice, Transplanted, Water use efficiency

In western parts of the Indo-Gangetic Plains (IGP), particularly in Punjab and Haryana, rice (*Oryza sativa* L.) is commonly grown by transplanting method. But the puddled transplanted rice (TPR) requires huge quantity of water (1357–1666 mm) (Brar *et al.* 2015) and later part of rice crop ontogeny. Additionally, TPR also requires high energy and labour for puddling and transplanting operations. The excessive water needs in TPR has caused the over-exploitation of ground water. The water table in this part has depleted at an alarming rate of 0.33 m per year (Narjary *et al.* 2014), which has led to the increased cost of pumping this water out (Mahajan *et al.* 2011).

Direct seeded rice (DSR) has been viewed as a potential alternative to unsustainable water-intensive TPR production system, worldwide (Pratap *et al.* 2023). DSR reduces water requirements expenditure on transplanting, emission of green house gases and cost of production (Singh *et al.* 2012, Chaudhary *et al.* 2017) and hence offers a good alternative to conventional transplanting despite poor weed management and nutrient availability under aerobic conditions (Pratap *et al.* 2023). Direct seeding has been reported to save 18–20% of irrigation water over conventional TPR (Bhullar *et al.* 2018). The extent of yield reduction may vary with the cultivar and its duration (Joshi 2016) as well as its tolerance to water stress (Mahajan *et al.* 2011). High yielding rice cultivars of medium (>135 days), mid-early (121–135 days) and early or short (<120 days) duration are grown in the areas of north-western IGP, including Haryana. Therefore, it has become essential to identify the rice cultivars of appropriate duration suitable for aerobic conditions to increase the yield and saving of water. Hence, study was conducted to evaluate rice cultivars of different phenology for yield, water use efficiency and

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profitability under the direct seeded (aerobic) conditions relative to the conventional transplanted control.

MATERIALS AND METHODS

The field experiment was conducted during rainy (*kharif*) seasons of 2019 and 2020 at Rice Research Station Kaul (Kaithal), Chaudhary Charan Singh Haryana Agricultural University, Hisar, Haryana. The soil of the experimental site wass clay loam in texture, alkaline in reaction (*p*H 7.9), low in organic carbon (0.38%), low in available N (160 kg N/ha), medium in available phosphorus (15 kg P/ha) and high in potassium (320 kg K/ha). The bulk density, field capacity, permanent wilting point and infiltration rate of the soil were 1.58 g/m^3, 25.1%, 3.8% and 1.8 mm/h, respectively. The experimental site has a semi-arid sub-tropical climate with an average annual rainfall of 500 mm, 80% of which is received during the rainy season (June to September). Climatic variables during the two crop seasons (2019 and 2020) were almost similar with mean monthly maximum temperature varying from 33.2°C (October) to 39.9°C (June) and minimum temperature from 16.0°C (October) to 25.8°C (July or August). The mean monthly sunshine duration was the highest (8.3 h/day) in June and the lowest in July (6.0 h/day). The mean pan evaporation was also the highest (7.3 mm/day) in June but it was the lowest (1.2 mm/day) in October. Total rainfall received during the crop growing period was 536 mm in 2019 and 556 mm in 2020 with the highest rainfall received during July in both years. However, the distribution of the rainfall (Table 1) varied considerably during the two seasons as the number of rainy days and total rainfall received during August were higher in 2019 than in 2020 but July had more rainy days and higher total rainfall in 2020.

The experiment consisted of two crop establishment methods, viz. direct seeding and transplanting and seven rice cultivars of varying duration, viz. HKR 09-93 (C_1) (medium), HKR 127 (C_2) (medium), HKR 14-30 (C_3) (mid early), HKR 47 (C_4) (mid early), IR 99-784-255-91-1-5 (C_5) (early), HKR 49 (C_6) (early) and HKR 48 (C_7) (early). Among the cultivars, C_1, C_3 and C_5 were advanced breeding lines whereas C_2, C_4, C_6 and C_7 were high yielding varieties recommended for the region. The different duration advance breeding lines were selected on the basis of their superior performance against their released checks (recommended varieties) under transplanted conditions in station trials so as to compare and assess their performance under direct seeded conditions too. Keeping in view the operational convenience, the treatments were laid out in split plot design (SPD) with the establishment methods in main plots and genotypes in sub-plots of size 5 m × 3 m.

Table 1 Rainfall distribution during the growing period of the experimental crop

Month	Total number of rainy days		Number of rainy days with more than 10 mm rainfall		Total rainfall (mm)	
	2019	2020	2019	2020	2019	2020
June	1	2	1	1	15	61
July	9	11	8	9	295	373
August	6	5	5	3	206	110
September	1	2	1	1	20	12
October	0	0	0	0	0	0
Total	17	20	15	14	536	556

The DSR was sown on June 17 and June 18 during 2019 and 2020, respectively by seed cum fertiliser drill in rows 20 cm apart using a seed rate of 20 kg/ha. Nursery for TPR was sown on the same day (day of DSR sowing). In TPR, 30-days old rice seedlings raised in conventional nursery were transplanted in puddled field at a row spacing of 20 cm and intra-row spacing of 15 cm with two seedlings/hill. The DSR plots were irrigated with 60 mm water immediately after sowing to provide soil moisture for seed germination followed by irrigation (50 mm) after 5 days of sowing to ensure good germination. Thereafter, the irrigations (50 mm each) in DSR were scheduled at 5 days after disappearance of ponded water (5 DADPW). For the first 15 days after transplanting, the plots under TPR received irrigation at frequent intervals to maintain shallow submergence (3–5 cm) in the field but subsequent irrigations (50 mm each) were applied at 1 DADPW up to the panicle initiation stage and at 2 DADPW thereafter. The irrigation was applied with the help of a Parshall flume. Irrigation in all the plots was stopped at least a week before the crop maturity. All other recommended agronomic and plant protection measures were followed to raise the crop.

The data on crop yield attributes (number of effective tillers or panicles/m^2, number of grains/panicle and 1000-grain weight) and grain yield were recorded at the crop maturity from all the experimental plots. The number of effective tillers was recorded with a quadrate (0.5 m × 0.4 m) placed randomly in each plot. At the same time,10 panicles were also taken randomly from each plot and their grains (obtained after threshing the panicles) were counted and weighed (after drying to 14% moisture) to determine the number of grains/panicle and 1000-grain weight. The matured crop from each plot was manually harvested and threshed to record the grain yield/plot and expressed in kg/ha at 14% moisture content.

Water was applied to the main plots with the help of Parshall Flume with a throat size of 7.5 cm and all the sub-plots received equal amounts of water. In both establishment methods, irrigation was stopped 10 days before the crop harvest. The quantity of water applied through each irrigation was summed up to work out the total water applied during the crop growing period. Water use efficiency (kg/ha/mm) was determined by dividing the grain yield with total water received through both irrigation and rainfall (Mahajan *et al.* 2011).

To work out the economics of different treatments, the net income (₹/ha) was computed as the difference between gross income (grain yield × minimum support price) and cost of cultivation (expenditure on inputs and field operations, including labour cost). The data were subjected to statistical analysis and the treatment means were compared using critical difference (CD) determined at 5% level of significance (p=0.05). Since the results were similar during both years, therefore, the data were pooled across the years for statistical analysis.

RESULTS AND DISCUSSION

Crop phenology: The phenology (days taken for 50% flowering and maturity) of the crop was not influenced significantly due to the method of crop establishment. However, cultivars differed among themselves in respect of days to 50% flowering and maturity with short duration cultivars being the earliest, followed by mid early and medium duration cultivars. Among short duration cultivars, HKR 48 (C_7) was the earliest in flowering (86 days) and maturity (116 days), followed by HKR 49 (C_6) or IR 99-784-255-91-1-5 (C_5) (flowering in 88.4–89.3 days and maturing in 118.4–119.3 days). Mid early cultivars HKR 47 (C_4) and HKR 14-30 (C_3), attained the flowering (100.1 and 101.1 days) and maturity (130.1 and 131.1 days) simultaneously and were significantly earlier than the medium duration HKR 09-93 (C_1) and HKR 127 (C_2) that too attained the flowering (102.9–103.9 days) and maturity (132.9–133.9 days) almost simultaneously. The variation in phenology of the cultivars was obviously due to their genetic constitution.

Yield and yield attributing characters: Mean (averaged over cultivars) number of grains/panicle, 1000-grain weight and ultimately grain yield of rice crop was significantly higher (15.1%) in transplanting than in the direct seeding (Table 2). Averaged over the establishment methods, new short duration cultivar HKR 49 (C_6) gave the highest mean grain yield and performed significantly better than all the other cultivars as it had higher 1000-grain weight than all other cultivars, except IR 99-784-255-91-1-5. Cultivar IR 99-784-255-91-1-5, despite having the highest mean 1000-grain weight, gave mean yield comparable to the that of the longer duration (medium and mid early) cultivars as it had significantly lower number of grains/panicle. The lowest mean number of grains and ultimately the lowest mean grain yield was obtained with HKR 48 (C_7).

Interaction between the establishment methods and cultivars was found significant in respect of number of grains/panicle, 1000-grain weight and grain yield (Table 2) which revealed that individual grain yield of all the short duration cultivars, viz. C_5 (7,028 kg/ha), C_6 (7,979 kg/ha) and C_7 (5,932 kg/ha) obtained under direct seeded conditions was statistically similar to that obtained under transplanted conditions (7,349, 8,076 and 6,095 kg/ha, respectively) with no reduction in their yield attributing characters, viz. number of grains/panicle and 1000-grain weight under direct seeding. But the yield attributes (number of grains/panicle and 1000-grain weight) and consequently grain yield of longer duration (mid early and medium duration) cultivars reduced significantly under aerobic conditions compared to that under the transplanted control and the yield reduction was comparatively more serious in medium duration cultivars [(25.0% in HKR 127 (C_2) to 26.2% in HKR 09-93 (C_1)] than in mid early cultivars [21.7% in HKR 47 (C_4) to 22.0% in HKR 14-30 (C_3)]. The reduction in yield of longer duration cultivars might be due to their exposure to moisture stress under aerobic conditions for comparatively longer period.

Among short duration cultivars, HKR 49 (C_6) and IR 99-784-255-91-1-5 (C_5), yielded significantly better than all the other cultivars under direct seeded environment but C_6 and C_5 yielded at par with the longer duration cultivars under transplanted conditions. Under direct seeding, the highest yield was achieved with HKR 49 (C_6) which proved significantly better than all the other cultivars whereas all the cultivars, except HKR 48 (C_7), yielded at par under transplanted conditions. The highest yield of HKR 49 (C_6) under direct seeded conditions could be attributed to its early vigour and better drought tolerance ability as also evident from the fact that it possessed significantly more grains/panicle than all the other cultivars, including the other short duration ones, under aerobic environment. Reduction in grain yield and its attributes in high yielding rice cultivars under direct seeded conditions has also been reported by Singh *et al.* (2012) and Singh *et al.* (2020). Gill *et al.* (2006) also found that short duration and early maturity rice variety was suitable in terms of yield and yield attributing parameters under direct sown conditions.

Water applied and water use efficiency: Irrigation water applied to the crop varied depending upon the establishment methods and cultivars or their duration (Table 3). Irrespective of the cultivars, quantity of applied irrigation water was less in DSR (735–835 mm) than in TPR (875–1025 mm), resulting into average saving of 24.6% of the water applied in DSR. The higher irrigation requirement of TPR could be because of the fact that the transplanted field required extra water for land preparation (puddling) and experienced more percolation losses (Bouman *et al.* 2005) than the aerobic field.

The water applied, averaged over the establishment methods, was markedly low in short duration cultivars (805–855 mm) than the cultivars of longer duration (955 mm) obviously because of fewer irrigations needed. Among the cultivars, maximum saving in irrigation water was obtained with HKR 48 (C_7) (27.6%), followed by HKR 49 (C_6) or IR 99-784-255-91-1-5 (C_5) (26.3%) whereas the water saving was minimum (24.0%) with longer duration cultivars. Water use efficiency in short duration cultivars improved significantly (21.6–25.6%) under direct seeded conditions because of less irrigation requirement with no yield penalty whereas the reduction in the yield of longer duration cultivars under direct seeded conditions outweighed the advantage of water saving, resulting into no improvement in their water use efficiency under direct seeded conditions. The highest water use efficiency (7.74 kg/ha/mm) was achieved with HKR 49 (C_6) when grown under aerobic conditions because of the highest yield of

Table 2 Phenology, yield attributes and grain yield of rice crop in relation to methods of establishment and cultivars

Establishment methods	Cultivars							
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	Mean
Days to 50% flowering								
DSR	105.1	106.3	103.4	102.1	89.2	88.4	86.0	97.2
TPR	106.7	107.5	104.8	104.1	89.4	88.4	86.0	98.1
Mean	105.9	106.9	104.1	103.1	89.3	88.4	86.0	
CD (p=0.05) for methods of establishment (E): NS; Cultivars (C): 1.1; E × C: NS								
Days to maturity								
DSR	135.1	136.3	133.4	132.1	119.2	118.4	116.0	127.2
TPR	136.7	137.5	134.8	134.1	119.4	118.4	116.0	128.1
Mean	135.9	136.9	134.1	133.1	119.3	118.4	116.0	
CD (p=0.05) for methods of establishment (E): NS; Cultivars (C): 1.1; E × C: NS								
Number of panicles/m^2								
DSR	287	290	291	289	300	312	302	296
TPR	300	299	298	299	302	306	295	300
Mean	294	294	294	294	301	309	299	
CD (p=0.05) for methods of establishment (E): NS; Cultivars (C): NS; E × C: NS								
Number of grains/panicle								
DSR	95.8	95.3	95.6	94.6	90.9	103.8	84.7	94.4
TPR	107.2	107.1	107.1	106.3	92.4	105.0	88.4	101.9
Mean	101.5	101.2	101.3	100.5	91.7	104.4	86.5	
CD (p=0.05) for methods of establishment (E): 2.4; Cultivars (C): 4.8; E × C: 6.9								
1000-grain weight (g)								
DSR	24.1	24.2	24.2	24.3	30.2	28.3	26.7	26.0
TPR	28.3	28.2	28.0	27.9	30.5	28.6	25.2	28.1
Mean	26.2	26.2	26.1	26.1	30.3	28.5	26.0	
CD (p=0.05) for methods of establishment (E): 0.5; Cultivars (C): 1.6; E × C: 2.3								
Grain yield (kg/ha)								
DSR	5842	5824	5999	5967	7028	7979	5932	6367
TPR	7919	7763	7689	7619	7349	8076	6095	7501
Mean	6881	6793	6844	6793	7188	8027	6014	
CD (p=0.05) for methods of establishment (E): 370; Cultivars (C): 398; E × C: 603								

NS, Not significant; DSR, Direct seeded rice; TPR, Transplanted rice. Cultivar details are given under Materials and Methods.

this cultivar in addition to lower quanity of water applied. Mahajan *et al.* (2009) also observed that irrigation water productivity decreased with the duration of cultivars as longer crop duration needs more irrigations which leads to lower irrigation water use efficiency. Singh *et al.* (2020) also reported higher water use efficiency in aerobic rice than in flooded transplanted rice.

Economic returns: Interaction between establishment methods and cultivars was found significant for net income (Table 3) which showed that net income obtained from the short duration cultivars was comparable in aerobic and transplanted conditions, but the income from longer duration cultivars reduced significantly under direct seeding despite decrease in the cost of cultivation. Moreover, short duration cultivars, except HKR 48 (C_7), gave higher net profit under aerobic conditions than the longer duration ones. This showed that net profit in the present study was governed mainly by the grain yield. In direct seeding, net profit from short duration cultivars, except HKR 48 (C_7), was significantly higher than that from the longer duration ones with HKR 49 (C_6) giving the highest net return (₹84,963/ha). Singh *et al.* (2020) also obtained higher net profit with short duration cultivar under the direct seeded than conventional transplanted conditions which could be due to the increased savings on account of the reduced water input and cost of cultivation (Chaudhary *et al.* 2023).

In conclusion, the short duration cultivars (<120 days) like HKR 49 should be preferred over the longer duration cultivars under the direct seeded aerobic conditions as they give higher yield, water use efficiency as well as net profit

Table 3 Irrigation water applied, water use efficiency and net income of rice crop (average of two years) in relation to methods of establishment and cultivars

Establishment methods	Cultivars							
	C_1	C_2	C_3	C_4	C_5	C_6	C_7	Mean
Irrigation water applied (mm)								
DSR	885	885	885	885	785	785	735	835
TPR	1025	1025	1025	1025	925	925	875	975
Mean	955	955	955	955	855	855	805	
Saving (%)	24.0	24.0	24.0	24.0	26.3	26.3	27.6	
Water use efficiency (kg/ha/mm)								
DSR	5.17	5.15	5.30	5.28	6.82	7.74	6.05	5.93
TPR	5.61	5.50	5.45	5.40	5.61	6.16	4.83	5.51
Mean	5.39	5.33	5.38	5.34	6.21	6.95	5.44	
CD (p=0.05) for methods of establishment (E): 0.28; Cultivars (C): 0.32; E × C: 0.49								
Net income (₹/ha)								
DSR	44578	44237	47492	46899	67255	84963	47154	54654
TPR	73155	70247	68866	67569	62532	76069	39189	65375
Mean	58867	57242	58179	57234	64894	80516	43172	
CD (p=0.05) for methods of establishment (E): 6897; Cultivars (C): 7419; E × C: 11232								

DSR, Direct seeded rice; TPR, Transplanted rice. Cultivar details are given under Materials and Methods.

besides saving appreciable amounts of irrigation water (26%). In view of the results of the present investigation, there is need to develop, identify and adopt suitable cultivars of short duration for the success of resource conservative (water, labour and energy saving) direct seeding method of rice cultivation so that it could be a good alternative to water guzzling conventional transplanting method for sustaining rice cultivation in ground water depleting areas of the north-west IGP. The research efforts should also be made for breeding and identifying suitable mid early and medium duration rice cultivars to improve their yield under direct seeded conditions.

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