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Field appraisal of seed priming to improve the growth, yield, and quality of direct seeded rice

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Abstract: Poor crop stand and high weed infestation are the major constraints of direct seeded rice. Seed priming has the potential to improve the seedling emergence and crop stand. This study was conducted to evaluate the on-farm assessment of direct seeded rice by employing different priming techniques such as on-farm priming, hydropriming, hardening, and osmohardening with $CaCl_2$ and KCl. Untreated seeds were taken as control. Among all the seed priming techniques, osmohardening with $CaCl_2$ improved the stand establishment, allometric response, agronomic traits, yield, and quality of harvested paddy compared with other priming techniques, and non-primed control in direct seeded culture. Improved crop stand as indicated by lower values of time to emergence and higher values for emergence index and final emergence, higher crop growth rate, and improved plant height, tiller numbers, and straw and kernel yield with high harvest index were recorded from osmohardening with $CaCl_2$. In addition, seed priming treatments also improved the kernel quality. Osmohardening with $CaCl_2$ was the best way to reduce sterile spikelets, abortive and chalky kernels, and improve kernel length. However, none of the seed priming techniques could improve the number of kernels per branch, 1000-kernel weight, kernel width, and kernel water absorption ratio. Moreover, improved phosphorus, calcium, and potassium contents were also observed from osmohardening with $CaCl_2$ followed by KCl. Osmohardening with $CaCl_2$ can therefore be employed for better crop stand, growth, yield, and quality in direct seeded rice.

Key words: Direct seeded rice, field appraisal, quality, seed priming, stand establishment

Introduction

Rice is the main staple of more than half of the world's population. It is the second staple after wheat in Pakistan, grown on an area of 2.58 Mha with an average yield of 2107 kg ha^{-1}. Besides meeting the dietary requirements of the people, it accounts for 5.7% of the total value added in agriculture and 1.3% of gross domestic product (GDP) and also contributes to the country's foreign exchange exchequer as an export item (Anonymous 2008).

Traditionally rice is grown by transplanting nursery seedlings into the puddle field, which requires a continuous supply of water throughout its growth (Farooq et al. 2007a). In addition to high water inputs, it demands a high labor cost, particularly at the critical time of transplanting, which not only increases the cost of production but can also result in delayed transplanting due to labor unavailability (Farooq et al. 2011). Considering water availability and opportunity cost of labor, alternative methods of

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rice establishment are needed (Pandey and Velasco 1998).

Direct seeded rice culture is a promising cost effective technology requiring less labor and water than the conventional transplanted one (Balasubramanian and Hill 2002; Farooq et al. 2011). But uneven crop stand and high weed infestations are among the main constraints for its wide scale adoption (De Datta 1986; Farooq et al. 2011).

Seed priming is a simple and low cost hydration technique in which seeds are partially hydrated to a point where pre-germination metabolic activities start without actual germination, and then re-dried until close to the original dry weight. Seed priming is employed for better crop stand and higher yields in a range of crops including rice (Khan 1992; Farooq et al. 2006a-f, 2007a, 2007b; Farooq et al. 2009; Kaymak et al. 2009).

Primed seeds, when planted, usually emerge faster with better, uniform, and vigorous crop stand persistent under less than optimum field conditions. Crop stands from primed seeds lead to earlier flowering and higher grain yield than non-primed seeds (Harris et al. 2001). Harris et al. (2002) reported that on-farm priming in direct seeded rice results in a faster rate of germination and emergence, more uniform and vigorous seedling growth, and a wide range of phenological and yield associated benefits. In some other studies, Farooq et al. (2006b, 2006c) reported early emergence and seedling growth, better crop stand, allometric response, increased kernel yield, harvest index, and improved quality from seeds primed with KCl and $CaCl_2$ in coarse and fine rice, respectively. Du and Tuong (2002) also reported that priming with KCl and $CaHPO_4$ is an effective method of improving plant density, tillering, and grain yield in dry direct seeded rice.

Many researchers have reported the improved performance of direct seeded rice by seed priming (Du and Tuong 2002; Harris et al. 2002; Farooq et al. 2006b, 2006c, 2006e) but most of these studies involve either development and optimization of seed priming techniques or monitor the physiological and biochemical basis of priming-induced benefits (Basra et al. 2005). However, quite a few studies report the role of seed priming in improving crop yield and quality (Farooq et al. 2006b, 2006c, 2006e). In addition, on-farm appraisal of these priming techniques has rarely been studied. This study was therefore conducted to affirm the potential of seed priming techniques in improving growth, yield and quality for the on-farm adoption in direct seeded rice.

Materials and methods

Seed source and experimental details

Seeds of the widely grown fine rice cv. Super Basmati (*Oryza sativa* L.) were obtained from the Rice Research Institute, Kala Shah Kakoo, Sheikhupura, Pakistan. The initial seed moisture contents were approximately 6.59% on dry weight basis. The experiment was conducted on a farmer's field in the rice growing belt (31°30′N, 73°05′E and 214 m msl) during the summer season of 2006-2007. The experimental soil was sandy clay loam with a pH of 8.4 (1:2.5 soil-H_2O mixture), EC 0.43 dS m^{-1} (1:2.5 soil-H_2O mixture), 1.23% of organic matter by the Walkley-Black method (Jackson 1982), total nitrogen 0.077% (Bremner 1996), available phosphorus 20 mg kg^{-1} (Olsen et al. 1954), and exchangeable potassium 104 mg kg^{-1} (NH_4O-Ac extraction, Helmke and Sparks 1996). The experiment was laid out in randomized complete block design (RCBD) with 3 replications.

Seed priming treatments

For all priming treatments, healthy rice seeds were used. The ratio of seed weight to solution volume was 1:5 (g mL^{-1}) (Farooq et al. 2006a). On-farm priming was carried out by soaking seeds for 12 h (overnight soaking) in tap water. For hydropriming, seeds were soaked in aerated distilled water for 48 h. To carry out hardening, seeds were soaked in tap water for 24 h, re-dried and the cycle was repeated. For osmohardening, seeds were hardened following the above mentioned procedure with $CaCl_2$ and KCl solutions having ψ_s of -1.25 MPa (Farooq et al. 2006a). Untreated dry seeds were taken as control. Except for on-farm priming, after each priming treatment, seeds were given 3 washings with tap water followed by re-drying under shade, with forced air at 27 ± 2 °C for 48-72 h until close to original moisture content was reached (Basra et al. 2006). Afterwards, seeds were sealed in polythene bags and stored in a refrigerator until used.

Crop husbandry

To achieve the required soil structure for rice direct seeding, the soil was plowed 5 times, followed by leveling with tractor drawn implements after each plowing. The previous crop was wheat. Primed and non-primed control seeds were drilled in 22 cm spaced rows with a single row hand drill at 75 kg ha^{-1} on 5 June 2006 at field capacity level. Based on a soil analysis report, 150, 90, 70, and 10 kg ha^{-1} N, P_2O_5, K_2O, and Zn were applied using urea (46% N), diammonium phosphate (18% N, P 46%), sulfate of potash (50% K_2O) and $ZnSO_4$ (35% Zn), respectively as source. The whole quantity of P_2O_5, K_2O, and Zn, and half of the N was applied prior to seeding as basal dose while the remaining half dose of N was applied in 2 equal splits each at tillering; that is, 30 days after sowing and at panicle initiation.

The irrigation was applied to keep the soil moisture at field capacity level with 7-10 days interval depending on the crop requirement. Irrigation was withheld about 1 week before harvesting when the signs of physiological maturity became visible. The soil was irrigated 12 times during the crop growth period. Fortunately, the crop was weed free; however, for control of paddy blast and bacterial blight, the crop was sprayed twice with Rabcide 30 WP at the rate of 617.5 g 100 L ha^{-1} and Copper Oxychloride 50% WP with dose of 2.5 kg ha^{-1}, respectively. Harvesting was done manually at harvest maturity when panicles were fully ripened at an approximate moisture of 23%. Threshing of each plot was done separately.

Seedling establishment, agronomic traits and yield components

Emergence was recorded daily according to the seedling evaluation handbook of the Association of Official Seed Analysts (1990). The time to start emergence was taken when first seedling emerged. The time to 50% emergence (E_{50}) was calculated following the formulae of Coolbear et al. (1984) modified by Farooq et al. (2005):

$$E_{50} = t_i + \left[\frac{N/2 - n_i}{n_j - n_i}\right](t_j - t_i)$$

where N is the final emergence count and n_i, n_j are the cumulative number of seedlings emerged on adjacent days t_i and t_j, respectively, when $n_i < (N + 1) / 2 < n_j$.

Mean emergence time (MET) was calculated according to the equation of Ellis and Roberts (1981).

$$\text{MET} = \sum (D_n) \Big/ \sum n$$

where n is the number of seeds, which were emerged on day D, and D is the number of days counted from the beginning of emergence.

Emergence index (EI) was calculated as following Association of Official Seed Analysts (1983):

$$\text{EI} = \frac{\text{No. of emerged seedlings}}{\text{Days of first count}} + \text{------} + \frac{\text{No. of emerged seedlings}}{\text{Days of final count}}$$

Data on agronomic and yield related traits were recorded at harvest maturity following the standard procedures. To calculate crop growth rate (CGR) [g m^{-2} day^{-1}], destructive plant sampling was done from a unit area (1 m^2), and CGR was calculated following the formula given by Hunt (1978):

$$\text{CGR} = (W_2 - W_1) / (T_2 - T_1)$$

where W_1 and W_2 are the total dry matter produced at the first and second harvest with date of observation at T_1 and T_2, respectively.

Kernel quality

An electric lamp with a flexible stand was used as a light source to determine the panicle and kernel characteristics (Nagato and Chaudhry 1969). A panicle was positioned in front of the lamp so that light was able to pass through it in order to differentiate between the different stages of kernel development. Sterile spikelets, abortive (kernels that do not develop after fertilization and look dull under light), and opaque kernels within a spikelet were separated. The chalky kernels were visually separated from normal kernels on the basis of chalky areas being present in different parts of the kernel, visible with a magnifying glass. The kernel water absorption capacity (WAC) was determined using following formula of Juliano et al. (1965):

WAC = weight of cooked rice /weight of raw rice

Mineral analysis

Paddy kernels harvested at maturity were analyzed for mineral contents according to the method described by Chapman and Parker (1961). Nitrogen content was determined by the Micro-Kjeldahl method. For the estimation of K, P, and Ca, nitric acid:perchloric acid (3:1 ratio), the digested samples were analyzed using a flame-photometer (Jenway, PFP7, Essex, UK), for K; a spectrophotometer (T60, PG instruments, UK) for P; and an atomic absorption spectrophotometer (JY24, Jobin-Yvon ISA, France) for Ca.

Statistical analysis

Data were statistically analyzed using computer software MSTAT-C. The analysis of variance was used to test the significance of variance sources while the difference among treatment means were compared using the LSD test (P = 0.05) (Steel et al. 1997).

Results

Seedling establishment

All of the priming treatments significantly reduced the time to start emergence, except for hardening, in which seedlings emerged at the same rate as that of untreated seeds (Table 1). There was no improvement in mean emergence time (MET) and time to 50% emergence (E_{50}) by any of the seed priming treatments. Nonetheless, the emergence index (EI) and the final emergence (FE) were substantially improved by seed priming treatments. The maximum FE was recorded from osmohardening with $CaCl_2$, followed by hardening and hydropriming. However, the maximum EI was noted from on-farm priming, followed by osmohardening with $CaCl_2$ (Table 1).

Agronomic and yield related traits

Although seed priming improved the agronomic and yield related attributes, the effect of seed priming varied for different traits studied and the number of branches per panicle and 1000-kernel weight remained unaffected (Table 2). The maximum straw and kernel yields were observed from osmohardening with $CaCl_2$, followed by on-farm priming. However, none of the seed priming treatments could improve the plant height, tiller number, number of kernels per panicle, and harvest index over the untreated control (Table 2).

Crop growth analysis

For growth analysis, samples were taken at 7 day intervals from individual plots, from tillering to physiological maturity. Crop growth response to various priming protocols also varied at different harvest times (Table 3). The maximum crop growth rate (CGR) was recorded for on-farm priming in harvests at 82 and 96 days after sowing (DAS), followed by osmohardening with $CaCl_2$ at 82 DAS, and hydropriming at 96 DAS. The maximum was at 89 DAS and 102 DAS for $CaCl_2$ and KCl treatments, respectively. It was statistically at par with on-farm priming at 89 DAS and similar to CGR values with KCl, hydropriming, and control treatments at 102 DAS (Table 3). However, overall maximum crop response to priming treatments in all the growth harvests was observed in $CaCl_2$ with osmohardening and on-farm priming treatments as compared to the untreated control (Table 3).

Table 1. Effect of seed priming on the seedling establishment in direct seeded rice.

Treatments	Time to start emergence(days)	MET (days)	E_{50} (days)	EI	FE
Control	5.67 a	10.6	6.762	323 e	544.7 d
On-farm priming	5.00 b	10.7	6.665	483 a	639.0 b
Hydropriming	5.00 b	10.5	6.755	380 d	529.3 d
Hardening	5.33 ab	10.2	7.020	403 c	639.7 b
Osmohardening ($CaCl_2$)	5.00 b	10.2	6.618	482 a	671.3 a
Osmohardening (KCl)	5.00 b	10.3	6.676	445 b	599.7 c
LSD at 0.05	**0.575**	**ns**	**ns**	**8.35**	**16.22**

Means sharing the same letters in a column do not differ significantly at P = 0.05;
MET = Mean emergence time, E_{50} = Time to 50% emergence, EI = Emergence index, FE = Final emergence, ns = non-significant.

Table 2. Effect of seed priming on agronomic traits, yield components in direct seeded rice.

Treatments	Plant height (cm)	No. of tillers (m^2)	No. of branches per panicle	No. of kernels per panicle	1000 kernel weight (g)	Straw yield (t ha^{-1})	Kernel yield (t ha^{-1})	Harvest index (%)
Control	88.3 a	569 ab	8.25	81.4 a	10.49	14.89 bc	2.29 b	15.67 ab
On-farm priming	86.6 ab	567 ab	9.85	76.9 ab	17.80	16.60 a	2.54 b	15.22 ab
Hydropriming	82.1 b	551 c	7.93	67.8 bc	16.61	14.55 c	1.87 c	13.36 b
Hardening	84.5 ab	574 ab	9.23	64.0 c	16.55	15.58 b	1.66 c	10.72 c
Osmohardening ($CaCl_2$)	88.2 a	576 a	8.57	74.8 ab	19.18	17.07 a	2.91 a	17.01 a
Osmohardening (KCl)	87.2 ab	564 b	9.73	82.1 a	16.42	14.52 c	2.29 b	15.66 ab
LSD at 0.05	**3.474**	**10.04**	**ns**	**10.49**	**ns**	**0.741**	**0.340**	**2.45**

Means sharing the same letter in a column do not differ significantly at P = 0.05;
ns = non-significant.

Table 3. Effect of seed priming on crop growth rate (CGR) in direct seeded rice (g m^{-2} day^{-1}).

Treatments	82 DAS	89 DAS	96 DAS	102 DAS
Control	3.55 c	17.21 bc	15.24 bc	10.27 a
On -farm priming	8.27 a	20.90 ab	17.52 a	1.92 c
Hydropriming	4.16 bc	16.59 c	15.51 b	10.72 a
Hardening	4.06 bc	19.11 abc	8.27 e	4.44 b
Osmohardening ($CaCl_2$)	5.16 b	21.64 a	13.61 c	10.48 a
Osmohardening (KCl)	4.66 bc	11.52 d	10.74 d	11.45 a
LSD at 0.05	**1.110**	**3.975**	**1.809**	**1.249**

Means sharing the same letter in a column do not differ significantly at P = 0.05; DAS = days after sowing.

Kernel quality

The priming response also varied between different quality attributes of the harvested paddy (Table 4). Minimum sterile spikelets were observed from osmohardening with $CaCl_2$ (Table 4), while maximum sterile spikelets were observed from hydropriming. The minimum numbers of opaque kernels were recorded from hardening and KCl osmohardening, but no significant difference was found between other priming treatments and the control. None of the seed priming treatments improved the number of normal and abortive kernels, kernel water absorption ratio, and kernel width, compared to the control (Table 4). Maximum chalky kernels were recorded from seed hardening and osmohardening with KCl. However, minimum chalky kernels were recorded from hydropriming and osmohardening with $CaCl_2$ as compared to the untreated control. Maximum kernel length was recorded from osmohardening with $CaCl_2$, followed by the untreated control (Table 4).

Mineral analysis

Improved uptake of mineral contents in response to priming techniques was one of the interesting findings of this study. Although no significant difference for kernel nitrogen contents was found among different priming treatments, phosphorus and calcium contents were significantly influenced by seed priming techniques (Table 5). Maximum phosphorus and calcium contents

Table 4. Effect of seed priming on kernel quality in direct seeded rice.

Treatments	**Sterile spikelets (%)**	**Opaque kernel (%)**	**Abortive kernels (%)**	**Chalky kernels (%)**	**Normal kernels (%)**	**Kernel length (mm)**	**Kernel width (mm)**	**Kernel water absorption ratio (%)**
Control	5.33 bc	27.33 a	0.00 c	17.67 b	82.67 a	11.22 a	1.76	2.68 a
On -farm priming	7.67 b	28.33 a	6.67 b	8.00 c	60.00 b	10.34 c	1.82	2.71 a
Hydropriming	14.00 a	21.67 b	0.00 c	12.67 bc	65.00 b	10.52 bc	1.76	2.78 a
Hardening	6.00 bc	17.67 b	10.00 a	32.33 a	41.67 c	10.69 abc	1.78	2.16 b
Osmohardening ($CaCl_2$)	3.33 c	28.33 a	0.00 c	12.67 bc	61.67 b	11.25 a	1.72	2.67 a
Osmohardening (KCl)	5.33 bc	21.67 b	6.67 b	27.33 a	41.67 c	10.41 bc	1.77	2.68 a
LSD at 0.05	**3.23**	**4.22**	**1.65**	**6.85**	**15.62**	**0.675**	**ns**	**0.191**

Means sharing the same letter in a column do not differ significantly at P = 0.05, ns = non- significant.

Table 5. Effect of seed priming on kernel mineral contents in direct seeded rice.

Treatments	**N (%)**	**P (%)**	**Ca (%)**	**K (%)**
Control	2.04	0.410 cde	0.210 c	0.420 d
On -farm priming	1.67	0.430 cd	0.213 c	0.440 d
Hydropriming	1.69	0.393 e	0.187 d	0.447 c
Hardening	2.16	0.450 ab	0.231 c	0.507 b
Osmohardening ($CaCl_2$)	1.69	0.467 a	0.270 a	0.477 bc
Osmohardening (KCl)	1.46	0.433 abc	0.241 b	0.550 a
LSD at 0.05	ns	0.0351	0.0256	0.0351

Means sharing the same letter in a column do not differ significantly at P = 0.05, ns = non-significant;
N = Nitrogen, P = Phosphorus, Ca = Calcium, K = Potassium.

were recorded from osmohardening with $CaCl_2$, followed by hardening and osmohardening with KCl. However, maximum potassium contents were recorded from osmohardening with KCl, followed by hardening (Table 5).

Discussion

This study pertained to field appraisal of seed priming techniques in direct seeded rice and was evaluated in terms of seedling stand, growth, kernel yield, and its quality characteristics to enhance the crop establishment. Seed priming techniques resulted in enhanced seedling vigor as indicated by the early field emergence in seeds subjected to different priming techniques and higher values of the emergence index; however, osmohardening with $CaCl_2$ and on-farm priming were the most effective among the priming techniques, as was obvious from improved values of emergence index (Table 1). Earlier emergence resulted in uniform stand establishment, which improved crop growth rate and ultimately the final kernel yield. Higher EI rates were reported in rice seeds treated with $CaCl_2$ by Ruan et al. (2002b). Our results also confirm the earlier findings of Farooq et al. (2006a-e) where $CaCl_2$ osmohardening was found to be the most effective vigor enhancement technique for improving rice seedling growth and yield. Nevertheless, the performance of KCl primed seeds was not in accordance with earlier reports by Du and Tuong (2002) and Farooq et al. (2006b), in which improved seedling establishment in direct seeded rice has been described by priming strategies using K salts. This contradiction is plausible due to the different rice types used in these studies. Farooq et al. (2007b) also reported that osmohardening with $CaCl_2$ and KCl were the best treatments for fine and coarse rice, respectively.

Improved crop growth rate from primed rice seeds sown in direct seeded rice culture might be the result of earlier seedling stand establishment that gave an energetic start as indicated by early emergence and high values of the emergence index (Table 1). Improved CGR had been observed in direct seeded rice osmoprimed with $CaCl_2$ under flooded (Zheng et al. 2002) and aerobic soil conditions (Farooq et al. 2006b, 2006c, 2006e). It was also reported that osmohardening with $CaCl_2$ is the best invigoration technique in direct seeded rice. Improved plant height in direct seeded rice seems to be the result of strong, healthy seedlings, which were given a vigorous start by osmohardening with $CaCl_2$, with no significant difference with KCl osmohardening and on-farm priming, as is evident from the results of earlier seedling stand establishment indicated from higher EI values (Table 1). Primed seeds had high vigor levels (Ruan et al. 2002a), which resulted in earlier emergence (Hampton and Tekrony 1995). Positive correlation also has been found between seed vigor and field performance in rice (Yamauchi and Winn 1996). A higher number of tillers from primed seeds was probably the result of higher final emergence in direct seeded rice (Table 1). Improved tillers from primed seeds by $CaCl_2$ and KCl in direct seeded rice (Ruan et al. 2002a; Farooq et al. 2006b, 2006c, 2006e) provide the evidence for our finding. The number of branches per panicle and 1000 kernel weight remained unaffected by seed priming, while increased kernel number per panicle was recorded for KCl osmohardening and the non-primed control. Maximum straw and kernel yield was recorded for osmohardening with $CaCl_2$. Improved harvest index by seed priming in direct seeded rice might be the result of enhanced dry matter partitioning toward the panicles that resulted in improved kernel yield as compared to the untreated control (Table 2).

Kurdikeri et al. (1995) compared the field performance of dry and seeds soaked in water and 0.5% $CaCl_2$ and reported enhanced emergence and kernel yield as compared with dry seeds which ended with poor and erratic crop emergence and final kernel yield. Similarly, an improved number of fertile tillers, kernel yield, and harvest index have been reported in dry direct seeded rice with KCl primed and seeds subjected to $CaCl_2$ osmohardening (Du and Tuong 2002; Farooq et al. 2006b, 2006c, 2006e). These findings show that employing seed priming not only enhances the crop stand, growth, and yield in field sown rice, but also improves the quality of the harvested paddy.

With the exception of hydropriming, followed by on-farm priming, all other priming treatments resulted in less sterile spikelets, with fewer in $CaCl_2$ osmohardening, which might possibly be the result of increased nutrient and moisture supply (Table 4). The improved nutrient and moisture supply from primed seeds might have resulted in enhanced fertilization, which might have ended in a lower number of sterile spikelets as reported by Thakuria and Choudhary (1995) for direct seeded rice primed with potassium salts. Mobilization of nutrients towards the panicles might have resulted in lower abortive and chalky kernels and an increased normal kernel because of uniform distribution of photoassimilates within the kernels. Improved kernel length from primed seeds might be the result of improved photoassimilation and its translocation and partitioning towards the kernels (Table 2). Improved kernel quality has been observed in direct seeded rice seeds osmoprimed with KCl and $CaCl_2$ under flooded conditions (Zheng et al. 2002), and similarly $CaCl_2$ and KCl osmohardened seeds under dry direct seeded conditions in fine and coarse rice cultivars (Farooq et al. 2006b, 2006c, 2006e). It was also reported that osmohardening with $CaCl_2$ was the most effective priming technique for improved quality in fine and coarse rice cultivars in direct seeded culture.

Nitrogen contents of the kernels remain unaffected by different priming treatments. Higher calcium contents by osmohardening with $CaCl_2$ may be due to Ca^{2+} treatments with osmotica. Higher P and K contents may be due to higher earlier seedling growth, which might improve the plant capability for nutrient uptake from the soil (Ajouri et al. 2004).

Conclusion

This study suggests that seed priming may help to enhance the performance of direct seeded rice. Osmohardening with $CaCl_2$ was found as the most effective priming technique to improve the crop stand, growth, yield, and quality of direct seeded rice. Nonetheless, more research efforts and participatory evaluation of the priming techniques in direct seeded rice are needed in this area.

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