Enhancing the Performance of Direct Seeded Fine Rice by Seed Priming

Muhammad Farooq¹, S. M. A. Basra¹, R. Tabassum² and I. Afzal¹

¹Department of Crop Physiology, University of Agriculture, Faisalabad-38040, Pakistan; ²National Institute for Biotechnology and Genetic Engineering, Faisalabad, Pakistan

Abstract : Higher water requirements and increasing labor costs are the major problems of the traditional rice production system. Direct seeded rice culture, growing rice without standing water, can be an attractive alternate. However, poor emergence and seedling establishment, and weed infestation are the main hindrances in the adoption of this culture. An attempt to improve the performance of direct seeded rice by seed priming was made in the present study. Priming tools employed were traditional soaking (soaking in tap water up to radicle protrusion), hydropriming for 48 h, osmohardening with KCl or CaCl₂ (osmotic potential of –1.25 MPa) for 24 h, vitamin priming (ascorbate 10 ppm) for 48 h and seed hardening for 24 h. All the priming techniques improved crop stand establishment, growth, yield and quality except traditional soaking, which resulted in impaired germination and seedling establishment that ended in reduced kernel yield and lower harvest index than that of control. Early and synchronized germination was accompanied by enhanced amylase activity and total sugars. Osmohardening with CaCl₂ resulted in the best performance, followed by hardening and osmohardening with KCl. Osmohardening with CaCl₂ produced 2.96 t ha⁻¹ (vs 2.11 t ha⁻¹ from untreated control) kernel yield, 10.13 t ha⁻¹ (vs 9.35 t ha⁻¹ from untreated control) straw yield and 22.61% (vs 18.91% from untreated control) harvest index. Mean emergence time and emergence to heading days, germination percentage and panicle bearing tillers; plant height and straw yield, 1000-kernel weight and kernel yield, α-amylase activity and total sugars, kernel proteins and kernel water absorption were correlated positively.

Key words : α-amylase, Direct seeding, Hardening, Osmohardening, Quality, Rice, Yield.
(Lee and Kim, 1999, 2000; Basra et al., 2003, 2004; Farooq et al., 2004a). Furthermore, the invigoration persists under less than optimum field conditions, such as salinity (Muhyaddin and Weibe, 1989), high and low temperature (Pill and Finch-Savage, 1988; Bradford et al., 1990), and high (Lee et al., 1998; Ruan et al., 2002) and low soil moisture contents (Du and Tuong, 2002). These invigoration techniques include hydropriming, osmoconditioning, osmohardening, hardening, and priming with growth promoters like growth regulators and vitamins.

Lee et al. (1998) reported that germination and emergence rates and time from planting to 50% germination (T₅₀) of primed seeds were 0.9-3.7 days less than those of untreated seeds. They suggested that priming of rice seeds might be a useful way for better seedling establishment under adverse soil conditions (Lee et al., 1998). Farooq et al. (2006b) concluded that osmohardened in CaCl₂ (having osmotic potential -1.25 M Pa) solution was the best for vigor enhancement compared with other salts and simple hardening. Significantly higher and more rapid germination of osmoprimed rice seeds under low temperature (5°C) stress and salt stress (0.58% NaCl) were observed, however, no significant changes in the activities of seed α-amylase and root system dehydrogenase were observed while activities of seed β-amylase and shoot catalase were enhanced under low temperature stress. Significant increase in the activity of seed α-amylase, β-amylase and root system dehydrogenase and moderate rise in the activity of shoot catalase occurred under salt stress (Zheng et al., 2002).

Priming is also thought to increase enzyme activity and counteract the effects of lipid peroxidation. Saha et al. (1990) showed that matripriming caused increased amylase and dehydrogenase activity in aged soybean seeds. During priming, de novo synthesis of α-amylase is also documented (Lee and Kim, 2000). Metabolic activities in seeds increase with α-amylase activity, thus indicating the higher vigor of the seed. In a greenhouse trial, osmopriming (CaCl₂ and CaCl₂+NaCl) improved the seedling vigor index, and seedling and stand establishment in flooded soil (Ruan et al., 2002). Du and Tuong (2002) concluded that when rice is seeded in very dry soil (near wilting point), priming (4% KCl or saturated CaHPO₄ solutions), increased plant density, final tiller number, and grain yield. In drought prone areas, seed priming can reduce the need for using high seeding rate, but priming can be detrimental if seeding takes place when soil is at or near saturation (Du and Tuong, 2002).

Information on possibility of enhancing the performance direct seeded rice by seed priming is scattered and many of the studies were based on only coarse rice type (Du and Tuong, 2002; Ruan et al., 2002). Quality of the harvested paddy has also not been addressed as affected by seed invigoration. Moreover, the physiological basis and biochemical implications of priming are also lacking or not reported along with morphological characters associated with such techniques in direct seeded rice.

The present study was therefore, aimed to develop appropriate invigoration technique/s for fine rice in direct seeded culture and to evaluate the quality of harvested paddy. Another objective was to investigate the biochemical and physiological characters associated with the primed seeds.

Materials and Methods

1. Seed source and general experimental details

Seed of a widely grown fine rice (Oryza sativa L.) cultivar Super Basmati was obtained from Rice Research Institute, Kala Shah Kakooh, Sheikhupura, Pakistan. The initial seed moisture content was 8.65%. The field experiment was conducted at a progressive farmer’s field in Kalar tract (an area popular for growing aromatic rice), Sialkot district (31.45° N, 73.26° E, and 193 m), Pakistan, during the year 2004-05. The experiment was laid out in the randomized complete block design (RCBD) with three replications.

Experimental soil was sandy clay loam having pH 8.1, total exchangeable salts 0.30 mS cm⁻¹ and organic matter 0.75%. The land was prepared by applying five ploughings followed by three plankings with tractor drawn implements to achieve the required seedbed. Previous crop was wheat.

The analytical work was carried out in the laboratories department of Crop Physiology, University of Agriculture, Faisalabad, Pakistan and National Institute for Biotechnology and Genetic Engineering, Faisalabad, Pakistan.

2. Seed treatments

A series of experiments were conducted to optimize different priming strategies for a widely grown fine rice cultivar in Pakistan, Super Basmati (Basra et al., 2003, 2004, 2005; Farooq et al., 2004a, b, 2005, 2006a, b). For all pre-sowing seed treatments, healthy seeds were used in sufficient amount. The detail of the seed treatments is as under:

For traditional soaking treatment (a common practice for rice nursery preparation), seeds were placed between the two layers of saturated jute mats up to just appearance of radicals (it took about 48 h) (Basra et al., 2003). Hydropriming was carried out by soaking seeds in aerated distilled water for 48 h. For hardening treatment, seeds were soaked in tap water at room temperature for 24 h, dried back and cycle was repeated once. To carryout osmohardening, the seeds were hardened following the above mentioned procedure with solutions of CaCl₂ or KCl with osmotic...
potential of –1.25 MPa (Farooq et al., 2006b). For vitamin priming, seeds were soaked in 10 mg L\(^{-1}\) ascorbate solution for 48 h. After each solution soaking treatment, seeds were given three surface washings with distilled water. Except for traditional soaking treatment, the soaked seeds were dried closer to original moisture level under shade with forced air at 27º C±3 (Lee et al., 1998; Basra et al., 2002). Afterward seeds were sealed in polythene bags and stored in a refrigerator until use.

### 3. Crop husbandry

Treated and untreated seeds were drilled in 22 cm spaced rows with a single row hand drill\(^{\dag}\) 65 kg ha\(^{-1}\) on June 1, 2004. Fertilizer materials used were urea (46%), single super phosphate (18% P\(_2\)O\(_5\)), sulphate of potash (50% K\(_2\)O) and ZnSO\(_4\) (35% Zn). According to soil analysis report, 150 kg N, 90 kg P\(_2\)O\(_5\) and 75 kg K\(_2\)O ha\(^{-1}\) were applied. The whole quantity of phosphorus, potash and zinc, and \(\frac{1}{2}\) of nitrogen were applied prior to seeding as basal dose. Remaining \(\frac{1}{2}\) of nitrogen was applied in two equal splits each at tillering and panicle initiation.

The soil was irrigated to field capacity level. In all 10 irrigations were applied during the crop growth period. Irrigation was withheld about one week before harvesting when the signs of physiologically maturity appeared. For weed control, mixture of Ethoxy sulphuran (Sunstar 15 WG) and Phenoxyprop-p-ethyl (Puma Super 7.5 EW) \@ 200 g and 370 mL ha\(^{-1}\) respectively was applied 20 days after sowing in saturated soil (it successfully controlled the weeds). Harvesting was done manually at harvest maturity when panicles were fully ripened at approximate moisture of 23%. Threshing of each plot was done separately.

### 4. Seedling establishment, agronomic traits and yield components

Number of emerged seeds was recorded daily according to the seedling evaluation Handbook of Association of Official Seed Analysis (1985). The time to 50% emergence (E\(_{50}\)) was calculated following the formulae of Coolbear et al. (1984) modified by Farooq et al. (2005). Mean emergence time (MET) was calculated according to the equation of Ellis and Roberts (1981) while emergence index (EI) was determined according to Association of Official Seed Analysis (1983). Energy of emergence (EE) was computed according to the method of Ruan et al. (2002), it is the percentage of emerged seedlings four days after seeding. At harvesting, observations regarding agronomic traits and yield components were recorded following the standard procedures.

### 5. Growth and development

Leaf area was measured with a leaf area meter (Licor, Model 3100). Leaf area index (LAI) was calculated as the ratio of leaf area to land area (Watson, 1947). Leaf area duration (LAD), crop growth rate (CGR) and net assimilation rate (NAR) were estimated following the formulas of Hunt (1978).

### 6. \(\alpha\)-amylase activity and total sugars

For \(\alpha\)-amylase activity one gram of ground seeds were mixed with 10 mL of phosphate buffer (pH 7) and left for 24 h at 4ºC. Supernatant was taken and the activity was measured by DNS method (Bernfeld, 1955).

For total sugars measurement seed (10 g each) were ground with the help of mortal and pestle; one gram of ground sample was mixed with 10 mL distilled water and left for 24 h at 25ºC (Lee and Kim, 2000). The mixture was filtered through a Whatman filter paper No. 42 and then the distilled water was added to get the final volume of 10 mL. Total sugars were

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

| Treatments           | Time to start emergence (days) | E\(_{50}\) (days) | MET (days) | EI     | EE (%) | FEP (%) | Emergence to heading (days) | Heading to maturity (days) |
|----------------------|--------------------------------|------------------|------------|--------|--------|---------|---------------------------|---------------------------|
| Control              | 4.00 a                         | 5.57 a           | 6.34 b     | 29.00 e| 21.33 f| 56.00 c  | 97.67 a                   | 39.33 a                   |
| Traditional soaking  | 4.00 a                         | 5.56 a           | 6.92 a     | 23.67 f| 25.00 e| 47.00 d  | 101.3 a                   | 42.00 a                   |
| Hydropriming         | 4.00 a                         | 4.03 cd          | 6.02 b     | 35.00 d| 36.33 d| 63.00 b  | 90.00 b                   | 35.33 b                   |
| Osmohardening (KCl)  | 4.00 a                         | 4.55 bc          | 5.45 c     | 41.00 bc| 46.67 c| 68.00 b  | 82.67 cd                  | 36.00 b                   |
| Osmohardening (GaCl\(_3\)) | 3.00 b          | 3.54 d           | 4.59 d     | 46.67 a| 66.33 a| 76.67 a  | 80.33 d                   | 30.67 c                   |
| Vitamin Priming      | 3.33 b                         | 5.20 ab          | 5.98 b     | 39.00 cd| 57.00 b| 65.00 b  | 87.00 bc                  | 35.00 b                   |
| Hardening            | 3.33 b                         | 4.49 bc          | 4.79 d     | 43.67 ab| 59.67 b| 76.00 a  | 82.67 cd                  | 31.67 c                   |
| LSD at 0.05          | 0.50                           | 0.89             | 0.44       | 4.02   | 3.51   | 6.62     | 6.26                     | 2.72                      |

Means sharing the same letter in a column do not differ significantly at p = 0.05.

E\(_{50}\)= Days to get 50% emergence; MET = Mean emergence time, EI = Emergence index; EE = Emergence Energy, FEP = Final emergence percentage.
determined by phenol sulfuric method (Dubois et al., 1956).

7. Kernel quality
A common electric lamp with a flexible stand was used as a source of light. A panicle was positioned in front of the lamp so that light may pass through it. Sterile spikelets, abortive and opaque kernels were separated. The chalky kernels were visually separated from normal kernels on the basis of chalky area present in different parts of the kernel with the help of high power magnifying glass.

Protein contents of rice kernels were determined by Micro-Jheldahl method. Kernel amylose contents were determined according to the method reported by Juliano (1971). Kernel dimension i.e. length and width were taken on 100-normal kernels from each replication with the help of a digital caliper and thereafter length/width ratio was calculated from the values. The water absorption ratio was determined by the formula of Juliano et al. (1965).

8. Statistical Analysis
Data were statistically analyzed using the software MSTAT-C. Analysis of variance was used to test the significance of variance sources, while LSD test (p=0.05) was used to compare the differences among treatment means. Trend lines were set and simple linear correlations were established to find the relationship of different attributes.

Results
1. Seedling establishment, agronomic traits and yield components
Minimum values of time to start germination, E50 and MET were recorded in seeds osmohardened with CaCl2 that was similar to that of seeds hydroprimed, hardened, and both vitamin priming and hardening treatments in case of E50, MET and time to start emergence, respectively (Table 1). Maximum values of time to start emergence and E50 were noted in untreated seeds (control), which was similar to that of traditional soaking in case of E50, and traditional soaking, hydropriming and osmohardening with KCl in case of time to start germination. Maximum MET was recorded in traditionally soaked seeds, followed by untreated control, which was similar to hydropriming and vitamin priming (Table 1).

All the seed treatments resulted in improved emergence energy, emergence index and emergence percentage except traditional soaking, which resulted in lower emergence index and emergence percentage than that of control (Table 1). Maximum EI, EE and FEP were recorded in osmohardening with CaCl2, which was similar to that of hardening in case of EI and FEP (Table 1). All the seed priming treatments resulted in lower emergence to heading and heading to maturity days except traditional soaking, which behaved similar to that of control (Table 1). Minimum

| Treatments              | Plant height (cm) | No. of tillers (m²) | No. of panicle bearing tillers (m²) | No. of branches per panicle | Number of kernels per panicle | 1000 kernel weight (g) | Straw yield (t ha⁻¹) | Kernel yield (t ha⁻¹) | Harvest index (%) | Leaf area duration (days) |
|------------------------|-------------------|---------------------|-------------------------------------|----------------------------|--------------------------------|------------------------|----------------------|----------------------|------------------------|--------------------------|
| Control                | 110.0 b           | 517.3 c             | 420.7 d                            | 21.66                      | 81.00                          | 14.67 cd                | 09.55 c              | 2.11 d               | 18.91 d                | 275.31 c                 |
| Traditional soaking    | 111.3 b           | 526.3 c             | 432.3 d                            | 22.00                      | 81.33                          | 14.33 cd                | 09.23 c              | 2.01 e               | 17.88 e                | 274.17 c                 |
| Hydropriming           | 115.0 ab          | 608.3 b             | 491.3 c                            | 21.00                      | 82.67                          | 15.33 bcd               | 09.65 b              | 2.71 b               | 21.92 a                | 281.27 b                 |
| Osmohardening (KCl)    | 113.0 ab          | 625.3 b             | 512.0 bc                           | 22.66                      | 86.33                          | 15.67 abc               | 10.01 a              | 2.76 b               | 21.61 a                | 285.46 b                 |
| Osmohardening (CaCl2)  | 119.3 a           | 684.7 a             | 545.7 a                            | 23.67                      | 84.00                          | 17.00 a                 | 10.13 a              | 2.96 a               | 22.61 a                | 291.35 a                 |
| Vitamin Priming        | 114.7 ab          | 608.3 b             | 533.7 ab                           | 21.66                      | 82.32                          | 14.00 d                 | 09.87 ab             | 2.63 c               | 21.04 c                | 282.23 b                 |
| Hardening              | 113.7 ab          | 640.3 b             | 541.0 a                            | 22.00                      | 84.00                          | 16.33 ab                | 10.00 a              | 2.75 b               | 21.56 b                | 287.66 ab                |
| LSD at 0.05            | 6.58              | 33.11               | 23.07 n.s.                          | n.s.                       | 1.51                           | 0.23 n.s.               | 0.061 n.s.            | 0.331 n.s.            | 4.71 n.s.               |                          |

Means sharing the same letter in a column do not differ significantly at p = 0.05.
emergence to heading and heading to maturity days were recorded in osmohardening with CaCl₂, which was similar to that of hardening and osmohardening with KCl in case of emergence to heading and only hardening in case of heading to maturity days (Table 1).

Positive correlation was noted between mean emergence time and emergence to heading days (Fig. 1).

Minimum plant height, number of tillers and number of panicles bearing tillers were measured for the plants grown from untreated seeds, which were similar to those of plants from seeds subjected to all the treatments except osmohardening with CaCl₂ in case of plant height, which resulted in maximum plant height (Table 2). Plants grown from traditionally soaked seeds also behaved in a similar fashion to that of control in case of number of tillers and number of panicles bearing tillers (Table 2). Maximum number of tillers and number of panicles bearing tillers were recorded for plants grown from seeds subjected to osmohardening with CaCl₂, which was similar to that of hardening and vitamin priming in case of number of panicles bearing tillers (Table 2).

The effect of priming techniques on number of branches per panicle and number of kernels per panicle was statistically non significant (Table 2). Maximum 1000-kernel weight was recorded for plants grown from seeds subjected to osmohardening with CaCl₂, which was similar to that of hardening and osmohardening with KCl, while minimum 1000-kernel weight was recorded for plants grown from seeds subjected to vitamin priming, which was similar to that of traditional soaking, hydoprime and untreated control.

All the seed priming treatments resulted in increased straw and kernel yield except traditional soaking, which resulted in similar straw and lower kernel yield than that of untreated control (Table 2). Maximum straw and kernel yield were recorded for plants grown from seeds subjected to osmohardening with CaCl₂, which was similar to that of plants grown from osmohardening with KCl, hardening and vitamin priming in case of straw yield (Table 2). Seed priming treatments resulted in improved harvest index except traditional soaking, which resulted in lower harvest index compared with control. Maximum harvest index was recorded for plants grown from osmohardening
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with CaCl₂, which was similar to that of osmohardening with KCl and hydropriming treatments. Positive correlation was observed between final emergence percentage and number of panicle bearing tillers (Fig. 2).

2. Growth analysis

All the seed priming treatments resulted in improved LAI except traditional soaking which behaved similar to that of control at 1st, 3rd and final harvest (Fig. 3). Maximum LAI was measured for the osmohardening with CaCl₂, which was similar to that of hardening, osmohardening with KCl and hydropriming. Seed priming treatments significantly affected the leaf area duration (Table 2). All the seed priming treatments resulted in improved LAD except traditional soaking, which behaved similar to that of control. Maximum LAD was recorded for the osmohardening with CaCl₂, which was similar to that of hardening (Table 2). Seed priming treatments resulted in improved CGR except traditional soaking, which behaved similar to that of control in all the three harvests (Fig. 4). Maximum crop growth rate was recorded in seeds subjected to osmohardening with CaCl₂ that was similar to that of osmohardening with KCl (Fig. 4).

Maximum NAR was recorded in seeds subjected to osmohardening with CaCl₂ that was similar to that of osmohardening with KCl in first harvest and to osmohardening with KCl, hardening and ascorbate priming in the second harvest (Fig. 5).

3. Biochemical basis

All the seed treatments resulted in increased α-amylase activity in fine rice with the response being in order osmohardening with CaCl₂ > traditional soaking = osmohardening with KCl > hardening > hydropriming > vitamin priming (Fig. 6). Highest total sugars were recorded in seeds osmohardened with CaCl₂, followed by traditional soaking, which was similar to seeds osmohardened with KCl (Fig. 7). Positive correlation was noted between amylase activity and total sugars (Fig. 8).

4. Kernel quality

The effect of seed priming treatments on the kernel quality was also significant (Table 3). All the seed treatments resulted in less sterile spikelets, abortive and chalky kernels except traditional soaking, which behaved similar to that of control. Minimum sterile spikelets, abortive and chalky kernels were recorded in osmohardening with CaCl₂ (Table 3). Minimum opaque kernels were counted in seeds subjected to osmohardening with CaCl₂, which was similar to that of hormonal priming, which was similar to all other treatments including control (Table 3). All the seed treatments resulted in improved number of normal kernels except traditional soaking and hydropriming, which behaved similar to that of untreated seeds. Maximum number of normal kernels was recorded in osmohardening with CaCl₂, which was similar to that of hormonal priming, which was similar to all other treatments including control (Table 3). 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Maximum kernel proteins and minimum amylose contents were recorded in seeds subjected to osmohardening with CaCl₂, which was similar to that of traditional soaking = osmohardening with KCl > hardening > hydropriming > vitamin priming (Fig. 6). Highest total sugars were recorded in seeds osmohardened with CaCl₂, followed by traditional soaking, which was similar to seeds osmohardened with KCl (Fig. 7). Positive correlation was noted between amylase activity and total sugars (Fig. 8).
of osmohardening with KCl and hardening in case of amylose contents (Table 3). Maximum kernel length was measured from seeds subjected to hardening, which was similar to all other treatments except control that resulted in minimum kernel length (Table 3). However, effect of seed priming techniques on the kernel width was non-significant (Table 3). All priming treatments resulted in higher kernel water absorption ratio compared with control. Maximum kernel water absorption ratio was calculated in seeds subjected to osmohardening with CaCl$_2$, followed by osmohardening with KCl, which was similar to that of hardening (Table 3).

Positive correlation was noted between kernel proteins and kernel water absorption ratio (Fig. 9).

Discussion

The present study has shown that different priming techniques can enhance seedling establishment in direct seeded rice. Seed priming techniques resulted in enhanced seedling vigor as well, however, osmohardening with CaCl$_2$ was the most effective as indicated by high energy of emergence, emergence index and emergence percentage. Traditionally soaked seeds behaved similar to or even inferior to that of the control, which might be the result of failure of...
immediate availability of moisture to the germinating seeds, which might have resulted in loss in seedling vigor. These results are in confirmation with that of Ruan et al. (2002) who reported improved EE and EI from rice seeds treated with KCl and CaCl₂. Yoon et al. (1997) also found that pansy seeds primed with CaCl₂ had significantly higher emergence than non-primed seeds. Lower emergence to heading and heading to maturity time seems the result of earlier and more uniform germination that gave a strong and energetic start as indicated by lower E₅₀ and MET in treated seeds (Table 1). This is evident from the positive correlation between MET and emergence to heading time (Fig. 1). Kathiresan et al. (1984) reported enhanced field emergence from ascorbic acid and CaCl₂ treated sunflower seeds.

Seed priming ensured the proper hydration, which resulted in enhanced activity of α-amylase that hydrolysed the macro starch molecules into smaller and simple sugars. The availability of instant food to the germinating seeds gave a vigorous start as indicated by lower E₅₀ and MET in treated seeds (Table 1). During priming, de novo synthesis of α-amylase is also documented (Lee and Kim, 2000). More the α-amylase activity the higher will be the metabolic activity in seeds, which indicates the higher vigor of the seed. The findings of these studies revealed that seed priming treatments enhanced the energy of emergence, emergence index and emergence percentage. This was plausibly due to dormancy breakdown in fresh rice seeds (Basra et al., 2005). Previous studies on these lines report that pansy seeds primed with CaCl₂ (–1.0 MPa) for 3 days at 23°C had significantly higher germination than non-primed seeds (Yoon et al.,
Osmopriming with KCl has been found effective for improving germination rate and germination percentage in wheat and barley (Al-Karaki, 1998). These data substantiate the practicability of the KCl, CaCl₂ and ascorbate as effective seed priming tools.

A very interesting and encouraging finding of the study was the priming induced seed vigor contributed in crop growth and development, led to higher harvest indices. Seed priming strategies led to improved yield and yield contributing factors, growth and quality of the harvested kernels. Higher number of tillers and number of fertile tillers is probably the result of higher final germination percentage (Table 1) as evident from positive correlation between final emergence percentage and number of fertile tillers (Fig. 2). Number of branches per panicle remained unaffected by seed treatments (Table 2), which resulted in statistically unaffected number of kernels per panicle by seed priming (Table 2). Improved straw yield as a result of seed priming might be due to earlier and uniform germination (Table 1), which resulted in higher plant height (Table 2), crop growth rate (Fig. 4) and net assimilation rate (Fig. 5), which ended in increased straw yield (Table 2). Improved kernel yield from primed seeds seems the result of improved yield contributing factors i.e. number of panicle bearing tillers and 1000-kernel weight (Table 2). Improved harvest index by seed priming in direct seeded rice might be result of enhanced dry matter partitioning towards the panicles that resulted in improved kernel yield. Improved LAI, LAD, CGR and NAR from primed rice seeds sown in direct seeded culture might be the result of earlier and uniform seedling stand establishment that gave a strong and energetic start as indicated by lower E₅₀ and MET and higher EE and EI (Table 1). Improved emergence to heading and heading to maturity days from primed seeds (Table 1) also seems the reason of improved leaf area duration (Table 2), which resulted in enhanced net assimilation rate (Fig. 5). Improved crop growth rate is possibly due to strong and energetic start, which resulted in improved leaf area index that ended in improved crop growth rate. Farooq et al. (2006b) and Basra et al. (2004) also reached on the conclusion that osmohardening is more effective than osmopriming and hardening, which supports the present study.

Means sharing the same letter in a column do not differ significantly at p = 0.05.

Means sharing the same letter in a column do not differ significantly at p = 0.05.

Table 3. Effect of seed priming on the kernel quality of direct seeded fine rice.

| Treatments          | Sterile Spikelets (%) | Opaque kernels (%) | Abortive kernels (%) | Chalky kernels (%) | Normal kernels (%) | Kernel protein (%) | Kernel amylose (%) | Kernel length (mm) | Kernel width (mm) | Kernel water absorption ratio |
|---------------------|-----------------------|--------------------|----------------------|------------------|-------------------|-------------------|-------------------|-------------------|-----------------|--------------------------|
| Control             | 7.36 a                | 17.33 a            | 2.26 a               | 27.00 a          | 53.40 b           | 7.62 c            | 55.44 b           | 1.06 b            | 6.11 b          | 1.46                     | 3.99 f |
| Traditional soaking | 7.50 a                | 17.67 a            | 2.24 a               | 26.67 a          | 53.42 b           | 7.60 c            | 28.74 a           | 6.24 ab           | 1.47            | 4.12 e                    |
| Hydropriming        | 6.98 b                | 17.00 a            | 1.89 b               | 25.67 ab         | 55.44 b           | 7.94 b            | 27.12 b           | 6.37 ab           | 1.45            | 4.21 d                    |
| Osmohardening (KCl) | 6.76 c                | 16.00 a            | 1.61 d               | 23.67 bc         | 58.75 a           | 8.00 b            | 26.17 cd          | 6.31 ab           | 1.46            | 4.35 b                    |
| Osmohardening (CaCl₂)| 5.93 e               | 13.67 b            | 1.51 e               | 22.33 c          | 61.49 a           | 8.16 a            | 25.61 d           | 6.34 ab           | 1.44            | 4.46 a                    |
| Vitamin Priming     | 6.83 bc               | 15.67 ab           | 1.70 c               | 22.33 c          | 60.29 a           | 7.91 b            | 26.82 bc          | 6.36 ab           | 1.45            | 4.26 cd                   |
| Hardening           | 6.25 d                | 16.33 a            | 1.58 de              | 22.67 c          | 59.42 a           | 7.98 b            | 26.24 cd          | 6.51 a            | 1.43            | 4.30 bc                   |
| LSD at 0.05         | 0.16                  | 2.19               | 0.079                | 2.19             | 3.28              | 0.159             | 0.783             | 0.31              | n.s.          | 0.056                      |

Fig. 9. Relationship between kernel proteins and kernel water absorption ratio in direct seeded fine rice as affected by seed priming.
priming techniques resulted in enhanced number of tillers and number of fertile tillers, which seems the result of improved germination by dormancy breakdown as fresh rice seeds were used in the present investigations, which have been reported to possess dormancy (Lee et al., 2002; Basra et al., 2005). Findings of Du and Tuong (2002) also support the present study, they reported improved number of fertile tillers, 1000-kernel weight, kernel yield and harvest index owing to seed priming with KCl in rice. Enhanced performance of direct seeded rice by sand priming is also reported more recently (Hu et al., 2005).

The improved nutrient and moisture supply from primed seeds might have resulted in enhanced fertilization, which ended in lower number of sterile spikelets as reported by Thakuria and Choudhary (1995) for direct seeded rice primed with salts of potassium. Mobilization of nutrients towards the panicles might have resulted in lower opaque kernels, abortive kernels, chalky kernels and increased normal kernels because of uniform distribution of photoassimilates within the kernels. Improved kernel proteins seem to be the direct result of improved root proliferation, which might had resulted in higher seedling nutrient uptake. This enhanced nitrogen availability might have contributed towards the improved kernel proteins. Improved kernel length from primed seeds might be the result of improved net assimilation rate (Fig. 5) that resulted in improved photo assimilation and its translocation and portioning towards the kernels. Improved kernel proteins and kernel length might be the reasons of improved kernel water absorption ratio (Table 3) as indicated by positive correlation between kernel proteins and kernel water absorption ratio (Fig. 9). Proteins are by positive correlation between kernel proteins and photo assimilation and its translocation and portioning towards the kernels. Improved nitrogen availability might have contributed towards the improved kernel proteins. Improved kernel length from primed seeds might be the result of improved net assimilation rate (Fig. 5) that resulted in improved photo assimilation and its translocation and portioning towards the kernels. Improved kernel proteins and kernel length might be the reasons of improved kernel water absorption ratio (Table 3) as indicated by positive correlation between kernel proteins and kernel water absorption ratio (Fig. 9). Proteins are by positive correlation between kernel proteins and

From the present investigations, it may be concluded that employing seed priming treatments in fine rice not only improved seedling establishment, which resulted in improved growth and yield but quality of the produce was also enhanced. Osmohardening with CaCl₂ performed better than all other treatments, followed by hardening and osmohardening with KCl.

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