Rice Seed and Seedling Priming

4

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Abstract

Earlier emergence and vigorous seedling stand are key indicators of crop performance. Seed priming as cost-effective hydration technique is central to enhance crop vigor to optimize input use in production and affect grain nutritional quality and food security in rice systems. Poor seedling growth and sub-optimal plant density associated with delayed transplanting of nursery seedling of low vigor is one of the major constraints in conventional flooded (CF) and water-saving aerobic (AR) and alternate wetting and drying (AWD) rice systems. Likely, poor and erratic stand restricts the success of direct seeded rice due to less weed competitiveness associated with low seed vigor. Seed hydropriming, osmopriming, and nutrient priming have been successfully employed in conventional transplanted system irrigated as AR or AWD and in direct seed rice systems to achieve healthy seedling stands, rapid crop development, high yields, and grain nutritional quality including input resource use efficiency. This chapter discusses the potential of priming for improving seed and seedling vigor, crop development, yields, grain nutritional quality, and their profitability in rice systems. This will help to reduce the yield gaps associated with crop vigor in actual and potential yields in rice production.

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4.1 Introduction

Rice (*Oryza sativa* L.) as staple feeds daily >3.5 billion people to fulfill their 20% daily calorie requirement (Ahmad et al. 2015; Rehman et al. 2019). More than 75% of world supplies are harvested from rice produced under flooded condition (CF) (Yang 2012; Van et al. 2001), and water as an important factor affects rice production (Ahmad and Hasanuzzaman 2012; Ahmad et al. 2008, 2009).

Irrigated rice in Asia is usually cultivated primarily by growing seedlings into nursery seedbeds and later their transplanting manually or mechanically into paddy fields maintained under CF or saturated condition with or without puddling. Depending on the freshwater availability, rice fields are maintained as flooded throughout crop growth cycle as in CF system, alternate wetting and drying (AWD) exposing soil to wet–dry cycles in AWD, at field capacity in aerobic rice (AR), and kept saturated under system of rice intensification (SRI) (Farooq et al. 2009a, b; Rehman et al. 2012). In each of these methods, wet bed method of nursery raising is mostly practiced by farmers in which rice seed is first soaked for 24 h in water. Then pre-germinated seeds incubated for 48 h are broadcasted uniformly on nursery raised bed resulting in poor and delayed emergence while producing nursery seedlings of uneven stand (Ahmad 1998; Farooq et al. 2008). These nursery seedlings of different ages ranging from 30 to 45 days are transplanted into the main rice fields (De Datta 1981; Singh and Singh 1999).

Nursery seedling with poor and delayed emergence raised by wet bed methods when transplanted results in sub-optimum planting density, and patchy and irregular crop stands subsequently have less growth rate. Nursery seedling of poor vigor is accompanied with delayed transplanting (>30 days) owing to scarce and high labor cost at critical time resulting in lower grain yields (Reddy 2004) and seed quality associated with poor seed setting owing to high temperature and high humidity at flowering (Rehman et al. 2019).

These effects are further increased on growth with transplanting shock when nursery of increased seedling age (Salam et al. 2001) is shifted. Nonetheless, seedling age is significant factor toward yield contribution in transplanting rice system by affecting tillers, dry matter production, and root traits, and several studies report transplanting of young nursery seedlings (≤25 days) with positive effects on grain yield (Randriamiharisoa and Uphoff 2002; Horie et al. 2005; Pasuquin et al. 2008). Studies on SRI report better crop performance in terms of higher yields by transplanting 2–3 weeks or even more younger seedlings (Makarim et al. 2002).

Transplanting younger rice seedlings affects four phyllochron stages and produces more number and fertile tillers, with better capture resources including nitrogen, extended crop duration, higher 1000-grain weight, and grain yields (Ashraf et al. 1999; Mishra and Salokhe 2008) compared to transplanting aged nursery seedlings with more competition for resources.

Therefore, it is imperative to grow seedlings of high vigor, and transplanting at younger age is the primary factor to obtain uniform crop stand and increased rice production. Padalia (1980) reported that 50% success of rice cultivation depends upon the seedling, irrespective of method of nursery raising.

Seedling vigor in rice defines the plant characteristics such as survival, height, thickness and uniformity of stem, and establishment and development of new roots, and these traits vary with age, production system, and seedling hills before and after transplanting. Therefore, nursery seedling health with improved vigor plays a greater role in improving rice yields by affecting their establishment subsequent growth such as tillering in transplanted rice (TeKrony and Egli 1991; Himeda 1994; Ros et al. 2003; Sasaki 2004).

Nonetheless, sustainable rice production depends on efficient use of labor, water, and fertilizer to improve productivity, profitability, and resource use efficiency while reducing environmental footprints (Foley et al. 2011; Farooq et al. 2011a, b; Hoang et al. 2019). On the other hand, climate change-induced emissions of potent methane (CH_4), decreasing freshwater resources, high labor, and production costs are major challenges to conventional rice system (Linquist et al. 2012; Nawaz et al. 2019). Rice production under CF degrades soil physical and chemical properties by disintegrating soil aggregate, porosity, and permeability with increase in bulk density owing to the development of hardpan at shallow depth under puddle condition and decreases wheat productivity and delay its cultivation (Farooq et al. 2008; Nawaz et al. 2017, 2019; Nadeem et al. 2020). This suggests water-wise production by growing rice alternatively under direct seeding condition (DSR), AWD, and SRI (Farooq et al. 2009a, b, Farooq et al. 2011a, b, Rehman et al. 2012; Hoang et al. 2019).

Worldwide, these different methods of rice production have been adapted to sustain its productivity, and rice direct seeding is also being practiced as alternative to conventional transplanting in the United States, Western Europe including Italy and France, India, Russia, Japan, Cuba, Sri, Lanka, Malaysia, Vietnam, Thailand, Philippines, Pakistan, and in some parts of Iran (Farooq et al. 2011a, b; Kumar and Ladha 2011).

Direct seeded rice is practiced by broadcasting of pre-germinated seed on puddled soil in wet seeding, broadcasting, or drilling of seed in dry soil or at field capacity in dry seeding and broadcasting of seed in standing water in case of water seeding (Farooq et al. 2011a, b). Compared to wet and water seeding methods, dry DSR is more popular in areas with unpredictable water supply and rainfall such as for lowland rice cultivation and has advantages of less labor and water consuming, timely establishment, and earlier maturity, including reduced methane emissions (Ella et al. 2011; Gathala et al. 2011; Chauhan et al. 2012).

Among several factors, high weed pressure, nutrient management, and poor crop stand due to anoxic condition during germination, seed viability, and un-leveled fields affect rice production under dry DSR condition (Ladha et al. 2009; Tripathi et al. 2005; Manigbas et al. 2008). Previously, research has focused on reducing weed pressure and high emergence rate to improve its adaption and very less on developing cultivars of high early seedling vigor, a trait to determine successful crop establishment, improve weed competitiveness, and achieve high yield (Zhang et al. 2005a, b; Foolad et al. 2007; Mahender et al. 2015).

Seed germination, early seedling vigor, and uniform crop stands are key determinants of successful crop production and susceptible stages of plant growth cycle to adverse soil and environmental factors (Harris 1996; Hadas 2004). Availability of good quality seed and its cost influence both the quality and quantity of crop produce ultimately influencing food and nutritional security. Early seedling vigor is indicator of good quality seed which translates into quick, uniform germination, and development of crop stand with strong seedling growth detrimental to adverse soil and climatic condition. Earlier and uniform crop stands establish deeper and vigorous root systems to overcome seedbed constraints such as harden and drying upper soil layers, resist to sub-, supra-optimal temperature, and suppress weeds growth by reducing competition for water and nutrient sources (Farooq et al. 2018).

Nonetheless, early seedling vigor is an agronomical trait and indicator to improve speed and uniformity of emergence, seedling growth, and uniform crop stand in direct seeded (Foolad et al. 2007) and transplanted rice systems (Farooq et al. 2011a), in addition to breeding, developing cultivars of high seed vigor, seed priming as low cost along with effective technique for improving earlier, and better crop emergence for uniform stand establishment which flowers earlier and produce productivity (Harris et al. 2007; Ullah et al. 2019) in many crops including rice.

This chapter discusses the potential of priming for improvement of seed and seedling vigor, nursery seedling development and uniform stands, effects on crop growth, increase in yields, nutritional quality of harvested grains, and their economic benefits in conventional and water-saving rice systems. The major objective is potential application of priming to effect on seed and seedling vigor to optimize crop stands and shrink the yield gaps in different rice systems.

4.2 Rice Seed Priming

Priming of seed is a hydration treatment which involves soaking seed in simple water (hydropriming, on-farm priming), salts to lower water potential (osmopriming or osmohardening), crop growth regulators (hormonal priming), and crop nutrients (nutrient seed priming), along with organic biostimulants with or without aeration. Soaking is followed by drying to lower the moisture contents to the original dry weight for routine handling and safe storage of seed until use (Farooq et al. 2018). These are low cost, practicable, and effective techniques for improving seed and crop (Fig. 4.1) performance to address challenges of low seed quality, seedling vigor, late planting, lower and higher temperatures, nutrient deficiency, and salinity along with drought (Finch-Savage and Bassel 2016; Antonino et al. 2000; Farooq et al. 2009a, b, 2011a, b, 2014). Primed crops usually emerge earlier, produce uniform and healthy stands, vigorous root system, flower, and mature earlier relatively with higher crop yields (Table 4.1; Rehman et al. 2011a; Singh et al. 2015). Among priming treatments, on-farm priming, hydropriming, hardening osmopriming, osmohardening and hormonal priming with synthetic and natural biostimulants, and nutrient priming have been successfully employed for improving nursery seedling emergence along with development, produce uniform crop stands, improve growth, and yield performance in transplanted and dry seed rice systems (Table 4.1; Farooq et al. 2006a, b, c, d). Among different priming treatments, osmopriming and osmohardening with $CaCl_2$ and KCl have been extensively evaluated to improve germination besides uniform rice crop stand establishment (Farooq et al. 2006b, c, 2007a; Rehman et al. 2011a, b, 2014a, 2015a, b).

Priming treatments have been optimized for concentrations and duration for soaking of different osmotica, natural or synthetic growth regulators, plant-based biostimulants, micronutrients, and water. For example, rice seeds are hydroprimed in water for 24 h, osmopriming for 36 or 48 h, and on-farm priming for 12 h (Farooq et al. 2006a; Rehman et al. 2015b). Seed osmopriming with KCl has been found effectively to improve crop stand in coarse rice (Farooq et al. 2006a), seedling development in nursery and field, and yield attributes in transplanted rice (Farooq et al. 2007a, b).

4.3 Effects on Seedling Growth, Yield, and Resource Use Efficiency

Raising rice nursery seedlings by seed priming and their transplanting have several advantages including rapid crop development, early phenological growth, and productivity benefits including improved resources use efficiency in conventional and water-saving systems for rice (Tables 4.1 and 4.3). Early transplanted seedlings (<30 days) raised by primed seeds also reduced the time from transplanting to heading and maturity than seedlings raised by traditional method and their transplanting after 45 days (Farooq et al. 2007a, b). Likely, timely transplanted seedlings also result in earlier heading and maturity when raised by different priming methods and priming agents including osmohardening, hardening, and hormonal priming (Farooq et al. 2007a, b) than with delayed heading and maturity in seedlings raised after traditional method.

This improvement in crop stand and nursery seedling growth is attributed to earlier emergence, better seedling growth, increased root growth and its traits, and nutrient uptake contributing toward healthy and vigorous stands in direct seeded and transplanted rice systems (Farooq et al. 2018). Likely, higher yields in these rice systems are associated with increased total emergence, competitive advantage over weeds, productive tillers, number of panicles and growth attributes including leaf area and duration, crop growth rate, and increased dry matter production in aerobic as well as submerged condition (Mahajan et al. 2011). Reduced spikelet sterility and increased tillering in aerobic rice with AWD and SRI (Khalid et al. 2015; Das et al. 2021).

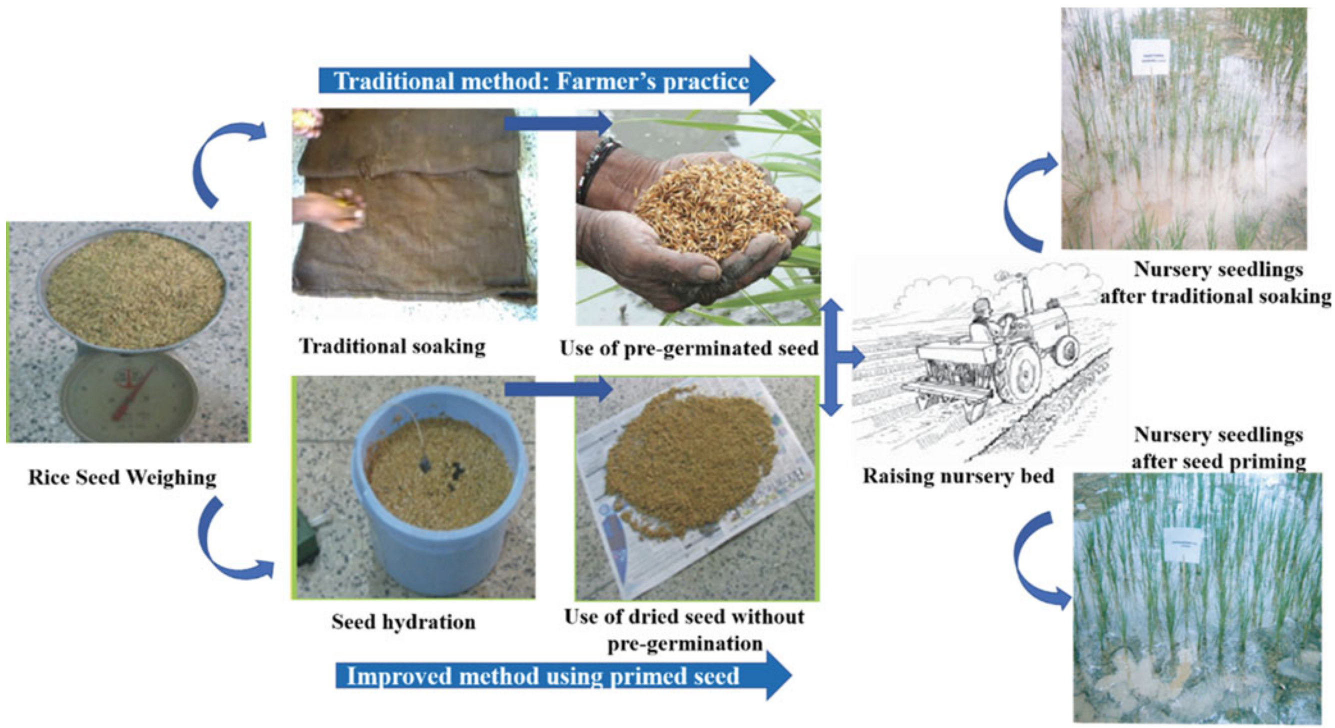

Fig. 4.1 Schematic presentation of improved nursery method "Rice Seed and Seedling Priming"

Table 4.1 Influence of seed priming on paddy yield in rice production systems

Seed priming type	Growing environment	Water-wise rice production system	% Increase in grain yield	References
Hydropriming	Field	CF	7.65	Rehman et al. (2016)
Hydropriming	Field	CF	−1.95	Rehman et al. (2014b)
Hydropriming	Field	CF	26.70	Farooq et al. (2007b)
Hydropriming	Field	AWD	−02.35	Rehman et al. (2016)
Hydropriming	Field	AWD	10.85	Rehman et al. (2014b)
Hydropriming	Field	DSR-SRI	36.00	
Hydropriming	Field	DSR	05.80	Rehman et al. (2016)
Hydropriming	Field	DSR	09.65	Rehman et al. (2014b)
Hydropriming	Field	DSR	−18.30	Rehman et al. (2011b)
Hydropriming	Field	DSR	03.70	Farooq et al. (2006d)
Osmopriming ($CaCl_2$)	Field	CF	42.80	Farooq et al. (2007b)
Osmopriming ($CaCl_2$)	Field	CF	42.80	Farooq et al. (2007b)
Osmopriming (KCl)	Field	DSR-AWD	09.55	Rehman et al. (2015b)
Osmopriming(CaCl2)	Field	DSR-AWD	14.10	Rehman et al. (2015b)
Osmopriming (CaCl2)	Field	DSR-SRI	31.50	
Osmopriming ($CaCl_2$)	Field	DSR	27.00	Rehman et al. (2011b)
Osmopriming (KCl)	Field	DSR	00.00	Rehman et al. (2011b)
Osmopriming (KCl)	Field	DSR	18.50	Farooq et al. (2006d)
Osmopriming ($CaCl_2$)	Field	DSR	14.80	Farooq et al. (2006d)
Osmopriming (KCl)	Field	DSR	10.50	Farooq et al. (2006c)
Nutripriming (B)	Field	CF	16.40	Rehman et al. (2014b)
Nutripriming (B)	Field	CF	27.00	Rehman et al. (2016)
Nutripriming (Zn)	Field	CF	41.10	Farooq et al. (2018)
Nutripriming (B)	Field	AWD	23.25	Rehman et al. (2014b)
Nutripriming (B)	Field	AWD	21.30	Rehman et al. (2016)
Nutripriming (B)	Field	DSR	17.80	Rehman et al. (2014b)
Nutripriming (B)	Field	DSR	17.55	Rehman et al. (2016)
Nutripriming (Zn)	Field	DSR and CF	02.90	Farooq et al. (2018)
Nutripriming (Zn)	Field	DSR	34.60	Farooq et al. (2018)

In addition to growth and yield advantages, seed priming has been reported to improve resource use efficiency regarding water productivity as by osmopriming with moringa leaf extracts (3%) (Rehman et al. 2015b) and osmopriming with Trichoderma and potassium nitrate under AWD (Das et al. 2021), reduce panicle sterility, and enhance gas exchange attributes by nutrient priming with micronutrients (Zn, B, Mn), thus affecting soil–plant water relationship in direct seeded and AWD rice systems (Rehman et al. 2014b, 2016). Likely, priming in rice genotypes efficient in purine permease 1 (*PUP1*) genes and low in seed phosphorus contents and also improvement in germination along with earlier seedling development in phosphorus-deficient soils (Pame et al. 2015), showing seed priming can be

Table 4.2 Influence of nutrient priming on increase in grain mineral concentration in rice production systems

Nutripriming (Nutrient and concentration)	Growing environment	Rice production system	% Increase in grain mineral concentration	References
H_3BO_3 (0.008 M)	Field	CF	700.00	Johnson et al. (2005)
B (0.001 and 0.01 B%)	Glasshouse	CF	33–47	Rehman et al. (2012)
B (0.1 mM)	Field	AWD	29.60	Rehman et al. (2014b)
B (0.1 mM)	Field	AR	27.50	Rehman et al. (2016)
Zn (0.5 M)	Field	DSR	26.67	Farooq et al. (2018)

combined with genetics to improve crop emergence in P-deficient soils. Weed competitive advantage by seed priming in direct seeded rice is owed to rapid emergence and increased seedling vigor at low seed rate reducing biomass of weeds which provide faster canopy development reducing 10% yield losses (Harris et al. 2002; Du and Tuong 2002; Anwar et al. 2012; Juraimi et al. 2012).

Seed nutrient priming by Zn can also reduce the soil application requirement especially under Zn-deficient soil by increased emergence, seedling growth, and crop stand producing better yields in rice (Table 4.2; Tehrani et al. 2003; Prom-u-thai et al. 2012).

4.4 Effects on Grain and Nutritional Quality Attribute

Seed priming induced improved seedling growth, and their transplanting at optimum age reduced mortality rate was associated with better capture resources of water and nutrients resulting in enhanced fertilization and less sterile spikelets. Moreover, increased pre- and post-anthesis net assimilation continued uniform supply of photosynthates throughout panicles producing maximum normal kernels, reducing kernel chalkiness, opaque, and abortive kernels in growing nursery seedlings (Table 4.2; Zheng et al. 2002; Farooq et al. 2007a, b, 2009a, b).

Similarly, Zn nutrient priming is promising strategy for agronomic biofortification in rice under transplanted and direct seeded water-saving rice systems (Farooq et al. 2018). Likely, Zn nutrient priming has been associated with decrease in antinutritional factors including grain phytic acid and Cd contents in grain and increase in protein contents (Seddigh et al. 2016; Rehman et al. 2018; Slamet-Loedin et al. 2015). Similarly, seed priming with boron (0.01 mM B) had been found to improve its grain concentration including panicle fertility under water-saving rice cultivation (Table 4.2; Johnson et al. 2005; Rehman et al. 2016).

Seed osmohardening with KCl and $CaCl_2$ has been observed to contain higher K and Ca contents in rice kernels under traditional and direct seeded rice systems. Likely, increases in seedling nitrogen are associated with increased number of secondary roots and reducing sugars with α-amylase activity in nursery transplanted rice (Farooq et al. 2007b; Rehman et al. 2011a).

4.5 Cost-Benefit Ratio (BCR) and Farmer's Practice

Success of seed priming depends on its cost-effectiveness, practicability, and adoption. The BCR varies among seed priming methods, and highest profit has been witnessed in rice under water-saving system, that is, hydropriming in AWD and DSR, and nutripriming with boron in AWD and with Zn in DSR (Table 4.3). These advantages of seed priming are associated with high yields and reduced inputs in terms of fertilizers and water. Nonetheless, seed priming has been practiced in various countries including Pakistan, Nepal, India, Bangladesh, China, and Australia in various crops including rice (Singh and Gill 1988; Harris et al. 2001; Farooq et al. 2006a, b, c; Hussain et al. 2013).

4.6 Rice Seedling Priming

In transplanted rice, rice seedlings are uprooted from the rice nursery area tagged into small-sized nursery bundles of 5–8 cm (or bunch) for transporting to the targeted field where transplanting is to be carried out. Before, uprooting the seedlings from the nursery, a short spell of stress is necessary to develop hardiness in the younger seedlings, so that these tender seedlings could bear the pulling or transplanting shock. In order to overcome this shock, the seedlings are being primed after uprooting and just before or prior to transplanting.

Seedling priming techniques involve the following, that is, (1) hydropriming (on-farm priming) as dipping the roots of uprooted seedlings in the standing water in a watercourse preferably under shade; (2) Zn priming as dipping the seedlings in Zn solution (35%) at the rate of 12.5 kg ha^{-1}, which is very effective for Zn application. The seedlings uptake the required quantity of Zn, which is required by the rice plant after transplanting; (3) nutripriming as application of biostimulants as booster dose to the younger seedlings; and (4) inoculation of rhizobacteria, which is carried out to enhance mineral nutrient uptake (N, P, K, etc.).

These above-mentioned seedling priming techniques are very cost-effective, practicable in nature, and very efficient to improve seedling performance in the field after transplanting to combat the issues of lower seed quality, seedling vigor, late planting, higher temperature, nutrient deficiency, salinity, and drought. Primed seedling re-start their re-growth after pulling or transplanting shock to perform better through producing uniform as well as healthy crops stands, vigorous root system, and mature earlier relatively with higher crop yields as compared to unprimed seedlings.

Table 4.3 Influence of seed priming on benefit-to-cost ratio in rice production systems

Seed priming type	Growing environment	Rice Production system	% Increase benefit: cost ratio over control	References
Hydropriming	Field	DSR-SRI	04.07	
Hydropriming	Field	CF	−02.30	Rehman et al. (2014b)
Hydropriming	Field	AWD	44.56	Rehman et al. (2014b)
Hydropriming	Field	DSR	07.48	Rehman et al. (2014b)
Hydropriming	Field	CF	05.82	Rehman et al. (2016)
Hydropriming	Field	AWD	09.78	Rehman et al. (2016)
Osmopriming ($CaCl_2$)	Field	DSR-SRI	05.88	
Nutripriming (B)	Field	DSR	12.63	Rehman et al. (2016)
Nutripriming (B)	Field	AWD	11.40	Rehman et al. (2016)
Nutripriming (B)	Field	CF	21.36	Rehman et al. (2016)
Nutripriming (B)	Field	DSR	16.82	Rehman et al. (2014b)
Nutripriming (B)	Field	AWD	57.60	Rehman et al. (2014b)
Nutripriming (B)	Field	CF	13.70	Rehman et al. (2014b)
Nutripriming (Zn)	Field	DSR	06.00	Farooq et al. (2018)
Nutripriming (Zn)	Field	DSR	18.18	Farooq et al. (2018)
Nutripriming (Zn)	Field	CF	15.38	Farooq et al. (2018)

4.7 Conclusion and Future Thrusts

Seed priming is viable and practicable solution to improve crop stand and seedling growth, productivity, nutritional quality, and profitability in traditional and water-saving rice systems. Seed priming can be integrated with genetics as evident from enhanced performance of rice varieties containing QTLs for *Sub1* such as Swarna and *Pup1* in IR74 under submerged and low soil P conditions, respectively (Ella et al. 2011; Sarkar 2012; Pame et al. 2015).

As seed vigor is less considered trait in traditional rice system, and priming had been found to induce stress memory in harvested progeny which needs to be investigated in case of traditional and water-saving rice systems. Such integration of stress-invoked memory in primed seed can be combined with molecular approaches to enhance seed vigor to translate this trait into next generations to address the challenges of seed and seedling vigor. With increasing nutritional deficiency of micronutrients, especially Zn, B, and Fe in human population worldwide, nutrient priming with these micronutrients can improve crop produce and grain micronutrient contents to help reduce malnutrition. In conclusion, as a cost-effective and practicable approach, seed priming can be effective technology to optimize yields using less resources, reduce the gaps between potential and actual yields, and improve socioeconomic condition of growers for sustainable food security.

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