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Seed Priming Improves the Performance of Poor Quality Wheat Seed

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Abstract

Late sowing of wheat experiences terminal heat stress which affects the grain development process and the harvested grains are of poor quality if used as seed for next crop. This study investigated the role of sowing time and seed priming on seed vigor and crop performance in wheat. Seed harvested from the crop sown on November 10, 25, December 10 and 25 were primed with $CaCl_2$ for 12 h, or not. The primed and non-primed seeds were sown under field conditions for two consecutive years. Seed harvested from late sown crop (December 10 and 25) caused poor stand establishment. However, seed priming improved stand establishment, allometric traits, yield contributing parameters, biological yield, grain yield and harvest index. Although, the grain yield was higher in seeds harvested from November 10 planted crop owing to more number of productive tillers per unit area, spike length, number of grains per spike, 1000-grain weight; seed priming also improved the grain yield of seeds harvested from late sown crop (December 10 and 25). These results suggest that seed priming can improve the field performance of poor quality wheat seeds.

Keywords: Sowing dates; Seed priming; Seed vigor; Rice-wheat system; Terminal heat stress

Introduction

Optimum sowing time ensures adequate plant population and produces good quality seed. Late sowing of wheat is the major reason of low yield. In late planted wheat, low temperature prevailing during crop establishment substantially affects the germination and seedling emergence. Late planting results in poor tillering, reduces tillering period and more chances of winter injury (Byerlee *et al.*, 1984; Joshi *et al.*, 1992). Delayed planting of wheat bears terminal heat stress during grain development and maturation. Late planted wheat plants have to complete all growth and developmental stages in lesser time (Khan *et al*., 2010) that results in great loss of yield due to high temperature during grain filling period (Riaz-ud-Din *et al*., 2010.). Evidences consistently reveal that exposure of the parental plant to high temperature influences seed quality (Hasan *et al*., 2013). Higher temperature after anthesis adversely affects grain development and growth in wheat because high temperature accelerates initial grain growth rate but shortens the grain growth period (Hasan and Ahmed, 2005). Short period of high temperature stress at reproductive stage reduced the grain quality in wheat (Randall and Moss, 1990; Savin *et al*., 1996). Under controlled conditions, it is estimated that wheat yield decreased by 4% for every 1˚C rise in temperature above the optimum (Wardlaw and Wrigley, 1994).

During grain filling stages of late sown wheat, high temperature limits the grain yield (Wardlaw *et al.*, 1989; Farooq *et al*., 2011) because soluble starch synthase involved in synthesis and deposition of starch is extremely sensitive to high temperature and decreases its activity when temperature touches the level beyond 20°C (Keeling *et al.*, 1994), which decreases grain weight and shrinks wheat yield. As a consequence, smaller and shriveled grains produced are of low vigor and viability if used as seed for next crop. Khah *et al*. (1989) found that low-vigor spring wheat seed produced lower yield.

Priming is a low risk technology (Harris *et al*., 1999) and low cost solution for poor stand establishment (Farooq *et al*., 2006a, 2009). Seed priming technique improves the germination, seedling emergence, growth and yield attributes of crop. Seed priming with KCl or $CaCl_2$ improved the seedling growth, stand establishment as well yield performance in direct seeded rice (Farooq *et al*., 2006b). Likely, vigorous seedling growth, emergence and yield performance by $CaCl_2$ priming has also been reported in wheat under late sown conditions (Farooq *et al*., 2008a). Priming of normal or low vigor seeds improved the vigor of seedling in term of radicle length, plumule length and their root, shoot ratio and fresh weight (Kausar *et al.,* 2009). Moosavi *et al*. (2009) reported that primed seeds significantly improved the germination percentage, speed of germination, root length and seed vigor. When low vigor seeds were primed showed improved germination performance (Bray, 1995). Seed priming with various salts of calcium, potassium and/or priming with growth regulators or hydropriming proved best to enhance vigor of seed and also improved stand establishment (Basra *et al.*, 2003). Priming improved the performance under stress

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conditions like drought stress and chilling stress (Du and Tuong, 2002; Farooq *et al*., 2008b). Priming led to better crop emergence, growth, earlier flowering and greater yield for summer grown maize (Harris *et al*., 1999; 2001). Farmers reported earlier flowering (7-10 days) and maturity (8- 10 days) by employing seed priming in rice and chickpea (Harris *et al*., 1999). Number of productive tillers per unit area, biological yield, grain yield and harvest index was maximum in osmoprimed wheat under late condition (Farooq *et al.*, 2008b; Sattar *et al.*, 2010). It is evident from previous studies that primed crops showed rapid and uniform emergence, good stand establishment and better performance even under stressful environment as compared to non-primed crops. Nonetheless, to best of our knowledge, limited information is available on influence of sowing date on seed vigor and, of seed priming on the field performance of poor quality wheat seed. This study was, therefore, undertaken to compare the performance and vigor of seeds obtained from early and late sown wheat crop and to appraise the potential of seed priming in improving the performance of poor quality seed harvested from different sowing dates.

Materials and Methods

Seed Source, Experimental Site, Soil and Design

Seeds of wheat cultivar seher-2006, used in this study were obtained from Wheat Research Institute, Faisalabad, Pakistan. Crop was sown at four different sowing dates viz. November 10, 25, December 10 and 25 during 2010 and 2011 under field condition at Agronomic Research Area, University of Agriculture, Faisalabad (31.25^o N, 73.06^o E and 184 msl). For seed bed preparation and better germination of wheat seed, soil was cultivated 2 times with tractor mounted cultivator followed by planking each time. A pre-sowing irrigation was applied and when soil reached at field capacity, again soil was cultivated 2 times with tractor mounted cultivator followed by planking each time. The experimental soil texture was sandy loam with pH 8.1, total exchangeable salts 0.29 dS m^{-1}, 0.81% of organic matter, total nitrogen 0.049%, available phosphorus 8 mg kg^{-1}, exchangeable potassium 110 mg kg^{-1} and exchangeable sodium 0.4 me 100 g^{-1}. At maturity, crop was harvested and seeds were stored for following year experimental trial. During 2010 and 2011, seeds from previous harvest sown at November 10, 25, December 10 and 25, 2009 and 2010 were soaked in aerated solutions of $CaCl_2$ (1.2%) for 12 h and sown on November 8, 2010 and 2011, respectively, while dry seeds were taken as control. The experiment was laid out in randomized complete block design with factorial arrangement having four replications. The crop was hand drilled in 22.5 cm spaced rows using seed rate of 125 kg ha^{-1}. Fertilizer was applied at 120-90 kg NP ha^{-1}. Whole phosphorus and one third of the nitrogen were applied as basal, while rest of nitrogen was applied in two equal splits at 1st and 2nd irrigation. Weather data during the course of experimentation are given in Fig. 1.

Stand Establishment

For recording observations regarding seedling establishment, field was visited daily according to the seedling evaluation handbook (Association of Official Seed Analysts, 1990). 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).

Allometry

Plant samples were collected randomly from each experimental unit starting from 45 days after sowing at fortnight interval until 105 days after sowing. Leaves were separated from the plants and leaf area was recorded by leaf area meter (CI-202, CID, Inc). Plant samples collected sun-dried for 24 h and then dried in an oven at 70°C for 5 days until constant dry weight. Leaf area index, leaf area duration, crop growth rate and net assimilation rate were calculated according to the method of Hunt (1978).

Agronomic and Yield Related Traits

Data on agronomic and yield related traits were recorded at harvest maturity following the standard procedures. For plant height, ten primary tillers were selected at randomly in each plot and measurement was taken from base to the spike tip. Productive tillers were counted from an area of 100×100 cm^2 from three different places of each plot and were averaged for per unit area (m^{-2}). Spike length, number of spikelets per spike and number of grains per spike were counted from ten primary tillers harvested randomly from each plot and was averaged separately. Data regarding 1000-grain weight from each replication was recorded in grams. For grain yield, crop from an area of 10.8 m^2 was harvested and threshed manually, and then clean grains were air dried, bulked and weighed while straw weight from each plot was determined from sundried samples and expressed in t ha^{-1}. Harvest index (%) was expressed as the ratio of grain yield to total above ground biomass and multiplied with 100.

The data collected were analyzed statistically by employing Fisher analysis of variance technique (Steel *et al.,* 1996) using computer software MSTAT-C and treatment means were compared by applying least significance difference (LSD) test at 5% probability level.

Results

Seed priming significantly improved seedling emergence and stand establishment in seed harvested from all previous sowing dates (Table 1). Seed priming reduced the time to start emergence, E_{50}, mean emergence time and final emergence compared with untreated seed harvested from wheat sown on November 10, 25, December 10 and 25 (Table 1). During both years of study, minimum time to start emergence, E_{50} and MET was recorded for seeds harvested from crop sown on November 10 and then primed, which was statistically similar to seeds harvested from crop sown on November 25 and then primed. Alike, higher final emergence was also recorded for seeds harvested from crop planted on November 10 and then primed. Maximum time to start emergence, E_{50}, MET and lower final emergence was recorded for seeds harvested from late sown crop and then sown without priming during both years (Table 1).

Seed priming also significantly improved leaf area index, leaf area duration, crop growth rate and net assimilation rate (Table 5). Higher value of leaf area index, leaf area duration, crop growth rate and net assimilation rate was recorded for seeds harvested from November 10 planted crop and then primed which was similar to seeds harvested from November 25 and then primed during both years 2010 and 2011 (Table 5). Lower value of these traits were recorded for non-primed seeds harvested from the late sown crop (December 25) during both years (Table 5). Seed priming improved the leaf area index, leaf area duration, crop growth rate and net assimilation rate in the seeds obtained from all sowing dates.

Yield and yield related traits of wheat were also affected by previous sowing dates and higher plant height, productive tillers per unit area, spike length, spikelets per spike, grains per spike, 1000-grain weight, biological yield, grain yield, straw weight and harvest index was recorded for seed harvested from November 10 planted crop and then primed, which was similar to currently primed seeds harvested from November 25 planted crop during both years (Tables 2-4). Nonetheless, seed priming progressively improved plant height, productive tillers per unit area, spike length, spikelets per spike, grains per spike, 1000-grain weight, biological yield, grain yield, straw weight and harvest index in the seed harvested from all sowing dates (Tables 2-4).

Discussion

Crop sown from the seed harvested from December 10 and 25 planted crop showed poor performance in term of emergence, allometric and agronomic attributes compared with crop grown from the seed harvested November 10 and 25 planted crop (Tables 1-5). The poor performance of following crop might be due to small seed size because seed harvested from the crop sown on December 10 and 25 were small and shriveled. It can be expected that high parent plant temperature (24-26˚C) during grain development resulted in small and poor quality seed (McDonald *et al*., 1983; Tewolde *et al*., 2006). Good quality seeds have higher vigor level, which allows rapid embryo growth and improves seedling establishment even under stressful field conditions (Ghanbari *et al*., 2013). Thomas *et al*. (2009) reported that high parent plant temperature significantly affected growth of subsequent seedling and dry weights. They also reported that seedlings grown from seed produced at 34/24˚C temperature were shorter in height with smaller total plant leaf area when compared to those seedlings grown from seed produced at 28/18˚C. High temperature during anthesis and grain filling adversely affects grain development in wheat (Tashiro and Wardlaw, 1990) because it accelerates the initial grain growth rate but shortens the grain growth period (Bauer *et al*., 1985; Bruckner and Frohberg, 1987). As a consequence, the final grains weight (Table 3) and size is greatly decreased at high temperature (Tashiro and Wardlaw, 1990). Shriveled and poor quality seeds, if used as seed for next crop, affect the seedling emergence, seedling vigor, green leaf area and crop yield (Table 1-3). Grass and Burris (1995) reported that seed harvested from the crop exposed to medium or high temperature stress during grain development exhibited low germination as compared to control during following wheat season. Our results also showed that seed harvested from crop sown on December 10 and 25exhibited low germination (Table 1). Timely planted wheat has longer growing period that results in better growth, development, dry matter accumulation (Spinks *et al*., 2000; Shahzad *et al*., 2002) and crop produces good quality seeds ensuring better crop performance during following season (Tables 1-5).

Seed size represents the amount of reserve that an embryo contains to start its first life stage (Quero *et al*., 2007). Large seeds germinate earlier and emerge faster on soil surface as compared to small size seeds (Roy *et al*., 1996; Larsen and Andreasen, 2004; Willenborg *et al*., 2005; Kaydan and Yağmur, 2008). Seed harvested from crop sown on November 10 and 25 were large and showed earlier emergence, plant height, higher tillering capacity and other components of yield (Table 1). Small grains have less vigor and consequently affect the early ground cover, tillering capacity of plant and other yield traits in following season. Plant height and fresh weight increased with increase in seed size increased (Karrfalt, 2004). Seed harvested from late sown wheat showed less leaf area index, tiller and other agronomic traits.

The earliness in emergence and lower mean emergence time might be the fact that seed priming induces a range of biochemical changes such as hydrolysis, activation of enzymes, DNA replication, increase RNA and protein synthesis enhances embryo growth and reduced leakage of metabolites (McDonald, 2000). This edge of primed seeds over non-primed results an improvement in field emergence. Primed seeds showed better leaf development and plants from primed seeds emerged earlier and grew faster, showed better leaf area index, crop growth rate and net assimilation rate as compared to non-primed seeds (Tables 1, 5). Previous studies also revealed that

Table 1: Effect of previous sowing date and current seed priming on time to start emergence, time taken to 50% emergence, mean emergence time and final emergence in wheat

Previous sowing date	Time to start emergence (days)		Time taken to 50% emergence (days)		Mean emergence time (days)		Final emergence (m^{-2})	
	Control	Osmopriming	Control	Osmopriming	Control	Osmopriming	Control	Osmopriming
2010-11								
10th November	5.75 cd	5.0e	7.94 b	5.74 c	9.94 b	7.51 c	316.50 b	344.25a
25th November	6.25 bc	5.0e	8.29 ab	5.73 c	10.57 ab	7.61 c	304.50 c	319.50 b
10th December	6.50 ab	5.25de	9.09 ab	6.61 c	10.73 ab	8.39 c	287.00 d	305.25c
25th December	7.0 a	5.75cd	9.39 a	8.16 b	11.29 a	9.76 b	279.50 e	288.75d
LSD value	0.61		1.17		1.05		6.71	
2011-12								
10th November	6.0ab	5.0 d	8.05 bc	5.58 e	9.82 bc	7.41 e	311.75 b	334.75 a
25th November	6.0ab	5.0 d	8.19 ab	5.62 e	10.37 ab	7.58 e	300.75 c	316.75 b
10th December	6.25 ab	5.25 cd	8.55 ab	6.53 de	10.53 ab	8.31 de	286.25 d	303.50 c
25th December	6.50 a	5.75 bc	9.19 a	7.01 cd	11.0 a	9.17 cd	274.75 e	284.00 d
LSD value	0.52		1.07		1.04		7.72	

Table 2: Effect of previous sowing date and current seed priming on plant height, number of productive tiller, spike length and number of spikelet per spike in wheat

Previous sowing date	Plant height at maturity (cm)		Number of productive tillers (m^{-2})		Spike length (cm)		Number of spikelets per spike	
	Control	Osmopriming	Control	Osmopriming	Control	Osmopriming	Control	Osmopriming
2010-11								
10th November	119.60 b	128.13 a	432.25 b	475.00 a	10.02 b	10.92 a	18.27 b	21.90 a
25th November	115.28 c	125.72 a	423.00 c	474.00 a	10.02 b	10.72 a	18.25 b	21.65 a
10th December	107.05 d	117.57 bc	355.50 e	421.00 c	8.27 e	9.67 c	15.37 d	16.95 c
25th December	99.50 e	114.78 c	336.75 e	408.75 d	7.67 f	8.62 d	13.80 d	15.95 cd
LSD value	3.32		7.81		0.34		1.18	
2011-12								
10th November	115.78 b	125.35 a	448.75 b	489.50 a	9.67 b	10.10 a	17.47 b	19.67 a
25th November	114.75 b	122.93 a	439.74 c	487.75 a	9.55 b	10.05 a	17.30 b	19.37 a
10th December	105.60 d	110.40 c	369.50 e	434.0 c	8.10 d	8.45 c	14.72 d	15.70 c
25th December	94.10 e	105.93 d	340.75 f	413.75 d	7.20 e	7.97 d	13.47 e	14.32 d
LSD value	3.39		8.26		0.21		0.46	

Table 3: Effect of previous sowing date and current seed priming on number of grains per spike, 1000-grain weight, biological yield and grain yield in wheat

Previous sowing date	Number of grains per spike		1000-grain weight (g)		Biological yield (t ha^{-1})		Grain yield (t ha^{-1})	
	Control	Osmopriming	Control	Osmopriming	Control	Osmopriming	Control	Osmopriming
2010-11								
10th November	47.40 b	55.37 a	39.13 b	39.63 a	13.67 b	14.93 a	4.83 b	5.54 a
25th November	46.80 b	54.72 a	39.12 b	39.62 a	13.41 c	14.91 a	4.69 c	5.52 a
10th December	40.62 d	44.05 c	38.50 c	39.01 b	11.22 e	13.26 c	3.89 e	4.68 c
25th December	37.62 e	40.25 d	37.16 d	38.08 c	10.71 f	12.90 d	3.62 f	4.56 d
LSD value	1.83		0.48		0.22		0.108	
2011-12								
10th November	45.05 b	48.65 a	39.23 b	39.85 a	14.03 b	15.39 a	4.93 b	5.77 a
25th November	44.95 b	48.10 a	39.20 b	39.63 a	13.75 c	15.29 a	4.85 c	5.74 a
10th December	38.12 d	41.47 c	38.53 c	39.13 b	11.54 e	13.60 c	4.00 e	4.84 c
25th December	32.40 e	37.87 d	37.22 d	38.46 c	10.93 f	12.99 d	3.72 f	4.70 d
LSD value	1.23		0.28		0.24		0.070	

when low vigor seeds were primed, improved vigor, early, uniform emergence and good stand establishment was found (Kausar *et al*., 2009; Khan *et al*., 2012). Primed seeds produced significantly more number of tillers and panicles as compared to non-primed plants in rice (WARDA, 2002). Similarly, Farooq *et al.* (2006c; 2008a; 2009) reported increase in tillering and growth of wheat and rice. As a result of improved yield contributing parameters, biological and grain yield was significantly increased (Table 3). In earlier study, Harris *et al.* (2001) reported that priming of wheat seeds resulted in 5-36% more yield as compared to non-primed seeds. Improvement in harvest index by seed priming indicates better assimilates and dry matter partitioning toward the grain (Rehman *et al*., 2011).

Table 4: Effect of previous sowing date and current seed priming on straw weight and harvest index in wheat

Previous sowing date	2010-11				2011-12			
	Straw weight (t ha^{-1})		Harvest index (%)		Straw weight (t ha^{-1})		Harvest index (%)	
	Control	Osmopriming	Control	Osmopriming	Control	Osmopriming	Control	Osmopriming
10th November	8.85 b	9.42 a	35.35 b	37.13 a	9.09 b	9.61 a	35.16 cd	37.58 a
25th November	8.67 c	9.42 a	35.23 b	37.03 a	8.90 bc	9.55 a	35.24 cd	37.53 a
10th December	7.32 d	8.57 c	34.67 c	35.42 b	7.53 e	8.75 c	34.70 d	35.61 bc
25th December	7.07 f	8.32 d	33.84 d	35.37 b	7.07 f	8.29 d	33.97 e	36.18 b
LSD value	0.15		0.51		0.69		0.69	

Table 5: Effect of previous sowing date and current seed priming on leaf area index, leaf area duration, crop growth rate and net assimilation rate in wheat

Previous sowing date	Leaf area index		Lead area duration (d)		Crop growth rate (g m^{-2} d^{-1})		Net assimilation rate (g m^{-2} d^{-1})	
	Control	Osmopriming	Control	Osmopriming	Control	Osmopriming	Control	Osmopriming
				2010-11				
10th November	5.24 b	5.59 a	222 b	241 a	20.23 b	22.2 a	7.44 b	8.29 a
25th November	5.04 b	5.57 a	216 c	239 a	19.85 c	22.07 a	7.20 c	8.25 a
10th December	4.64 c	5.05 b	206 d	215 c	18.11 e	19.08 c	6.49 d	7.17 c
25th December	4.05 d	4.75 c	201 e	207 d	17.14 f	18.53 d	5.89 e	6.47 d
LSD value	0.21		3.58		0.29		0.16	
				2011-12				
10th November	5.39 b	5.58 a	233 b	247 a	20.72 b	22.8 a	8.02 b	8.33 a
25th November.	5.32 b	5.53 a	225 c	246 a	20.4 b	22.59 a	7.81 c	8.27 a
10th December	4.86 d	5.20 c	206 e	226 c	18.68 c	20.43 b	7.27 d	7.83 c
25th December	4.07 e	5.12 c	201 f	214 d	17.53 d	18.95 c	6.66 e	7.20 d
LSD value	0.11		4.09		0.37		0.13	

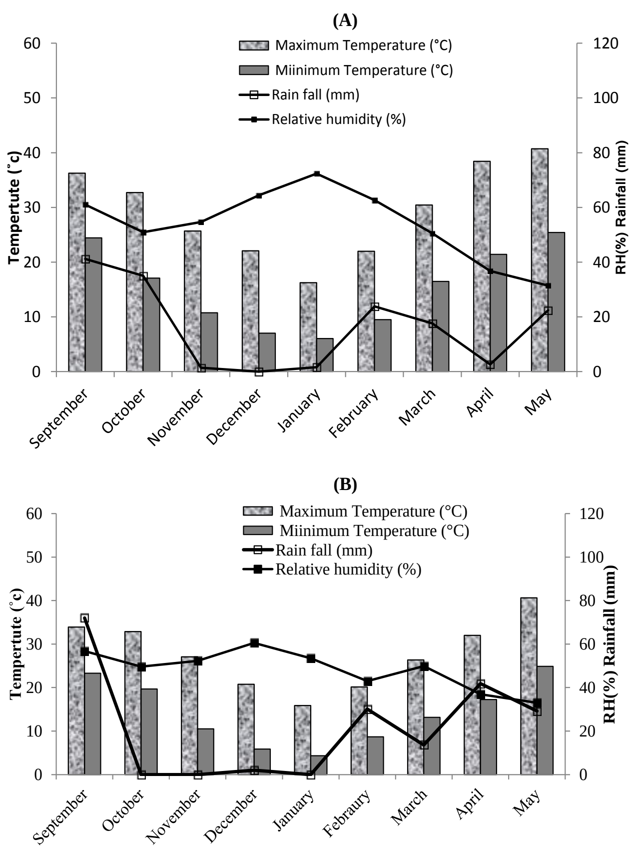

Fig. 1**:** Weather data for growing seasons of crops during (A) 2009-10 and (B) 2010-11

In conclusion, delay in sowing influence the grain development resulting in shriveled seeds of poor quality, which upon plant suppress the performance of crop. However, seed priming can improve the field performance of poor quality wheat seeds.

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References

Association of Official Seed Analysis (AOSA), 1990. Rules for testing seeds. *J. Seed Technol.,* 12: 1–112

Basra, S.M.A., M. Farooq and A. Khaliq, 2003. Comparative study of pre-sowing seed enhancement treatments in fine rice (*Oryza sativa* L.). *Pak. J. Life Soc. Sci.,* 1: 5–9

Bauer, A., A.B. Frank and A.L. Black, 1985. Estimation of spring wheat grain dry matter assimilation from air temperature. *Agric. J.,* 77: 743–752

Bray, C.M., 1995. Biochemical processes during the osmopriming of seeds. *In*: *Seed Development and Germination*, pp: 767–789. Kigel, J. and G. Galili. (eds.). New York: Marcel Dekker

Bruckner, P.L. and R.C. Frohberg, 1987. Rate and duration of grain filling in spring wheat. *Crop Sci.,* 27: 451–455

Byerlee, D., A.D. Sheikh, M. Aslam and P.R. Hobbs, 1984. *Wheat in the Rice Based Farming System of the Punjab: Implications for Research and Extension*. Pakistan Agricultural Council, Islamabad

Coolbear, P., A. Francis and D. Grierson, 1984. The effect of low temperature pre-sowing treatment on the germination performance and membrane integrity of artificially aged tomato seeds. *J. Exp. Bot.,* 35: 1609–1617

Du, L.V. and T.P. Tuong, 2002. Enhancing the performance of dry-seeded rice: effects of seed priming, seedling rate and time of seedling. *In: Direct Seeding: Research Strategies and Opportunities*, pp: 241–256. Pandey, S., M. Mortimer, L. Wade, T.P. Tuong, K. Lopes and B. Hardy (eds.). IRRI, Manila, Philippines

Ellis, R.A and E.H. Robert, 1981. The quantification of ageing and survival in orthodox seeds. *Seed Sci. Technol.,* 9: 373–409

Farooq, M., A. Wahid, O. Ito, D.J. Lee and K.H.M. Siddique, 2009. Advances in drought resistance of rice. *Crit. Rev. Plant Sci.,* 28: 199–217

Farooq, M., H. Bramley, J.A. Palta and K.H.M. Siddique, 2011. Heat stress in wheat during reproductive and grain filling phases. *Crit. Rev. Plant Sci.,* 30: 491–507

Farooq, M., S.M.A. Basra and K. Hafeez, 2006b. Rice seed invigoration by osmohardening. *Seed Sci. Technol.,* 34: 181–186

Farooq, M., S.M.A. Basra and M.A. Cheema, 2006a. Integration of pre-sowing soaking, chilling and heating treatments for vigor enhancement in rice (*Oryza sativa* L.). *Seed Sci. Technol.,* 34: 521–528

Farooq, M., S.M.A. Basra, A. Wahid and M.B. Khan, 2006c. Rice seed invigoration by hormonal and vitamin priming. *Seed Sci. Technol.,* 34: 775–780

Farooq, M., S.M.A. Basra, H. Rehman and B.A. Saleem, 2008a. Seed priming enhances the performance of late sown wheat (*Triticum aestivum* L.) by improving chilling tolerance. *J. Agron. Crop Sci.,* 194: 55–60

Farooq, M., S.M.A. Basra, K. Hafeez and N. Ahmad, 2005. Thermal hardening: a new seed vigor enhancement tool in rice. *J. Integr. Plant Biol.,* 1: 187–193

Farooq, M., T. Aziz, Z.A. Cheema, M. Hussain and A. Khaliq, 2008b. Activation of antioxidant system by KCl improves the chilling tolerance in hybrid maize. *J. Agron. Crop Sci*., 194: 438–448

Ghanbari, A., M.A. Najafi, M. Al-Athar and F. Mohajeri, 2013. Effect of priming on morphological characteristics, proline, carbohydrate and essential oil contents of basil seed (*Ocimum basilicum*) under salt stress. *Int. J. Agric. Sci.,* 3: 308–315

Grass, L. and J.S. Burris, 1995. Effect of heat stress during seed development and maturation on wheat seed quality. I. Seed germination and seedling vigor. *Can. J. Plant Sci.,* 75: 821–829

Harris, D., B.S. Raghuwanshi, J.S. Gangwar, S.C. Singh, K.D. Joshi, A. Rashid and P.A. Hollington, 2001. Participatory evaluation by farmers of on-farm seed priming in wheat in India, Nepal and Pakistan. *Exp. Agric.,* 37: 403–415

Harris, D.A., P.A. Joshi, P. Khan, P. Gothkar and S. Sodhi, 1999. On-farm seed priming in semi-arid agriculture: Development and evaluation in maize, rice and chickpea in India using participatory methods. *Exp. Agric.,* 35: 15–29

Hasan, M.A. and J.U. Ahmed, 2005. Kernel growth physiology of wheat under late planting heat stress. *J. Natl. Sci. Found. Sri Lanka,* 33: 193–204

Hasan, M.A., J.U. Ahmad, T. Hossain, M.A.K. Mian and M.M. Haque, 2013. Evaluation of the physiological quality of wheat seed as influenced by high parent plant growth temperature. *J. Crop Sci. Biotech.*, 16: 69–74

Hunt, R., 1978. *Plant Growth Analysis*, p: 37. Edward Arnald, London

Joshi, A.K., B. Rai and M.P. Sing, 1992. Technology for late sowing wheat in eastern Uttar Perdesh. *Ind. Farm*, 42: 15

Karrfalt, R.P., 2004. How acorn size influences seedling size and possible seed management choices. *In: National Proceedings: Forest and Conservation Nursery Associations*, pp: 117–118. Riley, I.E. (ed.). USDA Forest Service, Washington DC

Kausar, M., T. Mahmood, S.M.A. Basra and M. Arshad, 2009. Invigoration of low vigor sunflower hybrids by seed priming. *Int. J. Agric. Biol*., 11: 521-528

Kaydan, D. and M. Yağmur, 2008. Germination, seedling growth and relative water content of shoot in different seed sizes of triticale under osmotic stress of water and NaCl. *Afr. J. Biot.,* 7: 2862–2868

Keeling, P.L., R. Banisadr, L. Barone, B.P. Wasserman and G.W. Singletary, 1994. Effect of temperature on enzymes in the pathway of starch biosynthesis in developing wheat and maize grain. *Aust. J. Plant Physiol.,* 21: 807–827

Khah, E.M., E.H. Roberts and R.H. Ellis, 1989. Effects of seed aging on growth and yield of spring wheat at different plant population densities. *Field Crops Res.,* 20: 175–190

Khan, A., Z. Hammad, A. Khurram, Muhammad and Q. Iqbal, 2012. Exogenous application of polyamines improves germination and early seedling growth of hot pepper. *Chilean J. Agric. Res.*, 72: 429–433

Khan, M.B., M. Ghurchani, M. Hussain and K. Mahmood, 2010. Wheat seed invigoration by pre-sowing chilling treatments. *Pak. J. Bot.,* 42: 1561–1566

Larsen, S.U. and C. Andreasen, 2004. Light and heavy seeds differ in germination percentage and mean germination thermal time. *Crop Sci.,* 44: 1710–1720

McDonald, G.K., B.G. Sutton and F.W. Ellsion, 1983. The effect of time of sowing on the grain yield of irrigated wheat in Namoi Valley, New South Wales. *Aust. J. Agric. Res.,* 34: 224–229

McDonald, M.B., 2000. Seed priming. *In*: *Seed Technology and Biological Basis*, Black, M. and J.D. Bewley (eds.). Sheffield Academic Press

Moosavi, A., R.T. Afshari, F. Sharif-Zadeh and A. Aynehband, 2009. Effect of seed priming on germination characteristics, polyphenoloxidase, and peroxidase activities of four amaranth cultivars. *J. Food, Agric. Envt.,* 7: 353–358

Quero, J.L., R. Villar, T. Maranon, R. Zamor and L. Poorter, 2007. Seed mass effects in four Mediterranean Quercus species (Fagacea) growing in contrasting light environments. *Amer. Bot.,* 94:1795–1803

Randall, P.J. and H.J. Moss, 1990. Some effects of temperature regime during grain filling on wheat quality. *Aust. J. Agric. Res.,* 41: 603–617

Rehman, H., S.M.A. Basra and M. Farooq, 2011. Field appraisal of seed priming to improve the growth, yield and quality of direct seeded rice. *Turk. J. Agric For.,* 35: 357–365

Riaz-ud-Din, M.S. Ghulam, A. Naeem, H. Makhdoom and Aziz Ur Rehman, 2010. Effect of temperature on development and grain formation in spring wheat. *Pak. J. Bot.,* 42: 899–906

Roy, S.K.S., A. Hamid, M. Giashuddin Miah and A. Hashem, 1996. Seed size variation and its effects on germination and seedling vigor in rice. *J. Agron. Crop Sci.,* 176: 79–82

Sattar, A., M.A. Cheema, M. Farooq, M.A. Wahid, A. Wahid and B.H. Babar, 2010. Evaluating the performance of wheat cultivars under late sown conditions. *Int. J. Agric. Biol.*, 12: 561–565

Savin, R., P.J. Stone and M.E. Nicolas, 1996. Response of grain growth and malting quality of barley to short periods of high temperature in field studies using portable chambers. *Aust. J. Agric. Res.,* 47: 465–477

Shahzad, K., J. Bakht, W.A. Shah, M. Shafi and N. Jabeen, 2002. Yield and yield components of various wheat cultivars as affected by different sowing dates. *Asian J. Plant Sci.,* 1: 522–525

Spinks, J.H., T. Semere, D.L. Sparkes, J.M. Wahley, M.J. Foulkes R.W. Calre and R.K. Scatt, 2000. Effect of sowing dates n planting density of winter wheat. *Ann. App. Biol.,* 2: 179–188

Steel, R.G.D., J.H. Torrie and D.A. Dickey, 1997. *Principles and Procedures of Statistics: A Biometric Approach,* 3rd edition. McGraw Hill Book Co. Inc., New York, USA

Tashiro, T. and I.F. Wardlaw, 1990. The effect of high temperature at different stage of ripening on grain set, grain weight and grain dimensions in the semi dwarf wheat bank. *Ann. Bot.,* 65: 51–61

Tewolde, H., C.J. Fernandez and C.A. Erickson, 2006. Wheat cultivars adapted to post-heading high temperature stress. *J. Agron. Crop Sci.,* 192: 111–120

Thomas, J.M.G., P.V.V. Prasad, K.J. Boote and L.H. Allen, 2009. Seed composition, seedling emergence and early seedling vigour of red kidney bean seed produced at elevated temperature and carbon dioxide. *J. Agron. Crop Sci.,* 195: 148–156

WARDA, 2002. *In*: *Participatory Varietal Selection: Beyond the Flame*. Jones, M.P. Wopereis, Pura (eds.), West Africa Rice Development Association (WARDA), Bouake, Cote d'Ivoire

Wardlaw, I.F., I.A. Dawson, P. Munibi and R. Fewster,1989. The tolerance of wheat to high temperatures during reproductive growth. Survey procedures and general response patterns. *Aust. J. Agric. Res.*, 40: 1–13

Wardlaw, I.F. and C.W. Wrigley, 1994. Heat tolerance in temperate cereals: An overview. Australian *J. Plant Physiol*., 21: 695–703

Willenborg, C.J., 2005. Oat germination characteristics differ among genotypes, seed sizes and osmotic potentials. *Crop Sci.,* 455: 2023–2029

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