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Full Length Article

Surface Drying after Seed Priming Improves the Stand Establishment and Productivity of Maize than Seed Re-Drying

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Abstract

Good stand establishment and seedling emergence are the drivers of achieving higher cereal productivity. Seed priming offers a pragmatic option to trigger the stand establishment and subsequent growth and yield of field crops. The objective of this study was to compare various seed priming techniques followed by re-drying and surface drying before sowing for improving the seedling emergence and subsequent growth of autumn planted maize (*Zea mays* L.). The treatments of the experiment were (i) un-primed seed, (ii) osmoprimed seeds (with $CaCl_2$) and (iii) hydro-primed seeds, followed by seed surface drying and re-drying of each priming treatment. Maize hybrid 31-R88 was used as experimental material. The experiment was conducted in pots as well as under field conditions in Multan, Punjab, Pakistan. In pot study, all seed priming treatments significantly reduced the mean emergence time and improved the uniformity of emergence. Under field conditions, surface drying of hydro- and osmoprimed seeds was the most beneficial for improvement in time to start emergence and final emergence count than the other treatments. The yield parameters and grain yield was the highest in osmoprimed seeds with surface drying followed by hydro-primed seeds with surface drying. The re-drying of primed seeds was not useful for improving productivity of maize compared with surface drying. In crux, surface drying of primed seed is a pragmatic option to improve the seedling emergence and subsequent growth of autumn planted maize crop.

Keywords: Osmopriming; Surface drying; Re-drying; Stand establishment; Maize productivity

Introduction

Maize (*Zea mays* L.), one of the most important cereal crop, is used as food and feed for humans and livestock, respectively, across the globe (Hossain and Shahjahan, 2007). Maize seeds are usually consumed by humans directly or after processing and can be used as forage, feed for farm animals and making silage after fermentation of corn stocks (GOP, 2017). It occupies 3rd position in cereal production next to wheat and rice all over the world (Farnia and Shafie, 2015) including Pakistan (GOP, 2017). It contains more oil and starch than any other cereal grain (Langer, 1991). The seeds of maize contain about 73% starch, 9% protein, and 4% of the oil (Laurie *et al.,* 2004). However, increasing the maize yield has been a key issue for many agriculture researchers since last many years (Cai *et al.,* 2006). Maize yield may be influenced by many internal and environmental factors. One of the most important internal factors, which may affect the seedling emergence pattern and seed yield of maize is the seed vigor and its viability (Ghassemi-Golezani *et al.,* 2011).

Indeed, better stand establishment triggers the productivity of field crops (Harris *et al*., 1999) under optimal and sub optimal environmental conditions (Finch Savage *et al.,* 2004). Various factors such as seed quality, seed bed preparation, temperature extremity, weed competition, biotic stresses, soil salinity and soil moisture affects the field crops stand establishment (Townend *et al.*, 1996). When the seeds of the field crops are placed within the soil, they imbibe water followed by enzyme activation and radical protrusion (Mwale *et al*., 2003). Thus, the stand establishment is delayed due to late germination mostly under sub-optimal soil and environmental conditions.

In this scenario, seed priming offers a pragmatic option to improve the seedling emergence, seedling uniformity and subsequent growth and yield of field crops including cereals (Harris *et al.,* 2001). Indeed, seed priming refers to the pre-sowing hydration technique which initiates the metabolic activities within the seed without allowing the radical protrusion (Farooq *et al.,* 2005). Studies have reported that seeds after priming show quick germination and ensure the uniformity of seedling emergence (Farooq *et*

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Table 1: Weather data during the experimental period

Months	Monthly mean temperature (°C)	Monthly mean relative humidity (%)	Total rainfall (mm)
August	31.6	84.6	109
September	30.5	82.6	4.00
October	26.9	68.8	0.00
November	20.0	69.6	0.00
December	16.5	78.2	0.00

al., 2011a; Hussain *et al.*, 2016). Seed priming increases many biochemical changes, which are basically needed for starting the process of germination (Hartman *et al.*, 2002). Earliness in seed emergence due to seed priming also warrants earlier completion of the plant growth phases and hence improves the morphological and yield parameters of cereals (Foti *et al.,* 2008; Khan *et al.,* 2011; Farooq *et al.,* 2015) including the maize crop.

Two important seed priming techniques are hydro-priming (soaking in water) and osmopriming (soaked in aerated low water potential solution) (Ashraf and Foolad, 2005). Hydro-priming and osmopriming has the potential for ensuring a rapid and uniform seedling emergence, improved seedling growth and better productivity under any type of environmental and soil conditions (Chiu and Sung, 2002; Hussain *et al.*, 2016). In a study, seed priming with $CaCl_2$ enhanced the plant growth and productivity by increasing the shoot dry weight up to 90% as compared to non-primed seeds (Bahareh and Farid, 2012).

After seed priming, the primed seeds can be sown after re-drying to original weight or after surface drying. In re-drying methods after priming, seeds are surface washed with water followed by drying to original weight. In surface drying, the seeds are surface washed with water and then are immediately sown under field or laboratory condition (Chivasa *et al.*, 1999; Harris *et al.*, 2002; Farooq *et al.*, 2010a). In a study, Foti *et al.* (2008) revealed that in maize, seed priming improved emergence, growth and seed yield. Studies have reported that seed priming improved the stand establishment and seed yield of many field crops (rice, wheat, maize, canola) (Basra *et al.*, 2005); nonetheless no study has compared the surface drying and re-drying after seed priming to improve the seedling emergence and subsequent growth and seed yield of autumn planted maize. Thus, the present study was conducted to investigate the role of re-dried and surface dried primed seeds for improving the stand establishment and productivity of autumn planted maize.

Materials and Methods

This study was consisted of pot and field studies, conducted at wire house and agricultural research area of BZU Multan, Pakistan, respectively during the autumn season of 2016. The soil used in pot experiment was collected from the same field where the field study was conducted. Before sowing, soil sample (0–20 cm) was collected and analyzed to evaluate the soil fertility status. The experimental soil was clay-loam with pH 8.30, EC 1.74 dS m^{-1}, soil organic matter 0.98%, available phosphorus 6.00 mg kg^{-1}, available nitrogen 0.023% and available potassium 122 mg kg^{-1}. Weather data during the experimental period is given in Table 1.

Experimental Details

The seeds of hybrid maize (31-R88) were purchased from the Pioneer Seeds Pvt. Limited Sahiwal, Punjab, Pakistan. The seeds were hydro- or osmoprimed ($CaCl_2$; ψs -1.25 MPa) following the standard procedure as detailed in Farooq *et al.* (2017). After seed priming (hydropriming and osmopriming), the seeds were re-dried or surface dried as detailed in Farooq *et al.* (2011b). Untreated dry seeds were taken as control. Before sowing, primed and untreated dry seeds were treated with fungicide 'Actara (Thiamethoxam) at 1 g per kg seeds in 20–25 mL water for 5 min.

Pot Experiment

The pot study was laid out according to completely randomized design, replicated four times. The un-primed and primed seeds, 10 of each, were sown in earthen pots (50 cm length and 22 cm internal diameter) filled with 20 kg of soil on August 18, 2016. At 4 leaf stage, 4 plants per plot were maintained by thinning out the extra plants. Fertilizers were applied at the rate of 2 g N and 1.5 g P per pot on the basis of soil analysis report. Whole of the P, and one third of N was soil applied before the sowing of seeds in pot, while the second dose of N was applied at 8–10 leaves formation and the third one was applied on tassel formation. The pots were irrigated regularly and uniformly with 3–5 days interval depending on crop requirement. A FMC product Furadan (Carbofuran) was applied after 4th irrigation at the rate of 20 kg ha^{-1} for the control of shoot fly and maize borer. Four granules of Furadan were applied per head from the top of the plant. Mature crop was harvested on December 9, 2016.

Field Experiment

The field experiment was laid out under randomized complete block design, replicated thrice having a net plot size of 5 m × 3 m. The row to row and plant to plant distance was maintained at 75 cm and 25 cm respectively.

Crop Husbandry

Before seed bed preparation, pre-sowing irrigation was applied. When the soil reached at suitable moisture level, the required seed bed for maize crop was achieved by applying three cultivations (0.15 cm deep) each followed by planking with tractor drawn cultivator. Maize hybrid

(31R88) seeds were sown on August 23, 2016 on fully prepared soil at the rate of 25 kg ha^{-1}. The seeds were treated with fungicide Actara (Thiamethoxam) at the rate of 5 g per 5 kg seeds in 20–25 mL water for 5 min. The sowing was done on ridges manually with hand and thinning was done at 4 leaf stage. The synthetic fertilizers were soil applied at 200–150 kg N-P kg ha^{-1}, using the Urea and Di-ammonium phosphate as sources, respectively. Whole P and one third N was applied at the sowing time, while second and third N dose was applied at knee height (8–10 leave) and tassel formation (14–15 leave), respectively. The irrigation was given to experimental plots at 5–7 days interval on the basis of water requirement of maize crop. The irrigation was stopped ~2 weeks before the harvesting. Pre-emergence weedicide Primextra Gold (290 g L^{-1} S-Metolachlor + 370 g L^{-1} Latrazine) was used at the rate of 2 L ha^{-1}. A FMC product Furadan (Carbofuran) was used at 20 kg ha^{-1} to control the maize borer and shoot fly. Four grains of Furadan was applied per head from the top of the plant. The pesticides, Match Syngenta product (50 g L^{-1} Lufenuron) at the rate of 500 mL ha^{-1}, and Bifenthrin and Lefenuron (Exin Group of Pakistan) at the rate of, 650 mL ha^{-1}, 2 L ha^{-1} respectively were applied to keep the crop free from Army worm, whitefly and American worm. The crop was harvested on December, 07, 2016.

Data Recording

Germination data: Days to start emergence were observed in each plot individually after planting by choosing a uniform site from each treatment from both pot and field experiments. The 1st day of appearance of seedling was taken as a day to start emergence. Energy of emergence, mean emergence time, time to 50% emergence, and emergence index were calculated following the standard formulas of Ruan *et al.* (2002), Ellis and Robert (1981), Farooq *et al.* (2005) and Association of Official Seed Analysis (1983), respectively. Final emergence percentage was calculated as ratio of emerged seeds with total seeds sown expressed in percentage.

Morphological and Yield Related Traits

For measuring the plant height, 1 (for pot study) and 10 (for field study) plants were taken from each plot. After selection of plants, their height was determined by using measuring tape and average was calculated. Total number of cobs was counted of these selected plants (as per pot or field study) from each pot/plot and then averaged to get cob number per plant. The cob length of the same 1 (for pot study) and 10 (for field study) was recorded with measuring scale and then averaged for each experimental pot/plot. The same cobs were threshed manually to work out the number of grains per cob. A sample of 100 (for pot study) and 1000 (for field study) grains was taken from seed lot and were weighed to record the respective grain weight. The maize crop was harvest at maturity by separating cobs from the plants in each pot/plot. These cobs were sundried and threshed manually to measure the grain yield per pot/plot after weighing on an electric balance. Then grain yield was adjusted to 10% moisture contents and converted into g per plant and Mg ha^{-1} by simple unitary method for pot and field study respectively. The whole maize plants from each pot/plot were sundried, and weighed on a spring balance to record the stover yield. The stover yield was added to the grain yield to measure the biological yield which was later reported in g per plant and Mg ha^{-1} for pot and field study respectively. The harvest index was measured as the ratio of grain yield to the biological yield, expressed in percentage.

Statistical Analysis

The recorded data was subjected to the Fisher's analysis of variance technique for statistical analysis, followed by separation of significant treatment means by LSD test (5% probability level) (Steel *et al.,* 1997).

Results

Pot Experiment

This study indicated that various seed priming treatment significantly affected the mean emergence time and final emergence percentage, while results being non-significant for days to start emergence, emergence index and energy of emergence (Table 2). All seed priming treatments either with surface drying or re-drying of primed seeds significantly reduced the mean emergence time than control (Table 2). Likewise all seed priming treatments either with surface drying or re-drying of primed seeds significantly improved final emergence percentage than control which was also at par with osmopriming redrying and hydropriming surface drying (Table 2).

Seed priming treatments significantly affected the plant height, cob length, 100-grain weight, biological yield, grains yield and harvest index; results being non-significant for number of grains per cob (Table 3). The highest plant height was recorded in hydropriming-redrying and that was statistically similar with osmopriming-surface drying and hydropriming-surface drying. The cob length and 100-grain weight were also the maximum in osmopriming-surface drying and hydropriming-surface drying, and that was statistically similar with osmopriming-redrying and hydropriming-redrying for 100-grain weight. The biological yield and grain yield was the highest with osmopriming-surface drying and that was statistically similar with hydropriming-surface drying for grain yield (Table 3).

Field Experiment

This study indicated that various seed priming treatment significantly affected the time to start emergence and final emergence percentage; results being non-significant for emergence index, mean emergence time,

Table 2: Influence of seed priming followed by re-drying and surface drying on the stand establishment of maize grown in pots

Treatments	DSE (days)	EE (%)	MET (days)	EI	FEP (%)
Control	3.0	37.5	7.88A	7.86	94.2B
Hydropriming RD	3.0	56.3	6.61B	9.44	98.8A
Osmopriming RD	3.0	49.6	6.67B	8.87	97.1AB
Hydropriming SD	2.0	54.2	6.49B	8.90	97.5AB
Osmopriming SD	2.0	51.7	6.66B	9.04	98.8A
LSD ($p \leq 0.05$)	NS	NS	0.93	NS	3.84

Means sharing the same case letter for a parameter do not differ significantly at $p \leq 0.05$; RD= re-drying after seed priming; SD= surface drying after seed priming; NS= non-significant; EE= energy of emergence; DSE= days to start emergence; MET= mean emergence time; EI= emergence index; FEP= final emergence percentage

Table 3: Influence of seed priming followed by re-drying and surface drying on morphological/yield parameters, biological/grain yield and harvest index of maize grown in pots

Treatments	Plant height (cm)	Cob length (cm)	Number of grains per cob	100-grain weight (g)	Biological yield (g/plant)	Grain yield (g/plant)
Control	3.20B	14.0B	191	19.2B	54.2D	30.1D
Hydropriming RD	3.90A	14.0B	274	21.8A	65.0C	37.7BC
Osmopriming RD	3.33B	14.0B	230	22.3A	69.4BC	34.7CD
Hydropriming SD	3.67AB	15.3A	302	22.6A	78.9B	42.1AB
Osmopriming SD	3.67AB	16.7A	239	23.0A	92.1A	48.8A
LSD ($p \leq 0.05$)	0.54	2.63	NS	0.92	10.4	6.3

Means sharing the same case letter for a parameter do not differ significantly at $p \leq 0.05$; RD= re-drying after seed priming; SD= surface drying after seed priming; NS= non-significant

Table 4: Influence of seed priming followed by re-drying and surface drying on the stand establishment of maize in field experiment

Treatments	DSE (days)	EE (%)	MET (days)	EI	FEP (%)
Control	3.00A	48.0	6.63	9.35	94.5B
Hydropriming RD	3.00A	60.0	6.47	8.95	97.1AB
Osmopriming RD	2.67A	55.0	6.53	8.70	98.4A
Hydropriming SD	2.00B	56.3	6.25	8.73	97.5AB
Osmopriming SD	2.00B	53.6	6.36	8.50	99.2A
LSD ($p \leq 0.05$)	0.43	NS	NS	NS	3.56

Means sharing the same case letter for a parameter do not differ significantly at $p \leq 0.05$; RD= re-drying after seed priming; SD= surface drying after seed priming; NS= non-significant; EE= energy of emergence; DSE= days to start emergence; MET= mean emergence time; EI= emergence index; FEP= final emergence percentage

Table 5: Influence of seed priming followed by re-drying and surface drying on morphological/yield parameters, biological/grain yield and harvest index of maize in field experiment

Treatments	Plant height (cm)	Cob length (cm)	Number of grains per cob	1000-grain weight (g)	Biological yield (Mg ha^{-1})	Grain yield (Mg ha^{-1})	Harvest index (%)
Control	6.04D	20.5	670E	240D	13.5D	6.5D	48.1
Hydropriming RD	6.44C	21.5	743C	265BC	16.1C	7.6C	47.2
Osmopriming RD	6.59BC	21.5	739D	258C	16.2BC	8.0B	49.4
Hydropriming SD	6.81AB	22.0	761B	276B	16.6B	7.9B	47.6
Osmopriming SD	6.98A	22.5	780A	302A	17.5A	8.3A	47.4
LSD ($p \leq 0.05$)	0.24	NS	1.58	12	0.43	0.2	NS

Means sharing the same case letter for a parameter do not differ significantly at $p \leq 0.05$; RD= re-drying after seed priming; SD= surface drying after seed priming; NS= non-significant

and energy of emergence (Table 4).

The lowest time to start emergence was recorded in osmopriming and hydropriming-surface drying (Table 4). Maximum final emergence percentage was recorded in surface and re-drying osmopriming against control which was also at par with hydropriming surface and re-drying (Table 4).

Seed priming treatments significantly affected the plant height, 1000-grain weight, grains per cob, biological and grain yield; results being non-significant for cob length (Table 5). The highest plant height was recorded in osmopriming-surface drying and was statistically similar with hydropriming-surface drying. The number of grains per cob, 1000-grain weight, and biological and grain yield was the highest in osmopriming-surface drying that were statistically similar with hydropriming-surface drying (Table 5).

Discussion

This study indicated that osmopriming/hydropriming-surface drying were the best seed priming treatments from improving the maize performance as indicated through uniformity and earliness of seedling emergence and improved morphological parameters and grain yield under pot and field conditions. Indeed, seed priming initiates the metabolic activities within seed. When the seeds are re-dried to their original weight, these metabolic activities may go under dormant period due to reduction in starch metabolism, and these metabolic activities may take some time to resume when re-dried seeds are sown again into the soil (Farooq *et al*., 2010a). However, in surface drying, the seeds are sown immediately after the surface drying of primed seeds, and thus the metabolic activities are sharply started after imbibition of water from the soil as compared to re-drying of primed seeds to their original weight (Farooq *et al*., 2010a). Moreover, the improved stand establishment due to surface drying might be attributed to increased amylase activity and rapid starch hydrolysis in these seeds which possibly improved the dehydrogenase activity and soluble sugars than redrying (Farooq *et al*., 2010a). Some other studies have reported that sowing of surface dried primed seeds was most effective for improvement in stand establishment and starch metabolism in wheat (Farooq *et al.,* 2011b) and rice seeds (Farooq *et al*., 2010a). However, in another study, Rehman *et al.* (2011) found that re-drying after osmopriming was more beneficial than surface drying in rice. Thus, our assumptions may require future investigations at molecular and field level that why the surface dried primed seed perform better than the re-dried primed seeds.

Improvement in stand establishment due to hydropriming and osmopriming-surface drying ultimately improved the morphological and yield parameters (1000-grain weight, grain rows per cob) in maize in pot and field study. When the stand establishment of a plant is improved, the plant growth is improved that tends to produce longer roots that can penetrate into the soil and uptake more nutrient and water as compared to non-treated seeds (Alam *et al.,* 2013). Thus, better grain yield in surface dried primed maize seeds in this study was the outcome of early stand establishment (Tables 2 and 4) which possibly improved the crop growth and finally the yield parameters and grain yield (Tables 3 and 5).

In this study, osmopriming with $CaCl_2$ was most beneficial for improvement in stand establishment and maize productivity (Tables 2, 3, 4 and 5) which might be attributed to the role of Ca^{2+} in the metabolism of carbohydrates (Farooq *et al*., 2010b). Osmopriming with $CaCl_2$ is also believed to enhance the seed Ca^{2+}contents further improving the carbohydrate metabolism within osmoprimed seeds. During later crop growth stages, Ca^{2+} regulates various transport processes across the plasmalemma and triggers the activities of many enzymes (Taiz and Zeiger, 2006). Moreover, the gibberellic acid production in the seed scutellum, release of the hydrolases within the aleuronic layer, and their transfer to the seed endosperm for the mobilization of reserve towards the embryo in cereals is also regulated by Ca^{2+} (Srivastava, 2002). Therefore, osmopriming was more effective for improvement in stand establishment and productivity of maize than hydropriming in this study. Likewise, the improvements in the maize performance due to osmopriming might be due to the "hard start" given by osmopriming to the seeds to withstand adverse as well as normal environmental conditions (Chen, 2011) under pot and field conditions. The osmoprimed induced improvements in stand establishment and productivity of numerous arable crops have been reported by several other researchers (Farooq *et al.,* 2015, 2017; Khan *et al.,* 2015; Nawaz *et al.,* 2016; Hussain *et al*., 2017).

In crux, surface drying of osmoprimed seed is a viable option to improve the seedling emergence and productivity of autumn planted maize crop.

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