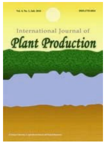

International Journal of Plant Production 9 (3), July 2015
ISSN: 1735-6814 (Print), 1735-8043 (Online)
www.ijpp.info

GUASNR

Meta-analysis of seed priming effects on seed germination, seedling emergence and crop yield: Iranian studies

E. Soltani[a,*], A. Soltani[b]

[a] *Department of Agronomy and Plant Breeding Sciences, College of Abourahian, University of Tehran, Tehran, Iran.*
[b] *Agronomy Group, Gorgan University of Agricultural Sciences and Natural Resources, Gorgan 49138-15739, Iran.*
*Corresponding author. E-mail: elias.soltani@ut.ac.ir

Received 28 September 2014; Accepted after revision 12 March 2015; Published online 10 May 2015

Abstract

A large body of research has documented the effect of seed priming on germination, emergence and crop yield. In such research, seed priming has been found to have a positive, negative or no effect. Meta-analysis can help to summarize and interpret a collection of experiments. The aim of this study was to conduct a meta-analysis to synthesize published data from studies addressing the effect of seed priming in Iran. Our results indicated that seed priming profoundly influences germination (rate or percentage), seedling emergence (rate or percentage) and crop yield. Among the studied traits, the crop yield increased the most (+28%), followed by the seedling emergence percentage (+19%), the germination rate (+17%), the seedling emergence rate (+15%) and the germination percentage (+4%). In general, hormonal priming was the best seed priming treatment. This was followed by hydropriming and osmopriming. The best priming durations were 12-24 h for the germination percentage (+14%), longer than 24 h for the germination rate (+16%), shorter than 24 h for the seedling emergence rate (+10 to + 14%) and the percentage (about +11%) and shorter than 12 h for the crop yield (+26%). Seed priming significantly increased in all of the traits of eudicots and monocots, except for the germination percentage in monocots. The differences were significant between the monocot and eudicot species in the germination stage. The differences became insignificant in the seedling emergence and crop yield. Finally, it was concluded that hydropriming is a practical treatment. This is due to its low cost and beneficial effects. We additionally concluded that durations shorter than 12 h are the most effective for this priming.

Keywords: Seed enhancement; Seed vigor; Seed viability; Yield improvement.

Introduction

Poor establishment is a major constraint for crop production. The seedling establishment of crops is influenced by the quality (e.g., viability and vigour) of the seed used (De Figueiredo et al., 2003). A higher quality of seed results in a shorter time between the sowing and seedling emergence. This results in a better crop establishment in the field, especially under adverse environmental conditions. The timing, pattern and extent of seedling emergence have a profound impact on crop yield and market value (Finch-Savage, 2004; Soltani and Farzaneh, 2014). It is well-known that rapid emergence can lead to an increase in the yield potential by shortening the number of days from sowing to complete ground (Soltani et al., 2001; Soltani and Galeshi, 2002; Soltani et al., 2008; Soltani et al., 2009; Soltani and Farzaneh, 2014).

To increase the seedling emergence rate and improve crop establishment, an adopted strategy is to prime seeds before sowing. This is known as seed priming. As reported by Khan (1992), the term "priming of seed" was coined by Malnassy (1971). Seed priming is a seed enhancement method (Taylor et al., 1998), which results in an increase in seed performance (germination and emergence), especially under stressful conditions (Foti et al., 2002; Ashraf and Foolad, 2005; Demir Kaya et al., 2006). In priming, seed hydration reaches the second stage of imbibition but does not permit radicle protrusion through the seed coat (Caseiro et al., 2004; McDonald, 1999). Subsequently, the seeds can be dried to attain their original moisture content for storage or planting using conventional techniques (Matsushima and Sakagami, 2013). Priming techniques can be grouped into two categories, depending on whether water uptake is non-controlled or controlled (Taylor et al., 1998). Non-controlled water uptake includes those methods in which water is freely available to the seeds and not restricted by the environment. This is known as “hydropriming”. Since water is not limited, seeds may eventually germinate. Thus, in non-controlled water uptake systems, the process must be stopped at a specific time to prevent the onset of phase III (Taylor et al., 1998). In controlled water uptake, three different methods can be used to prevent the completion of germination. These include priming with solutions, priming with solid particulate techniques and drum priming (Taylor et al., 1998). Additional seed priming methods have been used, e.g., hormonal priming (Afzal et al., 2002). Seed priming with optimal concentrations of phyto-hormones has been shown to be beneficial to the germination, growth and yield of some crops (Afzal et al., 2002; Rajasekaran et al., 2002; Shakirova et al., 2003; El-Tayeb, 2005; Thakare et al., 2011). Despite its potential benefits, seed priming has not achieved widespread circulation. This is because there are critical points undermining its practical use (Di Girolamo and Barbanti, 2012).

Although a large body of research has documented the effect of seed priming on germination, emergence and crop yield, most of these studies are homogeneous. They are homogenous according to species, seed quality, priming methods (including material, time, temperature and drying) and germination conditions. Studies differ in their results of seed priming. Some demonstrate a negative effect, whilst others indicate a significant positive effect. This has led to an uncertainty in using priming in practice. Meta-analysis can help to summarize and interpret the findings of a large collection of experiments, taking into account the chance character of such findings (Gurevitch and Hedges, 1999). Typically, in a meta-analysis, the outcome of each study is summarized as an index of effect size. These indices are summarized across studies. Statistical analyses of effect sizes can be constructed to answer many questions. For example, how large is the effect of seed priming overall? Is it positive or negative and is it reliably different than zero? Do any characteristics of the studies influence the magnitude of the observed effect? To answer such questions, a possible method is meta-analysis. Thus, the aim of this study was to conduct a meta-analysis to synthesize published data from studies addressing the effect of seed priming on seed germination, emergence and crop yield in Iran.

Material and Methods

Data

Data were collected from peer-reviewed papers published in Iranian journals before October 2013. Papers reporting the responses of seed germination percentage and rate, seedling emergence percentage and rate, as well as crop yield, were included if they met certain requirements. The first requirement was that the control and priming treatments were applied at the same time. The second was that the seed priming treatments were hydropriming, osmopriming, priming with solid particulate techniques, drum priming or hormonal priming. The third and final requirement was that the information regarding mean values and the number of replicates were reported for each treatment. Based on the above requirements, 47 peer-reviewed papers were selected for the meta-analysis (Appendix I). The mean values and the number of replications for the selected characteristics were extracted from the papers.

Seed priming is influenced by many factors. These include methods of priming, aeration, light, temperature, duration of hydration, drying and seed quality. In our meta-analysis, we intended to involve all of these impacting factors. Some factors, including aeration, light and seed quality, had been rarely investigated in Iranian studies on seed priming. Some factors, including priming temperature and drying, were mostly the same at 20 ^{o}C, air-dried in laboratory or were not reported by authors. Thus, in our meta-analysis, we only included priming methods, priming duration and plant species (eudicots or monocots).

Statistical Analysis

Meta-analysis evaluates the treatment effects from different studies on a common scale of effect size. The effect size was calculated as the natural log of the response ratio (ln R) (Hedges et al., 1999):

$$\ln R = \ln\left(\frac{\overline{X}_P}{\overline{X}_C}\right) \tag{1}$$

where $\overline{X}_P$ and $\overline{X}_C$ are the mean values of priming treatment and control. Studies were weighted by replication (Linquist et al., 2013):

$$w_i = n \tag{2}$$

where w_i is the weight for the *i*th observation and n is the number of replications per treatment combination. Weighting does have the desirable property of counting large studies more heavily than small ones, which often seems reasonable in summarizing the overall results (Gurevitch and Hedges, 1999). The mean effect sizes were estimated as follows:

$$\overline{\ln R} = \frac{\sum(\ln R_i \times W_i)}{\sum(W_i)} \tag{3}$$

where $\ln R_i$ is the effect size for the characteristic (seed germination percentage and rate, seedling emergence percentage and rate and crop yield) from the i^{th} observation. Confidence intervals for the average log response ratio were calculated as mentioned by Hedges et al. (1999). To help interpretation, the results for the analyses on effect size were back-transformed and reported as the percentage change with the seed priming treatment relative to the control treatment ([R−1]×100). Positive percentage changes indicated an increase, while negative values indicated a decrease. Treatment effects were considered significant when the 95% confidence intervals did not overlap with zero. Similarly, the differences between treatment categories were considered significant if their 95% confidence intervals did not overlap (Gurevitch and Hedges, 1999; Rotundo and Westgate, 2009; Huang et al., 2013; Linquist et al., 2013).

Results

In this investigation, 47 studies were identified (Appendix I) and matched our requirements. The minimum and maximum numbers of observations were 151 (for the crop yield) and 340 (for the germination percentage). Studies included the following crop species: barely, maize, cotton, sugar beet, soybean, canola, rice, wheat, chickpea, tomato, millet, triticale, sunflower, sorghum, mung bean (*Vigna radiata*), cowpea (*Vigna unguiculata*), bean, dill (*Anethum graveolens*), secale (*Secale montanum*), henbane (*Hyoscyamus niger* L.), tall wheatgrass (*Agropyron elongatum*), lemon balm (*Melissa officinalis* L.), *Festuca ovina*, *Festuca arundinacea*, fennel (*Foeniculum vulgare* Mill), *Agropyron desertorum*, *Bromus inermis*, *Lolium prenne*, *Cnicus benedictus*, *Cichorium intybus*, *Borago officinalis* and *Puccinellia distans*. There were three methods for seed priming: hydropriming, osmopriming (with different solutions, water potentials and durations) and hormonal priming (with different phyto-hormones, concentrations and durations). We could not find any previous study that has used priming treatments with solid particulate techniques or drum priming. The treatment durations ranged from 2 to 336 h for laboratory studies and varied from 4 to 24 h for field studies.

Overall Effects of Seed Priming

In general, the seed priming significantly increased in all of the studied variables compared with the untreated seeds (Figure 1). Among the studied variables, the crop yield increased the most (+28%). This was followed by the seedling emergence percentage (+19%), the germination rate (+17%), the seedling emergence rate (+15%) and the germination percentage (+4%). The effect of priming on the seed vigour variables (the germination rate, the seedling emergence percentage and the rate) appeared stronger than the seed viability variable (the germination percentage).

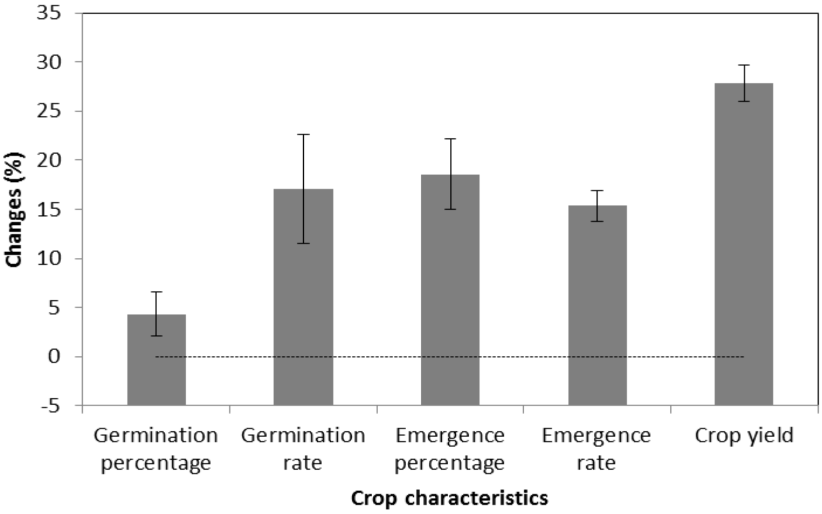

Figure 1. Influence of seed priming on percentage changes in germination percentage and rate, seedling emergence percentage and rate and crop yield. Error barsare 95% confidence intervals. Changes (%) were considered significant when the 95% confidence interval did not overlap with zero.

Effect of Experimental Conditions on the Effect Size of Crop Characteristics

Germination

Overall, seed priming significantly increased the germination percentage (GP) and germination rate (GR) by 4 and 17% (Figures 2, 3). This indicates that priming can slightly, but significantly, increase the GP in various species. It also demonstrates that priming has a greater effect on the GR. The best priming duration was 12-24 h hydration, which increased the GP by about 14%. The differences in the GP were significant among the duration of 12-24 h hydration with two other priming durations. However, all of the priming durations were significantly different from the control treatment (Figure 2). The results from the studies on the GR demonstrate that a longer duration of hydration (>24 h) results in a faster GR. In this study, the increased GR (+16%) was more than the other two priming durations (<12 h: 8% and 12-24 h: 11%) (Figure 3). The hydropriming and hormonal priming methods significantly increased the GP and GR (Figures 2, 3). The GP was not significantly affected by osmopriming and showed only a slightly negative response to it (-1.4%). The osmopriming significantly decreased the GR by 4%. The differences for effect size for the GP and GR were significant among priming methods. Additionally, the hormonal priming was the best treatment for seed priming (GP: +28%, GR: +34%). The hydropriming also had a positive effect on the GP (+11%) and GR (+23%). With regard to their response to seed priming, it was surprising to observe a difference between the monocots and eudicots. Seed priming significantly increased the GP (13%) and GR (23%) of the eudicots (Figures 2, 3). However, it had a negative impact on the GP of monocots (-4%). This effect was not significant (95% CI= -9.4 to 2.1%) with zero (control). However, the primed monocot seeds were germinated faster than the control seeds. Moreover, the magnitude of effect size was about +12% (Figure 3).

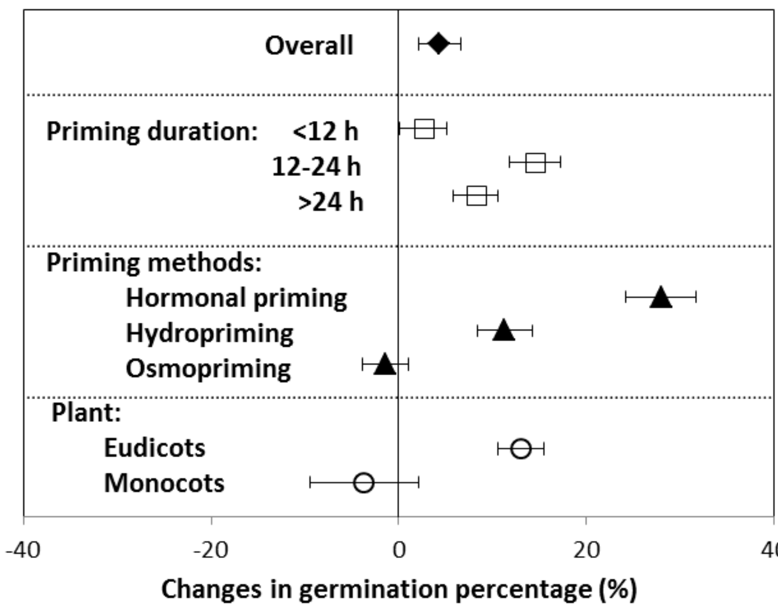

Figure 2. Relative response of germination percentage to priming duration, priming methods and plant species. Error bars are 95% confidence intervals.

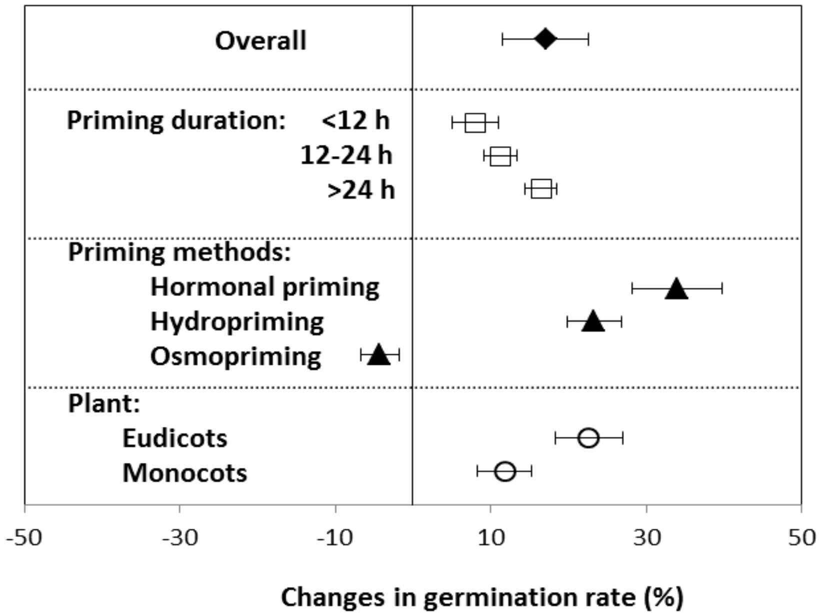

Figure 3. Relative response of germination rate to priming duration, priming methods and plant species. Error bars are 95% confidence intervals.

Seedling Emergence

The results indicated that the most pronounced effects of priming were observed in seed vigour, rather than seed viability. The seedling emergence percentage (EP) and seedling emergence rate (ER) increased more than the GP. The EP increased less under the 12-24 h durations (+10.9%) compared with the <12 h durations (+11.4%). The EP was significantly different from zero (control) (Figure 4). Consistent with these effects on the EP, the ER increased significantly in both the duration of hydration by 13.6% (<12 h) and 10.4% (12-24 h) from the zero (control) (Figure 5). There was no significant difference between the priming durations on the effect size of EP and ER (Figures 4, 5). There was no significant EP or ER response to the different priming methods (Figures 4, 5). In hormonal priming, the EP increased by 12.6% (CI=6.5-18.7%) in hydropriming, it increased by 16.0% (CI=13.2-19.0%) and in osmopriming, the EP increased by 16.0% (CI=13.6-18.4%). The percentage of increasing ER was not significant among hormonal priming (+14.8%), hydropriming (+11.8%) and osmopriming (11.1%). However, all of the priming methods were significantly different with control treatment (Figure 5). For the ER, the eudicot species showed a much stronger response to seed priming (+24%), compared with the monocot species (+13%). However, there was a wide variation in the eudicot species (CI=14-35%). This led to a non-significant difference between these two species (Figure 4). The ER of the eudicots (+18%) showed a greater, albeit insignificant, response to seed priming, compared with the monocots (+14%). Furthermore, seed priming significantly increased the ER, compared with the untreated seeds of both species (Figure 5).

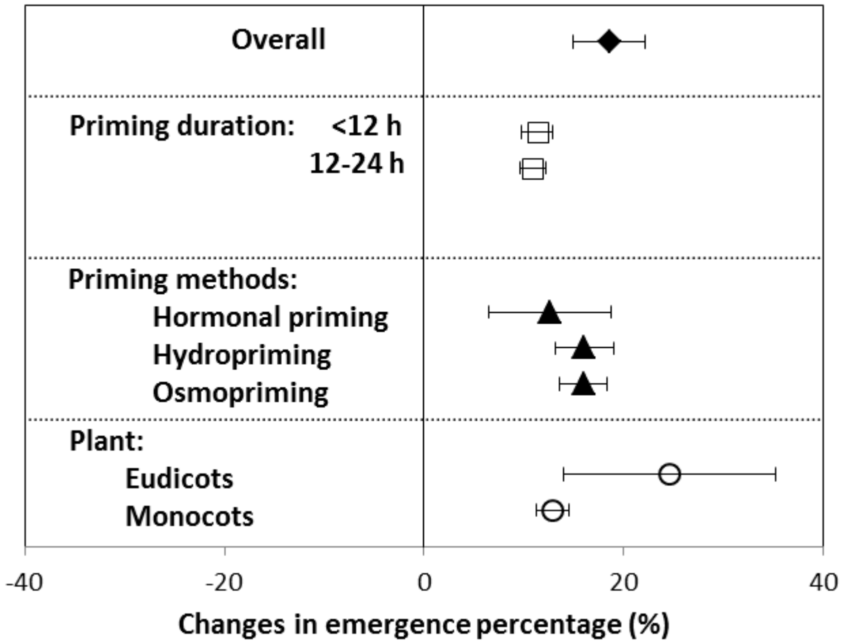

Figure 4. Relative response of emergence percentage to priming duration, priming methods and plant species. Error bars are 95% confidence intervals.

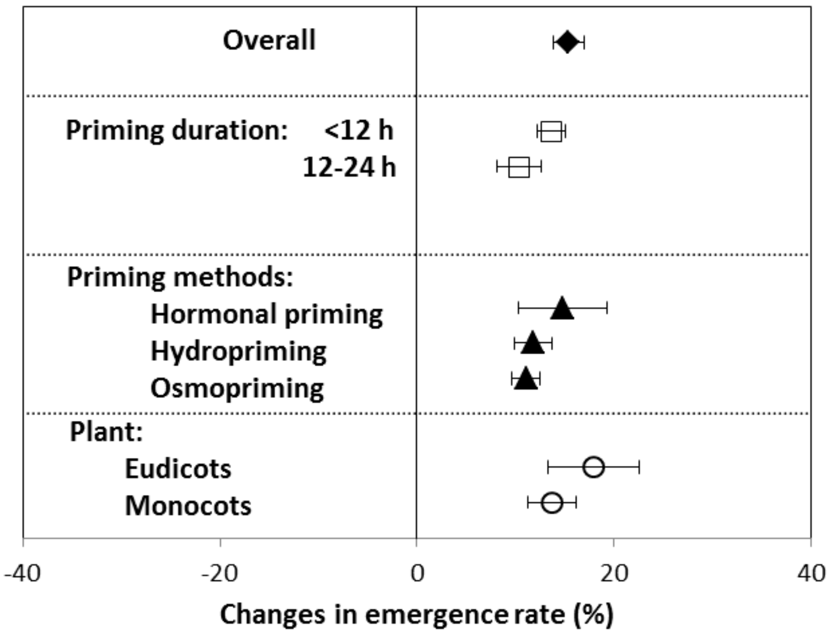

Figure 5. Relative response of emergence rate to priming duration, priming methods and plant species. Error bars are 95% confidence intervals.

Crop Yield

The duration of priming had a significant effect on the crop yield (Figure 6). Durations of less than 12 h (+26%) had a greater positive effect on the crop yield compared with the 12-24 h (+17%) duration. The difference between these two was significant (Figure 6). Hormonal priming resulted in the greatest increase in the crop yield, 31% (CI=29.3-31.8%) (Figure 6). Hydropriming increased the crop yield by 25% (CI=22.7-27.7%). Priming using the osmotic solution had the lowest positive effect (+6%). However, this effect was significantly different compared with the untreated seeds (Figure 6). In both the eudicots and monocots, the crop yield showed a positive response to priming (Figure 6). The priming increased the crop yield in the eudicots and monocots by 27% (CI=23.5-31.2%) and 28% (CI=24.9-32.0%), respectively.

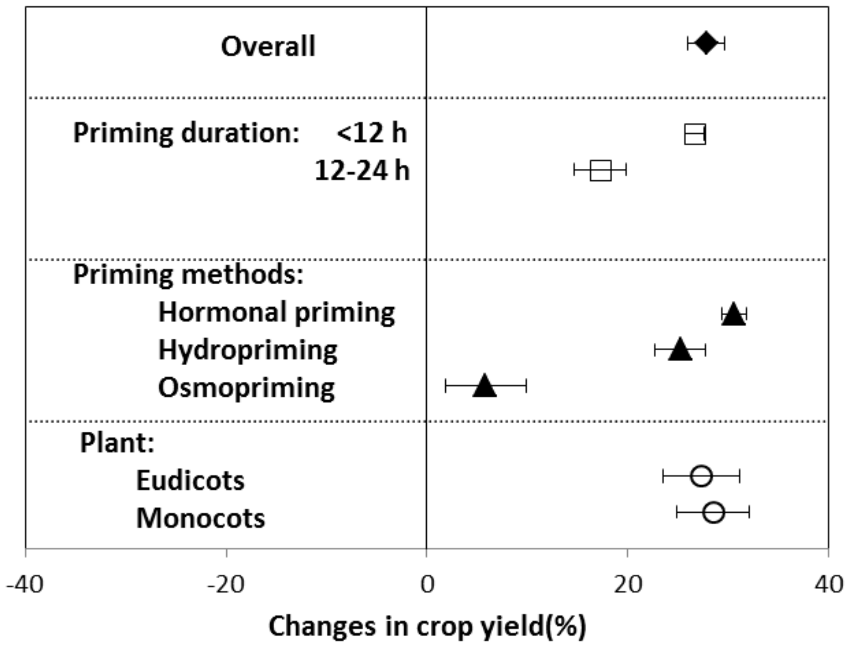

Figure 6. Relative response of crop yield to priming duration, priming methods and plant species. Error bars are 95% confidence intervals.

Discussion

The meta-analysis showed that seed priming profoundly influences the rapidity and percentage of seeds that germinate or emerge from the soil. The effect of priming on the seed vigour variables was stronger than that of the seed viability variables. The obtained results support the general consensus that the insignificant differences in germination ability can result in significant differences in the percentage of field emergence (Basu, 1995; Podlaski et al., 2003). For example, Podlaski, et al. (2003) reported that the differences found in the germination ability of differently treated seeds were below 10%. At the same time, the differences in the percentage of filed emergence were above 200%.

Di Girolamo and Barbanti (2012) reported an11% increase in the percentage of germination due to seed priming. They found a 36% shorter MGT as affected by seed priming. Previous studies argue that seeds that germinate first have an early start in growth and, therefore, produce larger seedlings (Khajeh-Hosseini et al., 2009). The higher rate of germination leads to a higher seedling emergence (Soltani et al., 2009; Soltani and Farzaneh, 2014). Severe conditions reduce seedling emergence, especially in seeds that have lower vigour. Seed priming can improve seed vigour. Thus, the main impact of seed priming is observed at the field or at the seed vigour tests.

There are several reasons for a greater seedling emergence percentage and rate due to seed priming. When a seed is hydrated, physiological and biochemical changes occur (Khan, 1992). The beneficial effects of priming have been attributed to membrane repair, increased protein synthesis and a more efficient mobilization of sugars and proteins (Srinivasan et al., 1999; Bittencourt et al., 2005). Furthermore, primed seeds show a greater ATP availability and faster embryo growth (McDonald, 2000; Varier et al., 2010). Some studies suggest that an increase in the germination percentage after a seed priming treatment may be due to processes like the breakdown of food reserve material, increased cell division and expansion of embryonic axis (Simon, 1984; Basra et al., 2005; Mahajan et al., 2011). During seed priming, a significant positive correlation is observed between α-amylase activity and sugar content (Lee and Kim, 2000; Farooq et al., 2006). These reports suggest that, in seed priming before sowing, the carbohydrate in the seed is ready to be used for cell elongation (Matsushima and Sakagami, 2013). The major effect of seed priming on seedling growth is early germination. Early germination gives seedlings more time to grow (Bittencourt et al., 2005).

The magnitude of the increase in the crop yield was greater than the seed viability or vigour variables. The increased crop yield might be a result of early seedling growth, an improvement in plant stands, reduced diseases and better plant nutrition (Rashid et al., 2002). Other explanations include uniform and vigorous seedling growth, well-developed root system and efficient subsequent growth that eventually lead to a higher grain yield (Harris et al., 2001). Environmental conditions have a considerable effect on seed priming. In years experiencing abnormal rainfall distribution, seed priming was more beneficial (Murungu et al., 2004). In a study by Ramamurthy et al. (2005), in improving yield, the maximum effect of seed priming was shown on medium deep soils

(22%), followed by shallow soils (8.1%). The minimum effect was shown on deep soils (4.8%).

The results of the meta-analysis showed that the duration of hydration had different levels of efficiency for different crop characteristics. The germination percentage (GP) increased the most when the duration of hydration was 12-24 h. However, the germination rate (GR) showed the greatest increase in 24< h. Increased GP was lower in 24< h compared with 12-24 h. A possible reason for this is that, in some studies, the seeds entered into phase three (radicle emergence from seed coats) and viability reduced as a result of damaged radicles. In such studies, the effect size became negative or small and reduced the total effect size. However, every additional hour of hydration resulted in an increasing GR. This was because a bigger part of the germination stage was performed in the priming treatment. This led to an improvement in the GR. The physiological and biochemical changes are responsible for the improvement in the GR, as mentioned above. There was no significant difference between the priming durations and the effect size of EP and ER. However, there was less of an increase in the EP and ER under 12-24 h, compared with the <12 h duration. Later, these insignificant changes during seedling emergence became significant and the durations of less than 12 h had a higher level of increased crop yield than 12-24 h. In general, as the yield is the utmost and final output of any crop, it can be argued that durations of hydration lower than 12 h are the most effective. However, all of the durations had a positive effect on crop characteristics, especially on the crop yield.

The hydropriming and hormonal priming methods led to a significant increase in the GP, GR, EP, ER and crop yield. The GP and GR showed a slightly negative response to osmopriming. There are some reports that are consistent with our results (e.g. Afzal et al., 2002; Giri and Schillinger, 2003; Mahajan et al., 2011). Afzal et al. (2002) observed that the seed germination of primed seeds with PEG was lower than other seed priming treatments and the control in maize. Mahajan et al. (2011) found out that the germination percentage of rice was lower in the primed seeds with KCl (85.3%) than in the control seeds (95.7%). Giri and Schillinger (2003) argued that higher concentrations of KCl, KH_2PO_4 and PEG were not generally beneficial. Moreover, they suggested that these high concentrations sometimes resulted in a lower germination percentage. The main reason for the negative effects of osmopriming is related to the phytotoxic impact on the germinating embryo (Giri and Schillinger, 2003; Mahajan et al., 2011). Patanè et al. (2008) reported that osmopriming with PEG solution is not suitable for seed treatment of sorghum with high content of tannin. This is because tannins can be removed with the solution treatment. In the present study, we found positive effects of osmopriming on the EP, ER and crop yield.

In general, the hormonal priming was the best treatment for seed priming, followed by hydropriming and osmopriming. However, in response to priming methods, there was no significant difference in the EP or ER. Seed priming with phyto-hormones has been shown to be beneficial to the germination, growth and yield of some crop species growth (Afzal et al., 2002; Rajasekaran et al., 2002; Shakirova et al., 2003; El-Tayeb, 2005; Thakare et al., 2011). The most common phyto-hormones are cycocel, ethephon, gibberellic, cytokinin, salicylic acid, abscisic acid (ABA), ascorbic acid and indol acetic acid (IAA). The meta-analysis showed that hormonal priming resulted in an increase in the crop yield by 31%, followed by hydropriming (+25%). In practice, hydropriming may be more beneficial. This is because of the expense of plant hormones. Thus, one can argue that it is more beneficial to use hydropriming treatment. This is due to its low cost and beneficial effects on the germination, seedling emergence and crop yield.

Seed priming significantly increased all the studied traits of the eudicots and monocots, except for the GP in monocots. In the germination stage, the differences were significant between the monocot and eudicot species. In the seedling emergence and crop yield, the differences became insignificant. As a result of seed priming, four species (barely, triticale, maize and rice) showed negative effects on the GP. Among these, triticale and maize showed the most negative impact. It is important to note that, in our meta-analysis, we did not study wheat in the germination stage. These species have caryopsesas propagation units. In some cereals (i.e., barley, rice), the glumellae (hull) adhering to the caryopsis represents another constraint for embryo germination, in addition to those already imposed by endosperm plus testa/pericarp. It seems that the presence of an adhered glumellae can be useful in the response of seed priming. It may delay water uptake of seeds and seeds will reach phase three of water uptake later. Khazaei et al. (2010), included in our study (Appendix I), investigated three durations of seed priming (6, 12 and 24 h) in triticale. They found that a 6 h hydration duration resulted in a higher germination percentage, compared with other durations. Giri and Schillinger (2003) reported that wheat seeds showed no germination advantage. Furthermore, they found that seeds which were soaked in any of the priming media for more than 12 h had a negative effect. Mohseni et al. (2010), included in our study (Appendix I), studied different osmotic solutions and hydropriming on maize germination. In their study, all of their treatments showed negative effects on the germination percentage but the reducing effect was much lower in hydropriming, compared with osmopriming treatments. Previous studies have highlighted the phyto-toxic effects of osmotic solution on the seed germination of maize (Afzal et al., 2002) and rice (Mahajan et al., 2011). Finally, it can be argued that cereal seeds have a greater sensitivity to phyto-toxic effects of osmotic solution and water uptake injury.

Conclusion

The meta-analysis showed that seed priming significantly increases seed germination, seedling growth and crop yield. The hormonal priming was the best treatment for seed priming, followed by hydropriming and osmopriming. Hydropriming was recommended due to its lower cost and beneficial effects on germination, seedling emergence and crop yield. Furthermore, we found that durations of hydration lower than 12 h were the most effective. We conclude that using osmotic solutions may have phyto-toxic effects, especially in the germination stage and in the monocots species (cereals).

Appendix I. Summary of experiments used in the meta-analysis of seed priming effects on seed germination, seedling emergence and crop yield. OP, HP and H are showing osmopriming, hydropriming and hormonal priming.

Authors (year)	Priming method	Duration (h)	Accesses link
Abasdokht and Edalatpisheh (2012)	HP	24	http://ijfcs.ut.ac.ir/article_29036_2510.html
Abdolrahmani et al. (2009)	OP	12	http://www.agrobreed.ir/journal/11-4-3.pdf
Abdolrahmani et al. (2009)	OP	12	http://www.agrobreed.ir/journal/11-4-3.pdf
Abootalebian et al. (2008)	OP, HP	12, 24	http://ijfcs.ut.ac.ir/article_19625_1952.html
Akramghaderi et al. (2008)	HP	16	http://fa.journals.sid.ir/ViewPaper.aspx?ID=84371
Akramian et al. (2008)	OP	24, 48, 72	http://jcesc.um.ac.ir/index.php/arable/article/view/894
Ansari et al. (2011)	OP, HP, H	24, 15, 15	http://ijfcs.ut.ac.ir/article_35108_3116.html
Azarivand et al. (2010)	OP, HP	6, 12, 18, 24, 30	http://fa.journals.sid.ir/ViewPaper.aspx?ID=111018
Dianati-Tilaki et al. (2011)	OP	24	http://fa.journals.sid.ir/ViewPaper.aspx?ID=149453
Esmaeilipour and Mojdem (2009)	HP	12, 24	http://fa.journals.sid.ir/ViewPaper.aspx?ID=117223
Fateh et al. (2010)	OP, HP, H	24, 12, 24	http://ppt.basu.ac.ir/article_236_38.html
Hamzehei et al. (2012)	OP, HP, H	16, 6, 10	http://jcpp.iut.ac.ir/browse.php?a_id=1744&sid=1&slc_lang=en
Hasanzadeh et al. (2012)	OP	24	http://fa.journals.sid.ir/ViewPaper.aspx?ID=182709
Hosseini and Koocheki (2008)	OP, HP	2	http://jcesc.um.ac.ir/index.php/arable/article/view/897
Jahanbakhshi et al. (2012)	OP	12	http://fa.journals.sid.ir/ViewPaper.aspx?ID=203057
Joodi and Sharifzadeh (2006)	HP	5, 10, 15	http://fa.journals.sid.ir/ViewPaper.aspx?ID=51815
Kafi et al. (2010)	HP, H	24	http://fa.journals.sid.ir/ViewPaper.aspx?ID=171982
Khazaei et al. (2010)	OP, HP	6, 12, 24	http://fa.journals.sid.ir/ViewPaper.aspx?ID=202717
Khodabakhsh et al. (2010)	OP, HP	12	http://uijs.ui.ac.ir/ijpb/browse.php?a_id=50&sid=1&slc_lang=fa
Latifzadeh et al. (2013)	OP, HP	5	http://ijfcs.ut.ac.ir/article_30481_3116.html
Mahmoodzadeh et al. (2010)	HP	4, 8, 12	http://fa.journals.sid.ir/ViewPaper.aspx?ID=135166
Makkizadeh et al. (2012)	OP	72, 120, 336	http://ijmapr.rifr-ac.org/article_4507_919.html

Continue Appendix I.

Authors (year)	Priming method	Duration (h)	Accesses link
Mansouri and Aboutalebian (2012)	HP	8	http://jopp.gau.ac.ir/article_1293_158.html
Mirshekari (2012)	OP	12	http://mistug.tubitak.gov.tr/bdyim/abs.php?dergi=tar&rak=1007-966
Mohseni et al. (2010)	OP, HP	-	http://fa.journals.sid.ir/ViewPaper.aspx?ID=129754
Mohseni et al. (2012)	OP, HP	24	http://www.ijsst.ir/fa/ManuscriptDetail?mid=59
Moosavi et al. (2012)	OP, HP	16	http://ijfcs.ut.ac.ir/article_24877_2510.html
Moradi et al. (2011)	OP, HP	24	http://fa.journals.sid.ir/ViewPaper.aspx?ID=142089
Najafi et al. (2010)	OP, HP, H	24, 18, 8	http://fa.journals.sid.ir/ViewPaper.aspx?ID=125154
Nikzad and Amooaghaie (2012)	OP	24	http://plant.ijbio.ir/article_185_42.html
Pakmehr et al. (2011)	H	4	http://fa.journals.sid.ir/ViewPaper.aspx?ID=152578
Rahchamandi et al. (2011)	OP, HP	4	http://ppt.basu.ac.ir/article_237_38.html
Ramezani and rezaei (2011)	OP, HP	5, 10, 15	http://www.civilica.com/Paper-SEEDTECH02-SEEDTECH02_013.html
Rezaei et al. (2011)	OP, HP	24	http://www.ijsst.ir/fa/ManuscriptDetail?mid=9
Rezaei et al. (2012)	OP, HP	24	http://pubj.ricest.ac.ir/index.php/code3tg/article/view/1105
Riaziet et al. (2007)	OP	72, 168, 336	http://www.pajouheshmag.ir/official/1048/f-view.asp?No=77&p=3&ID=554483
Saberi and Tavili (2010)	H	10, 24	www.sid.ir/fa/VEWSSID/J_pdf/71113893804.pdf
Salehi et al. (2010)	OP, HP, H	-	http://fa.journals.sid.ir/ViewPaper.aspx?ID=124014
Shafe et al. (2013)	OP	24, 48, 72	http://ijmapr.rifr-ac.org/article_2916_644.html
Shahsavand et al. (2010)	OP	24, 48, 72	http://fa.journals.sid.ir/ViewPaper.aspx?ID=101862
Shakarami et al. (2011)	OP, HP	24	http://ijrfpbgr.rifr-ac.org/article_8301_1460.html
Shekari et al. (2010)	H	4	http://mag.roostanet.com/details.php?id=2723
Shekari et al. (2010)	HP, H	24	http://fa.journals.sid.ir/ViewPaper.aspx?ID=112703
Soltani et al. (2008)	HP	16	http://fa.journals.sid.ir/ViewPaper.aspx?ID=72994
Soltani et al. (2009)	HP	16	http://jopp.gau.ac.ir/article_361_36.html
Tabatabaei et al. (2012)	OP, HP	12	http://www.ijsst.ir/fa/ManuscriptDetail?mid=65
Yari et al. (2012)	OP, HP	12	http://www.ijsst.ir/fa/ManuscriptDetail?mid=61

References

Afzal, I., Basra, S.M.A., Ahmad, N., Cheema, M.A., Warraich, E.A., Khaliq, A., 2002. Effect of priming and growth regulator treatments on emergence and seedling growth of hybrid maize (*Zea mays* L.). Int. J. Agric. Biol. 4, 303-306.

Ashraf, M., Foolad, M.R., 2005. Pre-sowing seed treatment-a shotgun approach to improve germination growth and crop yield under saline and none-saline conditions. Advan. Agron. 88, 223-271.

Basra, S.M.A., Farooq, M., Tabassum, R., 2005. Physiological and biochemical aspects of seed vigour enhancement treatments in fine rice (*Oryza sativa* L.). Seed Sci. Tech. 33, 623-628.

Basu, R.N., 1995. Seed Viability. In: Basra, A.S. (ed.), Seed Quality: Basic Mechanisms and Agricultural Implications: 15. The Haworth Press, Inc., 10 Alice Street, Binhamton, New York, USA.

Bittencourt, M.L.C., Dias, D.C., Dias, L.A., Araújo, E.F., 2005. Germination and vigour of primed Asparagus seeds. Sci. Agric. (Piracicaba, Braz.), 62, 319-324.

Caseiro, R., Bennett, M.A., Marcos-Filho, J., 2004. Comparison of three priming techniques for onion seed lots differing in initial seed quality. Seed Sci. Tech. 32, 365-375.

de Figueiredo, E., Albuquerque, M.C., de Carvalho, N.M., 2003. Effect of the type of environmental stress on the emergence of sunflower (*Helianthus annuus* L.), soybean (*Glycine max* L.) and maize (*Zea mays* L.) seeds with different levels of vigor. Seed Sci. Tech. 31, 465-479.

Demir Kaya, M., Okçu, G., Atak, M., Çikili, Y., Kolsarici, Ö., 2006. Seed treatment to overcome salt and drought stress during germination in sunflower (*Helianthus annuus* L.). Eur. J. Agron. 24, 291-295.

Di Girolamo, G., Barbanti, L., 2012. Treatment conditions and biochemical processes influencing seed priming effectiveness. Italian J. Agron. 7, 178-188.

El-Tayeb, M.A., 2005. Response of barley grains to the interactive effect of salinity and salicylic acid. Plant Growth Regul. 45, 212-24.

Farooq, M., Basra, S.M.A., Khalid, M., Tabassum, R., Mahmood, T., 2006. Nutrient Homeostasis, Metabolism of Reserves and Seedling Vigor as Affected by Seed Priming in Coarse Rice. Canadian J. Bot. 84, 1196-1202.

Finch-Savage, W.E., 2004. The use of population-based threshold models to describe and predict the effects of seedbed environment on germination and seedling emergence of crops. In handbook of seed physiology: applications to agriculture, (eds. R.L. Benech-Arnold and R.A. Sánchez), pp. 51-95. Food Products Press, Binghamton, USA.

Foti, S., Cosentino, S.L., Patanè, C., D'Agosta, G.M., 2002. Effects of osmoconditioning upon seed germination of sorghum (*Sorghum bicolor* (L.) Moench) under low temperatures. Seed Sci. Tech. 30, 521-533.

Giri, G.S., Schillinger, W.F., 2003. Seed priming winter wheat for germination, emergence and yield. Crop Sci. 43, 2135-2141.

Gurevitch, J., Hedges, L.V., 1999. Statistical issues in ecological Meta-Analysis. Ecology. 80, 1142-1149.

Harris, J.M., Wise, T.A., Gallagher, K.P., Goodwin, N.R. 2001. A survey of Sustainable Development: Social and Economic Dimensions, Washington, D.C. Island Press.

Hedges, L.V., Gurevitch, J., Curtis, P., 1999. The meta-analysis of response ratios in experimental ecology. Ecology. 80, 1150-1156.

Huang, S., Zeng, Y., Wu, J., Shi, Q., Pan, X., 2013. Effect of crop residue retention on rice yield in China: A meta-analysis. Field Crops Res. 154, 188-194.

Khajeh-Hosseini, M., Lomholt, A., Matthews, S., 2009. Mean germination time in the laboratory estimates the relative vigour and field performance of commercial seed lots of maize (*Zea mays* L.). Seed Sci. Tech. 37, 446-456.

Khan, A.A., 1992. Preplant physiological seed conditioning. pp. 131-181 m Jamck, J. (Ed) Horticultural reviews New York, John Wiley & Sons.

Lee, S.S., Kim, J.H., 2000. Total Sugars, α-Amylase Activity and Germination after Priming of Normal and Aged Rice Seeds. Korean J. Crop Sci. 45, 108-111.

Linquist, B.A., Liu, L., van Kessel, C., van Groenigen, K.J., 2013. Enhanced efficiency nitrogen fertilizers for rice systems: Meta-analysis of yield and nitrogen uptake. Field Crops Res. 154, 246-254.

Mahajan, G., Sarlach, R.S., Japinder, S., Gill, M.S., 2011. Seed priming effects on germination, growth and yield of dry direct-seeded rice. J. Crop Improv. 25, 409-417.

Malnassy, T.G., 1971. Physiological and biochemical studies on a treatment hastening the germination of seeds at low temperature. Ph.D. Thesis. Rutgers University. New Jersey.

Matsushima, K.I., Sakagami, J.I., 2013. Effects of seed hydropriming on germination and seedling vigor during emergence of rice under different soil moisture conditions. American J. Plant Sci. 4, 1584-1593.

McDonald, M.B., 1999. Seed deterioration: physiology, repair and assessment. Seed Sci. Tech. 27, 177-237.

Murungu, F.S., Chiduza, C., Nyamugafata, P., Lark, L.J., Whalley, W.R., Finch-Savage, W.E., 2004. Effects of on- farm seed priming on consecutive daily sowing occasions on the emergence and growth of maize in semi-arid Zimbabwe. Field Crops Res. 89, 49-57.

Patanè, C., Cavallaro, V., D'Agosta, G., Cosentino, S.L., 2008. Plant emergence of PEG-osmoprimed seeds under suboptimal temperatures in two cultivars of sweet sorghum differing in seed tannin content. J. Agron. Crop Sci. 194, 304-309.

Podlaski, S., Chrobak, Z., Wyszkowska, Z., 2003.Effect of parsley seed treatment on root yield. Plant Soil Environ. 49, 213-2-17.

Rajasekaran, L.R., Stiles, A., Caldwell, C.D., 2002. Stand establishment in processing carrots: effects of various temperature regimes on germination and the role of salicylates in promoting germination at low temperatures. Canadian J. Plant Sci. 82, 443-50.

Ramamurthy, V., Gajbhiye, S., Venugopalan, M.V., Parhad, V.N., 2005. On-farm evaluation of seed priming technology in sorghum (*Sorghum bicolor* L.). Agric. Trop. Subtrop. 38, 34-41.

Rashid, A., Harris, D., Hollington, P.A., Khattak, R.A., 2002. On-farm seed priming: A key technology for improving the livelihood of resource poor farmers on saline lands. Centre for Arid Zone Studies, University of Wales, UK, 82, 109-115.

Rotundo, J., Westgate, M.E., 2009.Meta-analysis of environmental effects on soybean seed composition. Field Crops Res. 110, 147-156.

Shakirova, F.M., Sakhabutdinova, A.R., Bezrukova, M.V., Fatkhutdinova, R.A., Fatkhutdinova, D.R., 2003. Changes in the hormonal status of wheat seedlings induced by salicylic acid and salinity. Plant Sci. 164, 317-22.

Simon, E.W., 1984. Early events in germination. In Seed physiology, vol. 2: Germination and reserve mobilization, edited by D.R. Murray, 77-115. Orlando, FL: Academic Press.

Soltani, A., Galeshi, S., 2002.Importance of rapid canopy closure for wheat production in a temperate sub-humid environment: Experimentaion and simulation. Field Crops Res. 77, 17-30.

Soltani, A., Galeshi, S., Zeinali, E., Latifi, N., 2001.Genetic variation for and interrelationships among seed vigor traits in wheat from the Caspian Sea coasts of Iran. Seed Sci. Tech. 29, 653-662.

Soltani, E., Farzaneh, S., 2014.Hydrotime analysis for determination of seed vigour in cotton. Seed Sci. Tech. 42, 260-273.

Soltani, E., Galeshi, S., Kamkar, B., Akramghaderi, F., 2008. Modeling seed aging effects on response of germination to temperature in wheat. Seed Sci. Biotech. 2, 32-36.

Soltani, E.,Galeshi, S., Kamkar, B., Akramghaderi, F., 2009.The effect of seed aging on seedling growth as affected by environmental factors in wheat. Res. J. Environ. Sci. 3, 184-192.

Srinivasan, K., Saxena, S., Singh, B.B., 1999. Osmo- and hydropriming of mustard seeds to improve vigour and some biochemical activities. Seed Sci. Tech. 27, 785-793.

Taylor, A.G., Allen, P.S., Bennet, M.A., Bradford, K.J., Burris, J.S., Misra, M.K., 1998. Seed enhancements. Seed Sci. Res. 8, 245-256.

Thakare, U., Patil, N., Malpathak, N., 2011. Performance of chickpea under the influence of gibberellic acid and oxygenated peptone during germination. Adv. Biosci. Biotechnol. 2, 40-45.

Varier, A., Vari, A.K., Dadlani, M., 2010.The subcellular basis of seed priming. Curr. Sci. 99, 450-456.