International Journal of Bio-resource and Stress Management 2013, 4(4):475-481

Vegetable Seed Priming: a Low Cost, Simple and Powerful Techniques for Farmers' Livelihood

Ratikanta Maiti[1*] and Kalipada Pramanik[2]

[1]Universidad de las Americas-Puebla, Santa Catarina Martir, Cholua C:P:72 820, Puebla, Mexico
[2]Institute of Agriculture, Visva-Bharati, Sriniketan, West Bengal (731 236), India

Article History

Manuscript No. 413
Received in 6th July, 2013
Received in revised form 6th September, 2013
Accepted in final form 6th December, 2013

Correspondence to

*E-mail: ratikanta.maiti@gmail.com

Keywords

Seed priming, vegetable, seedling emergence, vigour, yield

Abstract

Seed priming is a simple, low-cost, low-risk intervention and powerful technique for improve seedling emergence, seedling vigour and yields of several field crops. There exist different priming techniques viz. Hydro-priming, Halo-priming, Osmo-priming and solid matrix priming. On-farm priming has been practiced on maize, rice wheat and other field crops as well as vegetable crops with success. With respect to vegetable crops, priming techniques have been adopted to study their effect on seedling vigor and agronomic traits including yield of tomato, chilli, cucumber and cabbage. It was observed that few priming technique improved seedling emergence percent, seedling vigor as well as agronomic traits including yield of the crop species although varying among species. It is clearly observed that in all the crops studied the priming techniques improved growth and yield of all the crops although the cultivars showed variation in responses to different treatments. In almost all the cases seedling vigor improves and the agronomic traits.

1. Introduction

Seed may be defined as fertilized matured ovule consisting of an embryo, stored food material and it is surrounded by a protective coats. As per Indian Seed Act (1966), vegetative propagules like tubers (potato), rhizomes (turmeric) roots, bulbs (onion), setts (sugarcane), vine cuttings (sweet potato), root slips (Lucerne), all types of grafts and other vegetative propagules are also known as seed. Seed is a carrier of new technology and the basic input in agriculture upon which other inputs are applied. Agricultural practices begin and ending with seed. So, high quality seed is the key mandatory to successful agriculture. A good energetic seed utilizes all the resources and realized a realistic out put to the grower. It is wealth to the farmer, it is the yesterday's harvest and tomorrows hope. Good seed in good soil realize good yield. Modern high-tech agriculture with its modern technology demands that each and every seed material should readily germinate and produce a vigourous seedling for ensuring high marketable yield. Uniformity of growth and synchronous development are extremely desirable parameters for modern mechanized crop production. So, genetically pure and morphologically sound, pathologically diseases free and physiologically healthy seed is capable of increasing the productivity and fulfilled today's need and secured food supply for the coming day.

So, the essential prerequisites for optimum stand establishment are rapid and uniform field emergence under all environmental conditions and to increase yield, quality of crops. Uniformity and increased seedling emergence of direct-seeded crops have major impact on final yield and quality (Gupta et al., 2008). It is reported that seed priming is one of the most important developments to help rapid and uniform germination and emergence of seeds and to increase seed tolerance to adverse environmental conditions (Heydecker et al., 1973, 1975; Harris et al., 1999).

Seed priming is a pre-sowing method for improving germination, for the purpose of reducing the time from sowing to emergence, while improving emergence uniformity (Brocklehurst and Dearman, 1983) and finally to improve stand establishment (Gupta et al., 2008). Priming could be defined as controlling the hydration level within seeds so that the metabolic activity necessary for germination can occur but radicle emergence is prevented. Different physiological activities within the seed occur at different moisture levels (Leopold and Vertucci, 1989; Taylor, 1997). The last physiological activity in the germination process is radicle emergence. Prior to radicle emergence, the seed is considered desiccation tolerant, thus the primed seed moisture content can be decreased by drying. After drying, primed seeds can be stored untill time of sowing. The mechanism of seed drying after chemical priming is known as the hydration-dehydration process or dry back and is used to reduce the degree of moisture in seeds to levels compatible with storage and maintaining the beneficial effects of the treatment, without quality loss caused by rapid seed deterioration.

Poor crop stand establishment is one of the major abiotic constraints encountered by resource-poor farmers in marginal and sub-marginal areas particularly in developing and under developing countries. There are so many reasons like low quality seed, inadequate seedbed preparation, untimely sowing, poor sowing technique; abiotic stresses such as drought, high and temperature, salinity, and adverse soil properties (e.g. crusting) etc. Effective amelioration of these physical constraints is often beyond the means of resource-poor farmers in areas. Seed priming is one the means by which some of these constraints can be alleviate efficiently. It is a simple, low-cost, low-risk intervention that can be a useful technology for farmers and make a positive impact on farmers' livelihoods by increasing the rate of crop emergence, increasing rates of crop development, reducing crop duration and increasing production as well as productivity.

1.1. Benefits of priming

Direct benefits of seed priming are as follows:

(a) overcome or alleviate phytochrome-induced dormancy
(b) reducing the germination time
(c) to increase the rate of germination at any particular temperature
(d) faster emergence before soil crusting becomes fully detrimental
(e) improving emergence uniformity
(f) better and more uniform stands,
(g) less need to re-sow,
(h) more vigourous plants,
(i) better drought tolerance,
(j) Improves the resistance towards temperature stress
(k) earlier flowering and
(l) higher grain yield.

Indirect benefits of seed priming are as follows:

(a) earlier sowing of crops,
(b) enhance earlier harvesting of crops
(c) crops can compete more effectively with weeds,
(d) to eliminate or greatly reduce the amount of seed-borne fungi and bacteria
(e) increased willingness to use of fertilizer because of reduce risk of crop failure
(f) Increases the shelf life of seed
(g) Highly suitable for small seeds

1.2. Priming methods

Several different priming methods have been reported to be used commercially. They are as follows:

(a) Hydro-priming (use of water double the volume of seed)
(b) Halo-priming (use of salt solution-KNO_3, NaCl)
(c) Osmo priming (use of osmotic solution-PEG)
(d) Sand matric priming-(use of moist sand)

1.2.1. Hydro-priming

Hydro-priming (henceforth referred to as priming) is a simple low-cost method of seed priming that requires no sophisticated equipment and gives results which are easy to see (Foti et al., 2008). Nagar et al. (1998) observed a significant improvement in field emergency and seedling characteristics after hydro-priming maize for 16 hours. In a series of experiments, Harris et al. (1999) showed that hydro-priming greatly improved establishment and vigour of upland rice, maize and chickpea, and resulted in faster development, earlier flowering and maturity and higher yields. This simple, low-cost, low-risk intervention also had positive impacts on the wider farming system and livelihoods and the technology proved highly popular with farmers (Harris et al., 1999 and Harris et al., 2001). In this method, seeds are submerged in water with or without aeration. Therefore, water is freely available to seeds, its uptake only being governed by the affinity of the seed tissue for water (Taylor et al., 1998).

Drawback

(i) In this method, seed germination can proceed until radicle protrusion. So, the process needs to be stopped at a precise moment

(ii) Seeds are not equally hydrated, which results in a non-uniform activation of the physiological processes.

To overcome the drawback, drum priming is used for Hydro-priming, where seed water uptake can be regulated. In drum priming the seed is slowly spun in a rotating drum in which nebulized water is injected. The drum is linked to an electronic scale continuously monitoring the weight, thus the level of hydration. The process is stopped when the level of hydration set for a specific seed lot is reached (Rowse, 1996; Warren and Bennett, 1997). Drum priming consists of four stages: i) calibration necessary to determine the desired level of hydration of the seed; ii) hydration, consisting in the addition of water at different times; iii) incubation, where the seed keeps the level of hydration acquired during the priming process; iv) drying-back, where the hydrated seed is brought back to the pre-treatment moisture (Rowse, 1996). This method allows the treatment of large quantities of seed, but the most difficult step is the calibration, which is necessary to determine the right amount of water required to hydrate the seed.

1.2.2. Halo-priming

Pre-sowing seed treatment with inorganic salts is known as Halo-priming. It is an easy, low cost and low risk technique and an alternative approach to overcome the salinity problem in agricultural lands. It has been shown to improve germination and plant establishment under saline condition in different plants (Haigh and Barlo, 1987; Asharf and Rauf, 2001; Sivritepe et al., 2003). Generally salts which are used for Halo-priming are calcium chloride ($CaCl_2$), potassium chloride (KCl), Sodium chloride (NaCl), sodium nitrate ($NaNO_3$), manganese sulphate ($MnSO_4$), magnesium chloride ($MgCl_2$) and particularly potassium nitrate (KNO_3) for vegetable seed priming (Alvarado et al., 1987; Haigh and Barlow, 1987; Tiryaki and Buyukcingil, 2009). The accumulation of salts in the seed could decide toxicity (Bradford, 1995), reduce the osmotic potential and induce a high water absorption during treatment (Parera and Cantliffe, 1994), resulting in a more likely radicle protrusion.

1.2.3. Osmotic priming

Osmotic priming (Osmo-priming) is the process that involves the use of osmotic solutions with a low water potential to control water uptake by seed. The most common substances used for Osmo-priming are polyethylene glycol (PEG), mannitol and glycerol. PEG as an inert material can prevent embryo toxicity problems during priming (Cantliffe, 1983). The large size of PEG molecule (6000 to 8000 mw) also prevents its penetration into seed tissues, avoiding lowering the osmotic potential (Michel and Kaufman 1973; Brocklehurst and Dearman, 1984). The major disadvantage resulting from the use of PEG is the reduction of oxygen in the solution, because of its viscosity (Mexal et al., 1975); aerating the solution during PEG Osmo-priming can overcome this problem (Akers, 1990; Bujalski and Nienow, 1991). The difference in the response of different species to PEG may be due to a selective semi-permeable layer that surrounds the embryo. When selective semi-permeable layer is present, it allows the absorption of water, but prevents salt diffusion; when it is absent, ions can be absorbed and cause embryo damages (Welbaum et al., 1998). For example, tomato (*Solanum lycopersicum* L.), melon (*Cucumis melo* L.), lettuce (*Lactuca sativa* L.) and *Capsicum annuum* seeds possess this layer and may be safely subjected to Osmo-priming (Welbaum and Bradford, 1990; Taylor et al., 1997). On the contrary, this treatments is harmful to broccoli and cabbage seeds (*Brassica oleracea* L.), which lack this layer (Taylor et al., 1997).

1.2.4. Solid matrix priming

Solid matrix priming (SMP) involves the use of a wet organic or inorganic material (Parera and Cantliffe 1994), which simulates the natural imbibition processes taking place in the soil (McDonald, 2000). The substrate must possess the following characteristics like low matric potential; high seed safety; high specific surface; negligible water solubility; high adhesiveness to seed surface; high capacity to retain water (Khan, 1991). The substrates which are used as SMP are peat or vermiculite, or some commercial substrates such as Celite or Micro-cel. In order to improve the control of imbibition, pure water may be replaced by an osmotic solution, as in osmotic priming (Khan, 1991).

2. Materials and Methods

The priming techniques were followed and for all the vegetable seeds. There was a control treatment (without treatment) at the same date for each vegetable crop.

2.1. Tomato

Seeds of 6 tomato hybrids were used for priming. The experiment was conducted in small size plastic pots for each hybrid. The experiment consisted of six treatments and was replicated thrice. The treatments were as follows:

T_1=Control (without water soaking)

T_2=Hydro-priming-1 (Soaking of seeds in water for 10 hours)

T_3=Hydro-priming-2 (Soaking of seeds in water for 20 hours)

T_4=Halo-priming-1 (Soaking of seeds in 3% KNO_3 solution for 5 days)

T_5=Halo-priming-2 (Soaking of seeds in 3% KNO_3 solution for 7 days)

T_6=Osmo-priming (Soaking of seeds in polyethylene glycol (-1.0 MPa) solution for 7 days)

2.1.1. Hydro-priming

Soaking the seeds in water (submerged) for T_2: 10 hours and for T_3: 20 hours. Afterwards drain the excess water from soaked seed. Then the seeds were allowed to dry back to their original moisture content under the shade for 4-5 days for getting original moisture content.

2.1.2. Halo-priming

Soaking the seeds in 3% KNO_3 (30 g of soaking the seeds in 1 litre water) for T_4: 5 days and for T_5: 7 days and then drain the excess water from seeds and the seeds were allowed to dry back to their original moisture content under the shade for 4-5 days for getting original moisture content.

2.1.3. Osmo-priming

Soaking the seeds in-1 MP of polyethylene glycol (PEG, 6000) solution for 1 week. For making-1 MP of PEG (6000) solution, 273 g of PEG (6000) will be dissolved in 1 litre of water. After one of seed soaking, drain the water from seeds and drying the seeds in shade for 4-5 days for getting original moisture content.

2.2. Water melon

2.2.1. Hydro-priming

Soaking the seeds in water (submerged) for 36 hours. Afterwards drain the excess water from soaked seed. Then the seeds were allowed to dry back to their original moisture content under the shade for 4-5 days for getting original moisture content.

2.2.2. Halo-priming

Soaking the seeds in 3% KNO_3 (30 g of soaking the seeds in 1 litre water) for 36 hours and then drain the excess water from seeds and the seeds were allowed to dry back to their original moisture content under the shade for 4-5 days for getting original moisture content.

2.2.3. Osmo-priming

Soaking the seeds in-1 MP of polyethylene glycol (PEG, 6000) solution for 1 week. For making-1 MP of PEG (6000) solution, 273 g of PEG (6000) will be dissolved in 1 litre of water. After one of seed soaking, drain the water from seeds and drying the seeds in shade for 4-5 days for getting original moisture content.

2.3. Cucumber

The experiment was conducted in small size plastic pots for each hybrid. The experiment consisted of six treatments and was replicated thrice. The treatments were as follows:

T_1=Control (without water soaking)
T_2=Hydro-priming-1 (Soaking of seeds in water for 10 hours)
T_3=Hydro-priming-2 (Soaking of seeds in water for 16 hours)
T_4=Halo-priming-1 (Soaking of seeds in 3% KNO_3 solution for 10 days)
T_5=Halo-priming-2 (Soaking of seeds in 3% KNO_3 solution for 16 days)
T_6=Osmo-priming (Soaking of seeds in polyethylene glycol (-1.0 MPa) solution for 7 days)

2.3.1. Hydro-priming

Soaking the seeds in water (submerged) for T_2: 10 hours and for T_3: 16 hours. Afterwards drain the excess water from soaked seed. Then the seeds were allowed to dry back to their original moisture content under the shade for 4-5 days for getting original moisture content.

2.3.2. Halo-priming

Soaking the seeds in 3% KNO_3 (30 g of soaking the seeds in 1 litre water) for T_4: 10 days and for T_5: 16 days and then drain the excess water from seeds and the seeds were allowed to dry back to their original moisture content under the shade for 4-5 days for getting original moisture content.

2.3.3. Osmo-priming

Soaking the seeds in 1 MP of polyethylene glycol (PEG, 6000) solution for 1 week. For making-1 MP of PEG (6000) solution, 273 g of PEG (6000) will be dissolved in 1 litre of water. After one of seed soaking, drain the water from seeds and drying the seeds in shade for 4-5 days for getting original moisture content.

2.4. Chilli

The experiment was conducted in small size plastic pots for each hybrid. The experiment consisted of six treatments and was replicated thrice. The treatments were as follows:

T_1=Control (without water soaking)
T_2=Hydro-priming-1 (Soaking of seeds in water for 15 hours)
T_3=Hydro-priming-2 (Soaking of seeds in water for 30 hours)
T_4=Halo-priming-1 (Soaking of seeds in 3% KNO_3 solution for 5 days)
T_5=Halo-priming-2 (Soaking of seeds in 3% KNO_3 solution for 7 days)
T_6=Osmo-priming (Soaking of seeds in polyethylene glycol (-1.0 MPa) solution for 7 days)

2.4.1. Hydro-priming

Soaking the seeds in water (submerged) for T_2: 15 hours and for T_3: 30 hours. Afterwards drain the excess water from soaked seed. Then the seeds were allowed to dry back to their original moisture content under the shade for 4-5 days for getting original moisture content.

2.4.2. Halo-priming

Soaking the seeds in 3% KNO_3 (30 g of soaking the seeds in 1 litre water) for T_4: 5 days and for T_5: 7 days and then drain the excess water from seeds and the seeds were allowed to dry back to their original moisture content under the shade for 4-5 days for getting original moisture content.

2.4.3. Osmo-priming

Soaking the seeds in-1 MP of polyethylene glycol (PEG, 6000) solution for 1 week. For making -1 MP of PEG (6000) solution, 273 g of PEG (6000) will be dissolved in 1 litre of water. After one of seed soaking, drain the water from seeds and drying the seeds in shade for 4-5 days for getting original moisture content.

2.5. Cabbage

The experiment was conducted in small size plastic pots for each hybrid. The experiment consisted of four treatments and was replicated thrice. The treatments were as follows:

T_1=Control (without water soaking)

T_2=Hydro-priming-1 (Soaking of seeds in water for 16 hours)

T_3=Halo-priming-1 (Soaking of seeds in 3% KNO_3 solution for 10 days)

T_4=Halo-priming-2 (Soaking of seeds in 3% KNO_3 solution for 16 days)

2.5.1. Hydro-priming

Soaking the seeds in water (submerged) for T_2: 16 hours. Afterwards drain the excess water from soaked seed. Then the seeds were allowed to dry back to their original moisture content under the shade for 4-5 days for getting original moisture content.

2.5.2. Halo-priming

Soaking the seeds in 3% KNO_3 (30 g of soaking the seeds in 1 litre water) for T_4: 10 days and for T_5: 16 days and then drain the excess water from seeds and the seeds were allowed to dry back to their original moisture content under the shade for 4-5 days for getting original moisture content.

2.6. Ridge gourd and sponge gourd

Halo-priming

Soaking the seeds in 3% KNO_3 (30 g of soaking the seeds in 1 litre water) for 36 hours and then drain the water from seeds and the seeds were allowed to dry back to their original moisture content under the shade for 4-5 days.

2.7. Bitter gourd

Halo-priming

Soaking the seeds in 3% KNO_3 (30 g of soaking the seeds in 1 litre water) for 48 hours and then drain the water from seeds and the seeds were allowed to dry back to their original moisture content under the shade for 4-5 days.

2.8. Bottle gourd

2.8.1. Hydro-priming

Soaking the seeds in water (submerged) for 36 hours. Afterwards drain the excess water from soaked seed. Then the seeds were allowed to dry back to their original moisture content under the shade for 4-5 days for getting original moisture content.

2.8.2. Halo-priming

Soaking the seeds in 3% KNO_3 (30 g of soaking the seeds in 1 litre water) for 36 hours and then drain the excess water from seeds and the seeds were allowed to dry back to their original moisture content under the shade for 4-5 days for getting original moisture content.

3. Results and Discussion

3.1. Tomato

The results showed that emergence percentage was greater in Halo-priming-2 treatment. With respect to root length, the responses varied in different hybrids and treatments. It was observed that priming treatments improved seedling vigour markedly as illustrated in Plate 1 as well as yield in Plate 2. In general, both Hydro-priming and Halo-priming treatments had favorable responses with respect to agronomic traits specially yield, as shown in Plate 2.

3.2. Water melon

Results showed that priming treatments increased the seedling emergence (%), seedling vigour and plant height over no priming. Whereas, haloprimed seeded plant recorded greater the fruit size of the water melon than other priming treatments.

3.3. Cucumber

Priming treatments showed beneficial effects of some agronomic variables such as plant height, number of leaves, early fruiting, and number of fruits. Plate 3 describes the effect of different priming treatments on seedling vigour and agronomic traits in the cucumber hybrid Salad with respect to the control.

Control | Hydro-priming-1 | Hydro-priming-2 | Halo-priming-1 | Halo-priming-2 | Osmo-priming

Plate 1: Effect of priming on tomato (syno) seedling vigour

Control | Hydro-priming-2 (20 Hrs in Water) | Halo-priming-2 (7 Days in 3% KNO_3)

Control | Hydro-priming-1 (10 Hrs in Water) | Hydro-priming-2 (20 Hrs in Water)

Plate 2: Effect of priming treatments on yield of tomato (syno above and Lyco below)

3.4. Chilli

The results showed that priming treatments improved agronomic traits as well as days to flowering and fruiting were earlier than the control. Hydro-priming-1 gave about 67% increase in yield with respect to control. Plate 4 describes the plant growth characteristics in the chilli hybrid Spicy subjected to Hydro-priming treatment with respect to the control.

3.5. Cabbage

The response of cabbage to different priming treatments were distinctly significant. Priming treatments showed beneficial effects of some agronomic variables such as emergence percentage, plant height, number of leaves, and leaf length.

Control Hydro-priming-1 Hydro-priming-2 Halo-priming-1 Halo-priming-2 Osmo-priming

Control Hydro-priming-2 (16 hrs in Water) Halo-priming-1 (10 hrs in 3% KNO$_3$) Halo-priming-2 (16 hrs in 3% KNO$_3$)

Plate 3: Effect of Hydro-priming on seedling vigour (upper panel) and agronomic traits (lower panel) in the cucumber hybrid Salad compared to the control

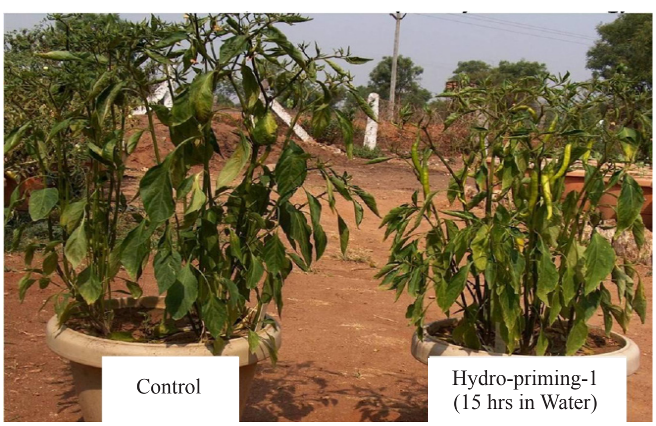

Plate 4: Effect of Hydro-priming on plant growth characteristics of the chilli hybrid Spicy

Control Hydro-priming-1 Hydro-priming-2 Halo-priming-1 Halo-priming-2 Osmo-priming

Control Hydro-priming-1 (10 hrs in Water) Halo-priming-1 (10 hrs in 3% KNO$_3$) Halo-priming-2 (16 hrs in 3% KNO$_3$)

Plate 5: Effect of Hydro-priming on seedling vigour (upper panel) and agronomic traits (lower panel) in the cabbage hybrid Accenta

Plate 5 describes the effect of different priming treatments on seedling vigour and agronomic traits in the cabbage hybrid Salad with respect to control.

3.6. Ridge gourd and sponge gourd

Results showed that priming treatments increased the seedling emergence (%), seedling vigour and plant height over no priming. Haloprimed seeded plant also recorded earlier flowering over the other priming treatments.

3.7. Bitter gourd and bottle gourd

Similar results were showed in case of bitter gourd. Priming treatments increased the seedling emergence (%), seedling vigour and plant height over no priming. Haloprimed seeded plant also recorded earlier flowering over the other priming treatments.

4. Conclusion

A comparative study on the effects of priming techniques showed that in all the crops studied the priming techniques improved growth and yield of all the crops although the different cultivars showed variation in responses to different treatments. In almost all the cases seedling vigour improves and the agronomic traits specially yield with priming. So, we can say, seed priming is a simple, low-cost, low-risk intervention that can be a useful technology for farmers and make a positive impact on farmers' livelihoods by increasing the rate of crop emergence, increasing rates of crop development, reducing crop duration and increasing production as well as productivity.

5. References

Akers, S.W., 1990. Seed response to priming in aerated solutions. Search 19, 8-17.

Alvarado, A.D., Bradford, K.J., Hewitt, J.D., 1987. Osmotic priming of tomato seeds: effects on germination, field emergence, seedling growth, and fruit yield. Journal of the American Society for Horticultural Science 112, 427-432.

Ashraf, M., Rauf, H., 2001. Inducing salt tolerance in maize (*Zea mays* L.) through seed priming with chloride salts: Growth and ion transport at early growth stages. Acta Physiologiae Plantarum 23, 407-417.

Bradford, K.J., 1995. Water relations in seed germination. In: Kigel, J., Galili, G. (Eds.), Seed Development and Germination. Marcel Dekker, Inc., New York, NY, USA, 351-396.

Brocklehurst, P.A., Dearman, J., 1983. Interactions between seed priming treatments and nine seed lots of carrots, celery and onion. Annals of Applied Biology 102, 577-584.

Brocklehurst, P.A., Dearman, J., 1984. A comparison of different chemicals for osmotic treatments of vegetable seed. Annals of Applied Biology 105, 391-398.

Bujalski, W., Nienow, A.W., 1991. Large-scale osmotic priming of onion seeds: a comparison of different strategies for oxygenation. Scientia Horticulturae 46, 13-24.

Cantliffe, D.J., 1983. Sowing primed seed. American Vegetable Grower 31, 42-43.

Foti, R., Abureni, K., Tigere, A., Gotosa, J., Gere, J., 2008. The efficacy of different seed priming osmotica on the establishment of maize (*Zea mays* L.) caryopses, Journal of Arid Environments 72, 1127-1130.

Gupta, A., Kumar, A., Roy, M., Naseem, M., Choudhury, V.K., Maiti, R.K., 2008. Seed Priming: Internal Journal of Agriculture, Environment and Biotechnology 1(4), 199-209.

Haigh, A.M., Barlow, E.W.R., 1987. Germination and priming of tomato, carrot, onion and sorghum seeds in a range of osmotica. Journal of the American Society for Horticultural Science 112, 202-208.

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

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

Heydecker, W., Higgins, J., Turner, Y.J., 1975, Invigoration of seeds? Seed Science and Technology 3(3/4), 881-888.

Heydecker, W., Higgins, J., Gulliver, R.L., 1973. Accelerated germination by osmotic seed treatment. Nature 246, 42-44.

Khan, A.A., 1991. Preplant physiological seed conditioning. Horticultural Reviews 13, 131-181.

Leopold, A.C.C.W., Vertucci, 1989. Moisture as a regulator of physiological reactions in seeds. In: Seed Moisture, eds. P.C. Stanwood and M.B. McDonald. CSSA Special Publication Number 14. Madison, WI: Crop Science Society of America, 51-69.

McDonald, M.B., 2000. Seed priming. In: Black, M., Bewley, J.D. (Eds.), Seed technology and its biological basis. Sheffield Academic Press, Sheffield, UK, 287-325.

Mexal, J., Fisher, J.T., Osteryoung, J., Reid, C.P., 1975. Oxygen availability in polyethylene glycol solutions and its implications in plant-water relations. Plant Physiology 55, 20-24.

Michel, B.E., Kauffmann, M.R.,1973. The Osmotic Potential of Polyethylene Glycol 6000. Plant Physiology 51, 914-916.

Nagar, R.P., Dadlan, M.I., Sharama, S.P., 1998. Effect of Hydro-priming on field emergence and crop growth of maize genotypes, Seed Research 26, 1-5.

Parera, C.A., Cantliffe, D.J., 1994. Presowing seed priming. Horticultural Reviews 16, 109-141.

Rowse, H.R., 1996. Drum priming. Seed Science and Technology 24, 281-294.

Sivritepe, N., Sivritepe, H.O., Eris, A., 2003. The effects of NaCl priming on salt tolerance in melon seedling grown under saline conditions. Scientia Holticuturae 97, 229-237.

Taylor, A.G., 1997. Seed storage, germination and quality. In: Wien, H.C. (Ed.), The Physiology of Vegetable Crops, Wallingford, U.K., CAB International, 1-36.

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

Taylor, A.G., Beresniewicz, M.M., Goffinet, M.C.,1997. Semipermeable layer in seeds. In: Ellis, R.H., Black, M., Murdoch, A.J., Hong, T.D. (Eds.), Basic and applied aspects of seeds biology. Kluwer Academic Publ., Dordrecht, The Netherlands, 429-436.

Tiryaki, I., Buyukcingil, Y., 2009. Seed priming combined with plant hor- mones: influence on germination and seedling emergence of sorghum at low temperature. Seed Science and Technology 37, 303-315.

Warren, J.M., Bennett, M.A., 1997. Seed hydration using the drum priming system. Hortscience 32, 1220-1221.

Welbaum, G.E., Shen, Z., Oluoch, M.O., Jett, L.M., 1998. The evolution and effects of priming vegetable seeds. Seed Technology 20, 209-235.

Welbaum, G.E., Bradford, K.J., 1990. Water relations of seed development and germination in muskmelon (*Cucumis melo* L.). IV. Characteristics of the perisperm during seed development. Plant Physiology 92, 1038-1045.

