Seed Priming Techniques

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Contributor: Françoise Corbineau , Nesrin Taskiran , Hayat El-Maarouf-Bouteau

Presoaking seeds in water (hydropriming) or in a solution, usually of polyethylene glycol (PEG) or various salts at low water potential (osmopriming), has been demonstrated to improve the germination of seeds of numerous species including vegetables (carrot, celery, leek, lettuce, tomato), floral plants (cyclamen, primrose, pansy) and others (sugar beet, rape, soybean, sunflower). This treatment allows the germination stricto sensu to occur but prevents the radicle protrusion. Germination of primed seeds is more rapid and uniform than that of unprimed ones. Primed seeds germinate in a wider range of temperatures and are less sensitive to oxygen deprivation. Interestingly, priming also improves the germination of aged seeds.

seed quality hydropriming osmopriming

1. Introduction

Successful stand establishment requires high-quality seeds, i.e., seeds that (1) all germinate, (2) germinate quickly and simultaneously, (3) give rise to normal and vigorous seedlings, (4) display low sensitivity to external factors (temperature, oxygen availability, water potential of the soil) and lastly, (5) germinate in a wide range of environmental conditions [1][2][3][4][5]. It is well known that acquisition of seed quality occurs during seed development and the maturation phase [6], and that seed quality can be improved by breeding and selection, two fundamental approaches. For example, quantitative trait loci (QTLs) related to germination rate have been detected in sunflower, rape and *Medicago truncatula* seeds [7][8][9][10]. Seed companies may also enhance seed quality at different steps of the seed production, by improving the methods of harvest but often by post-harvest treatments such as cleaning, sorting, coating, priming and controlling the storage conditions [1][11][12][13]. The treatments can be grouped in 3 groups: (1) conditioning (cleaning, purification, fractionation using size and density grading, color sorting, polishing and scarification), (2) seed protection by applying active compounds (fungicides and/or insecticides) and (3) seed invigoration, also called physiological enhancement, such as priming. Three mains strategies are used for improving seed quality by the priming technology [1][3][4][11][12][13]: seed hydration with water for various durations (hydropriming); submersion in solutions of osmotica (osmopriming); mixing seeds with moist solid particle materials (matrix priming).

2. Main Conventional Seed Priming Techniques

Seed priming, a technique now used commercially, has been demonstrated to improve the germination of seeds of numerous vegetable plants (leek, tomato, pepper, onion and carrot) [1][14][15][16][17][18][19] and the production of potted or bedding ornamental plants such as cyclamen, begonia, pansy and primrose, as well as for large volume of field crops such as sugar beet and turf grasses [1][3][4][20].

Hydropriming is a simple technique in which seeds are immersed in water for a specific period that does not allow radicle protrusion and permits seeds to dry back to their initial water content. However, it is difficult to avoid the radicle growth since hydropriming is a non-controlled water uptake [21]. Drum priming is a key technique that allows a controlled increase in water uptake and seed imbibition during the treatment by regularly measuring seed mass and the volume of water required to control seed hydration [22][23].

Osmopriming corresponds to seed submersion with aerated solutions of low water potential (usually −1.0 to −2.0 MPa): polyethylene-glycol (PEG), mannitol and sorbitol or different salts ($NaNO_3$, $MgCl_2$, KH_2PO_4, $KH(PO_4)_2$, K_3PO_4, KCl, KNO_3, $Ca(NO_3)_2$) [1][3][4][24][25]. The duration of priming depends on the species and varies from 1–2 days (lettuce, rice, sorghum) up to 5–7 days (tomato, sugar beet), 7–10 days (cauliflower, carrot, fennel, primrose, pansy) or 14 days (celery, leek). The seed industry generally dries back primed seeds before storage and sowing.

Figure 1 illustrates the priming process as related to water content and some metabolic changes [5][25][26][27]. Priming (hydro- or osmopriming) consists of partial hydration of the seed population, allowing the phase II of germination sensu stricto to occur but preventing the radicle emergence (phase III, growth) associated with the loss of desiccation tolerance. The seed moisture content (MC) is maintained during the priming treatment at 40–45% of the fresh weight basis which corresponds to an MC at about 90–95% that allows radicle emergence [1][3][4][24][25]. Treated seeds are redried to their initial moisture content and stored before sowing. During the imbibition phase, controlled water uptake allows the protein synthesis and induces respiration activity. Phase II, called “pregermination” or “activation”, is associated with several metabolic processes including protein synthesis, respiration, metabolism of sugar, etc. Seeds are then dehydrated in order to postpone seed sowing.

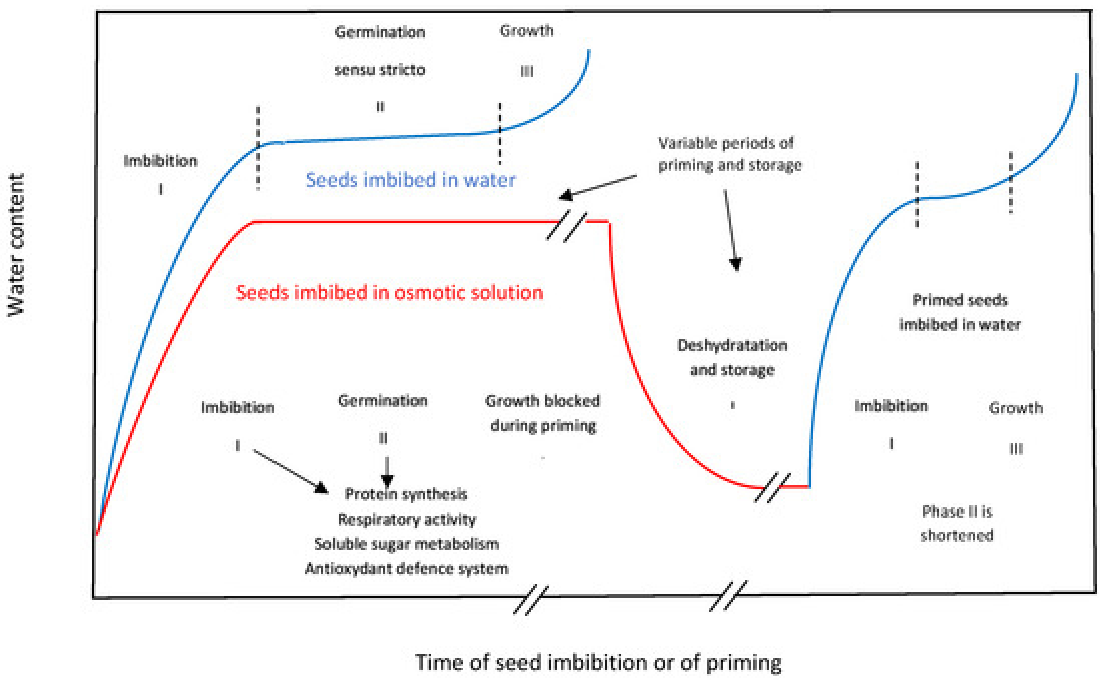

Figure 1. Seed priming process as related to seed water content. Priming consists of partial seed imbibition to a point where germination (phase II, germination sensu stricto) occurs but is not completed by radicle growth. The moisture content of the seeds is maintained during priming at 40–45% fresh weight basis, corresponding to about 90–95% of the moisture content that allow radicle growth. During phase I (imbibition), controlled water uptake allows protein synthesis and induces respiratory activity. Phase II is associated to various physiological, biochemical and molecular activities such as protein synthesis, respiratory activity, metabolism of soluble sugars and repair processes, but the radicle emergence is prevented. In seed company, seeds are dehydrated after priming and stored in order to postpone seed sowing. After sowing, primed seed germination rate is improved and phase II is shortened. “//” indicates a change in the x-axis scale depending on the duration of priming or the duration of storage of primed seeds.

Nanopriming and biopriming are advanced methods that have shown promising beneficial effects in agriculture. The nanoagents are silver and zinc oxide nanoparticles [28], and biopriming integrates biological aspects by inoculating seeds with beneficial microorganisms controlling seed-borne pathogens and biological treatment corresponding to partial seed imbibition [26][29].

3. Beneficial Effects of Priming

3.1. Seed Sensitivity to Temperature and Oxygen

Priming strongly improves the subsequent germination of seeds in water in a wide range of temperatures (**Figure 2**). For example, without priming, leek seeds germinate only in a narrow range of temperatures (10–20 °C), the thermal optimum being 15–20 °C, while they germinate easily between 5 and 40 °C after osmopriming (**Figure 2**) [19][30]. Osmoprimed tomato seeds germinate in higher percentages at 35 °C than unprimed ones and are able to germinate at 10 °C, whereas control seeds do not germinate at low temperatures (**Figure 2**) [31][32][33]. After osmopriming, the germination of carrot seeds is improved at low temperatures (5–10 °C) (**Figure 2**) [15][16][30], i.e., when sowing occurs early in spring. In case of a mixture of seeds from various genotypes, **Figure 3** shows that priming could homogenize the germination of *Primula* seeds from genotypes with blue, carmine and yellow flowers, which is a good tool to produce seedlings in greenhouse conditions and reduced time due to the manual planting out of seedlings in order to obtain homogeneous and simultaneous development.

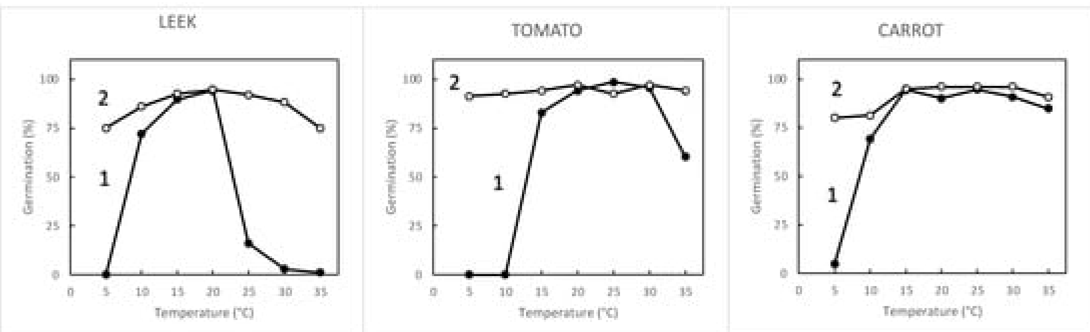

Figure 2. Effects of temperature on the germination percentages obtained after 7 days with unprimed seeds (1) and primed seeds (2) of leek, tomato and carrot. 1, control non-primed seeds; 2, seeds pretreated for 14 days (leek), 9 days (carrot) and 7 days (tomato) at 15 °C in the presence of a solution of polyethylene glycol at −1.0 MPa (tomato) or −1.5 MPa (leek, carrot). Means of 4 replicates of 50 seeds. Modified from [2][19][31][33].

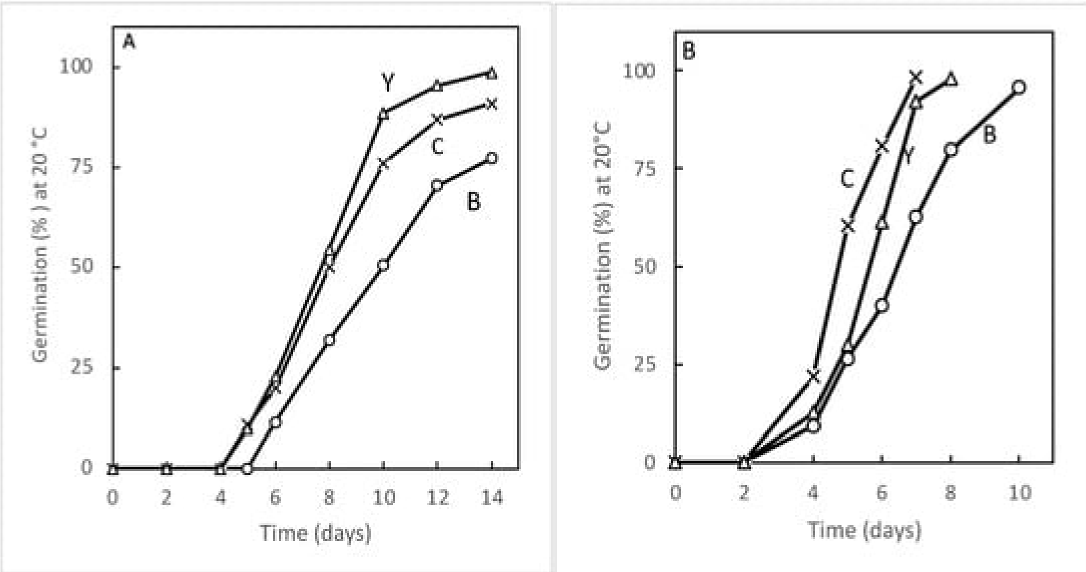

Figure 3. Germination at 20 °C of *Primula* seeds from genotype with blue (B), carmine (C) and yellow (Y) flowers. (**A**), seeds non-primed; (**B**), seeds primed on PEG solutions. Means of 4 replicates of 50 seeds. From Corbineau (unpublished data).

Primed seeds are also less sensitive to oxygen deprivation than control unprimed ones [2][19][31][33][34][35][36]. **Table 1** shows that primed seeds of carrot, Lamb's lettuce, leek, sunflower and tomato germinate faster and in higher percentages in low oxygen concentrations (5–15%) than non-primed seeds.

Table 1. Effect of priming on seed sensitivity to oxygen tension. Seeds are not primed or are osmoprimed for 7 days at 15 °C in the presence of PEG-8000 solution at −1 MPa (tomato, lamb's lettuce), 5 days at 15 °C with PEG-8000 solution at −2 MPa (sunflower), 9 days (carrot) and 14 days (leek) at 15 °C in the presence of PEG-8000 solution at −1.5 MPa. Germination percentages are counted after 4 days at 20 °C (carrot, leek, lamb's lettuce), after 2 days (tomato) or 4 days (sunflower) at 25 °C. Means of four replicates. Modified from [17][19][31][33][34][35][36].

Species	Seed Treatment	Germination (%) in Atmosphere Containing 1 to 21% Oxygen					
		1%	3%	5%	10%	15%	21%
Carrot [36]	Non-primed Primed	0 0	0 5.5	0 34.6	13.1 78.5	23.0 84.6	70.0 94.1
Lamb's lettuce [17][33]	Non-primed Primed	0 0	0 4.4	4.2 23.0	5.3 92.2	10.5 97.5	51.1 98.1

Species	Seed Treatment	Germination (%) in Atmosphere Containing 1 to 21% Oxygen					
		1%	3%	5%	10%	15%	21%
Leek [19][33]	Non-primed	0	0	3.1	20.2	52.2	53.2
	Primed	0	11.4	34.4	85.2	93.3	95.2
Sunflower [34][35]	Non-primed	4.6	40.7	55.6	79.6	92.5	100
	Primed	10.2	75.6	95.3	100	100	100
Tomato [31][33][36]	Non-primed	0	0	0	0	20.7	48.4
	Primed	2.2	10.1	50.1	76.7	92.4	95.5

uboptimal [16] -4 days in [37] range of [1][3][5][26] ... [38] flower [39], [40] [41] [42] [33][43] humidity for 31 h, rape seeds are still viable, but their germination rate is reduced compared to the control unaged seeds [33]; however, osmopriming at 25 °C in a PEG solution at −2 MPa enhances the germination of aged seeds. This improving effect increases with the duration of the treatment, and, after 6 days of priming, aged seeds germinate as well as the unaged ones. The more the seeds are aged the longer they must be primed for restoring their initial germination ability [33][43]. In the case of sunflower seeds, the re-invigoration during priming of seeds aged at 45 °C for 5 days is associated with a decrease in lipid peroxidation and the recovery of the detoxifying enzyme (superoxide dismutase, catalase, glutathione reductase) activities [41].

3.3. Examples of Priming Beneficial Effects on Several Species

The stimulatory effects of priming depend on the conditions (particularly temperature, water potential and oxygen availability) and the duration of the treatment [3][5][11][12][26]. Water potential during osmopriming varies between −0.5 and −2 MPa depending on the species, but generally the moisture content of the seeds is maintained at around 40–45% fresh weight basis, which is lower than the moisture content that would allow radicle protrusion [25]. The temperature range and oxygen concentrations which are effective during priming are similar to those which allow the germination of unprimed seeds, which demonstrates that priming corresponds to the realization of the germination stricto sensu (phase II of the germination process). For example, the optimal temperature for priming and germination of unprimed seeds is around 25 °C for tomato [31][32], 20–25 °C for sunflower [33] and 10–15 °C for leek [33].

To be efficient, the priming treatment requires more than 5% oxygen in the atmosphere (**Figure 4**) [32][33], indicating that metabolic processes are necessary for the syntheses associated with priming [25].

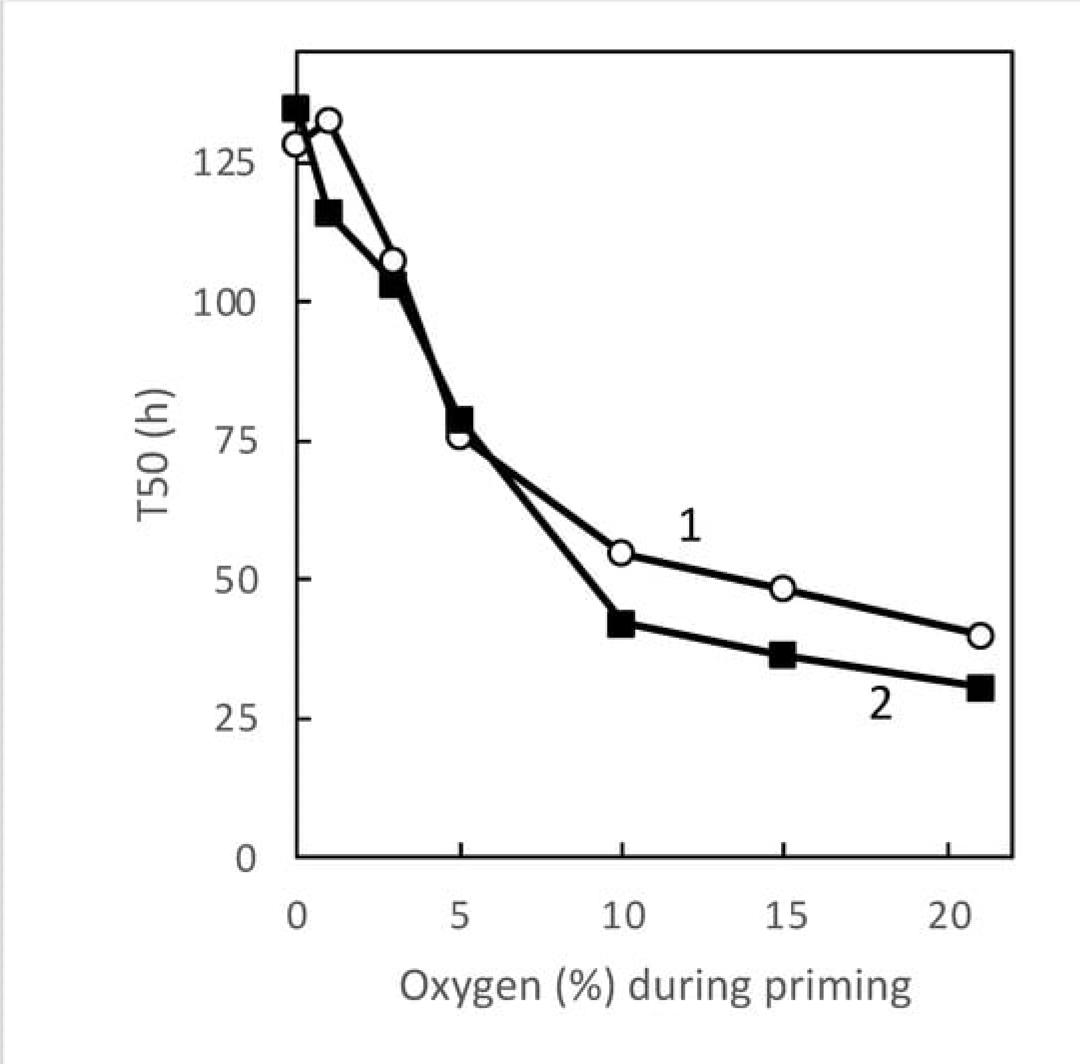

Figure 4. Effects of oxygen tension during priming for 7 days at 15 °C (1) or 25 °C (2) on a PEG solution at −1.0 MPa on the time to obtain 50% germination (T_{50}) with tomato seeds (cv Elko) transferred on water at 15 °C. Mean of 3 replicates of 50 seeds. T50 of dry non-primed seeds was 129 h. From [32][33].

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