

**Priming Improves Germination and Emergence of Combine-harvested Amaranths cruentus L. Seeds**

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**Abstract.** Hand-harvested and threshed grain amaranth seeds stored for 6.5 years and combine-harvested and threshed seeds (cylinder speed 26.4 m·s⁻¹) stored for 9.5 years were subjected to several osmotic priming treatments. The selected priming treatment (~1.25 MPa polyethylene glycol at 15°C for 10 days) increased percent radicle emergence of hand-harvested seeds and mechanically damaged, combine-harvested seeds and resulted in germination rates that were at least as high as those achieved with other priming treatments. In an incubator test, priming increased percent radicle emergence of hand-harvested seeds only at 15°C; however, it increased percent radicle emergence of combine-harvested seeds at 15 and 35°C. Priming also increased radicle emergence rate, but this response was more pronounced and exerted over a wider temperature range for the older, lower-vigor, combine-harvested seeds than for the younger, higher-vigor, hand-harvested seeds. In a greenhouse test, hand-harvested seeds had a higher percentage of normal seedlings and a lower percentage of abnormal seedlings than combine-harvested seeds. Priming had no effect on these variables. As a result of priming, normal seedling emergence rate and shoot fresh weight were higher from combine-harvested seeds than from hand-harvested seeds, such that values of these variables for primed, combine-harvested seeds were at least equal to those for nonprimed, hand-harvested seeds. Thus, the invigorating effect of priming was more pronounced for the lower-vigor, mechanically damaged, combine-harvested seeds than for the higher-vigor, hand-harvested seeds.

Amaranth is a dicotyledonous C₄ species that produces edible cereal grain and leaves that are valuable as a food and feed resource (Saunders and Becker, 1984). Amaranthus has been characterized as a “new crop that is in its adolescence” (Kauffman and Weber, 1988), although it was a basic food of the New World in pre-Columbian times (National Research Council, 1984; Vietmeyer, 1981).

Although most grain amaranth is hand-harvested, combine-harvesting and threshing is required in the United States for this crop to be economically competitive with other grain crops. Mechanical harvesting research of grain amaranth, initiated in 1980 at the Rodale Research Center in Kutztown, Pa., lead to recommended settings and modifications for different models of combine-harvesters to minimize grain losses (Weber et al., 1989). Amaranth seed is particularly vulnerable to mechanically induced damage because the embryo encircles the perisperm in one plane (Irving et al., 1981). Krishnan et al. (1994) established that the percentage of normal amaranth seedlings decreased and the percentage of abnormal seedlings increased as threshing cylinder linear speed increased from 8.1 to 30.7 m·s⁻¹. Although no mechanical damage was apparent at 8.1 m·s⁻¹, the seedcoat and endosperm were damaged at 12.8 and 22.4 m·s⁻¹. The damage extended to the embryos at 30.7 m·s⁻¹. That study, however, did not examine radicle emergence rate or seedling growth.

Germination of a seed lot is assessed by standard germination tests in which the number of seeds capable of producing normal seedlings under optimal conditions are recorded (International Seed Testing Association, 1985). There is no distinction between strongly or weakly terminable seeds. Poor seedling emergence may be associated with low vigor, resulting in the failure to complete the postgerminative-preemergence stage of growth (Doneen and McGillivray, 1943).

Osmotic seed priming is a presowing treatment in which seeds are exposed to an external water potential low enough to restrict germination and yet permit pregerminative physiological and biochemical activities (Bradford, 1986). Primed seeds may have a higher germination percentage and rate than nonprimed seeds, particularly under adverse seed-bed conditions such as low (Pill and Finch-Savage, 1988; Szafirowska et al., 1981) or high temperature. (Carpenter, 1989; Carpenter and Boucher, 1991) and decreased water availability (Pill and Pill, 1989). There is some controversy, however, regarding the merits of priming with respect to existing seed vigor. Szafirowska et al. (1981) noted that priming invigorated low-vigor carrot (Daucus carota L.) seeds more than high-vigor seeds, but Matthews and Powell (1986) suggested that priming can be of little benefit to low-vigor seeds.

In this study, we established the optimal priming conditions for hand- and combine-harvested and threshed grain amaranth seeds after extended storage (6.5–9.5 years) and assessed germination and seedling emergence responses of primed and nonprimed seeds.

**Materials and Methods**

*General.* 'RRC 1041' grain amaranth plants, grown at the Cheyenne Gap Amaranth farm in Luray, Kan., were harvested in Oct. 1982 using a combine (6620; John Deere, Moline, Ill.) equipped with a 56-cm rasp bar cylinder operated at 26.4 m·s⁻¹ linear speed (900 rpm) and a grated concave clearance of 7.9 mm in the front and 4.8 mm in the back. Hand-harvested and threshed seeds of the same cultivar, not available in 1982, were harvested from the same farm in Oct. 1985. Between the time of harvesting or threshing and germination testing, the seeds were stored in sealed plastic bags at 20 to 27°C.

Germination of these seeds was tested in Mar. 1992. Four 100-seed replications of the combine-harvested and threshed seeds and hand-harvested and threshed seeds were placed in 125 × 80 × 20-mm transparent polystyrene boxes containing two layers of germination paper (Seed Germination Blotters no. 385; Seedburo Co., Chicago) that were moistened with 15 ml of half-strength Hoagland solution (Hoagland and Arnon, 1950). They were maintained at constant 20°C in darkness. Germinated seeds (radicles visible) were counted daily and removed from the boxes. From these data, maximum percent radicle emergence and days to 50% of maximum percent radicle emergence (Gₜ) were calculated. Maximum percent radicle emergence and Gₜ values (mean ± SD) of the combine-harvested seeds were 34% ± 9% and 3.6 ± 0.1 days, respectively, and values for hand-harvested seeds were 86% ± 4% and 2.7 ± 0.1 days, respectively. Thus, the older combine-harvested seeds had lower germinability and vigor than the hand-harvested seeds.

**Optimal priming treatment.** Hand- and combine-harvested seeds were primed for 5, 10, 15, or 20 days in solutions of polyethylene glycol 8000 (PEG) with nominal water potentials of -0.50, 0.75, -1.00, or -1.25 MPa at 15°C (Michel and Kaufmann, 1973). The prim-
ing treatments were performed in boxes on papers (as previously described) moistened with 15 ml of PEG solution. Four replicate boxes each contained 100 seeds. Following priming, seeds were rinsed in demineralized water, allowed to dry at 21°C in 34% relative humidity for 1 week, then transferred to boxes containing two layers of germination paper moistened with 15 ml of half-strength Hoagland solution. Priming treatments were scheduled so that all germination tests (15°C in darkness) started at the same time. We recorded the number of seeds germinated (radicles first visible) daily until the numbers stabilized, and from these data, we calculated the maximum percent radicle emergence (and angular transformation) and G₅₀, and subjected them to analysis of variance.

**Germination temperature.** Combine- and hand-harvested seeds were primed (−1.25 MPa PEG at 15°C for 10 days), rinsed, and dried as previously described. The germination of the primed seeds and nonprimed, combine- and hand-harvested seeds was tested at 15, 25, or 35°C in half-strength Hoagland solution. Five replications of 0.100 seeds of the 2 (harvest method) × 2 (priming treatment) factorial were arranged in a completely randomized design within incubators set at one of the three temperatures. Data collection and analyses were as previously described, except that data from each temperature were analyzed separately.

**Seedling emergence in greenhouse.** Primed seeds, prepared using methods previously described, and nonprimed, combine- and hand-harvested seeds were sown into five 0.5-cm-deep × 12× 6-cm-long furrows in proprietary peat-based medium (Pro-Mix BX; Premier Brands, New Rochelle, N. Y.) contained in 17 × 12× 6-cm plastic flats. The sown seeds were covered with 0.5 cm of Redi-Earth (W.R. Grace and Co., Cambridge, Mass.). The 2 x 2 factorial was arranged in randomized complete blocks with 100 seeds in each of eight replications (flats). The study was conducted in a greenhouse under natural light (June 1992) with day/night ranges of 16–20°C/ 2–14°C. Flats containing two layers of germination paper (as previously described) moistened with 15 ml of PEG solution. Priming treatments were scheduled within incubators set at one of the three temperatures. Data were recorded daily. From these data, maximum percent seedling emergence and days to 50% maximum percent seedling emergence (E₅₀) were calculated. Fourteen days after sowing, the percentages of abnormal (with cracked or deformed hypocotyls and cotyledons) seedlings and of final (normal) seedling emergence were assessed. Shoots of all normal seedlings were cut at the growth medium surface 14 days after sowing, and their fresh weights were determined. Data were subjected to analysis of variance.

**Results and Discussion**

**Optimal priming treatment.** Excessive germination occurred during priming at −0.5 MPa; this treatment was excluded from statistical analysis. All priming treatments decreased G₅₀ relative to that of nonprimed seeds, resulting in an average 2.6-day reduction for hand-harvested seeds and an average 4.5-day reduction for combine-harvested seeds (Table 1). G₅₀ was affected less by water potential than by priming duration, with G₅₀ generally increasing quadratically with increasing days of priming. Water potential had little effect on G₅₀ when priming was <10 days. With >15 days of priming, the G₅₀ of combine-harvested seeds decreased as water potential decreased.

**Germination temperature.** Priming increased the radicle emergence rate of hand- and combine-harvested seeds at 15 and 25°C and of combine-harvested seeds at 35°C. The G₅₀ decrease due to priming was greater as germination temperatures decreased in combine-harvested seeds than in hand-harvested seeds. For example, G₅₀ at 15°C was reduced by 7 days in combine-harvested seeds and by 2.5 days in hand-harvested seeds. Priming only increased percent radicle emergence of hand-harvested seeds at 35°C; nonprimed, hand-harvested seeds had >90% radicle emergence at 25 and 35°C (Table 2). Priming increased percent radicle emergence of combine-harvested seeds by 7% at 15°C and by 18% at 35°C. The percent radicle emergence increase due to priming at 35°C (51% to 69%) could be of practical value if it could be retained under field conditions for seeds stored several years.

**Increased germination rate and percentage at low temperatures due to priming have been reported for carrot (Pill and Finch-Savage, 1988; Szafirowska et al., 1981). The greater***

<table>
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<th>Water potential (−MPa)</th>
<th>Days of priming</th>
<th>Hand</th>
<th>Combine</th>
<th>Hand</th>
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improvement in radicle emergence rate with priming lower-vigor, combine-harvested seeds than with priming higher-vigor, hand-harvested seeds agreed with the observations of Szafronska et al. (1981). They indicated priming benefited low-vigor more than high-vigor carrot seeds. At 35°C, priming increased the rate and percentage of radicle emergence of combine-harvested seeds but not of hand-harvested seeds (Table 2). Increased germination percentage and rate at high temperatures in response to seed priming were noted in pansy (Viola ×wittrockiana Gams.) (Carpenter and Boucher, 1991) and in salvia (Salvia splendens, F. Sellow ex Roem & Schutt) (Carpenter, 1989).

Priming exerted no discernible effect on seed morphology as revealed by scanning electron microscopy. However, combine-harvested seeds threshed at a cylinder linear speed of 26.4 m·s⁻¹ exhibited extensive mechanical injury that extended to the embryo (Krishnan et al., 1994), which encircles the perisperm (Irvine et al., 1981). Although priming cannot reverse mechanical injury, it can invigorate seeds through a combination of processes (Pill, 1994) that may include the following: cellular repair and improved membrane integrity; decreased seed exudation and concomitant decreased growth of pathogenic organisms; enhanced mobilization of seed protein, lipid, and starch as a result of activation or synthesis of key enzymes; osmotic adjustment and increase in radicle turgor; advanced embryo development; weakened restraining tissues around the radicle; and increased potential for oxidative phosphorylation and adenosine triphosphate accumulation.

**Seedling emergence in greenhouse.** Seedling emergence from combine-harvested seeds was slower than from hand-harvested seeds, but priming reduced the Eₜ of combine- and hand-harvested seeds so that the Eₜ of primed, combine-harvested seeds was equal to that of nonprimed, hand-harvested seeds (Table 3). The percentage of normal seedlings was 3.3 times higher from hand-harvested seeds than from combine-harvested seeds, but priming did not increase the percentage of normal seedlings from either combine- or hand-harvested seeds.

The average percentage of normal seedlings obtained (Table 3) from hand-harvested seeds (84%) and combine-harvested seeds (34%) was lower than the respective averages of 93% and 53% radicle emergence values achieved in incubators at 25 and 35°C (Table 2). The greater percentage of combine-harvested seeds than of hand-harvested seedlings that failed to complete the postgerminative–preemergence stage of growth reflected the lower vigor of the older and more damaged combine-harvested seeds. The higher percentage of abnormal seedlings of combine-harvested seeds (8.9%) than from 3-year-younger, hand-harvested seeds (2.6%) provided further evidence of the reduced vigor of the combine-harvested seeds (Table 3). Priming did not reduce the percentage of abnormal seedlings because mechanical injury cannot be reversed.


