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ARTICLE

Factors affecting germination and emergence of glyphosate-resistant hybrid corn (*Zea mays* L.) and its progeny

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Abstract: Laboratory and greenhouse experiments were conducted to compare the effects of agronomic and environmental factors on germination and emergence of glyphosate-resistant (GR) hybrid corn (Mycogen 2G681) and its progeny. The germination of GR hybrid corn and its progeny was 84% to 97% at day/night temperatures of 15/10 °C to 42.5/30 °C, while higher (45/35 °C) and lower (0/0 °C) temperatures reduced germination to ≤6%. Germination was >90% at all alternating as well as constant light and dark periods at a fixed day/night temperature of 30/20 °C. At osmotic stress level of 0 to −0.3 MPa, >90% of hybrid corn and progeny seeds germinated, while osmotic stress level of −0.4 to −1.3 MPa reduced germination to <65%. Greater than 90% germination was observed at a wide range of salt concentrations (0–160 mM), with the lowest germination (53%) at 320 mM. More than 87% cumulative seedling emergence of hybrid corn and its progeny occurred at a depth of 0.5–6 cm and hybrid corn emergence reduced from 86% to 23% compared with 21% to 2% reduction of progeny at 1 and 2 d of flooding, respectively.

Key words: flooding duration, light, osmotic stress, seed burial depth, temperature.

Résumé : Les auteurs ont effectué des expériences en laboratoire et en serre afin de comparer les effets de divers paramètres agronomiques et environnementaux sur la germination et la levée d'un maïs hybride résistant au glyphosate (RG) (Mycogen 2G681) et de sa progéniture. Le maïs hybride RG et sa progéniture ont enregistré un taux de germination de 84 % à 97 % aux températures diurnes/nocturnes de 15/10 °C à 42,5/30 °C, des températures plus élevées (45/35 °C) ou plus basses (0/0 °C) faisant chuter le taux de germination à ≤ 6 %. Le taux de germination dépassait 90 % pour toutes les périodes alternant la lumière et l'obscurité à un rythme constant, à une température diurne/nocturne fixe de 30/20 °C. À un stress osmotique de 0 à −0,3 MPa, plus de 90 % des graines du maïs hybride et de sa progéniture ont germé, mais un stress osmotique de −0,4 à −1,3 MPa porte la germination en-dessous de 65 %. Les auteurs ont observé un taux de germination supérieur à 90 % à une vaste gamme de concentrations de sel (de 0 à 160 mM), le taux de germination le plus faible (53 %) ayant été enregistré à 320 mM. Cumulativement, plus de 87 % des plantules du maïs hybride et de sa progéniture ont levé à une profondeur de 0,5 à 6 cm. La levée du maïs hybride est passée de 86 à 23 % après une et deux journées d'inondation, respectivement, contre 21 à 2 % pour la progéniture. [Traduit par la Rédaction]

Mots-clés : durée de l'inondation, lumière, stress osmotique, profondeur du semis, température.

Introduction

The United States is the world's largest corn producing country with 33.64 million ha harvested in 2014 (USDA 2014). Since commercialization in the late 1990s, glyphosate-resistant (GR) corn has been adopted rapidly by growers in the United States. In 2014, corn hybrids resistant to herbicides, insects, or a combination of both occupied 93% of the total corn area in the United States (USDA-NASS 2014*a*). Nebraska is among the top five corn producing states in the United States (USDA-NASS 2014*b*), with the majority of corn being glyphosate-resistant. The increased cultivation of GR corn has made volunteer corn a problematic weed in GR soybean grown in rotation (Marquardt et al. 2013).

Glyphosate-resistant volunteer corn is a major weed in Midwestern corn-soybean cropping systems that usually results from the corn seeds (progeny) left over in the field during harvesting of the hybrid corn planted in

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Abbreviations: ACCaase, acetyl Co-A carboxylase; **C**, celsius; **GR**, glyphosate-resistant; **mmol**, millimole; **MPa**, megapascal; **mM**, millimolar; **PEG**, polyethylene glycol.

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the previous season (Chahal and Jhala 2015). A failed hybrid corn stand may also result in volunteer corn populations under a replant situation in the same season (Steckel et al. 2009). Volunteer corn is a competitive weed and reduces yields in crops grown in rotation with hybrid corn, including corn (Jeschke and Doerge 2008), cotton (*Gossypium hirsutum* L.) (Clewis et al. 2008), soybean (Beckett and Stoller 1988; Chahal et al. 2016*a*), and sugarbeet (*Beta vulgaris* L.) (Kniss et al. 2012). In addition to crop yield loss, volunteer corn can also interfere with harvesting operations (Deen et al. 2006) and may harbor insect pests (Marquardt et al. 2012).

Germination and emergence are critical stages in weed establishment and persistence in an agroecosystem (Bewley and Black 1994). Several environmental factors play a role in seed germination and seedling emergence (Baskin and Baskin 1998), one of the most important being the temperature to which seeds are exposed (Cardwell 1984; Chauhan et al. 2006*b*; Tozzi et al. 2014). Light is another important factor for the germination of many weed species (Bewley and Black 1994). The optimum temperature, light, osmotic stress, and seed burial depth necessary for seed germination and seedling emergence vary considerably depending on the weed species (Egley and Duke 1985). For instance, germination of volunteer oilseed rape (*Brassica napus* L.) maintained at an osmotic potential of −0.15 mega Pascal (MPa) was reduced by 7% at 14 d after imbibition compared with 100% germination with an osmotic potential of 0 MPa at 12 °C temperature (López-Granados and Lutman 1998).

The germination and emergence response of corn to different environmental and agronomic factors may vary depending on the cultivar. For example, Idikut et al. (2012) reported significant difference between the germination rate of popcorn (40%–100%) and hybrid corn (5%–62%) genotypes at different temperatures and salt concentrations. Similarly, Andrew (1953) reported higher seedling emergence of two sweetcorn hybrids (≥94%) compared with their inbred parents (60%–90%) when planted at two depths (2.5 and 10 cm). In other grass species, such as rigid ryegrass (*Lolium rigidum* Gaudin), higher seedling emergence was observed from surface sown seeds (44%) than seeds planted 10 cm deep in the soil (0%) (Chauhan et al. 2006*a*). Previous research showed that hybrid corn and their progeny may have similar or different response to certain herbicides evaluated. For example, Anderson and Geadelmann (1982) reported dissimilar response of hybrid corn and its progeny to diclofop. Pornprom et al. (2003) reported that conventional corn hybrids can have different level of tolerance to glufosinate. A study to evaluate the response of two hybrid corn and their progeny to clethodim and glufosinate, Terry et al. (2012) reported no difference in their response of hybrid and their progeny to these two herbicides.

The germination and emergence response of hybrid corn may differ from its progeny due to segregation when exposed to a range of agronomic and environmental factors. Scientific literature, to our knowledge, is not available on the comparison of germination and emergence responses of GR hybrid corn (Mycogen 2G681) and its progeny to various environmental and agronomic factors. The objectives of this research were to compare (1) the germination of GR hybrid corn and its progeny in response to temperature, light, osmotic stress, and salt stress, and (2) the effect of seed burial depth and flooding duration on the emergence of GR hybrid corn and its progeny. In addition, this information will be useful developing integrated volunteer corn management programs.

Materials and Methods

Plant material and germination test

GR hybrid corn ('Mycogen 2G 681') was planted on 12 May 2012 at the South Central Agriculture Lab, University of Nebraska-Lincoln, Clay Center, Nebraska, USA. The harvested corn seeds were kept at 4 °C along with the fresh GR hybrid corn seeds to be used as progeny (volunteer corn) seeds in this study.

Germination procedure

Laboratory and greenhouse experiments were conducted in 2013 at the University of Nebraska-Lincoln. Before initiating the study, the seeds of hybrid corn and its progeny were surface-sterilized in a 0.5% sodium hypochlorite solution for 10–15 min, and were rinsed with running tap water for 5 min. Experiments to evaluate the effects of different temperature, light, osmotic stress, and salt stress conditions on the germination of GR hybrid corn and its progeny were conducted under laboratory conditions. The experiments were arranged in a factorial randomized complete block design with six replications, considering the corn seed type (hybrid corn and its progeny) and response variables as two factors. Fifteen sterilized seeds, each of GR hybrid corn and its progeny were placed on a filter paper (Whatman No. 4 filter paper, International Ltd., Maidstone, UK) in separate 9 cm petri dishes, unless stated otherwise, and 7.5 mL of distilled water was added to each petri dish. Petri dishes were sealed with parafilm (American National Company, Greenwich, CT 06836) to prevent desiccation during incubation. Each replication was arranged on a different shelf in the growth chamber and considered as a block. Petri dishes were kept in the growth chamber for 7 d at a day/night temperature of 30/20 °C and a 12 h photoperiod, except in the study of effect of light and temperature. Fluorescent lamps were used to produce a light intensity of 85 mmol m^{-2} s^{-1}. After 7 d, the germinated seeds were counted and converted to percent germination. Experiments to evaluate the effects of depth of sowing and flooding duration on the emergence of GR hybrid corn and its progeny were conducted under greenhouse conditions maintained at 30/20 °C day/night temperature and a 16 h photoperiod in a factorial completely randomized block design with four replications. The experiment was repeated immediately after completion of the first run.

Effect of temperature

Germination of GR hybrid corn and progeny seeds was determined in a growth chamber under eight fluctuating day/night temperature regimes of 0/0, 12.5/7.5, 15/10, 20/12.5, 30/20, 37.5/25, 42.5/30, and 45/35 °C. Photoperiod was set at 12 h (day/night).

Effect of light

Light regimes consisted of complete dark (24/0 h dark/light), complete light (0/24 h dark/light), and alternating dark and light conditions (4/20, 8/16, 12/12, 16/8, or 20/4 h dark/light). During this experiment, a constant day/night temperature of 30/20 °C was maintained in the growth chamber.

Effect of osmotic stress

Solutions with the osmotic potential of 0, −0.3, −0.4, −0.6, −0.9, and −1.3 MPa were prepared by dissolving 0, 154, 191, 230, 297, and 350 g of polyethylene glycol (PEG; polyethylene glycol 8000, Fisher Scientific, Fair Lawn, NJ 07410) in 1 L of deionized water (Michel 1983; Shaw et al. 1991). Petri dishes were placed in the growth chamber and maintained at a constant day/night temperature of 30/20 °C and a 12 h photoperiod.

Effect of salt stress

Solutions of sodium chloride (NaCl; Fisher Scientific, Fairlawn, NJ 07410) at 0, 10, 20, 40, 80, 160, and 320 mM were prepared and used as a germination media (Michel 1983). A solution of NaCl (7.5 mL) was added to each petri dish and was placed in the growth chamber with a maintained day/night temperature of 30/20 °C and 12 h photoperiod.

Effect of seed burial depth

Four replicates with 20 seeds of GR hybrid corn and its progeny were planted at depths of 0, 0.5, 1, 2, 4, 6, and 10 cm below the soil surface in 20 cm deep and 9 cm wide plastic pots. To evaluate the effect of deeper burial depths on germination, experiments were conducted in the large size plastic pots. Twenty seeds were planted at depths of 15 and 20 cm in 24 cm deep and 11 cm wide plastic pots, and fifteen seeds were planted at depths of 25 cm in 60 cm deep and 10 cm wide plastic pots filled with 80% soil and 20% commercial potting mix (Berger BM1 potting mix, Berger Peat Moss Ltd., Quebec, Canada).

The soil used in this study was collected from a field near Lincoln, Nebraska, USA with no history of herbicide application in the last 10 yr. The soil texture was silt-loam with a pH of 6.1, 22% sand, 54% silt, 24% clay, 2.8% organic matter, and a bulk density of 1.4 g cm^{-3}. The experiment was conducted under greenhouse conditions with a day/night temperature maintained at $25 \pm 5/20 \pm 5$ °C. Supplemental light in greenhouse was provided using metal halide lamps with 600 μmol photon m^{-2} s^{-1} light intensity to ensure a 16 h photoperiod. Pots were initially subsurface irrigated to field capacity and then surface irrigated daily to maintain adequate soil moisture. Emerged seedlings were counted at 7, 14, and 21 d after planting and were removed after weekly counts. Cumulative emergence data after 21 d of planting were used for analysis and discussed.

Effect of flooding duration

Four replicates of 25 seeds of GR hybrid corn and its progeny were planted 4 cm deep in a separate plastic pot (23 cm deep and 24 cm diam) filled with 80% soil (as described above) and 20% commercial potting mix. Results of the seed burial depth study indicated that maximum emergence occurred when seeds were buried at 4 cm. The treatments included flooding durations of 0, 1, 2, 4, 7, 14, and 21 d. Water was maintained 2 cm above the soil surface for the above mentioned period to stimulate flooding. After exposure to a given period of flooding, the excess water was drained by poking holes on the sides of the pots. The emerged seedlings were counted at 7, 14, 21, and 35 d after planting. The cumulative emergence data of hybrid corn and its progeny at 35 d after planting were used for analysis and discussed. Greenhouse conditions were the same as in the seed burial depth experiment.

Statistical analysis

Data analysis was performed using the PROC GLIMMIX procedure in SAS version 9.3 (SAS Institute Inc., Cary, NC). Percent germination data were arcsine square-root transformed before analysis to meet the homogeneity of variance assumption; however, back-transformed data are presented with mean separation based on transformed data. Treatments and corn types (hybrid corn and its progeny) were considered fixed effects, while replications and two runs (repeats) of the experiment were considered random effects in the model. Experiment-by-treatment interaction was not significant; therefore, data were combined over two runs of the experiment.

Regression analysis was used where appropriate; otherwise, means were separated using Tukey-Kramer's pairwise comparison test at $P \leq 0.05$. Percent germination values at different osmotic concentrations were best fitted to a three-parameter sigmoid model using Sigma Plot version 10.0 (Systat Software Inc., San Jose, CA 95110). The model fitted was:

$$G(\%) = G_{\max}/\{1 + \exp[-(x - x_{50})/G_{\mathrm{rate}}]\} \tag{1}$$

where G represents the total germination (%) at an osmotic concentration x, $G_{\max}$ represents the maximum germination (%), x_{50} represents the osmotic potential required to inhibit 50% of the maximum germination, and G_{rate} indicates the slope.

A polynomial quadratic model was fitted to the percent germination values obtained at different salt concentrations. The model fitted was:

$$G(\%) = G_{\max} + ax - bx^2 \qquad (2)$$

where G represents the total germination (%) at salt concentration x, $G_{\max}$ represents the maximum germination (%), and a, and b are the model parameters.

Results and Discussion

Effect of temperature

No significant two-way interaction for germination was observed among the corn types (hybrid corn and its progeny) and temperature treatments ($P = 0.9506$); therefore, data were combined over the corn type. Different day and night temperatures maintained under light and dark conditions in the growth chamber affected the seed germination ($P < 0.0001$) (Fig. 1). The highest germination (84%–97%) was recorded at a day/night temperature of 15/10 to 42.5/30 °C, whereas the lowest germination (≤6%) was observed at 45/35 and 0/0 °C with a 12 h photoperiod. At 12.5 /7.5 °C day/night temperature, the germination reduced to 62%; however, it was comparable with 15/10, 20/12.5, 37.5/30, and 42.5/30 °C. 94% of the hybrid corn and its progeny seeds exposed to 45/35 °C day/night temperature were destroyed due to excessive heat and did not germinate when exposed again to 37.5/30 °C for one wk; however, the seeds maintained at 0/0 °C temperature remained dormant and provided 82% germination when exposed later to 37.5/30 °C day/night temperature. In this study, GR hybrid corn and its progeny showed similar germination responses, demonstrating that the germination abilities of GR hybrid corn and its progeny did not differ in response to alternate day/night temperatures. However, Idikut (2013) reported higher germination of popcorn (72% and 77%) compared with dent (10% and 4%) and sweet corn (0.5% and 16%) at 17 and 30 °C, respectively.

Effect of light

Germination was not affected by corn type (hybrid corn and its progeny), light conditions, or the interaction among corn type and light conditions; therefore, data were combined over corn types (Fig. 2). Complete dark (24/0 h dark/light), complete light (0/24 h dark/light), and alternate light and dark conditions (4/20, 8/16, 12/12, 16/8, or 20/4 h dark/light) resulted in >90% germination at a constant day/night temperature (30/20 °C).

Fig. 1. Germination of glyphosate-resistant hybrid corn and its progeny under varying day/night temperatures. No significant difference was observed between germination of hybrid corn and its progeny, therefore data were combined. Bars with same letters are not significantly different at α = 0.05. Abbreviation: C, degree Celsius.

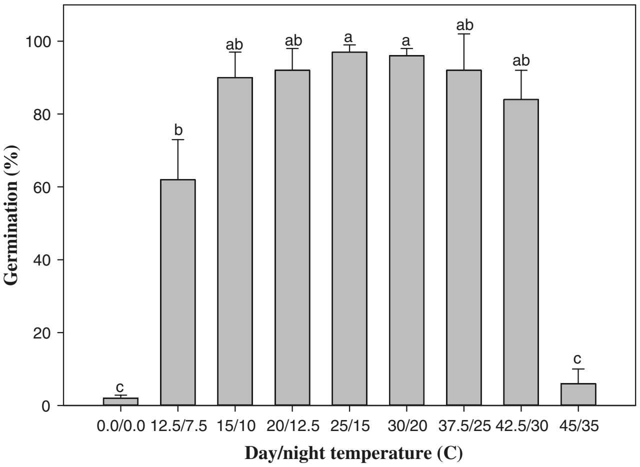
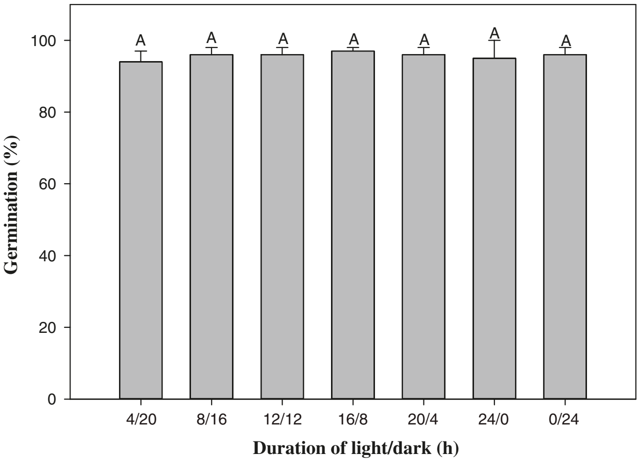


Fig. 2. Germination of glyphosate-resistant hybrid corn and its progeny under varying light and dark conditions. No significant difference was observed between germination of hybrid corn and its progeny, therefore data were combined. No significant difference was observed between the duration of light/dark conditions and percent germination. Abbreviation: h, hours.



Complete light or dark conditions and their alternate regimes did not affect the germination of GR hybrid corn and its progeny; thus, higher germination rates might not only occur in the surface-dropped seeds, but also in the seeds present deep in the soil. As the hybrid corn and progeny seeds can germinate in the absence of light, the crop canopy and residues present in the field may not play an important role in reducing the germination of volunteer corn, though the reduced light conditions might restrict corn growth after emergence. However, the germination response of corn to different light conditions can also vary with corn variety. For example, Idikut (2013) reported higher germination of popcorn (84% and 65%) compared with dent (5% and 4.5%) and sweet corn (9% and 10%) at complete light and 12/12 h dark/light conditions, respectively. Therefore, it might not be possible to expect similar

Fig. 3. Germination of glyphosate-resistant hybrid corn and its progeny under varying osmotic stress conditions. Percent germination values at different osmotic concentrations were best fitted to a three-parameter sigmoid model $G\ (\%) = G_{max}/\{1 + \exp[-(x - x_{50})/G_{rate}]\}$, where G represents the total germination (%) at an osmotic concentration x, G_{max} represents the maximum germination (%), x_{50} represents the osmotic potential required to inhibit 50% of the maximum germination, and G_{rate} indicates the slope. No significant difference was observed between germination of hybrid corn and its progeny, therefore data were combined. Abbreviation: G, germination; MPa, megapascal.

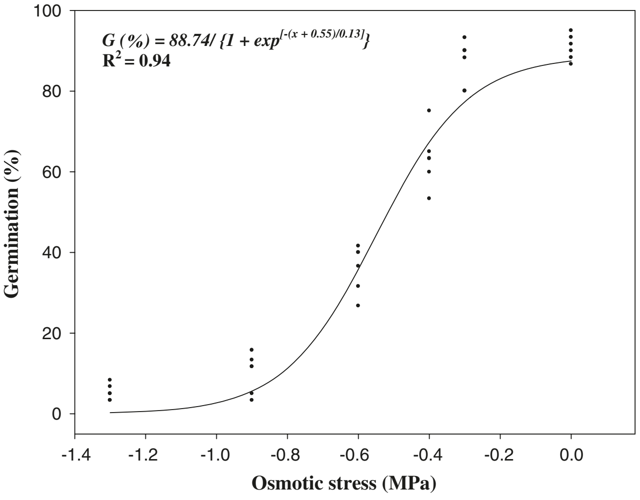
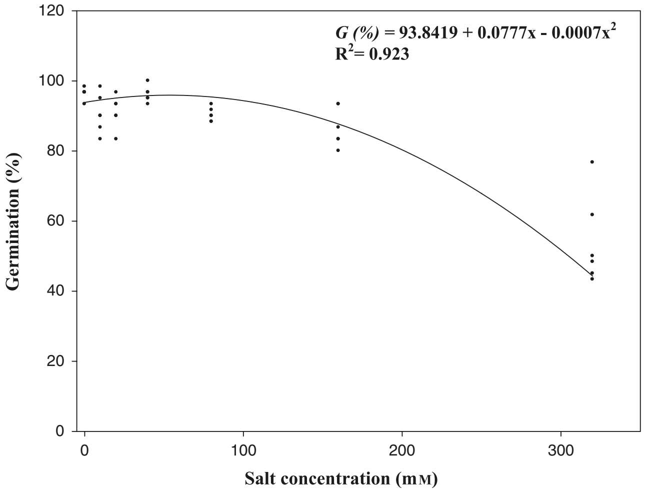


Fig. 4. Germination of glyphosate-resistant hybrid corn and its progeny at different salt concentrations after 1 wk of incubating at day/night temperature of 30/20 °C and 12 h photoperiod. Percent germination values at different osmotic concentrations were best fitted to a polynomial quadratic model $G\ (\%) = G_{max} + ax - bx^2$, where G represents the total germination (%) at salt concentration x, G_{max} represents the maximum germination (%), and a, and b are the model parameters. No significant difference was observed between germination of hybrid corn and its progeny, therefore data were combined. Abbreviation: mM, millimolar.



germination results from a different corn hybrid or its progeny under growth chamber or field conditions. A constant day/night temperature was maintained in the growth chamber during this study; however, under field conditions, the germination can vary due to fluctuating day/night temperatures.

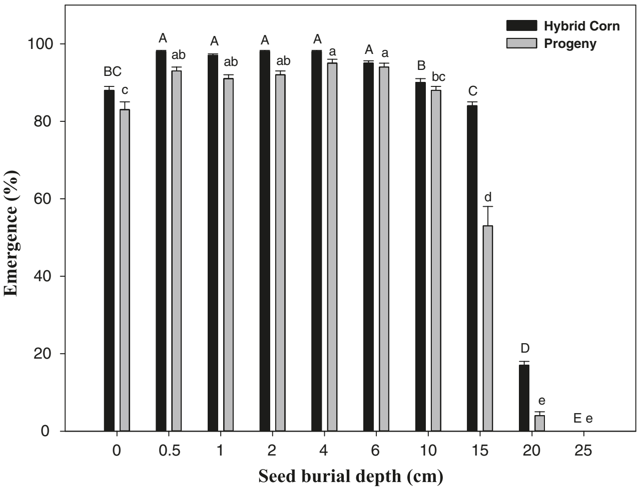
Effect of osmotic stress

A two-way interaction between corn type (hybrid corn and its progeny) and osmotic stress levels was not significant ($P = 0.2156$); therefore, germination data were combined over the corn types. The highest germination (>90%) was observed at osmotic stress levels of 0 to 0.3 mega Pascal (MPa), whereas germination was the lowest (≤5%) at osmotic stress levels of −0.9 to −1.3 MPa (Fig. 3). Germination was reduced to 63% and 36% at osmotic stress levels of −0.4 and −0.6 MPa, respectively. Similarly, Khodarahmpur (2011) reported the lowest germination (≤23%) of seven corn hybrids at osmotic stress levels of −0.9 to −1.2 MPa compared with the nontreated control (distilled water). Results of this study suggest that GR hybrid corn and its progeny can germinate and become volunteer corn under mild drought conditions. However, PEG was used to induce osmotic or moisture stress levels in this study and it has been documented that corn seeds can show differential responses to PEG-induced water stress compared with field conditions, as it has also been shown that the response to PEG-induced stress varies with the type of corn (Ashagre et al. 2014). Therefore, the germination response of the GR hybrid corn and its progeny to osmotic stress levels may vary with different corn hybrids and their progenies under both laboratory and field conditions.

Effect of salt stress

Analysis of variance suggested no significant interaction among the corn types and salt stress levels ($P = 0.4285$) showing that the germination ability of the progeny was not inferior to that of the hybrid corn. Germination of the hybrid corn and its progeny was >90% at salt stress levels of 0 to 160 mM and was reduced to 53% at the highest salt stress level tested (320 mM) (Fig. 4). In this study, the germination results showed that the selected GR hybrid corn and its progeny can germinate under mild to moderate saline conditions. However, germination response to salt stress levels can also vary with the corn hybrid. For example, Carpıcı et al. (2009) reported a linear decrease in the germination of different corn hybrids at salt stress levels of 0 mM (55%) to 250 mM (23%). Khayatnezhad and Gholamin (2011) also reported a linear decrease in the germination of five corn hybrids (53%–21%) with increasing salt concentrations (0–250 mM), respectively.

Fig. 5. Cumulative seedling emergence of glyphosate-resistant hybrid corn and its progeny at 21 d after seed planting at varying burial depths. Bars with the same letter(s) are not significantly different at α = 0.05. Capital letters represent comparison among hybrid corn and small letters represent comparison among progeny. Abbreviation: cm, centimeter.

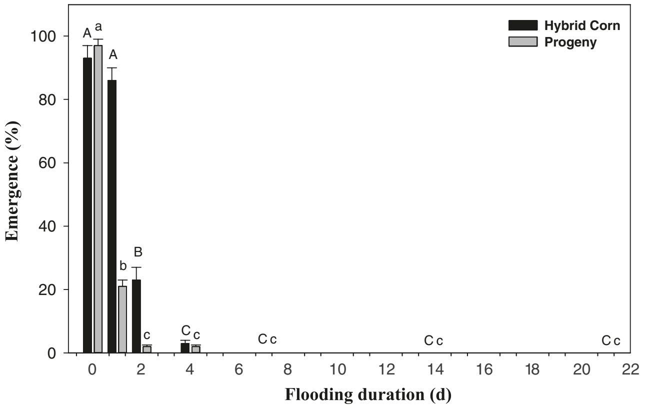


Effect of seed burial depth

At 21 d after planting, the effect of varying seed burial depths on cumulative seedling emergence of hybrid corn and its progeny was significant ($P < 0.001$). The highest cumulative seedling emergence (>87%) of hybrid corn and its progeny was observed at 0.5–6 cm burial depth without difference among them (Fig. 5). The cumulative emergence was slightly reduced (82%–84%) when seeds were sown on the surface of the soil. The cumulative emergence of hybrid corn and its progeny was 84% and 53%, respectively, even at the burial depth of 15 cm. The lower seedling emergence of progeny at deeper burial depth (15 cm) could be due to the variation in seed size compared with the even size of hybrid corn seeds. The cumulative seedling emergence was <20% and 0% at 20 and 25 cm burial depths, respectively, for GR hybrid corn and its progeny.

GR hybrid corn and its progeny emerged up to 15 cm planting depth, while the highest cumulative seedling emergence was observed at 0.5–6 cm burial depth. Similarly, Andrew (1953) reported no difference in the seedling emergence (≥94%) of two different sweetcorn hybrids planted at 2.5 and 10 cm depths. In this study, cumulative emergence was only slightly reduced (82%–84%) when seeds were sown on the surface of the soil, indicating that corn seeds lost during harvest and present on the surface of soil may emerge in spring if they survive winter and are not subjected to predation. Seed reserve can be a factor in seedling emergence behavior at increasing sowing depths (Mennan and Ngouajio 2006), as can weather and soil characteristics (Benvenuti and Macchia 1997). Thus, shallow tillage practices may not be the key agronomic practices to reduce volunteer corn emergence as the seeds incorporated in the soil may emerge even from 15 cm soil depth. In contrast, Knappenberger and Koeller (2012) reported higher corn seedling emergence at the seeding depth of 8–9 cm compared with shallow seeding (4–7 cm deep).

Fig. 6. Cumulative seedling emergence of glyphosate-resistant hybrid corn and its progeny at 35 d after planting at different flooding durations. Bars with the same letter(s) are not significantly different at α = 0.05. Capital letters represent comparison among hybrid corn and small letters represent comparison among progeny. Abbreviation: d, day (s).



Effect of flooding duration

Flooding duration influenced cumulative seedling emergence of GR hybrid corn and its progeny at 35 d after planting ($P < 0.0001$). Cumulative seedling emergence of hybrid corn was not affected by 1 d of flooding and was comparable to the no flooding treatment; however, emergence of progeny was ≤20% (Fig. 6). At 2 d of flooding, the cumulative seedling emergence of hybrid corn and its progeny was reduced to 23% and 2%, respectively. At 4 d of flooding duration, the cumulative emergence of hybrid corn and its progeny was less than 5%. No seedling emergence was observed beyond 4 d of flooding, indicating sensitivity of the hybrid corn and its progeny seeds to excess water conditions continuously for 4 d or more. Thus, results suggest that flooding could be a limiting factor for emergence of hybrid corn as well as for its progeny.

Fausey and McDonald (1985) reported higher emergence of corn inbred compared with the corn hybrids at 2 and 4 d of flooding under laboratory conditions. Temperature can also affect the emergence response of corn to different flooding durations. For example, Fausey and McDonald (1985) observed higher emergence of hybrid and inbred corn to different flooding durations at a lower temperature (10 °C) compared with a higher temperature (25 °C) under laboratory conditions. They also observed a higher emergence of both inbred and hybrid corn when exposed to different flooding durations under field conditions compared with laboratory conditions.

Results have shown that progeny seeds are showing similar germination and emergence response to different agronomic and environmental factors as hybrid corn, with the exception of seed burial depth and flooding duration. Results also suggest that the progeny of GR hybrid corn can germinate and emerge as volunteer corn in crops grown in rotation with corn in Midwestern United States and eastern Canada because of favorable environmental and agronomic conditions. The 30 yr average temperature for spring and summer months in Nebraska ranges from 9.2 °C to 22.2 °C, respectively (NOAA-NCDC 2014), temperatures that are conducive for volunteer corn germination. Similarly, 30 yr average rainfall in Nebraska is 38.8 cm during summer months (May to Sept.) (NOAA-NCDC 2014), sufficient to provide favorable condition for volunteer corn emergence. Thus, the increasing prevalence of GR volunteer corn in the Midwestern United States and eastern Canada can not only be correlated with increased adoption of GR corn, but also to favorable environmental factors for their progeny to emerge.

Practical implication

This is the first report comparing factors affecting germination and emergence of GR hybrid corn and its progeny. The progeny seeds showed similar germination and emergence response to most of the agronomic and environmental factors as hybrid corn. While conducting this study, a constant day/night temperature was maintained in the growth chamber; however, the germination can vary at different fluctuating day/night temperature conditions as maintained in this experiment. In addition, corn seeds (progeny) left over in the field during hybrid corn harvesting may also subject to predation by different insect pests and soil-born diseases resulting in lower germination and emergence as volunteer corn compared with hybrid corn seeds inoculated with fungicides and insecticides.

No pre-emergence herbicide is currently available that effectively controls volunteer corn in soybean (Chahal et al. 2014). Therefore, control of GR volunteer corn is totally dependent on the post application of Acetyl Co-A carboxylase (ACCase) inhibiting herbicides in GR soybean (Deen et al. 2006; Marquardt and Johnson 2013) and a single or sequential application of glufosinate in glufosinate-resistant soybean (Chahal and Jhala 2015). Since this study utilized only one type of corn hybrid and its progeny, the results may vary with different corn hybrids or progeny types under laboratory and specifically under field conditions due to more temperature and light fluctuations. More research needs to be conducted on the germination and emergence response of different corn hybrids (and their progenies) commonly grown in the Midwestern US and eastern Canada under field conditions. This information can be used to develop an integrated volunteer corn management program based on biology, germination ecology, use of improved agronomic practices, herbicide-resistant corn traits, and use of herbicides in corn-soybean cropping systems (Chahal et al. 2016*b*).

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