Factors Influencing Germination and Seedling Emergence of Corncockle (Agrostemma githago) : Insights for Weed Management in Agricultural Systems

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Abstract

Agrostemma githago, a poisonous, noxious, and competitive weed species, can threaten crop yields in various agricultural regions worldwide. Experiments were performed twice to ascertain the effect of temperature, salt stress, osmotic potential, and burial depth on the germination and seedling emergence of *A. githago*. Seeds germinated across various temperatures ranging between 5 and 35°C, while germination was completely inhibited at 40°C. The optimum temperature for maximum germination percentage (GP), maximum germination rate (GR), and minimum mean germination time (MGT) ranged from 17.47°C to 19.37°C. The 50% reduction in GP occurred at 27 ●C. The seeds of *A. githago* germinated over a wide range of osmotic potentials, from 0 to − 1.2 MPa, however, the GP decreased with increasing osmotic potential, where at − 1.2 MPa, germinability was 19%. Similarly, seeds germinated across a broad range of salinities, with a GP of 21% at 300 mM, however, no germination was observed at 350 mM. The osmotic potential and salinity concentration required to inhibit 50% of maximum GP were estimated to be -0.99 MPa and 272 mM, respectively. Thus, it is expected that *A. githago* can germinate in saline and arid environments. The maximum seedling emergence (99%) was observed when seeds were placed on the soil surface. In contrast, no seedling emergence was recorded when seeds were buried at depths greater than 4 cm. Accordingly, deep conventional tillage might be helpful for managing *A. githago*. This knowledge can be implemented for both future research and the development of effective management for *A. githago*.

Introduction

Agrostemma githago L. (common corncockle), a member of the Caryophyllaceae family, is an annual plant species that grows abundantly as a weed in cereal and arable crops (Firbank and Watkinson, 1987). *Agrostemma githago* is native to southwestern and eastern Europe, extending into western Asia, including northern Iran (Anonymous, 2023). Additionally, it has spread to various parts of the world, such as the USA, Canada, Argentina, China, South Africa, Russia, Norway, etc. (Anonymous, 2023). It is also known as a poisonous plant (Hebestreit and Melzig, 2003), as studies have demonstrated its cytotoxic activity (Hebestreit and Melzig, 2003). *Agrostemma githago* seeds have been found to contain saponins, agrostin, githagin, githagenin, and agrostemic acid (Siepmann et al., 1998). It is a mimetic, opportunistic, and competitive weed species that has the potential to reduce wheat yield by up to 10% (Barrett, 1983; Doll et al., 1995). With a strong root system and an erect stem reaching heights of 30–120 cm (Goodrich and Roach, 2013), *A. githago* exhibits strong competitiveness as a weed species. At maturity, *A. githago* seeds contain a complete embryo and typically exhibit physiological seed dormancy (Firbank, 1988; Cucchietti et al., 2021), classifying it as a noxious weed species.

A comprehensive understanding of the biological and ecological characteristics of weeds plays a pivotal role in the implementation of integrated weed management programs, e.g., in the precise timing of herbicide application and the judicious selection of suitable tillage systems (Minbashi Moeini et al., 2021). Although a recent survey indicated a preference for focusing directly on weed management in weed research priorities, there is still a need for further and updated knowledge regarding the biology

and ecology of weeds (Brainard et al., 2023). The processes of germination and seedling emergence are among those crucial ecological factors that provide essential information for understanding the growth and development of weeds (Scherner et al., 2017). Temperature and light are key environmental factors that significantly influence weed seed germination and, consequently, play a crucial role in the distribution of species (Nosratti et al., 2019). In addition to temperature and light, other factors such as pH, osmotic potential, salinity, and burial depth can also affect seed germination and seedling emergence (Chauhan and Johnson, 2009). The effects of these environmental factors have been studied for many weed species (e.g., (Colbach et al., 2002; Rodriguez et al., 2020; Dhanda and Chauhan, 2022; Asaduzzaman et al., 2023; Sousa-Ortega et al., 2023; Yadav et al., 2023; Zhang et al., 2023).

Although it has been suggested that *A. githago* seeds can germinate rapidly after ripening and throughout the year (Firbank and Watkinson, 1987) without the need for chilling (Rühl et al., 2016), there is still a scarcity of published information regarding the determinants of seed germination and seedling emergence of this weed species.

This information can not only be implemented in integrated weed management programs but also used to cultivate normal and healthy individuals of *A. githago* in research projects, such as studying its response to herbicides and competition with crops. Therefore, the objectives of this research were to investigate the effects of different abiotic factors, including temperature, salinity stress, osmotic potential, and seed burial depth, on the germination and seedling emergence of *A. githago.* The study determined the optimum germination temperature, tolerance indices for salinity and osmotic potential, and the detrimental burial depth inhibiting the emergence of *A. githago* seedlings.

Materials and Methods

Collection of Seeds and General Seed Germination Protocol

Fresh mature seeds were collected in May 2020 from a rainfed wheat field in Dezful province, Khuzestan, Iran (32.61964122°N, 48.59746564°E, 541 meters above sea level). The seeds were collected from 50 to 70 plants and were subsequently transferred to the weed laboratory, where they were dried for three days. An initial germination test was conducted, and the results indicated that the seeds did not exhibit dormancy.

As a standardized protocol in all experiments, seed germination tests were conducted using 25 *A. githago* seeds in 10 cm diameter Petri dishes, with a pair of filter paper sheets (Whatman No. 1) placed at the bottom of each Petri dish. The Petri dishes then were moistened with 5 ml of various solutions, including distilled water, polyethylene glycol, and salt concentrations corresponding to the experimental treatments. Immediately after the solutions were added, the Petri dishes were wrapped in Parafilm to minimize evaporation. Germinated seeds were counted every 12 hours and continued to be monitored until no new germination occurred for at least two successive days, as determined at the end of 14-day experimental period. Seeds were considered germinated when the radicle reached a length of at least 2–

3 mm. All experiments were carried out two times, with four replications per treatment at the College of Agricultural Sciences and Natural Resources University of Khuzestan- Iran.

Effect of Temperature on Germinability Traits

Eight constant temperature levels ranging from 5°C to 40°C were examined to determine the optimal germination temperature for *A. githago*. The Petri dishes containing the seeds were placed in an incubator with a photoperiod of 12/12 h light/dark cycle, where a supplementary light source was used to provide a photosynthetic photon flux density of 185 µmol m^{-2} s^{-1}.

Effect of Salinity Stress on Germinability Traits

To determine the maximum level of salinity tolerance in *A. githago* seeds, germination tests were conducted using various salinity concentrations. Eight salinity solutions (0, 50, 100, 150, 200, 250, 300, and 350 mM) were prepared using sodium chloride. The Petri dishes carrying the seeds and salinity solutions were placed in an incubator, following the same protocol as described for the temperature experiment.

Effect of Osmotic Potential on Germinability Traits

The impact of osmotic potential on germinability of *A. githago* was examined by incubating the seeds at osmotic potentials of 0, -0.2, -0.4, -0.6, -0.8, -1, -1.2 and − 1.4 MPa. To achieve these osmotic potentials, polyethylene glycol 6000 (PEG 6000) was dissolved in water. The test was conducted at a temperature of 20°C, which served as a benchmark for the concentrations of PEG 6000.

Effect of Seed Burial Depth on Seedling Emergence Traits

To evaluate the influence of sowing depths on seedling emergence, twenty-five *A. githago* seeds were sown at various burial depths in 10 cm diameter plastic pots. The eight burial depths included 0 (at the soil surface), 0.5, 1, 2, 4, 6, 8 and 10 cm. The pots were filled with field loam soil (clay, 37%; silt, 38%; sand, 25%). After sowing the seeds, the pots were watered as required, specifically when soil moisture exceeded field capacity. Seedlings that emerged were counted daily, with criterion for emergence of seedlings defined as the visibility of the cotyledon. The seedling emergence assay was terminated when no seedling was observed for at least three consecutive days.

Statistical Analyses

All laboratory experiments were conducted with four replications and arranged based on a completely randomized design (CRD). Each experiment was repeated twice. Microsoft Excel (version 2013) was used to calculate germination traits, including the percentage of final germination (GP), mean germination time (MGT), and germination rate (GR). The GP, MGT and GR were estimated using equations 1, 2, and 3, respectively.

The GP was calculated using Eq. 1 as follows:

$$GP\,(\%) = \frac{SG}{NS}$$

1

where GP (%) represents the percentage of final germination, SG is the final number of germinated seeds, and NS is the total number of viable seeds.

The following Eq. (2) was used to calculate the germination rate (GR),

$$GR = \sum \left(\frac{n}{t}\right)$$

2

where *n* represents the number of germinated seeds or emerged seedlings and *t* is the day after the initiation of the test.

The MGT was calculated using the Eq. 3,

$$MGT = \frac{\sum dn}{N}$$

3

where *N* represents the overall count of germinated seeds throughout the experiment, *n* is the number of germinated seeds or emerged seedlings on each day, and *d* is the time elapsed in days from the start of the test.

After calculating seed germination and seedling emergence traits using equations 1, 2, and 3, the obtained parameters were subjected to regression analysis to assess the influence of temperature, salinity, osmotic potential stresses, and seed burial depths on both germination traits and seedling emergence characteristics.

For GP% and SE%, the Eq. 4, a functional three-parameter sigmoidal model, was fitted to the temperature, osmotic potential, salinity, and seed burial depth data (SigmaPlot version 14.0). The three-parameter sigmoidal model was as follows.

$$GP\,(\%) = \frac{G_{max}}{1 + exp\left[-\frac{(x - x_{50})}{G_{rate}}\right]}$$

4

Where GP% represents the final germination percentage, *x* represents either temperature (°C), salinity (mM), osmotic potential (MPa), and/or seed burial depth (cm), EP% represents the percentage of final seedling emergence, G_{max} represents the maximum germination percentage or the maximum seedling

emergence percentage, x_{50} indicates the temperature (°C), salt (mM), osmotic potential (MPa), or seed sowing depth (cm) required for a 50% reduction of the maximum germination or seedling emergence, and G_{rate} represents the slope of the curve.

The effect of temperature on GR was fitted with the Eq. 5, a three-parameter peak Gaussian model.

$$GR\left(seedsperday\right) = GRmax \times exp\left(-0.5 \times \left(\frac{x-c}{b}\right)^2\right)$$

5

Where GR indicates the germination rate (seeds per day), *GRmax* is the maximum germination rate (seeds per day), *x* represents temperature, *b* indicates the slope, and *c* is defined as the temperature where the maximum germination rate occurs.

The effect of osmotic potential and salinity on GR was fitted with a two-parameter simple linear model (Eq. 6):

$$GR\left(seedsperday\right) = a + bx$$

6

where GR is the germination rate, *x* is either osmotic potential based on MPa, or NaCl concentration based on mM, and *b* is the slope.

For MGT, an exponential curve (Eq. 7) was fitted to osmotic potential and NaCl data.

$$MGT\left(Day\right) = a \times exp\left(b \times x\right)$$

7

where, MGT represent mean germination time (day), *x* represents either osmotic potential based on MPa or NaCl concentration based on mM, *a* indicates the intercept, and *b* is slope of curve.

Seedling emergence traits, including percentage of final seedling emergence (EP), mean seedling emergence time (MET), and seedling emergence rate (ER), were also calculated using similar approaches as for the germination traits.

Results

Effect of Temperature on Germination Traits

Seed germination of *A. githago* remained similar at the first four temperatures, including 5 ●C (98.5%), 10 ●C (97.5%), 15 ●C (98%), and 20 ●C (98.5%), respectively. However, seed germination decreased

significantly from 98–4% as the temperature increased from 20 ●C to 35 ●C and was completely inhibited at 40 ●C. The GP of seeds was 72%, 30%, and 4% at 25 ●C, 30 ●C, and 35 ●C, respectively. It is worth noting that a significant difference in the GP was observed between 25 ●C and 30 ●C. The sigmoid model (Eq. 4) fitted to the seed germination data estimated that the 50% reduction in germination took place at 27 ●C (Fig. 1-A). The MGT decreased (from 3.86 to 1.42 days) with the elevation of temperature from 5 ●C to 20 ●C, while it increased (from 1.42 to 3.56 days) at temperatures above 20°C. The minimum MGT was predicted at 19.37°C based on the four-parameter Gaussian equation (Fig. 1-B). The GR (i.e., germination rate) increased from 7.13 to 19.10 seeds per day as the temperature increased from 5 to 20 ●C, but it decreased at temperatures higher than 20°C, reaching 0.24 when the temperature increased to 35 ●C. The appropriate temperature providing the maximum GR was predicted to be 17.47°C based on the four-parameter Gaussian equation (Fig. 1-C).

Figure 1 *near here*

Effect of Osmotic Potential on Germination Traits

The three-parameter sigmoid model (Eq. 4) was fitted well to the GP data, indicating that the germinability of *A. githago* was affected by the concentrations of the osmotic potential. There was no significant decrease in GP until the osmotic potential reached − 0.4 MPa. As the osmotic potential increased from − 0.4 to -1.2 MPa, GP decreased from 95–19%. This means that *A. githago* can germinate across a broad range of osmotic potentials. At -0.6, -0.8, and − 1 MPa, seed germination were 87%, 70%, and 54%, respectively. The osmotic potential needed to inhibit 50% of the final germination was estimated at approximately − 0.99 MPa using the sigmoidal model fitted to the data (Fig. 2-A).

The MGT exhibited an exponential trend (Fig. 2-B). As the osmotic potential elevated from 0 to -1.2 MPa, the MGT increased from 2 to 6 days. The time required for the MGT at -1.2 MPa was three times longer compared to that at 0 MPa. Specifically, the MGT for the − 0.2, -0.4, -0.6, -0.8, and − 1 MPa treatments were 2.28, 3.14, 3.68, 3.92, and 5.53 days, respectively (Fig. 2-B). A linear decline in the relationship between GR and osmotic potential was observed. With increasing osmotic potential from 0 to -1 MPa, the GR significantly decreased from 15 to 2 seeds per day. The GR was 12, 8, 7, and 4 seeds per day at -0.2, -0.4, -0.6, and − 0.8 MPa of osmotic potentials, respectively. As expected, the maximum GR was detected under stress-free conditions (i.e., 0 MPa), while the minimum GR (i.e., 0.69 seeds per day) was observed at -1.2 MPa (Fig. 2-C).

Figure 2 *near here*

Effect of Salinity on Germination Traits

The GP decreased when seeds were exposed to salinity concentrations more than 200 mM. With increasing salinity from 200 to 300 mM, the GP decreased significantly from 98–21%. The GP fully suppressed at 350 mM. The salinity concentration necessary for achieving 50% reduction in the maximum GP was determined to be 272 mM (Fig. 3-A).

An exponential equation was fitted to the data of MGT as the best model. The MGT was below 2.5 days at salinity concentrations less than 150 mM. However, at 300 mM, the MGT increased to 4.5 days, nearly three times higher than the control treatment, which had an MGT of 1.65 days (Fig. 3-B). In contrast the GP and MGT, the GR followed a linear response to concentrations of NaCl. At 0 mM of salinity (non-stress), maximum GR, i.e., 17 seeds per day, was observed. The GR decreased from 14 to 1.2 seeds per day as salinity increased from 50 to 300 mM (Fig. 3-C).

Figure 3 *near here*

Effect of Seed Burial Depth on Seedling Emergence

The seedling emergence data were fitted against burial depths using the three-parameter sigmoid model. This means that seed sowing depth exerted a significant impact on the emergence of *A. githago* seedlings. At burial depths beyond 4 cm, no seedling emergence was recorded. When seeds were sown directly on the soil surface, the maximum seedling emergence was observed (99%). Seedling emergence decreased from 88–10% as the sowing depth increased from 0.5 cm to 4 cm. Seedling emergence at the sowing depths of 1 and 2 cm was 55% and 34%, respectively. The burial depth needed to reduce 50% of the maximum emergence was predicted to be 1.18 cm (Fig. 4-A).

The four-parameter Gaussian equation was used to analyze the trends in MET (i.e., mean emergence time) at various burial depths. The MET for the seeds at 2 cm burial depth was more than twofold compared to the seeds sown on the soil surface. The Gaussian equation predicted the maximum MET, where it was 7.85 days at the seed burial depth of 2.64 cm (Fig. 4-B).

The seedling emergence rate (i.e., SET) decreased as burial depths increased. The maximum SET of 10 seedlings per day was recorded when seeds were sown at the depth of 0 cm, i.e., on the soil surface. The buried depth required to reduce the SET by 50% of the maximum seedling emergence was predicted to be 0.57 cm. This estimation was based on fitting the four-parameter Gaussian equation to the SET data (Fig. 4-C).

Figure 4 *near here*

Discussion

A few researchers have evaluated the germinability of *A. githago*, and various results have been reported. For example, the germination of freshly harvested seeds of *A. githago* collected at three different locations was 73–86% within the first four days (Novakova, 1996), while, Steinbauer and Grigsby (1957) concluded that seeds of *A. githago* germinated promptly after harvest, with a GP of more than 97% at a range of temperatures (10 to 25°C). Similarly, the maximum germination of *A. githago* seeds occurred in the range of 20–24°C, and germination was entirely suppressed at 40°C (Thompson, 1973). This variation might be attributed to genetic diversity among weed populations, and, environmental factors, including parental effects, influence the germinability of weed seeds. These

variations highlight the need to regularly update our knowledge on the germination ecology *of A. githago* regularly.

Our findings indicate that A. githago exhibits a remarkable degree of temperature tolerance within a certain range of 5°C to 20°C. However, the inhibition of germination becomes significantly pronounced as temperatures rise above 20°C, with complete inhibition observed at 40°C. Given that high temperatures inhibited germination more significantly than low temperatures, it can be suggested that *A. githago* species may cause fewer challenges during warmer seasons, where GP are expected to be lower due to high temperatures. Consequently, this suggests that *A. githago* may be less competitive and less likely to establish during periods of extreme heat. In addition to GP, GR and MGT are other plant traits that are used to evaluate and measure the germinability response of weeds and crops to various ecological factors. This means the highest GP, maximum GR, and minimum MGT are considered key germination traits that enable plants to establish early and uniformly, enhancing their competitiveness under low-input growing conditions. The maximum GR and minimum MGT were predicted to be 17.47 and 19.37, respectively, meaning that the optimum temperatures for these two traits fall within appropriate temperature considering GP. Accordingly, it can be concluded that temperatures between 17°C and 20°C favor the germination ecology of the *A. githago* species.

This information holds substantial potential not only for integration into predictive models for germination timing in *A. githago* but also for its application in greenhouse-based research projects aimed at cultivating robust *A. githago* individuals. Importantly, our findings offer valuable insights for stakeholders and farmers in their selection of sowing dates and the appropriate varieties of autumn-sown crops. These decisions can be informed by monitoring regional weather forecasts, particularly when temperatures fall below 17°C or exceed 20°C.

To the most of our knowledge, no study has been conducted to evaluate response of *A. githago* to osmotic potential, salinity, and seed burial depths. The results presented in this study highlight the remarkable adaptability and tolerance of *A. githago* to challenging environmental conditions, i.e., osmotic potential and salinity, during the germination stage. Our findings demonstrate that *A. githago* can thrive across a wide range of osmotic potentials, showcasing its tolerance to high water stress conditions (a GP of 19% at -1.2 MPa) when germinating. This resilience aligns with observations in other weeds such as African mustard (*Brassica tournefortii*) (Chauhan et al., 2006) and Japanese brome (*Bromus japonicus*) (Li et al., 2015), which have also shown the ability to germinate at osmotic potentials as low as -1 MPa and − 1.1 MPa, with 22% and 7%, respectively. In the context of salinity stress, our results demonstrate that *A. githago* exhibits high tolerance to salt stress during germination (a GP of 21% at 300 mM). Notably, the GP of *A. githago* at 200 mM NaCl remained comparable to the control treatment, with a significant reduction occurring only at 250 mM NaCl. This observation is consistent with findings in other weed species such as African mustard (*Brassica tournefortii* Gouan) (Chauhan et al., 2006), American sloughgrass (*Beckmannia syzigachne*) (Rao et al., 2008), and muskweed (*Myagrum perfoliatum* L.) (Honarmand et al., 2016). Japanese brome (*Bromus japonicus*) also exhibited a wide range of salt tolerance, germinating across salt concentrations ranging from 20 to 320 mM, with

inhibition occurring only at 360 mM (Li et al., 2015). The increase in MGT in response to salinity, as observed in our study, aligns with the findings in other species like *Chenopodium album*, where MGT increased as salt concentration rose from 0 to 300 mM (Tang et al., 2022). The adverse impact of salinity and osmotic stress on seed germination can be attributed to the restriction of water imbibition by seeds. Subsequently, the reduced moisture availability can lead to delays or cessation in the initiation of essential internal biochemical processes (Tanveer et al., 2020), ultimately resulting in a postponement or cessation of the germination process. In general, adaptation to arid environments is associated with the ability of those species to germinate at low water potentials (Hu et al., 2015).

The resilience of *A. githago* to osmotic and salinity stress during the germination phase, suggests that *A. githago* has the potential to germinate and may thrive in agricultural fields prone to drought and saline lands contaminated with elevated salt concentrations. Accordingly, care must be taken by farmers when setting crop rotation programs as a weed management practice, especially those encompassing non-competitive autumn-sown crops such as sugar beet in arid regions and saline fields. In addition, the type of tillage is another highly important factor that must be considered in designing management strategies to tackle *A. githago*, as discussed below.

The results provided valuable insights into the impact of burial depth on the seedling emergence of *A. githago*, as all seedling emergence traits, including EP, MET, and SET, were significantly influenced. The results revealed that around 30% of seedling emergence occurred at the 2 cm burial depth. Accordingly, it might be concluded that light may not be a critical necessity for the seed germination of *A. githago.* Nevertheless, it is important to note that further precise and well-designed studies encompassing photosensitivity procedure are needed to test this hypothesis, as described elsewhere (Colbach et al., 2002; Ohadi et al., 2011). However, at burial depths greater than that of 4 cm, no seedling emergence was observed, indicating that seeds of *A. githago* buried at such depths were unable to emerge successfully. This finding has important implications for understanding the establishment and survival of *A. githago* in natural habitats, as it suggests that seeds buried too deeply may not contribute to the population's recruitment. Therefore, it is anticipated that conventional tillage practices, such as moldboard plowing, employed in the rainfed wheat fields of Khuzestan province, represent an effective strategy for controlling *A. githago* in the mentioned growing regions. Consistent with our findings, diminished seedling emergence and population density resulting from increased burial depth have been documented in numerous weed species (Benvenuti et al., 2001; Rao et al., 2008; Schutte et al., 2014; Li et al., 2015; Hussain et al., 2021).

As the four-parameter Gaussian equation revealed, a notable delay in seedling emergence i.e., MET occurred as burial depth increased, where the maximum MET of 7.85 days was predicted at a burial depth of 2.64 cm. This delay in MET might impact their competitiveness with other plant species or their vulnerability to adverse environmental conditions. For example, the result of research by (Rühl et al., 2016) indicated that *A. githago* plants, when experiencing a 7-day delay in germination, exhibited a reduction of 54% in stem count, a decrease of 57% in biomass, 52% fewer flowers, seeds that were 36% lighter, and seeds that were 23% shorter compared to the non-delayed control plants when competing

with barley. Thus, it might be inferred that conventional tillage practices, such as moldboard plowing, not only can hamper seedling emergence of *A. githago*, as mentioned above, but it can also significantly reduce the growth and seed production potential of this species due to delayed germination at greater burial depths.

Conclusions

In conclusion, the results of the present study provide significant insights into the germination ecology and seedling emergence characteristics of *A. githago*, a noxious weed prevalent in agricultural fields. It was revealed that A. githago germinated optimally at temperatures between 17°C and 20°C, with the highest germination percentage, maximum germination rate, and minimum mean germination time observed within this range. This suggests that this weed species may pose fewer challenges during warmer seasons. In response to osmotic potential, *A. githago* exhibited remarkable tolerance to low water potentials, germinating over a wide range of osmotic potentials. Even at -1.2 MPa, germination was still observed, highlighting its ability to withstand osmotic stress. Similarly, *A. githago* showed a high tolerance to salinity, germinating well at salinity concentrations up to 200 mM. Although germination decreased significantly at higher salinity levels, it remained at 21% at 300 mM NaCl. These indicate that *A. githago* can potentially germinate and thrive in challenging environments. Regarding seedling emergence, it was found that burial depths exceeding 4 cm led to no seedling emergence. The maximum seedling emergence (99%) was detected when seeds were sown on the soil surface.

To sum up, these findings enhance our understanding of the ecological characteristics of *A. githago* and provide valuable information for weed management strategies. The temperature and environmental conditions favoring its germination and emergence can inform timing and tactics for weed control e.g., selection of sowing dates and the appropriate varieties of autumn-sown crops. Additionally, the high tolerance of *A. githago* to osmotic stress and salinity implies its potential to thrive in saline and arid agricultural fields, necessitating careful consideration in crop rotation programs and weed management practices. Sensitivity of *A. githago* to burial depth suggests that deep conventional moldboard tillage in the fall, burying seeds beyond 4 cm, can be an effective strategy for managing this species in rainfed regions. These findings are relevant not only for weed management practices as mentioned but also for further studies on herbicide responses and crop competition.

Declarations

Author contribution statement

EZ and EK conceived and designed the experiments. EZ conducted the experiments. EZ and EK analyzed the data. EZ and EK wrote, read, and approved the manuscript.

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Conflict of interest

The authors declare no conflict of interest.

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Figures

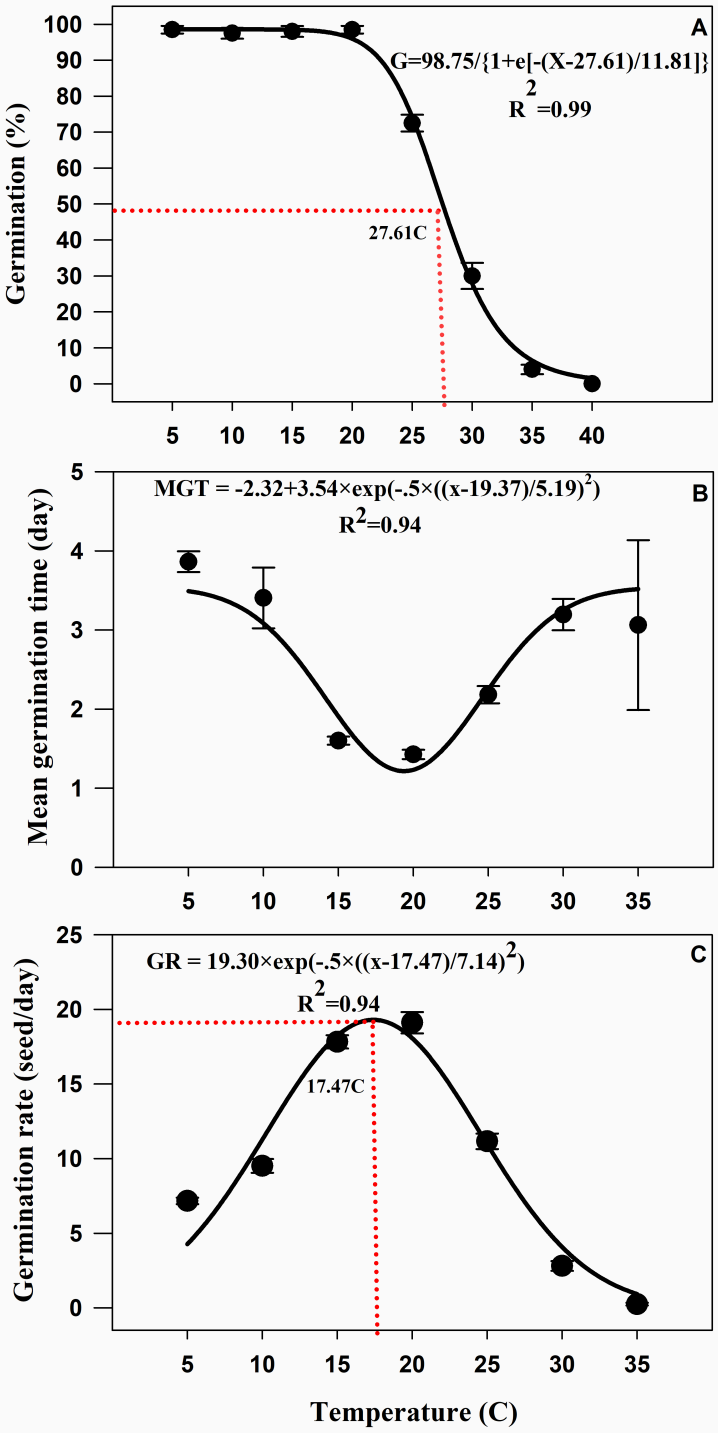

Figure 1

Effects of temperatures on germination traits of A. githago, including final germination (A), mean germination time (B) and germination rate (C). Error bars represent standard errors of the mean.

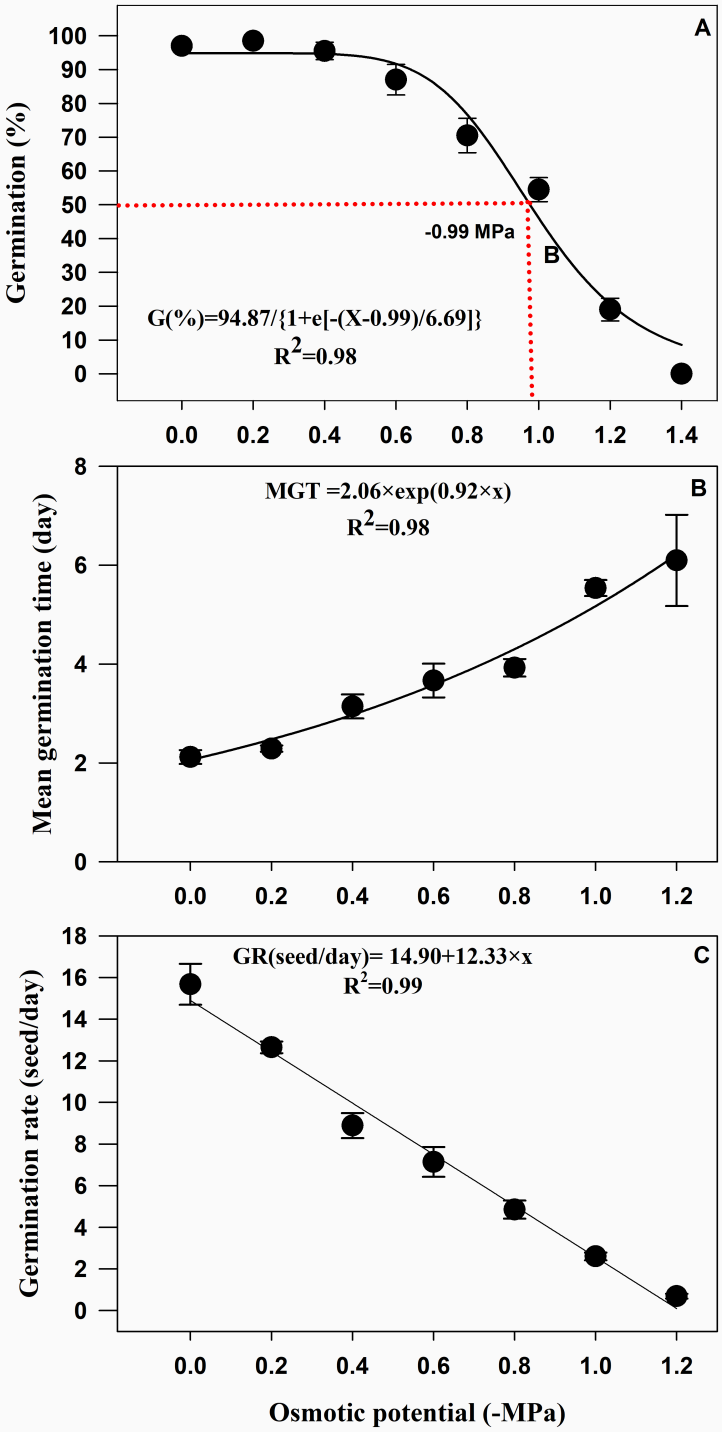

Figure 2

Effects of osmotic potential on germination traits of *A. githago*, including final germination (A), mean germination time (B), and germination rate (C). Seeds were incubated in a growth chamber at a temperature of 20 °C. Error bars represent standard errors of the mean.

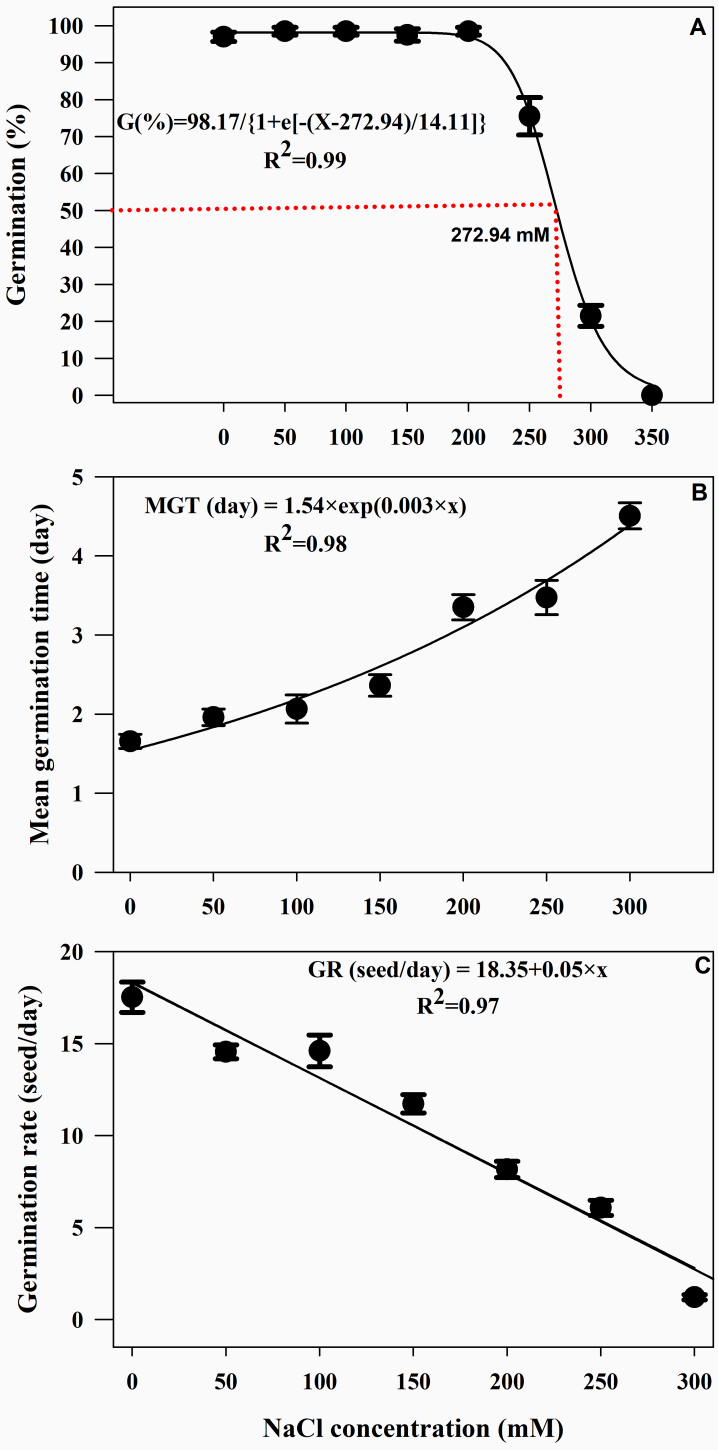

Figure 3

Effect of salinity concentrations on germination traits of *A. githago*, including final germination (A), mean germination time (B) and germination rate (C). Seeds were incubated in a growth chamber at a temperature of 20 °C. Error bars represent standard errors of means.

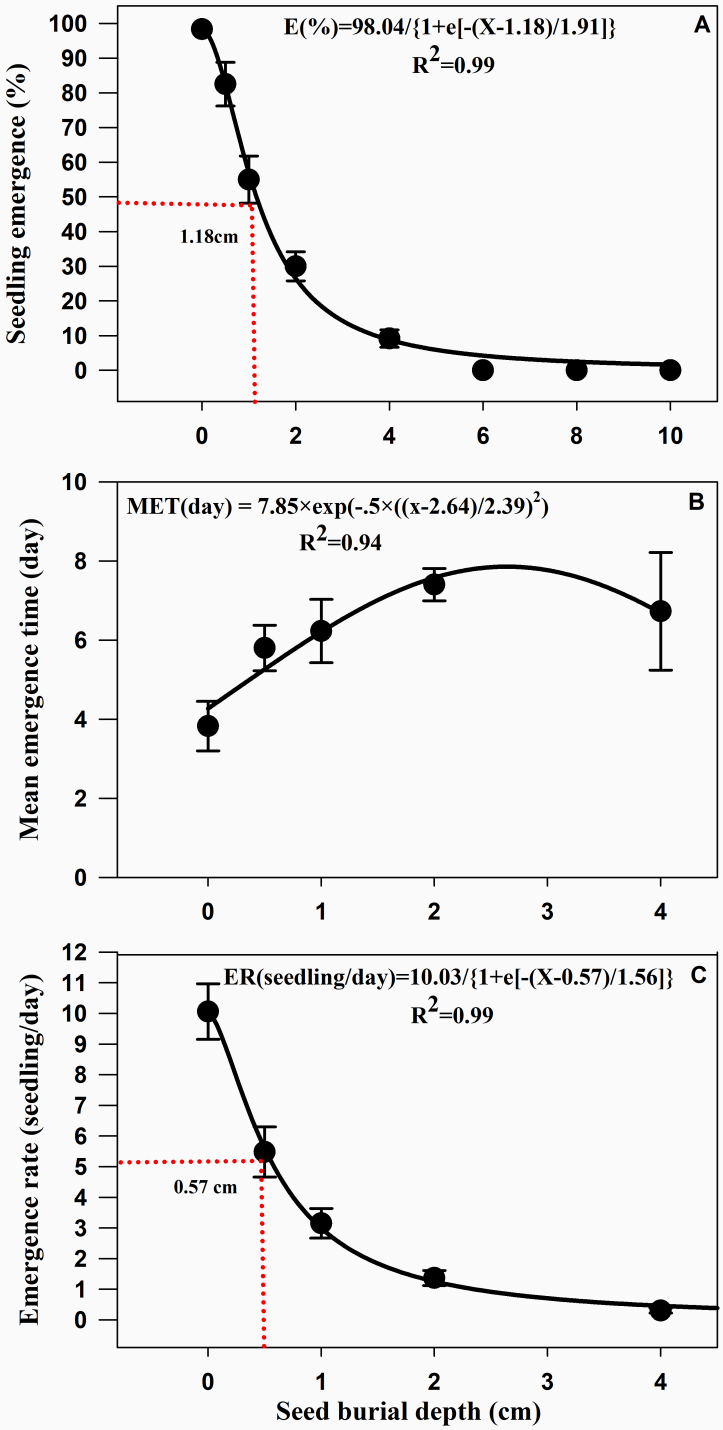

Figure 4

Effect of seed burial depth on seedling germination traits of *A. githago,* including final seedling emergence (A), mean emergence time (B), and emergence rate (C). Seeds were incubated in a growth chamber at a temperature of 20 °C. Error bars represent standard errors of means.