CHILEAN JOURNAL of AGRICULTURAL RESEARCH

CHILEANJAR
CHILEAN JOURNAL of AGRICULTURAL RESEARCH

RESEARCH ARTICLE

Effects of environmental factors on seed germination and seedling emergence of Tausch's goat grass (*Aegilops tauschii* Coss.)

Pei Zhang[1, 2, 3*], Xinyang Yuan[3], Xiangyu Wang[3], Hongliang Wang[3], Songwei Li[3], and Lin Zhou[2*]

[1]Henan Institute of Science and Technology, Postdoctoral Research Base, Postdoctoral Innovation & Practice Base, Xinxiang 453003, China.
[2]Henan Agricultural University, Postdoctoral Research Station, Zhengzhou 450002, China.
[3]Henan Institute of Science and Technology, College of Resources and Environment, Xinxiang 453003, China.
[*]Corresponding author (zhangpei0519@126.com; zhoulinhenau@163.com).
Received: 18 June 2024; Accepted: 28 September 2024, doi:10.4067/S0718-58392025000200206

ABSTRACT

Tausch's goat grass (*Aegilops tauschii* Coss.) is a troublesome and widespread weed that poses a significant challenge in winter wheat fields. Understanding the germination biology of Tausch's goat grass is crucial for predicting its potential distribution area. To better understand its germination and emergence ecology, this study evaluated the effects of various environmental factors on seed germination and seedling emergence in laboratory and greenhouse experiments. Seed germinations were settled across a range of constant temperatures (5, 10, 15, 20, 25, and 27 °C), and optimal germination rates were observed at 5, 15, 20, and 25 °C. The light and pH had no discernible effect on germination. Germination in this study was inhibited at osmotic potentials ranging from 0 to-0.7 MPa. The seedling emergence rate was highest (100%) when seeds were not buried (depth of 0 cm), emergence gradually declined while the depth of burial increased, no seedlings emerge at the depth of 6 cm. Those implied that deep plowing could effectively limit germination and emergence of this species. This study provides valuable insights into the germination conditions of Tausch's goat grass and lays the groundwork for scientific prediction and control measures.

Key words: *Aegilops tauschii*, biological characteristics, emergence, germination, weed.

INTRODUCTION

Tausch's goat grass (*Aegilops tauschii* Coss.) is a highly detrimental weed that proliferates rapidly within wheat fields. It is a major malignant weed in winter wheat planting areas of North China (Yu et al., 2021). Previous studies had indicated that Tausch's goat grass caused great damage in winter wheat fields across more than 20 provinces in China in 2007, including Hebei, Shanxi, Shandong, Henan, Shaanxi, Jiangsu, Anhui, and Inner Mongolia (Wang et al., 2019; Su et al., 2020; Wang et al., 2021). This invasive species competes with other wheat varieties for essential environmental resources such as water, nutrients, and light, significantly impacting the local growing environment. Consequently, it adversely affects the yield and quality of local winter wheat, resulting in substantial economic losses for farmers and growers. Studies have shown that when Tausch's goat grass is grown at densities of 50 and 200 plants per square meter, the annual wheat yield is reduced by 19.1% and 47.6%, respectively. Tausch's goat grass growth habit closely resembles that of wheat: It emerges in fields from early September to early November and ripens from late May to early June of the following year. The rachis gradually falls off during maturity (Yu et al., 2021).

Tausch's goat grass has the remarkable ability to grow and transmit seeds over long distances, facilitated by their introduction and sowing with combine harvesters. They could gradually form the seed bank once after seeds and spikelets fall onto the soil surface. Therefore, understanding these seed growth, germination and seed emergence could aid in predicting the potential distribution of Tausch's goat grass and developing effective management strategies. The germination of Tausch's goat grass seeds is closely related to both intrinsic and external environmental factors. These factors include soil temperature, light exposure, soil humidity, pH, and nitrite concentration (Chauhan et al., 2006; Zhao et al., 2018). Sufficient soil moisture is a fundamental condition for the growth and germination of Tausch's goat grass seeds. When soil water is scarce, it can lead to delayed germination, reduced growth rates, and even inhibition of germination (Javaid and Tanveer, 2014). Interestingly, weed seeds with better resistance to acid-base stress and salt stress exhibit improved germination rates and competitiveness (Chauhan and Johnson, 2008). However, sowing depth is a critical factor affecting the emergence rate of Tausch's goat grass seeds. Different sowing depths indirectly impact the growth and distribution of these seeds, which in turn directly affects their seedling emergence (Chauhan and Johnson, 2010). The objectives of this study were to determine the effects of temperature, light, salt and osmotic stress, pH and burial depth on germination and seedling emergence of Tausch's goat grass.

MATERIALS AND METHODS

Seed source and general protocol for germination tests

Tausch's goat grass (*Aegilops tauschii* Coss.) seeds were collected from several fallow fields in Xinxiang City, China (35°22' N, 113°54' E), in May 2019. Dried seeds were stored in paper bags at room temperature (25 ± 5 °C) until use.

The experiments were conducted using the petri dish method (Ebrahimi and Eslami, 2012; Huarte et al., 2016). Unless otherwise specified, seed germination was assessed by placing 20 seeds in a 9 cm petri dish containing two pieces of filter paper moistened with 5 mL either distilled water or a test solution. Each germination trial was repeated twice and consisted of three replicates. Parafilm was used to seal all dishes, which were then placed in an illumination incubator at a constant temperature of 20 °C. After 21 d of sowing, the number of germinated seeds, those with coleoptiles protruding 2 mm from the glume, was observed and counted for statistical analysis. Additionally, at the end of the experiment, the viability of non-germinated seeds was tested using a 0.4% tetrazolium chloride solution. A viable seed exhibited a pink to reddish color in the embryo after 4 h (Wu et al., 2015).

Effect of temperature and light on seed germination

In the constant temperature treatment, there are six temperature gradients: 30, 25, 20, 15, 10, and 5 °C, respectively. All other conditions remained unchanged (Akbari-Gelvardi et al., 2021; Chu et al., 2022). To evaluate seed germination, 20 seeds were positioned in a 9 cm petri dish with two moistened filter papers using 5 mL of either distilled water or a test solution. Each germination experiment was conducted twice, with each trial comprising three replicates. After 21 d following seed sowing, the germination count was taken, focusing on seeds whose coleoptiles had emerged 2 mm from the husk, for the purpose of statistical evaluation.

The light treatment regimens were 24:0 (continuous light), 12:12 (alternating 12 h light and darkness), and 0:24 (complete darkness). To ensure total darkness, the Petri dishes were encased in two layers of aluminum foil, which prevents any light penetration. All other conditions remained constant (El Rasafi et al., 2021; Xu et al., 2021).

Effect of pH on seed germination

Tausch's goat grass seeds were placed in a range of pH buffers (pH 4, 5, 6, 7, 8, 9 and 10), buffers for pH 9 and 10 were prepared with 1 mol·L^{-1} NaOH and 2 mmol·L^{-1} tricine at pH 9 and 10, respectively. The pH 7 and 8 buffers contained with 1 mol·L^{-1} NaOH and 2 mmol·L^{-1} 4-(2-hydroxyethyl) piperazine-1-ethanesulfonic acid (HEPES). Similarly, pH 5 and 6 buffers were made with 1 mol·L^{-1} NaOH and 2 mmol·L^{-1} 4-morpholineethanesulfonic acid (MES), respectively. A buffer with a pH value of 4 was created using 1 mol·L^{-1} HCl and 2 mmol·L^{-1} potassium hydrogen phthalate. The distilled water, with a pH of 6.7, served as the control, all other conditions remaining unchanged (Javaid and Tanveer, 2014; Tong et al., 2021).

Effect of osmotic potential and salt stress on seed germination

To assess the impact of osmotic stress on seed germination, the following quantities of polyethylene glycol 6000 (PEG6000) were weighed: 7.251, 11.238, 14.529, 17.241, 19.639, 21.813, and 23.816 g. Each amount was then dissolved in 100 mL distilled water to prepare the solutions. This process resulted in aqueous solutions with osmotic potentials of -0.1, -0.2, -0.3, -0.4, -0.5, -0.6, and -0.7 MPa, respectively. Tausch's goat grass seeds were immersed in these solutions, each representing a different osmotic potential gradient. Distilled water, with an osmotic potential of 0 MPa, served as the control, and all other experimental conditions were kept constant (Michel and Kaufmann, 1973; Evamoni et al., 2023; Çiğ et al., 2024).

NaCl was used to prepare treatment solutions with different concentration gradients; 0.058, 0.167, 0.234, 0.468, 0.935 and 1.870 g NaCl were dissolved in 100 mL distilled water, respectively. NaCl solutions with concentrations of 10, 20, 40, 80, 160 and 320 $mmol \cdot L^{-1}$ were obtained, and distilled water (0 $mmol \cdot L^{-1}$) was used as control (Tian et al., 2021).

Effect of sowing depth on seed emergence

This study examined the effects of various planting depths on the emergence of Tausch's goat grass seeds within a growth chamber. The seeds were sown at depths of 0.5, 1, 2, 3, 4, 5, 6, and 7 cm, constituting a total of eight treatments. The soil for the experiment was a 1:1 volumetric mixture of nutritional soil and medium loam soil (pH 7-8), sourced from fields in the Hongqi District of Xinxiang City, which are devoid of any existing Tausch's goat grass seedbank. Subsequently, the seeds were placed in plastic containers with perforated bottoms, lined with filter paper, measuring 9.0 cm in diameter at the base, 12.0 cm at the top, and approximately 10 cm in depth. Twenty Tausch's goat grass seeds were planted in each container. The containers were regularly watered to maintain the ideal soil moisture level for germination. For cultivation, the containers were placed in an incubator set to a constant temperature of 20 °C and equipped with consistent lighting. Seed emergence was identified when the germ protruded 2 mm above the soil surface. After 21 d from sowing, the number of emerged seeds and the germination of Tausch's goat grass seeds were recorded. From these data, the emergence and germination rates were calculated (Huarte et al., 2016).

Statistical analysis

The final germination percentage (FG %) was calculated:

$$FG\% = (SG/TS) \times 100 \qquad (1)$$

where SG is the number of germinated seeds per treatment and TS is the total number of seeds per treatment.

The trial was repeated at least three times and was completely randomized. The obtained data were sorted out and analyzed statistically. The process of seed germination and emergence was nonlinear fitting by SigmaPlot software (SYSTAT Software, San Jose, California, USA).

The fitting formula of the effects of salt stress and osmotic potential on the total germination rate of seeds is as follows (Eslami, 2011):

$$G(\%) = G_{max}/[1+(x/x_{50})^{g}] \qquad (2)$$

where G is the final germination rate (%) at NaCl concentration or osmotic potential X, G_{max} is the maximum germination rate, x_{50} is the NaCl concentration or osmotic potential when the maximum germination rate reaches 50%, and g is the slope of the equation.

The fitting formula of the influence of sowing depth on the total seed emergence rate is as follows (Norsworthy and Oliveira, 2006):

$$E(\%) = a/\{1+\exp[-(x- t_{E50})/b]\} \qquad (3)$$

where E indicates the total seedling emergence (%) at burial depth x, a is the maximum seedling emergence (%), t_{E50} is the depth with 50% of maximum seedling emergence, and b is the slope of the equation at t_{E50}.

RESULTS

Effect of temperature and light on seed germination

The seeds of paniculate Tausch's goat grass exhibit germination across a temperature range of 5-25 °C, with the optimal germination temperatures being 15-25 °C (Figure 1). Within this optimal range, the germination rate reaches 100%. At a lower temperature of 10 °C, the germination rate slightly decreases to 92%. Interestingly, even at the lower bound of 5 °C, the seeds maintain a germination rate of 100%. However, as temperatures rise above 27 °C, the germination rate declines sharply, falling to 84% at 27 °C. At 30 °C, germination is completely halted, indicating that high temperatures, even with sufficient cumulative effective temperature, impede the germination process. These findings underscore the significance of temperature as a critical factor influencing the germination of Tausch's goat grass seeds.

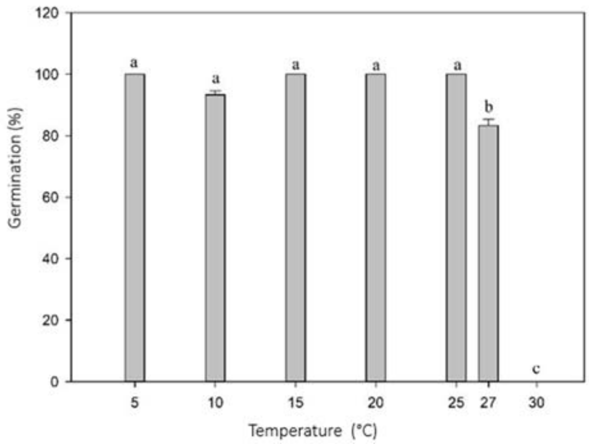

Figure 1. Effects of temperature on germination rate of Tausch's goat grass seeds.

Light is recognized as a significant factor in seed germination (Pons, 1991). During the light treatments (0:24 h, 12:12 h, 24:0 h), Tausch's goat grass seeds exhibited a germination rate of 100% after 21 d (Figure 2). These findings demonstrate that light exposure does not influence the germination of Tausch's goat grass seeds. Consequently, light is not a determining factor for the germination of these seeds, and variations in light duration do not affect their germination rates. The data also imply that the seeds are capable of germinating both within the soil and on its surface. The lack of sensitivity to light enhances the competitiveness of Tausch's goat grass in various environments, contributing to the plant's proliferation.

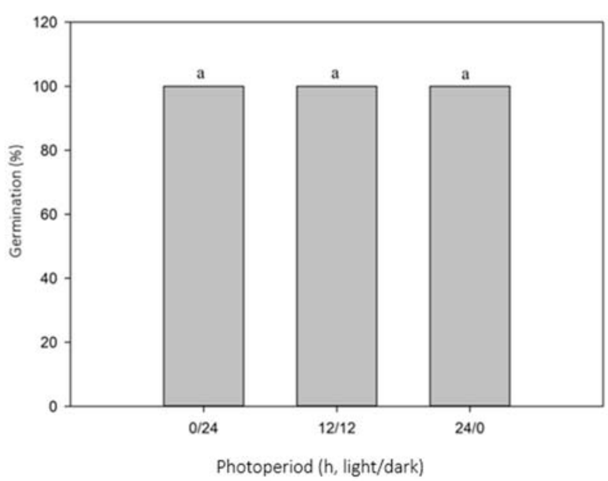

Figure 2. Effects of light on seed germination of Tausch's goat grass seeds.

Effect of pH on seed germination

The germination rate of Tausch's goat grass seeds in distilled water reached 100%. Across a pH spectrum of 4-10, the seeds consistently achieved a germination rate of approximately 100%, showing nonsignificant difference when compared to the control (Figure 3). This indicates that Tausch's goat grass seeds can germinate effectively within the pH range of 4-10, and fluctuations within this pH spectrum do not markedly affect their germination. The findings reveal that Tausch's goat grass seeds possess a degree of tolerance to varying acidic and alkaline environmental conditions.

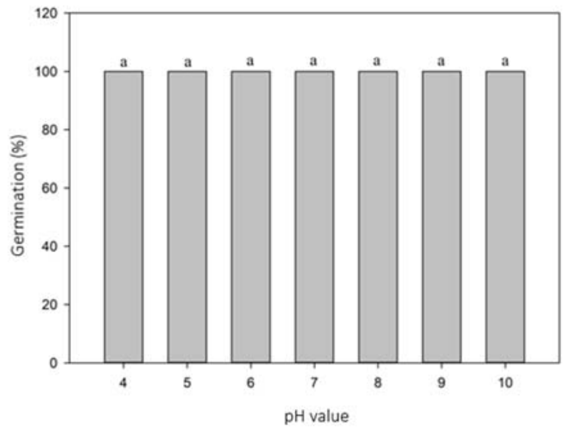

Figure 3. Effect of pH on germination rate of Tausch's goat grass seeds.

Effect of osmotic potential and salt stress on seeds germination

The germination rate of Tausch's goat grass seeds remained at 100% after 21 d for osmotic potentials of-0.1, -0.2, and-0.3 MPa, in line with the control group (Figure 4). However, at an osmotic potential of-0.4 MPa, the germination rate slightly declined to 96%. A further decrease in osmotic potential from-0.5 to-0.7 MPa resulted in a reduction of germination rates from 98% to 86%. These observations indicate that while the germination rate of Tausch's goat grass seeds diminishes as osmotic potential decreases, the seeds exhibit a degree of resistance to osmotic stress.

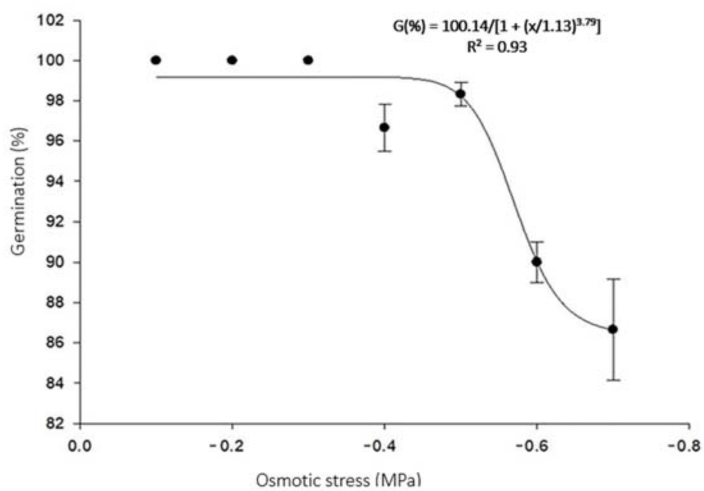

Figure 4. Effect of osmotic potential on germination of Tausch's goat grass seeds.

After 21 d of treatment, the germination rate of Tausch's goat grass seeds showed a decline with increasing concentrations of NaCl (Figure 5). The seeds maintained a germination rate of 100% at NaCl concentrations of 10, 20, 40, and 80 mmol·L^{-1}. However, at a concentration of 160 mmol·L^{-1}, the rate decreased to 88%. Germination was completely inhibited at a concentration of 320 mmol·L^{-1}. These findings demonstrate that Tausch's goat grass seeds are highly adaptable to NaCl stress and exhibit considerable tolerance even at elevated NaCl levels.

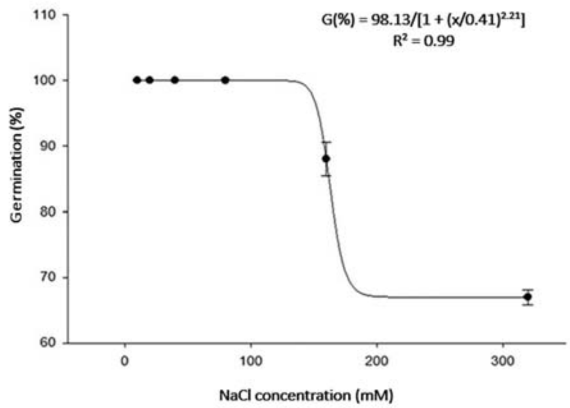

Figure 5. Effect of NaCl stress on germination of Tausch's goat grass seeds.

Effect of burial depth on seed emergence

The results in this study revealed that the germination rate of Tausch's goat grass seeds diminishes with increasing sowing depth (Figure 6). The highest seedling emergence rate (100%) was recorded for seeds placed on the soil surface. At a depth of 0.5 cm, the emergence rate was 80%. However, as the sowing depth increased, there was a marked decline in germination rates. At a depth of 4 cm, only 20% of the seeds germinated. No germination occurred at depths of 5 and 6 cm. According to the fitted model, a depth of 2.09 cm is required to reduce the maximum emergence rate by 50%. These findings suggest that the vertical distribution of seeds within the soil exerts a significant impact on both germination and seedling emergence.

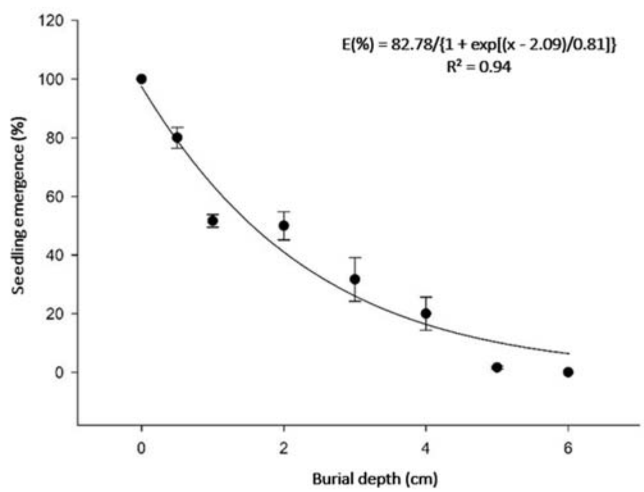

Figure 6. Effects of sowing depth on seed germination of Tausch's goat grass seeds.

DISCUSSION

Seed germination is influenced by dormancy and a variety of environmental factors. For a seed to be viable and germinate, it requires appropriate environmental conditions, including sufficient water, an optimal concentration of oxygen, appropriate temperature, light, inorganic salts, and organic matter (Chauhan, 2022). This pattern is consistent with other weed species found in wheat fields, which predominantly germinate within this temperature range. For instance, *Alopecurus aequalis* Sobol. exhibits its highest germination rate at temperatures between 15-25 °C (Zhao et al., 2018), while *Bromus japonicus* Houtt. maintains a germination rate above 98% across a broader temperature range of 5-30 °C (Li et al., 2015), indicating a germination advantage at constant temperatures compared to Tausch's goat grass. Our experimental observations suggest that Tausch's goat grass seeds are not dormant in dark conditions, as evidenced by the comparable proportion of seeds germinating in darkness to those in light.

The research on Tausch's goat grass adaptability to various pH levels holds significant biological importance for predicting its occurrence. In China, soil pH ranges from 3.3 to 10.5 from southeast to northwest, with most areas falling between 4.5 and 8.5 (Chen et al., 2019; Xie et al., 2022). These findings suggest that the soil pH range prevalent in agricultural settings is conducive to the germination of Tausch's goat grass. This also accounts for the widespread distribution of Tausch's goat grass in Chinese wheat fields. Consequently, soil pH does not constitute a limiting factor for the germination and dispersal of Tausch's goat grass seeds within this range. Additionally, the germination rate of Tausch's goat grass was 86.6% at an osmotic potential of -0.7 MPa, indicating a tolerance to osmotic stress. In contrast, another weed species, *Ipomoea eriocarpa* R. Br., exhibited only a 7% germination rate at an osmotic potential of 0 MPa (Tanveer et al., 2020). This disparity suggests that dry seeds have varying water requirements for cellular metabolism across different species (Larson and Kiemnec, 2005).

Salinity incrementally diminishes germination rates as concentrations rise, indicating that the species may struggle to thrive in highly saline environments. Certain weed species are known to resist NaCl concentrations and can germinate under saline stress (Li et al., 2015). Conversely, elevated NaCl levels can inhibit the germination of many weeds, potentially leading to mortality (Koger et al., 2004). Wild oat seeds demonstrate the ability to germinate across a NaCl concentration range of 0 to 320 mM, showcasing a robust tolerance to salinity. These seeds exhibit a broad adaptability to varying salt concentrations, enabling them to germinate and survive in most soil types across China, including the Northwest region (Wu et al., 2018).

Similar to Tausch's goat grass, other weed species such as *A. aequalis* (Zhao et al., 2018) and *B. japonicus* (Li et al., 2015) exhibit the highest germination rates when seeds are sown on the surface. The germination of Tausch's goat grass is completely inhibited at a sowing depth of 6 cm, demonstrating the significant role of light in seed germination. The maximum emergence rate (100%) occurs when seeds are sown at the soil surface, and it is completely inhibited at 6 cm. These findings indicate that the establishment of Tausch's goat grass becomes increasingly difficult when seeds are buried deeper than 2 cm, as evidenced by the reduced emergence rates. Therefore, plowing seeds to a depth of less than 6 cm during tillage operations may be an effective strategy for managing Tausch's goat grass.

CONCLUSIONS

Overall, this study indicates that Tausch's goat grass has the ability to propagate and germinate across a range of environmental conditions prevalent throughout much of northern China. However, due to the fact that Tausch's goat grass reaches maturity earlier than wheat and some of its seeds are shed prior to the wheat harvest, it can potentially outcompete other weeds. To manage this weed, control measures are often implemented in the autumn when the temperature is optimal for germination. The highest rate of seedling emergence is observed when seeds are sown at the soil surface, which contributes to Tausch's goat grass becoming a dominant weed in no-till farming systems, as the seeds are deposited on the soil surface following the harvest of the crop. Consequently, in agricultural fields with a heavier infestation of Tausch's goat grass, seeds can be tilled deeper than the level at which the weed's maximum emergence rate occurs.

Author contributions

Conceptualization: P.Z. Methodology: P.Z., X.Y. Software: X.Y., X.W. Validation: X.Y., X.W. Formal analysis: P.Z., X.Y., X.W. Investigation: P.Z., X.Y., X.W. Resources: P.Z. Data curation: P.Z., L.Z. Writing & original draft: P.Z., X.Y. Writing-review & editing: H.W., S.L., L.Z. Visualization: P.Z. Supervision: P.Z., L.Z. Project administration: P.Z. Funding acquisition: P.Z. All co-authors reviewed the final version and approved the manuscript before submission.

Acknowledgements
This work is supported by the Scientific and Technological Foundation of Henan Province in China (222102110074) and Postdoctoral research project of Henan Province (HN2022121).

References
Akbari-Gelvardi, A., Siahmarguee, A., Ghaderi-Far, F., Gherekhloo, J. 2021. The effect of environmental and management factors on seed germination and seedling emergence of Asian spiderflower (*Cleome viscosa* L.) Weed Research 61(5):350-359. doi:10.1111/wre.12493.

Chauhan, B.S. 2022. Germination biology of liverseedgrass (*Urochloa panicoides*) and its response to postemergence herbicides in Australian conditions. Weed Science 70(5):553-560. doi:10.1017/wsc.2022.50.

Chauhan, B.S., Gill, G., Preston, C. 2006. African mustard (*Brassica tournefortii*) germination in southern Australia. Weed Science 54(5):891-897. doi:10.1614/WS-06-053R.1.

Chauhan, B.S., Johnson, D.E. 2008. Germination ecology of goosegrass (*Eleusine indica*): An important grass weed of rainfed rice. Weed Science 56(5):699-706. doi:10.1614/WS-08-048.1.

Chauhan, B.S., Johnson, D.E. 2010. Chapter 6. The role of seed ecology in improving weed management strategies in the tropics. Advances in Agronomy 105:221-262. doi:10.1016/S0065-2113(10)05006-6.

Chen, S.C., Liang, Z.Z., Webster, R., Zhang, G.L., Zhou, Y., Teng, H.F., et al. 2019. A high-resolution map of soil pH in China made by hybrid modelling of sparse soil data and environmental covariates and its implications for pollution. Science of the Total Environment 655:273-283. doi:10.1016/j.scitotenv.2018.11.230.

Chu, L., Gao, Y.P., Chen, L.L., McCullough, P.E., Jespersen, D., Sapkota, S., et al. 2022. Impact of environmental factors on seed germination and seedling emergence of white clover (*Trifolium repens* L.) Agronomy 12(1):190. doi:10.3390/agronomy12010190.

Çiğ, F., Erman, M., Sabagh, A.E., Ceritoglu, M., Soysal, S., Uçar, Ö., et al. 2024. Screening of lentil genotypes during germination and early growth stages under PEG-induced drought stress. Chilean Journal of Agricultural Research 84:326-337. doi:10.4067/s0718-58392024000300326.

Ebrahimi, E., Eslami, S.V. 2012. Effect of environmental factors on seed germination and seedling emergence of invasive *Ceratocarpus arenarius*. Weed Research 52(1):50-59. doi:10.1111/j.1365-3180.2011.00896.x.

El Rasafi, T., Bouda, S., Hamdali, H., Haddioui, A. 2021. Seed germination and early seedling growth of fenugreek (*Trigonella foenum-gracium* L.) under Cu, Ni and As stress. Acta Ecologica Sinica 41(3):223-227. doi:10.1016/j.chnaes.2021.02.014.

Eslami, S.V. 2011. Comparative germination and emergence ecology of two populations of common lambsquarters (*Chenopodium album*) from Iran and Denmark. Weed Science 59(1):90-97. doi:10.1614/ws-d-10-00059.1.

Evamoni, F.Z., Nulit, R., Yap, C.K., Ibrahim, M.H., Sidek, N.B. 2023. Assessment of germination performance and early seedling growth of Malaysian indica rice genotypes under drought conditions for strategic cropping during water scarcity. Chilean Journal of Agricultural Research 83:281-292. doi:10.4067/s0718-58392023000300281.

Huarte, H.R., Zorraquin, M.D.P., Bursztyn, E.M., Zapiola, M.L. 2016. Effects of environmental factors on seed germination and seedling emergence of common teasel (*Dipsacus fullonum*). Weed Science 64(3):421-429. doi:10.1614/ws-d-15-00136.1.

Javaid, M.M., Tanveer, A. 2014. Germination ecology of *Emex spinosa* and *Emex australis*, invasive weeds of winter crops. Weed Research 54(6):565-575. doi:10.1111/wre.12111.

Koger, C.H., Reddy, K.N., Poston, D.H. 2004. Factors affecting seed germination, seedling emergence, and survival of texasweed (*Caperonia palustris*). Weed Science 52(6):989-995. doi:10.1614/WS-03-139R2.

Larson, L., Kiemnec, G. 2005. Germination of two noxious range weeds under water and salt stresses with variable light regimes. Weed Technology 19(1):197-200. doi:10.1614/WT-04-139R.

Li, Q., Tan, J.N., Li, W., Yuan, G.H., Du, L., Ma, S., et al. 2015. Effects of environmental factors on seed germination and emergence of Japanese brome (*Bromus japonicus*). Weed Science 63(3):641-646. doi:10.1614/ws-d-14-00131.1.

Michel, B.E., Kaufmann, M.R. 1973. The osmotic potential of polyethylene glycol 6000. Plant Physiology 51(5):914-916. doi:10.1104/pp.51.5.914%J Plant Physiology.

Norsworthy, J.K., Oliveira, M.J. 2006. Sicklepod (*Senna obtusifolia*) germination and emergence as affected by environmental factors and seeding depth. Weed Science 54(5):903-909. doi:10.1614/WS-06-070R2.1.

Pons, T.L. 1991. Induction of dark dormancy in seeds: Its importance for the seed bank in the soil. Functional Ecology 5(5):669-675. doi:10.2307/2389487.

Su, Y., Zou, M., Zhu, Y., Han, X., Li, Y., Zhang, D., et al. 2020. Analysis of population structure and origin in *Aegilops tauschii* Coss. from China through SNP markers. Genetic Resources and Crop Evolution 67(4):923-934. doi:10.1007/s10722-020-00890-y.

Tanveer, A., Khan, M.A., Ali, H.H., Javaid, M.M., Raza, A., Chauhan, B.S. 2020. Influence of different environmental factors on the germination and seedling emergence of *Ipomoea eriocarpa* R. Br. Crop Protection 130(6):105070. doi:10.1016/j.cropro.2019.105070.

Tian, X., Mao, P., Zheng, M., Meng, Q., Meng, L. 2021. Seed germination and biochemical responses of two *Elytrigia elongata* accessions exposed to abiotic stresses. Grassland Science 67(4):369-379. doi:10.1111/grs.12328.

Tong, R.Q., Liu, X.Y., Mu, B.F., Wang, J.F., Liu, M.X., Zhou, Y.C., et al. 2021. Impact of seed maturation and drought on seed germination and early seedling growth in white clover (*Trifolium repens* L.) Legume Research 44(6):Lr-555. doi:10.18805/lr-555.

Wang, N., Tian, Y., Chen, H. 2021. Effects of mesosulfuron-methyl on growth and competitiveness of *Aegilops tauschii* and *Triticum aestivum*. Acta Physiologiae Plantarum 43(2):39. doi:10.1007/s11738-021-03206-4.

Wang, N., Yuan, M.L., Chen, H., Li, Z.Z., Zhang, M.X. 2019. Effects of drought stress and rewatering on growth and physiological characteristics of invasive *Aegilops tauschii* seedlings. Acta Prataculturae Sinica 28(1):70-78. doi:10.11686/cyxb2018485.

Wu, X., Li, J., Xu, H.L., Dong, L.Y. 2015. Factors affecting seed germination and seedling emergence of Asia minor bluegrass (*Polypogon fugax*). Weed Science 63(2):440-447. doi:10.1614/ws-d-14-00093.1.

Wu, H., Zhang, P., Chen, G.Q., Pan, L., Li, J., Dong, L.Y. 2018. Environmental factors on seed germination and seedling emergence of *Phleum paniculatum* Huds. Chilean Journal of Agricultural Research 78:370-377. doi:10.4067/s0718-58392018000300370.

Xie, X., Qiu, J., Feng, X., Hou, Y., Wang, S., Jia, S., et al. 2022. Spatial distribution and estimation model of soil pH in coastal Eastern China. International Journal of Environmental Research and Public Health 19(24):16855. doi:10.3390/ijerph192416855.

Xu, T., He, K.N., Wang, H., Wang, W.L., Zhang, T. 2021. Effects of saline-alkali stress on seed germination of *Haloxylon ammodendron* and *Nitraria roborowskii* Kom in Qaidam Basin. Acta Agriculturae Scandinavica Section B-Soil and Plant Science 71(5):336-345. doi:10.1080/09064710.2021.1897157.

Yu, H., Yang, J., Cui, H., Abbas, A., Wei, S., Li, X. 2021. Distribution, genetic diversity and population structure of *Aegilops tauschii* Coss. in major wheat-growing regions in China. Agriculture 11(4):311. doi:10.3390/agriculture11040311.

Zhao, N., Li, Q., Guo, W.L., Zhang, L.L., Ge, L.A., Wang, J.X. 2018. Effect of environmental factors on germination and emergence of shortawn foxtail (*Alopecurus aequalis*). Weed Science 66(1):47-56. doi:10.1017/wsc.2017.42.