

Effect of environmental, seed burial depth, and straw mulch on germination and seedling emergence in *Cichorium glandulosum*

Research Article

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Abstract

Cichorium glandulosum Boiss. et Huet is a species that has recently spread widely in the autumn crops of northwestern Iran. A study was conducted to evaluate the effect of environmental factors on the germination, emergence, and management of two populations of *C. glandulosum*. The effects of temperature, photoperiod, NaCl concentration, osmotic potential, seed burial depth, and straw mulch on seed germination and seedling emergence were evaluated for two populations of *C. glandulosum* from Tabriz and Marand, Iran. The highest germination percentage was observed in the Tabriz (93%) and Marand populations (94%) at 20/10 C (day/night). In both populations, germination was 82% to 93% across a wide range of light/dark periods (8 to 24 h of light). However, germination was significantly reduced (~70%) under continuous darkness. The osmotic potential required to inhibit 50% of germination was 0.68 MPa for the Tabriz population and 0.62 MPa for the Marand population. The concentration of NaCl required to inhibit 50% of germination was 4.76 dS m⁻¹ for the Tabriz population and 3.81 dS m⁻¹ for the Marand population. The seed burial depths that caused a 50% decrease in emergence for the Tabriz and Marand populations were 1.86 cm and 2.22 cm, respectively. In the Tabriz and Marand populations, the application of 6000 kg ha⁻¹ of straw mulch resulted in a decrease in *C. glandulosum* emergence to 3% and 10%, respectively. This study's results inform the conditions required for *C. glandulosum* germination and establish a theoretical and practical foundation for predicting, preventing, and managing this species using scientific principles.

Introduction

Cichorium glandulosum Boiss. et Huet, a member of the Asteraceae family, is a biennial or perennial plant commonly used in traditional Uighur medicine. The primary distribution of *C. glandulosum* is in Europe, western Asia, and Australia (Ding et al. 2014). Observations indicate a significant increase in the frequency of this plant species in the autumn crops of northwestern Iran, such as wheat (*Triticum aestivum* L.) and safflower (*Carthamus tinctorius* L.). We estimate that a significant portion of the decrease in crop yields in this region in recent years can be attributed to the invasion of this species. Also, anecdotal evidence indicates that this species is adaptable to different cropping seasons, enabling it to be present year-round. Another species in this genus, *Cichorium intybus* L., is a native European weed that has naturalized in various regions of the world, including Africa, temperate and tropical regions of Asia, Europe, Australia, and North and South America (Imam et al. 2019).

Seed germination is an important event in the life history of a plant. Following seed germination, seedling emergence is the most critical phenological event affecting successful plant establishment, particularly in annual plant species (Forcella et al. 2000). Generally, several environmental factors, including temperature, light, water potential, salinity, and burial depth, can significantly influence the germination pattern and seedling growth of many plant species with nondormant seeds (Amini et al. 2021; Baskin and Baskin 1998; Nosratti et al. 2017).

Temperature can influence seed germination by regulating enzyme activities and promoting or inhibiting the synthesis of hormones involved in seed germination (Baskin and Baskin 1998; Xu et al. 2017). The effect of light on weed germination can vary depending on the weed species. Some weed species are classified as light-dependent germinators, while others are considered non-light dependent germinators. Light-dependent germinators require exposure to light in order to initiate the germination process (Chauhan and Johnson 2009). Water deficiency can reduce the final germination percentage, germination rate, and seedling growth through its adverse effects on the rate of seed imbibition. This has been well documented in previous studies (Abdellaoui et al. 2019; Bewley et al. 2013). For example, osmotic stress had a negative impact on

germination in African turnipweed (*Sisymbrium thellungii* O.E. Schulz), with an average of 54% of seeds able to germinate at -0.1 MPa (Mahajan et al. 2018). The soil and/or water salinity is a severe problem for many agricultural lands worldwide. Previous research has shown that seed germination may be influenced by the negative impacts of salt stress, both osmotically through reduced water uptake and ion toxicity caused by the accumulation of salt ions (Na^+ and Cl^-). These factors can affect metabolic cell activities during seed germination (Parmoon et al. 2018). According to Amini et al. (2017), germination was completely inhibited in two populations of *Caucalis platycarpus* L. at an NaCl concentration of 14 dS m^{-1} . Therefore, investigating the effect of salt stress on *C. glandulosum* seed germination could help determine the optimal environment for this plant.

The successful establishment of a plant depends on the depth at which the seeds germinate. In many plant species, seedling emergence declined with increasing burial depth. This could be attributed to small seed reserves or lower seed hydration at greater depths (Dinelli et al. 2013). However, some plant species such as tobacco (*Nicotiana glauca* Graham) (Florentine et al. 2016) and cantaloupe (*Cucumis melo* L. 'Agrestis') Naud (Xu et al. 2017) exhibited maximum seedling emergence when the seeds were placed on the soil surface because they required light for germination (Nosratti et al. 2017).

Mulch can have a significant impact on suppressing weeds in various ways. Mulch creates a physical barrier on the soil surface, blocking sunlight from reaching weed seeds (Chauhan et al. 2018). This lack of sunlight inhibits weed germination and reduces the frequency of weed emergence. Some types of mulch, such as organic mulches like straw, wood chips, or shredded leaves, can physically smother emerging weeds (Amini et al. 2017). These mulches prevent weed growth by covering the soil surface and blocking light from reaching the weeds. Mulch acts as an insulating layer, regulating soil temperature. This can hinder weed growth, because certain weed species have specific temperature requirements for germination and growth. Certain types of mulch, such as certain organic mulches, release natural chemicals that can inhibit weed growth. These compounds, known as allelochemicals, can inhibit weed seed germination or impede weed growth (Weston et al. 2013). It is important to note that the effectiveness of mulch in suppressing weeds can vary depending on factors such as the type of mulch used, the thickness of the mulch layer, and the specific weed species present.

Weed seeds that mature in different environmental conditions may have varying germination requirements. A better understanding of seed germination patterns and seedling emergence of *C. glandulosum* could contribute to the development of more effective control measures. This knowledge would enable us to predict the potential invasion of this species into new regions. To contribute to this goal, the study aimed to examine the effects of various factors on the germination and emergence of *C. glandulosum*. These factors included alternating temperature and photoperiod, water stress, salinity, seed burial depth, and the application of straw mulch.

Materials and Methods

Plant Material

Experiments were conducted at the Seed Technology Laboratory of the University of Tabriz, which is located in Tabriz, Iran. Fruits of *C. glandulosum* were collected in September 2021 from a naturally

occurring population in the dryland fields of East Azerbaijan, Iran. Specifically, they were collected from Tabriz (38.488°N , 46.068°E ; altitude: 1,390 m) and Marand (38.416°N , 45.766°E ; altitude: 1387 m). Long-term precipitation and temperature data for Tabriz and Marand are shown in Figure 1. Fruits were collected from 90 to 100 plants per population (Chauhan et al. 2018).

The harvested fruits of *C. glandulosum* were air-dried for several weeks at room temperature (20 to 22°C) to facilitate the extraction of seeds. Cleaning was done by hand-sorting, which involves meticulously removing debris and rubbish. The seeds of *C. glandulosum* were divided into two groups. The first group had no germination and was characterized by seeds that were partially green to yellow in color and smaller in size. They were considered immature seeds and were excluded. The second group consisted of larger, brown seeds with a germination percentage of greater than 90%. The 1,000-seed weight was 2.26 g for Tabriz and 2.7 g for Marand. This group consisted of mature seeds that had been dried for several days at room temperature. They were then stored in paper bags under the same conditions until they were used for the experiments (October 2021).

Procedures Common to All Experiments and General Protocol for Germination Tests

In all experiments, 25 mature seeds were randomly selected. They were then surface-sterilized in a 0.5% sodium hypochlorite solution for 10 min and thoroughly rinsed with distilled water (Amini and Namdari 2013). The seeds were placed equidistantly in covered petri dishes (9-cm diameter) containing sterilized filter paper. The filter paper was moistened with either distilled water or the appropriate experimental solutions, which were adjusted for osmotic potential or salinity. The treatment solutions were drained from the germination media and replaced with 5 ml of fresh solution every 2 d for 18 d to prevent the influence of seed leachates.

Germination (the protrusion of the radicle to 1 mm) was recorded every day. At the end of the 18-d period, the final germination percentage was recorded. The final germination percentage was calculated by dividing the number of germinated seeds by the total number of seeds and multiplying the result by 100.

Temperature and Light

The effect of temperature on the germination of *C. glandulosum* seeds was assessed by placing the seeds in a growth chamber with varying day/night temperature cycles (5/2, 10/5, 15/5, 20/10, 25/15, and 30/20 C) for a 12-h photoperiod. These conditions correspond to the average air temperatures in East Azerbaijan during autumn and early winter. The influence of different light/dark regimes—24/0, 12/12, 10/14, 8/16, and 0/24 h at 20/10 C—on the seed germination of *C. glandulosum* was evaluated daily for 18 d after treatment. Light intensity of $156 \mu\text{mol m}^{-2}\text{s}^{-1}$ was provided by fluorescent lamps in a growth chamber. To test germination in the dark, the petri dishes were wrapped in a double layer of aluminum foil (Baskin and Baskin 1998).

Osmotic Potential and Salt Stress

The *C. glandulosum* seeds were incubated at day/night temperatures of 20/10 C and a light/dark regime of 10/14 h. Osmotic potentials—0.0, -0.2 , -0.4 , -0.6 , -0.8 , -1.0 , and -1.2 MPa—were obtained in solution by dissolving specific amounts of polyethylene glycol 8000 (Michel 1983) in deionized water. NaCl solutions with salinity levels

of 0, 1, 2, 3, 4, 5, 6, 8, 10, and 12 dS m⁻¹ were prepared to induce 10 levels of salinity stress (Poljakoff-Mayber et al. 1994). A salinity of 0 dS m⁻¹ represented the control.

Burial Depth

To investigate the impact of burial depth on the emergence of *C. glandulosum* seedlings, we planted seeds at various depths in plastic pots (8-cm diameter, 10-cm height). The depths were 0 (retained on the soil surface), 0.5, 1.0, 1.5, 2.0, 3.0, 4.0, and 5.0 cm. Moist soil was placed over the sown seeds at the appropriate depth and compacted. Three pots (replications) were used for each burial depth, with 25 seeds per pot. The soil used for this experiment was a loam composed of 41% sand, 39% silt, and 20% clay. It had 0.51% organic matter and a pH of 6.8. Pots were placed in a growth chamber set at day/night temperatures of 20/10 C and a photoperiod of 10/14 h of light/darkness. Fluorescent lamps were used to produce a light intensity of 156 μmol m⁻²s⁻¹. Pots were watered to their field capacity weight every 3 d. The emerged seedlings were counted daily for 18 d after planting. At the end of the experiment, seeds that were buried at a depth of 5 cm in plastic pots were retrieved to assess the outcome of nongerminated seeds.

Straw Mulch

The wheat straw mulch was applied to the soil surface in each pot (8-cm diameter, 10-cm height). The seeds were planted at a soil depth of 0.5 cm, because the highest percentage of emergence was observed at this depth (according to the burial depth study). Straw mulch weighing 2000, 4000, and 6000 kg ha⁻¹ (equivalent to 2, 4, and 6 t ha⁻¹) was applied over the sown seeds to the specified depth and compacted. Three pots (replications) were used for each amount of straw mulch, with 50 seeds per pot. The soil used for this experiment was a loam composed of 41% sand, 39% silt, and 20% clay, with 0.51% and a pH of 6.8. Pots were placed in a growth chamber set at day/night temperatures of 20/10 C and a photoperiod of 10/14 h of light/darkness. Fluorescent lamps were used to produce a light intensity of 156 μmol m⁻²s⁻¹. Pots were watered to their field capacity every 3 d.

Experimental Design and Statistical Analysis

All experiments were conducted twice using a completely randomized design with three replications per treatment. The second run started within a month after the first run ended. As no significant differences were observed between the runs and treatments, the data were pooled over the experimental runs. Therefore, each treatment was implemented with 12 replications (2 populations × 3 replications × 2 runs). SAS v. 9.0.3 (SAS Institute, Cary, NC, USA) was used for the ANOVA. The data used in the ANOVA analysis met the assumptions of normality and homogeneity of variance and did not require any transformations. Nonlinear regression analysis was performed using GraphPad Prism v. 8.00 (GraphPad, CA, USA) to assess the influence of NaCl concentrations, osmotic potential, burial depth, and amounts of straw mulch on seed germination and emergence. The goodness of fit was evaluated using R² and the root-mean-square error (RMSE). A four-parameter sigmoid model (Equation 1) was used to analyze the germination response to osmotic potentials (MPa) and NaCl (dS m⁻²) concentrations.

$$G(\%) = c + \frac{d - c}{1 + e^{b(\log x - \log e)}} \quad [1]$$

where G represents the total germination (%) at concentration X (osmotic potential or NaCl). The variables d and c represent the upper and lower limits for the variable G , respectively. The variable e represents the concentration of osmotic potential or NaCl that is replaceable with any X_{50} value. X_{50} represents the concentration required (osmotic potential or NaCl) to halve the response between the upper and lower limits, while b refers to the slope (reduction rate).

The sigmoidal model was fit to the seedling emergence data obtained from different days for each seed burial depth (cm) and various amounts of mulch (kg ha⁻¹) (Equation 2).

$$E(\%) = c + \frac{d - c}{1 + e^{b(\log x - \log e)}} \quad [2]$$

where E represents the final seedling emergence (%) at time X . The variables d and c represent the upper and lower limits for the variable E , respectively. The variable e represents the time (day) and can be replaced with the T_{50} value. T_{50} represents the time (in days) required for 50% seedling emergence, while b refers to the slope (reduction rate).

Results and Discussion

Temperature Regime

Temperature regimes effected germination percentage of *C. glandulosum* were effective (Figure 2). The highest germination percentages for the Tabriz (93%) and Marand (94%) populations were observed at day/night temperatures of 20/10 C (Figure 2). Among the temperature regimes, the germination percentages of seeds at day/night temperatures of 5/2, 10/5, and 30/20 C were the lowest for both populations.

Although the seed germination percentage differed, both *C. glandulosum* populations germinated at all tested temperature regimes, indicating the species' ability to germinate and emerge under field conditions in different regions of Iran, especially in the northwest, throughout the spring, summer, and autumn seasons. In both the Tabriz and Marand populations, the highest germination occurred at 20/10 C (with a mean air temperature of 15 C), which is similar to the conditions in mid-autumn (November) and mid-spring (May) (Figures 1 and 2). Therefore, it is clear that the high density of this species during autumn and spring is attributed to its ability to effectively respond to a wide range of temperatures in these two regions. Relatively high optimal temperatures for maximum germination of this species indicate that conditions for increased germination and growth are likely to be provided due to the extreme climate change in Iran and the rising temperatures during cold seasons (Hasanfard et al. 2022). Eslami (2011) reported that the highest germination percentage for populations of lambsquarters (*Chenopodium album* L.) from Iran occurred at 25/15 C, while for populations from Denmark, it occurred at 20/10 C.

Photoperiod

Light/dark regimes affected the germination of *C. glandulosum* populations (Figure 3). The lowest germination percentage was observed in Tabriz (15%) and Marand (21%) populations in continuous darkness (light/dark, 0/24 h) (Figure 3). Germination in alternating light/dark regimes was 82% to 90% in the Tabriz population and 85% to 93% in the Marand population (Figure 3).

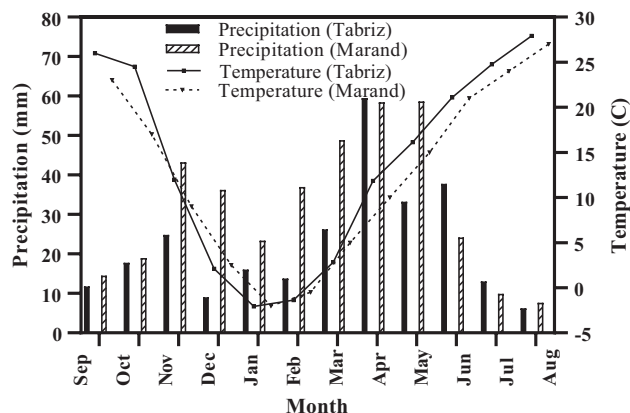


Figure 1. Long-term precipitation and temperature data for Tabriz and Marand, Iran.

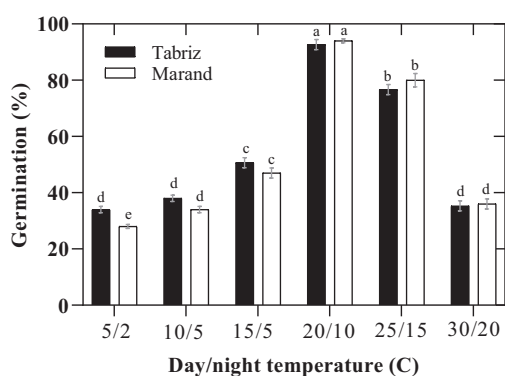


Figure 2. Effect of altering day/night temperatures on the germination percentage of *Cichorium glandulosum* populations from Tabriz and Marand, Iran. The vertical bars represent the standard error (\pm SE). Columns with the same letters indicate that there are no significant differences in the mean values by Fisher's protected LSD test ($P \leq 0.05$).

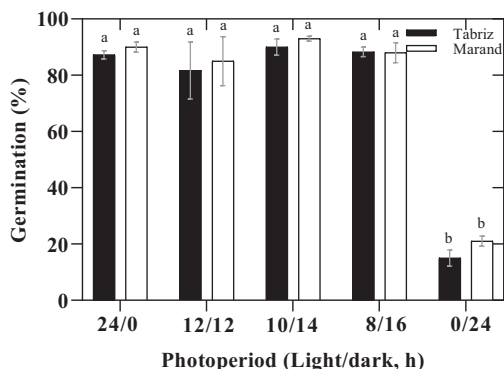


Figure 3. Effect of photoperiods on the germination percentage of *Cichorium glandulosum* populations from Tabriz and Marand, Iran. The vertical bars represent the standard error (\pm SE). Columns with the same letters indicate that there are no significant differences in the mean values by Fisher's protected LSD test ($P \leq 0.05$).

In the absence of light, the germination percentages in the Tabriz and Marand populations were 21% and 15%, respectively (Figure 3), while the seeds of both *C. glandulosum* populations had a similar germination percentage under various light/dark regimes. The more than 4-fold reduction in germination of the two *C. glandulosum* populations under continuous dark conditions compared with other light/dark regimes indicates that

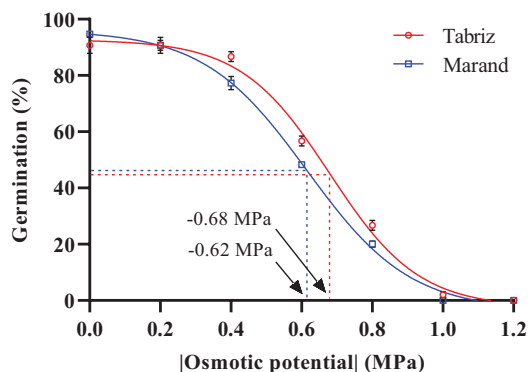


Figure 4. Effect of osmotic potential on the germination percentage of *Cichorium glandulosum* populations from Tabriz and Marand, Iran. The vertical bars represent the standard error (\pm SE). The arrow indicates the osmotic potential required to inhibit 50% of germination (X_{50}). G_{max} , maximum germination percentage; G_{rate} , slope of the curve; RMSE, root-mean-square error. Nonlinear regression analysis results
 Tabriz population : $G_{max} = 92.71$, $G_{rate} = -3.45$, $X_{50} = -0.68$,
 $R^2 = 0.9963$, RMSE = 2.475
 Marand population : $G_{max} = 96.10$, $G_{rate} = -2.97$, $X_{50} = -0.62$,
 $R^2 = 0.9985$, RMSE = 1.622.

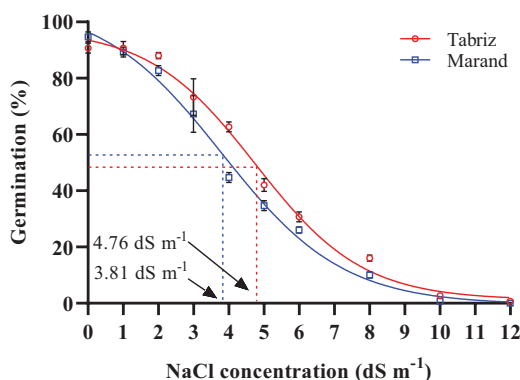


Figure 5. Effect of NaCl concentration on the germination percentage of *Cichorium glandulosum* populations from Tabriz and Marand, Iran. The vertical bars represent the standard error (\pm SE). The arrow indicates the concentration of NaCl required to inhibit 50% of germination (X_{50}). G_{max} , maximum germination percentage; G_{rate} , slope of the curve; RMSE, root-mean-square error. Nonlinear regression analysis results:
 Tabriz population : $G_{max} = 97.59$, $G_{rate} = -0.28$, $X_{50} = 4.76$,
 $R^2 = 0.9944$, RMSE = 2.698.
 Marand population : $G_{max} = 98.70$, $G_{rate} = -0.25$, $X_{50} = 3.81$,
 $R^2 = 0.9946$, RMSE = 2.696.

C. glandulosum seeds require light for optimal germination. The need for light indicates that germination occurs only at or near the soil surface (Amini et al. 2017). In our study, most of the seedlings emerged at or near the soil surface. The study by Chauhan et al. (2018) also showed that Australian fingergrass (*Chloris truncata* R. Br.) had a higher germination percentage on the soil surface compared with the seeds buried in the soil.

Water Stress

In both studied populations, seed germination was not affected up to an osmotic potential of -0.2 MPa (Figure 4). Meanwhile, with the decrease of osmotic potential to -0.6 and -0.8 MPa, seed germination decreased by 44% and 70% in the Tabriz population and by 49% and 69% in the Marand population, respectively

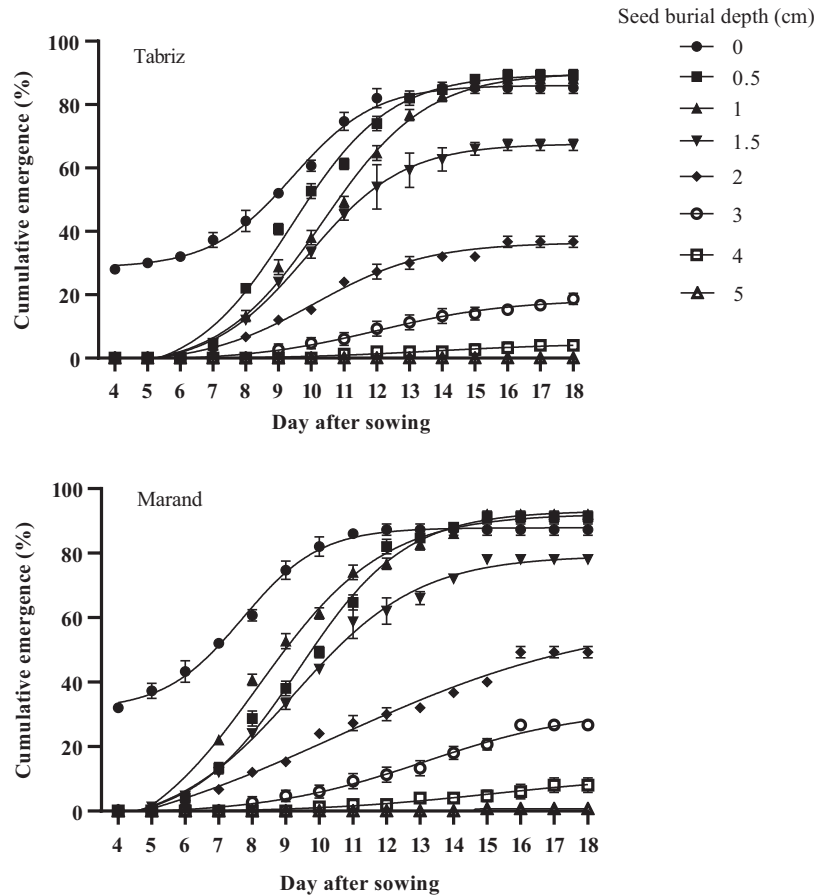


Figure 6. Effect of seed burial depth on seedling emergence of *Cichorium glandulosum* populations from Tabriz and Marand, Iran, during an 18-d period. The vertical bars represent the standard error (\pm SE).

(Figure 4). The osmotic potential required to inhibit 50% of the germination of *C. glandulosum* in the Tabriz and Marand populations was -0.68 and -0.62 MPa, respectively. The slope of the reduction in germination for the Tabriz population (-3.45) was lower than that of the Marand population (-2.98).

The germination percentage of the Tabriz and Marand populations showed a significant decrease starting from the osmotic potentials of -4 MPa and -2 MPa, respectively (Figure 4). The osmotic potential required for 50% inhibition of the maximum germination was -0.68 MPa for the Tabriz population and -0.62 MPa for the Marand population. This indicates that the Tabriz population exhibited relatively higher tolerance to osmotic stress compared with the Marand population. The results of our study showed that tolerance to drought stress was almost similar in both *C. glandulosum* populations. The likely reason for this is the adaptation of the *C. glandulosum* to the low-rainfall conditions of their place of origin. While some seeds from both populations germinated at -0.8 MPa, germination was completely inhibited at -1 MPa and -1.2 MPa (Figure 4). Similarly, Chauhan et al. (2018) showed that the germination of *C. truncata* is completely inhibited at an osmotic potential of -1 MPa. In a comparison of the germination of two populations of rigid ryegrass (*Lolium rigidum* Gaudin)—one population resistant to glyphosate (GR) and the other population susceptible to glyphosate (GS)—it was observed that the GS population demonstrated superior germination compared with the GR population at -0.4 MPa (Thompson et al. 2021). This study emphasizes the significance of management

strategies that consider the adaptability and extensive potential of these populations, which can survive under drought conditions.

Salt Stress

Increasing the NaCl concentration decreased the germination percentage of *C. glandulosum* seeds in both the Tabriz and Marand populations (Figure 5). In the Tabriz population, seed germination was $\sim 90\%$ up to a salinity of 2 dS m^{-1} , but it declined when the salinity exceeded 3 dS m^{-1} . In the Marand population, seed germination was 95% under no-salt conditions (0 dS m^{-1}), but it declined when the salinity exceeded 1 dS m^{-1} . In both populations, the germination percentage decreased significantly at salinities of 10 and 12 dS m^{-1} , almost reaching zero. The NaCl concentration required for 50% inhibition of seed germination was 4.76 and 3.81 dS m^{-1} for the Tabriz and Marand populations, respectively (Figure 5). The slope of germination reduction for the Tabriz population (-0.28) was lower than that of the Marand population (-0.25).

Salinity stress decreased the germination percentage in both *C. glandulosum* populations (Figure 5). However, the germination percentage of the Tabriz population was higher at various NaCl concentrations compared with the Marand population. In addition, the results of the concentration of NaCl required to inhibit 50% of germination showed that the Tabriz population (4.76 dS m^{-1}) is more salt-tolerant than the Marand population (3.81 dS m^{-1}). About 25% of Iranian soils are saline ($\text{EC} > 4 \text{ dS m}^{-1}$) (Mesgaran et al. 2017). Therefore, despite the decrease in the percentage of

Table 1. Nonlinear regression analysis results for different seed burial depths in populations of *Cichorium glandulosum* from Tabriz and Marand.^a

Population	Seed burial depth	$E_{max}(\pm SE)$	$E_{rate}(\pm SE)$	$t_{50}(\pm SE)$	R^2	RMSE
	cm	%		days		
Tabriz	0	86.05 (0.73)	0.35 (0.03)	9.43 (0.11)	0.99	1.33
	0.5	89.55 (1.65)	0.29 (0.03)	9.39 (0.16)	0.99	2.66
	1	90.01 (1.42)	0.28 (0.02)	10.37 (0.12)	0.99	1.91
	1.5	67.66 (0.64)	0.30 (0.01)	9.89 (0.08)	0.99	0.99
	2	36.50 (0.89)	0.25 (0.03)	10.09 (0.19)	0.99	1.15
	3	18.45 (0.94)	0.22 (0.03)	12.04 (0.28)	0.99	0.66
	4	4.70 (0.95)	0.19 (0.07)	13.70 (1.00)	0.96	0.32
	5	NE	NE	NE	NE	NE
Marand	0	87.86 (0.50)	0.38 (0.03)	7.70 (0.11)	0.99	1.11
	0.5	93.11 (1.53)	0.27 (0.02)	9.41 (0.15)	0.99	2.34
	1	92.18 (1.91)	0.23 (0.03)	8.19 (0.28)	0.99	2.86
	1.5	79.22 (1.31)	0.24 (0.20)	9.27 (0.16)	0.99	1.74
	2	60.77 (8.79)	0.11 (0.04)	10.52 (0.77)	0.98	2.01
	3	31.75 (2.71)	0.18 (0.03)	13.14 (0.44)	0.99	1.03
	4	11.28 (2.93)	0.16 (0.05)	15.19 (1.40)	0.97	0.43
	5	NE	NE	NE	NE	NE

^aAbbreviations: E_{max} , maximum seedling emergence; E_{rate} , slope; t_{50} , the time (days) required for 50% seedling emergence; RMSE, root-mean-square error. NE indicates that the seeds did not emerge at a burial depth of 5 cm.

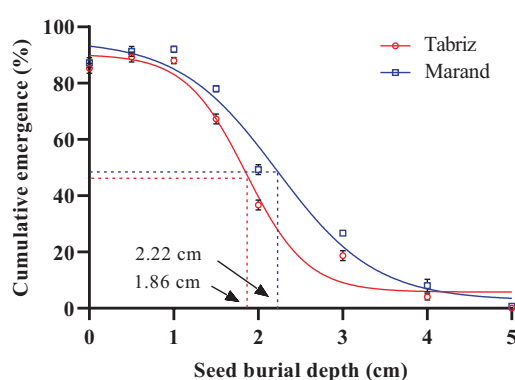


Figure 7. Effect of seed burial depth on cumulative seedling emergence of *Cichorium glandulosum*. The vertical bars represent the standard error ($\pm SE$). The arrow indicates the burial depth that caused a 50% decrease in emergence (X_{50}). E_{max} , maximum emergence; E_{rate} , slope of the curve; RMSE, root-mean-square error. Nonlinear regression analysis results:

Tabriz population : $E_{max} = 90.33$, $E_{rate} = -1.206$, $X_{50} = 1.86$,
 $R^2 = 0.9823$, RMSE = 5.097.

Marand population : $E_{max} = 95.17$, $E_{rate} = -0.7456$, $X_{50} = 2.22$,
 $R^2 = 0.9809$, RMSE = 5.293.

C. glandulosum germination with increasing NaCl concentration, the relatively high germination ability of both *C. glandulosum* populations in saline soils (Figure 5) probably enables them to colonize the saline areas of Iran.

Seed Burial Depth

In both populations, seedling emergence was influenced by the depth of burial and the number of days after burial (Figure 6). The results indicated that in both populations, the emergence of seedlings was low with an increase in the depth of seed burial. However, as the days passed after planting, the emergence of seedlings increased. According to our results, in the Tabriz population, the estimated time for 50% of the seedlings to emerge, as determined by the sigmoidal model, was 9.43 d for seeds that were placed on the soil surface (0-cm burial depth). However, it

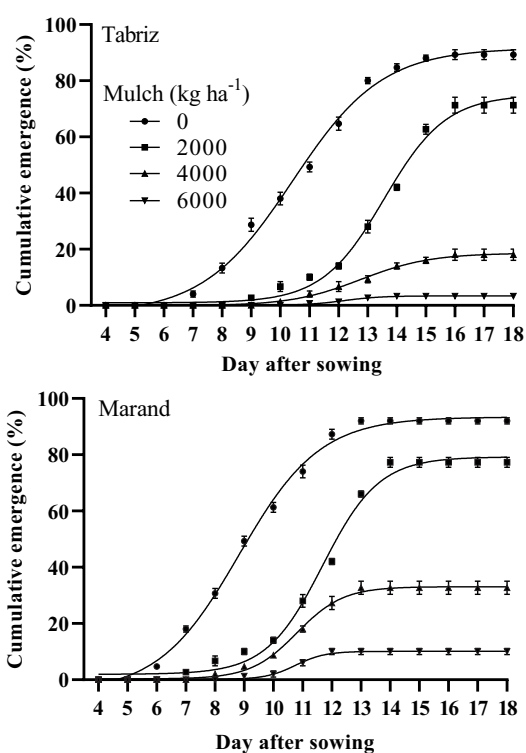


Figure 8. Effect of different amounts of straw mulch on seedling emergence of *Cichorium glandulosum* populations from Tabriz and Marand, Iran, during an 18-d period. The vertical bars represent the standard error ($\pm SE$).

took longer for seeds to emerge from greater depths. The estimated time for 50% of the seedlings to emerge for seeds buried at depths of 0.5, 1, 1.5, 2, 3, and 4 cm were 9.39, 10.37, 9.89, 10.09, 12.04, and 13.70 d, respectively (Table 1). In the Marand population, the estimated time for 50% of the seedlings to emerge was 7.70 d for seeds placed on the soil surface. This parameter for burial depths of 0.5, 1, 1.5, 2, 3, and 4 cm was 9.41, 8.19, 9.27, 10.52, 13.14, and 15.19 d, respectively (Table 1). Based on estimates from the sigmoidal model, no seedlings from the two studied populations emerged at a

Table 2. Nonlinear regression analysis results for the use of different amounts of mulch in populations of *Cichorium glandulosum* from Tabriz and Marand.

Population	Mulch	E_{max} (\pm SE)	E_{rate} (\pm SE)	t_{50} (\pm SE)	R ²	RMSE
	kg ha ⁻¹	%		day		
Tabriz	0	91.63 (1.64)	0.28 (0.02)	10.42 (0.13)	0.99	2.24
	2000	74.98 (2.11)	0.41 (0.04)	13.57 (0.12)	0.99	2.13
	4000	18.60 (0.36)	0.36 (0.03)	12.75 (0.09)	0.99	0.40
	6000	3.38 (0.05)	0.68 (0.06)	12.17 (0.06)	0.99	0.08
Marand	0	93.40 (1.06)	0.31 (0.02)	8.82 (0.11)	0.99	1.93
	2000	79.22 (1.61)	0.45 (0.05)	11.68 (0.12)	0.99	2.57
	4000	33.07 (0.35)	0.55 (0.04)	10.80 (0.06)	0.99	0.68
	6000	10.10 (0.15)	0.85 (0.11)	10.75 (0.07)	0.99	0.33

Abbreviations: E_{max} , maximum seedling emergence; E_{rate} , slope; t_{50} , the time (days) required for 50% seedling emergence; RMSE, root-mean-square error.

depth of 5 cm. The burial depths that caused a 50% decrease in emergence for the Tabriz and Marand populations were 1.86 cm and 2.22 cm, respectively (Figure 7).

Increasing the depth at which seeds were buried had a negative impact on the emergence of *C. glandulosum* seedlings in both populations (Figure 6). Decreased germination of *C. glandulosum* seeds with increasing burial depth is related to reduced exposure to light (Figure 3). In addition, one possible reason for the decrease in *C. glandulosum* emergence at greater burial depths is the exhaustion of seedling reserves before emergence. Chauhan and Johnson (2009) reported that large seeds, such as junglerice [*Echinochloa colona* (L.) Link], can emerge from deep burial. However, tiny seeds, like *C. truncata*, may suffer from limited energy reserves required for hypocotyl elongation. In both populations studied here, a seed burial depth of 1 cm resulted in the highest percentage of seedling emergence (Figure 7). The emergence of seedlings from seeds buried at a depth of 0 cm (on the soil surface) decreased compared with those buried at a depth of 1 cm. This decrease may be due to reduced water availability caused by limited soil contact (Amini et al. 2017).

Straw Mulch

Seedling emergence was affected by the amount of mulch and the number of days after sowing (Figure 8). As the amount of mulch applied increased, the emergence of seedlings was lower in both *C. glandulosum* populations (Figure 8). However, as the number of days after sowing increased, the emergence of seedlings showed an upward trend. The maximum final emergence of seedlings in the Tabriz and Marand populations was 89% and 92%, respectively, without the application of mulch (Figure 8). The minimum emergence was 3% and 10%, respectively, with the application of 6000 kg ha⁻¹ of mulch. In the Tabriz population, the time needed for 50% seedling emergence was 10.42, 13.57, 12.75, and 12.17 d for mulch amounts of 0, 2000, 4000, and 6000 kg ha⁻¹, respectively (Table 2). Also, in the Marand population, the time needed for 50% seedling emergence was 8.82, 11.68, 10.80, and 10.75 d for mulch amounts of 0, 2000, 4000, and 6000 kg ha⁻¹, respectively (Table 2).

Straw mulch suppresses weeds by blocking sunlight, which is necessary for weed seeds to germinate and grow. It also helps to conserve moisture by reducing evaporation from the soil surface (Hussain and Luqman 2022). Interestingly, increasing the amount of mulch application led to a decrease in seedling emergence in both *C. glandulosum* populations (Figure 8). The positive effect of straw mulch application in suppressing weeds has also been reported by other researchers (Amini et al. 2017; Anzalone et al. 2010; Jabran et al. 2015). These researchers attributed the positive effects of straw mulch to three factors: limited light penetration,

physical barrier, and the allelopathic effects of mulches on seed germination; this was similar to our findings. In general, straw mulch reduces the need for chemical herbicides or manual labor to remove *C. glandulosum*, potentially resulting in cost savings. Furthermore, straw mulch helps to retain soil moisture, thereby reducing the need for irrigation. The use of straw mulch can be a cost-effective strategy for weed management in agriculture.

Although there were differences in the germination ecology of the Tabriz and Marand *C. glandulosum* populations, the seed germination of both populations, especially the Tabriz population, showed a positive response to a wide range of temperatures, light, humidity, salinity, and burial depth. Because the environmental conditions in major parts of Iran and the world are suitable for the germination of this species, we predict that without effective management, it will continue to spread in the coming years. Therefore, evaluating the germination ecology of *C. glandulosum* from different cropping systems around the world will help us understand the germination patterns of this species and effectively manage it to prevent its invasion in pastures and cropping systems. Considering the positive impact of straw mulch in reducing the emergence of *C. glandulosum* in this study, we recommend integrating this strategy into the management plans for this species.

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