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Study of dormancy breaking and factors affecting germination of *Parapholis incurva* (L.) C.E.Hubb. as annual grass

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ABSTRACT: *Parapholis incurva* (curved parapholis) is an annual grass that is widely increasing its distribution in areas of barley production in northern Iran. Laboratory experiments were conducted to evaluate the type of dormancy and the effect of different methods of dormancy breaking, to determine cardinal temperatures using nonlinear regression models, and to test the effects of other ecological factors such as drought, salinity, heat shock and pH on germination of curved parapholis seeds. The results showed that the best method for dormancy breaking is applying 75 ppm gibberellic acid + 30 s of sulfuric acid, with highest germination percentage (84 %). It was also demonstrated that temperature significantly affects the germination rate and germination percentage of curved parapholis. The highest germination percentage was obtained between 18 and 25 °C, while the lowest germination percentage occurred at below 5°C and above 30 °C. Using a segmented model, the base, optimum and ceiling temperatures were estimated to be 1.25 °C, 23.29 °C and 35 °C, respectively. Seed germination declined as the osmotic potential increased from -0.6 to -1.2 MPa. With increasing drought stress and salinity stress, the germination percentage reached less than 50% at -0.88 and -0.84 MPa, respectively. The maximum germination percentage was observed at a pH of 6 and 7. According to this result regulating the soil microclimate (temperature) through field preparations, soil amendments and cultural practices can be employed to better long-term management of curved parapholis.

KEY WORDS: Cardinal temperature, dormancy, environmental stress, germination, heat shock, weed.

INTRODUCTION

Parapholis incurva (L.) C.E.Hubb. (curved parapholis) is a decumbent annual grass reaching up to 5-25 cm in height with a curved, brittle spike and is native to Europe, Asia and northern Africa and extensively naturalized elsewhere (https://powo.science.kew.org). The spikelets are solitary, one-flowered, and with two glumes as long as the lemma; the lemma has no awn (Yena, 2017). This weed is found in gray sand, calcareous loam, saline flats, salt lakes, saltmarshes, and beach sand hills (https://www.gbif.org/species). *Parapholis* and a few other genera of mostly annual grasses adapted to saline conditions are distinguished from typical Poaceae by their specific rat-tail inflorescence and glumes placed side-by-side (eFloras, 2008). Curved parapholis seeds germinate in autumn and flowers from May to June in most tropical environments. Seed ripening occurs in the first half of June, and seeds are buried by eroded soil and actively dispersed by ants (Boscagli *et al*., 1996). Dryland production systems, especially barley production systems in northern Iran, have recently been invaded by curved parapholis. This weed also exists in some wheat fields in Fars Province and Zabol. Curved parapholis grows in barley fields in northern Iran and causes crop yield loss and nowadays it turned to a troublesome weed of dry farming systems in the province of Golestan. There is no detailed information about its behavior in response to temperature while these studies could be valuable for selective management and reduced crop loss by it.

Successful establishment of weeds depends heavily on the weeds' ability to germinate. The variance in the timing of establishment among species is most likely due to temporal differences in soil salinity, soil moisture, seed dormancy characteristics, photoperiod, or temperature and differential responses of species to these abiotic factors (Allen *et al*., 2007; Benvenuti, 2022; Qasani and Ghaderi-Far, 2022). The rapid spread of many plants is frequently associated with germination and dormancy patterns. Specific requirements for effective germination often differ among related weed species, and a slight variation in environmental conditions can increase or decrease the rate of their emergence (Allen *et al*., 2007; Baskin and Baskin, 2004). Knowledge of the biology and germination characteristics of weeds can be an important tool when implementing integrated weed control strategies and can be used to prevent significant numbers of new weed seeds from being added to the soil seed bank (Chauhan and Johnson, 2010; Sohrabi *et al*., 2012; Gherekhloo *et al*., 2020; Khodapanah *et al*., 2022). It is important to gain a better understanding of the mechanism of seed dormancy and how seeds of curved parapholis germinate in response to different environmental factors, such as temperature, pH, heat stress and osmotic potential. A well understanding of curved parapholis seed dormancy breaking and germination can support the decision-making process of producers for optimal timing of tillage, fire, soil improvement and herbicide application. The options mentioned above could reduce the size of curved parapholis seed banks. Although it is a troublesome weed of dry farming systems in the province of Golestan, no additional data is available about the effect of environmental factors on its dormancy and germination. In addition, previous germination tests were not evaluating the impact of temperature and other abiotic factors, so these factors could be mentioned as the novelty of this study. Therefore, the aims of the current study were (i) to determine how to break seed dormancy, (ii) to estimate cardinal temperatures using different nonlinear regression models, and (iii) to evaluate the seed germination of curved parapholis in response to drought, salinity, heat stress and pH.

MATERIALS AND METHODS

Seed source

Mature seeds of curved parapholis were collected from barley fields located in the Golestan Province (N 36°85', E 54°27'), in northern Iran during August 2014. Mature seeds were collected from at least 100 plants. The seeds were bulked, cleaned manually, placed in a paper bag, and stored at room temperature (22°C) until the experiments were conducted.

General germination test protocol

Experiments were conducted at the Seed Technology Laboratory at Gorgan University of Agricultural Sciences and Natural Resources, Iran, during 2014. Germination was tested in 90 mm diameter Petri dishes lined with two pieces of Whatman No. 1 filter paper (GE Healthcare Bio-Sciences, PA, USA). Each Petri dish was soaked with 5 ml of distilled water (pH=6.5) or the test solutions. Twenty-five seeds were placed in each dish and kept at 20°C under constant darkness (covering with aluminium foil) for 21 days (ISTA, 2009), unless otherwise specified. Parafilm was used to seal the Petri dishes to reduce water evaporation. Each experiment was repeated twice. The seeds were considered to have germinated when the radicles projected outside the teguments, and germinated seeds were removed after every count. Ungerminated seeds were tested with 1% TTC (2, 3, 5-triphenyltetrazoliumchloride) at 20°C to assess viability. After 12 h, seeds showing a pink to reddish color were considered viable.

Dormancy breaking

Several treatments were applied to determine the requirements for dormancy breaking in curved parapholis:

Chemical scarification: Seeds of curved parapholis were soaked in sulfuric acid (98% v/ v) for 30 and 180 seconds and then washed thoroughly with distilled water three times before transfer to the germination assay.

Boiling water**:** Seeds were soaked in boiling water for 1, 2, 5 and 10 minutes. After treatment, the seeds were placed evenly in a 90 mm diameter Petri dish as explained above.

Chilling treatment: Seeds of curved parapholis were placed in Petri dishes with a 90 mm diameter with two sheets of round filter paper moistened by distilled water and then incubated at 3-5 °C for 1, 2, 4, 6, 8 and 10 weeks. For each treatment, the seeds were removed from the incubator and placed evenly in a 90 mm diameter Petri dish as mentioned above.

GA_3 treatment: Batches of seeds were immersed for 24 and 48 hours in a certain GA_3 solution at a range of GA_3 concentrations (0, 25, 50, 75, 100, 250, 500 and 1000 ppm) prepared according to Thomson (1996). Then seeds were washed and germination was tested.

KNO_3 effect: Seeds were treated with 0, 0.2, 0.5 and 1% (v/v) KNO_3 for 24 and 48 hours at 5 and 25°C. The experiment followed a completely randomized design with a factorial arrangement of the treatments.

Combination of sulfuric acid and GA_3 treatment: After scarification by sulfuric acid (98% v/v) for 30, 60 and 90 seconds, the seeds were placed in Petri dishes with a given GA_3 concentration (0, 25, 50, 75, 100, 250, 500 or 1000 ppm). Germination was evaluated by evenly distributing 25 seeds (in each replicate) on a moist paper. The experiment was performed in a factorial completely randomized design with three replicates per treatment.

Cardinal temperatures

After determining the best treatment for breaking dormancy (application of 75 ppm gibberellic acid and 30 s of sulfuric acid), seeds were placed into Petri dishes with moist germination paper and kept at seven constant temperatures (3, 5, 10, 15, 20, 25 and 35 °C) under constant dark for 21 days to determine the cardinal temperatures for germination of curved parapholis. Each replicate was inspected at approximately 8-hour intervals throughout the first day and at 12-hour intervals thereafter, always at an ambient laboratory temperature close to 20°C.

A 3-parameter sigmoidal function (equation 1) was fitted to the germination time-course data versus the temperature:

$$G=a / (1+ \exp (-(x-x_{50})/b)) \quad (1)$$

where G is the total cumulative germination percentage, a is the maximum cumulative seed germination percentage, x_{50} is the time to 50% of maximum seed germination and b is the slope of the curve or lag phase.

The reciprocal of time to reach 50% germination (t_{50}) was considered the germination rate (GR_{50}) (Soltani *et al.*, 2006) (equation 2):

$$GR_{50}=1 /t_{50} \quad (2)$$

The following model was used to quantify the response of the germination rate to temperature (equation 3) and to determine the cardinal temperatures for germination:

$$1/e=f(T)/f_o \quad (3)$$

where f(T) is a temperature function (reduction factor) that ranges between 0 at the base and ceiling temperature and 1 at the optimal temperature and $1/f_o$ is the inherent maximum rate of germination at the optimal temperature. Thus, f_o indicates the minimum number of hours required for germination at the optimal temperature (Soltani *et al.*, 2006). The 1/e also shows the germination rate of a given percentile. Dent-like, segmented and beta models that were fitted to germination rate data for evaluate cardinal temperatures of curved parapholis (Table 1).

The following equation for the root mean square error (RMSE, equation 7) was used to measure the difference between the measured and calculated values, where N is the number of data points, ($\sum_{i=1}^{n}(Yi-\hat{Y})$) is the sum of squares (SS) of the regression, Yi is the observed value and $\hat{Y}$ is the corresponding estimated value (Kobayashi and Salam 2000; Derakhshan *et al.*, 2014):

$$RMSE=\sqrt{\frac{1}{N}\sum_{i=1}^{n}(Yi-\hat{Y})^2} \quad (7)$$

Drought stress

To evaluate the effect of desiccation on seed germination of curved parapholis, an experiment was carried out in a completely randomized design with three replications. Solutions with osmotic potentials of 0, -0.2, 0.4, -0.6, -0.8 and -1 MPa were prepared by dissolving polyethylene glycol (PEG-6000) based on Michel and Kaufman (1973). Scarified seeds were placed in aqueous solutions of PEG at 20 °C.

Salt stress

To investigate the effect of salt stress on seed germination of curved parapholis, scarified seeds were incubated in 6 levels of salt concentration (0, 0.2, 0.4, 0.6, 0.8 and 1 MPa), which were created by using NaCl, at 20°C.

Solution pH

Buffered pH solutions were prepared by using potassium hydrogen phthalate in combination with 0.1 M HCl to obtain solution pH levels of 4, 5, and 6. A 25 mM sodium tetraborate decahydrate solution was used in combination with 0.1 M NaOH to prepare solutions with pH levels of 7, 8, or 9 (Sohrabi *et al.*, 2016a). Seeds were placed on moist paper containing 5 mL of the appropriate pH solution and placed in an incubator at 20ºC in the dark.

Heating stress

The effect of heat stress on curved parapholis seed germination was simulated in the laboratory at different temperatures for varying durations. Seeds were exposed to heated air in an oven using a completely randomised design with a factorial arrangement of the treatments. The effect of burning was simulated by exposing the seeds to five temperatures (40, 80, 120, 140, and 240 °C) over four exposure periods (2.5, 5, 7.5, and 10 minutes).

Table 1. Dent-like, segmented and beta models that were fitted to germination rate data for evaluate cardinal temperatures of curved parapholis.

Function	Formula
(4) Dent-like	$f(T)=(T-T_b)/(T_{o1}-T_b)$ if $Tb< T\le T_{o1}$
	$f(T)=(Tc-T)/(Tc-T_{o2})$ if $T_{o2}< T\le T_c$
	$f(T)=1$ if $T_{o1}< T\le T_{o2}$
	$f(T)=0$ if $T\le T_b$ or $T\ge T_c$
(5) Segmented	$f(T)=(T-T_b)/(T_o-T_b)$ if $T_b< T\le T_o$
	$f(T)=[1-(T-T_o)/(Tc-T_o)]$ if $T_o< T\le T_c$
	$f(T)=0$ if $T\le T_b$ or $T\ge T_c$
(6) Beta	$f(T)=((T_c-T)/(T_c-T_o))*((T-T_b)/(T_o-T_b))^{(To-Tb)/(Tc-To)}$

Table 2. Germination percentages of curved parapholis after scarification and chilling treatments.

H_2SO_4 (s)	Germination (%)	Chilling (weeks)	Germination (%)
0	0^{b}	0	0^{e}
30	8^{a}	1	12^{d}
60	8^{a}	2	20.67^{c}
90	8^{a}	4	35.33^{b}
120	0^{b}	6	34.67^{b}
150	0^{b}	8	49.33^{a}
180	0^{b}	10	49.33^{a}
LSD	1.87	LSD	3.97

Different letters show the mean difference based on LSD test at 0.05 level.

Statistical analysis

The data collected from the experiments were tested using an analysis of variance (ANOVA), and because there was no significant experiment-by-treatment interaction, the data were pooled for further analyses. Regression analyses were performed using Sigma Plot 8.0 to determine cardinal temperature, effects of osmotic potential and salt stress on seed germination. A one-way ANOVA analysis was performed using SAS 9.1 (SAS institute, Cary, NC, USA) to assess the dormancy breaking experiment and effects of pH on germination. Significant differences among treatments were identified using an LSD test ($P< 0.05$). The data m*et al*l normality conditions; therefore, data transformation was not required.

RESULTS AND DISCUSSION

Seed dormancy breaking

Germination of curved parapholis seeds was less stimulated by scarification with H_2SO_4. Eight perecnt germination was recorded when seeds were soaked in H_2SO_4 for 30, 60 and 90 seconds. There was no germination in the control treatment and when seeds were soaked for more than 90 seconds in H_2SO_4 (Table 2). Prolonged H_2SO_4 treatment resulted in poor germination or seed disintegration. The results showed that the seed coat did not cause a strong inhibition of seed germination of this annual grass.

The chilling treatment had a higher effect on germination than H_2SO_4. The highest germination was 49 % after 8 and 10 weeks in chilling conditions. Germination

Table 3. Germination percentages of curved parapholis after the combination of the gibberellic acid and Sulfuric acid treatment.

Scarification with H_2SO_4 (second)	GA(ppm)	Germination (%)
0	0	0
30		8^{k}
60		8^{k}
90		8^{k}
0	25	0^{l}
30		13.33^{j}
60		14.67^{ij}
90		8^{k}
0	50	0^{l}
30		41.33^{efg}
60		40^{fg}
90		13.33^{j}
0	75	0^{l}
30		84^{a}
60		80^{ab}
90		52^{d}
0	100	0^{l}
30		76^{bc}
60		73.33^{c}
90		73.33^{c}
0	250	0^{l}
30		38.67^{gh}
60		38.67^{gh}
90		36^{h}
-	LSD	2.70

Different letters show the mean difference based on LSD test at 0.05 level.

was not stimulated by gibberellin (GA_3), potassium nitrate (KNO_3) and boiling water (data for these treatments are not presented).

The highest germination was observed in response to a combination of gibberellic acid treatment plus sulfuric acid treatment; the percent germination of seeds treated with 75 ppm gibberellic acid and 30 second and 60 second of sulfuric acid was 84 and 80 %, respectively, and germination was approximately 76 % in seeds treated with 100 ppm gibberellic acid and 30 second of sulfuric acid (Table 3). Therefore, the best method for breaking dormancy in curved parapholis is the combination of 75 ppm gibberellic acid and 30 s of sulfuric acid, which resulted in a germination percentage of 84 %.

Soaking *Zaleya pentandra* (African purslane from Aizoaceae family) seeds in H_2SO_4 had little effect on seed germination (Munawar *et al*., 2015). For many grasses, prechilling at a temperature between 1 and 10°C for 6 weeks is enough for seeds to reach their peak germinability (Greipsson, 2001; Rogis *et al*., 2004; Huang *et al*., 2004). For the Poaceae family, it is well known that durations of stratification from 3 days to 6 weeks improve seed germination (Matus-Cádiz and Hucl, 2003), and even 18 weeks of stratification improves seed germination in some annual species (Milberg and Anderson, 1998). Amini *et al*., (2015) reported that prechilling had a moderate effect on seed dormancy breaking in three foxtail species (*Setaria glauca*, *S. verticillata and S. viridis*). A wet prechilling treatment increased germination of *Ranunculus ficaria* (Sohrabi *et al*., 2013b). The current results indicate that the minimum period for stratification is 8 wk, at which point some seeds exhibited a physiological response to the treatment.

Similar to this result, seeds of *Descurainia sophia* did not respond to GA_3 (Karimmojeni *et al*., 2014); and hot water and various concentrations of KNO_3 were ineffective in breaking *Zaleya pentandra* seed dormancy (Munawar *et al*., 2015). Seed treatments with hot water were found to improve germination of species with a hard seed coat by increasing the water and O_2 permeability of the testa (Aydýn and Uzun, 2001). However, in our study, the hot water seed treatments failed to promote curved parapholis seed germination.

In many cases, the factors inhibiting germination in Poaceae species are located in the embryo, but they may also be found in the grain-coat layers (Belderok, 1968; Adkins *et al*., 2002). Applying GA_3 and sulfuric acid had a positive effect on seed dormancy breaking in *Leymus chinensis* (Zhang *et al*., 2006). A high degree of germination was detected only in response to the combination of gibberellic acid and sulfuric acid. The results indicated that various dormancy mechanisms may exist in the species, and further studies are needed to elucidate them. The results will be helpful for selecting suitable treatments for improving seed germination and in the study of seed biology of curved parapholis.

Cardinal temperature

The segmented model structure was found to be the best model to predict germination rate (R^2=0.98, RMSE=0.0009, CV=14.48) (Table 4). Based on the output of this model, the base, optimum, and ceiling temperatures for curved parapholis germination were estimated to be 1.25, 23.29, and 35°C, respectively. Germination rate declined rapidly with increasing or decreasing temperatures above or below the optimum of 23.29 °C (Fig. 1).

According to the dent-like model, the base temperature was 1.30 °C, the optimum temperature varied between 18.65 and 25 °C, and the maximum temperature was 35°C. Based on the beta model, the base temperature was nonsignificantly 0.8°C, and the optimum temperature and ceiling temperature were 21.35 and 35.02 °C, respectively. Of the three models tested, the RMSE values indicate that the segmented model predicts the cardinal temperatures of curved parapholis better than the other two models tested based on the relative model fit as a function of model type, seeds and temperature (Table 4).

The best model for determination of cardinal temperatures varies depending on the weed species (Ansari *et al*., 2016; Sohrabi *et al*., 2011, 2013a, 2016b; Hosseini *et al*., 2017). The cardinal temperatures estimated in this

Table 4. Estimated parameters of three different models for estimating cardinal temperatures of curved parapholis.

models	t_b	t_o	t_{o1}	t_{o2}	t_c	f_o	R^2	P value	RMSE	CV%
Segmented	1.25(1.37)	23.29(3.68)	-	-	35(0.52)	67.77(4.40)	0.98	0.0001	0.0009	14.48
Dent like	1.30(NAN)	-	18.65(NAN)	25(NAN)	35(NAN)	85.15(NAN)	0.97	0.0006	0.001	16.34
Beta	0.8(3.06)	21.35(1.41)	-	-	35.02(0.68)	84.93(6)	0.96	0.009	0.001	15.79

Standard errors are presented in parentheses and NAN: indicated couldn't to estimate standard errors.

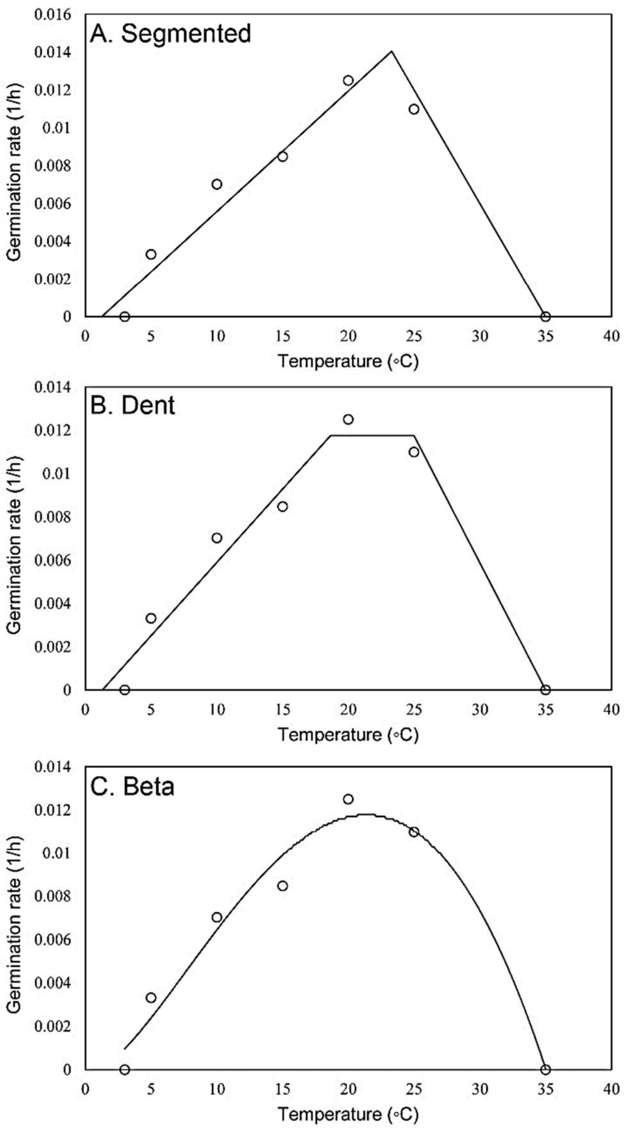

Fig. 1. Predicted germination rate at different constant temperatures using three different models. A. Segment. **B.** Dent. **C.** Beta.

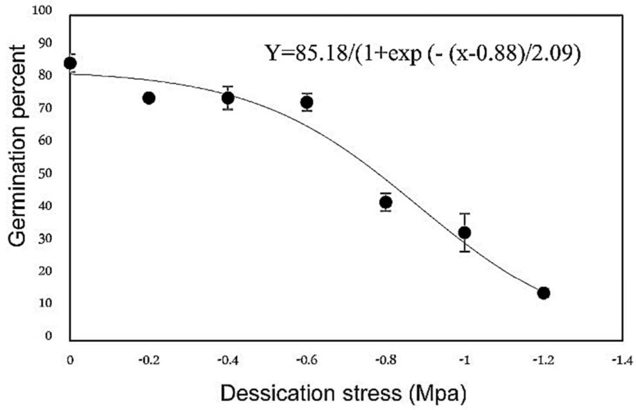

Fig. 2. Effect of osmotic potential on seed germination of curved parapholis.

study indicate that curved parapholis seeds need moderate temperatures for germination (Fig. 1). The results showed that this weedy grass germinates promptly and quickly, especially under the warmer conditions following the fall. Other researchers have also reported that the best germination temperature for two closely related species (*P. strigosa* and P. *incurva*) was from 16 to 21 °C (Noe and Zedler, 2000; Boscagli *et al*., 1996). Curved parapholis in Italy could not germinate at 2°C. This variation may be related to the geographical distribution of the species. Scherner *et al*., (2017) reported that silky windgrass (*Apera spica-venti*) and rattail fescue (*Vulpia myuros*) seeds were able to germinate at 1 °C, while the minimum temperature for annual bluegrass (*Poa annua*) germination was 5°C.

Results of the coefficient of determination (R^2), standard error, root mean square of errors (RMSE) and CV% for the three models revealed that the segmented model is more reliable than the dent-like and beta models (Table 4).

Effect of osmotic stress on germination

Seed germination decreased as the osmotic stress increased (Fig. 2). There were no significant differences in seed germination at -0.2 to -0.6 MPa osmotic stresses. At an osmotic potential of -0.2 to -0.6 MPa, seed germination was 74 %, while the G_{max} was 85 %. According to this result, at an osmotic potential of -0.88 MPa, seed germination declined to 50 %. The germination of curved parapholis decreased rapidly with increasing osmotic potential above -0.6 MPa (Fig. 2). These data suggest that curved parapholis germination could occur over a wide range of soil moisture contents. However, the seeds were sensitive to a higher water deficit (>-0.8 MPa), and this was consistent with the growing season, i.e., the germination and growing periods occur in the autumn months (rainy season). Germination reached its minimum percentage at -1.2 MPa, which suggested that the seeds may tolerate semiarid conditions. Three weedy grasses (*Poa annua* L., *Vulpia myuros* (L.) K. C. Gmel. and *Apera spica-venti* L.) were able to germinate under a low water potential (-1.0 MPa) (Scherner *et al*.,

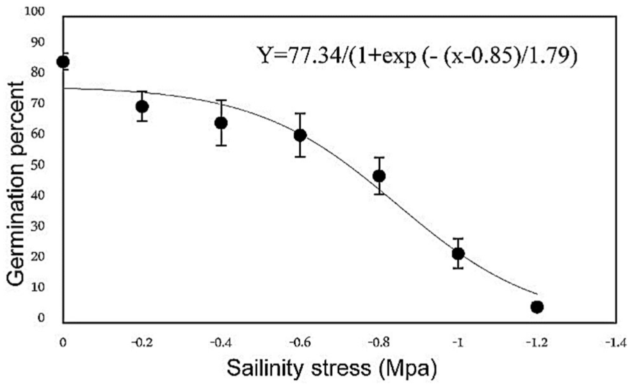

Fig. 3. Effect of salinity stress on seed germination of curved parapholis.

Table 5. Effect of pH solution on seed germination of curved parapholis.

pH	germination
4	0c
5	53.33b
6	77.33a
7	77.33a
8	48.66b
9	0c
distilled water (6.5)	85.33

Significant difference at P<0.5 level

2017). However, in an environment with changing moisture conditions, the opportunities for germination may not be limited for seeds of curved parapholis, which have wide moisture requirements. Pangola-grass [*Digitaria eriantha* Steud. subsp. pentzii (Stent) Kok.], when exposed to water stress, showed a reduction in total germination, although some germination could still be observed at a very low water potential (-1.5 MPa) (Brevedan *et al*., 2013). Awan *et al*., (2014) also been reported that *Urena lobata* L. seed germination decreased linearly when the osmotic potential fell from 0 to -0.8 MPa. Similar result was observed for *Eclipta prostrata* and *Ludwigia peruviana* in rice fields from Sri Lanka (Sashika Sumudunie and Gehan Jayasuriya, 2019).

Effect of salt stress on germination

Salt stress significantly delayed the start of germination and reduced the germination percentage of the seeds (Fig. 3). Seed germination decreased slightly as the salt concentration increased from 0 to -0.6 MPa but declined sharply at -0.8 to -1 MPa (Fig. 3). The seeds had the highest germination (85 %) in the control treatment. At -0.84 MPa NaCl, seed germination declined to 50 %. The lowest germination was observed at NaCl concentrations of -1.2 MPa. According to the model, the maximum germination was estimated to be 77 %. The results indicate that curved parapholis is able to germinate under a wide range of salinity values, which partially explains why this plant is one of the important weeds in barley fields with relatively saline soils in northern Golestan, Iran. Soils containing more than 100 mM (≈10 ds m-1) NaCl are considered to be highly saline (Awan *et al*., 2014). In this study, the germination percentage for curved parapholis was 50 % at -0.84 MPa NaCl (≈13 ds m-1), which showed that this weed has a tolerance to salinity. These results suggest that curved parapholis may be able to colonize saline areas because some seeds can still germinate at -1 MPa NaCl. The salinity and moisture effects were independent of each other for the proportion of curved parapholis seeds that germinated; this species is mostly tolerant of the high salinity and low moisture in southern California wetlands (Noe and Zedler, 2000). Soil salinity decreased the seed germination of curved parapholis. Salinity had a larger effect on the proportion of seeds that germinated than moisture (Noe and Zedler 2000). However, the effects of salinity on the germination of halophytes are most commonly osmotic (Tian *et al*., 2021). Boscagli *et al*., (1996) argued that increased rain and decreased surface soil salinity in autumn prompted the seed germination of curved parapholis. Also, Bocchieri *et al*., (1981) found that there was an after-ripening period in summer and that germination was affected by a salt solution.

Effect of pH on germination

A significant difference was observed in the seed germination of curved parapholis at various pH levels. The highest germination was detected across a pH range from 6 and 7. Germination at pH values of 4 and 9 was zero (Table 5). These data showed that a near-neutral pH is favorable for seed germination of curved parapholis and that the soil pH may act as a limiting factor for the distribution of this species. In fields invaded by this weed in Iran, most of the soil pH values are between 6.8 and 8.2; therefore, curved parapholis is well adapted to this pH range. By raising the soil pH levels, the germination of curved parapholis and its ability to grow and compete with barley may be reduced. Germination at limited pH values was observed in *Dactyloctenium aegyptium* (Burke *et al*., 2003) and *Origanum compactum* (Laghmouchi *et al*., 2017). Higher germination of *Alopecurus aequalis* was obtained at alkaline pH values ranging from 7 to 10 (Zhao *et al*., 2017).

Effect of heat shock on germination

After heat-shock treatment, germination was not observed in the seeds, and the seed vigor did not change among the tested durations and temperatures (according to TTC test). It seems that thermodormancy had been induced. These results indicate that heat shock would not have an effect on the survival of the seeds sown on the soil surface (data not shown). However, in the present study, a range of heat treatments had no effect on seeds of curved parapholis, and this factor is not a major limiter of seed viability. Approximately 80% of *Cucumis melo* L. subsp. *agrestis* var. *agrestis* (Naudin) Pangalo seeds could germinate after over 16 min at 100°C (Sohrabi *et al*., 2016a). In addition, approximately 20 % of Mexican sunflower seeds germinated after heat treatment for 30 min at 80°C (Wen, 2015).

CONCLUSION

According to the present research, scarification of seeds by concentrated sulfuric acid followed by the use of gibberellic acid is the most effective method for breaking the dormancy of its seeds. Although further work is needed, to determine the exact dormancy type which is an important adaptive trait and shows intraspecific variability by genetic and environmental factors during seed development (Baskin and Baskin, 2014). As presently shown, the necessary temperature for germination for curved parapholis includes relatively moderate temperatures (approximately 20 °C), which usually occurs over a period from October to late November in the Golestan region. Seeds of curved parapholis germinated across a wide range of environmental conditions. This grass was able to germinate under a low water potential (> -1 MPa), and it is highly tolerant of saline conditions. The seed germination of this species was not influenced by heat shock. It can germinate in a pH range of 5 to 8, which suggests that the pH is not an important limiting factor of the further spread of this weed. Regulating the soil microclimate (temperature) through field preparations, soil amendments and cultural practices can be employed to lower weed invasion by inhibiting weed germination. Based on the cardinal temperature results, to maximize the effectiveness of a soil-applied herbicide, the herbicide should be applied when the soil temperature is near 20 °C.

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LITERATURE CITED

Adkins, S.W., Bellairs, S.M., Loch, D.S. 2002 Seed dormancy mechanisms in warm season grass species. Euphytica**. 126**:13–20.

Allen, P.S., Benech-Arnold, R.L., Batlla, D., Bradford, K.J. 2007 Modeling of seed dormancy. In K. J. Bradford and H. Nonogaki (eds.) Seed Development, Dormancy and Germination. Annual Plant Reviews Volume **27**: 72–112. Blackwell Publishing Ltd, Oxford, UK.

Amini, V., Zaefarian, F., Rezvani, M. 2015 Effect of pre-chilling and environmental factors on breaking seed dormancy and germination of three foxtail species. Acta Agric. Slov. **105(2)**: 269–278.

Ansari, O., Gherekhloo, J., Kamkar, B., Ghaderi-Far, F. 2016 Breaking seed dormancy and determining cardinal temperatures for *Malva sylvestris* using nonlinear regression. Seed Sci. Technol. **44(3):** 447–460.

Aydýn, I., Uzun, F. 2001 Effects of some applications on germination rate of Gelemen clover seeds gathered from natural vegetation in Samsun. Pak. J. Biol. Sci. **4(2):** 181–183.

Baskin, C.C. Baskin, J.M. 2014 Seeds: ecology, biogeography, and evolution of dormancy and germination. 2nd edn, Elsevier Academic, San Diego, CA, USA.

Baskin, C.C., Baskin, J.M. 2004 A classification system for seed dormancy. Seed Sci. Res. **14(1)**: 1–16.

Belderok, B. 1968 Seed dormancy problems in cereals. Field Crops Abstracts **21:** 203–211.

Benvenuti, S. 2022 The toxic weed *Heliotropium europaeum* L.: Germination ecology, soil seed bank, and emergence dynamics in diversified cropping systems. Weed Biol. Manag. **22(2)**: 37–46.

Boscagli, A., Maccherini, S., Chiarucci, A. 1996 Germination of nine species of pioneer plant community of Pliocene clay soils of central western Italy under different photo and thermo-periods. Acta Soc. Bot. Pol. **65(3-4)**: 301–306.

Brevedan, R.E., Busso, C.A., Fioretti, M.N., Toribio, M.B., Baioni, S.S., Torres, Y.A., Fernández, O.A., Giorgetti, H.D., Bentivegna, D., Entío, J., Ithurrart, L., Montenegro, O., Mujica, M., de las, M., Rodríguez, G., Tucat, G. 2013 Water stress and temperature effects on germination and early seedling growth of *Digitaria eriantha*. Afr. J. Agric. Res. **8(32)**: 4345–4353.

Burke, I.C., Thomas, W.E., Spears, J.F., Wilcut, J.W. 2003 Influence of environmental factors on after-ripened crowfootgrass (*Dactyloctenium aegyptium*) seed germination. Weed Sci. **51(3)**: 342–347.

Chauhan, B.S., Johnson, D.E. 2010 The role of seed ecology in improving weed management strategies in the tropics. Adv. Agron. **105**: 221–262.

Derakhshan, A., Gherekhloo, J., Vidal, R.A., De Prado, R. 2014 Quantitative description of the germination of littleseed canarygrass (*Phalaris minor*) in response to temperature. Weed Sci. **62(2):** 250–257.

eFloras 2008 *Parapholis incurva* (Linnaeus) C.E.Hubbard. In Flora of China. Missouri Botanical Garden, St. Louis, MO & Harvard University Herbaria, Cambridge, MA. http://www.efloras.org/florataxon.aspx?flora_id=2&taxon_id=200025831.

Gherekhloo, J., Cruz, R. A., Osuna, M.D., Sohrabi, S. Prado, R. 2020 Assessing Genetic Variation and Spread of *Phalaris minor* Resistant to ACCase Inhibiting Herbicides in Iran. Planta Daninha **38:** e020195618.

Greipsson, S. 2001 Effects of stratification and GA3on seed germination of a sand stabilizing grass *Leymus arenarius* used in reclamation. Seed Sci. Technol. **29**: 1–10.

Hosseini, M., Mojab, M., Zamani, G.R. 2017 Cardinal temperatures for seed germination of wild barley, barley grass and hoary cress. Arch. Agron. Soil Sci. **63(3)**: 352–361.

Huang, Z.Y., Dong, M., Gutterman, Y. 2004 Caryopsis dormancy, germination and seedling emergence in sand, of *Leymus racemosus* (Poaceae), a perennial sand-dune grass inhabiting the Junggar Basin of Xinjiang, China. Aust. J. Bot. **52(4)**: 519–528.

ISTA 2009 International Rules for Seed Testing, International Seed Testing Association, Bassersdorf, Switzerland.

Karimmojeni, H., Taab, A., Rashidi, B., Bazrafshan, A.H. 2014 Dormancy breaking and seed germination of the annual weeds *Thlaspi arvense*, *Descurainia sophia* and *Malcolmia Africana* (Brassicaceae). J. Plant Prot. Res. **54(2)**: 179–187.

Khodapanah, G., Gherekhloo, J., Ghaderi-Far, F., Sohrabi, S., Golmohammadzadeh, S. 2022 Evaulation the seed dormancy and germination of black bindweed (*Polygonum convolvulus* L.). Iran. J. Weed Sci. **18(2)**: doi: 10.22092/ijws.2022.359019.1412

Kobayashi, K., Salam, M.U. 2000 Comparing simulated and measured values using mean squared deviation and its components. Agron. J. **92(2)**: 345–352.

Laghmouchi, Y., Belmehdi, O., Bouyahya, A., Senhaji, S.N., Abrini, J. 2017 Effect of temperature, salt stress and pH on seed germination of medicinal plant *Origanum compactum*. Biocatal. Agric. Biotechnol. **10:** 156–160.

Matus-Cádiz, M.A., Hucl, P. 2003 Comparison of pre-treatments for inducing germination in highly dormant wheat genotypes. Can. J. Plant Sci. **83(4)**: 729–735.

Michel, B.E., Kaufmann, M.R. 1973 The osmotic potential of polyethylene glycol 6000. Plant Physiol. **51(5)**: 914–916.

Munawar, S., Naeem, M., Ali, H.H., Jamil, M., Iqbal, M., Nazir, M.Q., Balal, R.M., Safdar M.E. 2015 Seed dormancy breaking treatments for African purslan (*Zaleya pentandra*). Planta Daninha **33(4):** 623–629.

Noe, G.B., Zedler, J.B. 2000 Differential effects of four abiotic factors on the germination of salt marsh annuals. Am. J Bot. **87(11)**: 1679–1692.

Qasani, NA., Ghaderi-Far, F. 2022 Investigating the elimination of dormancy and germination power of rice varieties under artificial storage in response to different temperatures. Eurasian Research Bulletin **13**: 157–163.

Rogis, C., Gibson, L.R., Knapp, A.D., Horton, R. 2004 Enhancing germination of eastern gamagrass seed with stratification and gibberellic acid. Crop Sci. **44(2)**: 549–552.

Sashika Sumudunie, H.G., Gehan Jayasuriya, K.M.G. 2019 Seed dormancy and germination of seven rice field weeds from Sri Lanka. Taiwania **64(3)**: 221–230.

Scherner, A., Melander, B., Jensen, P.K., Kudsk, P., Avila, L. 2017 Germination of Winter Annual Grass Weeds under a Range of Temperatures and Water Potentials. Weed Sci. **65(4)**: 468–478.

Sohrabi, S., Ghanbari, A., Rashed Mohasel, M.H., Gherekhloo, J., Vidal, R.A. 2016a Effects of environmental factors on *Cucumis melo* L. subsp. *agrestis* var. *agrestis* (Naudin) Pangalo seed germination and seedling emergence. S. Afr. J. Bot. **105**: 1–8.

Sohrabi, S., Ghanbari, A., Rashed Mohasel, M.H., Nassiri Mahalati, M., Gherekhloo, J. 2013a Effect of desiccation and salinity stress on seed germination and initial plant growth of *Cucumis melo*. Planta Daninha **31(4)**: 833–841.

Sohrabi, S., Gherekhloo, J., Kamkar, B., Ghanbari, A., Rashed Mohasel, M.H. 2016b The phenology and seed production of *Cucumis melo* as an invasive weed in northern Iran. Aust. J. Bot. **64(3)**: 227–234.

Sohrabi, S., Rashed-Mohasel, M.H., Nassiri Mahalati, M., Gherekhloo, J. 2013b Some biological aspects of lesser celandine (*Ranunculus ficaria*) invasive weed. Planta Daninha **31(3)**: 577–585.

Sohrabi, S., Gherekhloo, J., Rashed Mohassel, M.H., Ghanbari, A., Nassiri Mahalati, M. 2011. Cardinal temperatures of three invasive weeds in Iran. In: 3rd International Symposium on Weeds and Invasive Plants October 2–7, Ascona, Switzerland.

Sohrabi, S., Gherekhloo, J. 2012 Effect of drought stress on seed germination of *Prosopis farcta.* International Symposium: Current Trends in Plant Protection UDK: 582.736.3-114.2.

Soltani, A., Robertson, M.J., Torabi, B., Yousefi-Daz, M., Sarparast, R. 2006 Modeling seedling emergence in chickpea as influenced by temperature and sowing depth. Agric. For. Meteorol. **138(1-4)**: 156–167.

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. Grassl. Sci. **67(4)**: 369–379.

Wen, B. 2015 Effects of High Temperature and Water Stress on Seed Germination of the Invasive Species Mexican Sunflower. Plos One **10(10)**: e0141567.

Yena, A. 2017 *Parapholis incurva* (Linnaeus) C.E.Hubbard. [accessed 2022 May 21]. http://www.grid.unep.ch/bsein/redbook/txt/paraphol.htm?%20PLANTAE.

Zhang, W.D., Bi, J.J., Ning, T.Y., Liu, X.L., He M.R. 2006 Effects of temperature, light and other treatments on seed germination of *Leymus chinensis*. Can. J. Plant Sci. **86(1)**: 143–148.

Zhao, N., Qi, L., Guo, W., Zhang, L. 2017 Effect of Environmental Factors on Germination and Emergence of Shortawn Foxtail (*Alopecurus aequalis).* Weed Sci. **66(1)**: 47–56.