www.czasopisma.pan.pl PAN POLSKA AKADEMIA NAUK www.journals.pan.pl

Journal of Plant Protection Research ISSN 1427-4345

ORIGINAL ARTICLE

# Germination biology and phenological development stages of false jagged-chickweed (*Lepyrodiclis holosteoides*)

Mehdi Minbashi Moeini[1]*, Eshagh Keshtkar[2]*, Hamidreza Sasanfar[1], Mohammad Ali Baghestani[1]

[1] Iranian Research Institute of Plant Protection, Agricultural Research, Education and Extension Organization (AREEO), Tehran, Iran

[2] Department of Agronomy, Faculty of Agriculture, Tarbiat Modares University, Tehran, Iran

**Vol. 61, No. 4: 347–357, 2021**

**DOI: 10.24425/jppr.2021.139243**

Received: March 30, 2021
Accepted: June 14, 2021
Online publication: December 20, 2021

*Corresponding address:
m.minbashi@areeo.ac.ir
keshtkar@modares.ac.ir

Responsible Editor:
Kinga Matysiak

**Abstract**

False jagged-chickweed (*Lepyrodiclis holosteoides* (C.A. Mey.) Fenzl ex Fisch. & C.A. Mey.) is an invasive weed species distributed in many regions of Iran. Scientific knowledge about the biology and ecology of false jagged-chickweed is rare. In a series of laboratory experiments, the effect of chilling treatments, potassium nitrate ($KNO_3$), gibberellic acid ($GA_3$), concentrations, temperature regimes, and sowing depths on seed germination and breaking seed dormancy of false jagged-chickweed was studied. In two field experiments the phenology of false jagged-chickweed and winter wheat (*Triticum aestivum*) was also compared. Chilling treatment for 15 days, a $KNO_3$ concentration of 30 µmolar and a $GA_3$ concentration of 144 µmolar increased germination percentage and germination rate. However, chilling treatment for 15 days did not increase germination rate as well as the $KNO_3$ and $GA_3$ treatments. A quadratic polynomial model predicted that the optimum temperature giving the maximum germination percentage was 22°C. Seedlings emerged in a range of sowing depths from 0 to 8 cm, while no seedling emergence occurred at sowing depths greater than 10 cm. Based on a Gaussian model, the optimum sowing depth was predicted to be 3.9 cm. False jagged-chickweed required higher growing degree days (GDD) for seedling emergence than winter wheat, while the flowering stage of false jagged-chickweed occurred earlier than winter wheat. Results achieved in the present study are of interest not only for studying other life cycle aspects of this species but also as basic information for developing management strategies.

**Keywords:** chilling treatment, $GA_3$, growing degree days (GDD), $KNO_3$, sowing depth

## Introduction

False jagged-chickweed (*Lepyrodiclis holosteoides* (C.A. Mey.) Fenzl ex Fisch. & C.A. Mey.) is a dicotyledonous annual weed. It has a creeping and sprawling growth habit at its early life stages, while it grows rapidly and overtops crops such as winter wheat (*Triticum aestivum*) at the end of its life cycle (Rabeler 1992; Minbashi Moeini 2011). False jagged-chickweed is native to southwestern and central Asia (Rabeler 1992), however, it has been introduced into other parts of the world including Europe, Asia, and the USA (Rabeler 1992; Minbashi Moeini 2011; Annonymous GP 2020). It is considered to be a noxious weed species in 46 states of the USA (Annonymous GP 2020; Annonymous USDA 2020) and Iran (Deihimfard *et al.* 2018). False jagged-chickweed is one of the invasive weed species distributed in wheat and canola (*Brassica napus* L.) cropping systems in many regions of Iran, especially in Karaj and Shahriar districts (Minbashi Moeini 2011; Deihimfard *et al.* 2018). It has a substantial effect on wheat and canola yield production, so that 17 and 22 false jagged-chickweed $m^{-2}$ can cause up to 33 and 41% yield reduction in wheat and canola, respectively (Minbashi Moeini M. unpublished data). The yield reduction of crops might be due to lack of selective and effective herbicides for controlling false jagged-chickweed. However, little is known about the biology and ecology of false jagged-chickweed (Yaghoubi *et al.* 2011).

Comprehensive knowledge about the biology and ecology of the life cycles of weed species plays an important role in integrated weed management programs such as time of herbicide application, type of tillage system, etc. Seed germination is a key stage in the life cycle of plant species, such as false jagged-chickweed. Lack of scientific information about germination traits of false jagged-chickweed is also an obstacle for obtaining further knowledge about the other growth stages of this invasive weed species and is important for developing management programs. This basic information about seed germination can be useful for growing normal weed seedlings in research projects, where we want to decipher other aspects of weed biology. For instance, growing similar size weed seedlings is necessary whenever we want to evaluate the response of weeds to herbicides and crop density. Accordingly, finding the best weed seed dormancy breaking treatments and optimizing the above-mentioned growth conditions are very important in weed science.

Many environmental, physical, and chemical factors affect seed germination and dormancy. Seed prechilling, potassium nitrate ($KNO_3$), and gibberellic acid ($GA_3$) are the most commonly used treatments for promoting seed germination and releasing seed dormancy. For instance, it was reported that $GA_3$, $KNO_3$, and chilling treatments increased the germination percentage of *Papaver dubium* L., *P. rhoeas* L. (Golmohammadzadeh *et al.* 2015), hoary cress (*Cardaria draba* (L.) Desv.) (Rezvani and Zaefarian 2016), muskweed (*Myagrum perfoliatum*) (Honarmand *et al.* 2016), and *Solanum americanum* Mill. (Forte *et al.* 2019). Seed germination of weed/crop seeds could also be influenced by temperature and sowing depth, as reported for many weed species (for instance see Bakar and Nabi 2003; Begum *et al.* 2006; Guillemin and Chauvel 2011; Elahifard and Derakhshan 2018; Forte *et al.* 2019). Knowledge of the optimum germination temperature, the optimum time of seedling emergence, and the optimal sowing depth of false jagged-chickweed has practical implications in selecting the best tillage time, the appropriate tillage system, the proper application time of soil applied herbicides and the suitable crop sowing time. Awareness of phenological development stages of crop and weed species is also very important for developing optimum timing of management strategies including the proper application time of foliar applied herbicides to ensure sufficient performance or time of crop harvesting to lead to a decline in weed seed return to the soil seed bank.

To date, little research has been done to determine the biological and ecological requirements for seed germination of false jagged-chickweed. In addition, little is known about the phenological stages of this troublesome species. Therefore, the objectives of the present study were to: 1) find the best chemical ($KNO_3$ and $GA_3$) and chilling treatments on seed dormancy breaking, 2) determine the optimum germination temperature, 3) determine the optimal sowing depth for seedling emergence, and 4) investigate comparative phenological development stages of false jagged-chickweed and winter wheat.

# Materials and Methods

## Plant material and seed germination procedure

In mid-July 2017, seeds of false jagged-chickweed were collected from a winter wheat field in Shahriar area of Iran (35°40’37”N, 51°48’29”E, 1160 meters asl.). Seeds were collected from about 15 mother plants. The field had been under winter wheat cultivation for at least three years. The seeds were stored for two weeks at room temperature (approximately 25°C) under dry conditions (relative humidity of 40–50%) until the start of laboratory and field experiments in early September 2017.

As a standard procedure in all experiments, 50 seeds of false jagged-chickweed were placed on two layers of filter paper (Whatman No. 1) in 12.0 cm diameter Petri dishes. The Petri dishes were then saturated with 10 ml of different solutions such as distilled water, $KNO_3$, and $GA_3$ according to different experiments. There were four replications per treatment. The Petri dishes were incubated in a growth chamber under different conditions based on the aims of the experiments. The growth chamber provided a 16/8-h day/night photoperiod with a photosynthetic photon flux density of 185 $\mu mol \cdot m^{-2} \cdot s^{-1}$. The number of germinated seeds was counted every day for 21 consecutive days. A seed was considered as germinated when the radicle was visible (around 2 mm), then removed from the Petri dishes. Germination percentage (%) and germination rate (seed $day^{-1}$) were calculated by Equation 1 and Equation 2, respectively (Ranal and Santana 2006; Ranal *et al.* 2009).

$$\text{Germination percentage} = \frac{\sum_{i=1}^{k} N_i}{n} \times 100, \quad \text{(Eq. 1)}$$

where: $N_i$ – the number of germinated seeds in day $i$; $k$ – the last time of germination, and $n$ – the total number of seeds in each Petri dish.

$$\text{Germination rate} = \sum_{i=1}^{k} \frac{N_i}{T_i}, \quad \text{(Eq. 2)}$$

where: $N_i$ – the number of germinated seeds in day $i$; $k$ – the last time of germination, and $T_i$ – day $i$ when the germinated seeds were recorded.

### Effect of chilling, $KNO_3$, and $GA_3$ on breaking seed dormancy

In order to determine the effect of chilling, potassium nitrate ($KNO_3$), and gibberellic acid ($GA_3$) on breaking seed dormancy of false jagged-chickweed, an experiment with 11 treatments was conducted based on a completely randomized design with four replications. The freshly harvested seeds were exposed to chilling treatments (i.e., in a refrigerator at 4 ± 1°C in the dark) for 5, 10, 15 and 20 days, $GA_3$ treatments at three different concentrations of 144, 288 and 433 µmolar, and $KNO_3$ treatments at three different concentrations of 10, 20 and 30 µmolar. Four Petri dishes saturated with 10 ml distilled water i.e., without any further treatment were considered as control treatment.

### Effect of constant temperature on seed germination traits

In order to determine the optimum germination temperature of false jagged-chickweed, the germination of seeds was tested at eight constant temperatures: 2, 5, 10, 15, 20, 25, 30 and 35°C. The experiment was based on a completely randomized design with four replicates i.e., four Petri dishes. The Petri dishes were placed in a growth chamber at 16/8-h day/night photoperiods using a photosynthetic photon flux density of 185 $\mu mol \cdot m^{-2} \cdot s^{-1}$.

### Effect of alternating temperature on seed germination traits

The influence of fluctuating day/night temperature on germination of false jagged-chickweed was evaluated. Seeds were incubated at three different alternating temperature regimes including 15/5, 15/10 and 20/10°C (day/night) with 16/8-h day/night photoperiods and a photosynthetic photon flux density of 185 $\mu mol \cdot m^{-2} \cdot s^{-1}$. In addition, a constant temperature of 20°C with the previously mentioned photoperiod was evaluated alongside the three alternating temperature regimes. The 20°C temperature was considered as the control treatment based on our preliminary experiment, where the highest germination was observed. The experiment was a completely randomized design with four treatments, and four replications per treatment giving a total of 16 Petri dishes.

### Effect of sowing depth on seedling emergence traits

A pot experiment was carried out to estimate the optimum sowing depth (i.e., the best sowing depth giving the highest seedling emergence) of false jagged-chickweed. Four similar size seeds were sown in plastic pots (30 cm height) filled with field soil. The seeds were sown at 11 depths (0, 2, 4, 6, 8, 10, 12, 14, 16, 18, 20, 25 cm) with a similar distance between seeds. The pots were placed in a greenhouse at 15/10°C (light/dark) with 16/8-h day/night photoperiods. The pots were irrigated two or three times a week. The emerged seedlings were counted regularly for a period of up to three months. The pots were arranged based on a completely randomized design with eight replications.

### Comparative phenology of false jagged-chickweed and winter wheat

Comparative phenology of false jagged-chickweed and winter wheat (cv. Pishtaz) was studied in two fields located at Karaj, Iran and Shahriar, Iran, during the growing season of 2017–2018. Geographical and climatic information as well as soil characteristics of the two locations are presented in Tables 1 and 2. Both wheat fields were naturally infested with false jagged-chickweed.

The date of principle phenological stages of wheat and false jagged-chickweed, including seedling emergence, leaf development, tillering, stem elongation, booting, flowering (anthesis), fruiting, ripening and

**Table 1**. Geographical and climatic information of the two fields

| Location | Longitude | Latitude | Altitude [m] | Min temperature [°C] | Max temperature [°C] | Precipitation [mm] |
|---|---|---|---|---|---|---|
| Karaj | 50°56′27″E | 35°46′23″N | 1,312 | –20 | 40 | 247.3 |
| Shahriar | 51°50′27″E | 35°40′52″N | 1,160 | –19 | 42 | 224.5 |

**Table 2**. Soil characteristics of the two fields

| Location | Organic matter [%] | pH | EC [$dsm^{-1}$] | Soil texture | N [%] | $P_2O_5$ [ppm] | $K_2O$ [ppm] |
|---|---|---|---|---|---|---|---|
| Karaj | 0.58 | 7.50 | 4.54 | loamy clay | 0.012 | 17 | 367 |
| Shahriar | 0.61 | 7.30 | 5.23 | loamy | 0.024 | 19 | 456 |

seed shedding was recorded twice a week within three quadrates (2 $m^{-2}$) that were placed randomly.

The minimum and maximum daily temperatures were collected from the nearest meteorological stations to calculate accumulated thermal units (*GDD*, growing degree days). Accumulated *GDD* was estimated using Equation 3 (McMaster and Wilhelm 1997):

$$GDD = \sum_{i=1}^{n}\left(\frac{T_{max}+T_{min}}{2}\right)-T_{base}, \quad \text{(Eq. 3)}$$

where: $n$ – the number of days after the sowing date, $T_{max}$ – the maximum temperature in a day and $T_{min}$ – the minimum temperature in a day. $T_{base}$ for both winter wheat and false jagged-chickweed was considered to be 0°C as it was utilized by Deihimfard *et al.* (2018).

## Statistical analysis

The data were subjected to ANOVA and then means were compared by Fisher's protected least significant difference (LSD) test at the $p < 0.05$ probability level. The relationship between temperature and germination traits (germination percentage and germination rate) of false jagged-chickweed was described by a quadratic polynomial regression model in order to determine the optimum germination temperature. The optimum sowing depth was determined using a Gaussian model as described in Equation 4.

$$\text{Seedling emergence} = a \times \exp\left[-0.5-\left(\frac{x-c}{b}\right)^2\right], \quad \text{(Eq. 4)}$$

where: $a$ – the maximum seedling emergence (i.e., the peak of the bell-shaped curve), $x$ – sowing depth, $c$ – sowing depth at which the maximum seedling emergence occurs and $b$ – the slope of the curve around the inflection points. The curve is bell-shaped and shows two inflection points around the maximum value. The regression models were selected through the *F*-test and Akaike Information Criterion (AIC) where the model having the lowest AIC was considered to be the best fitted model. Statistical analysis and plots were made using R statistical software (R Core Team 2013). The add-on "agricolae" package was used to separate means using Fisher's protected least significant difference (LSD) test at the 0.05 probability level (R Core Team 2013).

# Results

## Effects of chilling, $KNO_3$, and $GA_3$ on seed germination traits

One-way ANOVA showed that germination traits including germination percentage and germination rate were influenced by treatments ($p < 0.01$, Table 3). All treatments increased the germination percentage

**Table 3.** Analysis of variance (mean squares) for the effects of different dormancy breaking treatments (chilling, $KNO_3$, and $GA_3$) on germination traits (germination percentage and germination rate) of false jagged-chickweed (*Lepyrodiclis holosteoides*)

| SOV | *df* | Mean square | |
|---|---|---|---|
| | | germination percentage | germination rate |
| Treatment | 10 | 304.1* | 151.7* |
| Error | 33 | 39.9 | 1.8 |
| CV [%] | | 7.9 | 14.2 |

*significant at the 0.01 probability level
SOV = source of variation; CV = coefficient of variation

significantly. Germination percentages ranged from 57.5% to 90.5% depending on the treatment (Fig. 1). The highest and lowest germination percentages were recorded in the chilling treatment for 15 days (Chil-15) and control treatment (Ctrl), respectively. However, there was no statistically significant difference in germination percentage between the Chil-15, Chil-10, Chil-20, and $KNO_3$ concentration of 30 μmolar ($KNO_3$-30). The $GA_3$ concentrations showed a similar effect on germination percentage. Even though there were no significant differences in germination percentages between $KNO_3$ treatments, increasing $KNO_3$ concentration tended to increase germination percentage.

The effects of treatments on germination rate are presented in Figure 2. The $GA_3$ and $KNO_3$ treatments significantly increased germination rate, while the chilling treatments did not affect germination rates except for the Chil-5 and Chil-10 (Fig. 2). The highest

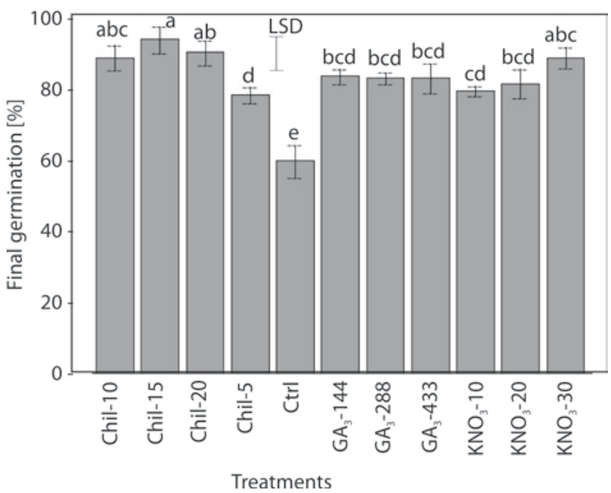


**Fig. 1.** Effects of different dormancy breaking treatments including potassium nitrate ($KNO_3$ concentrations of 10, 20 and 30 μmolar), gibberellic acid ($GA_3$ concentrations of 544, 288 and 433 μmolar) and chilling treatments (Chil. for 5, 10, 15 and 20 days) on final germination percentage of false jagged-chickweed (*Lepyrodiclis holosteoides*). Different letters indicate significant differences ($p < 0.05$) between treatments. Bars represent standard error

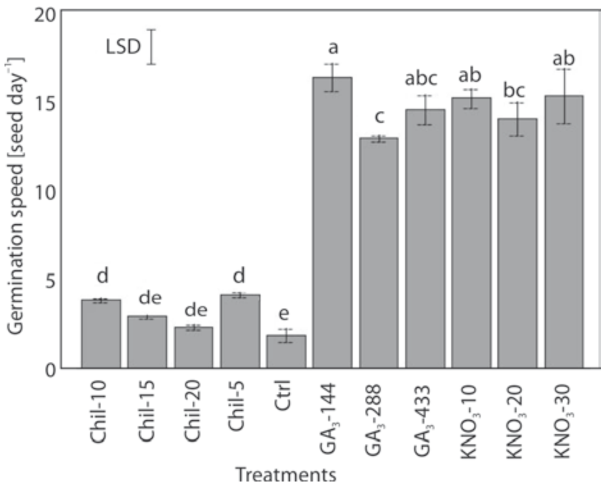


**Fig. 2.** Effects of different dormancy breaking treatments including potassium nitrate ($KNO_3$ concentrations of 10, 20 and 30 µmolar), gibberellic acid ($GA_3$ concentrations of 144, 288 and 433 µmolar) and chilling treatments (Chil. for 5, 10, 15 and 20 days) on germination rate of false jagged-chickweed (*Lepyrodiclis holosteoides*). Different letters indicate significant differences ($p < 0.05$) between treatments. Bars represent standard error

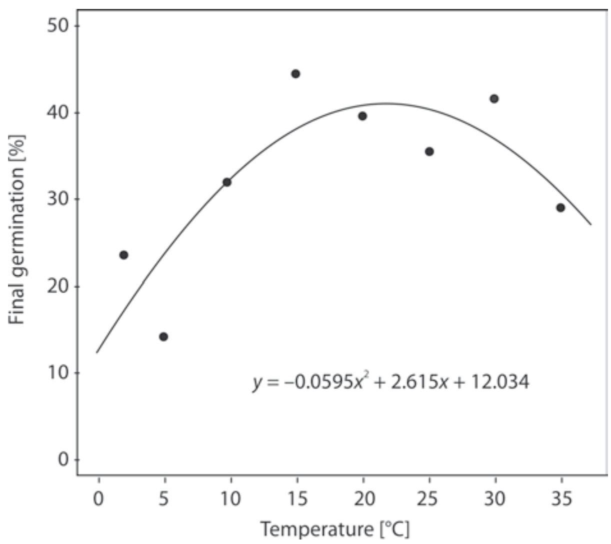


**Fig. 3.** Effects of different temperature treatments on germination percentage of false jagged-chickweed (*Lepyrodiclis holosteoides*). A quadratic polynomial model was fitted to the data. The highest germination percentage was estimated to be 40.75% at 22°C

and lowest germination rates were observed in the $GA_3$–144 µmol and the untreated seeds (Ctrl), respectively. Even though the $GA_3$ and $KNO_3$ treatments increased the rate of germination, no clear trend was observed between the concentration and the germination rate.

## Effects of constant temperature on seed germination traits

One-way ANOVA showed that germination percentage and germination rate were influenced by temperature ($p < 0.01$, Table 4). As the temperature treatment is a quantitative treatment, a comparison of temperature treatments is incomplete and meaningless. So, a regression analysis was made to make interpolation and find the best temperature for germination of seeds. It was found that the germination percentage followed a quadratic polynomial trend model over the increasing temperature (Fig. 3). The estimated temperature providing the highest germination percentage i.e., the optimum temperature for germination, was 22°C (Fig. 3). The quadratic polynomial model predicted that germination percentage might be 40.75% at 22°C. This meant that increasing the temperature from 2 to 22°C increased germination percentage and temperatures higher than 22°C decreased germination percentage of the seeds.

Similar to the final germination percentage, the germination rate followed a quadratic polynomial trend model over the temperature levels (Fig. 4). The quadratic polynomial model predicted that the highest germination rate i.e., 6.1 seeds day$^{-1}$ might occur at 24.7°C (Fig. 4). It is worth noting that, at the estimated optimum temperature for germination percentage (i.e., 22°C), the germination rate was 6.0 seeds day$^{-1}$, which is similar to the estimated optimum temperature for germination rate i.e., 6.1 seeds day$^{-1}$.

**Table 4.** Analysis of variance (mean squares) for the effects of different temperatures on germination traits (germination percentage and germination rate) of false jagged-chickweed (*Lepyrodiclis holosteoides*)

| SOV | *df* | Mean square | |
|---|---|---|---|
| | | germination percentage | germination rate |
| Temperature | 7 | 411.1* | 26.3* |
| Error | 48 | 32.9 | 0.36 |
| CV [%] | | 17.7 | 14.9 |

*significant at the 0.001 probability level
SOV = source of variation; CV = coefficient of variation

## Effects of alternating temperature on seed germination traits

One-way ANOVA showed that both germination traits including the final germination percentage and the germination rate were influenced by alternating temperature regimes ($p < 0.01$, Table 5). The highest germination percentage (76.5%) was observed at the constant temperature (20°C), while there were no statistically significant differences between alternating temperature regimes (Fig. 5). As it was observed for the final germination percentage, the highest germination rate (23.6 seed germination day$^{-1}$) occurred at the constant temperature (20°C). The lowest germination rate was recorded at the alternating temperature regime of 15/10°C (Fig. 6).

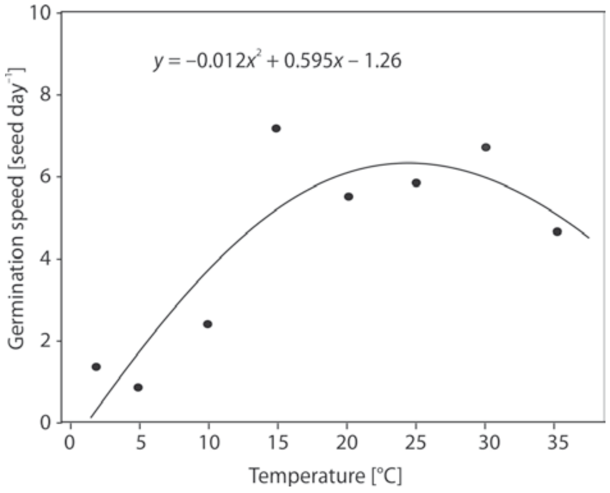


**Fig. 4.** Effects of different temperature treatments on germination rate of false jagged-chickweed (*Lepyrodiclis holosteoides*). A quadratic polynomial model was fitted to the data. The highest germination rate was estimated to be 6.1 seeds day$^{-1}$ at 24.7°C

**Table 5.** Analysis of variance (mean squares) for the effects of alternating temperatures on germination traits (germination percentage and germination rate) of false jagged-chickweed (*Lepyrodiclis holosteoides*)

| SOV | *df* | Mean square | |
|---|---|---|---|
| | | germination percentage | germination rate |
| Treatment | 3 | 1066.0* | 312.4* |
| Error | 12 | 137.8 | 3.9 |
| CV [%] | | 22.4 | 12.9 |

*significant at the 0.01 probability level
SOV = source of variation; CV = coefficient of variation

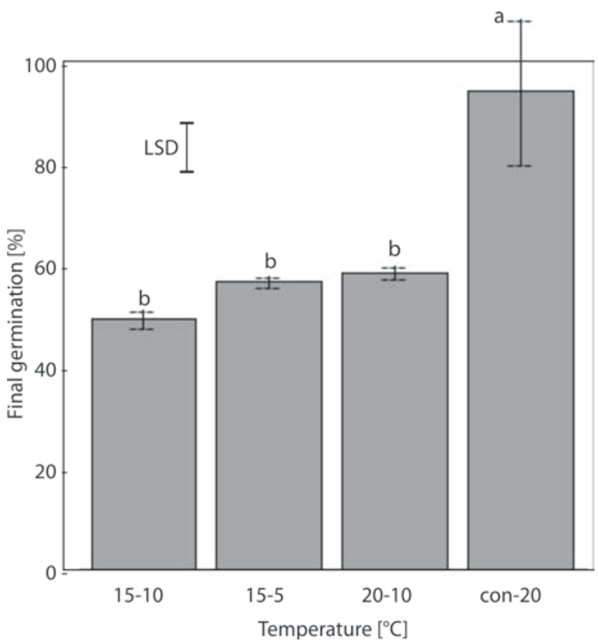


**Fig. 5.** Effects of alternating temperature regimes on germination percentage of false jagged-chickweed (*Lepyrodiclis holosteoides*). Different letters indicate significant differences ($p < 0.05$) between treatments. Bars represent standard error

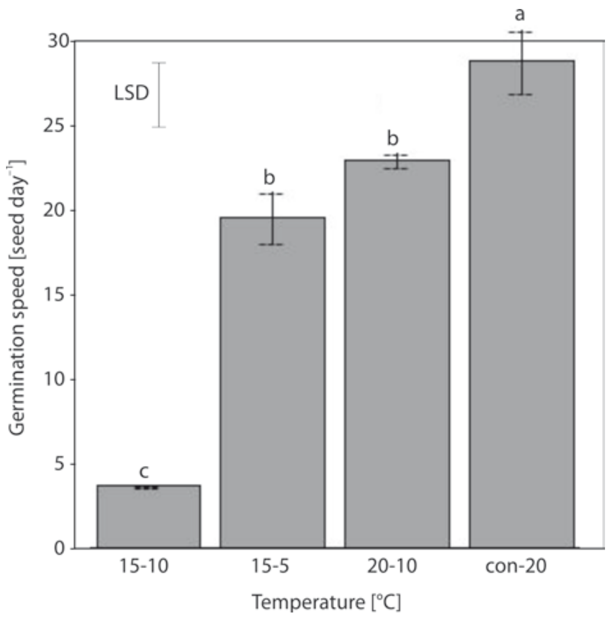


**Fig. 6.** Effects of alternating temperature regimes on germination rate of false jagged-chickweed (*Lepyrodiclis holosteoides*). Different letters indicate significant differences ($p < 0.05$) between treatments. Bars represent standard error

## Effects of sowing depth on seedling emergence traits

Seedling emergence of false jagged-chickweed was affected by sowing depth as it was illustrated in Figure 7. There was a nonlinear relationship between the sowing depth and the final seedling emergence so that a Gaussian model was fitted to the data. It meant, increasing

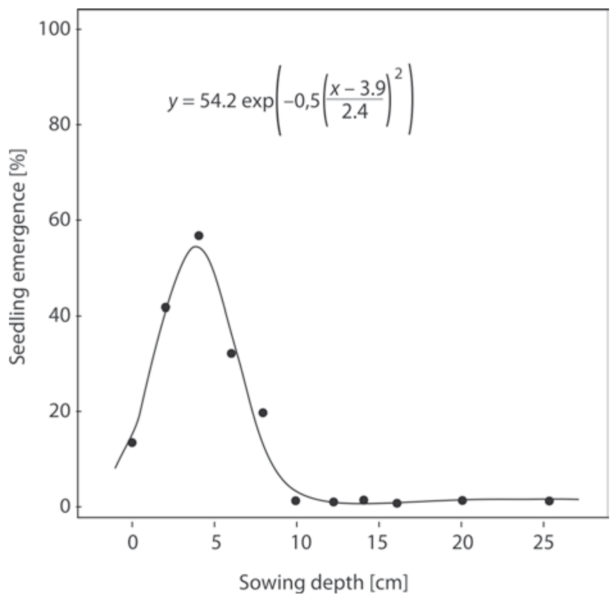


**Fig. 7.** Effects of sowing depth on seedling emergence of false jagged-chickweed (*Lepyrodiclis holosteoides*). A Gaussian model was fitted to the data. The highest seedling emergence occurred at 3.9 cm sowing depth, representing the optimal sowing depth for seedling emergence

sowing depth from zero to 4 cm increased final seedling emergence, while sowing depths greater than 4 cm decreased the final seedling emergence. Importantly, no seedling emergence was observed at sowing depths equal to or greater than that of 10 cm. The Gaussian model predicted that the highest final seedling emergence occurred (54.2%, i.e., the *a* parameter) at the sowing depth of 3.9 ± 1.4 cm. It meant that the optimum sowing depth for false jagged-chickweed was around 3.9 cm (Fig. 7).

### Comparative phenology of false jagged-chickweed and winter wheat

The *GDD* required to reach the seedling emergence for false jagged-chickweed and winter wheat were slightly different in both locations (Fig. 8). Overall, false jagged-chickweed seeds needed higher *GDD* for seedling emergence than winter wheat, where the *GDD* for seedling emergence of wheat (Zadoks 10) ranged from 154 to 160°C d, while it was 186 and 190°C d for false jagged-chickweed in Shahriar and Karaj, respectively (Fig. 8). The two-leaf growth stage (Zadoks 12) occurred simultaneously when the thermal unit ranged from 251 to 263°C d for both species (Fig. 8), meaning that the growth rate of false jagged-chickweed accelerated and compensated for the delayed seedling emergence. The *GDD* required to reach the six-leaf growth stage for false jagged-chickweed was 449 and 460°C d in Shahriar and Karaj, Iran, respectively. On the other hand, the six-leaf stage of false jagged-chickweed occurred when winter wheat was almost at the tillering stage (Zadoks 21), i.e., the tillering stage of winter wheat (Zadoks 21) initiated after the *GDD* reached 420 and 433°C d in Shahriar and Karaj, respectively. The *GDD* of winter wheat to reach the third-tiller stage (Zadoks 23) was registered between 584 and 608°C d in the two locations. The first detectable node of winter wheat coincided with the development of the first buds in false jagged-chickweed, when the mentioned growth stages occurred after the *GDD* reached 1,150 to 1,180°C d (Fig. 8). Moreover, the *GDD* of winter wheat needed to reach the second detectable node stage was between 1,171 and 1,261°C d in the two locations. The flowering stage of false jagged-chickweed started much earlier than winter wheat, where it was between 1,390 and 1,420°C d, while for winter wheat it was found to be between 1691 and 1736°C d.

## Discussion

### Effects of chilling, $KNO_3$, and $GA_3$ on seed germination traits

Several studies have examined the effect of environmental and managerial factors on seed germination and dormancy breaking of many plant species, as we did here. Similar to our results, naturally chilled seeds of *Datura ferox* (fierce thornapple) had

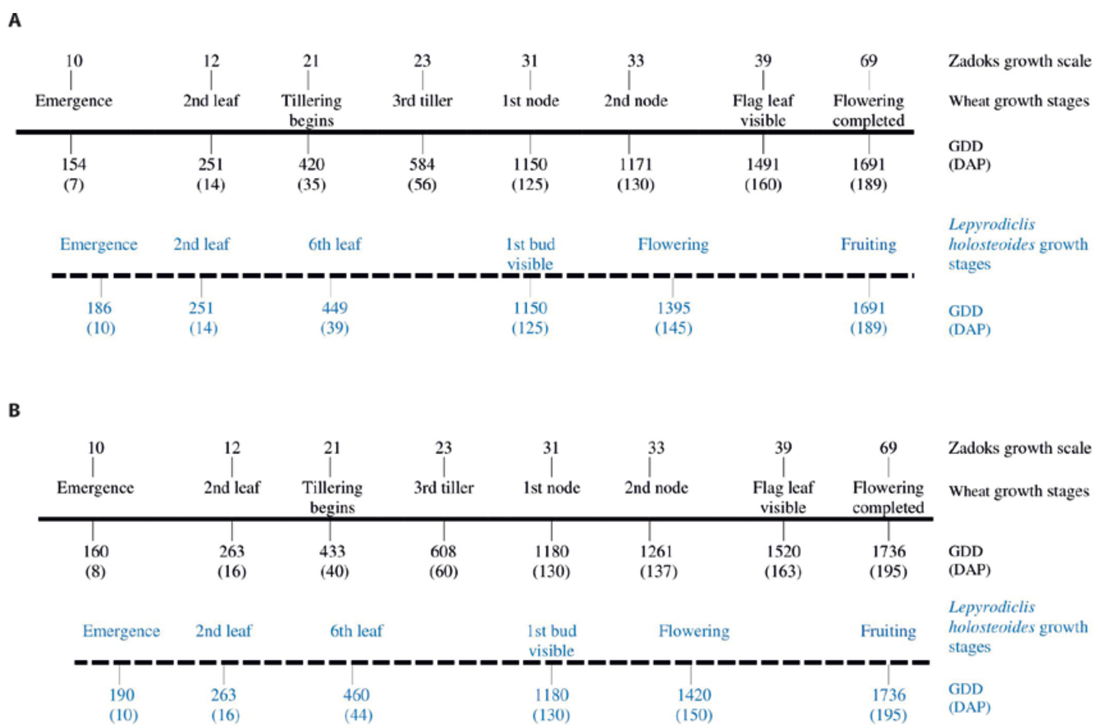


**Fig. 8.** Comparative phenological development stages of winter wheat (*Triticum aestivum*) and false jagged-chickweed (*Lepyrodiclis holosteoides*) based on thermal units (*GDD*, growing degree days) and days after planting (*DAP*) in the two studied locations, Shahriar, Iran (A) and Karaj, Iran (B)

higher germination than non-chilled seeds (Dorado *et al.* 2009). Chilling also promoted germination of other weed species including *Cardaria draba* (L.) Desv. (hoary cress) (Rezvani and Zaefarian 2016), *Euphorbia esula* L. (leafy spurge) (Foley 2004) and *Raphanus raphanistrum* (wild radish) (Malik *et al.* 2010). All three $KNO_3$ concentrations promoted final germination of false jagged-chickweed as with previous studies which showed that various concentrations of $KNO_3$ increased germination of several species such as *Solanum rostratum* Dunal (buffalobur) and *C. draba* (Rezvani and Zaefarian 2016; Wei *et al.* 2010). Applying pre-chilling with $GA_3$ provided the highest germination percentage in *Helianthus tuberosus* L. (Jerusalem artichoke) (Puttha *et al.* 2014). A concentration range of $GA_3$ (288–1,152 μmolar) increased germination of *Erica andevalensis* Cabezudo & Rivera (Rossini Oliva *et al.* 2009). Rezvani and Zaefarian (2016) showed that $GA_3$, $KNO_3$ and pre-chilling promoted the germination percentage of hoary cress. All the mentioned studies confirm our results.

In contrast to our results, Mighani and Khordostan (2019) found that $GA_3$ did not promote the germination percentage of false jagged-chickweed. It is worth noting that Mighani and Khordostan (2019) applied low concentrations of $GA_3$ (30 and 60 μmol), while here in this study a higher concentration of $GA_3$ which ranged from 144 to 433 μmol was used. So, the contrasting results by Mighani and Khordostan (2019) might be due to the low concentration of $GA_3$.

The obtained results in this study can be used as basic information for growing similar size false jagged-chickweed seedlings in greenhouse and field studies, whenever we want to evaluate the response of false jagged-chickweed to herbicides, crop density, etc. Accordingly, a $KNO_3$ concentration of 30 μmolar and a $GA_3$ concentration of 144 μmolar were two of the best dormancy breaking factors among all of the evaluated treatments, as they increased both germination percentage and germination rate.

### Effects of constant temperature on seed germination traits

The approximated optimum germination temperature of false jagged-chickweed (22°C) in this study was almost in accordance with the estimated optimal temperature (20°C) for a seed lot of false jagged-chickweed collected from Alborz province, Iran, where the maximum germination was 74% (Deihimfard *et al.* 2018). The difference in final germination of false jagged-chickweed between the present study and the study by Deihimfard *et al.* (2018) is not surprising, as variability between different seed collections exists (Marshall 2019). It was also reported that variability in germination is common among populations and seeds collected in different years (Andersson and Milberg 1998). As we found in this study, seed germination of false jagged-chickweed reduced dramatically at temperatures higher than 22°C. Mighani and Khordostan (2019) reported that germination of a false jagged-chickweed biotype was reduced by up to 50% when the seeds were grown at 30/21.5°C in comparison with 25/20°C. Also they reported that seed germination of false jagged-chickweed reduced dramatically, up to 5%, at temperatures higher than 35°C (Mighani and Khordostan 2019). This means that distribution of false jagged-chickweed can be limited to temperate climates and it may not be able to distribute to hot climates. In addition, the estimated optimum germination temperature allows us to grow false jagged-chickweed seedlings in a greenhouse and thus obtain further information about this species.

### Effects of alternating temperature on seed germination traits

Even though we did not find any differences between alternating temperatures, Mighani and Khordostan (2019) reported that the highest germination of false jagged-chickweed occurred at the alternating temperature regimes of 25/20 and 18/10°C. It is worth noting that Mighani and Khordostan (2019) did not compare the constant temperature of 20°C (i.e., the control treatment we used in this study) with the mentioned alternating temperatures. In the present study, the alternating temperature of 20/10°C was the best one among the alternating temperature regimes considering both final germination and speed of germination (Figs 5 and 6). However, in accordance with the results of our previous study, the constant temperature of 20°C caused the highest germination rate and percentage. These results are also of great importance for growing the seedlings of false jagged-chickweed under controlled conditions such as a greenhouse and a growth chamber. It is worth noting that seeds of plants never ever are faced with a constant temperature under real field conditions. Seeds are exposed to alternating temperatures due to day-night alternating temperatures in the field and adapt to conditions allowing them to maintain their generations in the future. So, the best temperature for laboratory studies is the constant temperature of 20°C, while in greenhouse and field studies we suggest the alternating temperature of 20/10°C.

### Effects of sowing depth on seedling emergence traits

We found that sowing depths greater than 4 cm decreased the final seedling emergence of false jagged-chickweed, so that at sowing depths equal to or greater than 10 cm seedling emergence did not occur. Our results are in accordance with the results presented by Mighani and Khordostan (2019) where at 9 and 12 cm sowing depths seedling emergence of false jagged-chickweed were 1.66% and 0%, respectively. Benvenuti *et al.* (2001) showed that seedling emergence of 20 weed species was totally inhibited at seedling depths greater than 12 cm. As it was mentioned, the optimum sowing depth of false jagged-chickweed was 3.9 cm, while Mighani and Khordostan (2019) showed that the optimum planting depth for false jagged-chickweed was 1 cm. The contrasting results might be due to different types of soil used in the present study and the study conducted by Mighani and Khordostan (2019). It is worth noting that, seedlings of false jagged-chickweed can emerge easily from soil depths greater than 3 cm (Sarhaddi *et al.* 2019). In addition, Mirtaheri *et al.* (2015) showed that seedling emergence of false jagged-chickweed was similar in a range of sowing depths from 0.5 to 4.5 cm. Emergence of seedlings from a soil depth between 4 and 5 cm, somehow suggests that false jagged-chickweed might be a light insensitive, i.e., neutral photoblastic species for seed germination, since any light penetration beyond 10 mm may not be significant (Tester and Morris 2006). However, it is suggested to evaluate the sensitivity of false jagged-chickweed seeds to light in further studies. It should be noted that experimental protocols such as sensitizing seeds to light must be taken into account to evaluate the sensitivity of seeds to light. The estimated optimum sowing depth (3.9 cm) can be used to grow normal and healthy seedlings of false jagged-chickweed in greenhouses, growth chambers and fields, where we want to study this species in more detail. In addition, as seedling emergence did not occur at sowing depths greater than 10 cm, which implies that deep moldboard ploughing might (>10 cm) be used as a weed management tool for suppressing seedling emergence, while shallow tillage might favor seedling emergence. However, it is suggested to test this hypothesis under field conditions in future studies.

### Comparative phenology of false jagged-chickweed and winter wheat

Despite a delay in seedling emergence of false jagged-chickweed in comparison to emergence of winter wheat, the vegetative growth rate of false jagged-chickweed was faster than winter wheat in both locations with the same climate conditions. Accordingly, it is expected that false jagged-chickweed might have more potential for obtaining common resources (e.g., water and nutrients) than winter wheat. Importantly, as most of the broad-leaved herbicides such as bromoxynil + 2,4-D (Buctril Universal®) and bentazone + dichlorprop (Basagran DP®) are used at the two- to the four-leaf stages of weeds in winter wheat (Zand *et al.* 2017), it might be concluded that the chemical control of false jagged-chickweed must be done before reaching the early tillering stage of winter wheat i.e., before the *GDD* reached 420 and 433°C d in Shahriar and Karaj, respectively. It is worth noting that the *GDD* required for certain growth stages may differ from cultivar to cultivar as stated by Salazar-Gutierrez *et al.* (2013). Indeed, from the results it can be concluded that the flowering stage of winter wheat coincided with the development of fruit in false jagged-chickweed. Consequently, thanks to acceleration of the reproductive processes, false jagged-chickweed seeds could ripen and shed earlier than winter wheat seeds allowing them to utilize it as an efficient survival mechanism.

As it was mentioned, false jagged-chickweed is a serious weed species in canola, so it is suggested to study the comparative phenology of false jagged-chickweed and canola in future studies. This knowledge can allow us to use available herbicides at appropriate times even though the lack of selective and effective herbicides for controlling false jagged-chickweed in canola is a problem.

## Conclusions

To sum up, the results achieved in the present study are very important not only for studying other life cycle aspects of false jagged-chickweed but they also can be applied in developing management programs of this invasive and problematic weed species. The chilling treatment for 15 days, $KNO_3$ concentration of 30 μmol and all of $GA_3$ concentrations increased the germination percentage of false jagged-chickweed. For promoting seed germination rate, a $KNO_3$ concentration of 30 μmol and a $GA_3$ concentration of 144 μmol were the best treatments. The results concluded that false jagged-chickweed seeds can germinate in a range of temperatures from 2 to 35°C, while the optimum temperature was 22°C. False jagged-chickweed seeds can germinate in a range of sowing depth from 0 to 8 cm, while the optimum soil depth was 3.9 cm. These results can be used for growing false jagged-chickweed in a greenhouse and filed, whenever we want to decipher other characteristics of this weed species. Importantly, it was found that no germination can occur at a sowing depth greater than 10 cm. Moreover, false jagged-chickweed seeds required higher *GDD* for seedling emergence than winter wheat, while the flowering stage of false jagged-chickweed occurred much earlier (i.e., at a lower thermal time around 300°C d) than winter wheat. Accordingly, as broad-leaved herbicides such as bromoxynil + 2,4-D (Buctril Universal®) and bentazone + dichlorprop (Basagran DP®) are used at the two- to the four-leaf stages of weeds in winter wheat, it might be concluded that the chemical control of false jagged-chickweed must be done before reaching the early tillering stage of winter wheat i.e., before the *GDD* reached 450°C d.

## Acknowledgements

The study was supported by the Iranian Research Institute of Plant Protection, Agricultural Research, Education and Extension Organization (AREEO) with grant No. 14-16-16-9252, Tehran, Iran. The authors wish to thank Professor Asghar Heydari (AREEO) for his comments and suggestions on an ealier version of this paper.

### References

Andersson L., Milberg P. 1998. Variation in seed dormancy among mother plants, populations and years of seed collection. Seed Science Research 8: 29–38. DOI: https://doi.org/10.1017/S0960258500003883

Anonymous G.P. 2020. Global Plants. Available on: https://plants.jstor.org/compilation/Lepyrodiclis.holosteoides

Anonymous USDA. 2020. Natural Resources Conservation Service. Available on: https://plants.usda.gov/home/plantProfile?symbol=LEHO7 [Accessed: 20 February 2021]

Bakar B.H., Nabi L.N.A. 2003. Seed germination, seedling establishment and growth patterns of wrinklegrass (*Ischaemum rugosum* Salisb.). Weed Biology and Management 3: 8–14. DOI: https://doi.org/10.1046/j.1445-6664.2003.00075.x

Begum M., Juraimi A.S., Amartalingam R., Bin Man A., Bin Syed Rastans S.O. 2006. The effects of sowing depth and flooding on the emergence, survival, and growth of *Fimbristylis miliacea* (L.) Vahl. Weed Biology and Management 6: 157–164. DOI: https://doi.org/10.1111/j.1445-6664.2006.00209.x

Benvenuti S., MacChia M., Miele S. 2001. Quantitative analysis of emergence of seedlings from buried weed seeds with increasing soil depth. Weed Science 49: 528–535. DOI: https://doi.org/10.2307/4046486

Deihimfard R., Nazari S., Qorani Y. 2018. Estimation of cardinal temperatures of *Lepyrodiclis holosteoides* using regression models. Iranian Journal of Seed Science and Technology 7: 107–117. DOI: https://doi.org/10.22034/ijsst.2018.116531

Dorado J., Fernández-Quintanilla C., Grundy A.C. 2009. Germination patterns in naturally chilled and nonchilled seeds of fierce thornapple (*Datura ferox*) and velvetleaf (*Abutilon theophrasti*). Weed Science 57: 155–162. DOI: https://doi.org/10.1614/WS-08-122.1

Elahifard E., Derakhshan A. 2018. Asian spiderflower (*Cleome viscosa*) germination ecology in southern Iran. Weed Biology and Management 18: 110–117. DOI: https://doi.org/10.1111/wbm.12154

Foley M.E. 2004. Leafy spurge (*Euphorbia esula*) seed dormancy. Weed Science 52: 74–77. DOI: https://doi.org/10.1614/P2002-146

Forte C.T., Nunes U.R., Filho A.C., Galon L., Chechi L., Roso R., Menegat A.D., Rossetto E.D.O., Franceschetti M.B. 2019. Chemical and environmental factors driving germination of *Solanum americanum* seeds. Weed Biology and Management 19: 113–120. DOI: https://doi.org/10.1111/wbm.12187

Golmohammadzadeh S., Zaefarian F., Rezvani M. 2015. Effects of some chemical factors, prechilling treatments and interactions on the seed dormancy-breaking of two Papaver species. Weed Biology and Management 15: 11–19. DOI: https://doi.org/10.1111/wbm.12056

Guillemin J.-P., Chauvel B. 2011. Effects of the seed weight and burial depth on the seed behavior of common ragweed (*Ambrosia artemisiifolia*). Weed Biology and Management 11: 217–223. DOI: https://doi.org/10.1111/j.1445-6664.2011.00423.x

Honarmand S.J., Nosratti I., Nazari K., Heidari H. 2016. Factors affecting the seed germination and seedling emergence of muskweed (*Myagrum perfoliatum*). Weed Biology and Management 16: 186–193. DOI: https://doi.org/10.1111/wbm.12110

Malik M.S., Norsworthy J.K., Riley M.B., Bridges W. 2010. Temperature and light requirements for wild radish (*Raphanus raphanistrum*) germination over a 12-month period following maturation. Weed Science 58: 136–140. DOI: https://doi.org/10.1614/WS-09-109.1

Marshall E.J.P. 2019. Reflections on 14 years as Editor-in-Chief. Weed Research 59: 1–4. DOI: https://doi.org/10.1111/wre.12350

McMaster G.S., Wilhelm W.W. 1997. Growing degree-days: one equation, two interpretations. Agricultural and Forest Meteorology 87: 291–300. DOI: http://dx.doi.org/10.1016/S0168-1923(97)00027-0

Mighani F., Khordostan Z. 2019. Study of some environmental factors on seed germination of *Lepyrodiclis holosteoides*. Applied Biology 31: 127–138. DOI: https://doi.org/10.22051/jab.2019.4239

Minbashi Moeini M. 2011. Preparation of weed species distribution of Iran wheat fields with GIS. Iranian Research Institute Plant Protection (IRIPP), 300 pp. (in Persian)

Mirtaheri S.M., Vazan S., Baghestani M.A., Paknejad F., Tohidloo G. 2015. Investigation effect of flooding and burial depth on germination and percentage of *Lepyrodiclis holosteoides* Fenzl. Biological Forum 7: 1840–1844.

Puttha R., Goggi A.S., Gleason M.L., Jogloy S., Kesmala T., Vorasoot N., Banterng P., Patanothai A. 2014. Pre-chill with gibberellic acid overcomes seed dormancy of Jerusalem artichoke. Agronomy for Sustainable Development 34: 869–878. DOI: https://doi.org/10.1007/s13593-014-0213-x

R Core Team. 2013. R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available on: http://www.R-project.org/

Rabeler R.K. 1992. *Lepyrodiclis holosteoides* (Caryophyllaceae), "New" to North America. Madroño 39: 240–242.

Ranal M.A., Santana D.Gd. 2006. How and why to measure the germination process? Brazilian Journal of Botany 29: 1–11.

Ranal M.A., Santana D.Gd., Ferreira W.R., Mendes-Rodrigues C. 2009. Calculating germination measurements and organizing spreadsheets. Brazilian Journal of Botany 32: 849–855.

Rezvani M., Zaefarian F. 2016. Hoary cress (*Cardaria draba* (L.) Desv.) seed germination ecology, longevity and seedling emergence. Plant Species Biology 31: 280–287. DOI: https://doi.org/10.1111/1442-1984.12113

Rossini Oliva S., Leidi E.O., Valdés B. 2009. Germination responses of *Erica andevalensis* to different chemical and physical treatments. Ecological Research 24: 655. DOI: https://doi.org/10.1007/s11284-008-0536-7

Salazar-Gutierrez M., Johnson J., Chaves-Cordoba B., Hoogenboom G. 2013. Relationship of base temperature to development of winter wheat. International Journal of Plant Protection 7: 741–762.

Sarhaddi M., Rastgoo M., Ezadi Darbandi E., Ghanbari A., Baghestani M. 2019. The study of dormancy, germination and emergence biological aspects of jagged-chickweed (*Lepyrodiclis holosteoides*) seeds. Iranian Journal of

Weed Science 15: 77–95. DOI: https://doi.org/10.22092/ijws.2019.1501.06

Tester M., Morris C. 2006. The penetration of light into soil. Plant, Cell & Environment 10: 281–286. DOI: https://doi.org/10.1111/j.1365-3040.1987.tb01607.x

Wei S., Zhang C., Chen X., Li X., Sui B., Huang H., Cui H., Liu Y., Zhang M., Guo F. 2010. Rapid and effective methods for breaking seed dormancy in buffalobur (*Solanum rostratum*). Weed Science 58: 141–146. DOI: https://doi.org/10.1614/WS-D-09-00005.1

Yaghoubi S., Aghaalikhani M., Ghelavand M., Zand E. 2011. Evaluation of important growth parameters of *Lepyrodiclis* (*Lepyrodiclis holosteoides* Fenzl.) under different light densities and nitrogen rates. Iranian Journal of Weed Science 7: 31–45.

Zand E., Nezamabadi N., Baghestani M.A., Shimi P., Mousavi S.K. 2017. A Guide to Chemical Control of Win Iran. JDM Press, Mashhad, Iran, 216 pp.