AGRONOMY (AGRONOMIA)

Revista Brasileira de Ciências Agrárias
ISSN (on line) 1981-0997
v.18, n.3, e3211, 2023
Recife, PE, UFRPE. www.agraria.pro.br
DOI: 10.5039/agraria.v18i3a3211 - Protocol 3211
Subm. 04/04/2023 • App. 07/07/2023 • Pub. 26/07/2023

Phenological response patterns and productive ability of *Fallopia convolvulus* to weather variability in Iran

Gita Khodapanah[1], Javid Gherekhloo[1]*, Sima Sohrabi[2], Farshid Ghaderi-Far[1], Sajedeh Golmohammadzadeh[1]

[1] Gorgan University of Agricultural Sciences and Natural Resources, Department of Agronomy, Gorgan, Golestan, Iran. E-mail: agma6341@gmail.com; gherekhloo@gau.ac.ir/gherekhloo@yahoo.com; farshidghaderifar@yahoo.com; sa_gmz@yahoo.com
[2] Ferdowsi University of Mashhad, Faculty of Agriculture, Mashhad, Razavi Khorasan, Iran. E-mail: simsoh@gmail.com

ABSTRACT: An understanding of phenology and reproductive ability of a weed species can provide valuable information to manage it incisively. Field studies were conducted in North of Iran, in 2020 and 2021 to evaluate the influence of weather variability on phenological response patterns and production ability of black bindweed. In six sowing dates from October to March, the required thermal time, development rate and seed production ability for each phenophases across different sowing date (SD) were recorded. Among the six sowing dates, the late-autumn SD had the highest emergence and development rate. Sowing dates had significant ($p < 0.005$) effect on the timing of key phenophases, and more importantly on the period each phenological growth stage spent. The estimated seed production of this weed upon to SD varied from 1,200 to 15,000 seeds per plant. Based on the result black bindweed can be a prevalent weed in a wide range of growing season. Also, late winter and early spring can be mentioned as a vital time to manage and deplete seed bank. The results of current study could help construct a basic framework for a variety of weed-management tactics for conserving the ecosystems and biodiversity on which we depend.

Key words: development rate; emergence; management tactics; phenophases; sowing date

Padrões de resposta fenológica e capacidade produtiva de *Fallopia convolvulus* à variabilidade climática no Irã

RESUMO: Uma compreensão da fenologia e capacidade reprodutiva de uma espécie de planta daninha pode fornecer informações valiosas para manejá-la de forma incisiva. Estudos de campo foram conduzidos no norte do Irã, em 2020 e 2021, para avaliar a influência da variabilidade do clima nos padrões de resposta fenológica e capacidade de produção de cipó-de-veado. Em seis épocas de semeadura, de outubro a março, foram registrados o tempo térmico necessário, a taxa de desenvolvimento e a capacidade de produção de sementes para cada fenofase em diferentes datas de semeadura (DS). Entre as seis épocas de semeadura, a DS de final de outono apresentou a maior taxa de emergência e desenvolvimento. As datas de semeadura tiveram efeito significativo ($p < 0,005$) no tempo das principais fenofases e, o mais importante, no período gasto em cada estágio de crescimento fenológico. A produção estimada de sementes dessa planta daninha até DS variou de 1.200 a 15.000 sementes por planta. Com base no resultado, a cipó-de-veado pode ser uma erva daninha predominante em uma ampla gama de estações de crescimento. Também o final do inverno e o início da primavera podem ser mencionados como um momento vital para gerenciar e esgotar o banco de sementes. Os resultados do estudo atual podem ajudar a construir uma estrutura básica para uma variedade de táticas de manejo de ervas daninhas para conservar os ecossistemas e a biodiversidade dos quais dependemos.

Palavras-chave: taxa de desenvolvimento; emergência; táticas de manejo; fenofases; época de semeadura

* Javid Gherekhloo - E-mail: gherekhloo@gau.ac.ir/gherekhloo@yahoo.com (Corresponding author)
Associate Editor: Leandro Galon

Introduction

Changes in local and regional atmospheric patterns are expected due to climate variations which could significantly affect plant phenology, productive ability, and management of weeds (Schwartz, 1999; Menzel, 2003; Danuso et al., 2012). Phenology refers to the timing of recurring biological cycles and is considered a sensitive indicator of climate change (Schwartz, 2003; Polgar & Primack, 2011). Temperature is the main variable driving changes in plant phenology (Godoy et al., 2009; Korner & Basler, 2010; Lesica & Kittelson, 2010; Sohrabi et al., 2011; Singh & Negi, 2019), together with photoperiod (Elliott et al., 2006; Dincer et al., 2010) and precipitation (Dalmolin et al., 2015). Phenology has emerged as an important focus to accurate predict the consequences of species and community responses to climate change (Otso Ovaskainen et al., 2020; Negi et al. 2022), evaluate the variation of air temperature on main agricultural ecosystems (Jones et al., 2005; Recasens et al., 2005) and joined broadly with new technologies such as remote sensing data from satellites (Nieto et al., 2021; Younes et al., 2021), as well as the assessment of future trends and impacts (Bock et al., 2011; Morellato et al., 2016). Therefore, it is essential to know how temperature influences both the reproductive cycle and vegetative development of weeds (Danuso et al., 2012; Loddo et al., 2013; Sohrabi Kertabad et al., 2013; Hatfielg & Prueger, 2015; Gherekhloo et al., 2023).

The successfulness' management of weeds is highly dependent on the well-recorded phonological data and finding the most sensitive phenophases of weed growth like emergence and 2-3 leaf stage which are more sensitive to herbicide (Sohrabi et al., 2014b, 2016; MacLaren et al., 2020). Besides, knowing the number of flushes and the most important flushes are another necessary issue to have an appropriate weed management. Most of the weeds have different flushes, like *Cucumis melo* var. *agrestis* (Sohrabi et al., 2016), *Cyperus difformis*, *Cyperus tenuspica*, *Fimbristylis miliacea* (Lal et al., 2016) and *Echinochloa crus-galli* var. *crus-galli* (Yoshioka et al., 1998). Having information of their flushes would be a key strategy to reach a weed free field along growing season especially for crop with low competitive ability (Brainard et al., 2009; Travlos et al., 2020). Besides, could come up with applying broad options of weed management (especially environmental-friendly methods) instead of only herbicide application because over reliance on herbicides can lead to environmental pollution and loss of natural vegetation and soil biodiversity (Relyea, 2005; Rose et al., 2016; MacLaren et al., 2020).

The seed production of annual weeds is especially important not only for initial weed infestation but also the continued survival (Naylor, 2017). Weed seed production is dynamic and is affected by weather, competitive ability, and cultivation practices (Yang et al., 2003; Lins Neto et al., 2013; Merfield, 2015; Sohrabi et al., 2016). An understanding of weed seed production is important as this governs how weed should be managed over a period of time to have a poor seed bank (Travlos et al., 2020).

Fallopia convolvulus (L.) A. Löve. (Black buckwheat) is an annual plant which is formed as a serious weed of 25 crops in 41 countries. It is native to Eurasia and introduced to Africa, America and Oceania, the invasive potential of it was reported in North of America and Oceania (http://powo.science.kew.org and http://www.cabi.org). Black buckwheat has higher plasticity, so it occurs in most regions of the world and mostly commons on arable lands. Its reproduction is by seed and can germinate throughout of growing season (Hume et al., 1983; Odero et al., 2010; Mozaffarian et al., 2012). The growth of *F. convolvulus* is an important issue to study because it currently has the highest expansion rate and significantly affects crop production in Iran and the consequent negative impacts on environment by inaccurate herbicide application (http://www.plantwise.org). Its twining growth greatly affects the growth and yield of wheat and canola (Gherekhloo & Sohrabi, 2014; Keshavarzi & Mosaferi, 2020). Therefore, it is essential to know how weather variability influences both the reproductive cycle and vegetative development of it (Vârban et al., 2021). The present study was conducted to assess the impact of temperature and precipitation on cumulative emergence, development rate, length of sensitive phenophases and seed production to regulate populations of black buckwheat and limit their negative impacts while conserving diversity in North of Iran.

Materials and Methods

Seeds of the *F. convolvulus* were collected in June 2020 from 27 wheat fields located in Golestan province in northern Iran. After harvesting, the seeds were pooled, cleaned manually, placed in a paper bag, and stored at room temperature until sowing.

The trials were done over 2020-2021 at growing season at the Research Farm of Gorgan University of Agricultural Sciences and Natural Resources, Iran (36° 85 N, 54° 27 E), with an annual rainfall of 556 mm year^{-1}. Plots of 6 m^2 (2.0 × 3.0 m) with silty-loam soil (18% sand, 45% silt, 37% clay, and 1% organic matter) and soil-water pH of 7.6. The descriptive statistics of weather during study are presented in Table 1. Figure 1 shows the mean temperature and rainfall during the experiment.

The field experiment was applied in a randomized complete block design with three replicates. Fifty seeds were sown at a depth of 3 cm in five rows spaced 50 cm apart between October and July, the intervals between sowings were about 30 days. Seeds were sown on the 10 sowing dates (SD) but only on six sowing dates the plant had growth. So, data of the six SDs including 21 October, 20 November, 20 December, 19 January,18 February, and 1 March of 2020 or 2021, was applied to evaluate the influence of varying temperatures on growth and development of *F. convolvulus*. The field experiment was managed without pesticides, fertilizers, and irrigation. To prevent initial plant mortality, plots were kept as weed free as possible during growing

Table 1. Descriptive statistics for minimum, maximum, average temperatures and rainfall during two years 2020 (1 October) and 2021 (1 October). Daily minimum and maximum air temperatures were recorded in a standard weather station (36° 85' N, 54° 27' E, 13.3 asl), ~6 km from the field site.

		Mean	Standard deviation	Range	Coefficient of variation (%)
Minimum temperature (°C)	Air	13.15	8.66	33.3	63.9
Maximum temperature (°C)		25.11	9.68	23.7	37.2
Average temperature (°C)		19.15	8.81	33.7	49.16
Minimum temperature (°C)	Soil	19.16	8.46	24.80	59.74
Maximum temperature (°C)		27.77	9.38	25.40	37.90
Average temperature (°C)		24.64	8.70	31.50	44.70
Rainfall		1.41	4.04	56.5	9.57

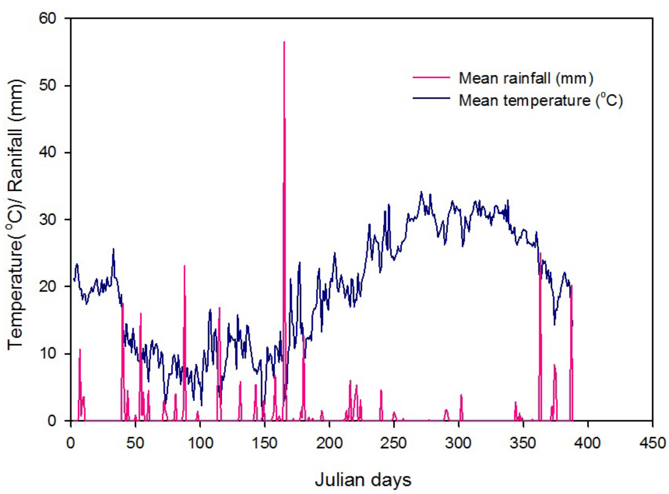

Figure 1. The mean temperature and rainfall during the experiment (started date is 1 October). Daily minimum and maximum air temperatures were recorded in a standard weather station (36° 85' N, 54° 27' E, 13.3 asl), ~6 km from the field site.

season after emergence by hand- weeding. When all plants had emerged, plants were thinned to achieve the target plant density (six plants per plot).

Measurements

Phenological characteristics of *F. convolvulus* plants were studied during the autumn of 2020 and winter and early spring of 2021. The time of emergence was the date when 50% of the plants had emerged through the soil surface. Emerged seedlings were counted twice a week following seed burial to calculate cumulative emergence. The field was visited twice a week and, on each occasion, leaf appearance (2-4 leaf appearance), branching (stem appearance), flowering stage (flower appearance), fruit set, seed rain and maturation were recorded. The number of fruits per plant was recorded at each replication were collected randomly to evaluate number of seeds per plant. The rained seeds were collected as possible as during the seed rain phase.

Data analysis

The thermal-time (TT) approach was used to predict black wild buckwheat development stages. The daily increment of thermal time was calculated as (Streck et al., 2003). Based on the following standard Equation 1, the degree-day of growth is determined for each phenophases (°C^{-1} day^{-1}).

$$DTT = (TP1D - TBD) \times f(T) \quad (1)$$

where: f (T) is the temperature function, the first component of the daily thermal time (TP1D-TBD) is constant, and non-optimal temperature will affect daily thermal time through f(T). f(T) is temperature function (as a reduction factor) that varies between 0 (outside the optimal range of temperatures) and 1 (optimal temperature) (Soltani et al., 2006; Sohrabi et al., 2016).

The reaction functions to temperature can be justified by the Equation 2.

$$\begin{aligned} f(T) &= \frac{R}{R\max} = \frac{(TMP - TBD)}{(TP1D - TBD)} \text{ if } TBD < TMP < TP1D \\ &= \frac{(TCD - TMP)}{(TCD - TP2D)} \text{ if } TP2D < TMP < TCD \\ & TP1D \le TMP \le TP2D \text{ if } = 1 \\ & TMP \le TBD \text{ or } TMP \ge TCD \text{ if } = 0 \end{aligned} \quad (2)$$

where: TBD, TP1D, TP2D, and TCD are the base, lower optimum, upper optimum and ceiling temperatures for germination of *F. convolvulus*, respectively (Table S1 and Figure S1). The base, lower and upper optimum and ceiling temperatures for given weed are 1, 20, 34 and 45 °C, respectively (Khodapanah et al., 2022). Values of the cardinal temperatures and weather data (Table 1) were inputted as parameters in the function to calculation of required thermal time for each SD. Development rate were obtained by nonlinear regression of the required thermal time of different phenophases (Equation 3).

$$f = \frac{a}{\left\{1 + e\left[-\frac{(x - x_{50})}{b}\right]\right\}} \quad (3)$$

where: f is phenophases, a is the maximum phenophases, x_{50} is the thermal time to reach 50% of phenophases and b is the slope of the curve or development rate.

LSD test (at 0.05) was done for determining the significant difference of seed production across different SD. Data was analyzed with SAS 9.1 (SAS Institute, 2009). The weather data were imported as parameter to calculate the required thermal time (Figure 1).

Results

Emergence

Higher cumulative and rate emergence were observed at fourth and third date of sowing, respectively. The greatest cumulative and rate of emergence (~50% and 5 plant day^{-1}) were concurrent with 30 to 45 of Julian days (Figure 2). Last date of sowing date had the lowest rate and percentage of emergence. The majority of seedlings emergence were recorded in February (at second date of sowing) that continued till end of March with the peak number in the fourth date of sowing. During the growing season of *F. convolvulus*, two distinct emergence flushes were detected at ~30 and 40 Julian days. The longest duration of emergence (about 70 days) was belonged to the 20 October while the shortes (19 days) was observed for the 19 January. The first order of sowing date needed more days to reach 50% of emergence, while it was contrast for fourth date of sowing.

According to germination test of seeds of *F. convolvulus*, the successful germination has high dependency to 20 and

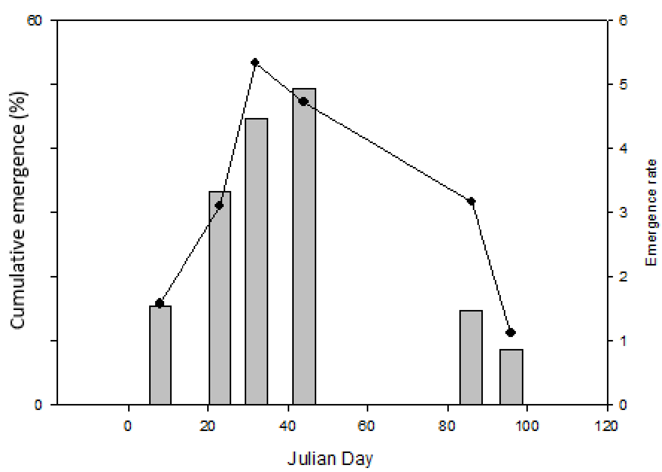

Figure 2. Bars and line show the cumulative emergence (%) and emergence rate (number per day) during the growing season, respectively. The vertical line above the x-axis shows the multiple distinct emergence flushes of *F. convolvulus* during six SD.

25 °C (Table S1 and Figure S1) which is accordance to mean temperature in early spring (Figure 1).

Phenophases

Eight phenophases were detected during growing season of *F. convolvulus* (Table 2 and Figure 3). The required thermal

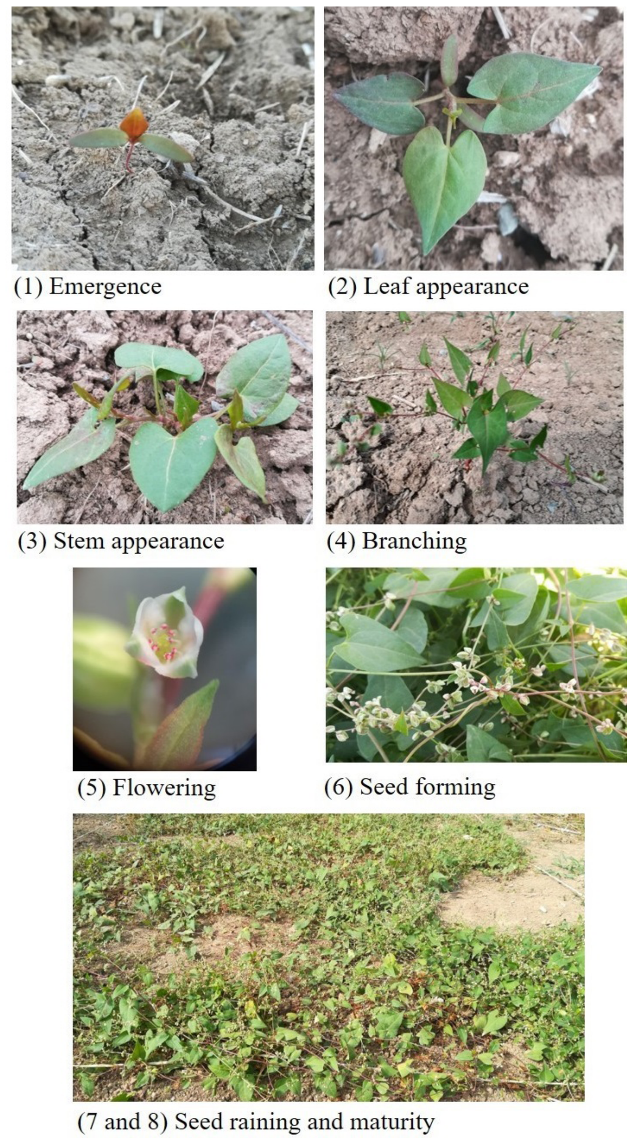

Figure 3. Different phenophases of *F. convolvulus*, 1 to 7: emergence, 2-3 leaves, stem forming, branching, flowering, fruit forming, and seed rain, respectively.

Table 2. The required thermal time for different phenophases of *F. convolvulus* across different SD according to function 1. The numbers in parentheses are represented the required days for each phenophases.

Phenophases	1 (21 October)	2 (20 November)	3 (20 December)	4 (19 January)	5 (18 February)	6 (1 March)
Emergence	786 (62)	366 (50)	322 (43)	184 (24)	400 (43)	654 (50)
2-3 leaf appearance	1098 (96)	640 (82)	604 (77)	475 (50)	1103 (83)	1207 (80)
Stem appearance	1204 (111)	795 (103)	769 (93)	644 (60)	1388 (98)	1492 (95)
Branching	1287 (121)	871 (113)	888 (103)	733 (65)	1483 (103)	1587 (100)
Flower appearance	1506 (141)	1057 (128)	1142 (118)	1079 (84)	1673 (113)	1682 (105)
Fruit appearance	1601 (149)	1160 (135)	1331 (128)	1267 (94)	1768 (118)	1872 (110)
Seed raining	1957 (169)	1611 (160)	1847 (156)	1571 (110)	1958 (128)	2061 (120)
Maturity	2472 (214)	2167 (193)	2056 (168)	1799 (123)	2034 (133)	2156 (131)

time for each phonological stage at six SD according to f (t), were various and the total TT ranged from 1,799 to 2,472 °C day^{-1}. The required time for each phenophases was dropped in the third and fourth sowing date. The required days were ranged from 24 to 62 days (for emergence), 50 to 96 days (for 2-3 leaf appearance), and 60 to 111 days (for stem appearance) upon sowing date (Table 2). Emergence phenophase could occur more than 200 days in whole of growing season however after 200 Julian days emergence did not happen (from August onwards).

The shorter phenophases were observed for third and last date of sowing orders. Last phenophases of 5th and 6th date of sowing almost occurred simultaneously and mostly confined to months of June and July. Flowering and fruit formation stages were recorded almost after 100 days of SD except at the first SD which it happens after 140 days of sowing (Figure 4). In the end of growing season especially in the latter SDs the length of phenophases was very short than former SDs.

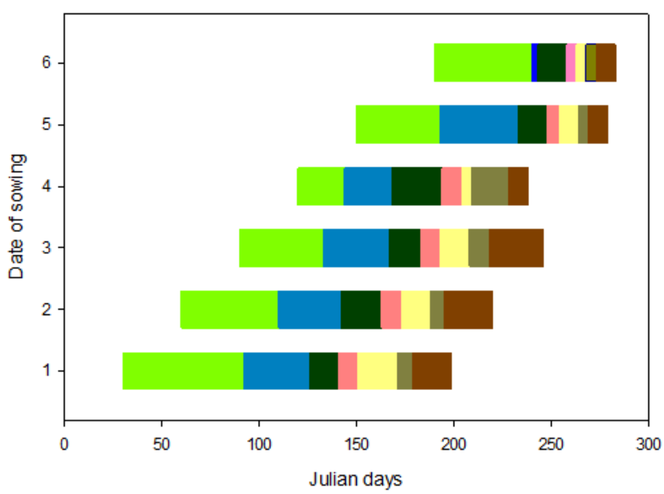

Figure 4. The length of each phenological stage (emergence to maturity) across different date of sowing (different colors show different phenophases from emergence to maturity).

Development rate

Sowing date affected a period of time that plants spent in each phenological stage. The highest development rate was belonged to fourth and third of SD, respectively. X_{50} is showing the thermal time for reaching 50 percent of phenophases which was lower for fourth date of sowing (912 °C day^{-1}). X_{50} were higher at fifth, sixth and first date of sowing (Table 3 and Figure 5). This result has shown coordinate with the

Table 3. The nonlinear Regression of the required thermal time for each different phenophases of *F. convolvulus* according to function 2.

Date of sowing	a	Development rate (b)	X_{50}	R^2
First (21 October)	7.9	269	1335	0.99
Second (20 November)	7.8	258.5	892.4	0.99
Third (20 December)	7.9	339.2	937.04	0.98
Fourth (19 January)	8.6	411.7	912.96	0.98
Fifth(18 February)	10.3	331.6	1789.3	0.98
Sixth (1 March)	8.5	281.8	1740.4	0.98

a: maximum phenophases, x50: the thermal time to reach 50% of phenophases and b: development rate.

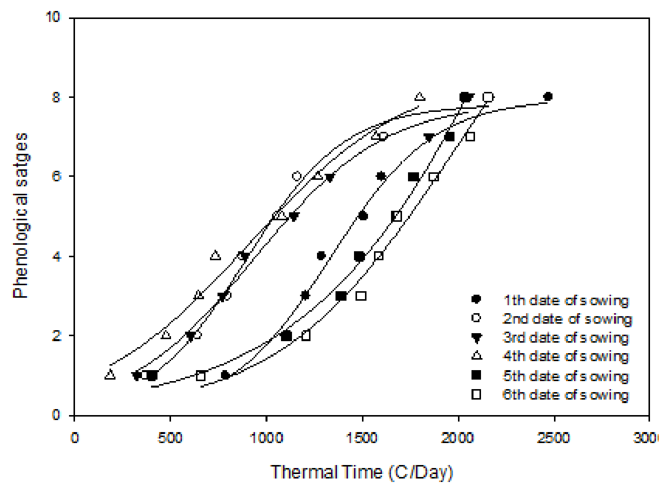

Figure 5. Development rate of *F. convolvulus* at six different date of sowing across seven phenophases.

germination response of seeds to temperature (Table S1 and Figure S1).

Productive ability

Seed production of *F. convolvulus* was highly reliance on the length of growing season of plant. Significant differences were observed in seed weight and seed production across different SD from October to March. Total seed number per plant varied from 1,200 to 15,000 seeds per plant in different SD. The highest seed production was detected at the first, second and third order of SD (Table 4). These dates had greater biomass (number of branches and length of plant) which produced ~40% more seeds than other dates of sowing. The maximum seed number (≈15,000 per plant) and the greatest seed weight (0.62 g per 100 seeds) were obtained from plants which have been sown in late October (Table 4).

Table 4. The seed production and some morphological characteristics of *F. convolvulus* at different date of sowing.

Date of sowing	Number of branches	Length of plant (cm)	Length of growth period from emergence to maturity(days)	Seed number per plant	Seed weight (g/100)
First (21 October)	15 a	287 a	214	14952.21 a	0.62 a
Second (20 November)	14 a	284 a	193	14385.02 b	0.60 b
Third (20 December)	14 a	239 b	168	12800.00 c	0.58 c
Fourth (19 January)	10 b	111 c	123	7127.78 d	0.57 d
Fifth (18 February)	9 b	54 d	133	3162.92 e	0.52 e
Sixth (1 March)	5 c	53 d	131	1229.30 f	0.48f

Values within a column followed by the same letter are not significantly different at p = 0.05 of LSD test.

Discussion

The result demonstrated that *F. convolvulus* has a prolonged emergence pattern from early winter through to spring. The maximum emergences were observed after 30 Julian days, this suggests that the start time for *F. convolvulus* management should be near spring and after about 60 Julian days and should be applied in about two periodical times.

F. convolvulus, like other annual weeds, is a problem throughout the growing season because it emerges at wide range of time, allowing it to escape from control operations, produce seed and create soil seed banks that may persist for several years (Kon et al., 2007; Baskin & Baskin, 2014). In addition to the winter crops (wheat and canola), long duration of black bindweed΄s emergence makes it's as a possible weed in summer crops like sugar beet, maize, sesame and sunflower (Hume et al., 1983; Royer & Dickinson, 1999; Odero et al., 2010; Vidotto et al., 2016; Keshavarzi & Mosaferi, 2020). In addition to it, its prolonged emergence is an advantage with regard to climate change, according to Chen et al. (2020) species with lengthened phenological periods will be more dominate under warming.

The main reason for lack of emergence on the last four SD of ten SD probably related to induced secondary dormancy of seeds due to unsuitable temperature. The inductions of secondary dormancy due to warm temperature were reported for various species by Murphey et al. (2015), Née et al. (2015), and Pawłowski et al. (2020).

This research highlights the main phonological response of P. convolvulus in end of winter and early spring. With the advancing of sowing date (from 1 to 4), the average length of the emergence phase was decreased. This pattern is observed for *Bidens frondosa* and *B. tripartite* (Danuso et al., 2012), *Abutilon theophrasti* and *Datura stramonium* (Loddo et al., 2013).

The appearance of flowers and seed forming were happened after 80 to nearly 150 days of sowing (Table 1). This duration is also critical for preventing seed banks formation due to long seed longevity (> 5 yr in the soil) of *F. convolvulus* (Baskin & Baskin, 2014).

Based on these results, *F. convolvulus* can grow in a period of more than 200 days (from 30 to 240 days) and the production of leaves and branches occurs in 90 to 250 days. Therefore, management tactics should be considered in a long period of time, especially in late winter and early spring. The recommendation time for management of *Lepyrodiclis holosteoides* as an important weed in winter wheat was proposed before the early tillering stage of winter wheat (Minbashi Moeini et al., 2021). Odero et al. (2010) reported the importance of the appropriate timing of control to attain efficient use of herbicides and other weed management tools. The length of each phenophases (emergence to maturity) was different due to thermal time requirements and development rate. For as much as the first and second phenophases of plant mostly were occupied large portion of plant growth, a long-term management should be considered to reach sustainable management. However, the lack of abiotic stress combined with an abundance of resources in early stages of growing season may leaded more competitor seedlings and seed setting, so applying management tactics will be crucial during in late winter and early spring. Stronger competitors have greater selection pressure to adapt to control (Comont et al., 2019). The importance of knowing phenology of weeds to allow targeting maintenance and remove them before seeds setting is illustrated by studies by Nagase et al. (2013) and Piskackova et al. (2020).

The rate of plant development was various based on the required thermal time for each different phenophases of *F. convolvulus*. Because of favorable temperature during the third and fourth sowing date, the required TT was lower than unfavorable temperatures during first and last date of sowing. The shorter phenophases might be related to highest rate of development or inaccurate time of plant growth because of unsuitable condition like temperature or day-length (Sohrabi et al., 2014a). Danuso et al. (2012) mentioned the greater emergence and ability to shorten the phase duration as depended on phase to sowing date. The flowering-maturity phase was very short, which it might be related to stress condition (water and unsuitable temperature) in the end of growing season. This pattern is observed in *B. frondosa* and *B. tripartite* (Danuso et al., 2012), and *Chloris virgata* (Asaduzzaman et al., 2022).

Reproductive plasticity in relation with various phenophases length reported by Bekker et al. (2003), Sohrabi et al. (2016), Mahajan et al. (2018), and Asaduzzaman et al. (2022), support the observed high weeds capacity to infest many crops and landscapes. Forsberg & Best (1964) reported ability of black buckwheat to produce up to 30,000 seeds per plant. The higher seed production along with seed longevity allowed it to be spread over subsequent years in many habitats, especially in agricultural habitats which are characterized by a high variability of disturbances. Lower seed production in later date of sowing could relate to facing stressful condition (higher temperature and lack of precipitation) during plant growth. The sexual reproduction of *Polygonum viviparumn* in the alpine meadow of the Qinghai-Tibet Plateau with increasing temperature decreased (Zhang et al., 2021). The effect of water stress on seed production of different biotype of *Sisymbrium thellungii* is reported by Mahajan et al. (2018). Cell metabolism, carbon accumulation and the appearance of shoots during the different phenophases are highly affected by temperature (Tanino et al., 2010). The relationship between plant size and reproductive output is central to a plant strategy to convert growth into fitness (Weiner et al., 2009). In *P. viviparumn*, more utilizable resources were allocated to vegetative growth under warming condition (Zhang et al., 2021). Based on our study, we can hypothesise that variation in reproductive fitness of *F. convolvulus* will be more regulated by the reproductive period and the prevalent temperature during this phenophasas.

Conclusion

The phenology information of *F. convolvulus* is a useful indicator and has practical applications in response to climate change and conserving biodiversity.

Following the comparative study of the different time of sowing, some differences were observed in terms of growth stages and development, productive ability, and succession of phenophases that can help the growers to reach sustainable strategies for managing of given species.

F. convolvulus can mostly emerge throughout February to April in North of Iran. As the dominant paradigm of weed management in Iran is currently founded on the two principal tools of herbicides and tillage to remove weeds, this information is essential to identify accurate time.

The result will be toward revealing different options to manage of this plant at the agroecosystem level that, rather than aiming to eradicate weeds, act to regulate populations to limit their negative impacts while conserving diversity, for example seed destructors.

Furthermore, understanding the secondary dormancy of *F. convolvulus* needs to be detailed. And the findings reported here can be used in decision support systems and for research of the plant population dynamics.

Acknowledgements

Gorgan University of Agricultural Sciences and Natural Resources (GUASNR), Iran supported this research.

Compliance with Ethical Standards

Author contributions: Conceptualization: JG; Data curation: SS; Methodology: JG; Software: SS; Supervision: JG; Validation: JG, SS; Writing – original draft: SS; Writing – review & editing: SS, FG-F, SG.

Conflict of interest: The authors declare no conflict of interest.

Financing source: The Gorgan University of Agricultural Sciences and Natural Resources.

Literature Cited

Asaduzzaman, M.; Wu. H.; Koetz. E.; Hopwood, M.; Shepherd, A. Phenology and population differentiation in reproductive plasticity in feathertop rhodes grass (*Chloris virgata* Sw.). Agronomy, v. 12, n. 3, e736, 2022. https://doi.org/10.3390/agronomy12030736.

Baskin, C.C.; Baskin, J.M. Seeds: Germination ecology of seeds in the persistent seed bank. In: Baskin, C.C.; Baskin, J.M. Seeds: ecology, biogeography, and, evolution of dormancy and germination. 2.ed. London: Academic Press, 2014. p.187-276. https://doi.org/10.1016/B978-0-12-416677-6.00007-X.

Bekker, P.M.; Forcella, F.; Grundy, A.C.; Jones, N.E.; Marshall, E.J.P.; Murdoch, A.J. Seedbanks: determination, dynamics and management. Aspects of Applied Biology, v. 69, p. 93–187, 2003.

Bock, A.; Sparks, T.; Estrella, N.; Menzel, A. Changes in the phenology and composition of wine from Franconia, Germany. Climate Research, v. 50, n. 1, p. 69–81, 2011. https://doi.org/10.3354/cr01048.

Brainard, D.; Mohler, C.; Schonbeck, M. Manipulating weed seed banks to promote their decline. Eorganic, 2009. https://eorganic.org/node/2807. 01 Apr. 2023.

Chen, J.; Luo, Y.; Chen, Y.; Felton, A.J.; Hopping, K.A.; Wang, R.W.; Niu, S.; Cheng, X.; Zhang, Y.; Cao, J.; Olesen, J.E.; Andersen, M.N.; Jørgensen, U. Plants with lengthened phenophases increase their dominance under warming in an alpine plant community. Science of the Total Environment, v. 728, e138891, 2020. https://doi.org/10.1016/j.scitotenv.2020.138891.

Comont, D.; Knight, C.; Crook, L.; Hull, R. Alterations in life-history associated with non-target-site herbicide resistance in *Alopecurus myosuroides*. Frontier in Plant Science, v. 10, e837, 2019. https://doi.org/10.3389/fpls.2019.00837.

Dalmolin, A.C. de.; Almeida, Lobo, F.; Vourlitis, G.; Silva, P.R.; Dalmagro, H.J.; Antunes, M.Z.; Ortíz, C. Is the dry season an important driver of phenology and growth for two Brazilian savanna tree species with contrasting leaf habits? Plant Ecology, v. 216, p. 407–417, 2015. https://doi.org/10.1007/s11258-014-0445-5.

Danuso, F.; Zanin, G.; Sartorato, I. A modelling approach for evaluating phenology and adaptation of two congeneric weeds (*Bidens frondosa* and *Bidens tripartita*). Ecological Modelling, v. 243, p. 33–41, 2012. https://doi.org/10.1016/j.ecolmodel.2012.06.009.

Dincer, I.; Midilli, A.; Hepbasli, A.; Karakoc, T.H. Global warming: engineering solutions. Boston: Springer, 2010. 685p. (Book series. Green energy and technology). https://doi.org/10.1007/978-1-4419-1017-2.

Elliott, S.; Baker, P.J.; Borchert, R. Leaf flushing during the dry season: the paradox of Asian monsoon forests. Global Ecology and Biogeography, v. 15, n.3, p. 248–257, 2006. https://doi.org/10.1111/j.1466-822X.2006.00213.x.

Forsberg, D.E.; Best, K.F. The emergence and development of wild buckwheat (*Polygonum convolvulus*). Canadian Journal Plant Science, v. 44, n.1, p. 100–103, 1964. https://doi.org/10.4141/cjps64-018.

Gherekhloo, J.; Sohrabi, S. Investigating the efficacy of some herbicides on control of black bindweed (*Polygonum convolvulus*). In: Iranian Plant Protection Congress, 21., 2014, Proceedings... Urmia: Urmia University, 2014.

Gherekhloo, J.; Sohrabi, S.; Ansari, O.; Bagherani, N.; De Prado, R. Study of dormancy breaking and factors affecting germination of *Parapholis incurva* (L.) C.E.Hubb. Taiwania, v. 68, n. 2, p. 185-192, 2023. https://taiwania.ntu.edu.tw/pdf/tai.2023.68.185.pdf. 01 May. 2023.

Godoy, O.; Richardson, D.M.; Valladares, F.; Castro-Diez, P. Flowering phenology of invasive alien plant species compared with native species in three Mediterranean-type ecosystems. Annals of Botany, v. 103, n.3, p.485–494, 2009. https://doi.org/10.1093/aob/mcn232.

Hatfielg, J.L.; Prueger, J.H. Temperature extremes: Effect on plant growth and development. Weather and Climate Extremes, v. 10, Part A, p. 4–10, 2015. https://doi.org/10.1016/j.wace.2015.08.001.

Hume, L.; Martinez, J.; Best, K. The biology of Canadian weeds. 60. *Polygonum convolvulus* L. Canadian Journal Plant Science, v. 63, n. 4, p. 959-971, 1983. https://doi.org/10.4141/cjps83-121.

Jones, G.V.; Duchêne, E.; Tomasi, D.; Yuste, J.; Braslavska, O.; Schultz, H.; Martinez, C.; Boso, S.; Langellier, F.; Perruchot, C.; Guimberteau, G. Changes in European winegrape phenology and relationships with climate. In: International GESCO Viticulture Congress, 14., 2005, Geisenheim. Proceedings... Geisenheim: GESCO, 2005. p.54–61. https://www.researchgate.net/publication/285632906. 10 Apr. 2023.

Keshavarzi, M.; Mosaferi, S. Genetic variability of invasive species, *Fallopia convolvulus* (Polygonaceae) in Iran. Plant Biosystems, v. 154, n.3, p. 369-375, 2020. https://doi.org/10.1080/11263504.2019.1635218.

Khodapanah, G.; Gherekhloo, J.; Ghaderi-Far, F.; Sohrabi, S.; Golmohammadzadeh, S. Evaluation the seed dormancy and germination of black bindweed (*Polygonum convolvulus* L.). Iranian Journal of Weed Science, v. 18, n. 2, p.35-45, 2022. https://doi.org/10.22092/ijws.2022.359019.1412.

Kon, K.F.; Follas, G.B.; James, D.E. Seed dormancy and germination phenology of grass weeds and implications for their control in cereals. New Zealand Plant Protection, v. 60, p. 174-182, 2007. https://doi.org/10.30843/nzpp.2007.60.4597.

Korner, C.; Basler, D. Phenology under global warming. Science, v. 327, n.5972, p. 1461–1462, 2010. https://doi.org/10.1126/science.1186473.

Lal, B.; Gautam, P.; Raja, R.; Tripathi, R.; Shahid, M.; Mohanty, S.; Panda, B.; Bhattacharyya, P.; Nayak, A.K. Weed seed bank diversity and community shift in a four decade old fertilization experiment in rice-rice system. Ecological Engineering, v. 86, p.135-145, 2016. https://doi.org/10.1016/j.ecoleng.2015.10.030.

Lesica, P.; Kittelson, P.M. Precipitation and temperature are associated with advanced flowering phenology in a semi-arid grassland. Journal of Arid Environment, v. 74, n.9, p. 1013–1017, 2010. https://doi.org/10.1016/j.jaridenv.2010.02.002.

Lins Neto, E.M.; Almeida, A.L.; Peroni, N.; Castro, C.C.; Albuquerque, U.P. Phenology of *Spondias tuberosa* Arruda (Anacardiaceae) under different landscape management regimes and a proposal for a rapid phenological diagnosis using local knowledge. Journal of Ethnobiology and Ethnomedicine, v. 9, e10, 2013. https://doi.org/10.1186/1746-4269-9-10.

Loddo, D.; Sousa. E.; Masin, R.; Calha, I.; Zanin, G.; Fernández-Quintanilla, C.; Dorado, J. Estimation and comparison of base temperatures for germination of European populations of velvetleaf (*Abutilon theophrasti*) and jimsonweed (*Datura stramonium*). Weed Science, v. 61, n.3, p. 443-451, 2013. https://doi.org/10.1614/WS-D-12-00162.1.

MacLaren, C.; Storkey, J.; Menegat, A.; Metcalfe, H. An ecological future for weed science to sustain crop production and the environment. A review. Agronomy for Sustainable Development, v. 40, e24, 2020. https://doi.org/10.1007/s13593-020-00631-6.

Mahajan, G.; George-Jaeggli, B.; Walsh, M.; Chauhan, B.S. Effect of soil moisture regimes on growth and seed production of two Australian biotypes of *Sisymbrium thellungii* O. E. Schulz. Frontiers in Plant Science, v. 9, p. 1241, 2018. https://doi.org/10.3389/fpls.2018.01241.

Menzel, A. Plant phenological anomalies in Germany and their relation to air temperature and NAO. Climate Change, v. 57, p. 243–263, 2003. https://doi.org/10.1023/A:1022880418362.

Merfield, C.N. False and stale seedbeds: the most effective non-chemical weed management tools for cropping and pasture establishment. (Report number 2-2015). Lincoln: The BHU Future Farming Centre, 2015. 25p. https://www.bhu.org.nz/wp-content/uploads/sites/155/ffc-files/weed-management/false-and-stale-seedbeds--the-most-effective-non-chemical-weed-management-tools-for-cropping-and-pasture-establishment-2015-ffc-merfield.pdf. 29 Mar. 2023.

Minbashi Moeini, M.; Keshtkar, E.; Sasanfar, H.; Baghestani, M.A. Germination biology and phenological development stages of false jagged-chickweed (*Lepyrodiclis holosteoides*). Journal of Plant Protection Research, v.61, n.4, p.347-357, 2021. https://doi.org/10.24425/jppr.2021.139243.

Morellato, L.P.C.; Alberton, B.; Alvarado, S.T.; Borges B.; Buisson E.; Camargo M.G.G.; Cancian L.F.; Carstensen D.W.; Escobar D.F.E.; Leite, P.T.P.; Mendoza, I.; Rocha, N.M.W.; Soares, N.C.; Sanna Freire Silva, T.; Staggemeier, V.G.; Streher, A.S.; Vargas B.C.; Peres C. A. Linking plant phenology to conservation biology. Biological Conservation, v. 195, p. 60–72, 2016. https://doi.org/10.1016/j.biocon.2015.12.033.

Mozaffarian, V. A revision of *Polygonum* L. sensu lato, (Polygonaceae) in Iran. Iranian Journal of Botany, v. 18, n.2, p. 159–174, 2012. https://doi.org/10.22092/ijb.2012.13326.

Murphey, M.; Kovach, K.; Elnacash, T.; He, H.; Bentsink, L.; Donohue, K. DOG1-imposed dormancy mediates germination responses to temperature cues. Environmental and Experimental Botany, v. 112, p. 33–43, 2015. https://doi.org/10.1016/j.envexpbot.2014.11.013.

Nagase, Y.; Dunnett, N.; Choi, M.S. Investigation of weed phenology in an establishing semi-extensive green roof. Ecological Engineering, v. 58, p. 156-164, 2013. https://doi.org/10.1016/j.ecoleng.2013.06.007.

Naylor, R.E.L. Weed seed biology. In: Thomas, B.; Murray, B.J.; Murphy, D.J. (Eds.). Encyclopedia of Applied Plant Sciences. 2.ed.. London: Elsevier, 2017. v.3, p. 485-492. https://doi.org/10.1016/B978-0-12-394807-6.00028-9.

Née, G.; Obeng-Hinneh, E.; Sarvari, P.; Nakabayashi, K.; Soppe, W.J. Secondary dormancy in *Brassica napus* is correlated with enhanced *BnaDOG1* transcript levels. Seed Science and Research, v. 25, n. 2, p. 221–229, 2015. https://doi.org/10.1017/S0960258514000427.

Negi, G.C.S.; Joshi, S.; Singh, P.; Joshi, R. Phenological response patterns of forest communities to annual weather variability at long-term ecological monitoring sites in Western Himalaya. Trees, Forests and People, v. 8, e100237, 2022. https://doi.org/10.1016/j.tfp.2022.100237.

Nieto, L.; Schwalbert, R.; Prasad, P.V.V.; Olson, B.J.S.C. An integrated approach of field, weather, and satellite data for monitoring maize phenology. Scientific Reports, v. 11, e15711, 2021. https://doi.org/10.1038/s41598-021-95253-7.

Odero, D.; Mesbah, A.; Miller, S.; Kniss, A. Wild buckwheat (*Polygonum convolvulus*) interference in sugarbeet. Weed Technology, v. 24, n.1, p. 59-63, 2010. https://doi.org/10.1614/WT-09-060.1.

Otso, O.; Meyke, E.; Lo, C.; Tikhonov, G.; Delgado, M.; Roslin, T.; Gurarie, E.; Abadonova, M.; Abduraimov, O.; Adrianova, O.; Akimova, T.; Akkiev, M.; Ananin, A.; Andreeva, E.; Andriychuk, N.; Antipin, M.; Arzamascev, K.; Babina, S.; Babushkin, M.; Kurhinen, J. Chronicles of nature calendar, a long-term and large-scale multitaxon database on phenology. Scientific Data, v.7, e 47, 2020. https://doi.org/10.1038/s41597-020-0376-z.

Pawłowski, T.A.; Bujarska-Borkowska, B.; Suszka, J.; Tylkowski, T.; Chmielarz, P.; Klupczyńska, E.A.; Staszak, A.M. Temperature regulation of primary and secondary seed dormancy in *Rosa canina* L.: Findings from proteomic analysis. International Journal of Molecular Sciences, v. 21, n.19, e7008, 2020. https://doi.org/10.3390/ijms21197008.

Piskackova, T.A.R.; Reberg-Horton, C.; Richardson, R.J.; Jennings, K.M.; Leon, G.R. Integrating emergence and phenology models to determine windows of action for weed control: A case study using *Senna obtusifolia*. Field Crops Research, v. 258, p. 107959, 2020. https://doi.org/10.1016/j.fcr.2020.107959.

Polgar, C.A.; Primack, R.B. Leaf-out phenology of temperate woody plants: from trees to ecosystems. New Phytologist, v. 191, n.4, p. 926–941, 2011. https://doi.org/10.1111/j.1469-8137.2011.03803.x.

Recasens, J.; Calvet, V.; Cirujeda, A.; Conesa, J.A. Phenological and demographic behaviour of an exotic invasive weed in agroecosystems. Biological Invasions, v. 7, p. 17–27, 2005. https://doi.org/10.1007/s10530-004-9625-x.

Relyea, R.A. The impact of insecticides and herbicides on the biodiversity and productivity of aquatic communities. Ecological Applications, v. 15, n.2, p. 618–627, 2005. https://doi.org/10.1890/03-5342.

Rose, M.; Cavagnaro, T.; Scanlan, C.; Rose, T.; Vancov, T.; Kimber, S.; Kennedy, K.R.; Van Zwieten, L. Impact of herbicides on soil biology and function. In: Sparks, D.L. (Ed.). Advances in Agronomy, v.136. London: Academic Press, 2016. p.133–220. https://doi.org/10.1016/bs.agron.2015.11.005.

Royer, F.; Dickinson, R. Weeds of the Northern U.S. and Canada. Alberta: The University of Alberta Press, 1999. 434p.

SAS Institute. SAS Version 9.3. Cary: SAS Institute, 2009.

Schwartz, M.D. Advancing to full bloom: planning phenological research for the 21st century. International Journal of Biometeorology, v. 42, p. 113–118, 1999. https://doi.org/10.1007/s004840050093.

Schwartz, M.D. Introduction.. In: Schwartz, M.D. Phenology: an integrative environmental science. Dordrecht: Kluwer Academic Publishers, 2003. p. 3–7. (Book series. Tasks for vegetation science, 39). https://doi.org/10.1007/978-94-007-0632-3.

Singh, P.; Negi, G.C.S. Impact of climate change on phenological responses of major forest tree species of Kumaun Himalaya. ENVIS Bulletin on Himalayan Ecology, v. 24, p. 112–116, 2019. https://gbpihedenvis.nic.in/ENVIS%20Bullitin/ENVIS%20Bulletin%20(Vol.%2024,%202016)/Impact_climate_change_P_Singh.pdf. 01 Apr. 2023.

Sohrabi Kertabad, S.; Rashed-Mohasel, M.H.; Nassiri Mahalati, M.; Gherekhloo, J. Some biological aspects of lesser celandine (*Ranunculus ficaria*) invasive weed. Planta Daninha, v.31, n.3, p. 577–585, 2013. https://doi.org/10.1590/S0100-83582013000300010.

Sohrabi, S.; Rashed Mohassel, M.H.; Ghanbari, A.; Gherekhloo, J. Phenological characteristics of the invasive weed *Cucumis melo*. 26. Deutsche Arbeitsbesprechung über Fragen der Unkrautbiologie und -bekämpfung, 11.-13. März 2014a in Braunschweig.

Sohrabi, S.; Gherekhloo, J.; Kamkar, B.; Ghanbari, A. The phenology and seed production of *Cucumis melo* as an invasive weed in northern Iran. Australian Journal of Botany, v. 64, n. 3, p. 227-234, 2016. https://doi.org/10.1071/BT15256.

Sohrabi, S.; Gherekhloo, J.; Rashed Mohassel, M.H.; Ghanbari, A.; Nassiri Mahalati, M. Cardinal temperatures of three invasive weeds in Iran. In: International Symposium on Weeds and Invasive Plants, 3., 2011, Ascona. Proceedings… Ascona: European Weed Research Society 2011. p.22. https://www.ewrs.org/en/documents/WGs-Invasive-Plants-EWRS-Invasive-Ascona-Abstracts-2011.pdf. 01 Apr. 2023.

Sohrabi, S.; Rashed Mohassel, M. H.; Nassiri Mahalati, M. Study the phenology of Lesser celandine (*Ranunculus ficaria*) and effect of planting depth on sprouting of its tuberous-roots. Journal of Iranian Plant Protection Research, v. 28, n.3, p. 285-291, 2014b. https://doi.org/10.22067/jpp.v28i3.43539.

Soltani, A.; Hammer, G.L.; Torabi, B.; Robertson, J.; Zeinali, E. Modeling chickpea growth and development: Phenological development. Field Crops Research, v. 99, n.1, p. 1-13, 2006. https://doi.org/10.1016/j.fcr.2006.02.004.

Streck, N.A.; Weiss, A.; Xue, Q.; Baenziger, P.S. Improving predictions of developmental stages in winter wheat: a modified Wang and Engel model. Agricultural and Forest Meteorology, v.115, n.3-4, p.139–150, 2003. https://doi.org/10.1016/S0168-1923(02)00228-9.

Tanino, K.K.; Kalcsits, L.; Silim, S.; Kendall, E.; Gray, G.R. Temperature-driven plasticity in growth cessation and dormancy development in deciduous woody plants: A working hypothesis suggesting how molecular and cellular function is affected by temperature during dormancy induction. Plant Molecular Biology, v. 73, p. 49–65, 2010. https://doi.org/10.1007/s11103-010-9610-y.

Travlos, I.; Gazoulis, I.; Kanatas, P.; Tsekoura, A.; Zannopoulos S, Papastylianou P. Key factors affecting weed seeds' germination, weed emergence, and their possible role for the efficacy of false seedbed technique as weed management practice. Frontiers in Agronomy, v. 2, e1, 2020. https://doi.org/10.3389/fagro.2020.00001.

Vârban, R.; Ona, A.; Stoie, A.; Vârban, D.; Crișan, I. Phenological assessment for agronomic suitability of some agastache species based on standardized BBCH Scale. Agronomy, v. 11, n.11, p. 2280, 2021. https://doi.org/10.3390/agronomy11112280.

Vidotto, F.; Fogliatto, S.; Milan, M.; Ferrero, A. Weed communities in Italian maize fields as affected by pedo-climatic traits and sowing time, European Journal of Agronomy, v. 74, p. 38-46, 2016. https://doi.org/10.1016/j.eja.2015.11.018.

Weiner, J.; Rosenmeier, L.; Massoni, E.S.; Vera, J.N.; Hernández Plaza, E.; Sebastia, MT. Is reproductive allocation in Senecio vulgaris plastic? Botany, v. 87, n.5, p. 475–481, 2009. https://doi.org/10.1139/B09-012.

Yang, Q.H.; Feng, H.L.; Ye, W.H.; Cao, H.L.; Deng, X.; Xu, K.Y. An investigation of the effects of environmental factors on the flowering and seed setting of *Mikania micrantha* H.B.K (Compositae). Journal of Tropical and Subtropical Botany, v. 11, n.2, p. 123–126, 2003.

Yoshioka, T.; Satoh, S.; Yamasue, Y. Effect of increased concentration of soil CO_2 on intermittent flushes of seed germination in *Echinochloa crus-galli* var. *crus-galli*. Plant, Cell & Environment, v. 21, n.12, p. 1301–1306, 1998. https://doi.org/10.1046/j.1365-3040.1998.00347.x.

Younes, N.; Joyce, K.E.; Maier, S.W. All models of satellite-derived phenology are wrong, but some are useful: A case study from northern Australia. International Journal of Applied Earth Observation and Geoinformation, v. 97, p. 102285, 2021. https://doi.org/10.1016/j.jag.2020.102285.

Zhang, C.; Li, X.; An, Y.; Zhang, Z.; Ren, F.; Zhou, H. Effects of experimental warming on vegetative and reproductive growth of *Polygonum viviparum* in the Qinghai-Tibet Plateau. Nordic Journal of Botany, v. 39, n. 11, e031572021, 2021. https://doi.org/10.1111/njb.03157.

Supplementary data

Seed germination response of F. convolvulus to temperature

According to germination test of *F. convolvulus* at different temperatures, the lowest final percentage of germination was obtained at high temperatures 35 and 40 °C and the highest final percentage of germination was observed in the 20 and 25 °C. No germination was observed at 45 °C. Although, the time (hours) to reach 50% germination decreased with increasing temperature from 5 °C and reached its minimum at 35 °C. The lowest T_{50} was observed at highest temperature which is coordinate with the phenology response and development rate of each phenophases of *F. convolvulus*.

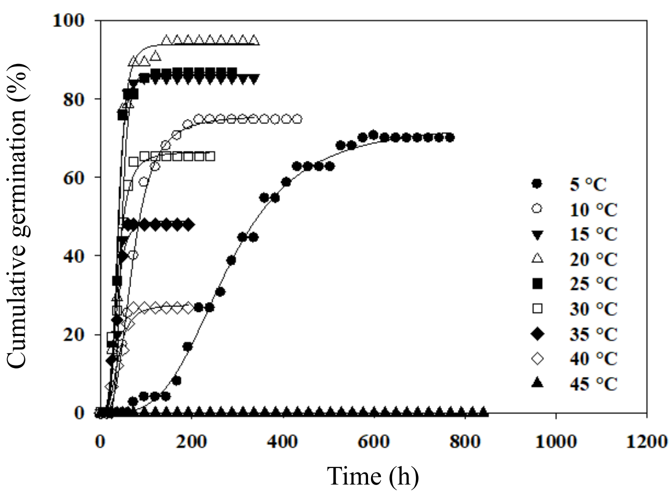

Figure S1. Cumulative germination percentages of *F. convolvulus* seeds at different temperatures.

Table S1. Parameters estimated by the three-parameter logistic function fitted to the germination time-course data against temperature for *F. convolvulus*.

Temperature (°C)	Parameters			R^2
	G_{max} (%)	b	T_{50} (hours)	
5	72.34(1.62)	3.52(0.16)	278.38(3.94)	0.99
10	75.75(0.94)	3.15(0.19)	69.91(1.50)	0.99
15	85.82(0.87)	6.76(0.68)	45.47(0.78)	0.99
20	94.05(1.26)	4.76(0.58)	39.22(1.12)	0.98
25	88.76(1.28)	4.92(0.64)	36.54(1.09)	0.98
30	66.49(1.33)	3.39(0.42)	36.44(1.45)	0.98
35	48.95(1.02)	3.98(0.520	33.73(1.24)	0.98
40	27.51(0.77)	3.16(0.43)	38.51(1.75)	0.98
45	-	-	-	-