Using Nonlinear Regression Model for Estimation of Cardinal Temperatures in Three Medicinal Plants

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ABSTRACT

Medicinal plants have been used as a source of remedies since ancient times. Most medicinal plants in Iran are herbs and they have dormancy and a special biological cycle. Knowledge of this cycle is required to grow these plants. Understanding the response of seed germination in medicinal plants to temperature involves selecting the best nonlinear regression models for the prediction of their seed germination, the characterization of their germination pattern and the prediction of the cardinal temperatures of medicinal plants. Thus, to understand the medicinal seed germination response to temperature, an experiment was conducted at the University of Tehran, Iran in 2011. The germination rate of three medicinal plants—wild oat (*Avena fatua* L.), wild mustard (*Sinapis arvensis* L.) and *Descurania Sophia* (L.)—was calculated at different temperatures (0, 5, 10, 15, 20, 25, 30, 35, 40 and 45 °C) based on a completely randomized design with three replications. Three nonlinear regression (segmented, dent-like, beta) approaches were applied to model the germination rate. The analysis of variance showed that temperature had a significant effect on the seed germination rate. Among models, the segmented model was the best for the three plants and the cardinal temperatures were estimated by this model. The base, optimum and ceiling temperatures for wild oat, wild mustard and *D. Sophia* were estimated as 1.6, 10.2 and 29.3 °C and 2.01, 15 and 30.6 °C and 1.2, 29.6 and 35 °C, respectively. The germination models based on temperature can used for the prediction of cardinal temperatures.

Keywords: medicinal plants, seed germination rate, nonlinear regression model, cardinal temperatures

INTRODUCTION

Medicinal plants have been used as a source of remedies since ancient times when people used different plants and plant products such as acacia, aloes, gums, myrrh, pomegranate, colocynth, linseed, coriander, cumin, onions, anise, grapes, castor oil and wine including some weed species such as wild oat and wild mustard and all plant organs such as roots, rhizomes, flowers, leaves, fruits, seeds, as well as oils can be used (Hochol, 2003).

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Wild oat (*Avena fatua* L.) belongs to the Poaceae family (Chevallier, 1996) and from ancient times until the present has been used for its medicinal properties (Bown, 1995). Wild oat helps to decrease cholesterol levels in the blood and also increases stamina (Chevallier, 1996). The seed is a mealy, nutritive herb that is antispasmodic, cardiac, diuretic, emollient, nervine and a stimulant (Lust, 1983). The seed contains the antitumor compound b-sitosterol and has been used as a folk remedy for tumors (Duke, 1983). Its alcoholic extraction has been reported to be a deterrent for smoking, though reports that wild oat extract helped correct the tobacco habit have been disproven (Duke, 1983).

Sinapis (mustard), a genus of Brassicaceae, has a long history of use as a condiment and as a herbal medicinal plant and in many developing countries, *Sinapis* spp. such as *Sinapis arvensis* (wild mustard) are used as food, fodder to livestock and in folklore medicine (Bendimerad *et al*., 2007). The essential oils of this plant have a pale yellowish color with a characteristic sulfurous odor and wild mustard contains different compounds including 1-butenyl isothiocyanate, cubenol, dimethyl trisulfide, dimethyl tetrasulfide, octadecane, 6,10,14-trimethylpentadecane-2-one and indole, while the oil of wild mustard has antimicrobial activity towards *Proteus vulgaris* (Al-Qudah *et al*., 2011).

Descurainia sophia L. Webb ex Prantl (*Sisymbrium sophia* L.) belongs to the Cruciferae (Brassiaceae) family and numerous species have economic importance as food such as cabbage, cauliflower, turnip and rape (Shahina, 1994). The species are utilized as salad plants due to their antiscorbutic content and their low content of erucic acids and many Cruciferous species are known for their use in folk medicine for the treatment of snake bites and as an antimicrobial agent for the relief of biliary colic and wound sores (Fenwick *et al*., 1983). They enhance the detoxification effect of chemical carcinogens and some species exhibit hypoglycemic and hypotension effects (Fenwick *et al*., 1983). *D. sophia* is used in China for the preparation of health cigarettes with a group of Chinese herb medicinal raw materials (Fan, 2002). It is also used in mixtures of Chinese herbs to prevent lung cancer (Zhao, 2001). The plant contains 15 amino acids and 10 fatty acids and the seeds of *D. sophia* have been used as a traditional medicine to relieve coughs, prevent asthma, reduce edema, promote urination and have a cardio tonic effect while some cardiac glycosides from the seeds have been reported (Chen *et al*., 1981; Zargari, 2008).

Ghaderi *et al*. (2009) noted that most of the medicinal plants in Iran are weeds and they exhibit dormancy and a special biological cycle and that to successfully raise these plants requires knowledge of this cycle (from the time of emergence and germination to flowering). They observed that the germination of seeds is the most important stage in the seed life cycle and germination is affected by many factors, both genetic and environmental (water potential, temperature, light quality and quantity, aeration). For non dormant seeds with adequate moisture, temperature is often the main environmental factor governing germination (Shafii and PriceSource, 2001).

Temperature affects the germination rate and the germination frequency as well as the incubation time (Kocabas *et al*., 1999; Flores and Briones, 2001). Appropriate temperature is probably the most important factor in regulating germination (Nerson, 2007). The range in temperature is characterized by the cardinal temperature consisting of the base temperature (Tb), ceiling temperature (TC) and optimum temperature (TO) according to Phartyal *et al*. (2003). Optimum temperatures produce the most rapid seed germination and plant growth but the germination rate ceases above the maximum and below the base temperatures (Hakansson *et al*., 2002).

The effects of temperature on plant development are the bases for models used to

predict the timing of germination (Forcella *et al*., 2000; Shafii and PriceSource, 2001; Bradford, 2002; Wang *et al*., 2004). In crop models, cardinal temperatures are required because a portion of the crop model is developed for prediction of the timing of germination (Jame and Cutforth, 2004).

A thermal time model utilizes temperature for predicting the seed germination of crop and medicinal plants and such a model may be applicable to other plants (Kevseroglu *et al*., 2000; Dürr, 2001; Baker and Reddy, 2001; Odabas and Mut, 2007; Ghaderi–Far *et al*., 2009; Hoseini *et al*., 2012; Jafari *et al*., 2012).

In Iran, there is limited information concerning the potential seed germination problems of wild oat, wild mustard and *D. sophia*. There is a lack of published literature on the comprehensive study of improving seed germination characteristics. Hence, the different objectives of the present study were: to understand the response of medicinal seed germination to temperature, to select the best nonlinear regression models for the prediction of medicinal seed germination, to characterize the germination pattern and to predict the cardinal temperatures of *D. sophia* L., wild mustard (*S. arvensis)* and wild oat (*A. fatua*) in a laboratory experiment.

MATERIALS AND METHOD

The experiment to develop an understanding of the medicinal seed germination response to temperature and determination of cardinal temperatures was conducted at the University of Tehran, Iran in 2011. A germination test with a completely randomized design was performed with three replications in a temperature-controlled plant growth cabinet pre-set to 10 different temperatures (0, 5, 10, 15, 20, 25, 30, 35, 40 and 45 °C). The medicinal seeds of wild mustard (*S. arvensis)*, *D. sophia*, and wild oat (*A. fatua*) were dormant before planting on Petri dishes treated with gibberellic acid (GA)

0. 1% (Tavili *et al*., 2010) and 100 seeds were sprinkled on circular filter paper (Watman No. 1) on each 9 cm Petri dish (International Seed Testing Association, 1996) of each seed lot within each temperature regime. Ten milliliters of distilled water were added to each Petri dish and the filter papers were regularly moistened to ensure saturation throughout the germination tests. Seeds were considered germinated when the radicle protruded at least 2 mm from the seed coat (Jeffrey *et al*., 1987). Germinated seeds and rotted seeds were counted and discarded at 24 hr intervals until no germination had occurred over four consecutive days (Samimy *et al*., 1987).

The germination percentage was obtained by dividing the number of germinated seeds at any time by the total number of seeds germinated multiplied by 100. Estimates of the time taken for cumulative germination to 50% (D50) in each replicate of each treatment were interpolated from the progress of emergence versus time curve. The daily germination rate (R50) was then calculated according to Soltani *et al*. (2001, 2002) as R50 =1/ D50.

Data from this experiment were first subjected to analysis of variance and means of treatments were compared using the least significant difference at the 5% level of probability. The following nonlinear regression models were used to quantify the response of the germination rate to temperature and to determine cardinal temperatures:

Segmented model Equations 1–4 (Ritchie and NeSmith, 1991)

$$f(t) = (T\text{-}Tb)/(To\text{-}Tb) \quad \text{if } Tb < T \leq To \qquad (1)$$
$$f(t) = (T\text{-}Tb)/(To\text{-}Tb) \quad \text{if } Tb < T \leq To \qquad (2)$$
$$f(t) = (Tc\text{-}T)/(Tc\text{-}To) \quad \text{if } To < T \leq Tc \qquad (3)$$
$$f(t) = 0 \qquad \qquad \text{if } Tc \leq T \text{ or } T \leq Tb \qquad (4)$$

Beta model Equations 5–6 (Yin *et al*., 1995):

$$f(t) = [((T\text{-}Tb)/(To\text{-}Tb) \times (Tc\text{-}T)/Tc\text{-}Tb))^{(Tc\text{-}To)/(Tc\text{-}Tb)}]^a \quad \text{if } Tb < T < Tc \qquad (5)$$
$$f(t) = 0 \quad \text{if } Tc \leq T \text{ or } T \leq Tb \qquad (6)$$

Dent-like model Equations 7-10 (Piper *et al*., 1996)

$$f(t) = (T-Tb)/(To1-Tb) \quad \text{if } Tb < T \leq To1 \quad (7)$$
$$f(t) = (Tc-T)/(Tc-To2) \quad \text{if } To2 < T \leq Tc \quad (8)$$
$$f(t) = 1 \quad\quad\quad\quad\quad\quad \text{if } To1 < T \leq To2 \quad (9)$$
$$f(t) = 0 \quad\quad\quad\quad\quad\quad \text{if } Tc \leq T \text{ or } T \geq Tc \quad (10)$$

where all temperatures were measured in degrees Celcius and T is the average temperature from sowing to germination, Tb is the base temperature, To is the optimum temperature, To1 is the lower optimum temperature and To2 is the upper optimum temperature (for dent-like model), Tc is the ceiling temperature and a is the shape parameter for the beta model which determines the curvature of the function and the parameters estimated using the SigmaPlot software (version 11; Systat Software, Inc.; San Jose, CA, USA). The root mean square error (RMSE), coefficient of determination (R^2) and correlation coefficient (r) were used to evaluate the models. Non-linear regression analyses were used to describe the relationship between the time requirement for germination and the germination rate with temperature in the laboratory experiment.

RESULTS AND DISCUSSION

The results showed that temperature had a significant effect on the seed germination rate (data not shown). Flores and Briones (2001) confirmed this result and concluded that temperature has significant effects on the onset, potential and rate of germination.

Different parameters were used to determine the adapted seed germination rate model—RMSE and R^2 for the relationship between germination rate (R50) and temperature in medicinal plants; and r for the relationship between the observed and predicted hours to germinate. The best model had a lower RMSE and a higher r and R^2. The predicted parameter estimates for the models tested to describe the relationship between the germination rate and temperature for wild oat, wild mustard and *D. sophia* L. are given in Table 1.

The thermal limits for germination are defined by the minimum (Tm), optimum (To) and maximum (TM) temperatures which can determine some of the ecological limitations for the geographic distribution of the species. Optimum temperatures produce both the most rapid seed germination and plant growth (Hakansson *et al*., 2002).

The segmented model was superior compared to the other models for wild oat, *D. Sophia* and wild mustard (Table 1). It was concluded that these models can be used to

Table 1 Parameter estimates for models describing relationship between germination rate and temperature for wild oat, wild mustard and *Descurania sophia* L.

Plant	Model	r	R^2	RMSE
Wild oat (*A. fatua*)	Segmented	0.91	0.83	0.00001
	Dent like	0.91	0.82	0.00001
	Beta	0.95	0.90	0.14
Wild mustard (*S. Arvensis*)	segmented	0.94	0.89	0.000003
	Dent like	0.91	0.83	0.000005
	Beta	0.67	0.45	0.81
D. sophia	segmented	0.99	0.97	0.000002
	Dent like	0.88	0.77	0.00002
	Beta	0.96	0.92	0.14

Root mean square of error (RMSE) and coefficient of determination (R^2) for the relationship between germination rate and temperature in medicinal plants described by various functions. Correlation coefficient (r) for the relationship between observed and predicted hours to germinate.

quantify the field germination response of medicinal plants to temperature and to obtain the cardinal temperatures of germination.

　　　　The segmented model for wild oat predicted a base temperature of 1.6 °C. The optimum (To) and ceiling temperature (Tc) were predicted to be 10.2 and 29.3 °C, respectively (Figure 1 and Table 2). Gismatov *et al*., (1967)

noted that Tb and Tc of wild oat were 5 and 8 °C, and 20 and 30 °C, respectively, and that the Tb difference may be related to the species of wild oat. Some authors have used the beta model because of its ability to describe the development rate over the full range of temperatures, its flexibility to take different shapes and its mathematical tractability (Steinmaus *et al*., 2000).

Table 2　Prediction of parameter a (beta model) and base (Tb), optimal (To), ceiling (Tc) temperatures and optimal temperature range (To1 to To2 for dent model) at 50% germination for wild oat, wild mustard and Descurania sophia L.

| Plant	model M	a	Tb	To	To1	To2	Tc
Avena fatua L	segmented	-	1.66±1.33	10.28±2.17	-	-	29.39±5.74
	Dent-like	-	5	-	8	10	37.64
	beta	3	2.00±1.10	12.00±1.48	-	-	30.00±31.90
Sinapis arvensis L.	segmented	-	2.01±1.52	15.00±2.45	-	-	30.61±2.51
	Dent-like	-	5	-	9	15	38.44
	beta	3	2.00±3.16	15.00±1.87	-	-	30.00±19.05
Descurania sophia L.	segmented	-	1.20±0.43	29.66±0.47	-	-	35.00±0.39
	Dent-like	-	2.00±4.06	-	19.33±7.92	28.76±5.03	41.66±2.69
	beta	3	0	27	-	-	35

Mean±SE values are shown.
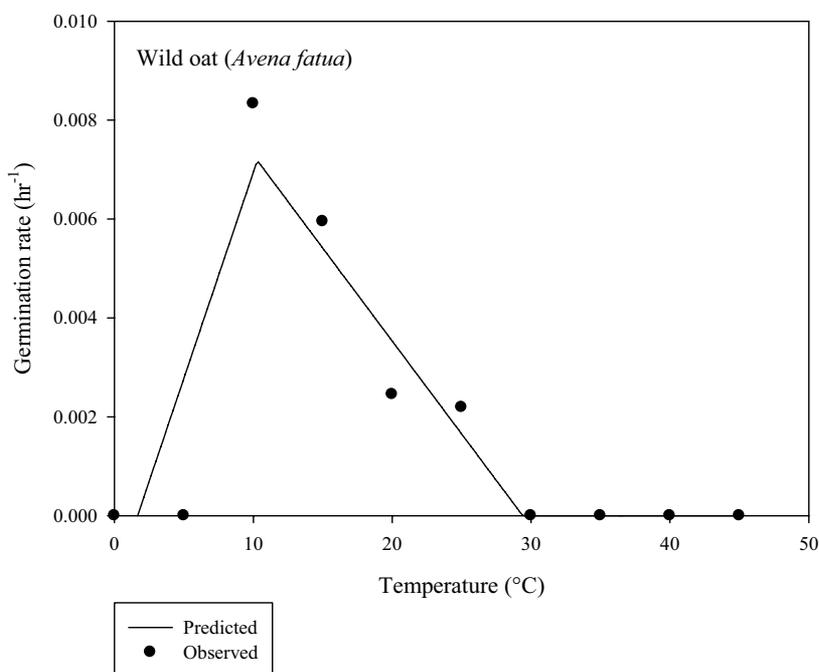
Figure 1　Effect of temperature on mean observed and predicted germination rate for *A. fatua* L. with best model (segmented model).

For wild mustard, the segmented model was the best and Tb, To and Tc were calculated to be 2.01, 15 and 30. 61°C, respectively (Figure 2 and Table 2). Nikitin (1983) reported the same results and affirmed the minimum temperature for seed germination was 2–4 °C and the optimum temperature was 14–20 °C. Based on these results, the germination of wild mustard started at 2 °C and increased to 15 °C, before decreasing and stopping at 30.6 °C. These results showed that wild mustard and wild oat had the same base and ceiling temperatures but different optimum temperatures. The current results confirmed that the life cycle of medicinal plants varied and different models must be used for the prediction of the cardinal temperatures (Chen *et al*., 1981; Steinmaus *et al*., 2000; Dürr *et al*., 2011).

The segmented model for *D. sophia* predicted Tb, To and Tc to be 1.2, 29.66 and 35 °C, respectively (Figure 3 and Table 2). Ulyanova (1998) noted that the base and optimum temperatures for *D. sophia* were 2 and 20 °C, respectively. Their differences from the current results may be related to the species of plants and experimental conditions.

CONCLUSION

The analysis of variance showed that temperature had a significant effect on all seed germination rates and that the germination model based on temperature can be used for the prediction of cardinal temperatures. The use of different nonlinear regression models for the prediction of cardinal temperatures and knowing the limitation temperature in the biological cycle of medicinal plants are very important. Among the nonlinear models studied in this research, the segmented model was suitable for the cardinal temperature prediction of wild mustard (*S. arvensis*) and *D. sophia* but for wild oat (*A. fatua*) the beta model was the best. The base, optimum and ceiling temperatures for wild oat, wild mustard and *D. sophia* were estimated to be 2, 12 and 30 °C; 2.01, 15 and 30.6 °C; and 1.2, 29.6 and 35 °C, respectively.
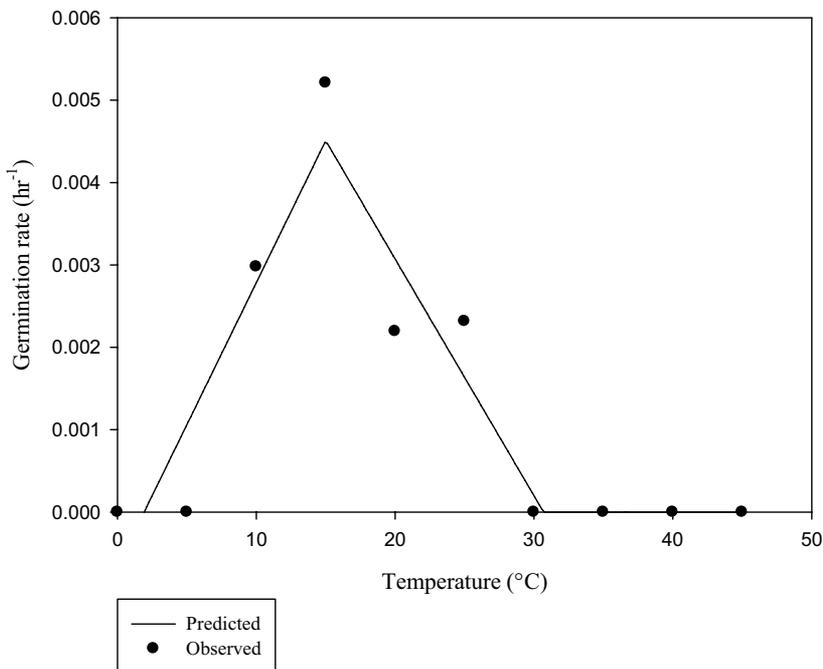

Figure 2 Effect of temperature on mean observed and predicted germination rate for *S. arvensis* L. with best model (segmented model).
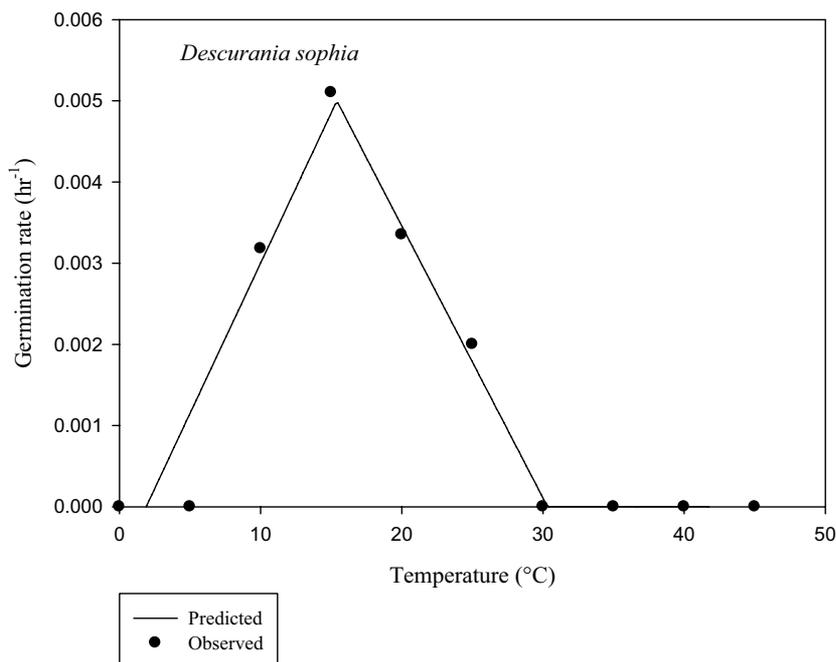
Figure 3 Effect of temperature on mean observed and predicted germination rate for *D. sophia* L. with best model (segmented model).

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