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Cardinal Temperatures of Germination in Medicinal Pumpkin (*Cucurbita pepo* convar. *pepo* var. *styriaca*), Borago (*Borago officinalis* L.) and Black Cumin (*Nigella sativa* L.)

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Abstract: The purpose of this study was to determine cardinal temperatures of germination in three medicinal plants include medicinal pumpkin, borago and black cumin. Wide ranges of temperatures (5, 10, 15, 20, 25, 30, 35, 40 and 45°C) were used. A segmented regression model was used to determine base (T_{b},), optimum (T_0) and ceiling, (T_c) temperatures for germination. T_b was estimated as 5.9°C for medicinal pumpkin, 5°C for borago and 5°C for black cumin. T_0 was estimated as 37.7°C for medicinal pumpkin, 29.9°C for borago and 28.6°C for black cumin and T_c was estimated 45°C for medicinal pumpkin, 39.9°C for borago and 35°C for black cumin. This information can be used in evaluation of new areas suitable for introduction of these species and optimization sowing management. In addition, it can be used to develop management models for prediction of timing of crop developmental processes.

Key words: Medicinal pumpkin, borago, black cumin, germination, base temperature, optimum temperature, ceiling temperature

INTRODUCTION

Germination is probably the most important event for the success of an annual crop and hence plays a key role in crop production (Khajeh-Hosseini *et al*., 2003; Soltani *et al*., 2006). Germination requirements are species-specific and the extent and rate at which the process occurs in a non-dormant seeds, is affected by environmental factors, such as light, oxygen, water and temperature (De Villiers *et al*., 2002). Generally, temperatures below the optimum result in progressively poorer germination (Nykiforuk and Flanagen, 1994). Germination rate usually increases linearly with temperature, at least within a well-defined range and declines sharply at higher temperatures (Mwale *et al*., 1994; Ramin, 1997; Kamkar *et al*., 2006). This temperature range characterized by cardinal temperatures, i.e., a minimum or base temperature (T_b), ceiling temperature (T_c) that germination rate at below and above which is zero and optimum temperature (T_o) at which the germination rate is highest (Phartyal *et al*., 2003).

Clear understanding of the germination response of seeds to temperature and estimates of cardinal temperatures are useful in: screening crop tolerance to either low and high temperatures, identifying geographical areas where a crop can germinate and establish successfully and developing management models for the prediction of timing of crop development processes (Garcia-Huidobro *et al*., 1982; Vigil *et al*., 1997; Madakadze *et al*., 2001; Jame and Cutforth, 2004; Hardegree, 2006; Adam *et al*., 2007). In crop models, cardinal temperatures are required because a portion of the crop models is devoted to prediction of the timing of crop developmental processes (Jam and Cutforth, 2004). This has led to the development of heat unit based models of the quantitative effects of temperature on germination and stand establishment (Madakadze *et al*., 2001).

Medicinal pumpkin (*Cucurbita pepo* convar. *pepo* var. *styriaca*), borago (*Borago officinalis* L.) and black cumin (*Nigella sativa* L.) are three species that used widely in traditional and industrial pharmacology (D'Antuno *et al*., 2002; El Hafid *et al*., 2002; Atta, 2003; Aroiee and Omidbaigi, 2004). Seeds these species contain many effective substances like fatty acids, beta-sitosterol, tocopherols, gamma-linolenic acid (GLA), anti-diabetic, antihistaminic, antihypertensive, anti-inflammatory, anti-microbial, antitumour and galactagogue with many therapeutic effects.

There are not any comprehensive information about cardinal temperatures and the response of seed germination to varying temperatures for black cumin,

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borago and medicinal pumpkin. Therefore, the purpose of this study was to investigate the effects of temperature on germination in these plants and to calculate the base (T_b), optimum (T_o) and ceiling (T_c) temperatures for them.

MATERIALS AND METHODS

Seeds of black cumin, borago and medicinal pumpkin were obtained from herbal market in Gorgan (Iran) and Ardebil (Iran) and used immediately for germination. The experiments were carried out at the Seed Laboratory of the Department of Agronomy and Plant Breeding, Gorgan University of Agricultural Sciences and Natural Research, Gorgan, Iran. The data described below were gathered using a randomized complete block design with 4 replications.

Seed germination was tested in the incubators at constant temperatures 5, 10, 20, 25, 30, 35, 40 and 45°C. Seed germination was tested on 4 replicates of 50 seeds in moist paper towels and randomly placed in a incubators, in darkness. Seeds were observed twice daily and considered germinated when the radicle was approximately 2 mm long or more. Water was added as required.

Germination percentage (GP) was measured and transformed by arcsine square root for analysis. Estimates of time taken for cumulative germination to reach 50% of its maximum at each replicate (D_{50}) were interpolated from the germination progress curve versus time. Germination rate (R_{50}, h^{-1}) was then calculated as (Soltani *et al*., 2001, 2002):

$$R_{50} = 1/D_{50} \quad (1)$$

To quantify the response of germination rate to temperature and to determine cardinal temperatures for germination, the following model was used (Soltani *et al*., 2006):

$$R_{50} = \frac{f(T)}{D_{min}} \quad (2)$$

where, f(T) is a temperature function (reduction factor) that ranges between 0 at base and ceiling temperature and 1 at optimal temperature(s) and D_{min} is the minimum number of hours for germination at optimal temperature. Thus, $1/D_{min}$, indicate maximum rate of germination or maximum inherent rate of germination. Segmented function was used (Soltani *et al*., 2006):

$$\begin{aligned} f(T) &= (T - T_b)/(T_o - T_b) && \text{if} \quad T_b < T \le T_o \\ f(T) &= (T_c - T)/(T_c - T_o) && \text{if} \quad T_o < T < T_c \\ f(T) &= 0 && \text{if} \quad T \le T_b \text{ or } T \le T_c \end{aligned} \quad (3)$$

where, T is the temperature, T_b the base temperature, T_o the optimum temperature and T_c the ceiling temperatures. The parameters were estimated by the least squares method using the non-linear (NLIN) regression (R_{50} as y and T as x) procedure in the Statistical Analysis System (Soltani, 2007).

RESULTS

Germination percentage (GP): Figure 1 shows cumulative germination of medicinal pumpkin, borago and black cumin at different temperatures and Fig. 2 shows

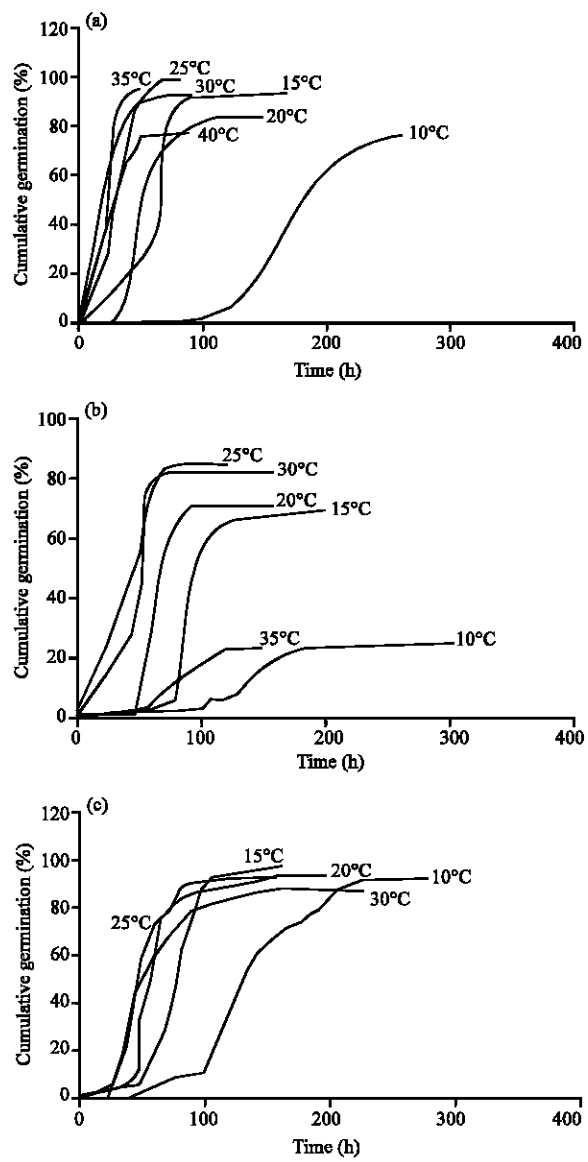

Fig. 1: Cumulative germination percentage of (a) medicinal pumpkin, (b) borago and (c) black cumin

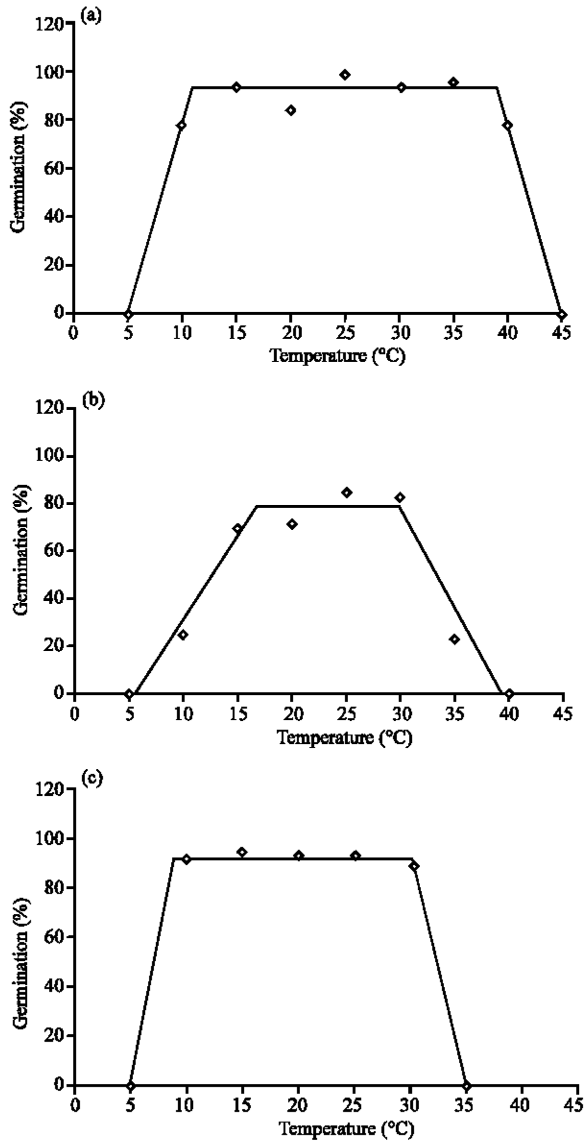

Fig. 2: The relationship between germination percentage and temperature in (a) medicinal pumpkin, (b) borago and (c) black cumin

influence of the temperature on GP which has been described by a Dent like function. For medicinal pumpkin maximum germination was about 83-98% between 11 to 40°C and it was zero below 5 and above 45°C. For borago, GP was between 70-84% from 16.75 to 29.83°C and GP reached to zero at 5.4 and 39.3 °C. At 5 and 35, the final germination for black cumin was zero and GP at 10 to 30°C was between 88-96%.

Germination rate (GR) and cardinal temperatures: Figure 3 shows the relationships between GR and temperature for medicinal pumpkin, borago and black

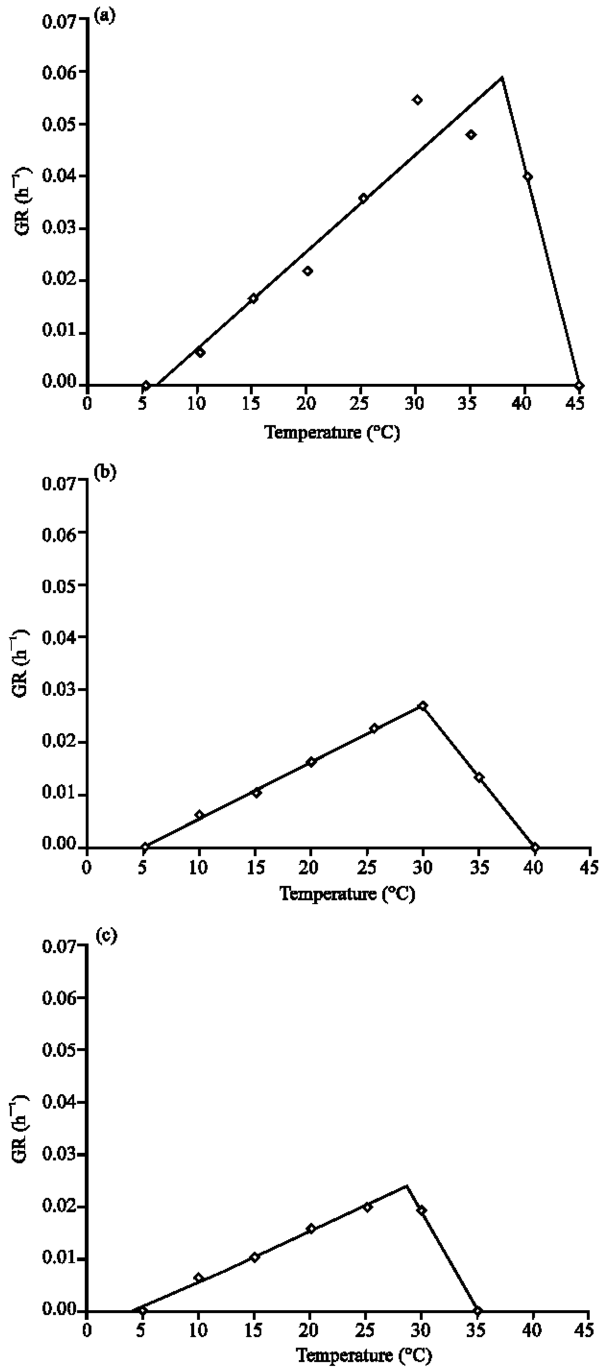

Fig. 3: The relationship between the rate of germination and temperature in (a) medicinal pumpkin, (b) borago and (c) black cumin

cumin. The influence of the temperature on GR was described by a segmented function. GR was strongly correlated with temperature as it is described by two linear relationships: one below and other above optimum temperature. The GR decreased linearly on either side of

Table 1: Estimate of base temperature (T_b, °C), optimum temperature (T_o, °C), ceiling temperature (T_c, °C) and D_{min}(h) for germination of medicinal pumpkin, borago and black cumin using segmented function

Plant	T_b	T_o	T_c	D_{min}
Medicinal pumpkin	5.93±0.855	37.66±0.424	45.00±0.303	17.12± 0.486
Borago	5.00±0.690	29.85±0.357	39.85±0.321	35.30± 0.998
Black cumin	5.00±0.561	28.55±0.255	35.00±0.198	37.02± 0.922

the optimum temperature and reached to zero at base and ceiling temperatures. Table 1 shows cardinal temperatures for medicinal pumpkin, borago and black cumin. Base, optimum and ceiling temperatures for germination were estimated 5.9, 37.7 and 45°C for medicinal pumpkin, 5, 29.9 and 39.9°C for borago and 5, 28.6 and 35°C for black cumin, respectively. Table 1 shows D_{min} for medicinal pumpkin, borago and black cumin. D_{min} of 17.12, 35.30 and 37.02 h^{-1} were determined for medicinal pumpkin, borago and black cumin.

DISCUSSION

The results of the present study confirm that, in the absence of other limiting factors (water, light and media), the germination of medicinal pumpkin, borago and black cumin seed influenced by temperature. This observation is consistent with past work on sunflower (Mwale *et al*., 1994), taree Irani (Ramin, 1997), warm season grasses (Madakadze *et al*., 2001), Himalayan elm (Phartyal *et al*., 2003), pea (Sincik *et al*., 2004) and rangeland grass species (Hardegree, 2006). The highest germination percentage has been obtained between 11 to 40°C for medicinal pumpkin, 16.7 to 29.2°C for borago and 10 to 30°C for black cumin.

Another aspect of seed germination that might be influenced by temperature is the rate of germination. The extreme temperature values had a greater deleterious effect on germination rate than on germination percentage. In addition, the results have shown that, for all medicinal plants studied here, GR was increased linearly to optimum temperature and then decreased. Similar linear relationships between GR and temperature have been observed by Covell *et al*. (1986) in grain legumes, Mwale *et al*. (1994) in sunflower, Kamkar *et al*. (2006) in millet and Jami Al-Ahmadi and Kafi (2007) in kochia and Berti and Johnson (2008) in cuphea.

Base, optimum and ceiling temperatures for germination were 5.93, 5 and 5°C, 37.66, 29.22 and 28.55°C and 45, 39.91 and 35°C for medicinal pumpkin, borago and black cumin, respectively. The cardinal temperatures for germination have been determined for different plants (Mwale *et al*., 1994; Ramin, 1997; Madakadze *et al*., 2001; Phartyal *et al*., 2003; Jami Al-Ahmadi and Kafi, 2007).

Based on the results of the present study, it can be concluded that when the soil temperature of a location is known, the cardinal temperatures and thermal time could be useful guidance to those considering introduction of this species in a new area or in selecting the sowing time. Moreover, the cardinal temperatures derived for seed germination rate could be used for prediction of subsequent developmental stages of growth (Ong, 1983; Covell *et al*., 1986). However, more works are needed to clarify this point.

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