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Original article

Determining the effect of drouth stress on the values of critical temperature thresholds for seed germination of volunteer rapeseed (*Brassica napus* L.) using hydrothermal time model

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Extended abstract

Introduction

Seed germination is largely regulated by two factors, temperature (T) and the amount of seedbed water potential (ψ). Hence, hydrothermal time models have been widely used to describe seed germination patterns in response to these two environmental factors. In this study, a new hydrothermal time model based on the Gumble distribution is presented that 1) by considering the thermoinhibition of germination at high temperatures, it simply explains the germination dynamics of seeds in response to drought stress in both sub- and supra-optimal range; 2) includes mathematical solutions for estimating critical T thresholds; and 3) explains well any systematic change in critical T thresholds due to water availability for different germination fractions (g). The developed model was fitted to the germination data of volunteer rapeseed in response to two factors T and ψ, based on which the effect of moisture stress on the values of critical germination T thresholds of this plant was modeled.

Materials and methods

The experiment was conducted at the Seed Technology Laboratory of Agricultural Sciences and Natural Resources University of Khuzestan in 2020. Germination test was performed at temperatures of 10, 15, 20, 25, 30, and 35 °C. In each of these T regimes, the germination response of seeds to different levels of drought stress, i.e., osmotic solutions with concentrations of 0, -0.3, -0.6, and -0.9 MPa was evaluated. The germination test was performed with four replications (each Petri as one replicate). In each replicate, 40 seeds were placed on a layer of Whatman No 1 filter paper in an 8-cm glass Petri, and then moistened with 5 ml distilled water or other osmotic solutions. The number of germinated seeds was counted twice daily until the end of the test or cessation of germination in each T regime. The following model was fitted to the cumulative germination data of volunteer rapeseed to explain the germination behavior of this species in response to different levels of ψ and T.

$$g = \exp\left[-\exp\left(-\frac{\left(\psi-\left(\theta_{HT}\Big/(T-T_b)t_{(g)}\right)\right)-\psi_{base(50)}-K_T(T-T_b)-\sigma\left[Ln\left(Ln(2)\right)\right]}{\sigma}\right)\right] \qquad (1)$$

The optimum (T_o) and maximum (T_m) temperatures for germination were also determined using the following equations:

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$$T_o = \frac{\psi - \psi_{base(50)} - \sigma\left[Ln\left(Ln(2)\right)\right] + \sigma\left[Ln\left(Ln\left(\frac{1}{g}\right)\right)\right]}{2K_T} + T_b \quad (2)$$

$$T_m = \frac{\psi - \psi_{base(50)} - \sigma\left[Ln\left(Ln(2)\right)\right] + \sigma\left[Ln\left(Ln\left(\frac{1}{g}\right)\right)\right]}{K_T} + T_b \quad (3)$$

Fitting of models to germination data was performed using SAS (version 9.4) and PROC NLMIXED procedure in this program.

Results and discussion

At each of the T regimes, the Gumble hydrotime model provided a good fit to the cumulative germination data of volunteer rapeseed in response to different water potentials. The two parameters θ_H (hydrotime constant) and μ (location) (and thus $\psi_{b(50)}$ (median base water potential)) showed a defined trend with increasing T, but the coefficient σ (scale) was not affected. The value of $\psi_{b(50)}$ linearly increased toward more positive values in response to an increase in T, whereas θ_H decreased curvilinearly with T. Whereas the increase in $\psi_{b(50)}$ implies that seeds need more water availability to proceed germination at higher temperatures, the decline in θ_H indicates a promoting effect of increased temperatures on germination speed. The Gumbel hydrothermal time model was able to describe the germination pattern of volunteer rapeseed reasonably well, as there was a close match between observed and fitted values. The model estimated the coefficients θ_{HT} (hydrothermal time constant), T_b (base T), $\psi_{base(50)}$ (median base water potential at $T=T_b$) and K_T (slope of changes in $\psi_{b(g)}$ with T) as 305.50 MPa °C h, 5.17 °C, -1.375 MPa and 0.044 MPa °C^{-1}, respectively. For this species, T_o and T_m were warmer for low percentiles, but they gradually became cooler with increasing g. Both these critical T thresholds also decreased proportionally with increasing drought stress intensity. The hydrothermal time model developed herein was able to reveal some adaptive characteristics in the germination response of volunteer rapeseed to T and ψ environments.

Conclusions

Based on the results obtained here, $\psi_{b(g)}$ showed an increasing trend in response to an increase in T in the range between T_b to $T_{m(g)}$, and its changes were limited to temperatures beyond T_o. Both T_o and T_m become cooler for higher germination percentiles and more severe drought stress levels. This means that volunteer rapeseed seeds can germinate only in a narrower T range under drought stress, which itself is a conservative strategy.

***Keywords*:** Base water potential; Gumble distribution; Maximum temperature; Optimal temperature; Seed germination modeling

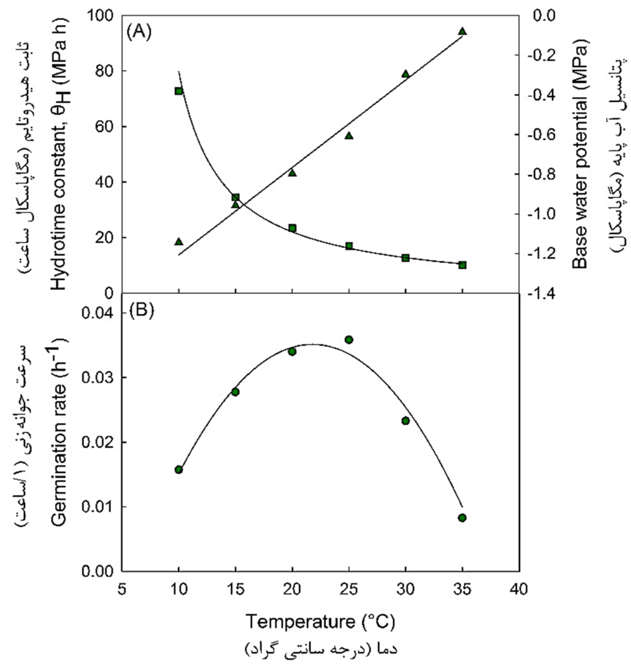

Fig. 1. Changes in hydrotime constant (θ_H; square symbols) and base water potential ($\psi_{b(50)}$; triangular symbols) as a function of temperature for volunteer rapeseed under unstressed water conditions (ψ=0 MPa) (A). The shape of the germination rate (GR) curve in the hydrothermal time model, which is based on the interaction between $\psi_{b(g)}$ and θH (Equation 14) in response to temperature (B).

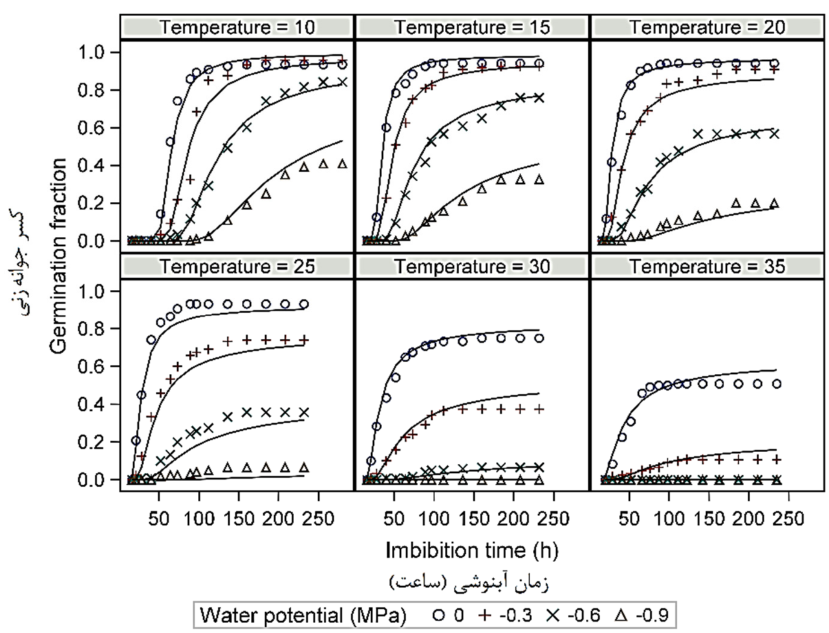

Fig. 2. Cumulative germination of volunteer rapeseed seeds at various temperature and water potential environments. The symbols represent the observed points and the lines represent the germination time courses predicted by the hydrothermal time model (Equation 13).

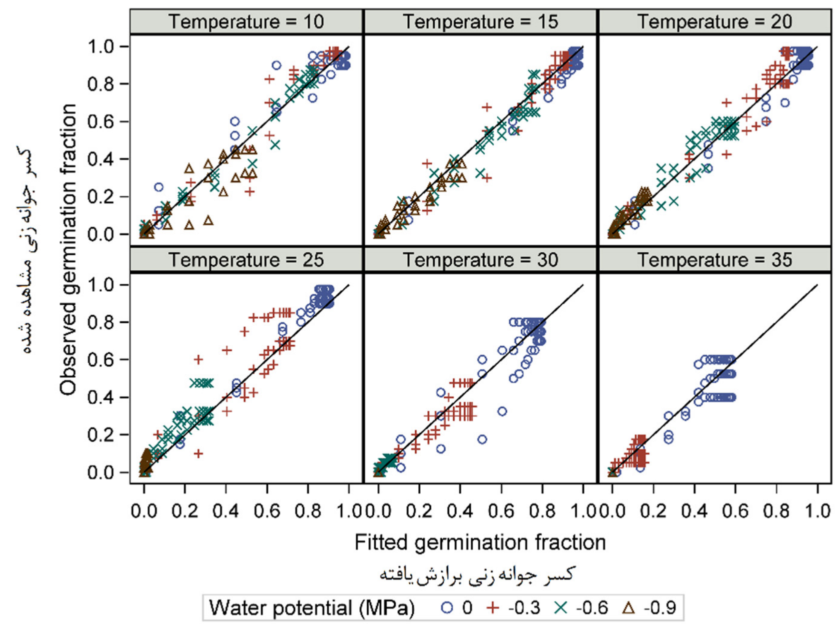

Fig. 3. Observed germination fraction versus fiited values by the hydrothermal time model (Equation 13) for volunteer rapeseed seeds at various temperature and water potential environments. The solid line indicates the 1: 1 line.

Table 1. Parameters estimates of the Gamble based hydrothermal time model fitted to volunteer rapeseed germination data in response to different temperature and water potential environments.

Parameters	Estimate	Standard error
θ_{HT} (MPa °C h)	305.500	5.230
T_b (°C)	6.169	0.074
$\Psi_{base(50)}$ (MPa)	-1.375	0.009
K_T (MPa °C^{-1})	0.044	0.000
σ (MPa)	0.246	0.003
RMSE	0.062	-

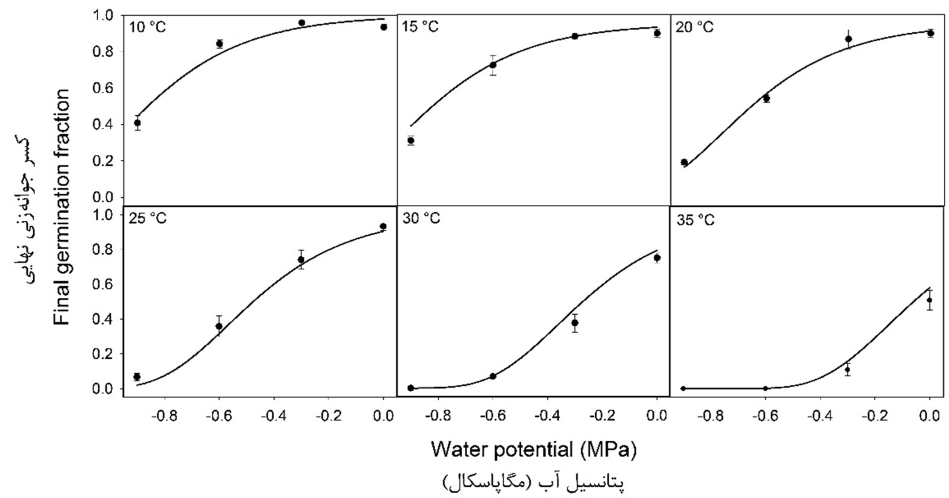

Fig. 4. Final germination fraction of volunteer rapeseed seeds after 10 days of imbibition at various water potential and temperature environments. The solid line indicates the predicted values by the model (Equation 13) for the same counting date (i.e. the 10th day). Vertical bars on data points indicate ±SE values.

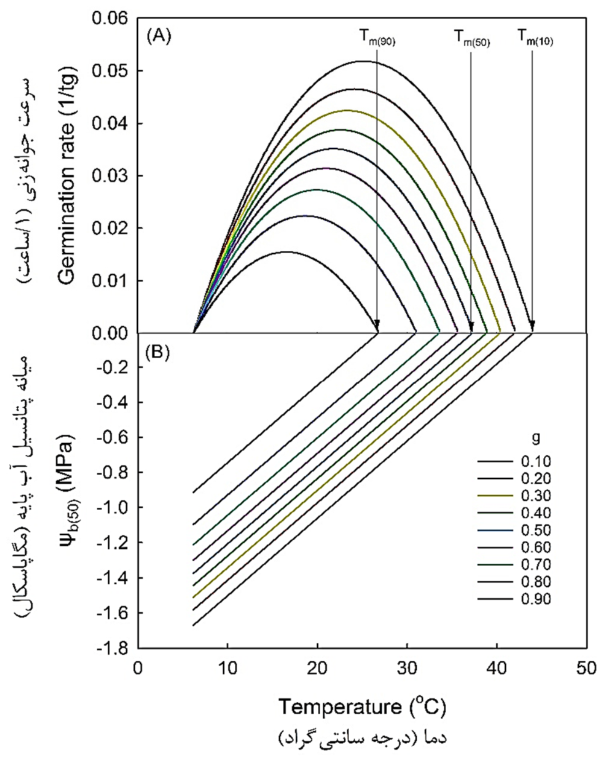

Fig. 5. Effect of temperature on germination rate (GR; Equation 16) and water potential ($\psi_{b(g)}$; Equation 6) for germination percentiles 10 (g = 0.1) to 90 (g = 0.9). Base temperature (T_b) was a constant feature of the studied seed population, but optimum (T_o; curvilinear peak) and maximum temperatures (T_m; indicated by arrows) varied among germination fractions. Tm for a given germination fraction is the temperature at which the line of $\psi_{b(g)}$ versus temperature intercepts zero.

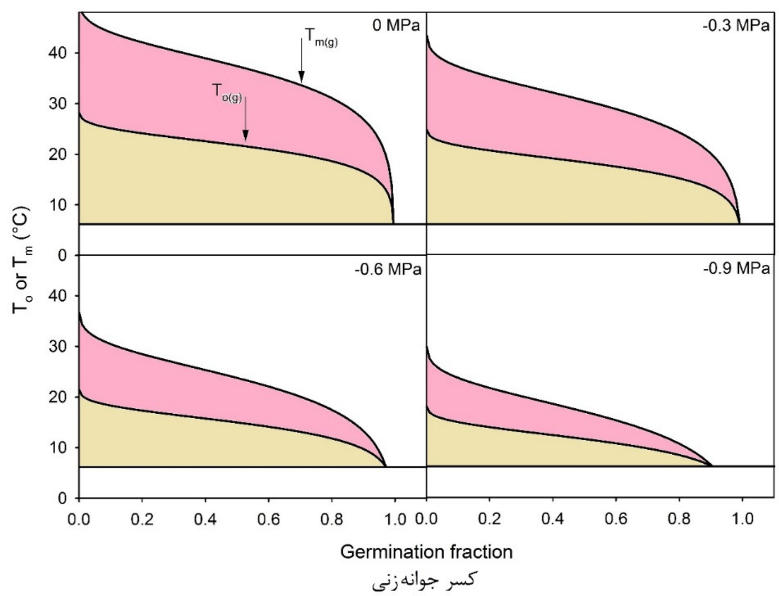

Fig. 6. Changes in optimal (To, Equation 17) and maximum temperatures (Tm; Equation 18) among germination fraction at various water potentials for volunteer rapeseed. The area under the curves decreases as the water potential decreases.

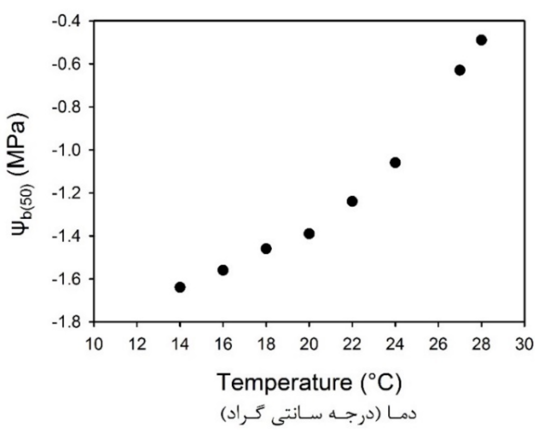

Fig. 7. Changes in $\psi_{b(50)}$ in response to temperature increase for data extracted from Table 1 in Alvarado and Bradford (2002). Temperatures from 14 to 18 °C were defined by the authors as sub-optimal range and $\psi_{b(50)}$ was assumed to be constant over this temperatures. As shown here, $\psi_{b(50)}$ increases uniformly with temperature, and no distinction can be made for differential behavior of $\psi_{b(50)}$ between sub- and supra-optimal ranges.