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Quantification of Barley Emergence to Temperature

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Abstract: **The response of seed emergence rate to temperature might be described as a non-linear function. In order to examine seed emergence responses of Barley (*Hordeumvulgare* L., Var. Sarasari) to temperature regimes and providing the necessary temperature parameters to model this procedure an experiment was performed as 12 sowing date with four replications in 2013-2014. For quantification of temperature effect on emergence rate of seeds, different non-linear regression models including Dent-like, Segmented, and Beta (B) were used. Standard Errors of estimates and regression coefficients (R^2) of emergence rate response to temperature and coefficient of determination (*a* and*b*) and correlation coefficient of predicted values versus observed were used to find the appropriate model. Investigating regression coefficients indicated that Beta model was more appropriate to quantification of temperature effect on emergence rate of barley. According to these coefficients, cardinal temperatures including T_b, T_o and Tc were predicted for as 3.5371±14.5382, 25.7390±1.1675, 39.3160±1.5143ºC, respectively. Also, required biological days from sowing to emergence using this model were calculated 3.7042±0.1679 days for barley. These parameters can be used in phenology sub-models, which is the most important component of crop simulation models.**

Keywords: **Emergence Rate, Cardinal Temperature, Nonlinear Fitting, Thermal Time, Biological Days, Barley.**

1. Introduction

Seed germination is probably the most important life stage transition for annual plants in arid and semi-arid climates [1]. Timing of emergence often determines whether a plant competes successfully with its neighbors, is consumed by herbivores, Infected with diseases. The timing of germination plays a critical role in seedling establishment in both natural ecosystems and cropping systems. The seedling stage usually has the highest mortality rate in the plant life cycle [2] and mechanisms such as delaying germination and spreading germination in time may result in better seedling establishment [3].

Temperature is the primary environmental factor regulating both seed dormancy and germination [4]. Temperature controls pre-emergent development of seedlings, and is generally the prime determinant of the duration from sowing to seedling emergence. Temperature has significant effects on the onset, potential and rate of germination [5], and is thereby always the most critical factor determining success or failure of plant establishment[6]. Nonlinear regression methods have been used to describe cardinal temperatures. Estimation of the cardinal temperatures is essential because rate of development increases between base and optimum, decreases between optimum and maximum, and ceases above the maximum and below the base temperatures [7]. Intersected lines model is one of these methods that have been used in many literatures [8]-[9]-[10]. The model consists of two linear regressions that describe response of germination rate to temperature at sub-optimal and supra-optimal temperatures; the first line indicates an increase in germination rate as the temperature increases up to an optimum threshold, and the other line shows a reduction in germination rate as the temperature increases further up to the upper limit for germination [11].

Non-linear curves may be used to model the time course of germination at various temperatures [12]. This kind of regression models have been used to describe development rate in many crops. [13]Showed that development rate from sowing to radicle emergence responds to temperature following a non-linear function. [14] Used a logistic model to study the emergence rate of wheat in terms of soil temperature and water potential.

Generally, the inverse of time required to complete a developmental stage is related to developmental rate. An inverse linear relation has been reported between the time taken to reach a given proportion of germination (e.g. 20%, 50%) and the temperature during germination [15]. [5]in a study of six desert species at three temperatures (12, 20, and 26 ºC) found that as temperature increased, the onset of germination was earlier and the time required for 50% germination decreased. Temperatures below 15ºC delayed germination of *Salicorniarubra*[16].

A clear understanding of the germination responses of seeds is useful in screening for tolerance of crops and cultivars to either low or high temperatures and in identifying geographical areas where a species or genotype can germinate and establish successfully by using the cardinal temperatures. Information on cardinal temperatures is lacking for germination of barley. This study was carried out to formulate and validate non-linear regression models that can be used to quantify cardinal temperatures and the effect of temperature on the time from sowing to germination of barley.

2. Materials and Methods

This study was carried out on barley var. Sarasari in 12 sowing dates (May-2013 to Apirl-2014 with one month intervals) with for replication.

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When the seedling appeared in top of soil, recorded as an emergence seed. Emergence rate (R50, h-1) was then calculated as [17]-[18]:

$$R50 = 1/D50 \quad (1)$$

Where D50 is the estimation of time taken for cumulative emergence to reach 50% of maximum where interpolated from the emergence progress curve versus time.

In order to formulate and validate mathematical functions that can be used to quantify the effect of temperature on required biological days to emergence of barley, three non-linear regression models were fitted to emergence rate as inverse of time from start of sowing date to emergence versus mean temperature (table 1), where T, Tb, To, To1, To2 and Tc for Dent-like (D), Segmented (S), Logistic (L) and Beta (B) models are mean temperature, base temperature, optimum temperature, lower optimum temperature, and upper optimum temperature, respectively.

Table 1. Dent-Like (D), Segmented (S), and Beta (B) Functions Formula

Function	Formula	
Dent-like (Abr. D)	$f(T) = \frac{(T-Tb)}{(To1-Tb)}$	if Tb<T≤To1
	$f(T) = \frac{(Tc-T)}{(Tc-To2)}$	if To2<T≤Tc
	$f(T) = 1$	if To1<T≤To2
	$f(T) = 0$	if T≤Tb or T≥Tc
Segmented (Abr. SE)	$f(T) = \frac{(T-Tb)}{(To-Tb)}$	if Tb≤T≤To
	$f(T) = \left[1 - \left(\frac{(T-To)}{(Tc-To)}\right)\right]$	if To≤T<Tc
	$f(T) = 0$	if T≤Tb or T≥Tc
Beta (Abr. B)	$f(T) = \left[\left(\left(\frac{(T-T_b)}{(T_P-T_b)}\right) \times \left(\frac{(T_C-T)}{(T_C-T_P)}\right)^{\frac{(T_C-T_P)}{(T_P-T_b)}}\right)^a\right]$	

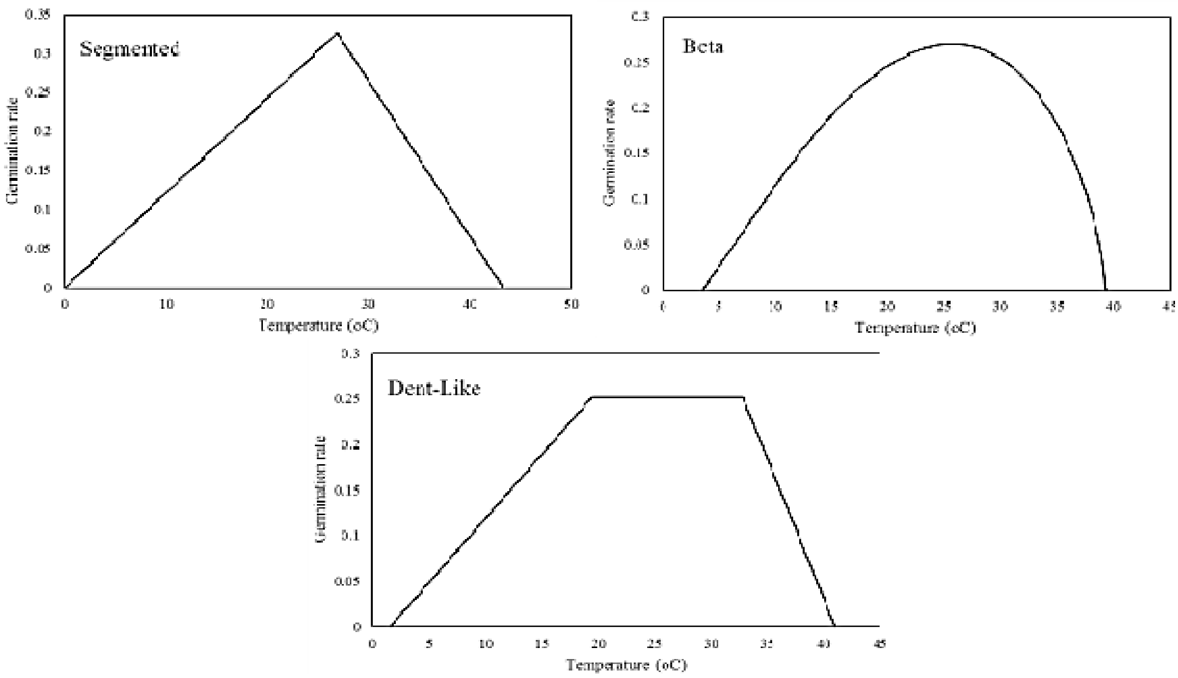

Fig.1. Used Equations For Emergence Response To Temperature.

The model with lower standard error of estimation, higher determination coefficient (R^2) of emergence response to the temperature; higher Pearson correlation coefficient and lower bias of linear regressed line between observed versus predicted emergence rate values from the 1:1 line, was selected as the best model to estimate emergence rate. *a* and *b* (as intercept and slop values of linear regression between observed versus predicted values of emergence rate) were compared with zero and 1. A closer *a* to 0 and closer *b* to 1 indicate better estimates of models.

In order to evaluate required biological days from sowing to emergence the following equation was used (Eq. 1):

(Eq. 1) $$1/e = f(T)/eo$$

Where 1/e, f(T) and eo indicate emergence rate, temperature function and minimum days to emergence at optimum temperature, respectively.

3. Results and Discussion

Fitted selected models to relative emergence rate versus mean experienced temperatures by individuals has illustrated in Fig. 2. Also estimated parameters for different models have presented in Table 2. The result indicated that Beta model was more appropriate model to predict emergence rate, because of higher R^2 (0.9542) and lower Standard Error of Estimation (0.0167) compared to Dent-like and Segmented models (SEE=0.0185 and 0.0193, respectively); on the other hand, this model has the higher Pearson correlation coefficient between observed and predicted values of emergence rate (r=0.97682) and there were no significant differences between *a* and *b* coefficients with zero and one, respectively (*a*=0.01120±0.01519, *b*=0.95460±0.06615) (Table 2).

Table 2.Regression coefficients (R^2) and standard error of estimation (SEE) of between Dent-like (D), Segmented (S) and Beta (B) models used to describe relationship between emergence rate versus temperature in barley. Pearson is correlation coefficient of observed and predicted emergence rate. *a* and *b* are regression coefficients related to regressed line between observed versus predicted values of days emergence for barley.

Equation	Rsqr	SEE	a±SE	b±SE	r
Dentlike	0.944	0.0185	0.01120 ±0.01519	0.94409 ±0.07273	0.97158
Beta	0.9542	0.0167	0.00907 ±0.01382	0.95460 ±0.06615	0.97682
Segmented	0.9301	0.0193	0.00671 ±0.01730	0.96349 ±0.08279	0.965

Estimated values for cardinal temperatures of barley emergence are presented in Table 3. These values are basic and primary data needed to simulate time to emergence. These parameters are used directly in thermal time calculation and determine extreme temperatures which will suppress seed emergence. This temperature range is defined as cardinal temperature, i.e., a minimum or base temperature (T_b), maximum temperature (T_c) that development rate above that will be zero and optimum temperature (T_o) at which the development rate is the highest [7]. Estimated base temperature based on models for Sarasari varied from 0.00±3.6279 to 3.5371±3.4543 °C, while estimated values by the more appropriat model was 3.5371±3.4543 °C.

Table 3. Estimated values of base temperature (Tb), optimum temperature (To), ceiling temperature (Tc) and minimum days to emergence under optimum temperature (eo) by Dent-like (D), Segmented (S), and Beta (B) models for barley var. Sarasari. a is the Beta model coefficient.

	Dentlike	Beta	Segmented
Tb	1.4726±4.1115	3.5371±3.4543	0.00±3.6279
To		25.7390±1.1675	26.8574±1.0587
To1	19.4293±1.1424		
To2	32.7921±1.1171		
Tc	41.0059±1.1744	39.3160±1.5143	43.2152±1.2909
eo	3.9685±0.1455	3.7042±0.1679	3.0666±0.1504
a			1.1227±1.3994

Related values of estimated optimum temperature based on these models varied from 19.4293±1.1424 to 32.7921±1.1171 ºC for barley, while estimated values by the more profitable model was 25.7390±1.1675 ºC. Estimated ceiling temperature by three used models for barley varied between 39.3160±1.5143 to 43.2152±1.2909 ºC, while estimated values by the Beta model was 39.3160±1.5143 ºC (Table 3).

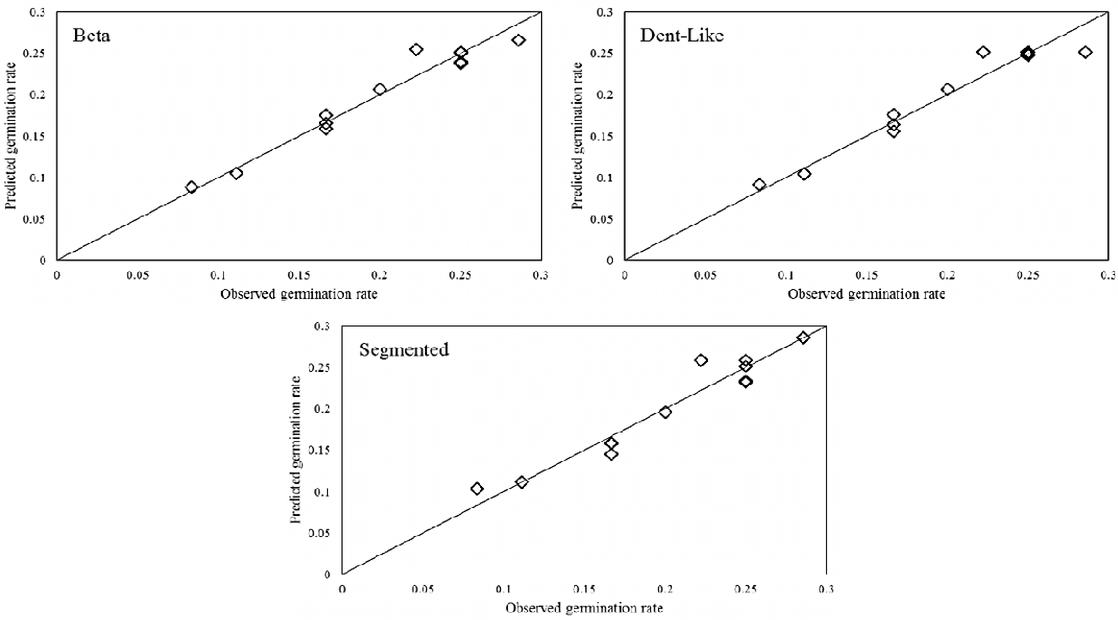

Fig.2. Right: Observed Vs. Predicted Values of Emergence Rate Beta, Dent-Like and Segmented Models. Lines Indicate 1:1 Line.

our results indicated that three linear regression models and their coefficient concepts can be used successfully to predict emergence time, as one of the most important and determinant phenological stages, especially in competition and interference studies. Also, these results revealed that tolerance range (ecological magnitude) of this variety of barley varies between about 0.00±3.6279 to 43.2152±1.2909 ºC. [19] concluded that kochia can adjust its germination over a wide range of temperatures, from 3.5°C (T_b) to 50°C (Tmax), with an optimum germination temperature of 24 °C.

Also, the number of required biological days for emergence for barley using the Beta model was 3.7042±0.1679 days (Table 3). [20] reported that dent-like, was chosen as the best model to describe the response of common millet germination to temperature (T_b = 7°C and T_c = 49.50°C). Also beta, was chosen for foxtail millet (T_b = 7°c, T_c = 49.50°c). Beta, was chosen as the best model for pearl millet (T_b = 6.50 and T_c = 47). Also, required biological days from sowing to emergence using these models varied from 3.57, 4.29 and 5.54, for common millet, foxtail millet and pearl millet, respectively.

These parameters can be used in phenology sub-models, which is the most important component of crop simulation models.

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