American Journal of
Plant Physiology

ISSN 1557-4539

Academic
Journals Inc.

www.academicjournals.com

American Journal of Plant Physiology 2 (5): 303-310, 2007
ISSN 1557-4539

Modeling the Effect of Temperature on Percentage and Duration of Seed Germination in Grain Legumes and Cereals

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Abstract: The aim of this study was to investigate the possibility to predict by mathematical models seed germination percentage and days to germination on the basis of temperature. Seed from legumes and cereals were used: faba bean (*Vicia faba* L.), bean (*Phaseolus vulgaris* L.), pea (*Pisum sativum* L.), cowpea (*Vigna sinensis* L.) and some cereals; bread wheat (*Triticum aestivum* L.), durum wheat (*Triticum durum* L.), Barleys (*Hordeum vulgare* conv. *distichon* and *Hordeum vulgare* conv. *hexastichon*), oat (*Avena sativa* L.), Triticale (*Triticale withmack*), Rice (*Oryza sativa* L.), rye (*Secale cereale* L.), pop corn (*Zea mays everta* Sturt.), maize (*Zea mays indentata* Sturt.) and Johnson grass (*Sorghum halepense* L.) was investigated by mathematical models based on temperature. For this reason a model $D = a-(b\times T)+(c\times T^2)$ produced earlier for predicting the time to emergence in relation to temperature for some vegetable crops was utilized. The final structure of the model did not change for predicting the days to germination of the tried grain legumes while it changed to $GP = a+(b\times T)-(c\times T^2)$ for predicting Germination Percentage (GP) of the crops tried. It was found that the new mathematical models obtained after adapting the present data to the above mentioned model could be applied in terms of the studied parameters. In addition, optimum temperature for seed germination was calculated by using the coefficients $T_0 = [-b/(2\times c)]$ obtained from the regression models of the days to germination.

Key words: Grain legumes, cereals, temperature, modeling, germination percentage, days to germination

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INTRODUCTION

Cereal-legume intercropping plays an important role in subsistence food production in developing countries, especially in situations of limited water resources. Crop simulation modeling can be used to assess risk for intercrop productivity over time and space (Tsubo *et al*., 2005; Rennan *et al*., 2007).

Germination is a critical stage in the life cycle of weeds and crop plants. It often controls population dynamics, with major practical implications and depends on temperature strictly (Keller and Kollmann, 1999; Kevseroğlu and Çalişkan, 1995). All growth processes within the seed are chemical reactions activated by the addition of water, decent temperature and oxygen presence. Therefore, the germination process requires moisture, oxygen and temperature ranges which are specific to particular crops. The higher the temperature raises the faster the rate of chemical reactions will be. But, there are biological limitations as to how the temperature can be raised. The upper limit of rising temperature varies with plant species (Flores and Briones, 2001; Uzun, 1996). Water is imbibed and activates growth processes, the rate of which depends on temperature. Germination rate usually increases until the temperature reaches 30-35°C. But imbibed seeds of some plant species exhibit thermo dormancy at the higher temperature (Villalobos and Peláez, 2001; Kevseroglu *et al*., 2000).

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On the other hand, it is revealed that it is not possible to mention of a certain optimum temperature value for germination (Meyer *et al*., 1965). Optimum temperature for germination is known as a temperature value which results in the highest germination rate in a short period of time (Hakansson *et al*., 2002; Sagsoz, 1990). Moreover, optimum germination temperatures are not the same for all the seed species. Generally, optimum temperatures are preferred for both seed germination and plant growth. Therefore, it will be useful to know minimum, optimum and maximum temperatures required for plant growth and development (Arechiga and Carlos, 2000; Meyer *et al*., 1965; Kevseroğlu, 1997).

Several studies have been carried out to examine the effect of temperature on seed germination and emergence for some plant species under field or Laboratory conditions such as Markus (2004) in *Bidens cernua* and *Bidens tripartite*, Manfred *et al*. (2004) in *Brachycome muelleri*, Seefeldt *et al*. (2002), Jame and Cutforth (2004) in *Triticum aestivum*, Nomizu *et al*. (2004) in *Hepatica nobilis*, Wang *et al*. (2004) in *Eurotia lanata*, Huang *et al*. (2003) in *Haloxylon ammodendron*, Malcolm *et al*. (2003) in *Prunus persica*, Barrera and Nobel (2003) in *Stenocereus queretaroensis*, Klips and Pêñalosa (2003) in *Lythrum salicari*. These kinds of models have been used by many researchers to determine plant growth, development and yield (Gayler *et al*., 2002; Sinclair *et al*., 2003; Prusinkiewicz, 2004; Yang *et al*., 2004) as well as seed germination, seedling emergence and seedling growth (Flerchinger and Hardegree, 2004; Wang *et al*., 2004; Hardegree *et al*., 2003) in recent years.

The effects of temperature in biology have long been a source of both confusion and controversy. For instance, from the temperature dependence of a complex process it has sometimes been inferred that a single rate-limiting step is operating or, in other cases, that phase transitions are taking place in membranes or other biological complexes. It is not our intention to adjudicate on such matters here, but rather to set out as simply as possible the essentials of our current understanding and to provide the researcher with the appropriate conceptual and analytical tools (Thorney and Jhonson, 2000).

In most instances where a sufficiently broad temperature range was examined, variously shaped parabolic relationships exist between germination, elongation, or emergence and temperature (Carberry and Campbell, 1989; Fyfield and Gregory, 1989).

In many field crops, several studies have been carried out under field conditions to examine seed germination and emergence.

In this study, it is aimed to examine the germination performance and germination duration of the seeds of these crops by adapting a mathematical model produced earlier.

MATERIALS AND METHODS

Materials

This experiment was carried out in the experimental Laboratory of Agricultural Faculty of Ondokuz Mayis University.

The seeds of Lara cv. (for Faba bean), Yunus cv. (for Bean), Utrillo cv. (for Pea), Akkiz cv. (for Cowpea), Aslim-95 cv. (for Rye sp.), Bezostaja-1 cv., Pehilvan cv. and Ankara-98 cv. (for Wheat sp.), Baldo cv. and Osmancik cv. (for Rice sp.), Tietar cv. and Ant cv. (for Maize sp.), Tatlicak97 cv. and Presto cv. (for Triticale sp.), Sladoran cv. and Kral cv. (for Barley sp.), Checota cv. (for Oat sp.) and Jumbo cv. (for Sorghum sp.) were used as seed material in this study. Most of these cultivars are specify in Turkey.

Methods

The study was performed in germination cabin adjusted to 0, 5, 10, 15, 20, 25, 30, 35, 40, 45 and 50°C, respectively and repeated four times for each temperature value. The seeds were placed on moisturized filter paper (Whatman No. 1) kept in glass made containers.

For each replication, 25 seeds for faba bean, bean, pea, cowpea, maize and 50 seeds for other cultivars were used. Observations for seed germination were taken every day and germinated seeds were counted according to different temperatures. The time at which 50% of seeds germinated was accepted as days to germination for each crop. A model was produced $D = \alpha-(b\times T)+(c\times T^2)$ to predict the time elapsing from seed sowing to emergence by carrying out multi regression analysis.

In the above model; D represents the time elapsing from seed sowing to emergence as days and T represents mean temperature (°C).

The rate of variation in seedling emergence can be obtained from derivative of the above equation $Dd/dt = -b+(2\times c\times T)$. If the rate of variation is zero, another equation determining optimum temperature (T_0) for emergence can also be obtained. Hence, the equation turns to $T_0 = -b/2\times c$.

By taking into consideration these stages of the model, optimum germination temperatures were determined, as well as standard equations predicting germination percentage and the time to germination for each crop were produced. On the other hand, the optimum temperatures predicted by evaluated equations from the present study were compared with those reported in the literatures.

RESULTS AND DISCUSSION

Assuming seeds are non-dormant, germination is the key component of seedling emergence. Although germination is a continuous process involving various physiological activities within seeds, it is typically considered from a practical point of view.

That is, germination is represented by the first visual appearance of the radicle from the outer most structure enveloping the embryo. Seed germination is perhaps the most thoroughly examined aspect of plant development. It has been studied extensively in controlled environments.

Nevertheless, the primary factors governing seed germination in arable soils are: temperature, water potential and air quality (Roberts, 1988; Roberts and Ellis, 1989).

The coefficients, their standard errors and degree of significance of the models are given in Table 1 and 2 by the data. In determining the most adapted model for each crop, analysis was carried out until the lowest standard errors of independent variables values (namely T and T^2) and the highest R^2 values (regression coefficients) of the equations were obtained.

The optimum germination temperature of seeds of Lara (for faba bean), Yunus (for bean), Utrillo (for pea) and Akkiz (for cowpea) are reported as 10-14, 20-30, 4-18 and 20-30°C, respectively (Akcin, 1988; Summerfield and Roberts, 1985).

Table 1: The coefficients, their standard errors and R^2 values of the new produced equations predicting the days to germination $D = a-(b\times T)+(c\times T^2)$ and germination percentage $GP = a+(b\times T^2)$ based on mean temperature for some grain legumes

	Coefficients for germination percentage (GP)			
Plant species	a	b	c	R^2
Faba bean (SE)	136.00±6.72***	-5.430±0.73**	0.090±0.02*	0.99***
Bean (SE)	275.14±15.21***	-17.540±1.29***	0.340±0.026***	0.98**
Pea (SE)	82.00±2.85***	-1.810±0.31*	0.097±0.007***	0.99***
Cowpea (SE)	-111.46±23.39*	-15.670±1.98**	0.320±0.04 *	0.97*

	Coefficients for days to germination (D)					
Plant species	a	b	c	R^2	T_0(°C) predicted by the models	T_0(°C) reported by literatures
Faba bean (SE)	0.24±0.01***	-0.012±0.001***	5.3E^{-04}±3.01E^{-05}***	0.99***	11.32	10-14
Bean (SE)	1.75±0.089***	-0.120±0.007 ***	0.0023±1.5E^{-04} ***	0.99***	26.08	20-30
Pea (SE)	-0.03±0.007***	0.014±7.6E^{-04}**	-3.6E^{-04}±1.89E^{-05}***	0.99***	19.44	4-18
Cowpea (SE)	0.40±0.068 **	-0.023±0.005*	4.9E^{-04}±1.1E^{-04}*	0.92*	23.46	20-30

*, **, ***: Significant at the level of $p<0.05$, 0.01 and 0.001, respectively

Table 2: The coefficients, their standard errors and R^2 values of the new produced equations predicting the days to germination a- ($b \times T$)+($c \times T^2$) and germination percentage GP = a- ($b \times T$)+($c \times T^2$) based on mean temperature for some cereals

Plant species	Coefficients for germination percentage (GP)			
	a	b	c	R^2
Bezostoya (SE)	-36.37±14.03	11.87±1.37	-0.29±0.030	0.97
Pehlivan (SE)	-49.57±17.41	12.88±1.69	-0.31±0.030	0.96
Kral (SE)	168.28±18.41	-10.40±1.79	0.22±0.030	0.91
Çavdar (SE)	162.85±13.36	-9.57±1.30	0.20±0.020	0.94
Tatlıcak (SE)	-49.42±23.99	13.80±2.33	-0.34±0.050	0.95
Sladoran (SE)	-55.42±27.21	14.47±2.65	-0.35±0.050	0.94
Ankara-98 (SE)	-180.48±9.970	21.46±0.84	-0.42±0.010	0.99
Çekota (SE)	-60.85±33.83	15.26±3.29	-0.37±0.070	0.92
Baldo (SE)	165.28±10.79	-6.28±0.90	0.08±0.010	0.99
Presto (SE)	-51.05±13.14	14.74±1.28	-0.37±0.020	0.98
Tietar (SE)	-34.64±38.02	11.41±3.35	-0.26±0.060	0.87
Ant (SE)	163.46±6.550	-6.11±0.50	0.08±0.009	0.99
Osmancık (SE)	-122.39±34.50	15.43±2.67	-0.27±0.040	0.91
Sorgum (SE)	152.85±15.21	-5.05±1.28	0.05±0.020	0.98

Plant species	Coefficients for days to germination (D)					
	a	b	c	R^2	T_0(°C) predicted by the models	T_0(°C) reported by literatures
Bezostoya (SE)	-0.510±0.13	0.0910±0.011	-0.0016±0.00040	0.94	23.11	20-25°C
Pehlivan (SE)	-1.550±0.15	0.2400±0.040	-0.0038±0.00080	0.93	24.22	20-25°C
Kral (SE)	-0.515±0.14	0.0870±0.014	-0.0018±0.00030	0.92	23.60	20-25°C
Çavdar (SE)	-1.540±0.14	0.2100±0.030	-0.0042±0.00070	0.92	24.91	20-25°C
Tatlıcak (SE)	-0.880±0.31	0.1340±0.003	-0.0023±0.00060	0.94	28.87	20-25°C
Sladoran (SE)	-1.240±0.29	1.1620±0.029	-0.0028±0.00060	0.96	27.98	20-25°C
Ankara-98(SE)	0.023±1.01	0.0130±0.080	0.00040±0.0010	0.86	13.50	20-25°C
Çekota (SE)	-1.330±0.62	0.1600±0.060	-0.00200±0.0010	0.87	29.85	20-25°C
Baldo (SE)	-1.102±0.30	0.1180±0.020	-0.00200±0.0005	0.93	27.50	28-35°C
Presto (SE)	-1.370±0.47	0.2200±0.040	-0.00500±0.0010	0.89	22.26	20-25°C
Tietar (SE)	-0.380±0.13	0.0600±0.010	-0.00090±0.0002	0.92	30.76	28-35°C
Ant (SE)	0.106±0.14	0.0029±0.010	$5.950E^{-5}$±0.0002	0.85	24.51	28-35°C
Osmancık (SE)	-1.050±0.26	0.1020±0.020	-0.00160±0.0003	0.91	30.41	28-35°C
Sorgum (SE)	-0.060±0.32	0.0079±0.020	0.00011±0.0005	0.89	35.77	28-35°C

*, **, ***: Significant at the level of $p<0.05$, 0.01 and 0.001, respectively

The optimum germination temperature of seeds of Aslim-95 (Rye sp.), Bezostoya, Pehilvan and Ankara-98 (Wheat sp.), Tatlicak 97 and Presto (Triticale sp.), Sladoran and Kral (Barley sp.), Checota (Oat sp.) have been reported as 20-25°C, whereas for Tietar and Ant (Maize sp.), Baldo and Osmancik (Rice sp.) and Sorghum (Sorghum sp.) as 28-35°C (Kun, 1988).

After following the modeling procedure, it was found that the model adapted to the data obtained from the present study did not show any structural change in terms of predicting the days to germination for D = a- ($b \times T$)+($c \times T^2$) to GP = a+($b \times T$)-($c \times T^2$) the studied legumes and cereals. However, it changed from to in terms of predicting the germination percentage (Table 1 and 2).

As shown in Table 1, the regression coefficients of the new produced equations for germination percentage in the tried plant species changed between 0.97 (in cowpea) and 0.99 (in faba bean and pea) as a result of model adaptation.

This result showed that the effect of temperature on germination percentage was much more important than the other possible effective parameters since 97 to 99% of the variation in germination percentage was explained by temperature depending on the plant species.

After model adaptation processes, it was also found that the regression coefficients of the new produced equations for days to germination in the tried plant species changed between 0.92 (in cowpea) and 0.99 (in faba bean, bean and pea). At this stage, we can say that very reliable equations have been obtained for predicting the days to germination as affected by temperature.

The relationship between actual germination percentage and predicted germination percentage by the new produced equations were also investigated in order to find out their prediction performances (Fig. 1) as well as comparing actual and predicted days to germination (Fig. 2).

As shown from Fig. 1 and 2, the coefficients of the solid lines were 0.98 for germination percentage and 0.99 for days to germination.

It was found that optimum temperatures for germination predicted by the current equations were in general in the limit of those reported in the literatures (Table 2). The regression coefficients of the new produced equations for germination percentage in the tried plant species changed between 0.91 (for barley) and 0.99 (for wheat and rice) as a result of model adaptation.

This result showed that the effect of temperature on germination percentage was much more important than the other possible effective parameters since 91 to 99% of the variation in germination percentage was explained by temperature depending on the plant species. After model adaptation processes, it was also found that the regression coefficients of the new produced equations for days to germination in the tried plant species changed between 0.85 (for maize) and 0.96 (for barley). At this stage, we can say that very reliable equations have been obtained for predicting the days to germination as affected by temperature.

The relationship between actual germination percentage and predicted germination percentage by the new produced equations were also investigated in order to find out their prediction performances (Fig. 3) as well as comparing actual and predicted days to germination (Fig. 4).

On the other hand, as explained in the section of Material and Methods, it could be possible to determine optimum temperatures (T_0) for germination by using the coefficients of independent variables (b and c) obtained from the equations belonging to the days to germination for each species.

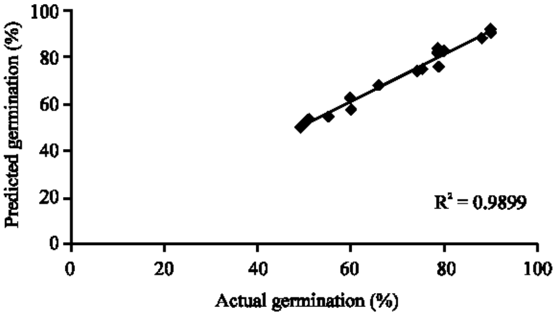

Fig. 1: Relationship between actual and predicted germination percentage for grain legumes

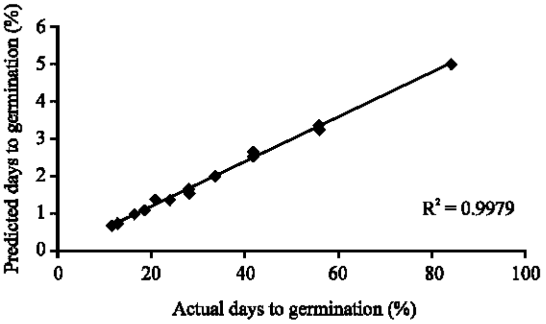

Fig. 2: Relationship between actual and predicted day to germination for grain legumes

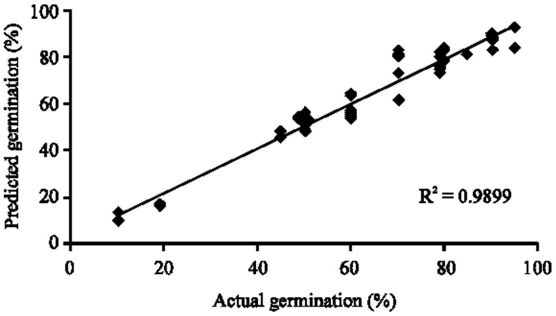

Fig. 3: Relationship between actual and predicted germination percentage for cereals

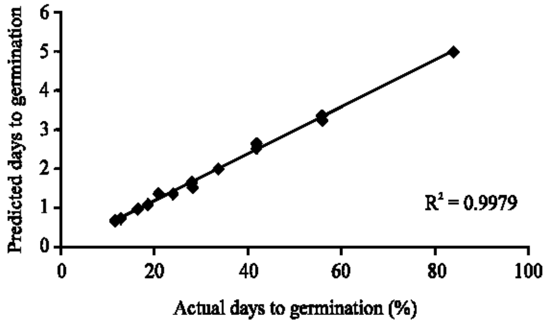

Fig. 4: Relationship between actual and predicted day to germination for cereals

CONCLUSIONS

To conclude, considering that there have been a marked interest by many workers in modeling plant growth and development in recent years, the equations produced in the present study may be used in this field. This kind of models such as those predicting days to germination or optimum temperatures could be used for adjusting a proper time for seed sowing according to different regions and utilizing the vegetation period of these regions more productively. The temperature limits (0 to 50°C) used in the present study also enables us to use these models safely.

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