Asian Journal of Plant Sciences

ISSN 1682-3974

science alert

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Asian Journal of Plant Sciences 5 (2): 316-319, 2006
ISSN 1682-3974

Cardinal Temperatures for Germination in Three Millet Specieses (*Panicum miliaceum, Pennisetum glaucum* and *Setaria italica*)

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Abstract: The purpose of this study was to quantify response of germination rate to temperature and to obtain cardinal temperatures in three millet specieses (*Panicum miliaceum*, *Pennisetum galucum* and *Setaria italica*). An experiment was conducted at the Institue de Agricultura Sostenible (CSIC, Cordoba, Spain) from March to August 2004. In this experiment, germination rate (the reciprocals of time to 50% of germination) was calculated at different constant temperatures (ranging from 5 to 45°C, with 5°C intervals). The experiment replicated once again to ensure about accuracy of results from the first experiment. Cardinal temperatures were obtained by fitting a intersected, non-linear regression model to data of germination rate versus temperatures. Results indicated that cardinal temperatures for germination varied slightly between different specieses. The mean of calculated cardinal temperatures (based on data of both experiments) were 9.9°C for base, 40.2°C for optimum and 47.8°C for ceiling temperature in common millet; these estimates were 7.7, 38.9 and 46.0°C for pearl millet and 9.3, 37.0 and 46.0°C for foxtail millet. This information can be used in evaluation of new areas for introduction of these specieses and selection of appropriate sowing date, or other objectives such as prediction of development stages and etc.

Key words: Millet, germination, cardinal temperatures, model

INTRODUCTION

Germination has often been used for evaluating response of development to temperature response functions. Many researchers (Covell *et al*., 1986; Ellis *et al*., 1986; Garcia-Huidobro *et al*., 1982) found that a linear relationship resulted when the inverse of time to germination (germination rate) was related to temperature. Temperature is the single most important factor governing the germination (Olivier and Annandale, 1998). Previous studies have shown that germination rate usually increases linearly with temperature, at least within a well-defined range (Mwale *et al*., 1994) and declines sharply in higher temperatures (Mwale *et al*., 1994; Ramin, 1997). This temperature range has been defined as cardinal temperatures, i.e., a minimum or base temperature (Tb), maximum temperature (Tc) that germination rate at above of that will be zero and optimum temperature (To) at which the germination rate is highest. Several researchers have shown that the cardinal temperatures for germination depend on species and within specieses vary significantly (Angus *et al*., 1981; Thompson, 1970).

Common millet (*Panicum miliaceum*), pearl millet (*Pennisetum galucum*) and foxtail millet (*Setaria italica*) are common millet specieses that are cultivated in arid and semi-arid regions of Iran. There is not any comprehensive information about cardinal temperatures for these specieses, especially for common millet and foxtail millet. Many conflicting and inconclusive results have been reported in the literatures concerning cardinal temperatures of pearl millet (Garcia-Huidobro *et al*., 1982; Ann and Binning, 1987). For example base temperature of pearl millet in different literatures changes from 8 (Aitken, 1974) to 12°C (Garcia-Huidobro *et al*., 1982), while other reports showed that base temperature of wild pearl millet is about 7°C (Ann and Binning, 1987). Garcia-Huidoboro (Garcia-Huidobro *et al*., 1982) revealed that germination rate of pearl millet increased linearly with temperature from a base of 10 to 12°C to a sharply defined optimum at 33 to 34°C and then declined to zero at 45 to 47°C.

Nonlinear regression models have been used to describe cardinal temperatures (Hadley *et al*., 1983; Kocabas *et al*., 1999; Phartyal *et al*., 2003). Intersected lines model is one of these methods that have been used

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in many literatures (Hadley *et al*., 1983; Kocabas *et al*., 1999; Phartyal *et al*., 2003). In this model Tb and Tc are derived from the interception of each regression line with the abscissa and To is the intersection point of two linear regression lines that describe response of germination rate to temperature at sub-optimal and supra-optimal temperature (Covell *et al*., 1986). The present study aimed to determine the cardinal temperatures of three mentioned specieses of millet by intersected lines model.

MATERIALS AND METHODS

Seeds of Common millet (*Panicum miliaceum*), pearl millet (*Pennisetum galucum*) and foxtail millet (*Setaria italica*) were obtained from South East of Iran (Birjand, 59°12'N longtitude, 32°52' E latitude, 1491 m altitude). All empty seeds were cleaned by soaking in water for 2 min. Experiments were conducted in germinators at the Instituto de Agricultura Sostenible (CSIC, Cordoba, Spain) from March to August 2004. Seeds were germinated at constant temperatures ranging from 10 to 45°C with 5°C intervals in petridishes, lined with two layers of germination papers which were wetted periodically with ordinary tap water as when required. Tests were conducted in total darkness. The experiment was replicated twice with 60 seeds that were drawn randomly from the original seed stocks. In each experiment, 4 randomized replications were used. The time was noted when a replicate had been prepared and placed in germinator. After beginning of germination, the seeds with a radicle equal the length of the seed (approximately 4 mm) were scored as germinated and removed. Collected data used to plot mean cumulative germination curves against time. From these curves, time to 50% of germination was determined by interpolation as Dumur *et al.* (1990). Intersected lines models were fitted to the data of the reciprocals of time to 50% of germination versus temperatures using below equations:

$$Y = a1 + b1x \quad \text{if } Tb < T \le To,\ b > 0$$
$$y = a2 + b2x \quad \text{if } To < T \le Tc,\ b < 0$$

Where, y = germination rate, T = mean temperature (°C), Tb = base temperature (°C), Tc = ceiling temperature (°C) and To = optimum temperature (°C), a1, a2, b1 and b2 are regression coefficients.

The model was fitted using nonlinear procedure in sigmaplot for windows version 7.0.2001.

RESULTS

Table 1 shows time to 50% of germination at different constant temperatures. Results indicated that time to 50% of germination changed as a U shape curve that is typical of the temperature reaction of many developmental stages, including germination (Olivier and Annandale, 1998).

Comparison of germination rate at different constant temperatures indicated that germination rate of all specieses increased with increase in temperature to 35°C. Regression of the rate of germination versus temperatures separately for the sub and supra-optimal temperatures ranges indicated highly significant linear relationship in each species (Table 2). Figure 1 shows the results of model fitting. Calculated cardinal temperatures, regression equations and R^2 are presented in Table 2. The slope of line showed positive response for temperature between Tb and To and negative response between To and Tc. Small differences between calculated cardinal temperatures in the two independent replications of experiments was related to extrapolation of two fitted lines to intersect X-axis (where germination rate is equal to zero) to determine base and ceiling temperatures. Therefore these small differences can be ignored and

Table 1: Time to 50% of germination (hours) against different constant temperatures

Temperature (°C)	Specieses: Common millet, Experiment No. 1	Common millet 2	Pearl millet 1	Pearl millet 2	Foxtail millet 1	Foxtail millet 2
10	380	380	214	210	218	222
15	140	125	76	72	64	72
20	74	70	48	40	39	43
25	45	42	40	37.5	39.5	38
30	40	40	20.3	22.5	19.5	20
35	28	29	17.5	18	14	15
40	17	19	17	17.5	20	18

Table 2: Equations, calculated cardinal temperatures and R^2 of fitted intersected lines models

Specieses	Temp. range	Equations, Exp. No. 1	Equations 2	Tb 1	Tb 2	To 1	To 2	Tc 1	Tc 2	R^2 1	R^2 2
Common millet	Tb<T≤To	0.0017T-0.0181	0.0014T-0.013	10.6	9.2	40.1	40.2	48	47.6	0.96	0.98
	To≤T<Tc	-0.008T-0.0129	-0.006T+0.2924	-	-	-	-	-	-	-	-
Pearl millet	Tb<T≤To	0.0020T-0.0166	0.0019-0.0136	8.2	7.3	39	38.7	45	47	0.98	0.99
	To≤T<Tc	-0.0103T+0.463	-0.01T+0.45	-	-	-	-	-	-	-	-
Foxtail millet	Tb<T≤To	0.00124T-0.0206	0.428T-0.201	8.9	9.7	37	37	45	47	0.97	0.97
	To≤T<Tc	-0.0087T+0.394	-0.0072+0.336	-	-	-	-	-	-	-	-

Tb, To and Tc are base, optimum and ceiling temperatures, respectively. R^2 is correlation coefficient

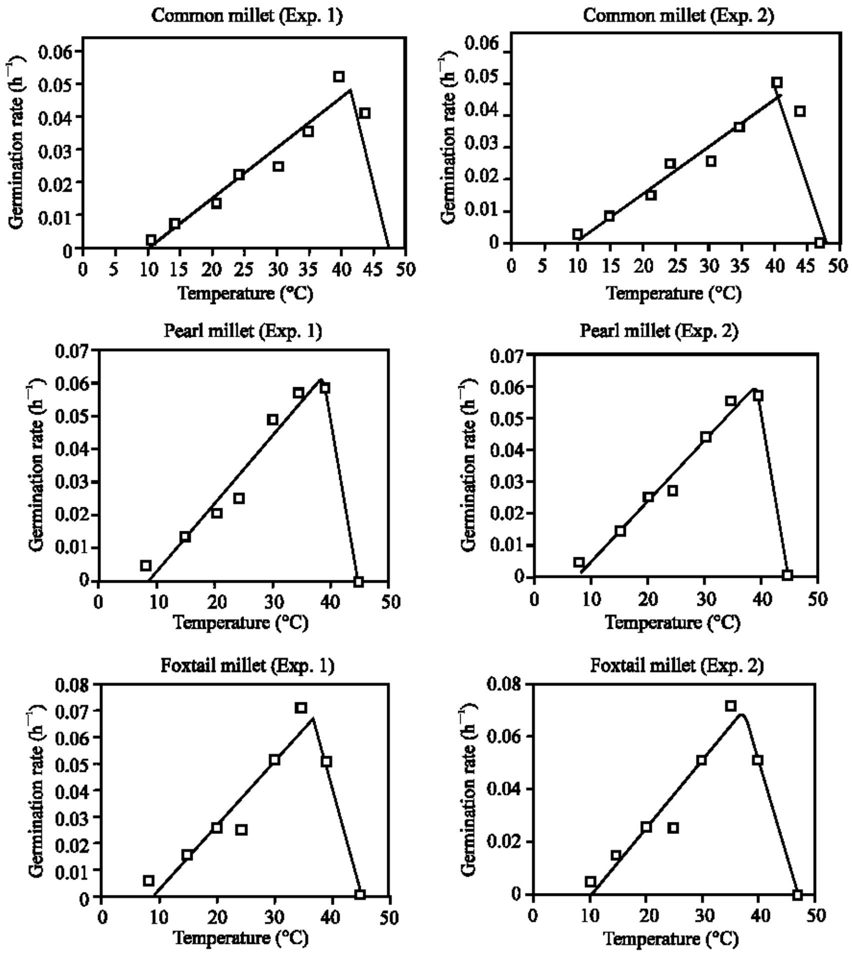

Fig. 1: Fitted intersected lines models to germination rate against different constant temperatures in studied millet specieses

mean of the two estimates of cardinal temperatures can be used.

DISCUSSION

The results of the present study confirmed that in the normal conditions, the germination rate of the specieses is highly affected by temperature and findings are consistent with past works on pearl millet (Garcia-Huidobro *et al*., 1982) and other crops (Covell *et al*., 1986; Elli *et al*.,1986; Mwale *et al*., 1994). Also, results indicated that cardinal temperatures changes between different specieses. Other studies have shown that the cardinal temperatures for germination depend on species and within specieses vary significantly between genotypes (Ann and Binning, 1987). Comparison of cardinal temperatures for different specieses showed that cardinal temperatures in common millet are more than two others one.

Intersected line model was successful in describing germination response to temperature. Consistency of calculated cardinal temperatures for pearl millet with previous studies (Garcia-Huidobro *et al*., 1982) revealed that calculated cardinal temperatures for common millet and foxtail millet (that there is not any information about their cardinal temperatures) should be exact and reasonable. Accurate control of temperature by using germinators (±0.3°C) and the consistency of the results of two separate experiments ensured us that the cardinal temperatures are valid and acceptable and can be used in other researches with different objects. For example, the cardinal temperatures could be used for prediction of subsequent developmental stages of the crop (Covell *et al*., 1986; Hadley *et al*., 1983).

ACKNOWLEDGMENTS

The authors wish to acknowledge the Instituto de Agricultura Sostenible (CSIC), Cordoba-Spain and especially Prof. F.J. Villalobos for all supports and providing all needed equipments to complete this research.

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