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# Cardinal temperatures for seed germination of three Quinoa (*Chenopodium quinoa* Willd.) cultivars

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## ABSTRACT
Quinoa (*Chenepodium quinoa* Willd.) is a grain-like crop which has a high potential of crop yield under arid environments. The objective of this study was to evaluate the responses of seed germination rate and percentage to temperatures and estimate cardinal temperatures in three quinoa cultivars (*i.e.*, Sajama, Titicaca and Santamaria). Germination of quinoa seeds were daily counted at the temperatures ranging from 5.0 to 40.0°C (5.0, 10.0, 15.0, 20.0, 25.0, 30.0, 35.0 and 40.0 °C). Four relevant regression models of segmented, beta, dent-like and modified beta were fit to germination rates with temperatures and subsequently the parameters including base temperature, optimum temperature, ceiling temperature and maximum germination rate were estimated. The accuracy of the model was measured by using RMSE (root mean square of error) and Aikaik Information Criteria (AIC). The interaction between temperature and cultivars effect was significant ($p\leq0.0001$). For Sajama and Santamaria, the highest germination percentage occurred between 15-35 °C, while for Titicaca the highest germination was taken place between 5-35 °C. The beta and beta modified models for Santamaria and Sajama and the dent-like model for Titicaca were found to be the best models for predicting the thermal parameters of germination. Optimum thermal range for germination of Sajama was estimated at a wider ranges (*i.e.*, 18-36 °C) rather than the other two cultivars of Santamaria (*i.e.*, 23-35°C) or Titicaca (*i.e.*, 22-35°C). The results of current study showed that quinoa is capable enough to germinate over a wide range of temperatures from 1.0 °C ($T_b$) to 54.0 °C ($T_c$).

**Keywords:** Beta, dent-like, germination percentage, model, thermal parameters.

# تعیین دماهای کاردینال سه رقم کینوا (*Chenepodium quinoa* Willd)

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## چکیده
کینوا (*Chenepodium quinoa* Willd) یک محصول شبه غله‌ای با پتانسیل کشت بالا در ایران است. در این راستا به منظور ارزیابی خصوصیات جوانه‌زنی بذر سه رقم کینوا (Sajama, Santamaria, Titicaca) و تعیین دماهای کاردینال در دماهای مختلف، آزمایشی در آزمایشگاه بذر دانشگاه تهران انجام گرفت. در این آزمایش هفت سطح دما ۵، ۱۰، ۱۵، ۲۰، ۲۵، ۳۰، ۳۵ و ٤۰ بر حسب درجه سانتی‌گراد بود. برای تعیین دقیق دماهای کاردینال و تعیین سرعت جوانه زنی در دماهای مختلف چهار مدل رگرسیونی دندان-مانند، دوتکه ای، بتا و بتا تغییر یافته به کار گرفته شد. برای تعیین دقت مدل از ضریب AIC استفاده گردید. برای دو رقم Sajama و Santamaria بهترین طیف دمایی برای جوانه‌زنی از ۱۵ تا ۳۵ درجه سانتی‌گراد بود، ولی برای رقم Titicaca از دمای ۵ تا ۳۵ درجه سانتی‌گراد بود. طبق نتایج بدست آمده، کینوا در طیف وسیعی از مجاز دمایی ۱ تا ٥٤ درجه سانتی‌گراد قابلیت جوانه‌زنی و سازگاری دارد. برای تعیین دماهای کاردینال دو رقم Sajama و Santamaria به ترتیب بتای تغییر یافته و بتا دقت بیشتری داشتند و برای رقم Titicaca مدل دندان-مانند دقت بیشتری داشت.

**واژه‌های کلیدی:** درصد جوانه‌زنی، بتا، دندان-مانند، مدل.

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## Introduction

Quinoa (*Chenopodium quinoa* Willd.), as an autogamous plant, originated from the Andean region of South America (Ceccato *et al*., 2011) and belongs to the Chenopodiaceae family, a plant family comprising the highest proportion (44 %) of halophytic plant species (Flowers *et al*., 1986). Quinoa is currently regarded as one of the most important grain crop, mainly in terms of fatty acid composition of seed oils (Ando *et al*., 2002), possessing high amounts of vitamins and minerals (Comai *et al*., 2007), protein content and amino acid balance for human nutrition because of its high lysine and methionine levels (Bhargava *et al*., 2006).

On the other hand, the world is mostly being encountered with more food production with less water availability (Geerts *et al*., 2008). In this sense, quinoa is argued to possess a high tolerance level against frost (Jacobsen *et al*., 2005), drought (Garcia *et al*., 2003) and soil salinity, as well (Prado *et al*., 2000; Jacobsen *et al*., 2003). There are reports of high adaptability of quinoa cultivars worldwide, including arid and high rainfall areas, hot or cold climate areas, tropical areas, altitudes over 4000 m above sea level and at sea level (Bertero *et al*., 2004). This has increased interest in its cultivation in various regions beyond the traditional production areas inside and outside of South America. Increasing drought and water shortages in Africa and parts of Asia such as Middle East including Iran have led agricultural organizations to work on Quinoa as a potential crop under such environments.

Seed germination as a key step for plants regeneration is a complex biological process which is influenced by various environmental and genetics factors (Shafii & Price, 2001). Environmental conditions determine germination success and subsequent seedling emergence and establishment. When moisture is adequate, the germination rate of seeds is usually controlled by temperature (Kamkar *et al*., 2012), as a critical factor affecting onset, rate and total seed germination (Verma *et al*., 2010). The seed germination response to temperature is a basis for models to predict the germination timing. Range of possible temperatures for germination is necessary to be determined in case that the suitability of a new region is being evaluated for introducing and cultivating a new plant (Adam *et al*., 2007). Cardinal temperatures [*i.e.*, base ($T_b$), optimum ($T_o$) and ceiling temperatures ($T_c$)] describe the range of temperature over which the seeds of a particular species can germinate successfully. In general, germination process increases between base and optimum temperatures, decreases between optimum and ceiling temperatures, and lastly stops beyond the ceiling and less than base temperatures (Kamkar *et al*., 2012). Cardinal temperatures are also important to determine the best planting date for crops (Kamkar *et al*., 2012).

Flores and Briones (2001) evaluated germination responses of six desert species of *Cercidium praecox*, *Prosopis laevigata*, *Neobuxbaumia tetetzo*, *Pachycereus hollianus*, *Beaucarnea gracilis* and *Yucca periculosa* to different temperatures. They reported that with increasing temperature, germination initiated earlier and the mean germination time (MGT) decreased. Jami Al-Ahmadi and Kafi (2007) studied the optimal temperatures for germination of *Kochia scoparia* and suggested that *K. scoparia* is able to adjust its germination over a wide range of temperatures, from 3.5 °C ($T_b$) to 50 °C ($T_c$), with an optimum germination temperature of 24 °C. Different types of mathematical model are used to describe relationship between germination rate and temperature. These models with biological meaning of parameters can satisfactorily predict cardinal temperatures (Soltani *et al*., 2006). Seed germination time of quinoa under coinciding condition of soil salinity and temperature was quantified using Weibull distribution or the log-logistic distribution (Pipper *et al*., 2012).

Four regression models of beta, modified beta, dent-like and segmented are being used to describe and predict seed germination response to temperature (Kamkar *et al*., 2012). Kamkar *et al*. (2008) also used segmented and logistic models to determine cardinal temperatures of germination in 3 millet varieties and emergence in wheat and segmented was the best one. To describe the germination rate response of *Salvia leriifolia* seed to temperature, three regression models, namely Intersected-Lines (ISL), Quadratic Polynomial (QPN) and Five-Parameters Beta (FPB) were used and beta model was the superior (Dashti *et al*., 2015). Regarding *Silybum marianum* L., four nonlinear regression models (*i.e.*, segmented, beta, beta modified, and dent-like) were used at six constant temperatures to describe the germination rate–temperature relationships, with the aim of identifying the cardinal temperatures and the beta model was evaluated as the best model (Parmoon *et al*., 2015).

Quinoa is at attention as a crop for nutrient and industrial purposes in arid areas including Iran. Therefore, the current study was aimed to determine the response of quinoa seed germination to temperature via different models.

## Materials and Methods

This study was conducted at the Seed Laboratory of Department of the Agronomy and Plant Breeding, University of Tehran, Iran, during 2014-2015. The seeds of three quinoa cultivars (*i.e.*, Sajama, Santamaria and Titicaca) were provided by Seed and Plant Improvement Institute, Ministry of Agriculture, Iran. The seeds were subjected to germination test in eight temperatures of 5.0, 10.0, 15.0, 20.0, 25.0, 30.0, 35.0 and 40.0 °C in a factorial arrangement of treatments (Temperatures*cultivars). The experimental design was a completely randomized design (CRD) with four replications. Fifteen seeds of each cultivar were placed on a filter paper moistened with 5.0 mL of distilled water in petri dishes of 90 mm diameter. The seeds were incubated under fluorescent light at constant temperatures ranging from 5.0 to 40.0°C in an incubator with a temperature variation of 1.0 °C. The germination papers were moistened periodically with distilled water as required. A seed was considered as germinated if the radicle was visible about 2 mm. Germination was daily recorded for 14 days (no germination was observed after 7 days) (Prado *et al*., 2000).

Data of final germination became normal after an arcsin transformation and were subjected to preliminary ANOVA to find out treatment effects. Germinated seeds were counted every 24 h and cumulative germination percentage was plotted against time. From this curve, the time required to reach 50 % germination ($D_{50}$) was determined by fitting a logistic model of cumulative germination percentage (G) against time(t) as described by as follows (Kamkar *et al*., 2012):

$$G = \frac{G_x}{1 + \exp\left[a(t - b)\right]}$$

Where (Gx) is the maximum

germination percentage, (t) is the time required for 50 % germination ($D_{50}$), and both (a) and (b) are constants. The reciprocal of time to reach cumulative germination percentage to 50 % ($D_{50}$) of total germinated seeds was considered as the germination rate ($R_{50}$).

The four relevant regression models of beta, modified beta, dent-like and segmented (Table 1, Soltani *et al.*, 2002) were fitted to $R_{50}$ versus temperature. The parameters of models were estimated at P-values lower than 0.05 and the standard error of parameters calculated. The response of germination rates to the increasing temperature commonly follows an asymmetric peak trend. Depending on the optimum temperatures, as being a range of temperatures or a single value, the shape of model would be different. The segmented and dent-like models are being used for describing the range of optimum temperature and single value, respectively. Models beta and modified beta are used when germination rates follow a nonlinear trend with increasing temperatures.

Data transformation, ANOVA and regression analysis were carried out in SigmaPlot (11.0). Parameters were estimated via an iterative optimization method (Table 1) and standard error of parameters (SE), root mean square error (RMSE) and the coefficient of determination ($R^2$) were used to evaluate model fit. RMSE was calculated using the following formula:

$$\mathrm{RMSE} = \sqrt{\left(\frac{1}{n}\right)\sum (Y_{obs} - Y_{pred})^2}$$

Where $Y_{obs}$ is the observed value, $Y_{pred}$ is the predicted value and n denotes the number of points (Timmermans, 2007).

Corrected Akaike information criterion (AICc) ( Burnham *et al.*, 2002) was also used to choose the most likely model:

$$\mathrm{AICc} = \mathrm{AIC} + \frac{2k(k+1)}{n-k-1}$$

Where AIC=2k- 2ln(SSE), SSE is the sum of square of error for the model, n denotes the total points and k is the number of parameters. The model with lower AICc value is considered as the better model.

Table 1. Beta, beta modified, segmented and dent-like models that were fitted to germination rate versus the range of temperatures (T). $T_b$ is the base temperature, $T_o$ is the optimum temperature, $T_{o1}$ is the lower optimum temperature (for 3-piece segmented function), $T_{o2}$ denotes the upper optimum temperature (for 3-piece segmented function), $T_c$ denotes the maximum temperature, and *c* is the shape parameter for the beta function which determines the curvature of the function

| Function | Formula | Reference |
|---|---|---|
| Beta | $f(T) = \left(\frac{(T-T_b)}{(T_o-T_b)}\right)\left(\frac{(T_c-T)}{(T_c-T_o)}\right)^{\left(\frac{(T_c-T_o)}{(T_o-T_b)}\right)^c}$ if $T > T_b$ and $T < T_c$<br>$f(T)=0$ *if* $T \le T_b$ *or* $T \ge T_c$ | Yin *et al.*, 1995 |
| Beta modified | $f(T) = \left(\frac{(T_c-T)}{(T_c-T_o)}\right)\left(\frac{(T-T_b)}{(T_o-T_b)}\right)^{\left(\frac{(T_o-T_b)}{(T_c-T_o)}\right)}$<br>$f(T)=0$ *if* $T \le T_b$ *or* $T \ge T_c$ | Yan & Hunt, 1999 |
| Dent-like | $f(T) = (T-T_b)/(T_{o1}-T_b)$ if $T_b < T < T_{o1}$<br>$f(T) = (T_c-T)/(T_c-T_{o2})$ if $T_{o2} < T < T_c$<br>$f(T) = 1$ if $T_{o1} \le T < T_{o2}$<br>$f(T) = 0$ if $T \le T_b$ *or* $T_c \le T$ | Piper *et al.*, 1996 |
| Segmented | $f(T) = (T-T_b)/(T_o-T_b)$ if $T_b < T < T_o$<br>$f(T) = 1-(\frac{T-T_o}{T_c-T_o})$ if $T_o \le T < T_c$<br>$f(T) = 0$ if $T \le T_b$ or $T_c \le T$ | Mwale *et al.*, 1994 |

## Results

### Total Germination percentage

The results showed that seed germination percentage and seed germination rate of all the quinoa cultivars were significantly affected by temperature ($P$<0.0001) (Table 2).

Table 2. Analysis of variance (ANOVA) for maximum germination percentage ($G_{max}$) and germination rate to reach 50 % germination ($R_{50}$) of quinoa seed

| SOV | df | MS | |
|---|---|---|---|
| | | $R_{50}$ | $G_{max}$ |
| C (Cultivar) | 2 | 0.006** | 1678.476** |
| T (Temperature) | 7 | 0.004** | 372.994** |
| T*C | 14 | 0.0003** | 119.661** |
| Error | 72 | 0.00002 | 41.904 |
| CV ( %) | | 10.51 | 7.27 |

Germination rate and percentage for the quinoa cultivars affected by temperature range were shown in Table 3. The highest total germination percentage was observed between the ranges of 15-35 °C, while the lowest germination percentage was observed at 5.0 and 40.0 °C (Table 3). Titicaca was able to germinate at more than 88 % even at temperatures 5.0 or 40.0 °C, while for Sajama the maximum germination percentage was 80-85 % occurred at the temperatures between 15.0 to 35.0 °C. For Santamaria, the final germination percentage was 92 % occurred at temperatures between 15.0 to 30.0 °C. For all the three cultivars, there was a significant growth in germination percentage I parallel with increasing temperatures up to 40.0 °C.

For Titicaca cultivar the lowest germination rate occurred at 5.0 °C, while the highest germination rate obtained at 35°C (optimum temperature). Furthermore, for Sajama and Santamaria, the highest germination rates (0.77 and 0.41, respectively) occurred at 35.0 °C (Table 3). The results revealed the capability of quinoa cultivars to keep high germination rate in the temperatures ranging from 15.0 to 35.0 ºC. This suggested high adaptability of quinoa cultivars to a wide range of environmental conditions. For Titicaca, the range of temperatures at which the highest germination rate occurred was even wider varied from 5.0 to 40.0 ºC. Therefore, a wide range of temperatures are known as optimum temperatures for qunioa. Quinoa has gained worldwide attention because of its capability to grow under various stress conditions like soil salinity, acidity, drought and forest (Bhargava *et al*., 2006; Ceccato *et al*., 2011).

Table 3. Mean comparison of effects of different temperatures on seed germination rate ($R_{50}$) and percentage in three quinoa cultivars

| Cultivars | Temperature (°C) | $R_{50}$ (1/day) | Germination (%) |
|---|---|---|---|
| Sajama | 5 | $0.010^{j}$ | $77.33^{def}$ |
| | 10 | $0.026^{ghi}$ | $73.33^{ef}$ |
| | 15 | $0.061^{d}$ | $85.33^{bcde}$ |
| | 20 | $0.072^{c}$ | $89.33^{abcd}$ |
| | 25 | $0.076^{abc}$ | $96^{ab}$ |
| | 30 | $0.075^{abc}$ | $80^{cdef}$ |
| | 35 | $0.0778^{abc}$ | $80^{cdef}$ |
| | 40 | $0.061^{d}$ | $77.3^{def}$ |
| Santamaria | 5 | $0.011^{j}$ | $80^{cdef}$ |
| | 10 | $0.019^{ij}$ | $70.66^{f}$ |
| | 15 | $0.033^{efg}$ | $92^{abc}$ |
| | 20 | $0.033^{efg}$ | $89.33^{abcd}$ |
| | 25 | $0.032^{fgh}$ | $100^{a}$ |
| | 30 | $0.037^{ef}$ | $92^{abc}$ |
| | 35 | $0.041^{e}$ | $68^{f}$ |
| | 40 | $0.022^{hi}$ | $66.3^{f}$ |
| Titicaca | 5 | $0.023^{hi}$ | $100^{a}$ |
| | 10 | $0.025^{ghi}$ | $98.66^{a}$ |
| | 15 | $0.057^{d}$ | $98.66^{a}$ |
| | 20 | $0.073^{bc}$ | $100^{a}$ |
| | 25 | $0.082^{ab}$ | $100^{a}$ |
| | 30 | $0.081^{abc}$ | $100^{a}$ |
| | 35 | $0.083^{a}$ | $97.33^{ab}$ |
| | 40 | $0.065^{cd}$ | $88^{abcd}$ |

### Determination of cardinal temperatures

For each cultivar, cardinal temperatures (*i.e.*, base, optimum, and ceiling temperatures) were estimated by fitting four regression models, as described in Table 1. For Sajama, the highest germination rate was taken place between

20.0 and 30.0 °C, demonstrating a range of optimum temperatures (Table 3). Therefore, segmented model would not be a suitable model to predict cardinal temperatures for Sajama. Parameter estimates and AICc value asserted the advantage of dent-like model over segmented one to describe germination rate with temperature and estimate cardinal temperatures parameters.

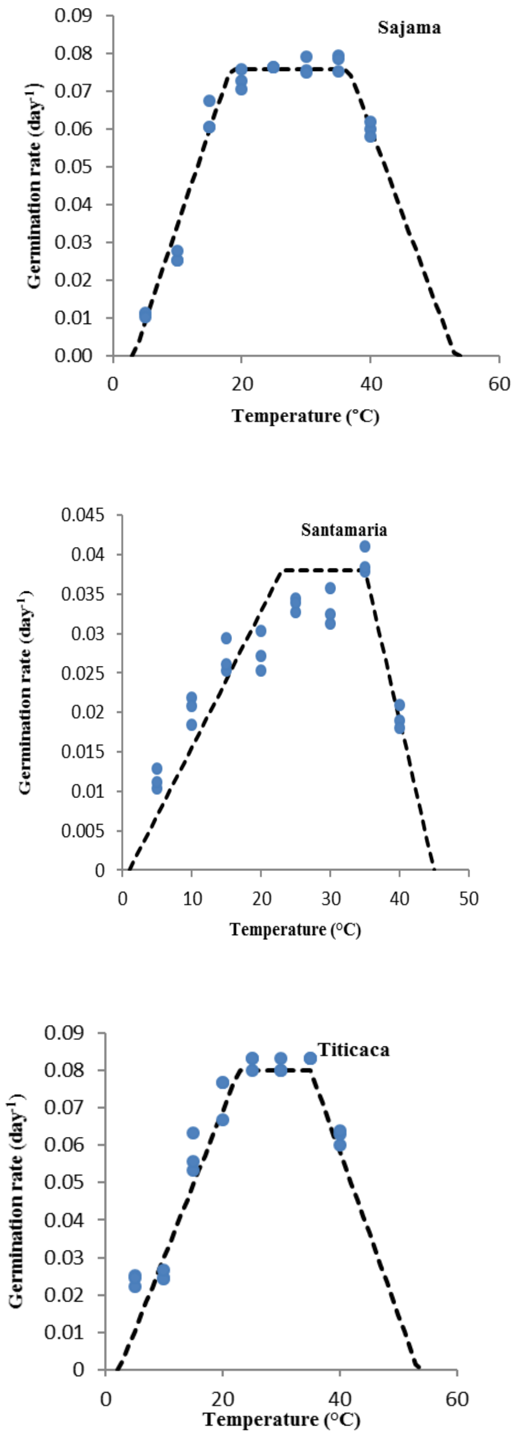


Figure 1. Germination rate of quinoa cultivars seeds as affected by increasing temperature described by dent-like model fitted to data.

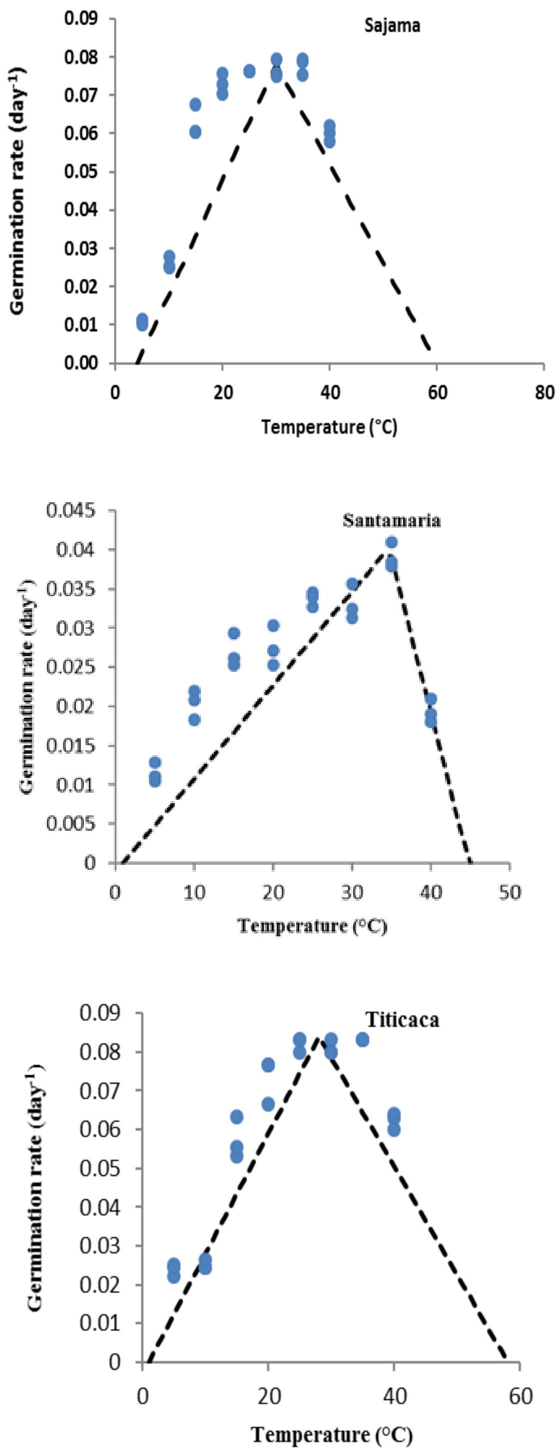


Figure 2. Germination rate of quinoa cultivars seeds as affected by increasing temperature described by segmented model fitted to data.

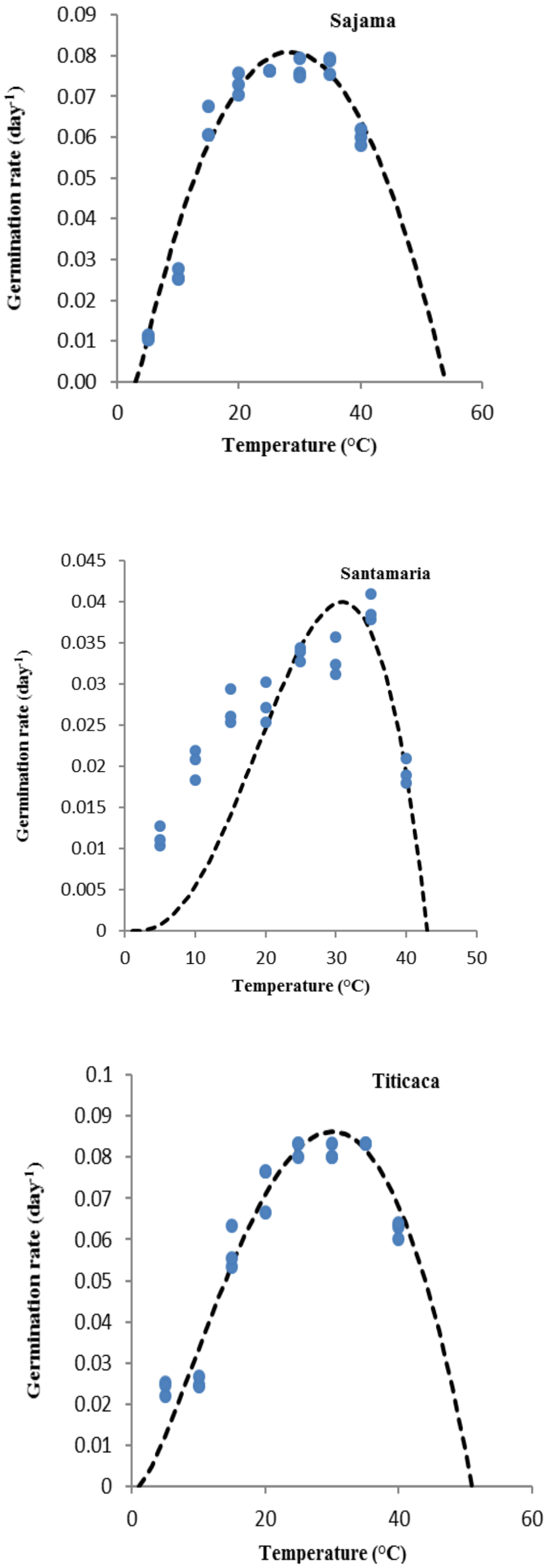


Figure 3. Germination rate of quinoa cultivars seeds as affected by increasing temperature described by beta model fitted to data

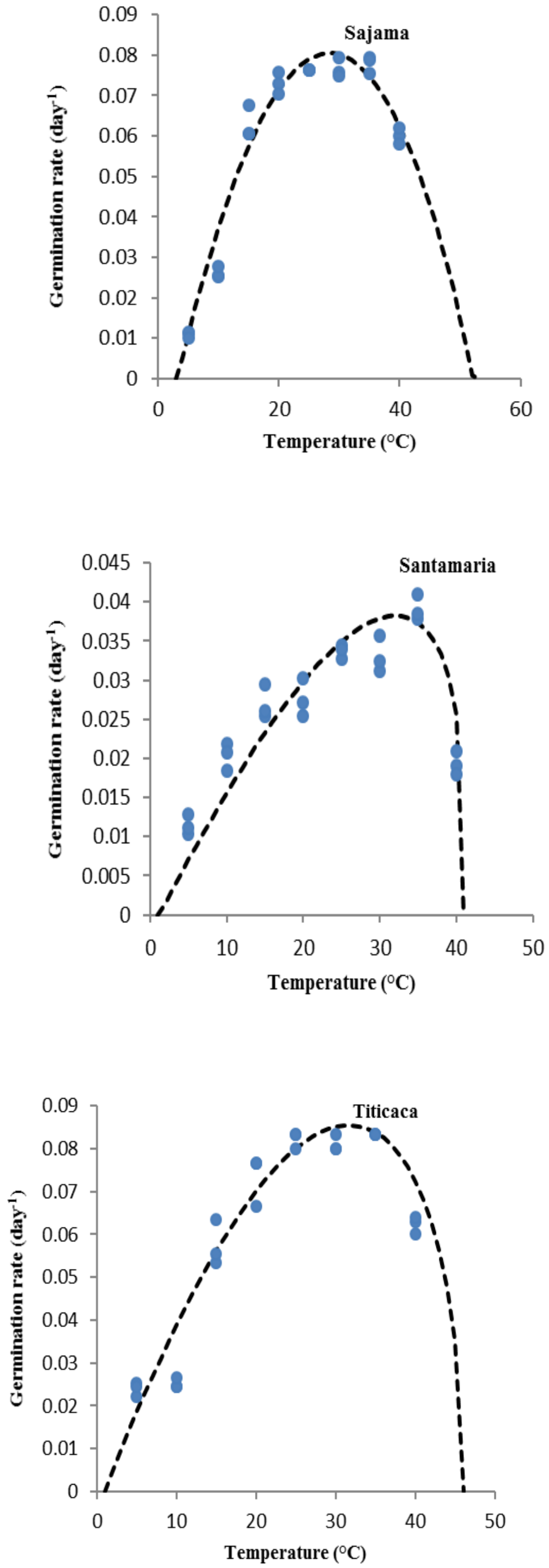


Figure 4. Germination rate of quinoa cultivars seeds as affected by increasing temperature described by modified beta model fitted to data.

Table 4. Estimated parameters of fitting the Segmented, Beta, Beta modified and Dent-like models to the germination rate of quinoa cultivars against increasing temperature. $T_b$, $T_o$, $T_c$, $T_{o1}$, $T_{o2}$, $c$, $R^2$ and RMSE are base temperature, optimum temperature, maximum temperature, lower optimum temperature, upper optimum temperature, and shape parameter, respectively. Standard error of estimates are shown in parenthesis (SE)

| Variety | Model | $T_b$ | $T_o$ | $T_c$ | $T_{o1}$ | $T_{o2}$ | $c$ | $R^2$ | RMSE | AICc |
|---|---|---|---|---|---|---|---|---|---|---|
| Sajama | Segmented | 4(±2.5) | 30(±4) | 60(±24) | _ | _ | _ | 0.60 | 0.01 | -50 |
| | Beta | 3.2(±1.3) | 26.1(±4) | 52.1(±2) | _ | _ | 1.16(±2.3) | 0.95 | 0.005 | -71 |
| | Modified Beta | 2.9(±1.4) | 30(±2.8) | 53(±1.8) | _ | _ | _ | 0.95 | 0.005 | -77 |
| | Dent-like | 2(±0.6) | _ | 53(±11) | 20(±0.53) | 36.6(±3) | _ | 0.97 | 0.004 | -73 |
| Santamaria | Segmented | 1(±2) | 34.7(±1) | 44.8(±2) | _ | _ | _ | 0.65 | 0.006 | -69 |
| | Beta | 1.2(±1.6) | 30.2(±3) | 44(±0.98) | _ | _ | 0.92(±1.1) | 0.83 | 0.004 | -77 |
| | Modified Beta | 2(±2.8) | 26(±1.4) | 52(±4.7) | _ | _ | _ | 0.70 | 0.004 | -76 |
| | Dent-like | 2(±1.9) | _ | 45(±7.3) | 24(±2) | 35(±4.5) | _ | 0.71 | 0.005 | -73 |
| Titicaca | Segmented | 1(±1.2) | 28(±1) | 58(±4.08) | _ | _ | _ | 0.90 | 0.008 | -69.7 |
| | Beta | 0.9(±1.3) | 30.2(±16) | 46(±4) | _ | _ | 0.86(±0.4) | 0.91 | 0.007 | -68 |
| | Modified Beta | 1(±5) | 30.(±8) | 51(±5) | _ | _ | _ | 0.80 | 0.01 | -59 |
| | Dent-like | 2.3(±1) | _ | 53.3(±4) | 22.8(±1.06) | 35.09(±2.3) | _ | 0.94 | 0.006 | -74 |

Based on AICc values which were used for model selection, modified beta was chosen as the best model for estimating cardinal temperatures of Sajama cultivar (Table 4). However, base temperature (2.0 to 3.0 °C) and ceiling temperature (53.0 °C) were identically estimated with beta, modified beta and dent-like models. As the modified beta showed the best fit, its estimation for optimum temperature was accepted (30.0°C). For Santamaria, the beta model was chosen as the best model for estimating cardinal temperatures. Based on parameter estimates, the base temperature would be 1.2 (±1.01) °C. Optimal temperature was estimated as 30.2 (±3) °C, and ceiling temperature would be 44.0 (±0.95) °C. For Titicaca, the dent-like model showed the best fit with the lowest AICc value (Table 4). Estimated parameters showed that the base temperature would be 2.3 (±1) °C. Optimum temperature ranged between 22 (±1.6) and 35 (±2.03) °C, and ceiling temperature was estimated as 53.3 (±4.7) °C.

## Discussion

Temperature plays a critical role in the regulation of plant vital processes such as seed germination (Bare *et al*., 1978). Each index for germination evaluation may show different responses to germination. As shown above, for all the quinoa cultivars, germination rate was more susceptible versus temperature. Total germination in Titicaca did not vary between the temperatures of 5.0 and 35.0 °C, suggesting a wide optimum temperature range for this cultivar. Range of optimum temperature was consistently reported in the earlier literatures (Tabrizi *et al*., 2004), albeit, the width of optimum temperature in quinoa was highly significant.

Estimated parameters suggested significant differences in germination response to temperature among the cultivars under study. Because of higher germination rate of Titicaca and Sajama in low and high temperatures, the base and ceiling temperatures were predicted at about 2.0 and 53.0, respectively, suggesting the germination capability of these cultivars in a wide range of environmental temperatures. As a complimentary test, we made a germination test for the Titicaca and Sajama at the temperature of 46.0 °C. Germination at this high temperature is not expected to occur at high rates. For example, it has been reported that the low germination of *Bidens pilosa* occur at temperature 45.0 °C (Reddy *et al*., 1992). It has been also reported that, *Cuscuta campestris* had the germination until 40.0 °C, while with increasing temperature up to 45.0 °C, the germination failed (Sarić-Krsmanović *et al*., 2013). The relatively high germination of quinoa cultivars from 5.0 to 40.0 °C suggested the capability of quinoa to survive under cold and hot environments.

Information about cardinal temperatures for germination is important in predicting areas of distribution of plant species (Singh *et al*., 2008). Exposure to any temperature beyond the optimum temperature range for germination can negatively affect seed germination. Maintaining high germination rate at non-optimum temperatures suggested the survival capability of plant species in varying temperature environments (Finch-Savage *et al*., 2006). Base temperatures of three cultivars were in the range of 1.0 to 3.3ºC, indicating that *C. quinoa* can germinate at low temperatures. This is an advantage for this plant species to germinate prior to other competitive species, so they would be successful in competition with neighboring plants (Kamkar *et al*., 2012). Such observations suggested the efficiency of using cardinal temperatures for predicting plant responses to to environmental factors. This is also used for prediction of the geographical areas where a species or genotype can germinate and establish successfully. Another interesting behavior of *C. quinoa* cultivars was their wide optimum temperatures. These results suggested that *C. quinoa* cultivars can reach their maximum germination under various environmental temperatures. An optimum condition for germination of *C. quinoa* could be ranged from a temperate environment (*i.e.*, 18-23 ºC) to a relatively hot soil temperature (*i.e.*, 35-36 ºC).

As the *C. quinoa* cultivars were different in germination response to temperature, an identical model was not suitable for describing germination rate. Therefore, for each variety, an especial model was used. Saeidnejad *et al*., (2012) reported various responses of *Bunium persicum* cultivars to temperature and subsequently suggested that the difference is mostly related to the genetic disparities among cultivars. Furthermore, Tolyat *et al*. (2014) reported differences between ecotypes of *Thymus daenensis* in response to temperature. Regarding *Silybum marianum* L., four nonlinear regression models (*i.e*., segmented, beta, beta modified, and dent-like) were used at six constant temperatures to describe the germination rate-temperature relationships, with the aim of identifying the cardinal temperatures and the beta model was evaluated as the best model (Parmoon *et al*., 2015).

**Conclusions**

The current study showed the differences among all the three *C. quinoa* cultivars in response to temperature. Therefore, for Titicaca and Sajama cultivars, the beta modified model and for the Santamaria cultivar the beta model were found more likely to describe the germination response to temperature. The main difference was found in ceiling temperature and the width of optimum temperature range. As a result, different models were used to describe specific behavior of each *C. quinoa* variety with increasing temperature. *C. quinoa* was found very tolerant to temperature, as was capable to germinate in a wide temperature ranges. Germination at very low temperatures (around 2.0 ºC) and very hot conditions (>46.0 ºC as observed, and more than 50.0 ºC as model predicted) indicates its tolerance and survival abilities under various environmental temperatures.

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