Scientific article

Estimating base temperature and thermal time requirement for chickpea (*Cicer arietinum* L.) emergence

Estimación de la temperatura base y el requerimiento térmico para la emergencia de garbanzo (*Cicer arietinum* L.)

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Abstract

In order to reach different growth stages, crops have a certain thermal time requirement, which includes mean ambient temperature and developmental base temperature (Tb). Calculating Tb allows estimating growing degree days (GDD) more precisely. This work aimed to determine the Tb and GDD required for cv. Norteño chickpea (*Cicer arietinum* L.) sowing-emergence stage. Pot and field trials were conducted to obtain and validate data. From July to December 2016, 15 pots were planted on each date, and 5 seeds per pot. In the field, they were planted on 6/4 and 6/19 of 2015, 4/15, 5/23, 6/14, 7/7, and 8/5 of 2016 in plots following a completely randomized design with 4 replications. Phenological records were kept daily. To estimate Tb, mathematical formulae of classical statistical methods were used: the coefficient of variation in GDD (CV_{GDD}), the regression coefficient (RC), and the lowest standard deviation (SD_{GDD}). Tb amounted to 3.75, 3.92, and 4.79°C, and GDD values for the sowing-emergence stage were 137.26, 135.57, and 126.93°C/d, respectively, as obtained with the CV_{GDD}, RC and SD_{GDD} methods. In order to validate these data, the refined index of agreement, the root mean square error, and the coefficient of determination were calculated. The parameters considered showed that the methods were adequate to predict the emergency, with SD_{GDD} being the most accurate at estimating Tb and GDD, which turned out to be 4.79°C and 126.93°C/d, respectively.

Keywords: Base temperature; Chickpea; Thermal time.

Resumen

Los cultivos presentan un determinado requerimiento térmico para alcanzar las diferentes etapas de desarrollo, que involucra la temperatura media ambiente y el valor de la temperatura base (Tb) de desarrollo. El cálculo de Tb, permite una estimación más precisa de grados días de desarrollo (GDD). El objetivo de este trabajo fue determinar la Tb y los GDD que caracterizan la etapa Siembra-Emergencia en garbanzo (*Cicer arietinum* L.), cv. Norteño. Para determinar y validar los datos se realizaron ensayos en maceta y a campo. Se sembraron desde los meses de julio a diciembre de 2016, 15 macetas en cada fecha, y 5 semillas por maceta, y a campo se sembraron los días 4/6 y 19/6 del 2015, 15/4, 23/5, 14/6, 7/7, y 5/8 del 2016 en parcelas siguiendo un diseño completamente aleatorizado con 4 réplicas. El registro fenológico se realizó diariamente. Para estimar la Tb se utilizaron fórmulas matemáticas, que derivan de la metodología estadística clásica: coeficiente de variación en GDD (CV_{GDD}), coeficiente de regresión (CR), y menor desvío estándar (SD_{GDD}). La Tb estimada fue de 3,75; 3,92 y 4,79°C, y los valores de GDD referidos al período siembra-emergencia fueron 137,26; 135,57; y 126,93°C/días respectivamente, obtenidos con los métodos de CV_{GDD}, CR y SD_{GDD}. Para la validación de los datos se calculó el índice refinado de adecuación, la raíz del error cuadrático medio y coeficiente de determinación lineal. Los parámetros considerados indicaron que los métodos son aceptables para predecir la emergencia, siendo el método de SD_{GDD} el más preciso para estimar la Tb y los GDD, con un valor de 4,79°C y 126,93°C/días respectivamente.

Palabras clave: Temperatura base; Garbanzo; Requerimiento térmico

Introduction

In Argentina, the area sown with chickpeas (kabuli type) was increasing since 2006, and so have chickpea exports (Espeche *et al.*, 2015). It is worth noting that Argentina has access to 13 of the 15 main chickpea importation markets in the world, which demonstrates that its product is highly accepted worldwide. Nevertheless, there is not a wide range of varieties available in the country. Chañarito S-156 and Norteño were the only ones for very long, until Kiara, Felipe, TUC 403 and TUC 464 cultivars were registered, with the first two being the most exploited commercially

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(Espeche *et al.*, 2015).

As an environmental factor, temperature is considered one of the main conditions influencing the growth and development of crops, and thus their yield. Crops require specific thermal time as they go through different growth stages, and these have to do with mean ambient temperatures and developmental base temperature values (Tb) (Luo, 2011; Salazar-Gutierrez *et al.*, 2013; Parra Coronado *et al.*, 2015; Zapata *et al.*, 2015).

The physiological Tb of a crop is the temperature at which there is no development, i.e. when crop growth rate equals zero. A correct calculation of Tb enables a more accurate estimation of growing degree days (GDD), which constitutes useful information for predicting phenological phases (Verghis *et al.*, 1999; Saiyed *et al.*, 2009; Pacheco de Souza *et al.*, 2011; Bouzo and Küchen, 2012).

Yang *et al.* (1995) suggest that Tb values statistically estimated would be the ones that present the lowest variation in thermal time requirement, measured GDD required for a crop to reach its different phenological phases.

It was observed that chickpea growth rate speeds as temperature rises (Roberts *et al.*, 1985), and that temperature (Ellis *et al.*, 1986), soil humidity (Saxena *et al.*, 1990), and sowing depth (Soltani *et al.*, 2006) are among the most influential factors regulating the duration of the sowing-emergence stage. A rapid, uniform and complete emergence of seedlings leads to a reduction in the time that elapses between sowing and full soil coverage by the crop, which results in an optimal canopy structure and a maximized crop yield (Soltani *et al.*, 2006).

Several studies considering specific agroecological areas (different from those in our country) and different chickpea varieties (desi and kabuli) reported Tb values ranging from 0°C to 8°C (Ellis *et al.*, 1986; Singh, 1991; Verghis *et al.*, 1999; Soltani *et al.*, 2006).

However, there is no information about Tb values and GDD for the sowing-emergence stage of chickpea varieties sown in Argentina.

This work aimed to establish both the Tb and GDD of the sowing-emergence stage of cv. Norteño chickpea.

Materials and methods

The trials described in this paper were conducted in an experimental field at Finca El Manantial, Faculty of Agronomy and Zootechnics (FAZ), National University of Tucumán (Tucumán province, Argentina) (26º 50’ 6.9’’ S – 65º 16’ 44.6’’ W). This field is located in the subhumid-humid central plain region, which has a monsoon subhumid-humid subtropical climate with a dry season. In the region, the average annual precipitation rate amounts to 950 mm, and mean annual temperature reaches 19.7ºC. Frosts are scarce and have low intensity (Torres Bruchmann, 1973).

The soil is Typic Argiudoll, silty loam in the upper 80 cm of the soil profile, with a moderately developed fine granular structure, a pH of 6.4, a 2.5-3.5% organic matter content, an bulk density of 1.23 g/cc, an electrical conductivity of 1.11 dS/m, and a 31.7% gravimetric moisture at field capacity (We_{cc}).

Daily maximum and minimum temperature data were obtained with an automatic Davis Vantage Pro2 weather station with wireless transmission, located 500 meters from the experimental site.

Kabuli chickpea seeds of cv. Norteño (100-seed weight 45 g) were used. This cultivar is characterized by being an erect and late season variety (Carreras, 2014), with a 75% germinating power. The seeds were treated with Carbendazim + Thiram (625 cc/100 kg seeds) and inoculated with *Mesorhizobium ciceri* (200 cc/50 kg seeds).

Estimation of Tb and GDD

Chickpea seeds were sown in pots from July to December 2016, at different dates: 7/7, 8/9, 8/20, 9/1, 10/11, 11/4, 11/14 and 12/5. These dates were selected so as to analyze seedling emergence under various thermal conditions. The pots were placed in the field (without any type of shelter), in the experimental site.

Black 5-litre polyethylene pots (27 cm tall, with a 15 cm diameter) were filled with superficial soil from the experimental field (upper 15 cm of the soil profile), keeping a similar bulk density to the original. The seeds were sown 5 cm deep. On the basis of We_{cc} value, it was possible to keep pot water levels close to field capacity at all the dates, using their weight as reference.

At each sowing date (S), 15 pots were sown with five seeds each. Phenological records were kept every day, considering that seedlings had reached emergence stage (E) when they exhibited an elongated plumular hook above the ground. Each replication reached emergence stage when 50% or more (D_{50}) of all the seedlings emerged in the pots (Fehr and Caviness, 1977). Days required for D_{50} were recorded for the 15 replications, and their average values were calculated for each sowing date. Final emergence percentage was determined by dividing the total number of emerged seeds by the total number of sown seeds.

In order to estimate Tb, the procedure proposed by Yang *et al.* (1995) was followed. These authors suggested using different mathematical formulae which derive from commonly used statistical methods (Pacheco de Souza *et al.*, 2011; Salazar Gutierrez *et al.*, 2013; Parra-Coronado *et al.*, 2015; Zapata *et al.*, 2015).

The above mentioned formulae are the following:

Coefficient of variation in GDD (CV_{GDD}):

$$Tb = \frac{\sum_{i=1}^{n} T_i d_i^2 \sum_{i=1}^{n} T_i d_i - \sum_{i=1}^{n} d_i \sum_{i=1}^{n} T_i^2 d_i^2}{\sum_{i=1}^{n} d_i^2 \sum_{i=1}^{n} T_i d_i - \sum_{i=1}^{n} d_i \sum_{i=1}^{n} T_i d_i^2} \quad (1)$$

Regression coefficient (RC):

$$Tb = \frac{\sum_{i=1}^{n} T_i \sum_{i=1}^{n} d_i T_i - n \sum_{i=1}^{n} d_i T^2}{\sum_{i=1}^{n} d_i \sum_{i=1}^{n} T_i - n \sum_{i=1}^{n} d_i T_i} \quad (2)$$

Lowest standard deviation in GDD (SD_{GDD}):

$$Tb = \frac{\sum_{i=1}^{n} T_i d_i \sum_{i=1}^{n} d_i - n \sum_{i=1}^{n} d_i^2 T_i}{\left(\sum_{i=1}^{n} d_i\right)^2 - n \sum_{i=1}^{n} d_i^2} \quad (3)$$

where Tb is base temperature, T_i is the average mean temperature at the sowing date (i), d_i is the average number of days the replications took (i) to reach emergence stage, and *n* being the number of sowing dates.

Mean daily temperature (Tm) was calculated using equation (4).

$$Tm = \frac{T_{max} + T_{min}}{2} \quad (4)$$

where Tmax and Tmin are daily maximum and minimum temperatures recorded during the growth stage considered.

The GDD of the S-E stage were determined with the following equation:

$$GDD = Tm - Tb \quad (5)$$

where GDD are the growing degree days, Tm is the mean daily temperature recorded in the S-E stage, and Tb is the developmental base temperature. Accumulated GDD (∑GDD) equal the sum of all the GDD recorded for the S-E stage. In order to estimate GDD accurately, it was considered that if daily minimum temperature were lower than Tb, the former would be replaced in equation (4) with the latter (McMaster and Wilhelm, 1997).

Validation of calculation methods

Chickpea (cv. Norteño) seeds were sown in plots in the experimental site. Sowing took place on 6/4 and 6/19 (2015), and 4/15, 5/23, 6/14, 7/7, and 8/5 (2016). Seeds were hand sown at 5 cm depth, with a density of 26 plants/m². Plot arrangement corresponded to a completely randomized design with 4 replications, consisting of six 13 m long rows, spaced 0.5 m apart. The plots were kept without water limitations, and weeds were controlled with hand tools and herbicides. Insecticides were also applied to maintain plant density. The plants were evaluated phenologically every day, following the same criterion as in the pot trial. The number of days that elapsed till D_{50} was recorded for each replication, considering three 0.5 m subsamples selected at random in each replication.

The results in this study were validated by predicting the number of days for the field trial on the basis of the Tb and ∑GDD values obtained in the pot trial, with the mean temperature value of the field trial being the variable for emergence. Assuming that Tb and ∑GDD are independent from temperature, equation (6) was used, as suggested by Trudgill *et al.* (2005).

$$Duration = \frac{\sum GDD}{(Tm - Tb)} \quad (6)$$

Where duration corresponds to predicted days, ∑GDD and Tb stand for accumulated growing degree days and base temperature estimated for the pot trial, and Tm is the mean temperature recorded in the S-E stage of the field trial.

Data analysis

The data obtained in this study were analyzed with InfoStat software (Di Rienzo *et al.*, 2017). Analysis of variance, general and linear mixed models and the DGC test for means comparisons (Di Rienzo *et al.*, 2002) were used ($\alpha = 0.05$). The corresponding assumptions were verified.

A linear regression analysis between the observed days and those predicted was run, so as to evaluate the fit and performance of the models as prediction tools.

The data were validated by calculating the refined index of agreement (dr) proposed by Willmott *et al.* (2012), as well as the root mean square error

(RMSE) and the coefficient of determination (R^2).

Results

Environmental conditions

Maximum, minimum and mean temperatures recorded during the pot trial are shown in Figure 1. Maximum temperatures ranged from 15.8°C (7/8) to 37.9°C (12/25), and minimum ones varied between 0.9°C (9/6) and 20.7°C (12/26). In no case were germination conditions triggered at a temperature above the one considered critical (Tc = 40 °C) for chickpeas (Soltani *et al.*, 2006).

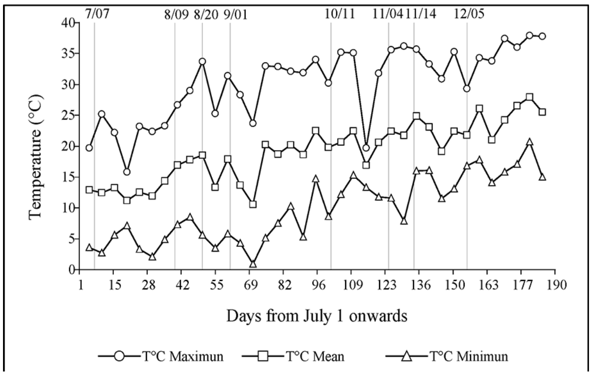

Figure 1. Maximum, minimum and mean temperatures recorded during the trial (from July to December 2016), in Finca El Manantial, Tucumán, Argentina. The dotted lines represent the eight sowing dates evaluated.

Determination of Tb and GDD

As can be observed in Table 1, the selected sowing dates corresponded to significantly different temperature conditions ($F = 5669.04$; $df_{error} = 102$; $P < 0.0001$). Significantly fewer days were required for D_{50} ($F = 131.04$; $df_{error} = 102$; $P < 0.0001$) as mean temperature increased. D_{50} took 6.45 ± 0.33 days when the sowing date was November 4, and the mean temperature recorded for the S-E stage in this case was 24.95°C ± 0.07 °C. When the sowing date was July 7, the values were 12.17°C ± 0.04 °C for mean temperature, and 16.40 ± 0.28 days for D_{50}. This shows how the selected sowing dates presented different mean temperatures in the S-E stage, which affected the number of days necessary for D_{50} (Table 1).

Regarding final emergence stage, no significant differences ($F = 1.23$; $df_{error} = 102$; $P = 0.2945$) were found among the different sowing dates, which indicates that there is an independence between the final number of germinated seeds and the range of temperatures recorded during the S-E stage (Table 1).

The Tb values estimated with equations (1), (2) and (3), which derive from the CV_{GDD}, RC and SD_{GDD} methods were 3.75, 3.92 and 4.79°C, respectively (Table 2).

The GDD values for the S-E stage are displayed in Table 2. This stage required 137.26 ± 4.53, 135.57 ± 4.48 and 126.93 ± 4.30 °C/d, calculated with the Tb values obtained with the CV_{GDD}, RC and SD_{GDD} methods, respectively. The sowing dates December 5 and October 11 were the ones that presented the lowest and highest requirement in °C/d, respectively, regardless of the method used for calculations. The three methods presented similar values for coefficient of variation and standard error (Table 2).

When assessing the fit between predicted days and observed days to emergence in the pot trial, it was observed that in the three methods used the regression coefficient β was significantly different from 0 (Table3) (CV_{GDD}: $T = 24.61$; $df_{error} = 108$; $P < 0.0001$; RC: $T = 24.60$; $df_{error} = 108$; $P < 0.0001$; and SD_{GDD}: $T = 24.48$; $df_{error} = 108$; $P < 0.0001$). By contrast, the regression coefficient α was not significantly different from 0 with the SD_{GDD} method (CV_{GDD}: $T = 4.07$; $df_{error} = 108$; P

Table 1. Mean values and standard error of: mean temperature in the S-E stage; median time of seedling emergence (D_{50}); and final emergence percentage.

Sowing dates	Mean T (°C)	D_{50} (days)	Final E (%)
July 7	12.17 ± 0.04 a	16.40 ± 0.28 f	78.67 ± 5.46 a
August 9	18.00 ± 0.15 d	10.27 ± 0.28 d	80.00 ± 5.46 a
August 20	15.50 ± 0.02 c	10.60 ± 0.28 d	70.67 ± 5.46 a
September 1	15.01 ± 0.05 b	12.87 ± 0.28 e	78.67 ± 5.46 a
October 11	21.67 ± 0.12 f	8.87 ± 0.28 c	77.33 ± 5.46 a
November 4	24.95 ± 0.07 h	6.45 ± 0.33 a	70.91 ± 6.37 a
November 14	20.61 ± 0.06 e	7.42 ± 0.32 b	61.67 ± 6.10 a
December 5	22.17 ± 0.11 g	6.58 ± 0.32 a	68.33 ± 6.10 a

Means with the same letter in the same column are not significantly different according to the DGC test ($P > 0.05$).

Table 2. Determination of ∑GDD and Tb with the methods used in this study. $\sum GDD_{mean}$: mean value of growing degree days accumulated at each sowing date (°C/d); $\sum GDD_{vmt}$: total mean value of growing degree days accumulated according to each calculation method (°C/d); Tb: base temperature (°C); s.e: standard error; CV%: coefficient of variation.

Estimated variables	Sowing dates	Calculation methods used		
		CV_{GDD}	RC	SD_{GDD}
Tb		3.75	3.92	4.79
∑GDDmean ± s.e.	July 7	140.69 ± 3.62	137.90 ± 3.53	123.63 ± 3.31
	August 9	145.43 ± 3.62	144.24 ± 3.53	135.31 ± 3.31
	August 20	124.45 ± 3.62	122.65 ± 3.53	113.43 ± 3.31
	September 1	144.99 ± 3.62	142.80 ± 3.53	131.61 ± 3.31
	October 11	158.48 ± 3.62	156.97 ± 3.53	149.26 ± 3.31
	November 4	136.93 ± 4.22	135.83 ± 4.12	130.22 ± 3.87
	November 14	124.94 ± 4.04	123.68 ± 3.95	117.23 ± 3.70
	December 5	121.62 ± 4.04	120.50 ± 3.95	114.77 ± 3.70
∑GDDtmv		137.26 ± 4.53	135.57 ± 4.48	126.93 ± 4.30
CV%		9.34	9.36	9.59

Table 3. Evaluation of the fit of the calculation methods used in this study. Mean values and standard error of: mean temperature for the Oi recorded for each sowing date (°C); Oi: days that elapsed between S and E, as observedin the pot trial; Pi: days predicted by means of each method.

Sowing dates	Mean T (°C)	Oi (days)	Pi (days)		
			CV_{GDD}	RC	SD_{GDD}
July 7	12.17 ± 0.04	16.4 ± 0.40	16.3 ±0.07	16.4 ± 0.08	17.2 ± 0.09
August 9	18.07 ± 0.15	10.3 ± 0.45	9.6 ± 0.11	9.6 ± 0.12	9.6 ± 0.12
August 20	15.50 ± 0.02	10.6 ± 0.21	11.7 ± 0.02	11.7 ± 0.02	11.9 ± 0.02
September 1	15.01 ± 0.05	12.9 ± 0.17	12.2 ± 0.05	12.2 ± 0.05	12.4 ± 0.06
October 11	21.67 ± 0.12	8.9 ± 0.24	7.7 ± 0.05	7.6 ± 0.05	7.5 ± 0.05
November 4	24.95 ± 0.07	6.5 ± 0.16	6.5 ± 0.02	6.4 ± 0.02	6.3 ± 0.02
November 14	20.61 ± 0.06	7.4 ± 0.19	8.1 ± 0.03	8.1 ± 0.03	8.0 ± 0.03
December 5	22.17 ± 0.11	6.6 ± 0.31	7.5 ± 0.04	7.4 ± 0.04	7.3 ± 0.04

= 0.0001; RC: T = 3.68; df_{error} = 108; P = 0.0004; and SD_{GDD}: T = 1.65; df_{error} = 108; P = 0.1022). When analyzing the RMSE, R^2 and refined index of agreement (dr) values obtained by using the observed and predicted values, it was observed that the three methods had an adequate fit (Figure 2).

Validation of results

The regression coefficient β between days observed (Oi) and the ones predicted (Pi) in the field trial was significantly different from zero in all the cases (CV_{GDD}: T = 9.94; df_{error} = 26; P < 0.0001; RC: T = 9.96; df_{error} = 26; P < 0.0001; and SD_{GDD}: T= 10.06; df_{error} = 26; p < 0.0001). By contrast, the regression coefficient α was not significantly different from 0 with the RC and SD_{GDD} methods (CV_{GDD}: T = 2.11; df_{error} = 108; P = 0.0451; RC: T = 1.92; df_{error} = 108; P = 0.0649; and SD_{GDD}: T = 1.03; df_{error} = 108; P = 0.3102). Oi ranged from 7.5 to 17.7 days to reach E, in relation to the mean temperature recorded in the S-E stage. Pi reached values of 8.4, 8.4 and 8.3 days with the highest mean temperature, and 17.4, 17.6 and 18.6 days with the lowest one as obtained with the CV_{GDD}, RC and SD_{GDD} models, respectively. R^2 and RMSE values indicated that the evaluated methods had a satisfactory fit (Table 4). The refined index of agreement (dr) led to values within the parameters suggested by its author, which demonstrated that the methods were acceptable (Table 4).

Coefficient β presented a value closest to 1, whereas coefficient α was closest to 0 in the equation obtained with the SD_{GDD} method (Figure 3), showing that Pi varied almost constantly in relation to Oi, within the temperature range considered (Table 4). Hence, the SD_{GDD} method can be held as the most accurate at estimating Tb and GDD, and at predicting these values for emergence.

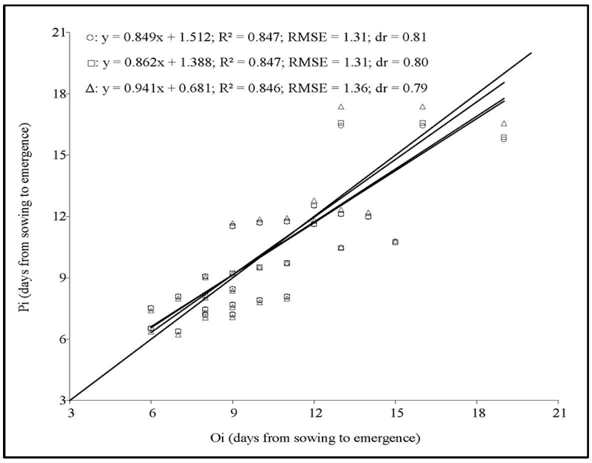

Figure 2. Evaluation of the fit of the methods used in this study. Regression between observed days (Oi) and those predicted (Pi) to emergence in the pot trial. The equation of fit is presented. R^2 is the coefficient of determination, RMSE: root mean square error, dr: refined index of agreement, regression coefficients β and α (slope and ordinate at origin). The solid line represents the equation of $PiSD_{GDD}$, whereas the dashed and dotted lines correspond to the $PiCV_{GDD}$ and PiRC, respectively. The line starting at the origin corresponds to the 1:1 line.

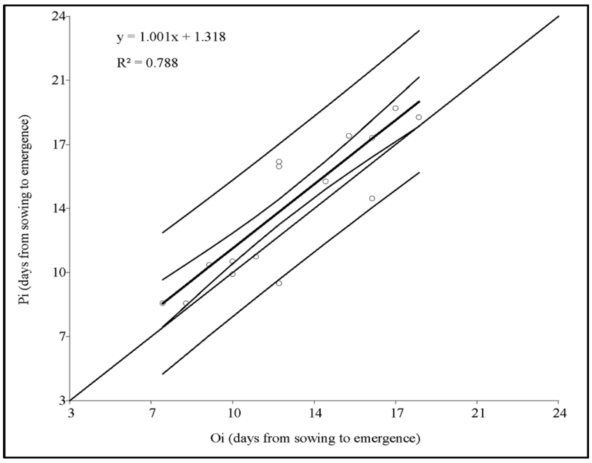

Figure 3. Validation of the method used for prediction with independent data. Regression between observed days (Oi) and those predicted (Pi) to emergence with the SD_{GDD} method in the field trial. The equation of fit is presented. R^2 is the coefficient of determination. The solid line represents the equation of best fit, whereas the dashed and dotted lines correspond to the confidence interval and the prediction limits, respectively, both with a 95% level of certainty. The line starting at the origin corresponds to the 1:1 line.

The overestimation of predicted and observed values (Figure 3) could be due to differences in sowing depth in the field trial, since it was difficult to keep it constant, in contrast to what happened in the pot trial, where sowing depth was always 5 cm. In addition, the soil of the pots would quickly adopt the ambient temperature, in comparison to the soil of the sowing bed, due to the smaller volume of the same content in the pots.

Discussion

Seedling emergence and establishment are probably the most important events determining whether an annual crop successfully develops or not (Hosseini *et al.*, 2009). This work led to the observation that the number of days necessary for chickpeas to reach emergence varied between 6 and 16 days, depending on ambient temperature.

Table 4. Validation of the methods used for prediction with independent data. Mean values and standard error (s.e.) of: Mean T°C: mean temperature for the Oi recorded for each sowing date (°C); Oi: days that elapsed between S and E, as observed in the field trial; Pi: days predicted by means of each method. RMSE: root mean square error, dr: refined index of agreement, R^2: coefficient of determination, regression coefficients β and α (slope and ordinate at origin).

Sowing dates	Mean T (°C)	Oi (days)	Pi (days)		
			CV_{GDD}	RC	SD_{GDD}
4-Jun-15	16.79 ± 0.12	9.8 ± 0.48	10.5 ± 0.10	10.5 ± 0.10	10.6 ± 0.11
19-Jun-15	13.12 ± 0.27	13.5 ± 0.96	14.7 ± 0.42	14.7 ± 0.43	15.3 ± 0.48
15-Apr-16	20.03 ± 0.01	7.5 ± 0.29	8.4 ± 0.01	8.4 ± 0.01	8.3 ± 0.01
23-May-16	12.83 ± 0.01	12.0 ± 0.01	15.1 ± 0.01	15.2 ± 0.01	15.8 ± 0.01
14-Jun-16	11.62 ± 0.04	17.7 ± 0.25	17.4 ± 0.10	17.6 ± 0.10	18.6 ± 0.12
7-Jul-16	12.08 ± 0.01	15.5 ± 0.29	16.5 ± 0.02	16.6 ± 0.02	17.4 ± 0.03
5-Aug-16	17.78 ± 0.17	10.5 ± 0.50	9.8 ± 0.11	9.8 ± 0.12	9.8 ± 0.12
RMSE			1.785	1.830	2.159
dr			0.755	0.750	0.908
R^2			0.784	0.784	0.788
β			0.877 ± 0.09	0.895 ± 0.09	1.001 ± 0.10
α			2.378 ± 1.13	2.219 ± 1.15*	1.318 ± 1.27*

(*) indicates that β and α were not significantly different from 0 (P > 0.05).

Low temperatures are unfavorable for the crop, as they extend S-E stage duration and make wilt and *Rhizoctonia* (*Rhizoctonia solani*) root rot more likely to occur (Hwang *et al.*, 1998). Moreover, if seeds are exposed to similar conditions, emergence might be delayed and seedlings might turn out to be less vigorous (Gan *et al.*, 2002).

Soltani *et al*. (2006) found that four kabuli chickpea varieties grown under temperatures ranging between 20°C and 29°C took 5-6 days to germinate, which coincides with the findings of this work: 6.4 days were required for germination when mean temperature was 24.9°C. However, in contrast to what was reported by these researchers, the present study recorded no significant differences in final emergence percentage with the range of temperatures considered in the trial.

As for other varieties, Verghis *et al.* (1999) found that Hernández chickpea variety (kabuli type) required 19 days for 50% germination to occur at a mean temperature of 12.8°C. Similarly, Gan *et al.* (2002) reported that Sanford variety needed 18 days to reach 50% germination at a mean temperature 12.6°C, which agrees with what was observed for Norteño cultivar in this study.

Also, in agreement with the results presented in this paper, Hosseini *et al.* (2009) found that both desi and kabuli genotypes needed 5-7 days to germinate in soils at field capacity, and under a temperature regime of 22/15°C (daytime/night-time).

In this work, a Tb of 4.79°C was estimated for cv. Norteño. Similar Tb values were reported for four kabuli chickpea varieties (Tb = 4.5°C) by Soltani *et al.* (2006), and for Hernández variety (Tb = 4°C) by Verghis *et al.* (1999). By contrast, Singh (1991) used a Tb of 8°C to calculate the thermal requirements of the E-flowering stage. On the other hand, Ellis *et al.* (1986) found a Tb value of 0°C when studying two desi chickpea varieties and three of the kabuli type.

The GDD value required for emergence was 126.93°C/d, similar to what was reported by Verghis *et al.* (1999) for Hernández variety (133°C/d), but different from the values published by Soltani *et al.* (2006) (94°C/d) and Gan *et al.* (2002) (110°C/d), who used an alternative methodology for GDD and Tb calculations.

Conclusion

The results of the present study suggest that cv. Norteño chickpea has a base temperature of 4.79°C and a thermal time requirement of 126.93°C/d for emergence. Using the developed thermal time model, it is possible to make an adequate choice of the sowing date based on the air temperature, and achieve an early emergence and a correct establishment of the crop.

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