

## Scientific article

**Influence of thermal factor on chickpea (*Cicer arietinum* L.) development, yield and yield components****Influencia del factor térmico en el desarrollo, rendimiento y componentes de rendimiento en garbanzo (*Cicer arietinum* L.)**

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**Abstract**

In Argentina, chickpea (*Cicer arietinum* L.) sowing date may take place any time between April and June, with crop yield ranging from 1200 to 3000 kg/ha. The distinct environmental scenarios that are set up by different sowing dates exert an important influence on the development of the phenological phases, the behavior of yield components, and yield. Temperature stands out as one of the main factors causing these variations, as its behavior changes over time and space. The impact of the thermal factor on the phenology, yield components, and yield of chickpea crops grown without water constraints was evaluated in a trial with a completely randomized design with 4 replications, where sowing dates were April 15, June 14, July 7, and August 5 (year 2016). Yield components and yield were assessed prior to harvest, and an index of adverse temperature events (IATE) was created to measure the severity and duration of such events. Significant differences were observed in the duration and occurrence of phenological phases, yield components, and yield, as well as in accumulated IATE values. Crops sown on April 15 presented higher seed weight and number, collected from more abundant branches with fewer pods, but with a higher number of large caliber seeds. Later sowing dates led to significant yield reductions.

**Key words:** Chickpea; Phenology; Temperature; Yield component.

**Resumen**

En Argentina la fecha de siembra del garbanzo (*Cicer arietinum* L.) puede variar de abril a junio, con rendimientos que oscilan entre 1200-3000 kg/ha. Los diferentes escenarios ambientales ocasionados por las distintas fechas de siembra, producen variaciones importantes en la ocurrencia de las etapas fenológicas, en el comportamiento de los componentes del rendimiento y en el rendimiento. Entre las causas de estas variaciones se destaca el efecto de la temperatura por su comportamiento heterogéneo en el tiempo y espacio. El objetivo de este artículo fue evaluar la influencia del factor térmico sobre la fenología, los componentes de rendimiento y el rendimiento del garbanzo, cultivado sin restricciones hídricas. Se realizó un ensayo siguiendo un diseño completamente aleatorizado con 4 repeticiones. Las siembras fueron el 15/04, 14/06, 07/07, y 05/08 del 2016. A cosecha se analizaron los componentes de rendimiento y el rendimiento. Para cuantificar la severidad y duración de los episodios con temperaturas adversas se generó el índice de episodio con temperaturas adversas (IETA). Se observaron diferencias significativas en los resultados de la duración y ocurrencia de las etapas fenológicas, en los componentes de rendimiento, en el rendimiento y en los valores acumulados de IETA. Se destacó la siembra del 15/04 con plantas que presentaron mayor peso y número de semillas, soportadas en un mayor número de ramas portadoras de un menor número de vainas y un mayor número de semillas de calibres grandes. El retraso de la siembra disminuyó significativamente el rendimiento del cultivo.

**Palabras clave:** Garbanzo; Fenología; Temperatura; Componente de rendimiento.

**Introduction**

In Argentina, kabuli type chickpea (*Cicer arietinum* L.) represents an alternative to wheat, since under adequate environmental conditions the crop yields 1200 to 3000 kg/ha, levels notably higher than the international average of 700-900 kg/ha (Carreras *et al.*, 2016). Among the cultivars available in the country, Norteño is one of the most

widely grown on account of its yield and good seed size.

In the last few years, the activities related to this crop have been intensified continuously, and this has implied increases in production, growing exports, and the publication of a greater number of technical reports and academic research papers (Farías *et al.*, 2018). However, despite advances in

Received 04/22/2020; Accepted 06/18/2020.

The authors declare to have no conflict of interests.

production technologies and the breeding of high yield cultivars, climate continues to be the major factor influencing crop productivity (Amiri Deh Ahmadi *et al.*, 2014).

The date at which chickpea is sown (sowing date: SD) in Argentina is set anytime between April and June during autumn, hence part of the crop cycle coincides with a gradual decrease in average temperature and luminous intensity, a shortened photoperiod, and scarce rainfall. By contrast, the rest of the cycle (mainly, the reproductive phase) unfolds under a continuous rise in the levels of all the climatic conditions previously mentioned.

Abiotic stress constitutes the major cause for crop production losses worldwide, leading to up to 50% yield reductions (Bhandari *et al.*, 2017; Sita *et al.*, 2017). One of the most important factors that may result in abiotic stress is temperature (Stone *et al.*, 1995; Luo, 2011; Hatfield and Prueger, 2015). Its fluctuation between maximum and minimum values is highly heterogeneous over time and space, as well as unpredictable, and its impact on crops depends on the duration and intensity of crop exposure, and temperature levels (Sita *et al.*, 2017). For most crops, it is assumed that extreme temperatures beyond the range of optimum ones for vegetative or reproductive growth cause stress (Chaturvedi *et al.*, 2009; Luo, 2011; Lake *et al.*, 2016). As such, crops show an adequate development rate when growing under optimal temperatures, but when adverse temperature events (ATE) take place, development rates are altered and there are negative impacts on yield (Luo, 2011). Optimum temperatures for chickpea reproductive phase range from 5 °C to 30 °C (Srinivasan *et al.*, 1999; Jumrani and Bhatia, 2014). These temperature values have been reported as factors limiting crop productivity. Detrimental effects deriving from ATE are more serious when these events coincide with the reproductive stage of the crop, even to the extent of causing total losses when they are highly frequent, severe, and long-lasting, and when they occur at crucial moments.

In all, yield is the result of a complex physiological process, and its components have a dynamic relationship, with permanent interactions with environmental factors (Chohan and Raina, 2010; Sadras *et al.*, 2015). Chickpea presents grain yield reduction and variations in yield components as a consequence of thermal stress, due to either low or high temperatures (Srinivasan *et al.*, 1999; Nayyar

*et al.*, 2005; Wang *et al.*, 2006; Arunkumar *et al.*, 2012; Devasirvatham *et al.*, 2015b). Therefore, sowing date must be chosen carefully, so that crop growth and developmental stages coincide with the best temperature conditions to be expected.

In chickpea, different environmental settings (different sites and SD) lead to important variations in the occurrence of phenological phases (Roberts *et al.*, 1985; Verghis *et al.*, 1999; Ruml and Vulić, 2005; Berger *et al.*, 2006; Jumrani and Bhatia, 2014), as well as in yield and its components (Verghis, 1996; Srinivasan *et al.*, 1999; Gan *et al.*, 2002; Ahmed *et al.*, 2011; Bazvand *et al.*, 2015; Sadras *et al.*, 2015), as a consequence of the differing thermal and water availability conditions under which the crop cycle develops.

As in the case of most grain crops, the main measurable yield components in chickpea are grain number per unit area, and individual grain weight. In addition, it was observed that plant number/ha, pod number/plant, and seed number/pod influence individual grain weight and grain number (Güler *et al.*, 2001; Noor *et al.*, 2003; Biabani *et al.*, 2011; Petrova and Desheva 2016; Eskandari and Aalizadeh Amraee, 2017). Moreover, branch number/plant modifies pod number/plant (Verghis, 1996; Chohan and Raina, 2010).

The proportion of flowers that develop pods is influenced by variety, SD, and the environmental conditions that prevail during flowering (Turner *et al.*, 2005; Padilla Valenzuela *et al.*, 2008; Ahmed *et al.*, 2011). Extreme temperatures affect reproductive organs, causing pollen infertility and suppressing flower buds and pods (Clarke and Siddique, 2004; Jumrani and Bhatia, 2014; Devasirvatham *et al.*, 2015b). Another important variable among yield components is seed size (Upadhyaya *et al.*, 2006), which depends on seed growth rate and duration, and source-sink relationship (Sita *et al.*, 2017). In turn, seed growth rate is conditioned by the number and volume of cotyledon cells (Turner *et al.*, 2005), which are hindered by hot temperatures (Wang *et al.*, 2006). Seeds can be classified as large (>9mm), medium (9-8mm), and small (8-7mm) (Tuba Biçer, 2009), with larger seeds having better market values (Gan *et al.*, 2003; Lines *et al.*, 2008; Farías *et al.*, 2018).

The analysis of how different thermal conditions alter the occurrence and duration of phenological phases, the behavior of yield components, and yield itself constitute a useful contribution to chickpea production. Therefore, this article aims to

evaluate the influence of different thermal scenarios determined by different SD on the occurrence and duration of the phenological phases, yield, and yield components of the Norteño chickpea cultivar.

## Materials and methods

### *Agricultural management and experimental design*

The trials were conducted in an experimental field from Finca El Manantial, which belongs to Facultad de Agronomía y Zootecnia of Universidad Nacional de Tucumán (Tucumán, Argentina) (26° 50' 6.9" S – 65° 16' 44.6" W). The field is located in the subhumid-humid central plain region, which has a monsoon subhumid-humid subtropical climate with a dry season. The soil is typical Argiudoll, silty loam in the upper 80 cm of the soil profile, with a pH of 6.4, 2.5-3.5% of organic matter contents, an apparent density of 1.23 g/cc, an electrical conductivity of 1.11 dS/m, and 31.7% gravimetric moisture at field capacity. Kabuli chickpea seeds of cv. Norteño (59 g/100 seeds, 90 days to flowering, and a cycle of 150-170 days) were used in the trial. This cultivar is characterized by being semi-erect and having indeterminate growth. Its leaves are normal, its flowers are white, and its seeds are cream color (Carreras *et al.*, 2016). The seeds were treated with Carbendazim + Thiram (625 cc/100 kg seeds) and inoculated with *Mesorhizobium ciceri* (200 cc/50 kg seeds). They were sown in plots of six 13-meter-long rows, spaced 0.5 m apart, following a completely randomized design with 4 repetitions. SD were as follows: April 15, June 14, July 7, and August 5 in 2016. SD were selected to create different thermal configurations during the crop cycle. Seeds were hand sown 5 cm deep, following commercial sowing density recommendations (26 seeds/m<sup>2</sup>). To ensure plant health and avoid weed competition, insecticides, fungicides and herbicides were applied. The trial was conducted with no water restrictions, and unperturbed soil samples were collected and weighed every 15 days. These values, as well as those of soil weight at field capacity, were considered for supplying extra water as needed.

### *Developmental stages*

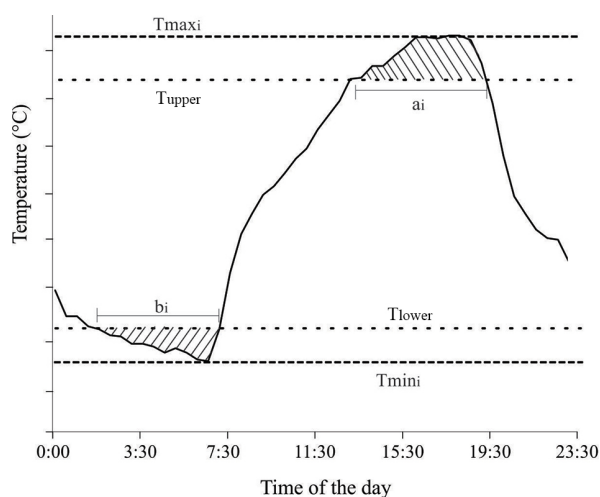
Phenological records were kept every two days, from emergence to physiological maturity, of three

1-meter-long samples chosen at random among the central rows of each plot. The scale applied to analyze soybean phenological stages (Fehr and Caviness, 1977) was adapted to chickpea. The emergence stage (Ve) was established as the time when the plumular hook elongates over the ground; flowering onset (R1) coincides with the first flower blooming anywhere in the plant; pod formation onset (R3) is due when the first 1 cm pod appears somewhere in the plant; pod filling onset (R5) occurs when pods change from being slightly flat and barely rigid, to being spherical and rigid; physiological maturity (R7) is reached when 50% of the pods in each plant have changed their color from green to yellow.

Each sample unit was considered to have reached a phenological stage once 50% of the plants were in that stage, and the days needed for that to happen were recorded.

### *Thermal factor*

For the purpose of assessing ATE severity and duration, an Index of Adverse Temperature Events (IATE) was devised, linking the time that a given developmental stage takes place under temperatures outside the optimum range, expressed as hours (h), and the temperature units exceeding optimal values to which the crop is exposed on a day (Figure 1).



**Figure 1.** Representation of the Index of Adverse Temperature Events in the graph showing temperature evolution on a day in August. The striped area represents the moment at which temperature reached values beyond the upper and lower thermal thresholds.  $T_{max_i}$  and  $T_{min_i}$  represent maximum and minimum temperature values on that day (i);  $T_{upper}$  and  $T_{lower}$  are the upper and lower thermal thresholds of the crop;  $a_i$  and  $b_i$  indicate how long (how many hours)  $T_{max}$  and  $T_{min}$  had values above the upper threshold and below the lower threshold, respectively, on that day (i).

Depending on the environment, a crop can face ATE related to hot or cold temperatures, or even both. Hence, the term  $IATE_h$  was used to refer to the time when the developmental phase takes place under temperatures exceeding the maximum threshold, whereas  $IATE_c$  referred to the time when developmental unfolds under temperatures below the minimum threshold. IATE corresponds to the algebraic sum of the two components (Equation 1).

$$IATE = IATE_h + IATE_c \quad (1)$$

To calculate accumulated IATE in a given period within the crop cycle, Equation 2 was used:

$$\Sigma IATE = \sum_{i=1}^n \frac{[(\pi(a_i + T_{max_i} - T_{upper})/3)^2]}{2} + \sum_{i=1}^n \frac{[(T_{lower} - T_{min_i})b_i]}{2} \quad (2)$$

Where  $\Sigma IATE$  is the accumulated index of daily thermal events in a selected period, expressed as  $^{\circ}C h$ ; the first term of Equation 2 corresponds to the accumulated value of the IATE hot component ( $IATE_h$ ); the second term shows the accumulated value of the cold component ( $IATE_c$ );  $T_{max_i}$  and  $T_{min_i}$  represent the maximum and minimum temperature values of the day (i);  $T_{upper}$  and  $T_{lower}$  are the upper and lower thermal thresholds of the crop;  $a_i$  and  $b_i$  correspond to the time (measured as hours) that  $T_{max}$  or  $T_{min}$  were above and below the upper and lower thresholds, respectively, on a day (i) (Figure 1); and  $\pi$  corresponds to Pi constant value.

When using Equation (2), the following was taken into account:

$$\Sigma IATE = \Sigma IATE_h + \Sigma IATE_c \quad (3)$$

when:  $T_{max_i} > T_{upper}$ ,  $T_{min_i} < T_{lower}$

$$\Sigma IATE = \Sigma IATE_h + 0 = \sum_{i=1}^n \frac{[(\pi(a_i + T_{max_i} - T_{upper})/3)^2]}{2} \quad (4)$$

when:  $T_{max_i} > T_{upper}$ ,  $T_{min_i} > T_{lower}$

$$\Sigma IATE = 0 + \Sigma IATE_c = \sum_{i=1}^n \frac{[(T_{lower} - T_{min_i})b_i]}{2} \quad (5)$$

when:  $T_{max_i} < T_{upper}$ ,  $T_{min_i} < T_{lower}$

Furthermore, ATE frequency was calculated, and the moments at which ATE coincided with the reproductive cycle were recorded for each evaluated SD.

Daily meteorological data (maximum and minimum temperatures, rainfall, relative humidity,

radiation) were measured and recorded every 0.5 h by a Davis Vantage Pro2 wireless automatic weather station, which was located near the experimental field.

To calculate photoperiod, a spreadsheet for astronomical variables VARAST 1.0 was used (Fernández-Long *et al.*, 2015).

### Yield components

Previous to harvest, three 1 m<sup>2</sup> samples were selected at random among the central rows of each plot. The plants in each sample were assessed in terms of the following variables:  $H_{max}$ : maximum plant height (m);  $H_{fp}$ : first pod height (m);  $Y_{pl}$ : grain yield per plant (g);  $N^{\circ}tp$ : total pod number per plant;  $P_f$ : percentage of filled pods per plant (%);  $N^{\circ}ts$ : total seed number per plant;  $N^{\circ}sp$ : seed number per pod;  $N^{\circ}bp$ : number of branches with pods per plant;  $N^{\circ}tp/bp$ : relation between total pod number and number of branches with pods per plant.

Besides, the index of seed size (ISS), which is the sum of the product of multiplying the percentage of seeds that passed through a sieve (10, 9, 8, 7 and < 7 mm calibers) by its diameter, divided by 100 (Lines *et al.*, 2008).

August 5 SD was excluded from the analysis, since precipitations prevented the crop from being harvested.

### Data analysis

Data were analyzed using Infostat (Di Rienzo *et al.*, 2018). An analysis of variance was run and a DGC test (Di Rienzo *et al.*, 2002) with ( $\alpha = 0.05$ ) was performed to compare means. The corresponding assumptions were thus verified.

## Results

### Environmental conditions

Meteorological data collected in this work are shown in Table 1. The highest and lowest mean monthly temperatures were recorded in December (25.2 $^{\circ}C$ ) and June (11.2 $^{\circ}C$ ), respectively. Absolute maximum temperature values ranging from 33 to 38 $^{\circ}C$  were observed in April, August, September, October, November, and December. Absolute minimum temperatures below 5 $^{\circ}C$  were registered in April, June, July, August, and September. Radiation and vapor-pressure deficit (VPD) values varied from 6.5 MJ/m<sup>2</sup> to 0.15 kPa in May, and

**Table 1.** Values of environmental variables considered from April to December 2016.

Months	Temperature (°C)			Average monthly radiation (MJ/m <sup>2</sup> /d)	Photoperiod (h)	Relative humidity: monthly average (%)	Mean VPD (kPa)
	Absolute maximum	Monthly average	Absolute minimum				
April	35.2	19.4	4.7	9.8	12.3	89.5	0.25
May	23.5	14.8	5.5	6.5	11.6	91.1	0.15
June	21.9	11.2	1.2	7.1	11.3	88.3	0.16
July	25.2	12.5	2.1	7.5	11.5	85.1	0.22
August	33.7	16.5	3.5	11.2	12.0	72.2	0.53
September	34.0	17.7	0.9	14.5	12.8	65.5	0.75
October	35.2	20.5	8.6	15.1	13.6	76.2	0.60
November	36.2	22.2	7.9	17.4	14.3	75.3	0.70
December	37.9	25.2	14.1	21.8	14.7	75.6	0.82

Mean VPD: average monthly vapor-pressure deficit value.

from 21.8 MJ/m<sup>2</sup> to 0.82 kPa in December. The photoperiod was shortest in June (11.3 h), and longest in December (14.7 h). Relative humidity was highest in May (91.1 %), and lowest in September (65.5%).

Plants sown on April 15 experienced mean temperature decreases from Ve to R1 (at the end of July). From that moment on, mean temperature increased till R7 (the beginning of October). By contrast, the other SD were exposed to a gradual rise in temperature from Ve to R7.

Only the first SD showed changes in the photoperiod, which became shorter in the period elapsing between sowing and June 21 (winter solstice). From that moment onwards, the photoperiod started to lengthen progressively until R7. The remaining SD coincided with gradual increases in photoperiod duration from Ve to R7.

Average daily radiation during the Ve-R7 period was 8.6, 11.5, 13.1, and 16.4 MJ/m<sup>2</sup>/day for SD April 15, June 14, July 7 and August 5, respectively. The crops were exposed to higher mean daily radiation levels when SD were postponed.

The lowest VPD values were recorded in the vegetative stage in the case of the first SD, and

these values were doubled and tripled in the reproductive stages. With the other SD, VPD values increased gradually from 0.53 to 0.82 kPa over the Ve-R7 period.

#### *Effect of temperature on developmental stages*

The thermal conditions recorded during the crop cycle, as determined by the four different SD considered in this work, had a significant influence on both the occurrence and duration of the evaluated phenological phases (Table 2). The evaluated SD presented significant differences in connection with the S-Ve phase ( $F = 181.35$ ;  $df_{\text{error}} = 12$ ;  $P < 0.0001$ ). This phase was shortest when April 15 was the SD ( $7.5 \pm 0.35$  days), and longest with June 14 as the SD ( $17.75 \pm 0.35$  days).

April 15 resulted in the vegetative stage (Ve-R1) lasting longest ( $100.5 \pm 1.08$  days); the last SD presented a vegetative state of  $65.5 \pm 1.08$  days, whereas for June 14 and July 7 this phase lasted about 57 days, thus leading to significant differences ( $F = 368.16$ ;  $df_{\text{error}} = 12$ ;  $P < 0.0001$ ).

There were also significant differences in the duration of reproductive phenological stages among the 4 evaluated SD. April 15 and July 7 presented

**Table 2.** Mean values of days  $\pm$  standard error needed to reach each phenological phase for the four evaluated sowing dates.

Phenological stage	April 15	June 14	July 7	August 5
S – Ve	7.50 $\pm$ 0.35 d	17.75 $\pm$ 0.35 a	15.50 $\pm$ 0.35 b	10.50 $\pm$ 0.35 c
Ve – R1	100.50 $\pm$ 1.08 a	56.50 $\pm$ 1.08 c	57.75 $\pm$ 1.08 c	65.50 $\pm$ 1.08 b
R1 – R3	23.25 $\pm$ 1.22 a	22.75 $\pm$ 1.22 a	8.75 $\pm$ 1.22 c	14.25 $\pm$ 1.22 b
R3 – R5	18.25 $\pm$ 1.30 a	11.50 $\pm$ 1.30 b	10.50 $\pm$ 1.30 b	10.75 $\pm$ 1.30 b
R5 – R7	29.00 $\pm$ 1.54 b	39.50 $\pm$ 1.54 a	40.75 $\pm$ 1.54 a	33.25 $\pm$ 1.54 b
R1 – R7	70.50 $\pm$ 1.70 a	73.75 $\pm$ 1.70 a	60.00 $\pm$ 1.70 b	58.25 $\pm$ 1.70 b
Ve – R7	171.00 $\pm$ 1.19 a	130.25 $\pm$ 1.19 b	117.75 $\pm$ 1.19 d	123.75 $\pm$ 1.19 c

S: sowing; Ve: emergence; R1: flowering onset; R3: pod formation onset; R5: grain filling onset; R7: physiological maturity. Mean values followed by the same letter are not significantly different according to the DGC test ( $P > 0.05$ ).

the highest and lowest values, respectively, in the number of days that the R1-R3 period lasted ( $F = 33.24$ ;  $df_{\text{error}} = 12$ ;  $P < 0.0001$ ).

With respect to the R3-R5 stage, only April 15 differed significantly from the other SD ( $F = 8.02$ ;  $df_{\text{error}} = 12$ ;  $P = 0.0035$ ). July 7 presented the longest R5-R7 period ( $40.75 \pm 1.54$  days), whereas April 15 led to the shortest duration of that stage, with significantly different values ( $F = 12.69$ ;  $df_{\text{error}} = 12$ ;  $P = 0.0005$ ).

In Table 2, it can be observed that SD April 15 and June 14 differed significantly from July 7 and August 5 ( $F = 20.31$ ;  $df_{\text{error}} = 12$ ;  $P = 0.0001$ ) in relation to the reproductive stage (R1-R7), which lasted longer in the case of the first two dates. Crop cycle duration (Ve-R7) was significantly different among the 4 evaluated SD ( $F = 408.10$ ;  $df_{\text{error}} = 12$ ;  $P < 0.0001$ ). The longest duration corresponded to April 15, with  $171.00 \pm 1.19$  days, whereas the shortest one resulted from July 7 as the SD, with  $117.75 \pm 1.19$  days.

In Table 3, it can be observed that 2 of the 4 evaluated SD led to  $7 \pm 0$  and  $4 \pm 0$  days with temperatures lower than, or equal to,  $5^\circ\text{C}$  at some point within the reproductive cycle. April 15 and August 5 were the SD that presented the lowest and highest frequency of temperatures above  $30^\circ\text{C}$  ( $16 \pm 1.09$ , and  $26 \pm 1.09$  days), respectively, in contrast to June 14 and July 7, which had intermediate frequency values.

Significant differences were found among the evaluated SD ( $F = 16.76$ ;  $df_{\text{error}} = 12$ ;  $P = 0.0001$ ) with respect to the accumulated index of thermal events ( $\Sigma\text{IATE}$ ), with the lowest value being recorded for April 15 ( $186.10 \pm 30.45$ ), and the highest one for August 5 ( $484.95 \pm 30.45$ ). Some intermediate values were obtained with SD June 14 and July 7 ( $305.40 \pm 30.45$  and  $282.65 \pm 30.45$ , respectively) (Table 3).  $\Sigma\text{IATE}_h$  presented different values for April 15, June 14-July 7, and August 5, whereas  $\Sigma\text{IATE}_c$  values were only recorded for the first two SD, without significant differences between them. For the last 2 SD, there were

no records of temperatures below the minimum threshold ( $5^\circ\text{C}$ ) during the reproductive stage, thus  $\Sigma\text{IATE}_c$  was 0.

In Figure 2, the distribution of hot and cold ATE over the reproductive stages, as determined by the four different analyzed SD, is shown. April 15 and June 14 had a similar distribution of hot and cold ATE in stages R1-R3, R3-R5 and R5-R7.

In the case of SD July 7 and August 5, hot ATE coincided most frequently with the R5-R7 stage, but the former date contrasts with the latter in that it led to fewer ATE in stages R1-R3 and R3-R5 (Figure 2).

#### *Effect of temperature on crop yield components*

The results of the correlation analysis of yield components are shown in Table 4, with  $r > 0.90$  values between  $Y_{\text{pl}}$  and  $N^{\circ}\text{tp}$ ,  $N^{\circ}\text{ts}$ , and  $N^{\circ}\text{bp}$ . At the same time, high and positive association values were found among  $N^{\circ}\text{tp}$ ,  $N^{\circ}\text{ts}$ , and  $N^{\circ}\text{bp}$ . By contrast, a negative correlation was found between  $N^{\circ}\text{tp/bp}$  and the assessed yield components. Similarly, ISS had a negative correlation ( $r = -0.70$ ) with  $N^{\circ}\text{tp/bp}$ .

The results of the analysis of the morphological variables and yield components are displayed in Table 5. There were significant differences among the three evaluated SD regarding  $H_{\text{max}}$  and  $H_{\text{fp}}$  ( $F = 51.35$ ;  $df_{\text{error}} = 25$ ;  $P < 0.0001$ ), with the highest values obtained with April 15 as the SD, and the lowest with June 14. April 15 was the SD with the highest  $Y_{\text{pl}}$  value ( $37.84 \pm 2.09$  g), with significant differences with respect to June 14 and July 7 ( $F = 33.72$ ;  $df_{\text{error}} = 25$ ;  $P < 0.0001$ ). The lowest  $Y_{\text{pl}}$  was recorded for July 7 ( $13.40 \pm 2.20$  g) (Table 5).

In Table 5, it can also be observed that the variables  $N^{\circ}\text{tp}$ ,  $P_f$ ,  $N^{\circ}\text{ts}$ , and  $N^{\circ}\text{sp}$  reached their highest values in the case of April 15 SD, with significant differences with respect to June 14 and July 7 ( $F = 21.18$ ;  $df_{\text{error}} = 25$ ;  $P < 0.0001$ ) ( $F = 8.84$ ;  $df_{\text{error}} = 25$ ;  $P = 0.0012$ ) ( $F = 29.31$ ;  $df_{\text{error}} = 25$ ;  $P < 0.0001$ ) ( $F = 16.30$ ;  $df_{\text{error}} = 25$ ;  $P < 0.0001$ ), which in turn showed no significant differences

**Table 3.** Mean values of days with frequent adverse temperatures  $\pm$  standard error for the four evaluated sowing dates.

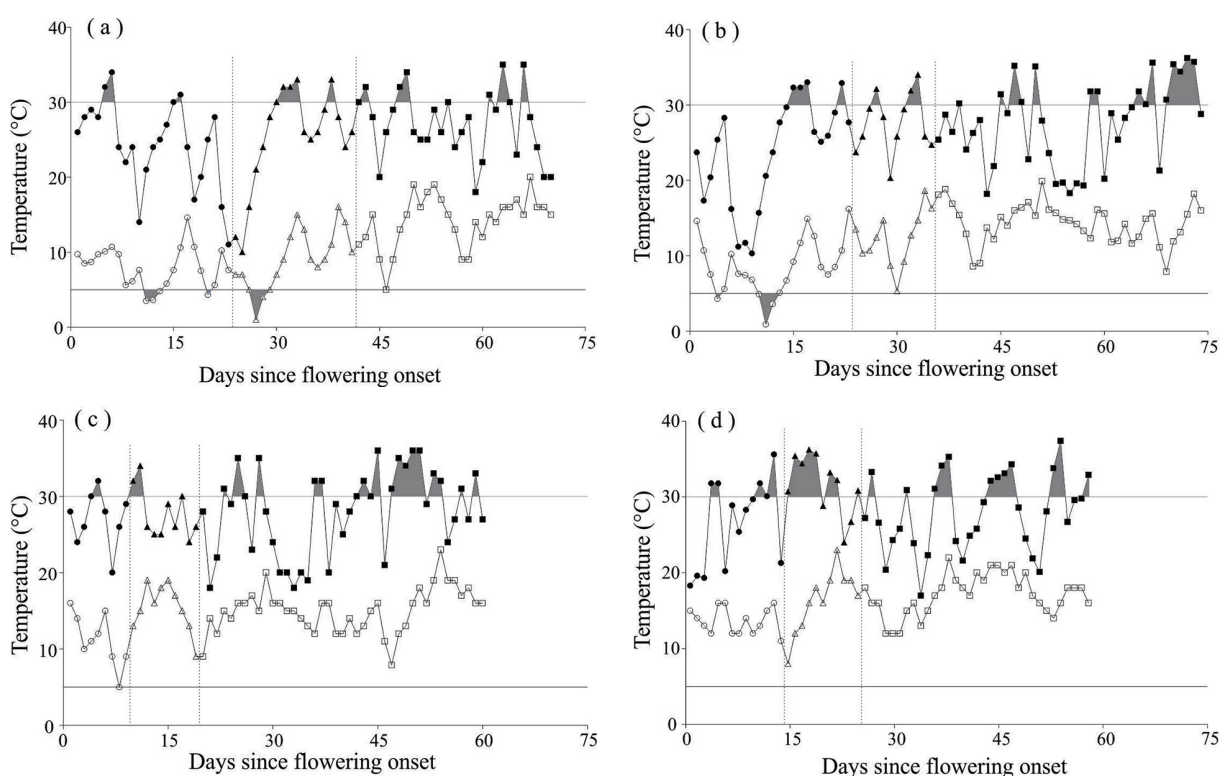
Variables	April 15	June 14	July 7	August 5
Days with $T \leq 5^\circ\text{C}$	$7.00 \pm 0.00$	$4.00 \pm 0.00$	$0.00 \pm 0.00$	$0.00 \pm 0.00$
Days with $T > 30^\circ\text{C}$	$16.00 \pm 1.09$	$21.75 \pm 1.09$	$21.75 \pm 0.09$	$26.00 \pm 0.25$
$\Sigma\text{IATE}_{\text{hot}}$	$158.00 \pm 29.40$	$273.13 \pm 29.40$	$282.65 \pm 29.40$	$484.95 \pm 29.40$
$\Sigma\text{IATE}_{\text{cold}}$	$28.10 \pm 1.75$	$32.30 \pm 1.75$	$0.00 \pm 1.75$	$0.00 \pm 1.75$
$\Sigma\text{IATE}$	$186.10 \pm 30.45$ c	$305.40 \pm 30.45$ b	$282.65 \pm 30.45$ b	$484.95 \pm 30.45$ a

T: temperature. Values of the indexes accumulated during the reproductive cycle (R1-R7)  $\pm$  standard error (s.e.).  $\Sigma\text{IATE}$ : accumulated index of adverse temperature events ( $^\circ\text{C h}$ );  $\Sigma\text{IATE}_h$ : accumulated IATE hot component ( $^\circ\text{C h}$ );  $\Sigma\text{IATE}_c$ : accumulated IATE cold component ( $^\circ\text{C h}$ ). Mean values followed by the same letter are not significantly different according to the DGC test ( $P > 0.05$ ).

between each other. April 15 was also the SD that presented the highest  $N^{\circ}bp$  value ( $11.64 \pm 0.68$ ), whereas July 7 had the lowest one ( $3.38 \pm 0.72$ ), with significant differences among the 3 SD ( $F = 32.18$ ;  $df_{error} = 25$ ;  $P < 0.0001$ ).

The  $N^{\circ}tp/bp$  variable reached its highest and lowest values with SD July 7 and April 15, respectively, and there were significant differences among the 3 SD ( $F = 39.00$ ;  $df_{error} = 25$ ;  $P < 0.0001$ ). June 14 led to the best ISS, as opposed to July 7 (which produced the worst value) (Table 5), and there were significant differences when comparing April 15 and June 14 with July 7 ( $F = 28.77$ ;  $df_{error} = 25$ ;  $P < 0.0001$ ).

In Figure 3, the averages of seeds with 10, 9, 8, 7 and <7 mm calibers produced per plant are shown. The largest number of seeds with 10 mm caliber was obtained with the first SD ( $5.73 \pm 1.45$ ), and the second largest number corresponded to June 14 ( $0.67 \pm 0.31$ ). No production of seeds with this caliber was recorded when July 7 was the SD. The average values of seeds produced with 9 mm caliber were  $38.88 \pm 3.83$  (April 15);  $29.43 \pm 2.49$  (June 14);  $2.18 \pm 0.46$  (July 7). This last SD led to the largest production of seeds with 8, 7 and < 7 mm calibers ( $28.89 \pm 1.81$ ;  $9.22 \pm 0.84$ ;  $1.13 \pm 0.33$ , respectively). Mean values for April 15 were:  $24.33 \pm 2.98$  (8 mm caliber);  $8.92 \pm 1.48$



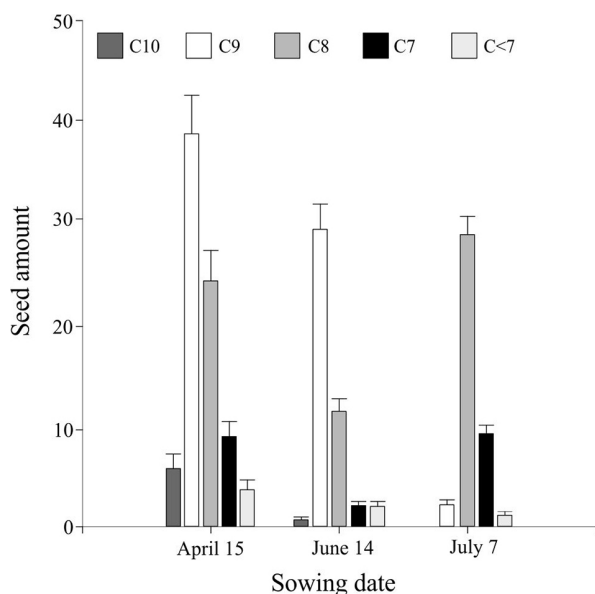
**Figure 2.** Maximum (filled circles) and minimum (empty circles) daily temperatures recorded during the reproductive cycle (R1-R7), as determined by the evaluated SD: April 15 (a), June 14 (b), July 7 (c), and August 5 (d). Horizontal lines indicate thermal thresholds (5°C and 30°C). Vertical dotted lines show limits among periods: R1-R3 (circles); R3-R5 (triangles) and R5-R7 (squares).

**Table 4.** Pearson correlation coefficient between yield components.

	$Y_{pl}$	$N^{\circ}tp$	$N^{\circ}ts$	$N^{\circ}sp$	$N^{\circ}bp$	$N^{\circ}tp/bp$	ISS
$Y_{pl}$	1.0000						
$N^{\circ}tp$	0.9407***	1.0000					
$N^{\circ}ts$	0.9564***	0.9791***	1.0000				
$N^{\circ}sp$	0.6384**	0.5312**	0.6871	1.0000			
$N^{\circ}bp$	0.9530***	0.8960***	0.9058***	0.5747	1.0000		
$N^{\circ}tp/bp$	-0.6592***	-0.4892***	-0.5040**	-0.3623	-0.7673***	1.0000	
ISS	0.6186**	0.3975	0.3754**	0.1517	0.5696***	-0.7046***	1.0000

$Y_{pl}$ : grain yield per plant (g);  $N^{\circ}tp$ : total pod number per plant;  $N^{\circ}ts$ : total seed number per plant;  $N^{\circ}sp$ : seed number per pod;  $N^{\circ}bp$ : number of branches with pods per plant;  $N^{\circ}tp/bp$ : relation between total pod number per plant and number of branches with pods per plant; ISS: index of seed size. \*\*\*  $p < 0.001$ , \*\*  $p < 0.01$ .

(7 mm caliber); and  $3.64 \pm 1.00$  (< 7 mm caliber). Finally, for June 14, averages of seed production were the following:  $11.42 \pm 1.25$  (8 mm caliber);  $2.10 \pm 0.37$  (7 mm caliber); and  $1.99 \pm 0.52$  (< 7 mm caliber) (Figure 3).



**Figure 3.** Mean value of the amount of seed produced per plant  $\pm$  standard error, and distribution of seed size for the evaluated sowing dates.

## Discussion

Coincidentally with the findings reported in this article regarding the effect of temperature on the shortening of reproductive stages, Verghis *et al.* (1999), Ahmed *et al.* (2011), and Devasirvatham *et al.* (2015a) found a similar tendency in kabuli type chickpeas. Padmakar Tripathi *et al.* (2009), as well as Jumrani and Bhatia (2014), discovered

that temperature increments (day/night) reduced the number of days necessary for flowering, pod formation onset, and physiological maturity in desi type chickpea. Besides, and in agreement with reports by Roberts *et al.* (1985), it was found that temperature caused variations in vegetative stage duration in cv. Norteño.

It was shown that cv. Norteño presented a strong and positive correlation between grain yield and pod number ( $r = 0.941$ ), similar to what has been reported for other cultivars by Güler *et al.* (2001), Noor *et al.* (2003), Biabani *et al.* (2011), Devasirvatham *et al.* (2015a), Sadras *et al.* (2015), and Petrova and Desheva (2016). Results concerning the relationship between seed number and pod number, as well as between seed number and grain yield published in this article also coincide with findings reported by Güler *et al.* (2001), Biabani *et al.* (2011) and Sadras *et al.* (2015). In this respect, the first SD led to the highest values, with significant differences in relation to the other dates. Contrary to what Petrova and Desheva revealed in 2016, cv. Norteño showed a strong and positive correlation between  $Y_{pl}$  and  $N^{°tp}$ , and  $N^{°sp}$ .

The developmental stages of the plants sown on April 15 took place under favorable thermal conditions that boosted crop yield, as compared to what happened with plants sown on June 14 and July 7. Chickpea reproductive stage coincided with adverse thermal conditions as sowing was delayed, hence late SD led to the highest  $\Sigma IATE$  values, together with the lowest yield and yield component values.

Similar results concerning the impact of different thermal scenarios on the reduction of yield

**Table 5.** Mean values of morphological variables, yield components, and yield  $\pm$  standard error for the evaluated sowing dates.

Variables	April 15	June 14	July 7
$H_{max}$	$0.80 \pm 0.01$ a	$0.63 \pm 0.01$ c	$0.69 \pm 0.01$ b
$H_{fp}$	$0.39 \pm 0.01$ a	$0.30 \pm 0.01$ c	$0.34 \pm 0.01$ b
$Y_{pl}$	$37.84 \pm 2.09$ a	$21.87 \pm 2.20$ b	$13.40 \pm 2.20$ c
$N^{°tp}$	$78.25 \pm 3.72$ a	$51.64 \pm 3.92$ b	$45.44 \pm 3.92$ b
$P_f$	$90.59 \pm 1.36$ a	$84.56 \pm 1.44$ b	$82.67 \pm 1.44$ b
$N^{°ts}$	$80.83 \pm 3.93$ a	$45.41 \pm 4.15$ b	$41.43 \pm 4.15$ b
$N^{°sp}$	$1.03 \pm 0.02$ a	$0.88 \pm 0.02$ b	$0.92 \pm 0.02$ b
$N^{°bp}$	$11.64 \pm 0.68$ a	$6.44 \pm 0.72$ b	$3.38 \pm 0.72$ c
$N^{°tp/bp}$	$6.93 \pm 0.39$ b	$8.08 \pm 0.41$ b	$11.73 \pm 0.41$ a
ISS	$8.41 \pm 0.07$ a	$8.54 \pm 0.08$ a	$7.77 \pm 0.08$ b

$H_{max}$ : maximum plant height (m);  $H_{fp}$ : first pod height (m);  $Y_{pl}$ : grain yield per plant (g);  $N^{°tp}$ : total pod number per plant;  $P_f$ : percentage of filled pods (%);  $N^{°ts}$ : total seed number per plant;  $N^{°sp}$ : seed number per pod;  $N^{°bp}$ : number of branches with pods per plant;  $N^{°tp/bp}$ : relation between total pod number per plant and number of branches with pods; ISS: index of seed size. Mean values followed by the same letter are not significantly different according to the DGC test ( $P > 0.05$ ).

per plant, and of some of the yield components of chickpea, were revealed by various authors (McKenzie and Hill, 1995; Verghis, 1996; Gan *et al.*, 2002; Wang *et al.*, 2006; Lines *et al.*, 2008; Kobraee *et al.*, 2010; Ahmed *et al.*, 2011; Sadeghipour and Aghaei, 2012; Jumrani and Bhatia, 2014; Bazvand *et al.*, 2015; Devasirvatham *et al.*, 2015a; Lake *et al.*, 2016; Eskandari and Aalizadeh Amraee, 2017).

The N<sup>°</sup>sp variable was the one that suffered less variation in the different thermal scenarios evaluated, as was previously reported for desi and kabuli chickpeas (McKenzie and Hill, 1995; Verghis, 1996; Ahmed *et al.*, 2011; Sadeghipour and Aghaei, 2012; Jumrani and Bhatia, 2014; Bazvand *et al.*, 2015). Contrary to what has been reported for cv. Norteño, Eskandari and Aalizadeh Amraee (2017) found that the largest seed size was achieved with plants with fewer branches, especially in the case of cv. ILC482.

The different thermal conditions under which the crop developed caused a decrease in N<sup>°</sup>bp as SD were postponed. The first SD presented an approximate value of 12 for N<sup>°</sup>bp, which reduced by 44.64% and 71%, respectively, for the two later SD. Conversely, N<sup>°</sup>tp/bp had its lowest value in the case of the first SD ( $6.93 \pm 0.39$ ), and the highest value resulted from the last evaluated SD ( $11.73 \pm 0.41$ ). This means that plants seeded at the first date had a greater number of branches, which presented fewer pods.

In addition, plants sown on July 7 produced the smallest number of seeds with 9 and 10 mm calibers, as distinct from 8 and 7 mm calibers. By contrast, plants seeded on April 15 yielded more seeds with 9 and 10 mm calibers than with 8 and 7. Thus the lowest ISS value was recorded for July 7, and the values for SD April 15 and June 14 were alike.

In this work, it was observed that the reproductive stage coincided with more frequent hot weather as SD were delayed, which could have resulted in the production of smaller size seeds. Furthermore, it was observed that later SD led to longer R5-R7 stages, but with a weaker source-sink relationship, as they showed a better N<sup>°</sup>tp/bp relationship as compared with the first date.

The four SD originally proposed led to a wide range of variations in the frequency, duration, and intensity of thermal events below and above the optimum thresholds cited for chickpea. By calculating  $\Sigma$ IATE, it was possible to quantify and compare the occasions on which values exceed-

ing these thresholds were recorded in the different evaluated thermal configurations.

With later SD,  $\Sigma$ IATE values grew significantly, from 186°C h ( $\pm 30.45$ ) for the first SD, to 484°C h ( $\pm 30.45$ ) for the last one. No significant differences were found in  $\Sigma$ IATE values for SD June 14 and July 7, but yield and yield component values did differ significantly. Differences could be attributed to the distribution of ATE during the reproductive cycle, as chickpea yield diminishes more when the crop suffers high temperature stress during pod development, than when this stress occurs at the onset of flowering (Wang *et al.*, 2006).

The results presented in this work are in agreement with those reported by Devasirvatham *et al.* (2015b), Sadras *et al.* (2015), Lake *et al.* (2016), Bhandari *et al.* (2017), in that they reveal that temperature constitutes one of the main environmental factors influencing chickpea growth, development, and yield. Moreover, the negative impact of adverse temperature conditions on crop yield in chickpea was also reported for wheat, peanuts, corn, and various horticultural crops and legumes (Stone *et al.*, 1995; Vara Prasad *et al.*, 1999; Luo, 2011; Hatfield and Prueger, 2015; Sita *et al.*, 2017)

## Conclusions

The different sowing dates evaluated in this work caused important variations in thermal conditions, photoperiod duration, radiation levels, and vapor-pressure deficit values prevailing during chickpea growth and development in Tucumán. It was observed that the thermal factor was clearly influential, with high temperatures having a particularly notable impact on crop productivity.

By means of the IATE, it was possible to quantify the moments at which the crop was exposed to temperatures outside the optimum range, while also comparing these situations with others deriving from different thermal scenarios.

Late sowing had a significantly detrimental effect on the production capacity of the crop, since it shortened the duration of its phenological stages, and exerted a negative influence on the behavior of yield components.

Early sowing (on April 15) secured environmental conditions that led to higher seed number and seed weight values per plant. Moreover, a greater number of seeds presented better calibers, and grew in plants with a larger number of branches that developed fewer pods.

## Acknowledgements

The authors would like to thank Engineers Esteban Medina and Mauricio Costa, Dr. Roque Interdonato, and farm personnel of FAZ for their collaboration. Thanks are also due to anonymous referees, who made contributions to this article. This work was financed by Consejo de Investigaciones of Universidad Nacional de Tucumán (PIUNT, A612). We also thank Adriana Manes for translating the manuscript into English.

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