Article

Base temperatures and degrees days development of 10 Mexican corn accessions

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Abstract

The temperature variation of a place is a function of the elements and factors of the climate, which are altered to a greater or lesser extent by climate change, which is a challenge to determine the periods of thermal growth, optimum sowing for various crops by region. Based on the above, the objective of this study was to determine the base temperature (T_b) and the degree days development (GDD) of the sowing to flowering (male and female) for 10 accessions of corn that are protected in the Germplasm Bank of CIMMYT. The information was collected and analyzed (duration in days (t) of the periods of Sowing to Flowering and its respective average temperature) of different field experiments of the field stations (Agua Fria, Puebla and Tlaltizapan, Morelos) of the years 2008, 2009, 2011, 2012 and 2013. Which was adjusted to a linear model by linear regression between the development rate (1/t) and the average temperature of the period. The GDD were estimated by accession with the ratio 1/α where α is the parameter of the regression and T_b. The results indicate that T_b varied from 7.1 to 13 °C for male flowering and 5.4 to 12.1 °C for female flowering with an accumulation of GDD between 880 and 1696 male flowering and 1115 to 1860 female flowering, which allows to characterize the accessions evaluated in order of highest to lowest precocity: Chis337, Yuca91, Vera617, Yuca158, Yuca47, Vera616, Vera64, Vera623, Snlp277, Hida275, confirming that knowing the agroclimatic requirements of crops allows selecting regions that favor growth , development, reduction of losses and increase yields as well as preserving the genetic variability of the species.

Keywords: base temperature, degree days development, linear model.

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Introduction

Several studies have shown the effect of temperature on the growth and development of crops as they influence different phenological stages, such as seed germination (Butler *et al*., 2014; Fowler *et al*., 2014); likewise, temperature variations can modify the length of the emergence-anthesis or before-filling period of grain (Shim and Lee, 2017), flowering is also affected by high temperatures (Noriega *et al*., 2011), which can un-synchronize female flowering and anthesis (Cicchino *et al.*, 2010).

High temperatures affect the pollen viability during pollination (Hatfield and Prueger, 2015), which can generate abortions in grains (Cantarero *et al*., 1999) and will reflect a lower number of grains per ear and therefore less accumulation of biomass (Rincón *et al.*, 2006; Hatfield and Prueger, 2015), the rate of leaf production and spread is also affected (García and López, 2002) as well as the duration of the different phenological stages (Soto *et al*., 2009; Liu *et al*., 2013).

Therefore, it is important to determine the temperature range and thus be able to measure the growth by means of the daily integration of the thermal energy or day degree of growth (D°) within said range, which is known as days of development (GDD). There are several thermal models to estimate the GDD in the corn crop, these can be linear and non-linear (Cross and Zuber, 1972; Bonhomme *et al.*, 1994; McMaster and Wilhelm, 1997; Kumudini *et al*., 2014; Archontoulis and Miguez, 2015).

Non-linear models are better suited to temperature variations, however, they need to be calibrated by crop and region and the accuracy depends on the temperature range at which they were calibrated, as is the case with the CHU (Crop Heat Units) model that is used mainly in Canada, this model calculates the daily CHU by means of two functions: a linear one for the night and another polynomial for the day (Brown, 1975). Cutforth and Shaykewich (1989) found that the CHU model overestimates the rate of development at low temperatures, which generates a higher value of CHU in the sowing-flowering period (SF).

On the other hand, linear models are based on the linear relationship between the rate of development and temperature, within a minimum temperature range (base temperature T_b) from which the crop develops at a maximum temperature (temperature optimal T_o) where the greatest development occurs; few degrees above the optimum temperature is the threshold temperature (T_u) from which the growth decreases considerably (Monteith, 1977). The thermal models require the T_b and T_o of each crop to estimate the GDD, the values most used in the corn crop are: T_b= 10 °C and T_o= 30 °C (Hou *et al*., 2014).

From this, several researchers have evaluated the accuracy of thermal models for corn cultivation in different environments (Cross and Zuber, 1972, Cutforth and Shaykewich, 1989, Bonhomme *et al*., 1994, Archontoulis and Miguez, 2015). In some models temperature values were used for T_b= 10 °C and T_o= 30 °C, the differences found in the results suggest variations in the T_b by crop.

Authors such as Singh *et al*. (1976) found values of T_b= 10 °C and T_o= 35 °C for the pioneer hybrid 3388; likewise, Warrington and Kanemasu (1983) obtained T_b= 11 °C and T_o= 28 °C, on the other hand, Hernández and Carballo (1984) estimated T_b= 7 °C and T_o= 27 °C for High

Valley in Mexico and whose T_b matches that found by Narwal *et al*. (1986) for winter in the North-West of India. Other researchers such as García and López (2002) found T_b= 7.5 °C for foliar extension and Ruiz *et al*. (1998) obtained T_b between 2 °C and 10 °C for 49 Mexican corn races.

In Mexico, there is a great diversity of races and varieties of corn, adapted to different altitudes and climates and with different environmental requirements, which is why to preserve this genetic variability of corn, CIMMYT has a germplasm bank with seed samples (corn accessions) taken in different parts of the country. In the present study, sowing-flowering data from 10 accessions of said bank were used and a linear model was applied to calculate the value of T_b and GDD.

Materials and methods

The present study was carried out from the use of agroclimatic data recorded during the establishment of experimental plots of corn from the CIMMYT Germplasm Bank, which were obtained in the autumn-winter and spring-summer agricultural cycles during the years: 2008, 2009, 2011, 2012 and 2013. The experimental corn plots were located in two CIMMYT field stations: Agua Fria and Tlaltizapan (Figure 1), which have meteorological stations and a historical record of climate data.

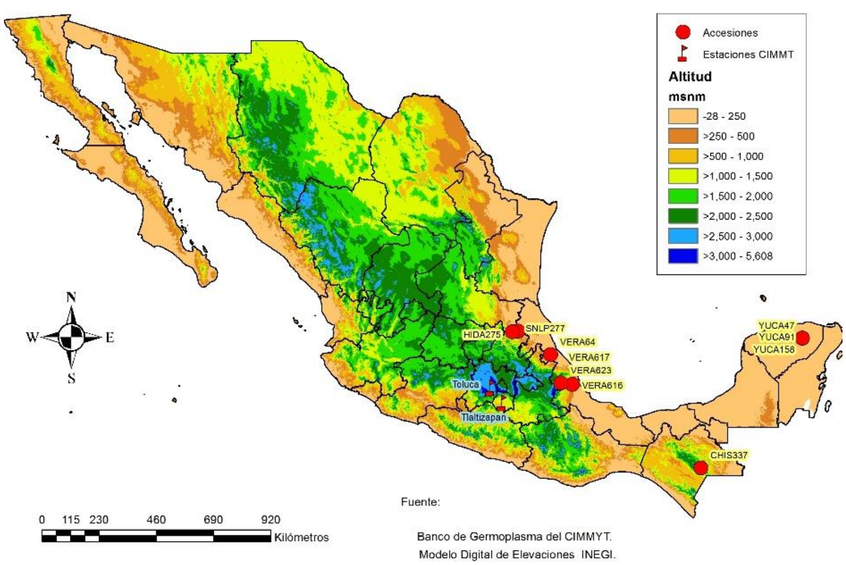

Figure 1. Location of CIMMYT stations and collection sites.

The Agua Fria station is located in the municipality of Venustiano Carranza in Puebla at coordinates latitude 20° 27’ north latitude and longitude west 97° 38.4’ at an altitude of 102 m. The Tlaltizapan station is located in Morelos at coordinates North latitude 18° 40.8’ and longitude West 99° 7.2’ with an altitude 943 m.

To maintain the seed inventory, the germplasm bank follows the considerations proposed by Cutforth *et al*. (1994), for the conservation of the accessions of corn, for this reason it carries out sowings every year according to the demand of the same one by researchers. For the management of the plot, it is divided into lots of 5 meters in length with separation between rows of 70 cm and with two seeds per bush between 5 and 10 cm deep. During the agricultural cycle the dates of sowing and number of days elapsed were recorded when 50% of the plants reached the male flowering, the feminine flowering and the senescence, for all the sowings irrigation, fertilizer and herbicides were applied.

The sowing records of 3 142 corn accessions were consulted and analyzed, from which the T_b of the sowing-male flowering and sowing-female flowering periods was calculated for 41 accessions for having the highest number of sowing repetitions (from 3 to 5, where each point represents an experiment). Finally, 10 were selected (Table 1 and 2) because they had the highest coefficient of determination and correlation, so for each sowing-flowering period the average temperature was calculated (Table 3) and sowing with unreliable data was ruled out. The origins of the accessions are: Chiapas, Hidalgo, Veracruz and Yucatan (Figure 1).

Table 1. Origin of corn accessions.

Accession	Latitude, longitude	Altitude (m)	Municipality	Location	Collection
CHIS337	16.33 N, 91.94 W	1494	The Margaritas	Margaritas	01/ene/72
HIDA275	21.27 N, 98.55 W	140	San Felipe O.	Piedra Hincada	05/jun/07
SNLP277	21.25 N, 98.76 W	125	Tamazunchale	Guaxcuaco	17/ago/07
VERA64	20.43 N, 97.38 W	109	Papantla	The Tajin	01/ene/48
VERA616	19.35 N, 96.59 W	262	Emiliano Zap.	Rafael Lucio	01/ene/77
VERA617	19.35 N, 96.59 W	262	Emiliano Zap.	Rafael Lucio	01/ene/77
VERA623	19.4 N, 97 W	1221	Tlacolulan	Tlacolulan	01/ene/77
YUCA47	21.017 N, 88.28 W	23	Espita	Espita	01/ene/48
YUCA91	21.017 N, 88.28 W	23	Espita	Espita	01/ene/48
YUCA158	21.017 N, 88.28 W	23	Espita	Espita	01/ene/48

Table 2. Breeds of corn accessions.

Accession	Race	Sub-race	Common name
CHIS337	Comiteco	Oloton	Yellow
HIDA275	Ancho	Olotil	Broad corn
SNLP277	Olotillo	Tuxpen	Large white corn
VERA64			Small
VERA616	Coscomatepec		
VERA617			Creole Pinto
VERA623			Pinto
YUCA47	DZIT-BACAL		XNUC-NAL
YUCA158	DZIT-BACAL		

Table 3. Planting dates, male flowering (date FM) and female (Date FF); average temperature for sowing-flowering male (TM-FM) and sowing-flowering female (TM-FF).

Planting site	Accession	Planting date	Date FM	Date FF	TM-FM (°C)	TM-FF (°C)
Tlaltizapan	CHIS337	16-jun-11	3-sep-11	14-sep-11	24.75	24.53
Tlaltizapan	CHIS337	19-jun-12	5-sep-12	14-sep-11	23.49	24.26
Tlaltizapan	CHIS337	14-nov-12	14-mar-13	2-mar-13	20.87	20.99
Tlaltizapan	CHIS337	28-nov-13	11-mar-14	25-mar-14	21.28	21.96
Tlaltizapan	HIDA275	20-apr-13	13-jul-13	17-jul-13	25.73	25.61
Agua Fria	HIDA275	4-jun-09	24-ago-09	27-ago-09	29.54	29.43
Tlaltizapan	HIDA275	14-nov-12	19-mar-13	14-mar-13	20.84	21.12
Tlaltizapan	HIDA275	28-nov-08	4-abr-09	7-abr-09	21.49	21.64
Agua Fria	HIDA275	8-jul-14	26-sep-14	29-sep-14	27.83	27.79
Tlaltizapan	SNLP277	28-nov-13	10-mar-14	15-mar-14	21.25	21.48
Tlaltizapan	SNLP277	14-nov-12	10-mar-13	1-mar-13	20.76	20.98
Agua Fria	SNLP277	4-jun-09	11-ago-09	14-ago-09	29.61	29.59
Tlaltizapan	SNLP277	28-nov-08	20-mar-09	21-mar-09	21.09	21.13
Tlaltizapan	VERA616	16-jun-11	2-sep-11	8-sep-11	24.79	24.66
Tlaltizapan	VERA616	19-jun-12	1-sep-12	5-sep-12	23.49	24.27
Tlaltizapan	VERA616	14-nov-12	28-feb-13	19-feb-13	20.63	20.77
Tlaltizapan	VERA616	28-nov-13	7-mar-14	15-mar-14	21.17	21.48
Tlaltizapan	VERA617	16-jun-11	29-aug-11	2-sep-11	24.81	24.75
Tlaltizapan	VERA617	17-jul-12	29-sep-12	9-oct-12	23.34	23.93
Tlaltizapan	VERA617	14-nov-12	25-feb-13	16-feb-13	20.57	20.72
Tlaltizapan	VERA617	28-nov-13	4-mar-14	12-mar-14	21.07	21.36
Tlaltizapan	VERA623	16-jun-11	2-sep-11	9-sep-11	24.79	24.63
Tlaltizapan	VERA623	14-nov-12	3-mar-13	26-feb-13	20.74	20.87
Tlaltizapan	VERA623	28-nov-13	8-mar-14	19-mar-14	21.21	21.61
Agua Fria	VERA64	8-jun-11	5-aug-11	7-ago-11	28.76	28.76
Tlaltizapan	VERA64	14-nov-12	21-feb-13	17-feb-13	20.5	20.72
Tlaltizapan	VERA64	28-nov-13	4-mar-14	10-mar-14	21.07	21.32
Agua Fria	YUCA158	31-may-12	14-aug-12	16-ago-12	26.41	26.44
Tlaltizapan	YUCA158	14-nov-12	22-mar-13	10-mar-13	20.9	21.03
Tlaltizapan	YUCA158	28-nov-13	18-mar-14	27-mar-14	21.51	22.05
Agua Fria	YUCA47	31-may-12	13-aug-12	16-ago-12	26.44	26.44
Tlaltizapan	YUCA47	14-nov-12	15-mar-13	11-mar-13	20.89	21.05
Tlaltizapan	YUCA47	28-nov-13	20-mar-14	28-mar-14	21.59	22.09
Agua Fria	YUCA91	31-may-12	11-aug-12	7-ago-12	26.47	26.41
Tlaltizapan	YUCA91	14-nov-12	14-mar-13	3-mar-13	20.87	20.97
Tlaltizapan	YUCA91	28-nov-13	18-mar-14	2-abr-14	21.51	22.32

Yes, the corn cultivar is not sensitive to the photoperiod (Gouesnard *et al*., 2002), or does not require vernalization, the development of the sowing-flowering period follows a positive linear behavior of the temperature in a range of base temperature and optimum temperature (Ruiz *et al*., 2002).

Within the interval between T_b and T_o (Figure 2), it is possible to use the following linear model (Monteith, 1977):

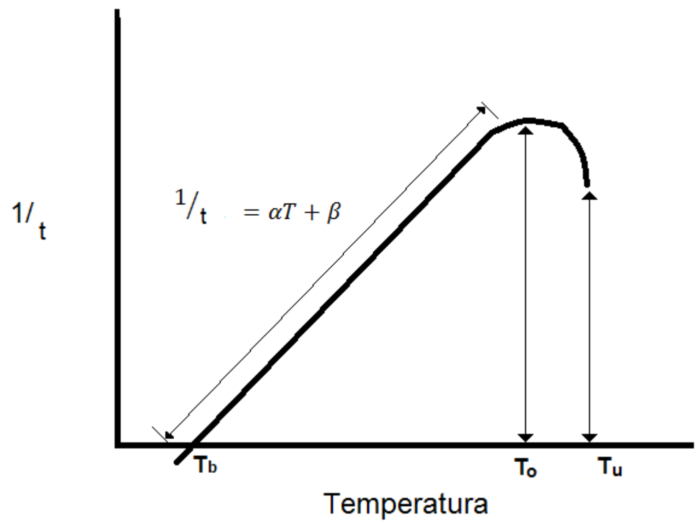

Figure 2. Crop development between base and optimum temperature.

$$^{1}/_{t}=\alpha T+\beta \qquad 1)$$

Where: t is the duration in days of the sowing-flowering period, T is the average temperature of the period, α and β are parameters obtained by a simple linear regression. To know the temperature from which the growth begins (1/t = 0), equate equation 1 to zero and express it as a function of T to obtain T_b:

$$T_b=-\frac{\beta}{\alpha} \qquad 2)$$

For the calculation of GDD, the following quotient was used (Mullens and Rutz, 1983):

$$1/\alpha \qquad 3)$$

Results and discussion

The values of T_b obtained for the 10 accessions, as well as the parameters of linear regression, the coefficient of determination and correlation and the GDD are shown in Table 4 and 5. The values of T_b and GDD for male and female flowering were plotted for analyze their behavior (Figure 3).

Table 4. Regression parameters, coefficients of determination and correlation, base temperatures and GDD, for maize accessions, male flowering.

Accession	α	β	r^2	ρ	T_b	GDD
CHIS337	0.00113526	-0.014775	0.88	0.939	13.01	880.85
HIDA275	0.0005896	-0.0042653	0.91	0.953	7.23	1696.05
SNLP277	0.0006552	-0.0046727	0.98	0.99	7.13	1526.24
VERA64	0.0008743	-0.0079089	0.99	0.909	9.05	1143.78
VERA616	0.00093642	-0.0096216	0.84	0.914	10.27	1067.89
VERA617	0.00096652	-0.009908	0.91	0.952	10.25	1034.64
VERA623	0.00085814	-0.0084257	0.99	0.90	9.82	1165.3
YUCA47	0.00094535	-0.01148306	0.99	0.646	12.15	1057.81
YUCA91	0.00098333	-0.01213178	0.99	0.642	12.34	1016.95
YUCA158	0.00094939	-0.0117027	0.98	0.621	12.33	1053.31

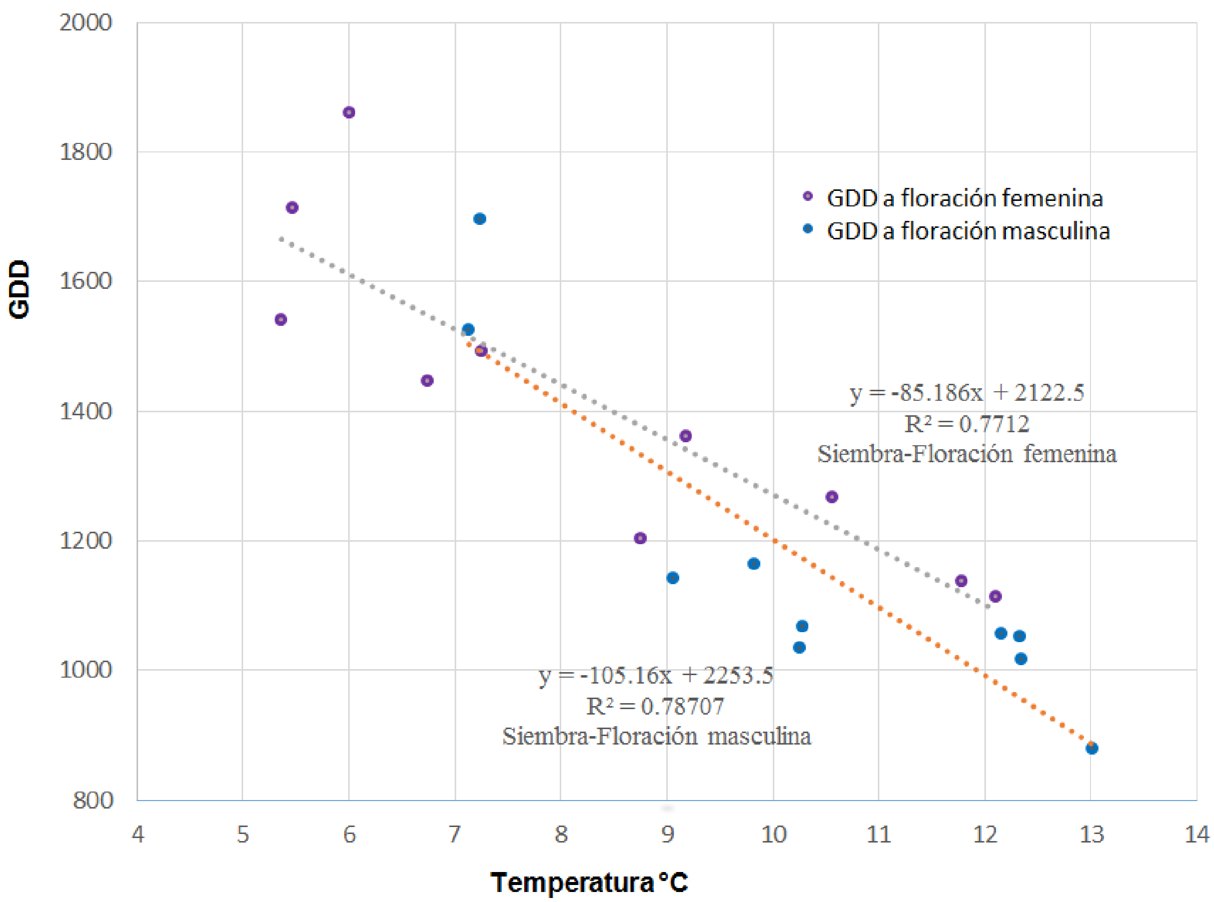

Figure 3. Relationship between T_b and GDD from sowing to flowering (female and male) for different accessions of corn.

High values were obtained in the coefficients of determination, which can be by the number of repetitions of sowing-flowering, since the germplasm bank performs sowing only to maintain seed stocks.

On the other hand, great correlation coefficients were obtained in most of the accessions, which gives greater certainty to the linear models developed, except for the accessions Yuca47, Yuca91 and Yuca158, which presented correlations between 0.6 and 0.7 (Table 4), which suggests collecting more data from future plantings, to improve the model.

For the accessions Vera64, Vera616, Vera617 and Vera623 T_b values close to 10 °C were obtained (Table 4), these values coincide with those used by various authors (Cross and Zuber, 1972; Kumudini *et al.*, 2014). The Accessions Hida275 and SLP277 presented a T_b close to 7 °C (Table 4), similar to that found by Hernández and Carballo (1984) for High Valley and the one reported by Ruiz (1998) for the Ancho, Jala, Coscomatepec, Reventador, Onaveño and Dulcillo races; as well as the average calculated by Sánchez *et al*. (2014) for male flowering. The accessions Yuca47, Yuca91, Yuca158, Chis337 presented T_b between 12.3 °C and 13 °C, values close to 12.6 °C average calculated by Sánchez *et al* (2014) for the development of roots. On the other hand, the accession Yuca158, has a value of T_b= 11.7 °C, for female flowering (Table 5), this value is close to 11 °C reported by Warrington and Kanemasu (1983) for anthesis.

Table 5. Regression parameters, coefficients of determination and correlation, base temperatures and GDD, for maize accessions, female flowering.

Accession	α	β	r^2	ρ	T_b	GDD
CHIS337	0.00073418	-0.00673683	0.796	0.892	9.17	1362.05
HIDA275	0.00053737	-0.00322956	0.895	0.946	6	1860.89
SNLP277	0.00058353	-0.00318764	0.99	0.995	5.46	1713.68
VERA616	0.00069075	-0.00465105	0.751	0.866	6.73	1447.7
VERA617	0.00064908	-0.00348244	0.811	0.9	5.36	1540.63
VERA623	0.00067007	-0.00486002	0.848	0.921	7.25	1492.37
VERA64	0.00083059	-0.00726978	0.973	0.987	8.75	1203.96
YUCA158	0.00087787	-0.01033777	0.951	0.975	11.77	1139.12
YUCA47	0.00089663	-0.01083809	0.951	0.975	12.09	1115.28
YUCA91	0.00078849	-0.00832139	0.788	0.888	10.55	1268.25

In Figure 3, it is observed that male flowering requires higher T_b than female flowering (Tables 4 and 5); however, it requires less thermal energy (GDD), which corresponds to the flowering dates, since the masculine one appears before.

Regarding altitude and temperature, no direct relationship was found between elevation and GDD, which suggests the existence of errors in the geographic coordinates during the collection of the accessions, which, not having a more detailed record of the location, there is no way to correct these coordinates.

Conclusions

The importance of the evaluation of the bioclimatic requirements, in this case thermal (T_b and GDD) of the maize accessions, allows to evaluate the periods of thermal growth for different sites, independent of a civil calendar, since it is determined based on the thermal offer of the place.

With the thermal requirements obtained for the sowing-flowering periods, the sowing dates can be planned to tune the flowering and thus make crosses.

Knowing the thermal supply of a place allows selecting actions that can complete their agricultural cycle and thus preserve the genetic variability of these; It is also possible to change the current crop for another equivalent in its thermal demand.

Of the different accessions, T_b ranged between 7.13 and 13.01 with requirements varying between 800 and 1 696 GDD, from sowing to male flowering; similarly, T_b ranged between 5.36 and 12.09 with requirements that vary between 1 115 and 1 540 GDD from sowing to female flowering. The above values correspond to the climate, being the accessions of warm climates those that demand more T_b and those of High Valley those of lower thermal requirement.

In the ten accessions studied, there is a variability in the requirements of T_b and GDD, which expresses a broad spectrum of adaptation of these materials that have been collected by CIMMYT.

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