Article

Grain production potential of soybean cultivation in the Puebla Valley

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Abstract

In Mexico, soybean production does not meet demand, so it is imported from other countries. This crop, produced mainly in the tropics, can be extended to the temperate zone to increase domestic production. Therefore, the present study evaluated the productive behavior of seven experimental selections and two commercial varieties of soybean in 2018, in three sites of the Puebla Valley with altitudes ranging from 2 190 to 2 240 m. The experimental design was in random blocks with four repetitions analyzed in a combined way. The experimental unit was four furrows five meters long and 70 cm wide. The variables evaluated were flowering, plant height, canopy width and grain production. The earliest varieties to flowering were 'Hoja Seca Original', 'Hoja Seca Vainas Abundantes' and 'Varita' with 81, 78 and 82 days, respectively, compared to the others that had 99 days on average. The locality where flowering occurred the fastest was Coronango (89 days). The varieties that differed the most in yield were Varita and Nainary, which on average had 3.42 and 2.02 t ha^{-1}. The locality of La Ciénega had a higher yield (3.77 t ha^{-1}) than the other two localities. In conclusion, the early varieties Varita, Hoja Seca Vainas Abundantes and Hoja Seca Original were the earliest and had the highest grain yield, therefore, they may be the most recommended for the area in question, which shows some potential.

Keywords: early varieties, grain production, high plateau,

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Introduction

Soybean is a crop of high economic value because of the multiple uses in human and animal food, due to the high concentrations of protein and oils it has (Pagano and Miransari, 2016). In Mexico, the cultivation of this species is concentrated in regions with a warm climate (mainly in the states of Campeche, Veracruz, San Luis Potosí, Tamaulipas and Chiapas, among others) and its production was 324 011 t in 2018 (SIAP-SIACON, 2018), which does not counteract imports, which, for the same year, were 6 195 000 t (USDA, 2019). On the other hand, in regions with a temperate climate, which are associated with altitudes above 2 000 m, there is a lack of a protein-energy crop for animal production, since the existing ones (broad beans, chickpeas and beans, mainly) are exclusively intended for human consumption.

Therefore, it is important to venture into the adaptation of soybean to temperate climates of the High Valleys, which are areas of productive potential that can be an option to meet the existing demand for this grain, in addition to being areas where there is a rural population that needs improvements in its nutrition and is also where the largest points of consumption are located. To adapt to cold environments, plants respond by changing their gene expression, having an impact on their distribution, survival and yield (Yepes and Silveira, 2011). According to Sanghera *et al*. (2011), many plants of tropical or subtropical origin die from being exposed to low temperatures that do not reach the freezing point or are damaged, manifesting cold injuries commonly in chlorosis, necrosis or growth retardation.

In soybean cultivation, it has been found that low temperatures (7 °C) have no effect on the oxidation of thylakoid proteins of the leaves, the damage was observed when the temperature changed from 7 to 25 °C, observing a decrease in the photosynthetic capacity (Tambussi *et al*., 2004). Other studies indicate that the soybean grown in southern Ontario, Canada and northern United States of America in a humid continental climate initially tolerate temperatures of 3 to 10 °C and only shows effects of reduction in germination, which can range from 44 to 58% as the temperature decreases (Vanhiea *et al*., 2015).

Soybean plants subjected to temperatures of 15 °C in the day and 10 °C at night decrease the elongation of the pods, values that range from 70 to 90%, until reaching 40% (Ohnishi *et al*., 2010). In North America and South Africa, some varieties of soybean tolerate a temperature range of 2 to 5 °C, decreasing the rate of development from 0.8 to 0.85, respectively, which affects the time to reach flowering, which can be up to 120 days (Piper, 1996). In Mexico, there are reports of soybean production at altitudes that range from 989 to 2 013 m (López and Muñoz, 1989), where the production of seven varieties was evaluated in the Mixteca Poblana in tropical, semi-arid and temperate climates. These authors found that the production ranged from 456 to 950.3 kg ha^{-1} in the locality with a temperate climate. Additionally, they found that, when going from 989 to 2 013 masl, the time to reach flowering increased from 14 to 39 days depending on the variety, which interacted with the presence of drought faced by the crop.

Based on the above, the response of soybean adaptation in the High Valleys, where the effect of low temperatures could be greater, is still unknown. It was hypothesized that some early selections can adapt to the thermo-pluviometric regime of the high valleys and have productive potential. Therefore, the objective of this study was to evaluate the grain production potential of seven experimental selections and two commercial varieties of soybean in three localities at altitudes of 2 190 to 2 240 m. The purpose is to make available to producers, in the near future, a new species and varieties for planting that help in the agricultural production systems of some of the temperate zones.

Materials and methods

Location of the study area

The establishment of soybeans was carried out at a site in the municipality of Calpan and two sites in the municipality of Coronango (in the municipal seat and in a place called La Ciénaga, separated three kilometers away), state of Puebla, Mexico. The municipality of Calpan is in the central western part of the state of Puebla at coordinates 19º 06’ 36” and 19º 41’ 12” north latitude and 98º 23’ 54” and 98º 32’ 24” west longitude. According to INAFED (2017), it has a more or less flat topography to the east, with a slight elevation in the southeast-northwest direction, soft and regular with an altitude of 2 240 m. Its climate is temperate subhumid with rains in summer. The municipality of Coronango is in the central western part of the state of Puebla at coordinates 19º 06’ 36” and 19º 10’ 42” north latitude and 98º 14’ 54” and 98º 19’ 40” west longitude. It has a flat topography with an altitude of 2 190 m. Its climate is temperate subhumid with rains in summer (INAFED, 2017). Precipitation data were recorded weekly using a TFA rain gauge, temperatures were also recorded weekly with an Extech RHT10® datalogger thermometer.

Plant material

Seven experimental selections of early cycle soybeans (BM2 Verde, Hoja Seca Original, Hoja Seca Vainas Abundantes, Hoja Seca Ombligo Negro, Hoja Verde Temporal, Hoja Verde Ramificada and Varita) and two commercial early cycle varieties (Cajeme and Nainary) were used. These commercial varieties were chosen because in a previous experiment (data not reported) the late varieties did not thrive and were damaged by frosts.

Soil preparation and sowing

The land was under the rainfed regime. The preparation of the land was done by plowing and harrowing. The sowing was done manually by placing a seed at a depth of approximately two centimeters, with a separation between seeds of eight centimeters and a distance between furrows of 70 cm. It was fertilized at the same time with the formula 28-75-75 of N-P-K, using the sources 18-46-00 and potassium sulfate (00-00-52). The sowing was carried out on May 15, 2018, in the locality of Calpan, on May 30, 2018, in Coronango and on June 1, 2018, in La Ciénega, dates on which there was sufficient availability of moisture for sowing.

Soybean harvest

The harvest was carried out when more than 50% of the plants reached a brown coloration. In the locality of Calpan the harvest was carried out from November 17 to 20, 2018, in Coronango the harvest was carried out from December 2 to 6, 2018, and in La Ciénega the harvest was carried out from December 13 to 17, 2018.

Study variables

Data for days to flowering were taken by counting the days that passed from sowing to the appearance of the first flowers in 50% of the population of the experimental unit. Plant height and canopy width were measured when flowering began, with the height being from the base of the soil to the tip of the plant. The canopy was measured considering the area that the plant covered. The grain production per hectare was determined from what was obtained from the threshing of the experimental unit. Likewise, pods per plant and number of grains per pod were counted in a sample of 20 plants as components of yield.

Experimental design and statistical analysis

A randomized complete block design with four repetitions was used. The experimental unit consisted of four furrows 0.7 meters wide and five meters long. A combined analysis of variance was performed including localities as a factor (Cochran and Cox, 1992) with the PROC GLM procedure of the statistical program SAS 9.4 (2002-2012). The comparison of means was performed with the Tukey test with α= 0.05.

Results and discussion

The effects of the interaction variety by locality only appeared for the variables of canopy, pods per plant, grains per plant and grains per pod, Table 1. The plants grown in the locality of Coronango registered the greatest heights, being 20% higher compared to the plants that grew in Calpan and La Ciénega (Table 2), this could be due to factors such as temperature, in Calpan there was a lower average than in the other two sites (15 *vs* 19 °C). The locality of Calpan had lower temperatures in the rainiest months, compared to the locality of Coronango (Figures 1 and 2), and greater variability in it.

Table 1. Parameters of the analysis of variance for the cultivation of soybean at three sites in the Puebla Valley.

Variable	Model Pr> F	R^2	CV	Mean	Type III Error Pr> F					
					Locality		Variety		Loc∗Var	
Flowering	<0.0001	0.95	2.9	93.29	<0.0001		<0.0001		0.819	ns
Height	<0.0001	0.67	14.5	71.11	<0.0001		0.009		0.152	ns
Canopy	0.0007	0.58	14.1	45.62	0.01		0.046		0.043	
Pods per plant	0.0027	0.55	35.1	40.23	0.1297	ns	0.056	ns	0.002	
Grains per plant	0.0023	0.55	36.2	72.08	0.02		0.075	ns	0.002	
Grains per pod	0.0004	0.59	51.1	1.7	<0.0001		0.02		0.02	
Yield	<0.0001	0.69	37.6	2579.8	<0.0001		0.005		0.09	ns
Empty seed	<0.0001	0.73	70.8	39.76	<0.0001		0.575	ns	0.264	ns

≤0.05= are significant; ≤0.01= are highly significant; ns= are not significant.

Table 2. Average behavior of the variables measured in the cultivation of soybean in three localities of the Puebla Valley.

Variable	Locality		
	Calpan	Ciénega	Coronango
Height (cm)	65 b	65.5 b	82.7 a
Canopy (cm)	48.4 a	44.7ab	43.4 b
Days to flowering	91 b	102 a	89 c
Pods per plant	38 a	38 a	44 a
Grains per plant	66 b	68 ab	82 a
Seeds per pod	1.5 c	2.4 a	1.7 b
Yield (t ha^{-1})	1.95 b	3.77 a	2.2 b
Empty grain (kg ha^{-1})	8 c	83.9 a	34 b

Different letters in the same row are statistically significant (p< 0.05).

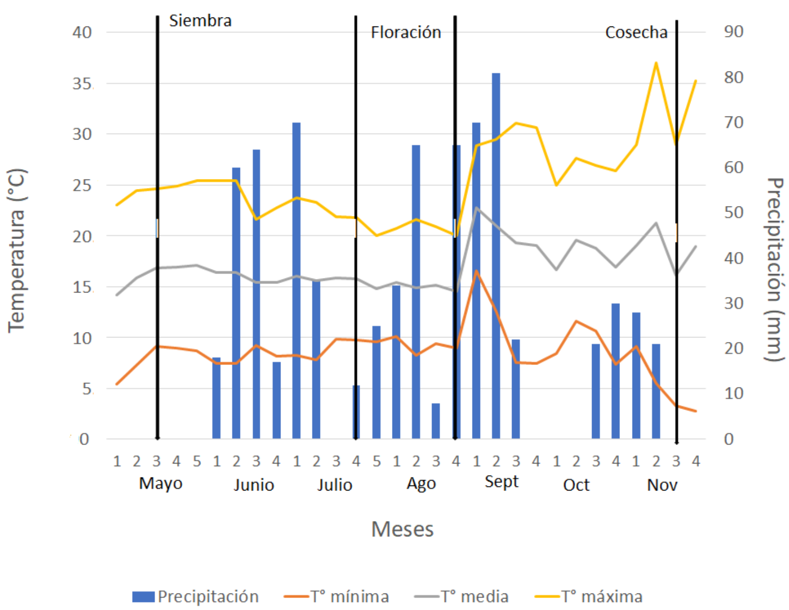

Figure 1. Weekly temperature and precipitation of the municipality of Calpan for the 2018 cultivation cycle.

The average minimum temperature in Calpan during the growing months of the crop was 9 °C, while in Coronango it was 12 °C (Figure 2). In this regard, Sanghera *et al*. (2011) found that subjecting soybean plants to low temperatures causes a delay in growth, which can have a negative impact on height. Ohnishi *et al*. (2010); Janas *et al*. (2000) mentioned that the minimum optimum temperature for the development of soybean is 25°/20 °C during the day and at night, respectively. Although this condition was not met at the three sites, Calpan had the lowest values. In the locality of La Ciénega, there was a hailstorm when the plants were in the vegetative stage, a phenomenon that delayed their growth, which had an impact on the final height reached.

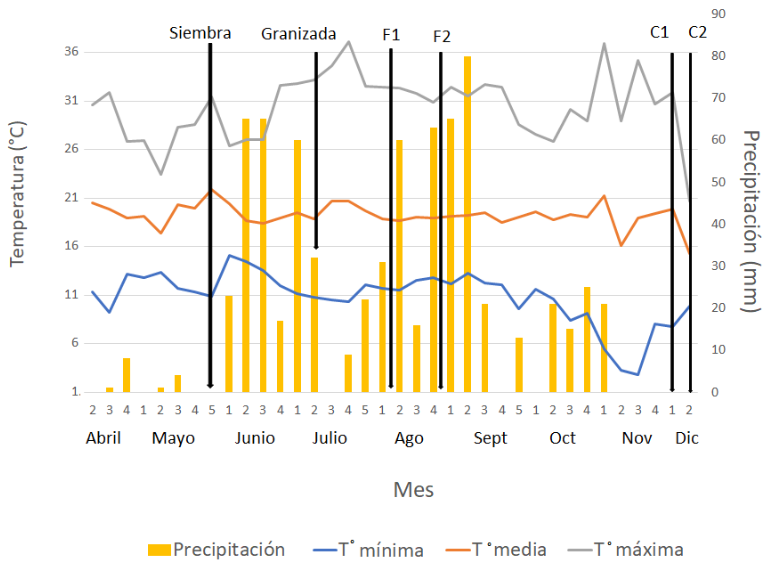

Figure 2. Weekly temperatures and precipitations corresponding to the municipality of Santa María Coronango for the 2018 cultivation cycle. F1= flowering in Coronango; F2= flowering in La Ciénega; C1= harvest in Coronango; C2= harvest in La Ciénega.

There were also differences between varieties (Table 3), although this was more noticeable in the Cajeme variety, which reached 79.6 cm compared to the Hoja Seca Ombligo Negro variety, which had 65.2 cm. In this case, the average was higher due to the high average height obtained in the locality of Coronango, in which the greatest heights were observed in all varieties. Overall, the varieties reached relatively similar values. Early soybean varieties were used in this study; however, within this group of maturity, it was possible to find varieties that continued to grow even after having begun the reproductive stage, as indicated by the OECD (2000).

Table 3. Behavior of the variables measured in nine varieties of soybean in the Puebla Valley.

Variety	Variable							
	Height (cm)	Canopy (cm)	Days to flow	Pods per plant	Seeds per pod	Grains per plant	Yield (t ha^{-1})	Empty grain (kg ha^{-1})
BM2	66.5 ab	45.7 a	100 a	44 a	1.9 ab	80 a	2.73 ab	49.6 a
C	79.6 a	44.4 a	97 a	42 a	1.4 b	76 a	2.76 ab	43.6 a
HSO	69.1 ab	41.7 a	81 b	34 a	1.5 ab	63 a	2.07 ab	32.51 a
HSON	65.2 b	43.1 a	100 a	33 a	1.5 ab	57 a	2.08 ab	38.4 a
HSVA	67.3 ab	43.1 a	78 b	50 a	2.6 a	88 a	2.36 ab	41.49 a
HVR	71.9 ab	49.5 a	98 a	50 a	1.9 ab	90 a	3.1 ab	42.13 a
HVT	65.8 ab	48.3 a	100 a	38 a	1.7 ab	65 a	2.45 ab	24.8 a
N	78.2 ab	49.7 a	99 a	35 a	1.4 b	61 a	2.02 b	51.05 a
V	74.5 ab	44.8 a	81 b	39 a	1.6 ab	73 a	3.42 a	34.4 a

BM2= BM2 Verde: C= Cajeme: HSO= Hoja Seca Original; HSVA= Hoja Seca Vainas Abundantes; HVR= Hoja Verde Ramificada; HVT= Hoja Verde Temporal; N= Nainary; V= Varita. Different letters in the same column are statistically significant ($p < 0.05$).

The days to flowering were different between localities (Table 2). The locality of La Ciénega had the longest periods to start flowering, followed by Calpan and Coronango. The long period to start flowering in La Ciénega was due to a hailstorm that occurred in the second week of July when the plants were in the vegetative stage, as shown in Figure 2. This phenomenon had a negative effect on the growth of soybean plants, observing defoliation of most of the plants and, in the case of the Hoja Seca Vainas Abundantes variety, the plants did not resist the phenomenon and perished.

The temperatures of Calpan at the time of cultivation are lower than those of Coronango (Figures 1 and 2); according to Piper (1996), when soybean is subjected to low temperatures (2 to 5 °C), the time to reach flowering can take up to 120 days (Piper, 1996). According to Abrahão and Costa (2018), the days to flowering are affected by low temperatures, water deficit and photoperiod. These authors mention that short photoperiods accelerate the flowering of plants, on the contrary, long photoperiods delay the start of flowering, in areas where the photoperiod is constant (for example, in equatorial areas), an increase is observed in the days to flowering if temperatures decrease, on the other hand, if the temperature is above 27 °C, flowering is inhibited (Gavioli, 2013).

Differences ($p < 0.001$) were found in the days to flowering between varieties (Table 3) of which, three varieties began their reproductive stage between 78 to 81 days after sowing (Hoja Seca Vainas Abundantes, Hoja Seca Original y Varita), so they can be considered as the earliest within the study group.

The behavior of the width of the canopy was different according to the locality ($p \leq 0.01$), the widest canopies (48.4 cm) were obtained in Calpan, compared to the Coronango site, Table 2. The production of more biomass before the appearance of the fruit tends to increase the number of grains and the yield of soybean (Nicoa *et al*., 2015). Although aerial biomass was not measured in the present study, it was related to the width of the canopy. A greater number of pods and grains was thus expected; however, the number of pods was the same in the three localities and the number of grains was higher in Coronango.

This may imply that there are other characteristics of the plant that are influencing the number of pods and grains, characteristics other than the width of the canopy, even the aerial biomass, which determine the variables of pods and grains per plant. Such characteristics may be related to some variables of soil fertility, for example, the soil of Calpan is sandy with low moisture retention, low content of organic matter and has little availability of nutrients. Also, some studies are opposed to what was reported by Nicoa *et al*. (2015), where it has been found that plants with more biomass have fewer grains, thus decreasing their yields (Masino *et al*., 2018), but this behavior was not detected in the present study as no differences were found between the varieties.

Both the number of pods and the number of grains per plant were not different between localities or between varieties (Table 2 and 3). As for the grain yield per hectare, the site that had the highest yield was La Ciénega, which exceeded the other sites by 55% on average. The yield of a crop depends on many variables, among them are those of the genetic type and the action of climatic factors such as temperature, precipitation, solar radiation, as well as soil characteristics such as the percentage of organic matter, content of nitrogen, phosphorus and potassium, among others (Simorte *et al*., 1995).

The yield of soybean in the locality of La Ciénega was higher compared to the other localities (Table 2) even though plant growth was affected by a hailstorm. This could be explained by the physical characteristics of the soil (Table 4), whose texture is sandy loam, suitable for all kinds of crops, in addition to having a very high content of organic matter (>8%) and being a soil very rich in nitrogen content (>0.25%). The higher fertility of the soil and the longer time of growth possibly had an impact on the number of grains reached per pod (Table 2).

Table 4. Physical characteristics of the soil of the municipalities of Calpan and Coronango.

Physicochemical property of the soil	Site		
	Ciénega	Coronango	Calpan
pH	6.15	7.08	5.59
Electrical conductivity (dS m^{-1})	0.06	0.14	0.15
Organic matter (%)	12.64	2.89	1.69
Inorganic N (mg kg^{-1})	18.2	18.2	9.1
P (mg kg^{-1})	24.62	10.33	20.38
K (mg kg^{-1})	486	610	146
Ca (mg kg^{-1})	4 198	2 305	343
Mg (mg kg^{-1})	949	594	77
Fe (mg kg^{-1})	34.58	5.55	7.98
Cu (mg kg^{-1})	0.83	1.91	1.2
Zn (mg kg^{-1})	3.13	1.56	0.57
Mn (mg kg^{-1})	5.51	13.94	1.39
B (mg kg^{-1})	3.01	1.36	0.82
Bulk density (g cm^{-3})	0.87	1.3	1.66
Sand (%)	58.2	60.2	88.2
Silt (%)	35.3	31.3	7.3
Clay (%)	6.5	8.5	4.5
Texture	Loam-sandy	Loam-sandy	Sandy

As for the average yield of the three sites between varieties, the contrasting difference was only between Varita and Nainary (3.1 *vs* 2.02 t ha^{-1}). Varita was statistically equal to the other varieties, but it was the variety with the highest ($p< 0.05$) yield in La Ciénega with 5.25 t ha^{-1}, although in Calpan and Coronango it had lower values, 2.58 and 2.43 t ha^{-1}, respectively, but without significant differences with respect to the other varieties in both localities. The average yield obtained in the locality of La Ciénega and the average yield of the varieties studied is comparable with the yields in the country (1 to 2 t ha^{-1}) and worldwide (2.1 and 2.6 t ha^{-1}) reported by FAOSTAT (2017).

The High Valleys of the state of Puebla have potential for soybean production, since the average yields obtained in each of the localities are higher than the average national yield of 1.67 t ha^{-1} obtained between 2012 and 2018, the locality of La Ciénega even had a higher yield of 3 t ha^{-1} obtained in the same period (SIAP, 2018). On the other hand, the productive potential of soybean in the High Valleys of Puebla can be determined by comparing the yields of commercial varieties reported in some studies conducted in soybean-producing areas; for example, Cortez *et al*. (2013) reported average yields of the Cajeme variety of 1.53 t ha^{-1} in Valle del Fuerte, Sinaloa, while Gómez *et al*. (2014) reported average yields of 1.5 and 1.9 t ha^{-1} obtained in the state of Hidalgo under rainfed conditions for Cajeme and Nainary, respectively, and 3.5 and 3.9 t ha^{-1} under irrigation conditions for Cajeme and Nainary, respectively, whose yields are comparable to those obtained in the present study.

Conclusions

The varieties with the best potential to be cultivated were Varita, Hoja Seca Vainas Abundantes and Hoja Seca Original since they reached flowering in less time and had acceptable average grain yields, this is important to prevent crop losses due to early frosts. The locality of the Puebla Valley with the most favorable conditions for the cultivation of soybean was La Ciénega, located in the municipality of Santa María Coronango. In this first approximation of test of varieties in the High Valley of Puebla, some potential for soybean production is observed; however, it is advisable to conduct more evaluations to confirm this assertion.

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