World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(Research Article)

Check for updates

Effect of temperature on productivity of common bean (*Phaseolus vulgaris* L.) sown during the fall in southern Sonora, Mexico

Pedro Félix-Valencia, Guillermo Fuentes-Dávila *, María Monserrat Torres-Cruz, José Eliseo Ortiz-Enríquez and Isidoro Padilla-Valenzuela

INIFAP, Campo Experimental Norman E. Borlaug, Apdo. Postal 155, km 12 Norman E. Borlaug entre 800 y 900 Valle del Yaqui, Cd. Obregón, Sonora, México.

World Journal of Advanced Research and Reviews, 2022, 16(02), 1037–1047

Publication history: Received on 10 October 2022; revised on 20 November 2022; accepted on 23 November 2022

Article DOI: https://doi.org/10.30574/wjarr.2022.16.2.1239

Abstract

During the last ten years, the agricultural area in southern Sonora, Mexico, has had greater hourly temperature oscillation associated to the growth cycle of common bean sown during the fall. The objective of this work was to evaluate the thermal impact caused by the high frequency of extreme temperatures on production of commercial bean during the fall-winter season 2021-2022. Four commercial fields were selected based on the irrigation system used (drip and gravity), two in each of the Yaqui and Mayo Valleys. Weather data were recorded by the automated weather station network of Sonora closest to each field and also from digital sensors installed within the crop. The results obtained indicated that the temperature recorded with the digital sensor, provided better relationship with the data taken in the commercial bean fields than the temperature recorded by the weather stations. The periods of extreme temperature ≥ 33 °C affected production of trifoliates, flowers, and pods in both cultivars evaluated Pinto Saltillo and Azufrado Higuera. The highest grain yield 3,860 kg ha^{-1} was obtained in the drip irrigated field in the Mayo Valley with a total water sheet of 42 cm, followed by the gravity irrigated field in the Yaqui Valley with 3,560 kg ha^{-1} and a total water sheet of 62 cm.

Keywords: Extreme temperature; Sowing date; *Phaseolus vulgaris*; Common bean; Irrigation

1. Introduction

Common bean (*Phaseolus vulgaris* L.) is a primary component in human consumption in many countries. For a number of years in the 2010´s, Brazil led bean production with 16%, followed by India (15.9%), Myanmar (10.5%), China (8.9%), and Mexico (5.8%) [1]. During the period 2003-2016, Mexico has shown a reduction in the area sown with bean (20.01%) as well as in productivity (23.05%) [2]; although the per capita consumption of bean in Mexico is 9.9 kg and production in 2016 was 1.08 million t which covered 89.24% of the domestic consumption, and the rest was supplied by importations from the United States (84.07%), Canada (13.47%), and China (2.05%). The production of bean in Mexico is based on the sowing season (spring, spring-summer, and fall-winter), if it is cultivated under rainfed conditions (76.07%) or irrigated, and on socioeconomics either for subsistence farming or for business agriculture [3]. The main bean types sown and consumed are: national and american pinto, regional azufrado and peruvian azufrado, flor de mayo, flor de junio, negro and bayo [4]. Common bean production in Mexico during the spring-summer season 2020 under irrigation and rainfed conditions was 729,337.97 t, from an area of 1,314,933.40 ha in 29 states with an average yield of 0.55 t ha^{-1}; the state of Zacatecas had the largest area sown with bean (639,850.50 ha) [5]. In the state of Sonora during the fall-winter 2020-2021, there were 8,695 ha harvested with a production of 20,038.93 t ha^{-1} and an average yield of 2.3; in southern Sonora during the fall-winter 2021-2022, there were 3,420 ha, 62% sown in the District

* Corresponding author: Guillermo Fuentes-Dávila, E-mail:fuentes.guillermo@inifap.gob.mx
INIFAP, Campo Experimental Norman E. Borlaug, Apdo. Postal 155, km 12 Norman E. Borlaug entre 800 y 900 Valle del Yaqui, Cd. Obregón, Sonora, México.

038 (Navojoa-Mayo Valley) and 38% in the District 041 (Cajeme-Yaqui Valley), and the average grain yield was 2.23 t ha^{-1} [6].

In southern Sonora, farmers use several ways for irrigation: flooding, furrow (the most common), drip, center pivot, frontal move, and spray irrigation [7]. In the case of beans which have increased in area in the last few years [8], farmers use primarily furrow irrigation and secondly drip irrigation. The most important bean diseases in the state of Sonora are dumping off [*Macrophomina phaseolina* (Tassi) Goid., *Sclerotium rolfsii* Sacc., *Rhizoctonia solani* Kühn, *Fusarium solani* (Mart.) Sacc. and *F. oxysporum* Schlechtend.:Fr. f. sp. *phaseoli* Kendrick & Zinder], white mold [*Sclerotinia sclerotiorum* (Lib.) de Bary], rust [*Uromyces appendiculatus* (Pers.:Pers.) Unger], powdery mildew (*Erysiphe polygoni* DC), halo blight [*Pseudomonas syringae* pv. *phaseolicola* (Burkholder) Young, Dye & Wilkie], common bacterial blight [*Xanthomonas axonopodis* pv. *phaseoli* (Smith) Vauterin, Hoste, Kersters and Swings], Bean common mosaic virus, Bean southern mosaic virus, Bean chlorotic mosaic virus, Bean golden yellow mosaic virus, Pumpkin leaf curly, and rust caused by the fungus *Uromyces appendiculatus* var. *appendiculatus* [9,10,11].

Since the temperature tendency to rise during the crop season, based on weather data from the las 10 years [12], it is important to consider the harmful effect on crop production by this climatic variance. It has been reported that the thermal range of bean growth is between 10 and 27 °C, with an optimum of 15 to 20 °C [13]; Baradas [14] indicates that the thermal range for bean growth is between 10 and 30 °C, with an optimum of 16 to 24 °C, while Hall [15] reported that the optimum temperature for growth ranges from 15.6 to 21.1 °C, the maximum being near 27 °C and the minimum near 10 °C. Padilla-Valenzuela *et al*. [9] reported that in southern Sonora the optimum thermal level for bean growth and production cycle is between 16 to 28 °C. According to its area of domestication and production, common bean is a warm-season annual grown primarily in subtropical or temperate areas, in the highlands, or during the cool, dry season in tropical areas [15]. Bean is a plant species highly sensitive to extreme temperatures; high temperatures induce abscission of reproductive organs which in turn affect grain yield [16]. Bean tissue is often killed by short exposure to freezing temperatures [15]. Extreme temperatures of 5 or 40 °C reduce flower production and cause sterility, irreversible damage to the crop [17].

Therefore, it is preponderant to take into consideration the changing climatic regime, for crop seasons in the near and medium term future, updating and defining the risk level that key agricultural practices like sowing dates and irrigation management may represent, so that timely recommendations for technological changes could be provided to farmers in order to achieve a sustainable production. The objective of this work was to evaluate the thermal impact on production of commercial bean, associated to the damage caused by the high frequency of extreme temperatures for sowing during the fall-winter crop season, under two irrigation systems.

2. Material and methods

This work was carried out in four commercial bean fields with progressive cooperating farmers, two in the Yaqui Valley and two in the Mayo Valley in the southern part of the state of Sonora, Mexico, during the crop season fall-winter 2021-2022. The bean cultivars used, the irrigation system, the sowing dates, and the periods of the reproductive stages are shown in Table 1.

Table 1 Bean cultivars, irrigation system, sowing dates, and periods of the reproductive stages during the crop season fall-winter 2021-2022, in the Yaqui and Mayo Valleys, Sonora, Mexico

Irrigation system/locality[y]	Cultivar	Sowing date	Reproductive stage[z]		
			Flowering	Pods	Abortion
D – YV	Pinto Saltillo	Sep 17, 2021	Oct 22 – Dec 15	Oct 27 – Dec 22	Nov 17 – Dec 15
D – MV	Pinto Saltillo	Sep 30, 2021	Oct 28 – Dec 8	Nov 01 – Dec 15	Nov 11 – Dec 15
G – YV	Azufrado Higuera	Oct 10, 2021	Nov 01 – Dec 8	Nov 05 – Dec 15	Not found
G – MV	Azufrado Higuera	Sep 24, 2021	Oct 25 – Dec 15	Oct 28 – Dec 15	Nov 11 – Dec 15

[y]D= drip irrigation, G= gravity. MV= Mayo Valley, YV= Yaqui Valley; [z]Periods of detection.

The growth habit of bean cultivar Pinto Saltillo is indeterminate type III postrate with a short terminal guide without climbing ability. Average height of the canopy is 38 cm and the terminal guide length 84. Flowering and physiological maturity take place between 62 and 70, and between 115 and 123 days after sowing, respectively, under irrigated conditions, and between 48 and 59, and between 87 and 100 days, respectively, under rainfed conditions The seed is medium in size with an average weight of 34 g for each of 100 seeds and it is highly resistant to oxidation; the seed is truncate or fastigiate in shape, light cream with light brown spots (Figure 1A), and does not darken under storage from 1 to more than 2 years, and therefore, its shelf life is longer than other beans. Average protein content is 21%, and cooking time is 80 min. The average grain yield under irrigation is 2,304 kg ha^{-1} and 1,139 under rainfed conditions. Pinto Saltillo is tolerant to anthracnose [*Colletotrichum lindemuthianum* (Sacc. and Magnus) Lams.-Scrib.], rust, damping off, and bacterial blight [18,19,20,21].

Figure 1 A) Seed of bean cultivar Pinto Saltillo; B) seed of bean cultivar Azufrado Higuera

Bean cultivar Azufrado Higuera has shown its greatest grain yield potential when sowing is carried out during the fall in October in northwestern Mexico, and it has minor phytosanitary problems if sown at the end of September and beginning of October. Growth habit is determinate type I, without terminal guide and produce a reduced number of primary branches (4 to 6). The canopy height is 40 cm, and flowering and physiological maturity are reached in 42 and 104 days after sowing, respectively. This cultivar is tolerant to rust and to virus diseases. The experimental average grain yield in four crop seasons in the northern part of the state of Sinaloa during the fall-winter is 3,183 kg ha^{-1} [22]. The seed is strong yellow in color, retains its color 24 months after harvest (Figure 1B), the protein content is 21%, and the cooking time is 50 min [23].

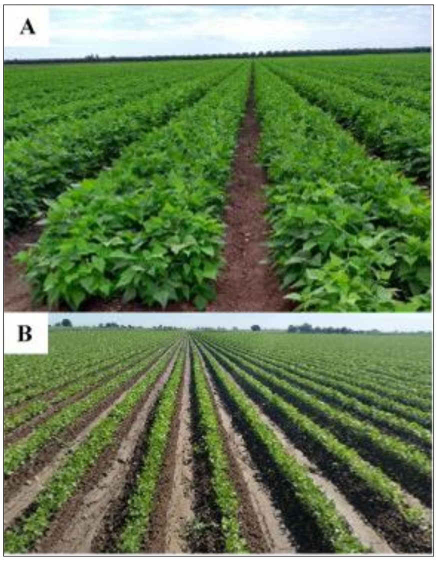

Figure 2 Bean fields of cultivar Pinto Saltillo, under A) drip irrigation and B) irrigation by gravity

Fields with drip irrigation (Figures 2A and 3A) used Stream Line 8000 strips [24] with droppers separated 30 cm apart from each other, which provide 0.89 liters per hour each. Beds were 0.50 m wide with two rows and the Netafim stream line strips were separated by 0.8 m. The field with irrigation by gravity in the Mayo Valley (Figure 2B), had an irrigation for seed germination and two complementary irrigations during the crop season with total water sheet of 48 cm, while the field in the Yaqui Valley (Figure 3B), and additional third irrigation of 14 cm was applied. In these two fields beds were separated by 0.8 m and had one row. Fields were located in Capetamaya and the experimental site (SEMAY) in the Mayo Valley, and in blocks 1922 and 2110 in the Yaqui Valley.

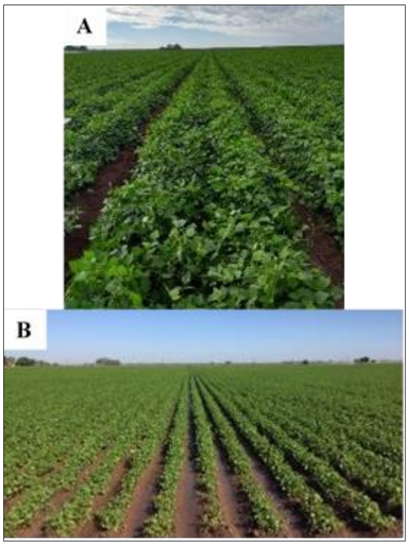

Figure 3 Bean fields of cultivar Azufrado Higuera, under A) drip irrigation and B) irrigation by gravity

The number of plants, trifoliates, flowers and pods were recorded during the season. Bean grain yield from each field was based on a sample of 1 m² and four random replications; plants were pulled out manually and let dry under the sunlight during a week. The counts of reproductive structures and the average grain yields were related to the critical threshold levels through the model for damage utilized by Félix Valencia *et al*. [25], through the analysis of variance [26] and the mean comparison by Tukey´s test (p = 0.05).

Temperature data were obtained from the closest weather station to each field, and from the data obtained from the digital sensors (Omega, serie OM-EL-WIN-USB, with Data Logger Software v7.2.1) installed within each field at the canopy level. The stations belong to the automated weather station network of Sonora (REMAS). The weather variables recorded in an hourly format were temperature and relative humidity.

3. Results and discussion

3.1. Comparison between temperature recorded by the weather stations and dataloggers within the crop

According to the model for damage utilized by Félix Valencia *et al*. [25], the periods recorded by days and continuous hours with temperature equal or greater than 33 °C, initiated from October 27 up to November 17, 2021 (Table 2), and the number of hours within that critical level during October and November, 2021, are shown in Table 3.

Table 2 Periods of risky temperature ≥ 33 °C, in four commercial bean fields during the fall-winter season 2021-2022, in the Yaqui and Mayo Valleys, Sonora, Mexico

Irrigation system/locality	Datalogger within the crop		Weather station		
Drip – Mayo Valley	Oct 28 – Nov 10	Nov 12 – 15	Oct 28 – Nov 09	Nov 11 – 17	
Drip – Yaqui Valley	Oct 27 – Nov 07	Nov 13 - 16		Nov 14 – 16	
Gravity – Mayo Valley	Oct 28 – Nov 02			Nov 13 – 16	
Gravity – Yaqui Valley	Oct 27 – Nov 11		Oct 28 – 30	Nov 01 – 07	Nov 14 – 16

The information provided in Table 2 between the weather stations closest to the fields of study and the dataloggers within the crop, indicates that the latter recorded constant periods more congruent to the information obtained from the fields than the temperature data recorded by the weather stations; for example, dataloggers recorded two risk periods for fields with drip irrigation while the weather stations recorded two for drip irrigated field in the Mayo Valley and one for field in the Yaqui Valley; for gravity irrigated fields, dataloggers recorded one risk period while weather stations recorded one risk period for the field in the Mayo Valley and three for the field in the Yaqui Valley.

The total number of hours with continuous temperature ≥ 33 °C recorded by the weather stations in fields with drip and gravity irrigation in the Mayo Valley were 103 and 37, and 26 and 55 in the Yaqui Valley, respectively, while dataloggers recorded in the same order 85 and 61, and 78 and 98 (Table 3). Therefore, the risk of the bean reproductive stage was measured based on the data obtained from the dataloggers. However, under drip irrigation these digital sensors recorded similar number of hours with continuous temperature ≥ 33 °C between fields in both valleys, but those under gravity irrigation had a greater difference.

Table 3 Number of hours with continuous temperature ≥ 33 °C, recorded by the sensor and the weather stations closest to each of four commercial bean fields, in the Yaqui and Mayo Valleys, Sonora, Mexico, under two irrigation systems, during the fall-winter 2021-2022

Period	Drip – Mayo Valley		Drip – Yaqui Valley		Gravity – Mayo Valley		Gravity – Yaqui Valley	
	W. station	Datalogger	W. station	Datalogger	W. station	Datalogger	W. station	datalogger
October 27				5				5
28	6	5	4	6	3	5	4	6
29	6	6		5	3	7	4	6
30	5	4		4		7	3	5
31	5	4		3		5		5
November 01	6	6	3	6	3	7	4	7
02	5	5	5	7	4	6	5	7
03	5	6		4			4	6
04	4	4		3		4	3	6
05	5	4		3		3	3	6
06	5	5		3	3		3	6
07	6	8		5	3	3	3	7
08	4	3						5
09	5	4		3		3	4	5
10		3						4
11	5							4
12	5	4						
13	4	4		4	3	5		
14	6	5	5	6	5	6	5	4
15	7	5	6	7	6		6	4
16	6		3	4	4		4	
17	3							
Total	103	85	26	78	37	61	55	98

3.2. Relationship between the period of extreme temperature and production of flowers and pods

To determine the effect of the extreme high temperature on the production of trifoliates, flowers, and pods, a representative sample was evaluated in each of the four fields from a one square meter.

3.2.1. Drip irrigation

Yaqui Valley. Bean cultivar Pinto Saltillo was sown on September 17, 2021, so the initial flowering stages and first pod formation occurred between October 22 and 27, therefore, they were affected by extreme temperatures ≥ 33 °C that were present from October 27 to November 17 (Figure 4), although there were no extreme temperatures on November 8 and 10-12. This field had the lowest number of trifoliates (T), flowers (F), and pods (P), although, not the highest number of abortions of F and P. The aborted P had a size ranging from 1 to 20 cm long. While 43 T, 27 F, and 30 P were recorded in this field, 107, 36, and 96, respectively, were detected in the drip irrigated field in the Mayo Valley; in the fields irrigated by gravity in the Yaqui and Mayo Valleys, there were 95, 46, and 88, and 168, 56, and 114, respectively.

The lowest production of T, F, and P could be attributed to deficient irrigation, since this field received 8 irrigations with a total water sheet of 27 cm, 15 cm less than in the field with drip irrigation in the Mayo Valley and 35 and 21 cm less than in the fields irrigated by gravity in the Yaqui and Mayo Valleys, respectively. Padilla-Valenzuela *et al*. [9] mention that bean is highly sensitive to hydric deficit during flowering, because it causes a reduction in the root system due to death of older roots, and the effect is irreversible. They indicate that for bean cultivated during the fall-winter in northwest Mexico, requires about 34 cm and for the spring-summer crop season about 41. Efetha [27] reported that dry bean grown under optimal conditions requires from 30 to 37.5 cm of water per growing season in southern Alberta, Canada.

Mayo Valley. Bean cultivar Pinto Saltillo was sown on September 30, 2021, flowering started around October 28 and from November 1 the first pods were produced. With the exception of November 11, extreme high temperature periods occurred from October 28 to November 15 (Figure 5), with the consequent flower abortion as well as pods shorter than 5 cm. Registration of the number of abortions were taken from November 11 to December 15; pods shorter than 20 cm were affected by the temperature lower than 33 °C after the extreme period, and were the most frequently found in the ground. A high production of pods were observed after November 18 under sufficient irrigation.

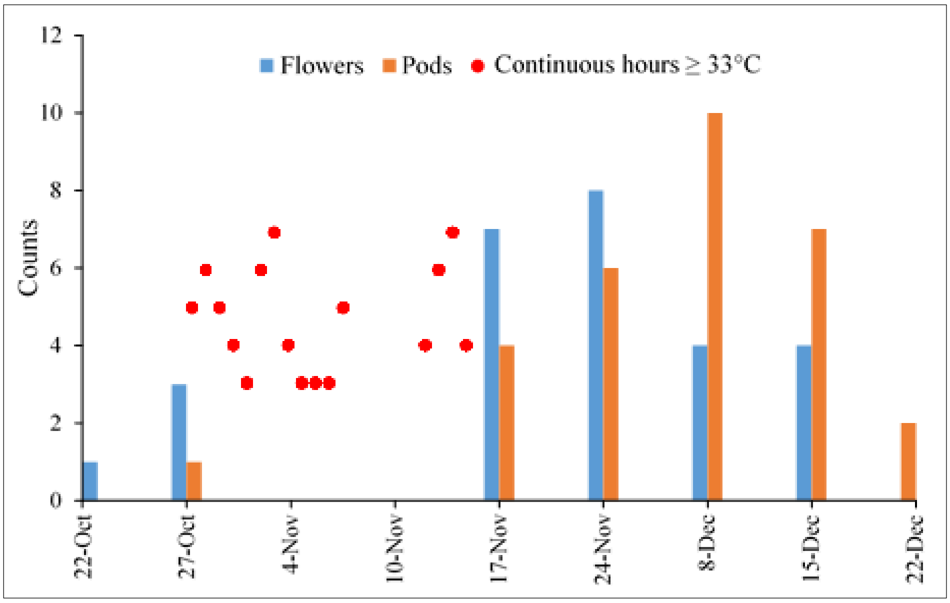

Figure 4 Occurrence of temperature ≥ 33 °C during the reproductive stage of bean cultivar Pinto Saltillo, in a commercial field under a drip irrigation system in the Yaqui Valley, Sonora, Mexico, during the crop season fall-winter 2021-2022

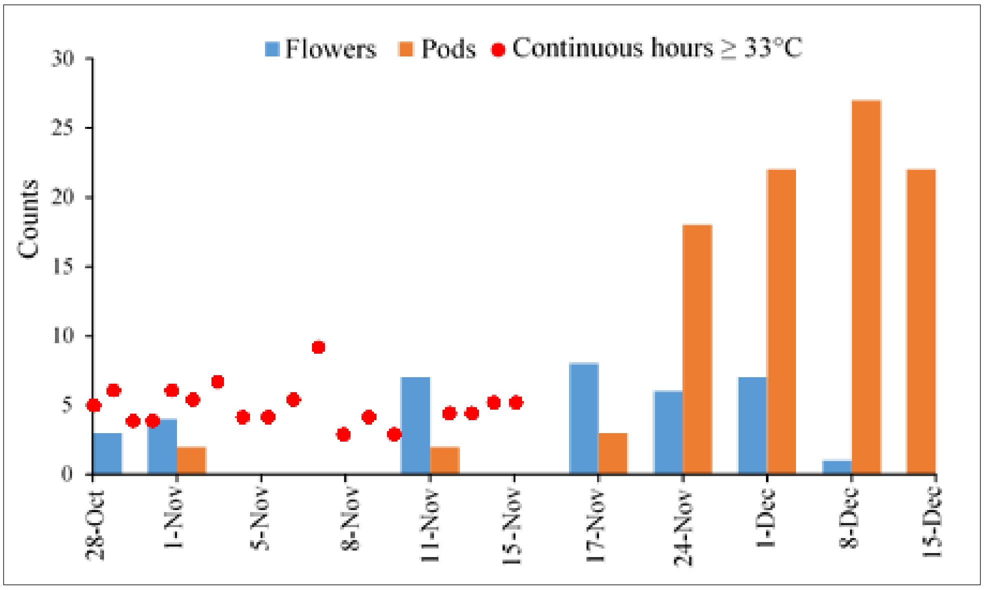

Figure 5 Occurrence of temperature ≥ 33 °C during the reproductive stage of bean cultivar Pinto Saltillo, in a commercial field under a drip irrigation system in the Mayo Valley, Sonora, Mexico, during the crop season fall-winter 2021-2022

3.2.2. Gravity irrigation

Yaqui Valley. Bean cultivar Azufrado Higuera was sown on October 10, 2021. Flowering initiation and pod formation were detected between November 1 and 5, period in which F and P detected were few in number, but after November 15, the crop escaped part of the extreme high temperature periods that occurred between October 27 and November 11 (Figure 6). There were no abortion of neither flowers nor pods during the whole reproductive stage (Table 1); however, it is noteworthy a lower production of T, F, and P than the gravity irrigated field in the Mayo Valley (95, 46, and 88, and 168, 56, and 114, respectively). This field had the highest water sheet with 62 cm.

Mayo Valley. Bean cultivar Azufrado Higuera was sown on September 24, 2021. Flowering initiation and pod formation were detected between October 25 and 28. There were several periods of extreme temperature after October 28, with a gap of one day between November 2 and 4, 5 and 7, 7 and 9, and three days between November 9 and 13, and after November 14 (Table 3). The highest number of T, F, and P were detected between November 17 and December 1 (Figure 7).

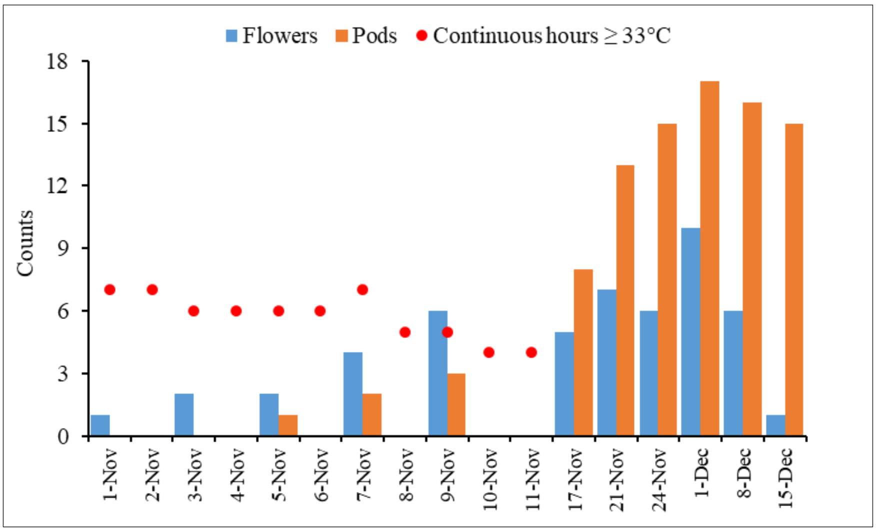

Figure 6 Occurrence of temperature ≥ 33 °C during the reproductive stage of bean cultivar Azufrado Higuera, in a commercial field under a gravity irrigation system in the Yaqui Valley, Sonora, Mexico, during the crop season fall-winter 2021-2022

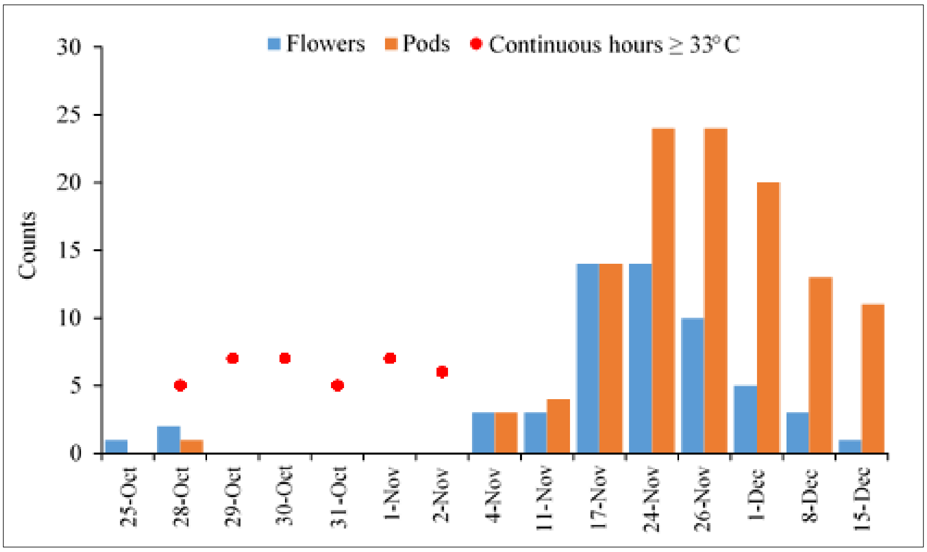

Figure 7 Occurrence of temperature ≥ 33°C during the reproductive stage of bean cultivar Azufrado Higuera, in a commercial field under a gravity irrigation system in the Mayo Valley, Sonora, Mexico, during the crop season fall-winter 2021-2022

3.2.3. Bean grain yield obtained by the irrigation systems and water sheets applied

The analysis of variance showed highly significant differences between localities, irrigation systems, and their interaction. The coefficient of variation (CV= 6.5%) and the coefficient of determination (R^2 Adjusted= 0.96) showed that the model is reliable. Mean comparison of grain yield (Table 4) showed that the drip irrigated field in the Mayo Valley had the highest yield with 3,860 kg ha^{-1}, followed by the gravity irrigated fields in the Yaqui and Mayo Valleys with 3,560 and 3,040 kg ha^{-1}, respectively (Figure 8). These results agree with the evaluation of Padilla-Valenzuela *et al.* [9], where the grain yield of a drip irrigated field was 48% greater than a gravity irrigated field in southern Sonora; the total water sheet used for the irrigated field was 29 cm, while for the gravity irrigated field it was 78 cm. It is evident that the drip irrigated field in the Yaqui Valley did not fulfilled the expectations, since according to the cooperating farmer, the system had leaks which ultimately affected the final outcome with only 1,340 kg ha^{-1}.

Table 4 Mean comparison of grain yield from two fields sown with bean cultivar Pinto Saltillo under drip irrigation, and two with Azufrado Higuerilla under gravity irrigation in the Yaqui and Mayo Valleys, Sonora, Mexico, during the crop season fall-winter 2021-2022. Tukey (α= 0.05)

Locality	Irrigation system	Cultivar	Mean
Mayo Valley	Drip	Pinto Saltillo	0.386 A
Yaqui Valley	Gravity	Azufrado Higuera	0.356 A
Mayo Valley	Gravity	Azufrado Higuera	0.304 B
Yaqui Valley	Drip	Pinto Saltillo	0.134 C

LSD= 0.04045.

The differences among the water sheets applied influenced greater efficiency in the drip irrigated field from the Mayo Valley, as the average number of pods in a one square meter was 655, followed by the gravity irrigated field in the Yaqui Valley with 563, 480 for the field in the Mayo Valley with gravity irrigation, and 272 in the drip irrigated field in the Yaqui Valley. The percentage of pods without grain, in the same order, were 2, 21.7, 22.5, and 28.7%, respectively.

The wide environmental adaptability reported in some edible bean types, indicates that some cultivars may stand extreme temperatures between 5 and 40 °C [28], but the low production of trifoliates, flowers, and pods by cultivars Pinto Saltillo and Azufrado Higuera showed that do not stand extreme high temperature (Figures 4-7). Barrios-Gómez *et al.* [29] indicated that high canopy temperature reduced seed yield, final aerial biomass, number of pods per m^2, and weight of 100 seeds. Rainey and Griffiths [30] reported that a day/night temperature of 33/30 °C caused an average reduction of 83, 63, 47, and 73%, in seed and pod number, mean seed weight and seeds/pod, respectively, during an evaluation of 24 common bean (*P. vulgaris*) genotypes; however, a day/night temperature of 30/27 °C may be used to screen for genotypes with moderate heat tolerance, since some showed stable yields. They indicated that data will help to use nonallelic heat tolerance genes in the development of bean cultivars grown in high temperature environments.

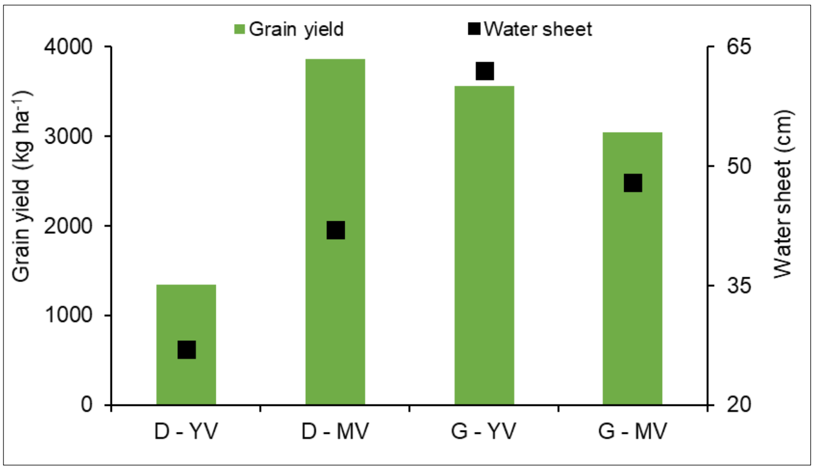

Figure 8 Grain yield of bean cultivars Pinto Saltillo and Azufrado Higuera in the Yaqui (YV) and Mayo (MV) Valleys, under drip (D) and gravity irrigation (G), during the crop season fall-winter 2021-2022 in the state of Sonora, Mexico

It is highly important the availability of sufficient water to the plant, since the drip irrigated field in the Mayo Valley with a total water sheet of 42 cm, had a grain yield greater than the two gravity irrigated fields in the Yaqui and Mayo Valleys with 62 and 48 cm, respectively, which in turn physiological responses are triggered. Bean leaves are plant organs more affected by intermittent drought stress [31], and water deficit at the beginning of the crop growth [vegetative growth (V1-V2) stage], dramatically reduce dry bean growth and development, and result in a significant reduction in seed yield [32]. Martínez *et al*. [33] found that after subjecting several bean cultivars to two frequencies of irrigation (every 7 and 21 days), there was a strong negative correlation between the drought resistance index (DRI) and palisade cell size under water stress conditions (r^2 = 0.85), and a strong positive one between palisade cell size and turgid weight to dry weight ratio (TW/DW) (r^2 = 0.86); thus, the higher DRI was associated with small palisade cell size and small TW/DW. Parsons and Howe [34] compared Tepary bean (*Phaseolus acutifolius* Gray var. *latifolius*), a drought resistant species, with the susceptible *P. vulgaris* L. cvs Pinto and White Half Runner (WHR) under water stress conditions, and reported that Tepary had significantly lower osmotic potential than the *P. vulgaris* cultivars, but little difference in osmotic potential between Pinto and WHR. They indicated that determining the differences in osmotic and turgor potentials among and within species, could be useful in breeding for drought resistance in *Phaseolus*. Stoyanov [35] determined that water stress imposed to leaves of young common bean (*P. vulgaris*) 14 days after the emergence, by withholding water until soil water potential reached -0.9 MPa, led to a decrease in osmotic potential at full hydration and turgor loss point, in the primary and the first trifoliate leaves of all the cultivars evaluated. In contrast, high osmotic adjustment was found in three cultivars which displayed significant differences in their adaptive response to drought. They indicated that osmotic adjustment is one of the major adaptive mechanisms of *P. vulgaris* to survive drought, and that the main difference among cultivars appears to be due to turgor maintenance, which may be more representative of the physiological status of the leaves in these cultivars.

4. Conclusion

Temperature recorded with a digital sensor (datalogger) within the crop, provided better relationship with the data taken in the commercial bean fields than the temperature recorded by the weather station. The periods of extreme temperature ≥ 33 °C affected production of trifoliates, flowers, and pods in both cultivars evaluated Pinto Saltillo and Azufrado Higuera. The highest grain yield 3,860 kg ha^{-1} was obtained in the drip irrigated field in the Mayo Valley with a total water sheet of 42 cm, followed by the gravity irrigated field in the Yaqui Valley with 3,560 kg ha^{-1} and a total water sheet of 62 cm.

Compliance with ethical standards

Acknowledgments

This research was financially supported by the Mexican National Institute for Forestry, Agriculture, and Livestock Research (INIFAP), Competitive SIGI Grant No. 16402335149.

Disclosure of conflict of interest

The authors declare that No conflict of interest.

References

[1] Lépiz IR, Sánchez PS, López AE, López AJJ, Chavarín EIE, y Meza VKE. El cultivo de frijol en Jalisco. Tecnología para altos rendimientos. Universidad de Guadalajara. Las agujas, Municipio de Zapopan, Jalisco, México. 54 p. 2015. Available at: http://www.cucba.udg.mx/sites/default/files//adjuntos/el_cultivo_de_ frijol_ en_jalisco.pdf.

[2] SAGARPA (Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación). Planeación agrícola nacional. Frijol mexicano. 2017. https://www.gob.mx/cms/uploads/ attachment/file/256428/B_sico-Frijol.pdf. Accessed on September 15, 2021.

[3] Acosta GJA, Rosales SR, Navarrete MR y López SE. Desarrollo de variedades mejoradas de frijol para condiciones de riego y temporal en México. Agricultura Técnica en México. 2000; 26(1): 79-98.

[4] Castellanos ZJ, Guzmán MH, Jiménez A, Mejía C, Muñoz RJJ, Acosta GJA, Hoyos G, López SE, González ED, Salinas PR, González AJ, Muñoz VJA, Fernández HP y Cáceres B. Hábitos preferenciales de los consumidores de frijol común (*Phaseolus vulgaris* L.) en México. Archivos Latinoamericanos de Nutrición. 1997; 47(2): 163-167. Available at: https://www.alanrevista.org/ediciones/1997/2/art-13/.

[5] SIAP (Servicio de Información Agroalimentaria y Pesquera). Anuario estadístico de la producción agrícola. 2021. https://nube.siap.gob.mx/cierreagricola/. Accessed on May 20, 2021.

[6] OIAPES (Oficina de Información Agropecuaria y Pesquera del Estado de Sonora). Agricultura, Subsector Agrícola. Producción Agrícola Estatal – Reporte Ejecutivo; avance de producción agrícola 2022. http://oiapes.sagarhpa.sonora.gob.mx/datosagp/infcierreagriedoejep.asp. Accessed on September 18, 2022.

[7] SAGARHPA (Secretaría de Agricultura, Ganadería, Recursos Hidráulicos, Pesca y Acuacultura, Sonora). Estudio sobre la Situación de la Tecnificación del Riego en el Estado de Sonora. Hermosillo, Sonora, México. 2011. 111 p.

[8] INIFAP (Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias). Avanza en Sonora el proyecto: Refrescamiento de semilla de frijol para México. 2020. https://www.gob.mx/inifap/articulos/avanza-en-sonora-el-proyecto-refrescamiento-de-semilla-de-frijol-para-mexico?idiom=es. Accessed on July 15, 2021.

[9] Padilla-Valenzuela I, Castillo-Torres N, Ramírez-Arredondo JA, Armenta-Cárdenas I, Cabrera-Carbajal F, Madrid-Cruz M y Ortiz-Enríquez JE. Manual para la producción de frijol en el Sur de Sonora. Folleto Técnico No. 69. SAGARPA-INIFAP-Campo Experimental Valle del Yaqui. Ciudad Obregón, Sonora, México. 2009. 122 p. Available at: https://www.compucampo.com/tecnicos/manualproduccion-frijol-son.pdf.

[10] Ramírez AJA. Control químico de Uromyces phaseoli var. typica y Erysiphe polygoni en frijol en el Valle del Mayo, Sonora. XVIII Congreso Nacional de Fitopatología. 24 al 26 de julio de 1991. Puebla, Puebla, México.

[11] Valenzuela LJ y Armenta CI. Guía para cultivar frijol en el sur de Sonora. Folleto para productores No 1. 1990. Campo Experimental Valle del Mayo. SAGARPA-INIFAP-CIANO. Cd. Obregón, Sonora, México. 16 p.

[12] REMAS (Red de Estaciones Metereológicas Automáticas de Sonora). Descargar datos. 2021. http://www.siafeson.com/remas/. Accessed on July 10, 2022.

[13] Doorenbos J y Kassam AH. Efectos del agua sobre el rendimiento de los cultivos. Estudio FAO: Riego y Drenaje No. 33. 1979. FAO. Roma, Italia. 212 p.

[14] Baradas MW. Crop requirements of tropical crops. pp. 189-202. In: Handbook of agricultural meteorology. 1994. JF Griffiths (Ed.). Oxford University Press. New York, New York, USA. p. 320. ISBN: 0-19-506240-x.

[15] Hall R. Compendium of Bean Diseases. American Phytopathological Society. 1991. APS Press. St. Paul, MN, USA. 73 p.

[16] Benacchio SS. Algunas exigencias agroecológicas en 58 especies de cultivo con potencial de producción en el Trópico Americano. FONAIAP-Centro Nacional de Investigaciones Agropecuarias. Ministerio de Agricultura y Cría. 1982. Maracay, Venezuela. 202 p.

[17] White WJ. Conceptos básicos de fisiología en frijol. pp. 43-60. In: Frijol, investigación y producción. 1985. Compilado y editado por M. López, F. Fernández y A. Schoonhoven. CIAT. Cali, Colombia.

[18] Sánchez Valdez I. Pinto Saltillo: nueva variedad de frijol para el sureste del estado de Coahuila. Desplegable Técnica No. 8. 2001. INIFAP - Campo Experimental Saltillo. Saltillo, Coahuila, México.

[19] Sanchez-Valdez I, Acosta-Gallegos JA, Ibarra-Pérez FJ, and Rosales-Serna R. Registration of “pinto Saltillo” common bean. Crop Science. 2004; 44(5): 1865-1866. doi:10.2135/cropsci2004.1865a.

[20] Sánchez Valdez I, Acosta Gallegos JA, Ibarra Pérez FJ, Rosales Serna R, Cuéllar Robles EI. Pinto Saltillo: variedad mejorada de frijol para el estado de Durango. Folleto Técnico Número 36. 2009. Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Centro de Investigación Regional Norte Centro, Campo Experimental Valle de Guadiana. Durango, Durango, México. 28 p.

[21] Sánchez Valdez I, Ibarra Pérez FJ, Rosales Serna R, Singh SP, Acosta Gallegos JA. Pinto Saltillo: nueva variedad de frijol para el Altiplano de México. Agricultura Técnica en México. 2001; 27(1): 73-75. Available at: https://www.redalyc.org/pdf/608/60827108.pdf.

[22] Salinas Pérez RA, Navarro Sandoval FJ, Rodríguez Cota FG y Padilla Valenzuela I. Azufrado Noroeste y Azufrado Higuera: Nuevas variedades para Sinaloa. Folleto Técnico No 11. 1995. INIFAP, Campo Experimental Valle del Fuerte. Juan José Ríos, Sinaloa, México. 16 p.

[23] Cruz-Cruz E, Acosta-Gallegos JA, Reyes-Muro L, Cueto-Wong JA. Variedades de frijol (*Phaseolus vulgaris* L.) del INIFAP. Libro Técnico Número 2. 2021. Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias. Ciudad de México, México. 98 p.

[24] NetafimTM. Stream line plusTM gotero integrado. 2022. https://www.netafim.com.mx/bynder/5056FFE6-B315-41F9-BEFCDB6A0A50D5DC-streamline-plus-one-page-pdf---spa.pdf. Accessed on March 13, 2022.

[25] Félix Valencia P, Ortiz Enríquez JE, Cabrera Carbajal F, Chávez Villalba G, Fuentes Dávila G y Figueroa López P. Daños a la producción de trigo causado por heladas en el sur de Sonora. Diagnóstico del ciclo de trigo OI-2010-2011. 2012. INIFAP, Centro de Investigación Regional del Noroeste, Campo Experimental Norman E. Borlaug. Folleto Técnico No. 87. Cd. Obregón, Sonora, México. 70 p.

[26] InfoStat. Manual del Usuario, versión 2008. Facultad de Ciencias Agropecuarias, Universidad Nacional de Córdoba. 2008. Córdoba, Argentina. 334 p.

[27] Efetha A. Irrigation scheduling for dry bean in southern Alberta. Agri-Facts. 2011. Available at: https://open.alberta.ca/publications/5333897-2011

[28] White JW, and Singh SP. Breeding for adaptation to drought. pp. 501-560. In: Art Van Schoonhoven and O. Voysest (Eds.) Common bean: Research for Crop Improvement. CAB International (Centre for Agricultural Bioscience International) and CIAT (Centro Internacional de Agricultura Tropical). 1991. Cali, Colombia. 980 p.

[29] Barrios-Gómez EJ, López-Castañeda C. y Kohashi-Shibata J. Relaciones hídricas y temperaturas altas en frijol del tipo “Flor de Mayo”. Agronomía Costarricense. 2011; 35(1): 131-145. Available at: https://www.redalyc.org/pdf/ 436/43622353008.pdf.

[30] Rainey KM, and Griffiths PD. Differential response of common bean genotypes to high temperature. Journal of the American Society for Horticultural Science. 2005; 130(1): 18-23. doi:https://doi.org/10.21273/JASHS.130.1.18

[31] Acosta Díaz E, Acosta Gallegos JA, Amador Ramírez MD y Padilla Ramírez JS. Relación entre índice de área foliar y rendimiento en frijol bajo condiciones de secano. Agricultura Técnica en México. 2008; 34(1): 13-20. Available at: https://www.scielo.org.mx/pdf/agritm/v34n1/v34n1a2.pdf.

[32] Rai A, Sharma V, and Heitholt J. Dry bean (*Phaseolus vulgaris* L.) growth and yield response to variable irrigation in the arid to semi-arid climate. Sustainability. 2020; 12(9): 3851. doi:10.3390/su12093851.

[33] Martínez JP, Silva H, Ledent JF, and Pinto M. Effect of drought stress on the osmotic adjustment, cell wall elasticity and cell volume of six cultivars of common beans (*Phaseolus vulgaris* L.). European Journal of Agronomy. 2007; 26(1): 30-38. https://doi.org/10.1016/j.eja.2006.08.003.

[34] Parsons LR, and Howe TK. Effects of water stress on the water relations of *Phaseolus vulgaris* and the drought resistant Phaseolus acutifolius. Physiologia Plantarum. 1984; 60(2): 197-202. https://doi.org/10.1111/j.1399-3054.1984.tb04564.x.

[35] Stoyanov ZZ. Effects of water stress on leaf water relations of young bean plants. Journal of Central European Agriculture. 2005; 6(1): 5-14. Available at: https://jcea.agr.hr/en/issues/article/194.