Colegio de Postgraduados

Response of improved common bean (*Phaseolus vulgaris* L.) varieties to intermittent drought

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ABSTRACT

Objective: To evaluate the response of 16 improved bean varieties to intermittent drought.

Design/Methodology/Approach: A randomized complete block design was used, with four replications each under irrigated and drought conditions. The drought treatment consisted of suspending irrigation for 15 days in the flowering stage. The irrigation treatment consisted of maintaining available moisture above 60% throughout the cycle. The yield, its components, and days to physiological maturity were recorded. The drought tolerance of each variety was estimated using the drought susceptibility index, geometric mean, and productive mean.

Results: Drought reduced yield by 36%, the number of pods per plant by 28.5%, and days to physiological maturity by 0.7%. In contrast, the weight of 100 seeds increased by 4.9% and the number of seeds per pod was not affected. The Flor de Mayo Eugenia and Negro 8025 varieties were more tolerant to drought ($p \leq 0.05$) than the rest of the varieties analyzed. These varieties recorded yields of 2,768 and 2,854 kg ha^{-1} (irrigation) and 1,905 and 1,843 kg ha^{-1} (drought), respectively.

Study Limitations/Implications: The drought intensity applied was relatively low, which could reduce the visibility of the differences between treatments.

Findings/conclusions: The secondary attribute with more sensitivity to intermittent drought was the number of pods per plant. The varieties with highest tolerance to droughts were Flor de Mayo Eugenia and Negro 8025.

Keywords: Drought tolerance, water stress, yield components.

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INTRODUCTION

The common bean (*Phaseolus vulgaris* L.) (Fabaceae) holds the second place in sown area in Mexico, 88% of which is grown under rainfed conditions (SIAP, 2021). In the north and center of the country, intermittent drought is the abiotic factor that most limits the production of this legume in the main producing regions (Acosta *et al.*, 2021). Yield losses between 12 and 92% have been recorded, depending on the duration and intensity of the drought, as well as the phenological stage and the genotype of the bean (Muñoz-Perea *et al.*, 2006). For example, Darkwa *et al.* (2016) found that some bean genotypes are not affected by a drought intensity of 30%, while others reduced seed yield a >60%. The phenological stage more sensitive to drought is flowering, followed by formation and filling pods (Beebe *et al.*, 2013).

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Developing drought-adapted bean varieties is essential to achieve a better understanding of the relationship between drought and yield, based on drought tolerance or susceptibility indices, yield components, phenology, and other attributes (Beebe *et al.*, 2013; Chaves-Barrantes *et al.*, 2018). The drought susceptibility index indicates yield stability and therefore is one of the soundest methods used to select drought resistant bean genotypes (Sánchez-Reinoso *et al.*, 2020); however, its capacity to detect potential high-yielding genotypes (which is also an important characteristic for selection) is known to be imprecise (Papathanasiou *et al.*, 2022). This deficiency is resolved through the use of complementary productivity indices, such as the geometric mean of yield and the productive mean (Rosales-Serna *et al.*, 2000). Chaves-Barrantes *et al.* (2018) pointed out that, due to the randomness of intermittent droughts throughout the cycle, the selected genotypes nevertheless show high performance under optimal and stress conditions. The analysis of the yield components (pods per plant, seeds per pod, and individual seed weight) helps to determine, in a given situation, which of them puts more limits on the seed yield and to choose the appropriate corrective measures (Kohashi, 1996). They are also useful as secondary criteria in the selection of varieties based on drought tolerance (Rai *et al.*, 2020). Phenological plasticity —which is the modification of the duration of the phenological stages, as a consequence of moisture availability— is a valuable drought tolerance mechanism in places with intermittent droughts (Beebe *et al.*, 2013), while greater precocity is essential in places where terminal drought prevails (Tosquy-Valle *et al.*, 2014).

In northern and central Mexico, few studies have been carried out on intermittent drought and its impact on bean seed yield, and they have mainly considered Flor de Mayo genotypes (Barrios *et al.*, 2011; Romero-Félix *et al.*, 2018; Romero-Félix *et al.*, 2019). Therefore, studies of genotypes with other seed types and market demand are required. The objective of this research was to evaluate the response of 16 improved varieties of common bean, with different seed coat colors, to intermittent drought in the flowering stage.

MATERIALS AND METHODS

Experiment location

The experiment was established in the San Agustín del Pulque ejido, in Cuitzeo, Michoacán (19° 57' 41" N, 101° 06' 4" W, 1,872 m.a.s.l.), with an average annual precipitation of 670 mm and an average annual temperature of 17.9 °C.

Evaluated varieties

Sixteen varieties were evaluated. Twelve were generated by the Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias: Alteño 2000, Azufrasin, Flor de Junio (FJ) Marcela, Flor de Mayo (FM) Anita, FM Dolores, FM Eugenia, FM M38, Negro (N) 8025, N Comapa, N Guanajuato, N Tacaná, and Pinto Saltillo. Three experimental varieties were obtained at the Universidad de Guadalajara (FM-98004, FM-98041 and MX-9065-4M). Finally, a local commercial variety known as Japonés was also used.

Experimental design and recorded variables

A randomized complete block experimental design was used, with four replications each under irrigation and drought conditions. The irrigation treatment consisted of maintaining available moisture above 60% throughout the cycle, while the drought treatment consisted of suspending irrigation for 15 days in the flowering stage. The experimental unit were four row 5.0 m in length and 0.8 m row width, and the two central rows 4 m long furrows as a useful plot. The following variables were recorded: days to physiological maturity, pods per plant, seeds per pod, weight of 100 seeds, and seed yield. In addition, drought tolerance was estimated based on the drought susceptibility index (DSI) (Fischer and Maurer, 1978), geometric mean (GM) (Samper and Adams, 1985), and productive mean (PM) (Rosielle and Hamblin, 1981).

The following equation was used to calculate the DSI (ISS):

$$ISS_i = \frac{1 - \frac{RS_i}{RR_i}}{1 - \frac{RS}{RR}}$$

Where ISS_i = drought susceptibility index of the *i*-th genotype; RS_i = average drought yield of the *i*-th material; RR_i = average irrigation yield of the *i*-th genotype; RS = general average yield in drought; and RR = general average irrigation performance.

The GM of yield was obtained as follows:

$$MG_i = \left(RS_i * RR_i\right)^{0.5}$$

Where MG_i = geometric mean of the *i*-th genotype; RS_i = average drought yield of the *i*-th material; RR_i = average irrigation yield of the *i*-th genotype.

The PM of a genotype is the arithmetic mean of its yield, based on its values under irrigation and drought. A variety is drought tolerant if its DSI value is less than the unit and it is relatively more tolerant to stress, to the extent that it has a higher GM and PM value (Rosales-Serna *et al.*, 2000).

Statistical analysis

The PM and GM were subjected to an analysis of variance and Tukey's mean comparison (MSD, $p \leq 0.05$), based on seed yield, days to physiological maturity, pods per plant, seeds per pod, and weight of 100 seeds, both under irrigation and drought conditions, with the SAS 9.2 statistical package.

Experimental management

The beans were sown on March 8, 2012, at a density of 180,000 plants per hectare. Two to three irrigations per week were applied with drip tape. Weeds were controlled with a hoe

25 days after sowing by hand 21 days later. A 18-46-00 fertilization dose was used, applying diammonium phosphate at the moment of sowing. In the middle of the cycle, whiteflies (*Bemisia tabaci*) were controlled with 375 g/L of Herald (Fenpropathrin).

RESULTS AND DISCUSSION

The analyses of variance reported significant differences ($p \leq 0.05$) in GM and PM between varieties. Significant differences were also reported between genotypes, in all the variables evaluated under irrigation, and in days to physiological maturity, seeds per pod and weight of 100 seeds, under the drought treatment, but not in pods per plant.

Drought tolerance

The drought intensity index was 0.36, equivalent to a moderate drought, according to Beebe *et al.* (2013), who recommend 0.6-0.8 indices. However, enough stress was applied to reach permanent wilting in all varieties.

Based on the DSI, the drought-tolerant varieties were Japonés, FM M38, Pinto Saltillo, FM Eugenia, FM Anita, N 8025, FM-98041, and N Guanajuato, with values between 0.44 and 0.98 (Table 1).

Table 1. Drought tolerance, pods per plant, and days to physiological maturity of 16 improved bean varieties.

Genotype	DSI	MG	MP	RS (%)	VPP			DMF		
		(kg ha^{-1})			R	S	RS (%)	R	S	RS (%)
FJ Marcela	1.18	2329 *	2428 *	43	15.3 *	7.3	52.3	90 *	89 *	1.1
N 8025	0.95	2287 *	2348 *	35	16.2 *	11.2	30.9	89 *	86	3.4
FM Eugenia	0.85	2292 *	2337 *	31	14.8 *	7.8	47.3	91 *	89 *	2.2
FM Dolores	1.23	2124 *	2234 *	45	13.0 *	9.7	28.7	90 *	89 *	1.1
FM Anita	0.94	2098 *	2156 *	35	13. 6 *	10.2	21.5	90 *	89 *	1.1
FM-98004	1.00	2073 *	2139 *	37	11.4 *	7.9	30.7	88 *	89 *	−1.1
FM-98041	0.96	2065 *	2118 *	35	14.9 *	10.0	32.9	90 *	89 *	1.1
Alteño 2000	1.09	2016 *	2090 *	40	14.5 *	10.8	25.5	90 *	90 *	0.0
N Guanajuato	0.98	1988 *	2046 *	36	16.7 *	10.3	38.3	89 *	87 *	2.2
Pinto Saltillo	0.82	1973 *	2010 *	30	13.9 *	9.9	28.8	79	78	1.3
N Comapa	1.03	1886 *	1944 *	38	15.4 *	11.8	23.4	88 *	86	2.3
FM M38	0.57	1927 *	1942 *	21	11.8 *	9.6	18.6	90 *	91 *	−1.1
N Tacaná	1.17	1746	1820	43	13.1 *	11.8	9.9	90 *	87 *	3.3
MX-9065-4M	1.40	1688	1805	51	13.7 *	10.4	24.1	88 *	90 *	−2.3
Japonés	0.44	1764	1772	16	7.5	7.9	−5.3	78	80	−2.6
Azufrasin	1.00	1713	1758	36	13.2 *	9.9	25.0	89 *	90 *	−1.1
Mean	0.98	1998	2059	36	13.7 a[§]	9.8 b	28.5	88 a	87 b	0.7
coefficient of variation (%)	__	9.9	12.8	__	20.7	28.9	__	1.5	1.6	__
MSD (0.05)	__	511.7	513.7	__	7.3	ns	__	3.4	3.5	__

* Statistically superior genotypes, according to the MSD; DSI=drought susceptibility index; GM=geometric mean; MP=productive mean; VPP=pods per plant; DPM=days to physiological maturity; R=irrigation; S=drought; RS%=percentage reduction due to drought stress; [§] statistically different pairs of means with different letter; FM=Flor de Mayo; FJ=Flor de Junio; N=Negro.

The genotypes that, due to their GM, are tolerant to drought were FJ Marcela, FM Eugenia, N 8025, FM Dolores, FM Anita, FM-98004, FM-98041, Alteño 2000, N Guanajuato, Pinto Saltillo FM M38, and N Comapa, with values between 1,886 and 2,329 kg ha^{-1}. The varieties with the highest PM were the same as those with the highest GM, with FJ Marcela being the most productive with 2,428 kg ha^{-1}, followed by N 8025, FM Eugenia, FM Dolores, and FM Anita, with averages of 2,348, 2,337, 2,234, and 2,156 kg ha^{-1}, respectively. Combining the three drought tolerance criteria, FM Eugenia, N 8025, FM Anita, FM-98041, N Guanajuato, Pinto Saltillo, and FM M38 were considered to be drought tolerant. Other authors (Barrios *et al.*, 2011; Romero-Félix *et al.*, 2019; Acosta-Gallegos *et al.*, 2020) have also documented that FM Eugenia, Pinto Saltillo, N 8025, N Guanajuato, and FM M38 have adapted to environments with water stress in the center and north of the country. In contrast with the findings of this study, Tosquy-Valle *et al.* (2014) report that N Tacaná is tolerant to water stress in the tropics. This discrepancy can be attributed to the relativity of the DSI of a given variety, which is influenced by the level of tolerance of the genotypes with which it is being compared (Fischer and Maurer, 1978). Except for N Guanajuato, the seven selected varieties were highly productive during drought (Figure 1), an essential attribute of water stress-tolerant varieties (Beebe *et al.*, 2013). However, in places with intermittent droughts, they should also show high yield under irrigation conditions (Chaves-Barrantes *et al.*, 2018), like FM Eugenia and N 8025, which recorded values of 2,768 and 2,854 kg ha^{-1} (irrigation) and 1,905 and 1,843 kg ha^{-1} (drought) (Figure 1). On the contrary, Azufrasin, N Tacaná, and Mx-9065-4M were the least productive varieties. In conclusion, FM Eugenia and N 8025 could potentially be grown in areas exposed to intermittent drought.

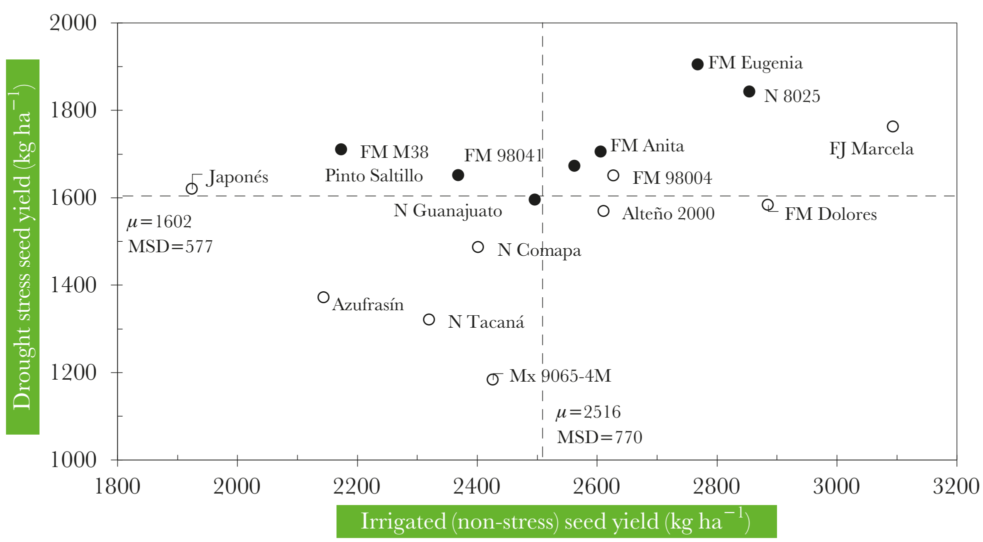

Figure 1. Seed yield of 16 improved bean varieties evaluated under irrigation and drought stress. Varieties with a full circle are drought tolerant, according to their drought susceptibility indices, geometric mean, and productive mean.

Yield components and phenology

Table 1 shows that the yield component most affected by drought was pods per plant (average reduction: 28.5%), followed by weight of 100 seeds (increase: 4.9%), and seeds per pod (unaffected by stress). The mean number of pods per plant was 13.7 and 9.8, under irrigation and drought conditions, respectively; there was a slight variability between varieties in the two moisture conditions. The reduced variability may be associated with the low drought intensity applied and with the low genetic variability of the materials evaluated (Tosquy-Valle *et al.*, 2014). Several authors have reported that pods per plant is the most drought-sensitive component, followed by weight of 100 seeds, and seeds per pod, especially when drought occurs in the reproductive phase (Tosquy-Valle *et al.*, 2014; Darkwa *et al.*, 2016; Romero-Félix *et al.*, 2018; Mazengo and Tryphone, 2019). The variable that was most associated with seed yield ($r=0.60$, $p \leq 0.01$) was pods per plant; therefore, it can be considered a reliable indirect criterion in the selection of species with tolerance to intermittent drought (Rai *et al.*, 2020). The weight of 100 seeds is highly affected by terminal drought (Mazengo and Tryphone, 2019); meanwhile intermittent drought during the flowering stage may not affect and, just as in the case of this research, it may even increase weight per 100 seeds (Nielsen and Nelson, 1998). This phenomenon was a response to the compensation of flower and pod abscission, caused by the reestablishment of the favorable moisture condition during the pod filling stage.

Days to physiological maturity were reduced by 0.7% (one day) due to stress, from a mean of 87 days in drought to 88 days in irrigation, with significant differences ($p \leq 0.05$) between varieties (Table 1). Pinto Saltillo was the more precocious variety, with 79 days in irrigation and 78 in drought, and FM M38 matured the latest, with 90 days in irrigation and 91 in drought. The rest of the varieties, with the exception of Japonés, took between 87 and 90 days to mature. The slight impact of intermittent drought on bean phenology in flowering was reported by Mazengo and Tryphone (2019), who concluded that, when the drought is not severe, genotypes can recover from stress (Beebe *et al.*, 2013).

CONCLUSIONS

Pods per plant was the secondary variable with the highest sensitivity to water stress and the one most associated with seed yield; consequently, it could be used as a reliable auxiliary attribute in the selection of bean genotypes with tolerance to intermittent drought.

Based on the drought susceptibility index, geometric mean, and productive mean, FM Eugenia, N 8025, FM Anita, FM-98041, N Guanajuato, Pinto Saltillo, and FM M38 were drought tolerant varieties. FM Eugenia and N 8025 also showed a remarkably high performance, under both irrigation and drought conditions, which makes them the most viable alternatives for places prone to intermittent droughts.

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