Revista Mexicana Ciencias Agrícolas volume 12 number 8 November 12 - December 31, 2021

Article

Yield and accumulated biomass in common bean under irrigation and rainfed

Celia Selene Romero-Félix[1§]
Cándido López-Castañeda[1]
Josué Kohashi-Shibata[1]
Carlos Gustavo Martínez-Rueda[2]
Salvador Miranda-Colín[1]
Víctor Heber Aguilar-Rincón[1]

[1]Montecillo *Campus*-Postgraduate College. Mexico-Texcoco highway km 36.5, Montecillo, Texcoco, State of Mexico, Mexico. CP. 56230. Tel. 595 9520200, ext. 1587. (cgmartinezr@uaemex.mx). [2]Faculty of Agricultural Sciences-Autonomous University of the State of Mexico. El Cerrillo, Piedras Blancas, Toluca, State of Mexico, Mexico. CP. 50090. (clc@colpos.mx; jkohashi@colpos.mx; smiranda@colpos.mx; aheber@colpos.mx).

[§]Corresponding author: celiaromero82@hotmail.com.

Abstract

Common bean (*Phaseolus vulgaris* L.) grown under rainfed conditions is affected by terminal drought, considerably reducing the seed yield and biomass accumulated in the canopy of the plant. The objective of this study was to evaluate the variability in seed yield, phenology and aerial biomass accumulated during the reproductive stage, in a group of common bean varieties, under irrigation (I) and drought (D) conditions, at the College of Postgraduates, Montecillo Campus. Eight genotypes of 'Flor de Mayo'-type bean were used, three with black testa and one native, under a randomized complete block design with three repetitions in I and three in D, in the 2014 summer-autumn cycle. The fertilization dose 80-40-00 was used. D decreased seed yield (30%), biomass accumulated at the beginning of flowering (BMBF) (22%), biomass accumulated at anthesis (BMA) (19%) and biomass accumulated at physiological maturity (BMPM) (19%) and harvest index (14%) with respect to I. D also reduced the days and degree days to the beginning of flowering, anthesis and physiological maturity. There was variability within the group of bean varieties evaluated, with FM 2000 standing out for having high seed yield, on average of I and D, and in each moisture condition (I and D). While FM RMC stood out for exhibiting higher BMBF, BMA and BMPM, both in I and D.

Keywords: *Phaseolus vulgaris* L., degree days, phenology, rainfed.

Reception date: August 2021
Acceptance date: October 2021

Introduction

Common bean (*Phaseolus vulgaris* L.) is the most important legume for human consumption (Calero *et al*., 2018). Globally, it is estimated that more than 60% of the cultivated area is affected by moisture shortages (Rao *et al*., 2013). Drought stress, either as a recurrent seasonal phenomenon or as an effect of climate change, is currently the main threat to the global food supply (Budak *et al*., 2013). In recent decades, this environmental stress has become a great challenge for the livelihood of bean producers in marginal or unfavorable environments (Beebe *et al*., 2013; Asfaw and Blair, 2014), especially in rainfed conditions, where it depends on the rains that occur during its crop cycle, so that in years where it rains little, the quantity and quality of its production can be severely reduced (Rainey and Griffiths, 2005; Ligarreto *et al*., 2015); drought greatly affects rainfed bean yield, especially when it coincides with the reproductive stage (Rosales *et al*., 2012; Osuna *et al*., 2013); for example, in bean varieties of type III indeterminate habit, the water deficit during the vegetative phase reduced the seed yield by 39%, and when the drought occurred in flowering and the seed formation period, the yield decreased by 51% (Acosta and Kohashi, 1989).

Depending on the intensity, type, and length of drought stress, yield can decrease by 20 to 100% when it occurs right in the reproductive stage (López *et al*., 2011; Beebe *et al*., 2013). Similarly, aerial biomass can reduce by 25% under rainfed with respect to irrigation conditions (Barrios *et al*., 2010). Water stress can also alter the ontogenetic cycle of the bean, shortening the number of days to the beginning of flowering, anthesis and physiological maturity, as well as the duration of the interval between anthesis and physiological maturity (Morales *et al*., 2015).

Under drought conditions, the reduction or increase in the grain-filling period can be advantageous, Blum (1998) considers that a shorter period for grain filling may allow some evasion of terminal stress, while a longer duration allows greater use of stem reserves for grain filling under this type of stress.

However, bean yields could increase if agronomic and physiological characteristics that contribute to increasing dry matter production and translocation of assimilates to the grain are identified; to achieve greater production of aerial biomass, the growth rate of the crop and the net assimilation rate can be increased through greater leaf area that favors interception and efficiency in the use of radiation (Blum, 2013).

In bean, a high aerial biomass is associated with greater production of photoassimilates that are translocated into pods and seeds, improving grain yield (Ramírez and Kelly, 1998; Romero *et al*., 2015), so the identification of genotypes with high production of aerial biomass, greater efficiency in the use of water, greater allocation of photoassimilates to the formation and filling of pods and grain can be a strategy to obtain varieties with greater tolerance to drought (Hall, 2012; Omae *et al*., 2012). Considering the above, the present research work was carried out with the aim of evaluating the variability in seed yield, phenology and aerial biomass accumulated during the reproductive stage, in a group of varieties of common bean, under irrigation and rainfed conditions.

Materials and methods

Experimental site

This work was carried out at the Experimental Field of the College of Postgraduates, Montecillo, Texcoco, State of Mexico (19º 21’ north latitude, 98º 55’ west latitude and 2250 masl), in the 2014 summer-autumn cycle. The experimental site has a temperate subhumid climate type Cb (wo) (w) (i´) g with rainfall in summer, average annual temperature and rainfall of 15.2 °C and 637 mm, respectively (García, 2004). Clay-textured soil with pH of 8.2, organic matter of 2.1% (Walkey-Black), electrical conductivity of 0.5 dS m^{-1}, nitrogen content of 0.2% (MicroKjeldhal), phosphorus of 9.5 mg kg^{-1} (P_2O_5; Olsen) and 1.7 cmol kg^{-1} of potassium on average from strata 0-20, 20-40, 40-60 and 60-80 cm of the soil profile.

Genetic material

The germplasm used included eight varieties of ‘Flor de Mayo’-type bean (FM Anita, FM Corregidora, FM 2000, FM M38, FM Sol, FM Bajío, FM Noura and FM RMC), obtained by INIFAP for rainfed areas and soils with favorable moisture in the region of the Mexican Plateau (Rosales *et al*., 2004), three varieties of black bean (Criollo San Andrés, Negro Cotaxtla 91 and Negro Veracruz) collected in the southern region of the state of Veracruz (Morales *et al*., 2015) and Michoacán 128 (similar to the ‘Flor de Mayo’-type varieties) collected in Michoacán, Mexico (Barrios *et al*., 2010). All varieties are of type III indeterminate growth habit (CIAT, 1982).

Experimental design

A randomized complete block design was used with three repetitions under irrigation (I) and three under drought (D), the experimental unit consisted of four furrows of 5 m in length and at a distance of 0.8 m. Sowing was carried out on June 11, 2014, in slightly moist soil. A fertilization treatment of 80-40-00 was used, with urea as a source of nitrogen and calcium triple superphosphate as a source of phosphorus, half of the nitrogen and all phosphorus was applied during sowing and the second half of nitrogen at 49 days after sowing (das). An approximate population density of 148 000 plants ha^{-1} was used. Cultivation work was carried out at 37 and 49 das. Water was applied at two das in I and D and then at 25, 33, 44 and 60 das only in I, later both treatments of soil moisture were subject to rainfall until physiological maturity.

Flex® (Fomesafen) herbicide was applied for the control of broad-leaved weeds at 23 das, and Fusiflex® (Fluazifop-p-butyl) herbicide for the control of narrow-leaved weeds at 34 das. Also, Afidox® (Dimethoate) insecticides were applied at a dose of 1 L ha^{-1} at 31 and Nugor® (Dimethoate) at 91 das for the control of whitefly (*Bemisia tabaci*) and Mexican bean beetle (*Epilachna varivestis*). Additionally, the liquid foliar fertilizer Nutriplant plus® was applied at 55, 67 and 78 das. The presence of foliar diseases during the crop cycle was not observed.

Study variables

Degree days of growth to the beginning of flowering (DDBF, ºCd)

The beginning of flowering was determined when 50% of the plants in each experimental unit had at least one open flower.

Growth degree days to reach anthesis (DDA, °Cd)

It was determined when 50% of the plants in each experimental unit had open flowers.

Growth degree days to reach physiological maturity (DDPM, °Cd)

It was recorded when 90% of plant pods lost their green pigmentation (Acosta *et al*., 2009). The degree days (DD, ºCd) to the beginning of flowering, anthesis and physiological maturity were calculated with the following equation: $DD= \sum_{i=0}^{n}(\bar{X}i\text{-}Bt)$. Where DD= degree days (ºCd), $\bar{X}i$= average daily temperature and Bt= base temperature with a value of 8.2ºC for bean (Barrios and López, 2009).

Aerial biomass accumulated at the beginning of flowering (BMBF, g m^{-2}), aerial biomass accumulated at anthesis (BMA, g m^{-2}) and aerial biomass accumulated at physiological maturity (BMPM, g m^{-2})

They were determined by harvesting the plants present in an area of 0.4m^2 in the lateral furrows of each experimental unit. The plants were placed in an oven (Riossa$^{®}$) with forced air at a temperature of 75 °C for a period of 72 h, to later obtain their dry weight.

Seed yield (SY, g m^{-2})

It was determined by weighing normal seeds and dividing the weight of the seed by the harvested area.

Harvest index (HI, %)

It was calculated by dividing the seed yield (SY) by the final aerial biomass (FABM) (100) (Kohashi *et al*., 1980). Data on maximum and minimum air temperature (°C) and rainfall (mm) during the experiment were recorded daily during the plant cycle with a maximum and minimum mercury column thermometer (Taylor brand), and a portable rain gauge, placed at the site where the experiment was conducted.

Statistical analysis

The analysis of variance was performed with the SAS (2009) statistical program, version 9.1 for Windows, in combined form I and D as a series of experiments ($Y_{ijk} = \mu + G_i + M_j + GM_{ij} + B\,(_{i})_{j} + E_{ijk}$), to determine the differences between the treatments of soil moisture (M), genotypes (G) and the G x M interaction. For the comparison of means, the least significant difference test (LSD, $p \leq 0.05$) was used.

Results and discussion

Meteorological data

A wide variation in the maximum and minimum air temperature (°C) was observed, with high temperatures dominating during the reproductive phase of the crop, which presented an average weekly value above 25 °C and variable minimum temperature with average values >10 and 7 °C after the anthesis stage (Figure 1).

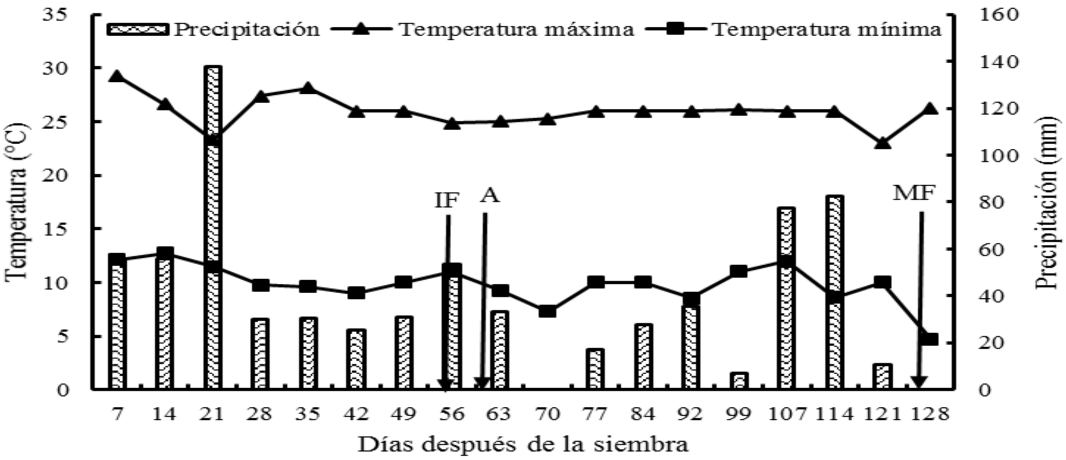

Figure 1. Maximum and minimum average weekly air temperature, and weekly accumulated precipitation during the 2014 summer-autumn cycle. Montecillo, Texcoco, State of Mexico. IF= beginning of flowering; A= anthesis; MF= physiological maturity.

The weekly accumulated precipitation during the crop cycle (712 mm) also had strong variations, being scarce during the reproductive phase of the crop (Figure 1), where the water content of the surface layer of the soil (30 cm) decreased, reaching levels close to PMP during the period of seed formation, a period considered the most sensitive to drought (Acosta and Kohashi, 1989; Nielsen and Nelson, 1998) and where yield (Ambachew *et al*., 2015; Polania *et al*., 2016) and seed quality (Rainey and Griffiths, 2005) are more affected by water stress.

Moisture content in the soil

The usable moisture content (UM) in different soil strata (0-20, 20-40, 40-60 and 60-80) was determined weekly, using the gravimetric method [% UM= ((moist soil weight - dry soil weight) /dry soil weight) 100]. Soil moisture content in I remained close to field capacity (FC) during the experiment (data not shown). Under rainfed conditions, the availability of soil moisture decreased as the crop cycle progressed in the strata of 0-80 cm, from the beginning of flowering, the level of soil moisture decreased in the strata that include the 0-60 cm of the soil profile, presenting values below PMP (Figure 2).

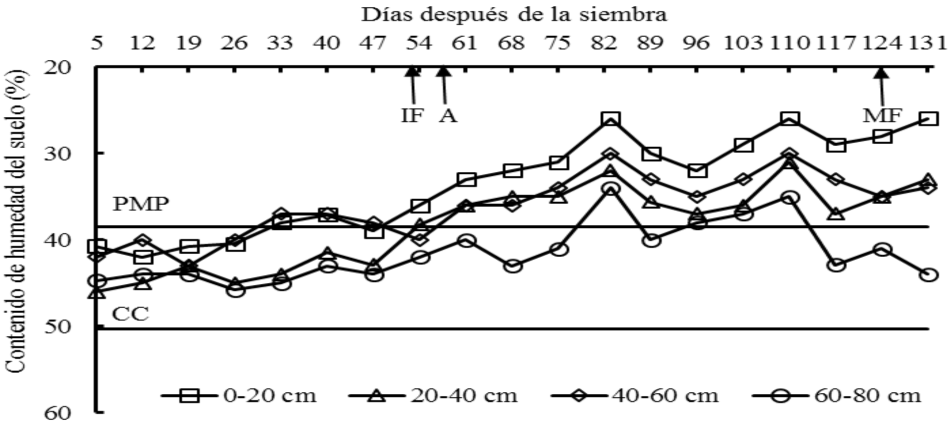

Figure 2. Soil moisture content in strata 0-20, 20-40, 40-60 and 60-80 cm under rainfed conditions during the experiment. 2014 summer-autumn cycle. Montecillo, Texcoco, State of Mexico. CC= field capacity; PMP= permanent wilting percentage; IF= beginning of flowering; A= anthesis and MF= physiological maturity.

Field capacity refers to the state in which a soil is totally wet after having drained by gravity, while the permanent wilting percentage is the water content of the soil with which the plants wither (Azcón and Talón, 2013). Chicas *et al*. (2014) mention that the difference between the field capacity and the permanent wilting point determines the moisture retention capacity in soils, a multipurpose parameter for agricultural planning.

Seed yield, biomass accumulated in the plant canopy and phenology of the crop

The combined analysis of variance (Anova) showed statistically significant differences between genotypes for seed yield (F= 12.06, $p< 0.0001$), aerial biomass accumulated at: the beginning of flowering (F= 27.98, $p< 0.0001$), anthesis (F= 24.62, $p< 0.0001$) and physiological maturity (F= 4.33, $p< 0.0002$), degree days accumulated: at the beginning of flowering (F= 16.03, $p< 0.0001$), anthesis (F= 16.63, $p< 0.0001$) and physiological maturity (F= 10.07, $p< 0.0001$). There were no statistical differences between varieties for the harvest index (F= 1.73, $p> 0.05$).

The comparison of means between genotypes showed that FM 2000 had higher seed yield, FM RMC greater aerial biomass accumulated at the beginning of flowering; FM RMC and FM Sol high aerial biomass accumulated at anthesis, FM 2000, FM RMC, FM Sol, Michoacán 128 and FM Corregidora greater aerial biomass accumulated at physiological maturity; FM M38, Michoacán 128, FM Noura, FM Corregidora and Negro Cotaxtla 91 high number of days and degree days at the beginning of flowering; FM M38, Michoacán 128, FM Noura, FM Corregidora, Criollo San Andrés, Negro Cotaxtla 91 and Negro Veracruz high number of days or degree days at anthesis and FM 2000, FM M38, FM Noura, FM Corregidora and Negro Cotaxtla 91 high number of days or degree days at physiological maturity than the other varieties, on average of I and D (Table 1).

Table 1. Seed yield, aerial biomass and phenology of 12 varieties of bean, on average under irrigation and drought. 2014 summer-autumn cycle. Montecillo, Texcoco, State of Mexico.

Varieties	SY	BMBF	BMA	BMPM	HI	DDBF	DDA	DDPM
FM 2000	238	51	75	411	44	514 (52)	560 (56)	1 248 (130)
FM RMC	196	86	105	421	40	502 (50)	556 (56)	1 180 (122)
FM M38	196	46	77	274	45	543 (55)	587 (59)	1 253 (131)
FM Sol	115	58	105	356	37	485 (49)	538 (54)	1 162 (120)
Michoacán 128	136	53	83	355	36	570 (57)	607 (61)	1 207 (125)
FM Noura	166	58	87	287	38	564 (57)	600 (61)	1 281 (134)
FM Anita	137	42	72	236	45	500 (50)	554 (56)	1 166 (121)
FM Corregidora	130	49	90	331	36	551 (55)	592 (60)	1 277 (133)
FM Bajío	162	37	64	206	43	551 (53)	571 (58)	1 152 (119)
Criollo San Andrés	139	37	59	233	40	541 (54)	584 (59)	1 204 (125)
Negro Cotaxtla 91	114	37	57	167	39	560 (56)	600 (61)	1 251 (130)
Negro Veracruz	110	37	48	243	37	541 (54)	584 (59)	1 222 (127)
Media general	154	49	77	293	40	533 (53)	578 (58)	1 217 (126)
LSD ($p \leq 0.05$)	37	8	10	111	7	20 (2)	15 (2)	41 (5)

SY= seed yield (g m^{-2}); BMBF= aerial biomass accumulated at the beginning of flowering (g m^{-2}); BMA= aerial biomass accumulated at anthesis (g m^{-2}); BMPM= aerial biomass accumulated at physiological maturity (g m^{-2}); HI= harvest index (%); DDBF= degree days (DD, °Cd) accumulated at the beginning of flowering (BF); DDA= degree days (DD, °Cd) accumulated at anthesis (A); DDPM= degree days (DD, °Cd) accumulated at physiological maturity (PM); LSD= value of the least significant difference for the comparison between genotypes.

The seed yield and the final aerial biomass, on average of varieties, obtained in this work were 34 and 22% lower compared to the results of Barrios *et al*. (2010), while the number of days to physiological maturity was prolonged 20 days with respect to what was reported by Barrios *et al*. (2010), in ‘Flor de Mayo’-type bean varieties on average of three environments. The crop cycle and temperature play a determining role in the phenological stages of the plants, therefore, these differences are partly attributed to the fact that in this study the sowing was carried out late in summer-autumn and the average maximum temperature fluctuated between 25 °C and Barrios *et al*. (2010) sown in spring-summer and the average temperature during the crop cycle was 31.7 °C, accelerating the stages of beginning of flowering and physiological maturity.

Irrigation vs rainfed

The combined Anova for the two moisture conditions detected significant differences for seed yield (F= 70.82, $p< 0.0001$), aerial biomass accumulated: at the beginning of flowering (F= 62.71, $p< 0.0001$), anthesis (F= 58.5, $p< 0.0001$) and at physiological maturity (F= 7.87, $p= 0.0073$), harvest index (F= 16.58, $p= 0.0002$), degree days accumulated at: the beginning of flowering (F= 24.28, $p< 0.0001$), anthesis (F= 18.74, $p< 0.0001$) and physiological maturity (F= 10.81, $p= 0.0019$).

Drought stress reduced the expression of all the characters evaluated in this study; seed yield, final aerial biomass, aerial biomass accumulated at the beginning of flowering, aerial biomass accumulated at anthesis, aerial biomass accumulated during physiological maturity and harvest index, on average of genotypes, decreased 30, 20, 22, 19, 19 and 14% under drought with respect to irrigation (Table 2).

Table 2. Seed yield, aerial biomass and phenology on average of 12 bean varieties under irrigation and drought. 2014 summer-autumn cycle. Montecillo, Texcoco, State of Mexico.

Moisture level	SY	BMBF	BMA	BMPM	HI	DDBF	DDA	DDPM
Irrigation	181	55	85	325	43	543 (54)	584 (59)	1 230 (128)
Drought	126	43	69	262	37	523 (52)	571 (57)	1 199 (124)
LSD ($p \leq 0.05$)	13	3	4	45	3	8 (1)	6 (1)	19 (2)

SY= seed yield (g m^{-2}); BMBF= aerial biomass accumulated at the beginning of flowering (g m^{-2}); BMA= aerial biomass accumulated at anthesis (g m^{-2}); BMPM= aerial biomass accumulated at physiological maturity (g m^{-2}); HI= harvest index (%); DDBF= degree days (DD, °Cd) accumulated at the beginning of flowering (BF); DDA= degree days (DD, °Cd) accumulated at anthesis (A); DDPM= degree days (DD, °Cd) accumulated at physiological maturity (PM); LSD= value of the least significant difference for the comparison between genotypes.

Drought also caused a reduction in the days after sowing and degree days (DD) accumulated at the beginning of flowering (20 DD), anthesis (13 DD) and physiological maturity (31 DD) (Table 2). The tendency of these characters to decrease when going from irrigation to drought under rainfed conditions has been observed in other studies; seed yield, aerial biomass, harvest index (Acosta *et al*., 2004, 2009; Barrios *et al*., 2010; Romero *et al*., 2019), days to the beginning of flowering (Barrios *et al*., 2010), days to anthesis and days to physiological maturity (Tosquy *et al*., 2017; Romero *et al*., 2018).

The biomass accumulated in the stages of the beginning of flowering, anthesis and physiological maturity in all varieties was lower under drought than under irrigation, since under drought, the genotypes presented fewer days to reach each of these phenological stages, reducing the period for the accumulation of biomass and the effective mobilization of assimilates to the formation and growth of the grain; drought influences the duration of phenological stages (Rosales *et al*., 2001); for their part, Asfaw *et al*. (2012) states that the senescence of the leaves can reduce the duration of the photosynthetic period, as well as the rate of photosynthesis; however, leaf senescence can also effectively contribute to the grain-filling period through the remobilization of carbon from vegetative tissues to grain.

Under irrigation, significant statistical differences between varieties were detected for seed yield (F= 6.95, $p< 0.0001$), aerial biomass accumulated at: the beginning of flowering (F= 26.71, $p< 0.0001$), anthesis (F= 12.33, $p< 0.0001$) and physiological maturity (F= 2.19, $p= 0.05$), degree days accumulated at: the beginning of flowering (F= 8.47, $p< 0.0001$), anthesis (F= 6, $p< 0.0002$) and physiological maturity (F= 3.57, $p= 0.0054$). No statistically significant differences were observed for the harvest index (F= 1.29, $p> 0.05$).

Varieties FM 2000, FM M38 and FM RMC had higher seed yields (Figure 3a); FM RMC showed high biomass accumulation at the beginning of flowering (Figure 3b); FM RMC and FM Sol greater biomass accumulation when reaching anthesis (Figure 3c) and FM 2000, FM RMC, FM Sol, Michoacán 128, FM Corregidora and FM Noura (Figure 3d) had greater accumulation of aerial biomass at physiological maturity than the rest of the varieties. On the other hand, FM M38, FM Noura, Michoacán 128, FM Corregidora and Negro Cotaxtla 91 showed greater accumulation of degree days or days to the beginning of flowering (Figure 3f), anthesis (Figure 3g) and physiological maturity (Figure 3h). Also, Negro Veracruz had greater accumulation of degree days to physiological maturity (Figure 3h).

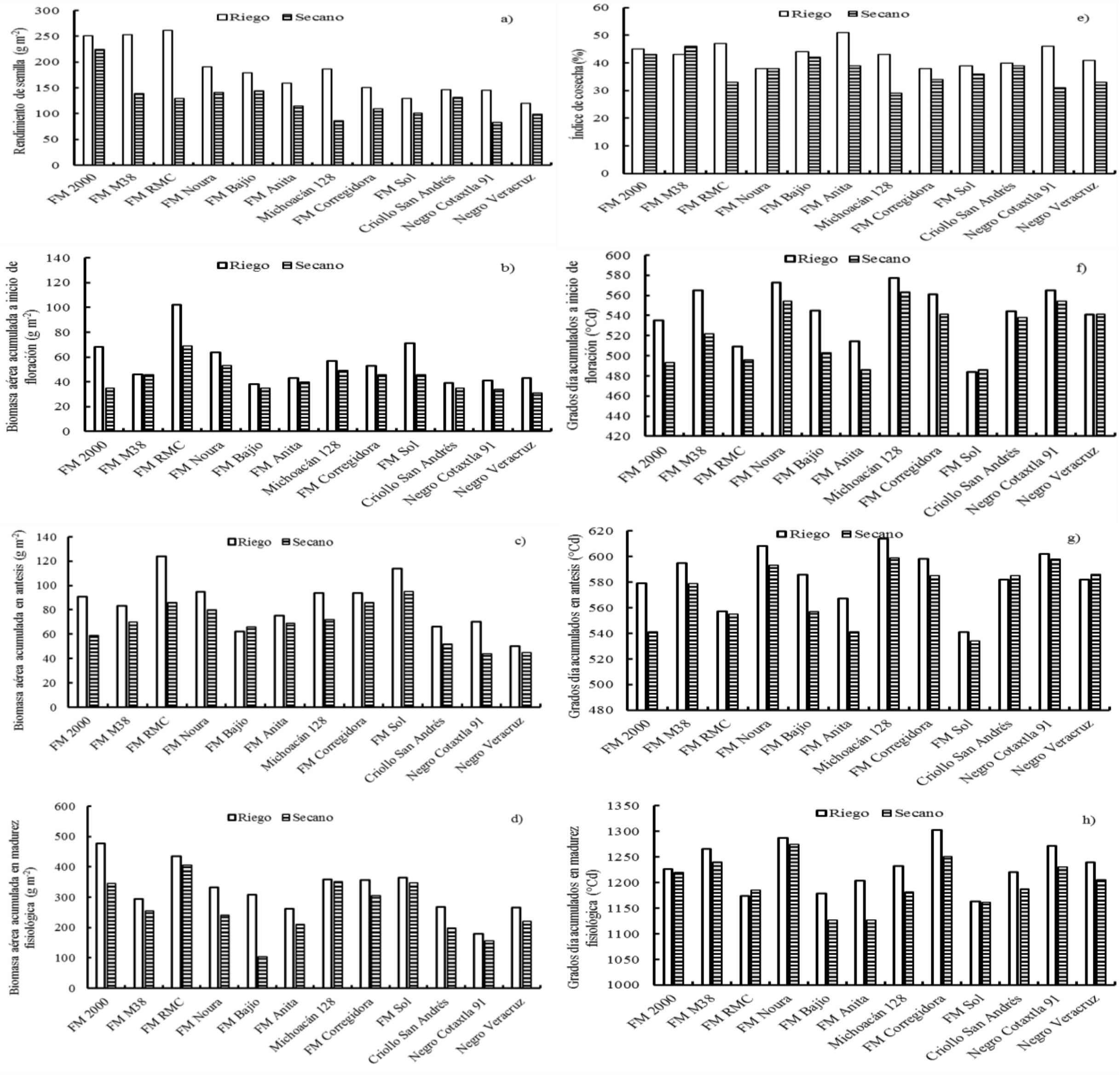

Figure 3. Seed yield (a); aerial biomass accumulated at: the beginning of flowering (b), at anthesis (c) and at physiological maturity (d); harvest index (e); degree days accumulated at: the beginning of flowering (f), at anthesis (g) and at physiological maturity; and (h) of 12 bean varieties under irrigation and rainfed. 2014 summer-autumn cycle. Montecillo, Texcoco, State of Mexico.

Under drought conditions, significant statistical differences were observed for all the characters evaluated; seed yield (F= 10.9, $p < 0.0001$), aerial biomass accumulated at: the beginning of flowering (F= 7.58, $p < 0.0001$), anthesis (F= 15.39, $p < 0.0001$) and physiological maturity (F= 2.86, $p = 0.01$), harvest index (F= 2.53, $p = 0.03$), degree days accumulated: at the beginning of flowering (F= 8.66, $p < 0.0001$), anthesis (F= 13.62, $p < 0.0001$) and physiological maturity (F= 4.16, $p = 0.0022$).

The varieties had a differential behavior in seed yield, phenology and aerial biomass accumulated in each of their phenological stages under drought; the FM 2000 variety had a higher seed yield (Figure 3a); FM RMC higher aerial biomass accumulated at the beginning of flowering (Figure 3b); FM RMC, FM Corregidora and FM Sol greater aerial biomass accumulated at anthesis (Figure 3c); FM 2000, FM M38, FM RMC, Michoacán 128, FM Corregidora and FM Sol greater aerial biomass accumulated at physiological maturity (Figure 3d) and FM 2000, FM M38, FM Noura, FM Bajío, FM Anita and Criollo San Andrés higher harvest index (Figure 3e). While the varieties FM Noura, Michoacán 128, FM Corregidora, Criollo San Andrés, Negro Cotaxtla 91 and Negro Veracruz accumulated more in degree days to the beginning of flowering (Figure 3f) and anthesis (Figure 3g), varieties FM 2000, FM M38, FM Noura, FM Corregidora and Negro Cotaxtla 91 showed greater accumulation of degree days during physiological maturity (Figure 3h).

In the genotype-by-humidity level interaction, genotypes FM RMC, FM M38, Michoacán 128 and Negro Cotaxtla 91; FM 2000, FM RMC and FM Sol; and FM 2000, FM RMC, Michoacán 128 and Negro Cotaxtla 91 showed greater reductions in seed yield, aerial biomass accumulated at the beginning of flowering and aerial biomass accumulated at anthesis when going from irrigation to drought. Varieties that present a greater decrease in yield or some other component of the yield or characteristic when going from irrigation to drought are considered varieties susceptible to drought (Romero *et al*., 2019).

The relationship between seed yield under irrigation and drought indicated that the FM 2000 variety was more drought tolerant and performed well under irrigation; similarly, Polania *et al*. (2016) identified common bean genotypes that, in addition to showing drought tolerance, had high yields under favorable moisture conditions, where drought-resistant lines owed their best behavior to high effective water use and harvest index.

Under irrigation conditions, the varieties of ‘Flor de Mayo-type bean and with seeds of black testa had the highest seed yield than those that were under rainfed conditions; seed yield (SY) was positively and significantly related to aerial biomass accumulated at the beginning of flowering (BMBF) under irrigation [SY= 1.42 (BMBF) + 102.2, r= 0.53, $p \leq 0.05$] (Figure 4a), while under rainfed [SY= -0.25 (BMBF) + 135.9], the relationship was positive and not significant ($p > 0.05$) (Figure 4a), under irrigation, seed yield was positively and significantly related to aerial biomass accumulated at physiological maturity (BMPM) [SY= 0.37 (BMPM) + 60.5, r= 0.61, $p \leq 0.05$] (Figure 4b) and under rainfed, the relationship was positive but not significant ($p > 0.05$) (Figure 4b), the seed yield was positively but not significantly related to the harvest index (HI) under irrigation [SY= 4.09 (HI) + 4.96, r= 0.33, $p > 0.05$] (Figure 4c); however, under rainfed the relationship was positive and significant [SY= 5.29 (HI) - 70.18, r= 0.72, $p \leq 0.005$] (Figure 4c).

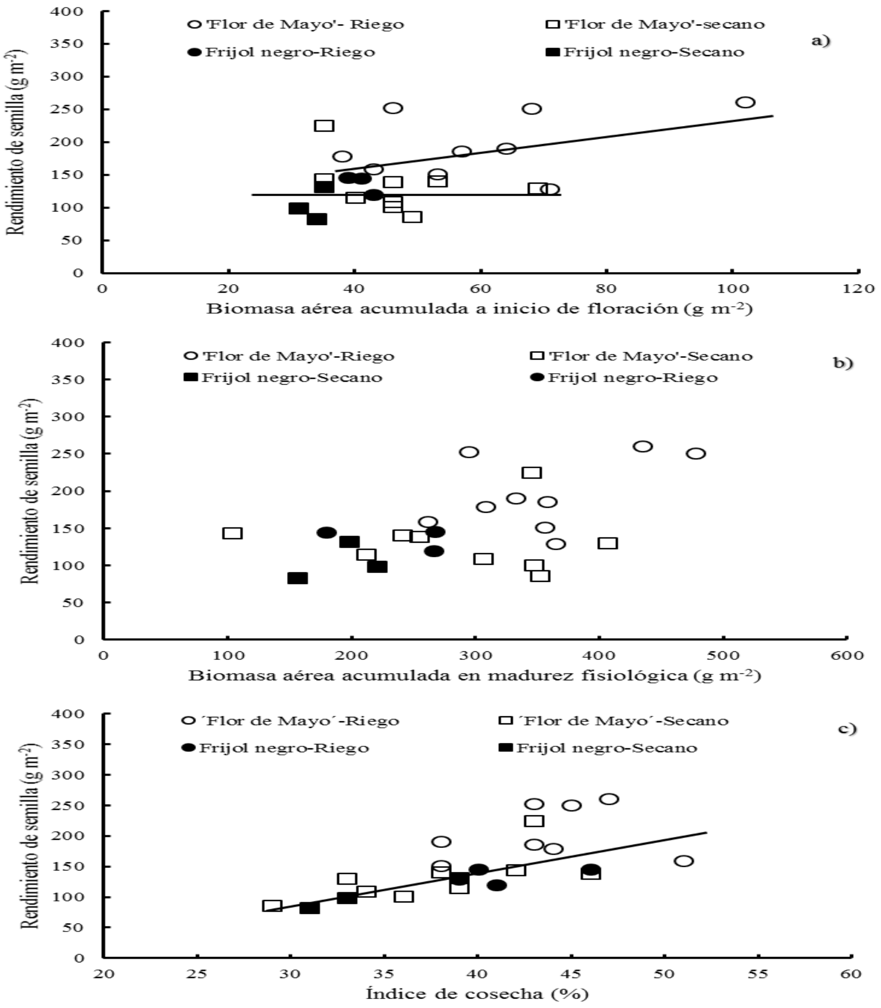

Figure 4. Relationship between the seed yield with the final aerial biomass (a) and the harvest index; and (b) under irrigation and drought for the varieties of 'Flor de Mayo'-type bean and seeds with black testa. 2014 summer-autumn cycle. Montecillo, Texcoco, State of Mexico.

In another research paper, a positive and significant correlation was observed between seed yield and harvest rate on average of 25 varieties of common bean under drought conditions in Ethiopia (Asfaw and Blair, 2014) and a positive and significant correlation between seed yield and aerial biomass on average of five varieties of common bean of different growth habit under irrigation and drought (Ramirez and Kelly, 1998).

Conclusions

Variability was observed within the group of bean varieties evaluated, with FM 2000 standing out for having high seed yield, on average under irrigation and drought and in each moisture condition (irrigation and drought). While the FM RMC variety stood out for exhibiting greater aerial biomass accumulated at the beginning of flowering, anthesis and physiological maturity, both under irrigation and drought. Drought under rainfed conditions decreased seed yield and aerial biomass accumulated at the beginning of flowering, anthesis and physiological maturity, as well as the number of days to the beginning of flowering, anthesis and physiological maturity.

Cited literature

Acosta, D. E.; Trejo, L. C.; Ruiz, P. L. del Mar.; Padilla, R. J. C. y Acosta, G. J. A. 2004. Adaptación del frijol a sequía en la etapa reproductiva. Terra Latinoam. 22(1):49-58. http://redalyc.uaemex.mx/src/inicio/ArtPdfRed.jsp?iCve=57311208006.

Acosta, D. E.; Acosta, G. J. A.; Trejo, L. C.; Padilla, R. J. S. and Amador, R. M. D. 2009. Adaptation traits in dry bean cultivars grown under drought stress. Agric. Téc. Méx. 35(4):416-425.

Acosta, G. J. A and Kohashi, S. J. 1989. Effect of water stress on growth and yield of indeterminate dry-bean (*Phaseolus vulgaris*) cultivars. Field Crops Res. 20(2):81-93. https://doi.org/10.1016/0378-4290(89)90054-3.

Ambachew, D.; Mekbib, F.; Asfaw, A.; Beebe, S. E. and Blair, M. W. 2015. Trait associations in common bean genotypes grown under drought stress and field infestation by BSM bean fly. The Crop J. 3(4):305-316. https://doi.org/10.1016/j.cj.2015.01.006.

Azcón, B. J. y Talon, M. 2013. Fundamentos de fisiología vegetal. 2ª. (Ed.). en español. McGraw-Hill Interamericana de España, S. L. 651 p.

Asfaw, A.; Blair, M. W. and Struik, P. C. 2012. Multienvironment quantitative trait loci analysis for photosynthate acquisition, accumulation, and remobilization traits in common bean under drought stress. G3: Genes, Genomes, Genetics. 2(5):579-595. doi: 10.1534/g3.112.002303.

Asfaw, A. and Blair, M. W. 2014. Quantification of drought tolerance in ethiopian common bean varieties. Agric. Sci. 5(2):124-139. http://dx.doi.org/10.4236/as.2014.52016.

Barrios, G. E. J. y C. López-Castañeda. 2009. Temperatura base y tasa de extensión foliar en frijol. Agrociencia. 43(1):25-35.

Barrios, G. E. J.; López, C. C.; Kohashi, S. J.; Acosta, G. J. A.; Miranda, C. S. y Mayek, P. N. 2010. Rendimiento de semilla y sus componentes en frijol flor de mayo en el centro de México. Agrociencia. 44(4):481-489.

Beebe, S. E.; Rao, I. M.; Blair, M. W. and Acosta-Gallegos, J. A. 2013. Phenotyping common beans for adaptation to drought. Frontiers in Physiol. 4(35):1-20. doi: 10.3389/fphys.2013.00035.

Blum, A. 1998. Improving wheat grain filling under stress by stem reserve mobilisation. Euphytica. 100(1-3):77-83. https://doi.org/10.1023/A:1018303922482.

Blum, A. 2013. Heterosis, stress, and the environment: a possible road map towards the general improvement of crop yield. J. Exp. Bot. 64(16):4829-4837. doi:10.1093/jxb/ert289.

Budak, H.; Kantar, M. and Kurtoglu, K. Y. 2013. Drought tolerance in modern and wild wheat. Sci. World J. 2013(548246):1-16. http://dx.doi.org/10.1155/2013/548246.

Chicas, S. R. A.; Vanegas, C. E. A. y García, A. N. 2014. Determinación indirecta de la capacidad de retención de humedad en suelos de la subcuenca del río Torjá, Chiquimula, Guatemala. Rev. Cienc. Técnic. Agropec. 23(1):41-46. http://scielo.sld.cu/pdf/rcta/v23n1/rcta07114.pdf.

Calero, A.; Castillo, Y.; Quintero, E.; Pérez, Y. y Olivera, D. 2018. Efecto de cuatro densidades de siembra en el rendimiento agrícola del frijol común (*Phaseolus vulgaris* L.). Rev. Fac. Cienc. 7(1):88-100. https://doi.org/10.15446/rev.fac.cienc.v7n1.67773.

CIAT. 1982. Centro Internacional de Agricultura Tropical. Etapas de desarrollo de la planta de frijol común. Cali, Colombia. 26 p.

García, E. 2004. Modificaciones al sistema de clasificación climática de Köppen (para adaptarlo a las condiciones de la República Mexicana 5$^{ta.}$ (Ed.). Instituto de Geografía-Universidad Naional Autónoma de México (UNAM) (CD con el programa modifica). México, DF. 71 p.

Hall, A. E. 2012. Phenotyping cowpeas for adaptation to drought. Frontiers in physiology. 3(155):1-8. Doi: 10.3389/fphys.2012.00155.

Kohashi, S. J.; da Costa, J. C. and Miranda, S. C. 1980. Harvest index in *Phaseolus vulgaris* (L.). Ann. Rep. Bean Improv. Coop. 23:87-89. https://www.alice.cnptia.embrapa.br/bitstream/doc/885721/1/BIC198001.pdf.

Ligarreto, M. G. A.; Castro, H. O. A. and Cháves, B. 2015. Estabilidad fenotípica de una colección de fríjol andino (P*haseolus vulgaris* L.) tipo arbustivo. Rev. UDCA Actualidad and Divulgación Científica. 18(1):109-118. https://revistas.udca.edu.co/index.php/ruadc/article/view/459.

López, S. E.; Acosta, G. J. A.; Tosquy, V. O. H.; Salinas, Pérez, R. A.; Sánchez, G. B. M.; Rosales, S. R.; González, R. C.; Moreno, G. T.; Villar, S. B.; Cortinas, E. H. M. y Zandate, H. R. 2011. Estabilidad de rendimiento en genotipos mesoamericanos de frijol de grano negro en México. Rev. Mex. Cienc. Agríc. 2(1):29-40.

Morales, R. A.; López, C. C.; Kohashi, S. J.; Miranda, C. S. y García, E. A. 2015. Comparación de los componentes del rendimiento en variedades de frijol en condiciones de acidez y humedad residual del suelo en el sur de Veracruz. Terra Latinoam. 33(4):309-319.

Nielsen, D. C. and Nelson, N. O. 1998. Black bean sensitivity to water stress at various growth stages. Crop Sci. 38(2):422-427. https://doi.org/10.2135/cropsci1998.0011183X003800020025x.

Omae, H.; Kumar, A. and Shono, M. 2012. Adaptation to high temperature and water deficit in the common bean (*Phaseolus vulgaris* L.) during the reproductive period. J. Bot. 2012(803413):1-6. doi:10.1155/2012/803413.

Osuna, C. E. S.; Reyes, M. L.; Padilla, R. J. S.; Rosales, S. R.; Martínez, G. M. A.; Acosta, G. J. A. y Figueroa, S. B. 2013. Rendimiento de genotipos de frijol con diferentes métodos de siembra y riego-sequía en Aguascalientes. Rev. Mex. Cienc. Agríc. 4(8):1209-1221.

Polania, J.; Poschenrieder, C.; Rao, I. and Beebe, S. 2016. Estimation of phenotypic variability in symbiotic nitrogen fixation ability of common bean under drought stress using 15N natural abundance in grain. European J. Agron. 79:66-73. http://dx.doi.org/10.1016/j.eja.2016.05.014.

Rainey, K. M. and Griffiths, P. D. 2005. Differential response of common bean genotypes to high temperature. J. Am. Soc. Hortic. Sci. 130(1):18-23. https://doi.org/10.21273/JASHS.130.1.18.

Ramirez, V. P. and Kelly, J. D. 1998. Traits related to drought resistance in common bean. Euphytica. 99(2):127-136. https://doi.org/10.1023/A:1018353200015.

Rao, I.; Beebe, S.; Polania, J.; Ricaurpe, J.; Cajiao, C.; Garcia, R. and Rivera, M. 2013. Can Tepary bean be a model for improvement of drought resistance in common bean? Afri. Crop Sci. J. 21(4):265-281.

Romero, F. C. S.; López, C. C.; Miranda, C. S.; Kohashi, S. J.; Aguilar, R. V. H. y Martínez, R. C. G. 2015. Variabilidad del rendimiento de semilla y sus componentes en frijol común bajo condiciones de temporal. Ciencias Agrícolas Informa. 24(1):7-17.

Romero, F. C. S.; López, C. C.; Kohashi, S. J.; Martínez, R. C. G.; Miranda, C. S. y Aguilar, R. V. H. 2018. Ambiente y genotipo: efectos en el rendimiento y sus componentes, y fenología en frijol común. Acta Universitaria. 28(6):20-32. doi: 10.15174/au2018.1760.

Romero, F. C. S.; López, C. C.; Kohashi, S. J.; Miranda, C. S.; Aguilar, R. V. H. y Martínez, R. C. G. 2019. Cambios en el rendimiento y sus componentes en frijol bajo riego y sequía. Rev. Mex. Cienc. Agríc. 10(2):351-364.

Rosales, M. A.; Ocampo, E.; Rodríguez, V. R.; Olvera, C. Y.; Acosta, G. J. A; Covarrubias, A. A. 2012. Physiological analysis of common bean (*Phaseolus vulgaris* L.) cultivars uncovers characteristics related to terminal drought resistance. Plant Physiol. Biochem. 56(2012):24-34. doi:10.1016/j.plaphy.2012.04.007.

Rosales, S. R.; Ochoa, M. R. y Acosta, G. J. A. 2001. Fenología y rendimiento del frijol en el altiplano de México y su respuesta al fotoperiodo. Agrociencia. 35(5):513-523.

Rosales, S. R.; Acosta, G. J. A.; Muruaga, M. J. S.; Hernández, C. J. M.; Esquivel, E. G. y Pérez, H. P. 2004. Variedades mejoradas de frijol del Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (INIFAP). Libro técnico 6. 148 p.

SAS. 2009. The SAS System Program release 9.1 for Windows. SAS Institute, Inc. Cary, North Carolina, USA. Software of statistical analysis.

Tosquy, V. O. H.; López, S. E.; Zetina, L. R.; Villar, S. B. y Rodríguez, R. J. R. 2017. Producción de genotipos de frijol negro en condiciones de humedad residual y sequía terminal. Terra Latinoam. 35(1):29-39.