Article

Changes in yield and its components in bean under irrigation and drought

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Abstract

The common bean (*Phaseolus vulgaris* L.) is affected by drought, which when occurring during the reproductive stage can significantly affect its morphological and physiological components. The objective of this study was to evaluate the genetic variability in seed yield and its components and phenology of the plant in thermal weather (°Cd) in varieties of beans ‘Flor de Mayo’ and black beans of southern Veracruz, in irrigation and drought under a plastic cover, at the Postgraduate College, *Campus* Montecillo in spring-summer 2014. In irrigation, the varieties FM M38, FM Sol and FM RMC stood out for presenting higher seed yield (RS), aerial biomass (BMA), harvest index (IC), day to flowering degrees (GDF) and day degrees to physiological maturity (GDMF), while in drought, FM M38 and FM Sol had high values in RS, BMA, GDF and GDMF. Drought decreased RS (42.1%), BMA (31.7%), IC (13.4%), number of pods per plant (VP, 36.5%), seeds per plant (SP, 43.9%), seeds per pod (SV; 10.3%) and individual seed weight (PIS, 16.2%) with respect to irrigation. The RS of the varieties ‘Flor de Mayo’ and black beans, under irrigated conditions, was positively and significantly related to the BMA, the IC and the PIS. Under drought, RS was positively and significantly related to BMA and IC.

Keywords: *Phaseolus vulgaris* L., biomass, humidity levels, physiological maturity.

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Introduction

Drought is the main factor limiting grain yield (RG) of crops in rainfed environments, such as beans (*Phaseolus vulgaris* L.) where the effects of water deficit in the plant depend on the variety, phenological stage, duration and severity of stress (López *et al*., 1996; Assefa *et al*., 2013). The RG is positively related to the accumulated biomass (Escalante, 1999; Apaéz *et al*., 2011). Some authors point out that high RG in crops are the result of a higher production of dry matter in the leaves and the increase in carbon accumulation (Geiger *et al*., 1989), in beans a high aerial biomass is associated with higher production of photoassimilates that are translocated to pods and seeds improving the RG (Ramírez and Kelly, 1998; Romero *et al*., 2015).

On the other hand, the RG under conditions of water deficit decreases due to the reduction in some of its components, López *et al*. (1996); Assefa *et al*. (2013) indicate that the number of pods and seeds per plant can reduce seed yield up to 70% depending on the duration and intensity of the stress period. Núñez *et al*. (2005) when studying the response of the variety of bean Seafarer under irrigation and drought conditions from the beginning of flowering, determined that the yield of seed, harvest index, number of pods per plant, seeds per pod and individual weight of seed in drought decreased 80, 26, 63, 29 and 22%, compared with irrigation. Acosta *et al*. (1997) mention that the reduction in yield was linked to the decrease in the number of pods and seeds per plant and to a lesser degree to the number of seeds per pod and the weight of 100 seeds.

Water stress has its most adverse effect during the reproductive phase (Costa *et al*., 2000). Several studies show that the number of flowers, pods and seeds is reduced per pod (Xia, 1997), in some varieties of beans the drought decreases to 47% the number of flowers, affecting the number of pods per plant (Núñez *et al*., 2005). It has also been observed that pod abortion under water stress conditions can vary from 21 to 65% (Mwanamwenge *et al*., 1999).

In field evaluations for selection by drought tolerance, soil moisture content is usually a difficult factor to control due to the natural variability in depth and soil moisture retention profile and the occurrence of rainfall when stress conditions are desired by drought. To study the phenotypic response to soil water deficit, plant breeders generate validation contexts under controlled conditions that allow them to more accurately discriminate genotypes more tolerant to this adverse factor and identify morphological and physiological attributes associated with tolerance to this type of stress.

In the present investigation, 12 Mexican common bean varieties were evaluated under controlled irrigation and drought conditions, in order to know their tolerance to edaphic water stress, as well as to study the changes in the physiological and numerical components of seed yield when the crop is subjected to drought conditions.

Materials and methods

Experimental site

This work was carried out in the Postgraduate College, Montecillo, Texcoco, State of Mexico, Mexico (19º 21' North latitude, 98º 55' West longitude and 2 250 masl), in the spring-summer 2014 cycle under irrigation conditions and drought in PVC containers. A sandy loam soil (63% sand, 27% silt and 9.8% clay) was used, with field capacity (CC) of 41.6% and percentage of permanent wilting (PMP) of 28.2%.

Genetic material

Eight commercial varieties of beans of the 'Flor de Mayo' type was used (FM Anita, FM Corregidora, FM 2000, FM M38, FM Sol, FM Bajío, FM Noura and FM RMC), two varieties with black seed testa (Black Cotaxtla 91 and Negro Veracruz) and two creole varieties: Michoacan 128 (similar to the varieties of 'Flor de Mayo') and creole San Andres (with black seed testa).

Experimental design and soil moisture treatments

The twelve varieties were evaluated under a randomized complete block design with three replications under irrigation (R) and in drought (S), the experimental unit consisted of one plant for each container or PVC tube of 1 m high and 10 cm in diameter. In each container, a cylindrical plastic bag of the same dimensions of the tube was introduced, it was filled with soil previously disinfected with Furadan® (Carbofuran) and Quatz IV® (Sulfosuccinate) at a dose of 1 ml per container. The soil was taken to CC and its initial weight (PICC) was determined. Planting was done on April 12, 2014. It was fertilized with 40 kg N ha^{-1} and 40 kg P_2O_5 ha^{-1} at sowing and 40 kg N ha^{-1} at 35 days after sowing (dds).

In the treatment of R the containers were weighed every third day, to calculate the amount of evapotranspired water (ET) and add the water required to bring the soil of each container to the PICC and maintain the humidity level close to CC from planting to the physiological maturity of plants.

In the treatment of S we proceeded in the same way as in R. However, at 45 dds (near the beginning of flowering stage) the application of water was suspended and only the weight of the containers was recorded until physiological maturity. The plants were kept under a transparent polyethylene cover at a height of 2.5 m to avoid falling rainwater during the experiment and allow the plants to be exposed to ambient temperature. For the control of whitefly, Nugor® (Dimetoate) was applied at a dose of 1 L ha^{-1} at 23 and 30 dds.

Measured variables

Degrees day of growth to reach flowering (GDF, °Cd)

Flowering was determined when each individual plant showed one or more open flowers.

Degrees day of growth to reach physiological maturity (GDMF, °Cd)

Physiological maturity was determined when 90% of the pods in each individual plant presented a straw color.

The day degrees (GD, ºCd) at flowering and physiological maturity were calculated with the following equation.

$$GD=\sum_{i=0}^{n}(Xi-Tb)$$

Where: GD= degree day (ºCd), Xi= average of the maximum and minimum daily air temperature and Tb= base temperature with value of 8.2 ºC for beans (Barrios and López, 2009).

Pods per plant (VP)

The total number of pods containing at least one normal seed with the size and characteristic color of each genotype was counted.

Seeds per plant (SP)

The total number of seeds in each experimental unit was counted.

Seeds per pod (SV)

The number of seeds produced in each of the normal pods of each individual plant was counted.

Individual seed weight (PIS, mg)

It was determined as the quotient between the yield of seed per plant and the number of seeds per plant.

Seed yield per plant (RS, g)

It was determined by weighing all the normal seeds produced by the plant.

Aerial biomass (BMA, g)

The weight of the dry matter of the plant at physiological maturity was recorded; the weight of all the vegetative organs (petioles, leaflets and branches) and reproductive organs (buds, flowers and pods) that suffered abscission were included, which were collected during the biological cycle of the plants.

Harvest index (IC)

It was calculated by dividing the RS between the BMA [IC= (RS/BMA)∗100].

Statistical analysis

An analysis of variance (Andeva) was carried out under an experimental design in random blocks with two factors (varieties and humidity levels) and an individual Andeva for irrigation and drought. The minimum significant difference (DMS, $p\leq 0.05$) was used to compare means. The SAS program (SAS, 2014) version 9.4 for Windows was used.

Results

Weather data

The maximum and minimum air temperatures were recorded with a maximum and minimum mercury column thermometer, Taylor® brand. The maximum and minimum temperatures average during the cycle of the plants were 33 and 11 °C, respectively; the maximum varied between 25 and 40 °C during most of the biological cycle, with a tendency to decrease toward physiological maturity, while the minimum varied between 7 and 13 °C, with a tendency to increase after flowering (Figure 1).

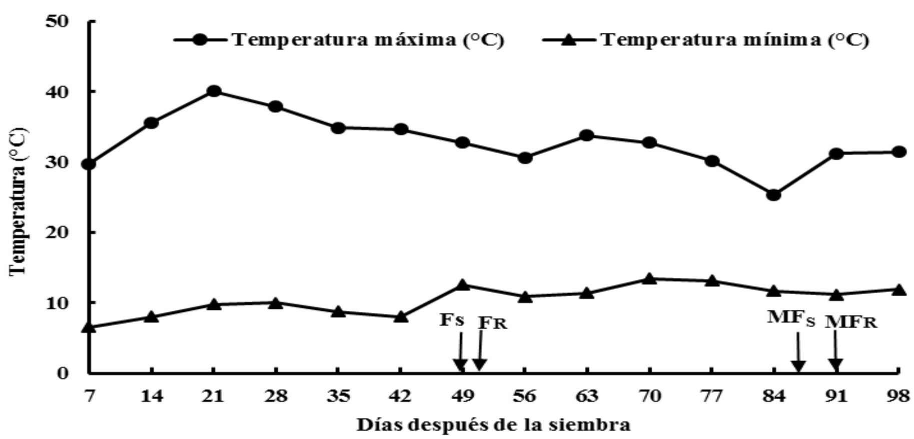

Figure 1. Maximum and minimum average weekly air temperature. Spring-summer 2014 cycle. Montecillo, Texcoco, State of Mexico. Fs= number of days to flowering in drought; F_R= number of days to flowering in irrigation; MF_R= number of days at physiological maturity in irrigation; MF_S= number of days at physiological maturity in drought.

Edaphic moisture content

Irrigation treatment remained close to CC (41.6%) from sowing to physiological maturity without the plants experiencing water stress. In drought, the application of water was suspended at 45 dds. The water content of the soil decreased during the biological cycle of the plants until reaching a level lower than the PMP (28.2%) during the period of seed formation and the physiological maturity stage (Figure 2).

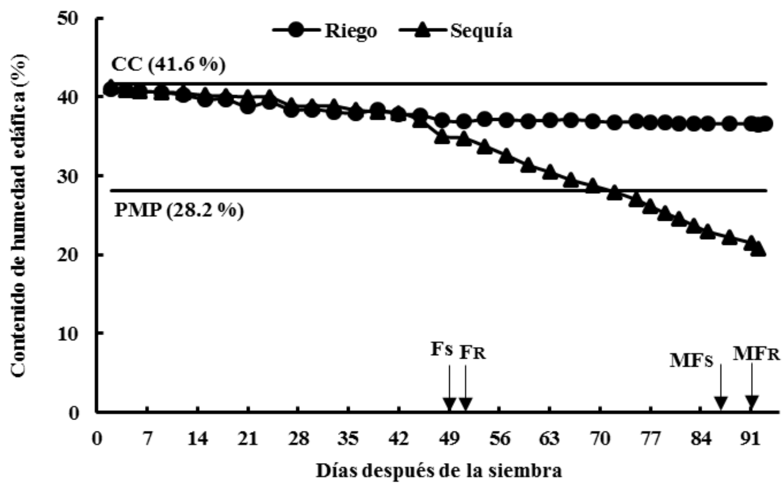

Figure 2. Content of soil moisture in irrigation and drought. Spring-summer 2014 cycle. Montecillo, Texcoco, State of Mexico. CC= field capacity; PMP= percentage of permanent wilting; Fs= number of days to flowering in drought; F_R= number of days to flowering in irrigation; MF_R= number of days at physiological maturity in irrigation; MF_S= number of days at physiological maturity in drought. Each point represents the general average of all genotypes for each moisture level.

Irrigation

The individual variance analysis (Andeva) for the irrigation conditions detected significant statistical differences between varieties for the RS (F= 6.7, p< 0.0001), BMA (F= 9.4, p< 0.0001), IC (F= 3.6, p= 0.0134), VP (F= 22.3, p< 0.0001), SP (F= 6.7, p= 0.0013), SV (F= 6.9, p= 0.0085), PIS (F= 11, p< 0.0001), GDF (F= 9.2, p< 0.0001) and GDMF (F= 13.5, p< 0.0001), the varieties FM M38, FM Sol and FM RMC had higher RS, BMA, IC, GDF and GDMF; likewise, the variety FM M38 showed high number of SP and SV, FM Sol had high number of VP and PIS and FM RMC presented high PIS. Additionally, FM Anita, FM Noura, FM 2000, Negro Veracruz, Michoacán 128 and FM Bajío varieties presented higher values in IC, IC and PIS, PIS, IC, VP and IC, respectively (Table 1).

Table 1. Yield of seed and its components and phenology of the plant under irrigation. Spring-summer 2014 cycle. Montecillo, Texcoco, State of Mexico.

Varieties	RS	BMA	IC	VP	SP	SV	PIS	GDF	GDMF
FM M38	18.5	33.2	57.5	11	76.5	6	340	707 (52)	1282 (95)
FM Sol	18.6	35.2	53	17	55.5	3.5	450	716 (53)	1259 (94)
FM RMC	16.5	31.9	51.3	10.7	41	3.5	405	722 (53)	1272 (95)
FM Anita	14.5	26.7	52.5	16.5	59	4	306.7	666 (48)	1168 (86)
FM Noura	13.4	25.7	56	7.5	30.5	4	420	700 (51)	1237 (92)
FM 2000	12.5	27.9	44.3	11	31	2	460	670 (49)	1223 (91)
FM Bajío	11.2	22.1	50.6	14.7	43	3	263.3	661 (48)	1156 (85)

Varieties	RS	BMA	IC	VP	SP	SV	PIS	GDF	GDMF
FM Corregidora	11.2	23	47	8.5	41	5	350	683 (50)	1219 (90)
Negro Veracruz	13.5	25.9	53.5	10	46.3	4.5	290	680 (49)	1251 (93)
Negro Cotaxtla 91	9.6	21.9	40	12.5	57.5	4.5	185	700 (51)	1218 (90)
Creole San Andres	9.6	22.5	42.3	13	57	4.5	190	688 (50)	1237 (92)
Michoacan 128	12.1	24.9	46	19	57	3	235	683 (50)	1223 (91)
General average	13.3	26.5	49.2	12.6	49.2	3.8	325.9	689 (50)	1228 (91)
DMS ($p\leq 0.05$)	3.4	4.1	8.9	2.2	15.3	1.3	83.3	19 (2)	30 (2)

RS= seed yield (g); BMA= aerial biomass (g); IC= harvest index (%); VP= pods per plant; SP= seeds per plant; SV= seeds per pod (g); PIS= individual seed weight; GDF= degrees day to flowering; GDMF= degrees day to physiological maturity; DMS= significant minimum difference.

Drought

The individual Andeva showed significant statistical differences between varieties for the RS (F= 3.9, p= 0.0032), BMA (F=7.1, p< 0.0001), IC (F= 23.5, p< 0.0001), VP (F=9.7, p< 0.0001), SP (F= 10.8, p< 0.0001), SV (F= 8.2, p= 0.0012), PIS (F= 11.3, p= 0.0001), GDF (F= 6.3, p< 0.0001) and GDMF (F= 7.7, p< 0.0001), the varieties FM M38 and FM Sol had high values in RS, BMA, GDF and GDMF; in addition, FM M38 had high IC and SV number, FM RMC, FM Anita, FM 2000, Negro Veracruz, Michoacán 128, FM Bajío, Negro Cotaxtla 91 and Creole San Andres showed high mean values in BMA, SV, GDF and GDMF, VP, PIS, SV, BMA, VP, SP, SV and GDF, IC, VP and SP, SP, SV, GDF and GDMF and VP, SP and SV, respectively (Table 2).

Table 2. Seed yield and its components and plant phenology under drought. Spring-summer 2014 cycle. Montecillo, Texcoco, State of Mexico.

Varieties	RS	BMA	IC	VP	SP	SV	PIS	GDF	GDMF
FM M38	10.1	19.8	51.5	7	31	4	245	707 (52)	1233 (91)
FM Sol	10.3	21.5	48	7.6	22.7	3	350	688 (50)	1206 (89)
FM RMC	6.6	20.9	33	6.5	23	4	283.3	707 (52)	1240 (92)
FM Anita	7.9	17.9	47	11	27	2.5	275	652 (47)	1163 (86)
FM Noura	7.6	18.3	39	6	23.7	3.5	323.3	700 (51)	1235 (92)
FM 2000	7.7	15.6	44.5	7	15.5	2	435	642 (46)	1176 (87)
FM Bajío	7.9	16.7	53	11.5	35.5	3	260	647 (47)	1128 (83)
FM Corregidora	7.8	18.4	39	7.3	23	3.3	285	680 (49)	1160 (86)
Negro Veracruz	6.4	17.5	39.5	6.3	23.5	4	240	666 (48)	1160 (86)
Negro Cotaxtla 91	6.8	17.4	41	7	38	5	175	683 (50)	1210 (90)
Creole San Andrés	5.9	13.3	44.3	10.5	39.5	4	150	661 (48)	1177 (87)
Michoacan 128	7.6	19.5	35.5	10.5	37.5	4	225	683 (50)	1132(83)
General average	7.7	18.1	42.6	8	27.6	3.5	273.1	676 (49)	1185 (88)
DMS ($p\leq 0.05$)	1.9	2.5	3.8	1.9	6.8	1	68.7	26 (2)	41 (3)

RS= seed yield (g); BMA= aerial biomass (g); IC= harvest index (%); VP= pods per plant; SP= seeds per plant; SV= seeds per pod (g); PIS= individual seed weight (mg); GDF= degrees day to flowering; GDMF= degrees day to physiological maturity; DMS= significant minimum difference.

Irrigation *vs* drought

The combined Andeva showed significant statistical differences between the general means of irrigation and drought for the RS (F= 231.2, *p*< 0.0001), BMA (F= 331.6, *p*< 0.0001), IC (F= 38.4, *p*< 0.0001), VP (F= 276.1, *p*< 0.0001), SP (F= 203, *p*< 0.0001), SV (F= 6.1, *p*= 0.0234), PIS (F= 30, *p*< 0.0001), GDF (F= 16.8, *p*= 0.0002) and GDMF (F= 69.9, *p*< 0.0001). The drought reduced the RS, BMA, IC, VP, SP, SV and PIS 42.1, 31.7, 13.4, 36.5, 43.9, 10.3 and 16.2% with respect to irrigation; the drought also decreased the degree's day and days after sowing to reach flowering and physiological maturity 13 (1 dds) and 43 degrees (3 dds), respectively (Table 3).

Table 3. Seed yield and its components and phenology of the plant on average of varieties for irrigation and drought. Spring-summer 2014 cycle. Montecillo, Texcoco, State of Mexico.

Moisture levels	RS	BMA	IC	VP	SP	SV	PIS	GDF	GDMF
Irrigation	13.3	26.5	49.2	12.6	49.2	3.9	325.9	689 (50)	1228 (91)
Drought	7.7	18.1	42.6	8	27.6	3.5	273.1	676 (49)	1185 (88)
DMS ($p \leq 0.05$)	0.7	1	2.2	0.5	2.9	0.2	20.6	6 (0.5)	10 (0.8)

RS= seed yield (g); BMA= aerial biomass (g); IC= harvest index (%); VP= pods per plant; SP= seeds per plant; SV= seeds per pod (g); PIS= individual seed weight; GDF= degrees day to flowering; GDMF= degrees day to physiological maturity; DM = significant minimum difference.

Interaction of varieties x levels of soil moisture

The combined ANDEVA showed significant effects in the interaction of varieties x moisture levels for seed yield and plant phenology; RS (F= 3.2; *p*= 0.0025), BMA (F= 4, *p*= 0.0004), IC (F=4.2, *p*= 0.0012), VP (F=7.5, *p*< 0.0001), SP (F=4.3, *p*= 0.0007), SV (F= 3, *p*= 0.0169) and GDMF (F= 2.8; *p*= 0.007). No significant effects were detected for the PIS (*p*> 0.05) and GDF (F= 0.9, *p*> 0.487).

The varieties FM M38, FM Sol, FM RMC, FM Anita and Negro Veracruz (Figure 3a), FM M38, FM Sol, FM 2000 and FM RMC (Figure 3b), FM RMC and FM Noura (Figure 3c), Michoacán 128, FM Sol, FM Anita and FM 2000 (Figure 3d), FM M38, FM Sol, FM Anita, Negro Veracruz, FM 2000, Michoacan 128, Negro Cotaxtla 91, FM Corregidora, FM RMC and Creole San Andres (Figure 3e) and FM M38, FM Anita and FM Corregidora (Figure 3f) showed greater reduction of RS, BMA, IC, VP, SP and SV in drought with respect to irrigation.

The varieties Michoacán 128, Negro Veracruz, Creole San Andres, FM Corregidora and FM Sol accumulated more GDMF than the other varieties when going from irrigation to drought.

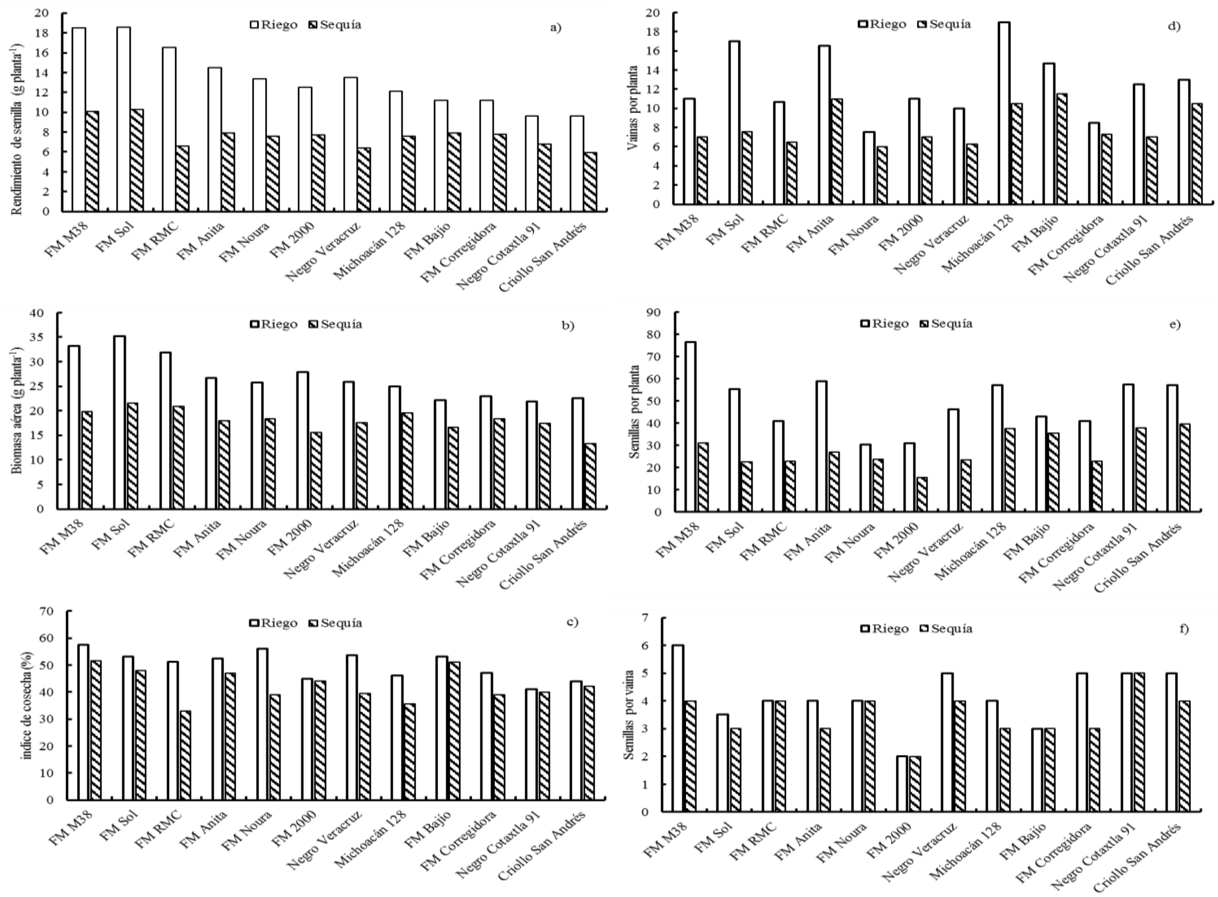

Figure 3. Interaction of varieties x soil moisture levels for seed yield. a) aerial biomass; b) harvest index; c) number of pods per plant; d) seeds per plant; e) seeds per pod; and f). Spring-summer 2014 cycle. Montecillo, Texcoco, State of Mexico.

Relationship between seed yield and its components

The RS in the varieties of the type 'Flor de Mayo' and blacks of the south of Veracruz in conditions of irrigation and drought had close relationship with some of its main physiological and numerical components, under irrigated conditions, both types of beans had the highest yield and yield components with respect to drought; in irrigation, RS was positively and significantly related to BMA (RS= 0.66 (BMA) -4.18, r= 0.96, $p \leq 0.01$.

Figure 4a), as well as having a positive and significant relation in drought (RS= 0.34 (BMA) + 1.49, r= 0.58, $p \leq 0.02$, Figure 4a), the RS was positively and significantly related to the IC in irrigation and drought, under irrigation the RS= 0.43 (IC) - 7.81, r= 0.77, $p \leq 0.005$ (Figure 4b), in drought, RS= 0.12 (IC) + 2.42, r= 0.57, $p \leq 0.02$ (Figure 4b), in irrigation the RS was also positively and significantly related to the PIS, RS= 0.02 (PIS) + 6.80, r= 0.64, $p \leq 0.01$ (Figure 4c), while in drought, the relationship was positive but not significant [RS= 0.01 (PIS) + 5.71, r= 0.42, $p > 0.05$ (Figure 4c)], on the other hand, the BMA in irrigation, was positively and significantly related to the IC [BMA=0.48 (IC) + 2.92, r= 0.59, $p \leq 0.02$ (Figure 4d), although in drought, this relationship was positive but not significant [BMA= - 0.07 (IC) + 21.16, r=0.19, $p > 0.05$] (Figure 4d), in irrigation, PIS showed a negative and not significant relationship with the SP number, [PIS= -3.37 (SP) + 491.70, r= 0.46, p> 0.05] (Figure 4e), while in drought, this relationship was negative and significant [PIS=-8.53 (SP) + 512.26, r= 0.87, p< 0.01] (Figure 4e) and finally , in irrigation the PIS had a negative and not significant relation with the SV, [PIS= -26.25 (SV) + 428.49, r= 0.29, p> 0.05] (Figure 4f) and in drought, this relationship was negative and significant [PIS= -73.67 (SV) + 530.24, r= 0.79, p< 0.01] (Figure 4f).

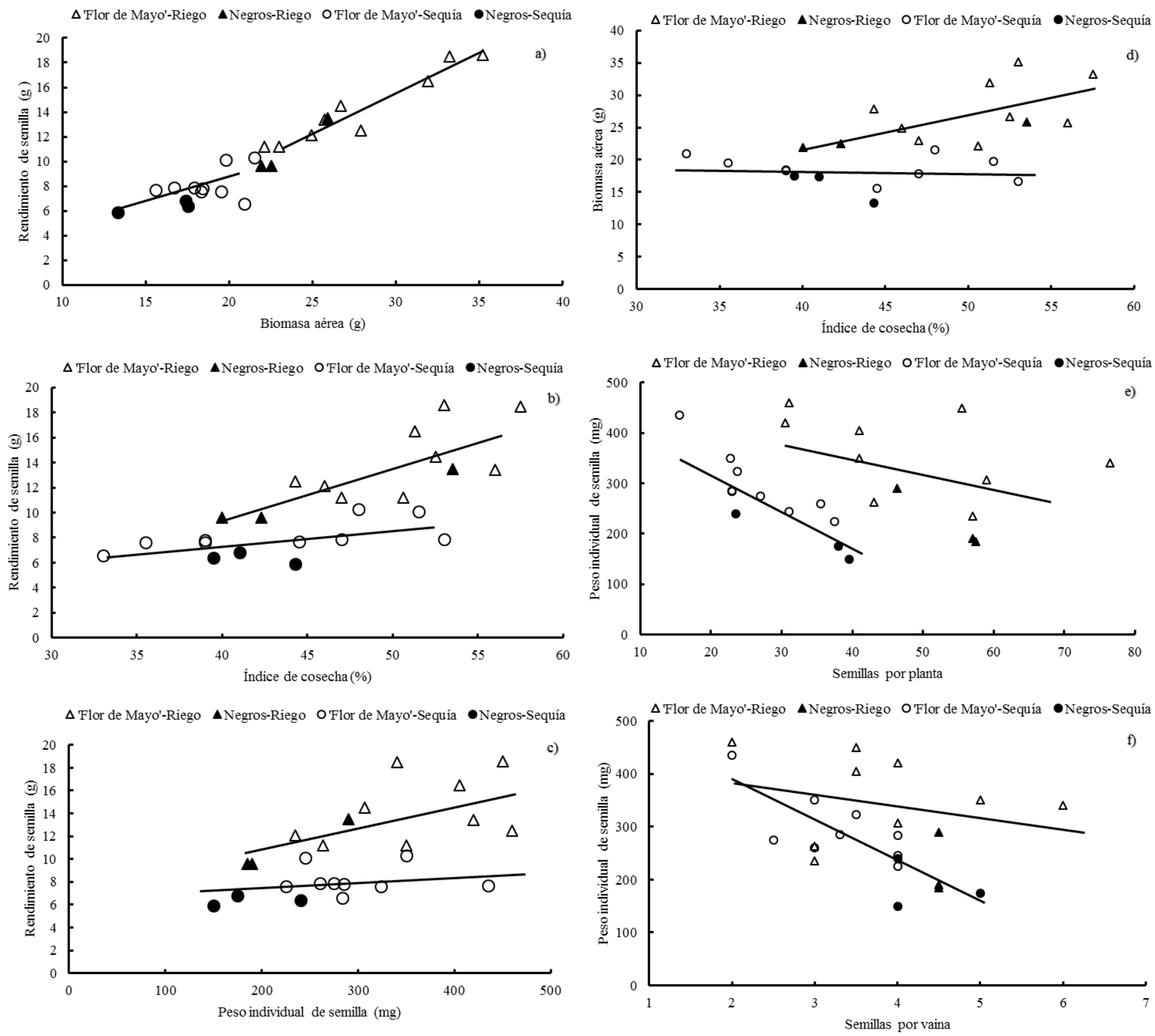

Figure 4. Relationship between seed yield and aerial biomass, a) seed yield and harvest index; b) seed yield and individual seed weight; c) aerial biomass and harvest index; d) individual seed weight and number of seeds per plant; e) individual weight of seed and number of seeds per pod; and f) for varieties of the type 'Flor de Mayo' and blacks of the south of Veracruz in irrigation and drought. Montecillo, Texcoco, State of Mexico.

The varieties of the type 'Flor de Mayo' had the highest RS compared to the varieties with black seed, both in irrigation and in drought, except the variety Negro Veracruz which had high yield due to its higher BMA and high PIS in both humidity levels.

Discussion

Temperature and soil water content

There was wide variation in the maximum temperature (25-40 °C) and minimum (7-13 °C) during the experiment; the minimum temperature in the emergence stage of the seedlings was lower than the base temperature (8.2 °C) (Barrios and López, 2009) and tended to increase toward the end of the crop cycle. The maximum temperature was higher than the optimum temperature for the development of the common bean (24 °C) and at the beginning of the crop cycle reached values of 34.1 °C, at which the growth rate is zero (Ferreira *et al*., 1997), staying close to 31 °C between anthesis and physiological maturity.

The moisture content of the soil in the drought treatment was similar to that of the irrigation treatment until the beginning of flowering stage, later, in the drought treatment, the soil moisture decreased to levels below the point of permanent wilting, coinciding with this decrease with the reproductive stage, stage considered to be the most sensitive to drought in beans (Acosta and Kohashi, 1989; Martínez *et al*., 2007).

Irrigation

The average yield of seed of all varieties in irrigation was similar to the yield obtained in beans ‘Flor de Junio’ in greenhouse irrigation in Cieneguillas, Zacatecas, Mexico (Acosta *et al*., 2007) and in greenhouse irrigation in Montecillo, Texcoco, State of Mexico (Castañeda *et al*., 2009). The number of VP and SP obtained in the present work were 69 and 71% higher than those obtained by Castañeda *et al*. (2009), these differences between the number of VP and SP are due to the habit of growth, the varieties included in this work are of indeterminate habit, while the cultivar ‘Otomí’ has habit of determined growth (Castañeda *et al*., 2009). The average IC of all the genotypes in irrigation was similar to the average IC of six bean varieties of different growth habit and contrast in their response to drought, under greenhouse irrigation, in Germany (Gebeyehu, 2006).

Drought

The average yield of seed of all the varieties obtained under drought conditions was similar to the yield obtained in beans ‘Flor de Junio’ in severe drought (50% of soil moisture during the cycle) in greenhouse in Cieneguillas, Zacatecas, Mexico (Acosta *et al*., 2007). In contrast, compared to ‘Otomí’ bean, the yield was 65% higher in the greenhouse with drought during the stage of pod production (Castañeda *et al*., 2009); the differences in yield are due to the lower effect of drought on the number of VP and SP determined in the present study, which were 66 and 74% higher than those observed in ‘Otomi’ beans (Castañeda *et al*., 2009).

The average IC of the 12 varieties in drought was only 3% higher than the one determined by Gebeyehu (2006) in average of six bean varieties of different growth habit and contrasting in their response to drought, under greenhouse drought in Germany.

Irrigation *vs* drought

Drought during flowering and the period of seed formation reduced the RS and its components. This same effect has been observed by other authors under greenhouse conditions, for RS, BMA, VP and SP (Boutraa and Sanders, 2001; Rainey and Griffiths, 2005; Núñez *et al.*, 2005; Acosta *et al.*, 2009; Lanna *et al.*, 2016). As also observed by Acosta *et al*. (2009) in the IC, which was also affected by the drought, especially in the period of seed formation in eight bean genotypes of different growth habit subjected to drought in the reproductive stage.

The water deficit also decreased the GDF and GDMF; the GDF went from 689 in irrigation to 676 °Cd in drought, while the GDMF of 1228 changed to 1185 °Cd when going from irrigation to drought. On the other hand, Barrios *et al*. (2011) observed the same effect in the physiological maturity of six varieties of beans ‘Flor de Mayo’, a variety ‘Flor de Junio’ and a creole Michoacán 128, under irrigated and temporary conditions in the field.

Interaction of varieties x humidity levels

The varieties that show the greatest decrease in the RS or some other component of the yield or characteristic when going from irrigation to drought, are considered varieties susceptible to drought, on average, the decrease in the RS and its components was 38% for the RS, 33% in the BMA and 38% in the number of VP when going from irrigation to drought. In Germany Gebeyehu (2006) under greenhouse conditions observed a reduction in RS and BMA similar to that observed in this research work. Castañeda *et al*. (2009) observed that the drought during the pod formation period reduced the number of VP by 40% with respect to irrigation in the 'Otomi' cultivar under greenhouse conditions in Montecillo, Texcoco, State of Mexico.

Relationship between seed yield and its components

The correlation between the RS and its components, showed that when passing from irrigation to drought the bean varieties that decreased their RS to a greater extent also decrease those components of the yield that are more closely related to said reduction. Szilagyi (2003) indicates that the decrease in RS (78%) under water stress conditions in field beans was more associated with the decrease in the number of pods per plant (60%) than with the number of seeds per pod (26%) and weight of 100 seeds (13%), the yield of seed (60%) and number of pods (63%) more than the number of seeds per pod (29%), the harvest index (26%) and seed size (22%) (Núñez *et al*., 2005).

The varieties ‘Flor de mayo’ showed higher yield of seed and components of the yield than the varieties with black testa, both in irrigation and in drought, playing an important role the final aerial biomass, the harvest index and the individual weight of seed in the determination of yield.

In another study, under dry conditions in 12 bean varieties, Romero *et al*. (2015) when working with nine genotypes of beans of the type ‘Flor de Mayo’ suggested that they can maintain high yield thresholds with the same number of seeds per m^2 and a greater individual weight of seed, while for black beans, a higher yield threshold could be obtained with a higher number of seeds per m^2.

On the other hand, Rao *et al*. (2013) observed that two genotypes of common bean and two of Tepari bean produced higher yield of seed under conditions of terminal drought due to their greater capacity of mobilization of photosynthates of leaves and stems for the development of the seed. They also observed that higher leaf biomass, allocation of dry matter to the pod, reduction of stem biomass and harvest index are characters that could be used for the selection of superior genotypes for conditions of terminal water stress.

Conclusions

There were significant effects between the two moisture regimes evaluated and significant variation between varieties for seed yield and their main physiological and numerical components. The Flor de Mayo type FM M38, FM Sol and FM RMC varieties showed higher seed yield potential in irrigation and FM M38, FM Sol in drought. The yield of seed and its components were strongly affected by the drought induced from the beginning of flowering. The final aerial biomass, pods per plant, seeds per pod and individual seed weight were the components of yield most affected by water stress.

Varieties with lower yield reduction and drought yield components can be used as parents in breeding programs for rainfed areas.

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