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Evaluation of common bean genotypes for drought tolerance

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ABSTRACT: The aim of this study was to evaluate twelve genotypes of common bean for intermittent drought stress and for root growth angle. The water deficit experiments were conducted in 2015 and 2016 in a randomized block experimental design with split plots and three replications. Two treatments were applied: an irrigated treatment and a water deficit treatment, in which irrigation was suspended in pre-flowering and remained suspended up to the time at which the matrix potential of the soil was measured to be near -199 kPa. At the maximum point of water deficit, physiological and morphological traits were evaluated, and at physiological maturity, the yield compounds and grain yield. To evaluate root growth angle in 2016, a growth pouch system was used in a randomized block design, with five replications.

Water deficit reduced genotype performance for all the traits except leaf temperature and first pod height. In relation to grain yield, the genotypes SEA 5 and Carioca Precoce performed better under water restriction conditions in both evaluations. The genotype Gen TS 4-7 performed better in the 2015 evaluation, and Gen TS 3-1 and Gen TS 3-3 in 2016. SEA 5, Gen TS 3-1, and Carioca Precoce had the highest harvest indexes in 2015; and Gen TS 3-1, Gen TS 3-2, Gen TS 3-3, Gen P5-4-3-1, IAPAR 81, Carioca Precoce, and SEA 5 in 2016. SEA 5 and Carioca Precoce had the best root growth angle and were considered sources of tolerance to water deficit.

Key words: *Phaseolus vulgaris*, water deficit, grain yield, root growth angle.

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INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) or dry edible bean, hereinafter bean, is one of the main agricultural crops in Brazil and in the world and plays an important role in the diet of African and Latin American populations as a source of plant protein, carbohydrates, dietary fiber, B complex vitamins, iron, calcium, and minerals (Beebe 2012).

The main producers of this legume, according to data from FAO (2014), are Myanmar (4,651,094 metric tons [t]), India (4,110,000 t), Brazil (3,294,586 t), the United States of America (1,311,340 t), Mexico (1,273,957 t), and the United Republic of Tanzania (1,114,500 t). However, production in these countries has tended to decline over the years due to increasingly significant climate changes and concerns over temperature and rainfall profiles that increase the occurrence and severity of drought events (Lobell et al. 2011). According to data from CONAB (2016), these events were also perceived in Brazil and led to a 21% decline in production in relation to the previous crop season.

To reduce the damage caused by water restriction and keep low production costs, plant breeding programs have concentrated on identifying and incorporating the drought tolerance trait in new bean genotypes, seeking to develop better adapted cultivars that produce even under unfavorable conditions.

In this regard, various studies have been undertaken to understand the mechanisms of drought tolerance. Root architecture can allow deeper and moister soil layers to be exploited to escape from water deficit, and thus it can be a promising trait for crop performance under stress conditions (Vadez 2014). Morphological traits, such as lower leaf area index, and physiological aspects, such as lower stomatal conductance, are also considered to be mechanisms of adaptation to water shortage, allowing the plant to reduce evapotranspiration area (Beebe et al. 2013; Rao 2014). Other important traits are biomass production, partitioning of dry matter to promote grain production, and harvest index (Rao et al. 2013). Plants have diverse mechanisms for response and adaptation to water stress; therefore, determination of their distinct morphological, physiological, and agronomic traits for drought tolerance is indispensable to ensure efficiency in the selection process (Beebe et al. 2013).

Under the hypothesis that bean genotypes have wide variability and respond differently to degrees of stress, the aim of this study was to evaluate the effect of water deficit

applied to twelve bean genotypes with traits of commercial interest through evaluation of physiological, morphological, agronomic traits and root growth angle.

MATERIALS AND METHODS

Plant material

To carry out evaluations of drought tolerance (first-harvest, 2015 and 2016) and root growth angle (2016), the following genotypes were used: Gen TS 3-1, Gen TS 3-2, Gen TS 3-3, Gen TS 4-7, H96A31-P2-1-1-1-1, IAC Sintonia, Gen P5-4-3-1, Carioca Precocce, IAC Carioca Eté, and IAC Apuã (susceptible control), from the breeding program of the Instituto Agrônômico (IAC); IAPAR 81, from the Instituto Agrônômico do Paraná (IAPAR); and SEA 5 (tolerant control), from the Centro Internacional de Agricultura Tropical (CIAT).

Drought tolerance experiments

Two experiments were conducted of the first-harvest of 2015 and 2016 at the Experimental Center of the Santa Elisa Farm of the IAC in the municipality of Campinas, São Paulo, Brazil (22°54' S, 47°03' W, and altitude of 854 m). The experiments were conducted in the ground in a greenhouse through a randomized block design, with split plots and three replications. The plots consisted of the irrigated and water deficit treatments and the split plots consisted of the genotypes.

Before setting up the experiments, the chemical characteristics of the soil at the depth of 0 – 20 cm were determined according to Rajj et al. (1997). Nitrogen fertilizer was applied at planting, consisting of 40 kg·ha⁻¹ N through urea and 40 kg·ha⁻¹ K₂O through KCl. Topdressing with urea was performed 25 days after sowing, applying 80 kg·ha⁻¹ N. Twenty four plants of each genotype were grown in 2.0 m rows, with a 0.50-m spacing between rows. Plots received two daily irrigations of three minutes, at 7:00 a.m. and 6:00 p.m., up to the R5 (pre-flowering) stage by an automated system with drip nozzles spaced at 0.15 m and flow rate of 0.90 L·h⁻¹. At this stage (R5), irrigation was interrupted in the plot under water deficit for 22 days in 2015 e 20 days in 2016, up to the time at which the matrix potential of the soil was measured to be near -199 kPa, indicating the absence of available water in the soil at a depth of 0.40 m.

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During the experiments, the soil matric potential (Ψ_m) was monitored by moisture sensors, with readings taken by the Watermark meter.

At the time of maximum water deficit, the following evaluations were performed: stomatal conductance (Porometer Type AP4 – Delta T Devices), leaf temperature (Telatemp model AG-42D, Telatemp, Fullerton, CA), relative chlorophyll index (SPAD-502 Plus – Konica Minolta), leaf area (area meter - Model LI-3100C - LI-COR), total shoot dry matter and leaf dry matter. After that, irrigation was continued in the plot under water deficit, and at physiological maturity of the plants, the following evaluations were made: plant height, first pod height, 100 seed weight and grain yield. Harvest index ($HI = \text{seed biomass dry weight at harvest} / \text{total shoot biomass dry weight at mid-podfilling} \times 100$) and the water stress intensity index ($WSI = [1 - (\text{Stress} / \text{No stress})] \times 100$) were calculated as described by Beebe et al. (2013). The data obtained were evaluated by the R statistical program through individual analysis of variance. Mean values were compared by the Scott-Knott test at $p > 0.05$ probability.

Root angle experiment

The experiment was conducted in 2016 at the Experimental Center of the Santa Elisa Farm of the IAC in the municipality of Campinas, São Paulo, Brazil. A randomized block experimental design was used, with five replications, according to the methodology of Vieira et al. (2008). The seeds of the bean genotypes were pre-germinated and the seedlings were placed in a growth pouch system. This system consisted of a 28×38 cm sheet of Germitest paper with neutral pH, which was folded in the middle and inserted in a polyethylene bag (growth pouch system). In the upper part of the polyethylene bag, a V cut was made to accommodate the seedling. The growth pouches were supported crosswise by plastic channels in the upper part of rectangular glass vessels. The open part of the polyethylene was turned to the inside of the vessel, allowing the Germitest paper to remain in direct contact with the nutrient solution and allowing it to touch the seedling roots through capillarity.

The nutrient solution used was developed in the common bean plant breeding program of the IAC, described by Silva et al. (2014), without any kind of abiotic stress. The nutrient solution was prepared at half strength (50%) since the complete solution is used for developed plants and this study was carried out with common bean seedlings. The pH

was maintained between 6 and 7 and electrical conductivity at $620.56 \mu\text{S}\cdot\text{cm}^{-1}$. The vessels were lined with aluminum foil so as to maintain the roots in darkness and placed in a climate-controlled chamber (temperature of 26°C during the day and 20°C at night; 12 hour photoperiod) for seven days. Seven days after transplanting, the angles ($^\circ$) in relation to vertical of the intact roots in the growth pouches were determined using a protractor, considering the relation between the basal roots and the main growth axis. The data obtained were evaluated by the R statistical program through analysis of variance, and comparison of mean values by the Scott-Knott test at $p > 0.05$ probability.

RESULTS AND DISCUSSION

In the 2015 evaluation, with a water stress intensity index of 71%, performance of the genotypes declined for all the traits evaluated, except for leaf temperature (LT) and first pod height (FPH). Analysis of variance showed a significant difference for water treatment for all the traits and, in regard to genotypes, for leaf area (LA), leaf dry matter (LDM), total shoot dry matter (TDM), plant height (PH), first pod height (FPH), 100 seed weight (100SW), and grain yield (GY), indicating genetic variability among the genotypes (Tables 1 and 2). The mean square of the water treatment \times genotype interaction exhibited a significant difference for GY, showing different performance of the genotypes from the imposition of water deficit (Tables 1 and 2).

In the 2016 evaluation, the water stress intensity index was 68%, leading to lower performance of genotypes for all the evaluated traits, except LT and FPH. Analysis of variance showed a significant difference for water treatment for all the traits and between genotypes for relative chlorophyll index (RCI), LA, LDM, TDM, PH, FPH, 100SW, and GY (Tables 1 and 2). The mean square of the water treatment \times genotype interaction exhibited significance for 100SW and GY, showing different performance of the genotypes when subjected to water deficit (Tables 1 and 2). The coefficients of variation (CV%) of both experiments were considered to be of low to medium magnitude, showing the reliability of the results obtained (Tables 1 and 2).

Water restriction led to a significant reduction of 46% in the RCI of the genotypes evaluated in 2015, lowering the content of leaf pigments in the plants subjected to this restriction. The joint test presented an overall mean of 33.68 un.

SPAD (Table 3), with no significant difference being detected between the genotypes. In the 2016 evaluation the RCI overall mean observed in the joint test was 27.78 un. SPAD (Table 4) and there was a significant reduction of 18% in RCI. The genotypes Gen P5-4-3-1 (22.64 un. SPAD), Gen TS 3-1 (23.00 un. SPAD), IAC Sintonia (24.80 un. SPAD) and SEA 5 (25.97 un. SPAD) differed from the others with the lowest RCI (Table 4). The results obtained in this study are in agreement with those presented by Darkwa et al. (2016), who observed lower RCI values and reported that this is a characteristic manifested in plants grown under water deficit; loss of chlorophyll is common, which is normally followed by progressive decline in the photosynthetic ability of the plants. Nevertheless, the genotypes evaluated in this study showed

similar behavior in relation to RCI in the two evaluations, except for Gen P5-4-3-1, Gen TS 3-1, IAC Sintonia, and SEA 5 in 2016, making it difficult to select superior genotypes through this characteristic.

For stomatal conductance (g_s), there was a significant reduction of 82% in 2015 and 53% in 2016. The joint test presented an overall mean of 167.30 $\text{mmol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ in 2015 and 96.04 $\text{mmol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$ in 2016 (Tables 3 and 4), nevertheless, significant differences between the genotypes were not detected. Although reduction in stomatal conductance protects plants from desiccation, it negatively affects photosynthesis, reducing the CO_2 availability for the photosynthetic process and, consequently, biomass accumulation is inhibited (Ribeiro et al. 2013; Sales et al. 2015). In this respect, regulation of

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Table 1. Mean squares of analysis of variance for chlorophyll index (RCI), stomatal conductance (g_s), relative leaf temperature (LT), leaf area (LA), leaf dry matter (LDM), and total shoot dry matter (TSDM) of 12 bean genotypes (G) that underwent two water treatments (WT), irrigated and water deficit. Harvest 2015 and 2016, Campinas, São Paulo, Brazil.

Source of variation	DF	Mean squares											
		RCI (un. SPAD)		g_s ($\text{mmol}\cdot\text{m}^{-2}\cdot\text{s}^{-1}$)		LT ($^{\circ}\text{C}$)		LA (dcm^2)		LDM (g)		TSDM (g)	
		2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Block	2	36.1369	127.5376	0.2044	15.1552	1.9755	0.4405	0.1115	0.6977	0.1354	0.4792	0.0146	0.0515
WT	1	7244.869**	562.242*	55.761**	253.923*	503.502*	105.851**	19.812**	12.550**	37.955**	17.180**	2.812**	2.933**
Residue a	2	36.2194	13.8143	0.3952	15.4593	15.0555	1.0516	0.0812	0.0015	0.1172	0.0738	0.0098	0.0087
Genotype	11	45.8966	55.534**	0.0829	1.4852	1.0958	0.6943	0.3872*	0.627**	0.4398*	0.254*	0.083**	0.042*
WT x G	11	40.9646	41.0925	0.1605	2.8502	0.9097	0.2406	0.1095	0.1203	0.1262	0.2035	0.0173	0.0144
Residue b	44	30.9183	20.6599	0.2012	3.7352	1.3060	0.4733	0.1604	0.1047	0.1983	0.1378	0.0218	0.0235
Total	71												
CVa (%)		17.85	13.38	13.34	41.74	17.74	3.91	4.20	0.54	13.47	13.44	6.14	6.56
CVb (%)		16.49	16.36	9.51	20.51	5.22	2.62	5.90	4.58	17.95	18.35	9.11	10.74

** and * significant at 1% and at 5% probability by the F test, respectively.

Table 2. Mean squares of analysis of variance for plant height (PH), first pod height (FPH), number of pods per plant (NPP), number of seeds per pod (NSPod), number of seeds per plant (NSP), 100 seed weight (100SW), and grain yield (GY), of 12 bean genotypes (G) that underwent two water treatments (WT), irrigated and water deficit. Harvest 2015 and 2016, Campinas, São Paulo, Brazil.

Source of variation	DF	Mean squares													
		PH (cm)		FPH (cm)		NPP (un.)		NSPod (un.)		NSP (un.)		100SW (g)		GY ($\text{Kg}\cdot\text{ha}^{-1}$)	
		2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Block		118.190	0.0793	0.0059	11.9062	0.1478	0.0432	0.1069	1.8256	0.0619	0.5691	2.9159	3935.12	0.1368	0.2802
WT	2	700.93**	5.866**	73.750*	101.53*	17.25**	2.4047*	19.71**	5.924**	6.862*	92.93**	629.59**	9918**	51.663**	34.303**
Residue a	1	6.865	0.0019	1.137	5.6562	0.0012	0.0032	0.1500	0.0267	0.0049	0.1363	1.6890	274.881	0.1177	0.0222
Genotype	2	1581.92**	0.480**	8.588**	40.59**	0.1191	0.0272	0.3421	0.1098**	0.0266	1.976**	52.98**	7159.23**	0.254**	0.726**
WT x G	11	179.656	0.1176	3.1094	11.3797	0.1258	0.0408	0.2612	0.0733	0.0319	1.1206*	4.2211	4959.14**	0.261**	0.352**
Residue b	11	43.100	0.0417	1.9150	7.6903	0.0690	0.0454	0.2603	0.0372	0.0196	0.4240	1.5653	1787.15	0.0710	0.0710
Total	44														
CVa (%)	71	5.04	1.16	12.98	18.56	1.56	3.99	9.02	10.00	3.28	9.88	5.36	11.13	6.56	3.25
CVb (%)		12.64	5.45	11.11	21.64	11.83	15.06	11.88	11.82	6.57	17.43	5.16	28.38	5.10	5.81

** and * significant at 1% and at 5% probability by the F test, respectively.

stomatal opening by genotypes tolerant to water deficit allows reduction in transpiration and the operability of the photosynthetic apparatus, making crop production possible under unfavorable conditions.

For leaf temperature (LT), there was a significant increase of 5.29 °C in the leaves of plants grown under water deficit in

2015 and 2.43 °C in 2016. The joint test presented an overall mean of 21.87 °C in 2015 and 26.17 °C in 2016 (Tables 3 and 4). Leaf temperature is directly related to *gs*, which declines under water restriction conditions, decreasing leaf transpiration and dissipation of latent heat, hindering cooling of plants (Kumar and Portis Jr. 2009). Fernandes et al.

Table 3. Mean values of relative chlorophyll index (RCI), stomatal conductance (*gs*), leaf temperature (LT), leaf area (LA), leaf dry matter (LDM), total shoot dry matter (TDM), plant height (PH), first pod height (FPH), 100 seed weight (100SW), and grain yield (GY) of 12 genotypes of common bean subjected to two water treatments (joint (J), irrigated (I) and water deficit (WD)). Crop of 2015, Campinas, São Paulo, Brazil.

Genotype	RCI (un. SPAD)	<i>gs</i> (mmol m ⁻² s ⁻¹)	LT (°C)	LA (dm ²)	LDM (g)	TDM (g)	PH (cm)	FPH (cm)	100SW (g)	GY (kg ka ⁻¹)	
	J	J	J	J	J	J	J	J	J	I	WD
Gen TS 3-1	31.67a	108.34a	21.82a	8.17b	1.84b	3.58 c	30.56 c	12.05b	24.23b	1488.89Aa	366.67Bb
Gen TS 3-2	39.98a	179.17a	21.70a	10.71b	2.45b	7.13a	39.72 c	11.56b	21.92 c	1196.30Aa	396.30Bb
Gen TS 3-3	35.70a	137.83a	21.80a	8.52b	1.85b	8.04a	33.94 c	11.39b	25.89b	1337.04Aa	340.74Bb
Gen TS 4-7	32.22a	187.60a	21.79a	9.29b	1.92b	8.74a	59.84b	13.03a	30.43a	1533.33Aa	559.26Ba
IAC H96A31P2-1-1-1-1	34.29a	188.44a	21.20a	12.48b	2.22b	5.89b	33.89 c	11.17b	19.24 d	1344.44Aa	184.67Bb
IAC Sintonia	31.12a	176.42a	22.34a	8.97b	1.89b	7.60a	59.95b	12.67a	25.07b	1374.07Aa	366.67Bb
Gen P5-4-3-1	31.90a	190.00a	22.65a	9.99b	1.79b	7.60a	60.94b	13.81a	21.31 c	1325.93Aa	325.93Bb
IAPAR 81	35.43a	178.74a	21.52a	11.20b	2.10b	6.85a	60.50b	12.92a	23.21 c	1425.93Aa	281.48Bb
Carioca Precoce	30.60a	131.80a	21.82a	8.87b	1.89b	10.48a	79.28a	14.78a	22.19 c	1244.44Aa	540.74Ba
Carioca Eté	32.59a	138.35a	21.64a	15.31a	2.89a	8.75a	64.45b	13.25a	23.99b	1907.41Aa	400.00Bb
IAC -Apuã	36.62a	182.43a	21.57a	19.17a	4.26a	11.14a	65.00b	12.28b	25.77b	1170.37Aa	299.56Bb
SEA 5	32.39a	208.45a	22.52a	8.67b	2.06b	7.87a	34.95 c	10.59b	27.22b	1166.67Aa	585.19Ba
Mean value	33.71	167.30	21.87	10.94	2.26	7.81	51.92	12.46	24.21	1376.23	387.27

Different lowercase letters in the columns indicate statistical differences ($p < 0.05$) by the Scott-Knott test between the genotypes under the same water condition, and different uppercase letter represent statistical differences between the irrigation treatments.

Table 4. Mean values of relative chlorophyll index (RCI), stomatal conductance (*gs*), leaf temperature (LT), leaf area (LA), leaf dry matter (LDM), total shoot dry matter (TDM), plant height (PH), first pod height (FPH), 100 seed weight (100SW), and grain yield (GY) of 12 genotypes of common bean subjected to two water treatments (joint (J), irrigated (I) and water deficit (WD)). Crop of 2016, Campinas, São Paulo, Brazil.

Genotype	RCI (un. SPAD)	gs (mmol m ⁻² s ⁻¹)	LT (°C)	LA (dm ²)	LDM (g)	TDM (g)	PH (cm)	FPH (cm)	100SW (g)		GY (kg ka ⁻¹)	
	J	J	J	J	J	J	J	J	I	WD	I	WD
Gen TS 3-1	23.00 b	78.70 a	26.62 a	9.23 b	0.98 b	5.74 a	34.67 b	11.34 b	18.22 Ab	17.46 Aa	735.04 Ab	444.52 Ba
Gen TS 3-2	28.25 a	102.93 a	25.65 a	11.25 b	1.25 b	3.88 a	34.83 b	12.50 b	16.95 Ab	17.40 Aa	780.81 Ab	259.81 Ba
Gen TS 3-3	29.67 a	96.67 a	26.00 a	8.38 b	1.00 b	4.92 a	34.50 b	15.50 a	20.31 Aa	16.59 Aa	736.89 Ab	335.15 Ba
Gen TS 4-7	31.50 a	93.83 a	26.26 a	10.13 b	1.00 b	4.17 a	36.00 b	12.00 b	24.75 Aa	14.51 Ba	725.26 Ab	229.63 Ba
IAC H96A31P2-1-1-1-1	29.39 a	107.08 a	26.08 a	29.36 a	1.67 a	5.27 a	34.67 b	11.17 b	14.96 Ab	5.11 Bb	342.81 Ac	102.26 Bc
IAC Sintonia	24.80 b	98.58 a	26.63 a	12.98 b	1.75 a	5.59 a	59.34 a	14.00 b	21.32 Aa	18.41 Aa	709.85 Ab	272.96 Ba
Gen P5-4-3-1	22.64 b	161.67 a	26.75 a	12.16 b	0.84 b	3.84 a	47.00 b	8.83 b	16.50 Ab	13.12 Aa	643.00 Ab	165.52 Bb
IAPAR 81	30.70 a	102.00 a	26.25 a	11.03 b	0.85 b	3.77 a	53.50 a	11.83 b	20.29 Aa	14.29 Ba	746.93 Ab	259.26 Ba
Carioca Precoce	27.33 a	102.86 a	25.86 a	17.80 a	1.42 a	7.84 a	70.67 a	12.34 b	20.88 Aa	9.63 Bb	1101.15 Aa	302.74 Ba
Carioca Eté	30.85 a	77.33 a	26.03 a	20.56 a	1.84 a	5.14 a	61.84 a	15.34 a	19.13 Aa	16.54 Aa	1056.48 Aa	183.78 Bb
IAC -Apuã	29.18 a	103.33 a	25.88 a	21.60 a	1.42 b	4.10 a	60.83 a	18.42 a	21.61 Aa	7.13 Bb	980.63 Aa	93.89 Bc
SEA 5	25.97 b	85.66 a	26.08 a	14.43 b	1.22 b	5.55 a	34.67 b	10.50 b	20.83 Aa	17.36 Aa	1082.11 Aa	360.41 Ba
Mean value	27.78	96.04	26.17	13.98	1.27	4.98	46.88	12.82	17.58	14.00	803.41	250.83

*Different lowercase letters in the columns indicate statistical differences ($p < 0.05$) by the Scott-Knott test between the genotypes under the same water condition, and different uppercase letter represent statistical differences between the irrigation treatments.

(2015) reported a 2 °C increase in leaf temperature of cowpea subjected to a 10-day period of water deficit. The authors did not find a significant difference between genotypes, just as the result of the present study, which made selection of tolerant genotypes by means of this characteristic unfeasible.

For leaf area (LA) there was significant decrease of 65% in the plants grown in the treatment under water deficit in 2015 and of 56% in 2016. This can be explained by the decrease in plant moisture content, which causes reduction in cell turgor pressure. Ghanbari et al. (2013) evaluated eight common bean genotypes and found a 27% reduction in LA in plants grown under water deficit conditions. In the present study, the genotypes that showed the biggest reductions in LA in the 2015 evaluation were IAC Apuã (75%), Carioca Precoc (73%), Gen TS 3-1 (71%), H96A31P2-1-1-1-1 (70%), SEA 5 (69%), Gen TS 4-7 (69%), and Carioca Eté (69%). The joint test presented an overall mean of 10.94 dm² and the genotypes that showed the largest LA were IAC Apuã (19.17 dm²) and Carioca Eté (15.31 dm²) (Table 3). In the 2016 evaluation, the biggest reductions in LA were in H96A31P2-1-1-1-1 (76%), IAC Sintonia (65%), Gen P5-4-3-1 (61%), Gen TS 4-7 (59%), Gen TS 3-3 (58%), and SEA 5 (57%). The joint test presented an overall mean of 13.98 dm² and genotypes that exhibited the largest LA were H96A31P2-1-1-1-1 (29.36 dm²), IAC Apuã (21.60 dm²), Carioca Eté (20.56 dm²) and Carioca Precoc (17.80 dm²) (Table 4).

For leaf dry matter (LDM) there was a significant decrease of 75% with the imposition of water deficit in 2015. The joint test presented an overall mean of 2.26 g and the genotypes with the highest values of LDM were IAC-Apuã (4.26 g) and Carioca Eté (2.89 g) (Table 3). In 2016, there was a significant reduction of 63%. The joint test presented an overall mean of 1.27 g and the genotypes with highest LDM were Carioca Eté (1.84 g), IAC Sintonia (1.75 g), H96A31P2-1-1-1-1 (1.67 g) and Carioca Precoc (1.42 g) (Table 4).

For total shoot dry matter (TDM), there was a significant reduction of 62% in the treatment under water deficit in 2015 and 67% in 2016. The joint test presented an overall mean of 7.81 g in 2015 and 4.98 g in 2016 (Tables 3 and 4). The genotypes with greatest reduction in accumulation of TDM in the treatment under water deficit in 2015 were Gen TS 3-1 (76%), Carioca Eté (72%), SEA 5 (71%), and Carioca Precoc (71%). In 2016, those with greatest reduction were Gen P5-4-3-1 (85%), Gen TS 3-3 (76%), Gen TS 3-1 (72%), SEA (71%), IAC Sintonia (69%), and Carioca Precoc (69%). Reductions in LDM and TDM under water restriction conditions were

also reported by Assefa et al. (2015) and Rao et al. (2013), who emphasized the importance of these characteristics in selection for the drought tolerance trait, highlighting that tolerant genotypes show greater ability in remobilization of photoassimilates in the shoots for production of pods and grains.

In relation to plant height (PH) under water deficit conditions, there was a significant reduction of 11% in 2015 and 43% in 2016. This reduction is directly related to limitation of cell expansion, giving rise to plants of reduced growth and lower yield. The reductions in PH indicated in this study were greater than the reduction reported by Moraes et al. (2010), who found a 5% reduction in PH in plants grown for a period of 15 days under water deficit. For FPH in the two evaluations, the genotypes under water deficit exhibited first pod height greater than the genotypes of the irrigated treatment, except for the genotype SEA-5 (10.59 cm) in 2015 and genotypes H96A31-P2-1-1-1-1 (11.17 cm) and IAPAR 81 (11.83 cm) in 2016, suggesting that this variable can be considered as indicating the occurrence of pods abortion of the plant's lower part. The joint test presented an overall mean of 12.46 cm in 2015 and 12.82 cm in 2016 for FPH (Tables 3 and 4). In 2015, the genotype Carioca Precoc exhibited the highest FPH (14.78 cm) and the genotype SEA-5, the lowest (10.59 cm) (Table 3). In 2016, the genotype IAC Apuã (18.42 cm) exhibited the highest FPH and Gen P5-4-3-1 (8.83 cm), the lowest (Table 4). FPH is an important trait when considering mechanical harvest because lower pod height and high lodging rates make harvest with self-propelled machines unfeasible. The ideal plant for mechanical harvest has a height of more than 50 cm, resistance to lodging, and pods concentrated in the upper 2/3 of the plant. This is a characteristic that should be considered in release of a new common bean cultivar to ensure acceptance by producers. In the present study, the genotypes that had PH greater than 50 cm in 2015 were Carioca Precoc (79.28 cm), IAC Apuã (65.00 cm), Carioca Eté (64.45 cm), Gen P5-4-3-1 (60.94 cm), IAPAR 81 (60.50 cm), IAC Sintonia (59.95 cm) and Gen TS 4-7 (59.84 cm) (Table 3); and in 2016 were Carioca Precoc (70.67 cm), Carioca Eté (61.84 cm), IAC Apuã (60.83 cm), IAC Sintonia (59.34 cm) and IAPAR 81 (53.50 cm) (Table 4); however these genotypes had pods concentrated below the upper 2/3 of the plant in the two evaluations (2015 and 2016) (Tables 3 and 4).

For 100 seed weight (100SW), the genotypes under water restriction exhibited a significant reduction of 22% in 2015

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and 20% in 2016. Reductions in 100SW found in this study were greater than those reported by Assefa et al. (2015), who indicated reduction of 9%; however, these authors reported sporadic rains during the field experiment, which may have favored the crop. Beebe et al. (2008) emphasized that tolerant genotypes exhibited better grain filling and grain quality, ensuring crop yield under unfavorable conditions. In the present study, the joint test presented an overall mean of 24.21 g in 2015 and the genotypes that stood out in 100SW were Gen TS 4-7 (30.43 g), SEA 5 (27.22 g), Gen TS 3-3 (25.89 g), IAC-Apuã (25.77 g), IAC Sintonia (25.07 g), Gen TS 3-1 (24.33 g), and IAC Carioca Eté (23.99 g) (Table 3). The genotypes that stood out in 100SW in 2016 in the treatment under water deficit were: IAC Sintonia (18.41 g), Gen TS 3-1 (17.46 g), Gen TS 3-2 (17.40 g), SEA 5 (17.36 g), Gen TS 3-3 (16.59 g), Carioca Eté (16.54 g), Gen TS 4-7 (14.51 g), IAPAR 81 (14.29 g) and Gen P5-4-3-1 (13.12 g) (Table 4).

The imposition of water deficit led to a significant reduction of 72% in GY in 2015 and a 69% reduction in 2016. Padilla-Chacón et al. (2017) reported similar results, indicating reduction from 41% to 76% in yield of common bean genotypes grown under water deficit conditions. Asfaw and Blair (2014) also presented similar results using three environments in their evaluation, reporting mean reduction of 55% in common bean yield under water deficit. This emphasizes the relationship between climate conditions and crop yield, which, according to Gris et al. (2015), is the characteristic most affected under these conditions. In 2015, the highest yielding genotypes in the treatment under water deficit were SEA 5 (585.19 kg·ha⁻¹), Gen TS 4-7 (559.26 kg·ha⁻¹), and Carioca Precoc (540.74 kg·ha⁻¹) (Table 3). Under water deficit conditions, these higher yielding genotypes exhibited the greatest reduction in LA; and genotypes SEA 5 and Carioca Precoc, the greatest reduction in TDM. In 2016, the genotypes with high reduction in TDM also had GY above the overall mean for the treatment under water deficit ((Gen TS 3-1 (444.52 kg·ha⁻¹), SEA 5 (360.41 kg·ha⁻¹), Gen TS 3-3 (335.15 kg·ha⁻¹), and Carioca Precoc (302.74 kg·ha⁻¹)) (Table 4). The genotypes Carioca Precoc and SEA 5 exhibited similar values of TDM in the treatment under water deficit in the two evaluations (Carioca Precoc: 4.69 g in 2015 and 4.67 g in 2016; and SEA 5: 3.55 g in 2015 and 3.27 g in 2016) and had GY above the overall mean for the treatment under water deficit (Table 3 and 4). In 2015, the genotype TS 3-1 had the lowest value for TDM (1.39 g) in the treatment under water deficit and, consequently, a GY

(366.67 kg·ha⁻¹) below the overall mean (Table 3). However, the same genotype in 2016 had twice the amount of TDM (2.97 g), and GY (444.52 kg·ha⁻¹) above the overall mean for the treatment under water deficit (Table 4), indicating the importance of the evaluation of these characteristics in selection of genotypes tolerant to water deficit. In contrast, some genotypes exhibited high values of TDM, and GY below the overall mean for the treatment under water deficit. According to Cortés et al. (2013), these results can be explained by variation in the dynamic of remobilization of biomass for pod and grain production; this is an important parameter that was recently integrated in selection of common bean genotypes tolerant to water deficit. Determination of remobilization of biomass for grain production is an important factor for selection of common bean genotypes tolerant to water deficit, and can be achieved by the harvest index (HI) (Beebe et al. 2013).

In regard to the Harvest Index (HI) in 2015 for the treatment under water deficit, the following genotypes stood out: SEA 5 (93%), Gen TS 3-1 (86%), Carioca Precoc (65%), IAC Carioca Eté (58%), Gen TS 4-7 (54%) and Gen TS 3-2 (50%). Lower HI for water deficit was shown by the genotypes: IAC Sintonia (45%), IAC Imperador (40%), Gen TS 3-3 (37%), IAPAR 81 (33%), IAC Apuã (32%) and IAC H96A31- P2-1-1-1-1 (29%). The genotypes SEA 5, Carioca Precoc, IAC Carioca Eté, and Gen TS 4-7 exhibited GY above the overall mean under water deficit conditions; and the genotypes Carioca Precoc and Gen TS 4-7 exhibited TDM above the overall mean for water deficit (Table 3). The genotype Gen TS 3-1 showed high HI, however, it had GY below the overall mean (Table 3). This result can be explained by genotype Gen TS 3-1 having had the lowest value of TDM, which hurt its GY under water deficit conditions.

In 2016, the genotypes with the highest HI for the treatment under water deficit were IAPAR 81 (86%), Gen TS 3-1 (84%), Gen TS 3-3 (81%), Gen TS 3-2 (80%), Carioca Precoc (64%), Gen P5-4-3-1 (62%), SEA 5 (62%) and IAC Sintonia (58%). Lower HI for water deficit was shown by the genotypes: Gen TS 4-7 (43%), IAC H96A31- P2-1-1-1-1 (42%), Carioca Eté (40%) and IAC Apuã (30%). The genotypes Gen TS 3-1, Gen TS 3-3, Gen TS 3-2, SEA 5, and Carioca Precoc had GY above the overall mean, and the genotype Carioca Precoc had the highest TDM in the treatment under water deficit (Table 4). The genotype Gen TS 3-1 once more exhibited higher HI and, in this evaluation, exhibited TDM and GY above the overall mean for the treatment under water deficit (Table 4).

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In the results obtained, we can highlight the importance of evaluation of TDM, HI, and GY in selection of genotypes tolerant to water deficit since genotypes with lower mean values of TDM may exhibit lower GY, even with high HI, just as genotypes with higher mean values of TDM may exhibit lower HI and lower GY, which are highly affected by water deficit. In the two evaluations, the genotypes SEA 5, Gen TS 3-1, and Carioca Precoce had higher HI. Sea 5 and Carioca Precoce had higher HI, TDM and GY under conditions of water deficit for the two evaluations. The SEA 5 genotype was also highlighted in the study of Polania et al. (2016), with combined significantly higher canopy biomass and with higher values of grain yield under drought conditions. The authors emphasized that the genotypes resistant to drought are associated with higher canopy biomass a more efficient photosynthate remobilization to pod formation and grain production, as observed in the present study. Similar results were observed by Gonçalves et al. (2015), who recommended the genotype SEA 5 for breeding programs aimed at drought tolerance, due to its general combining ability, considering grain yield. Lower HI for water deficit was shown by the genotype IAC Apuã in 2015 and 2016, with GY below the overall mean for the two evaluations (Table 3 and 4).

In relation to evaluation of root growth angle (RGA), there was significant difference among genotypes, indicating genetic variability and allowing selection using this trait (Table 5).

When we consider drought tolerance, roots play an important role, providing for better use and uptake of the resources available in the soil. According to Hossain et al. (2015), drought tolerant genotypes have a greater root angle and greater growth and branching, reaching deeper soil layers, whereas genotypes susceptible to water deficit have more superficial roots. In this respect, evaluation of root growth angle can assist and ease selection of tolerant genotypes since larger angles indicate deeper roots, allowing better absorption of water from the soil (Uga et al. 2015).

For RGA, the overall mean was 51°, and the following genotypes stood out: SEA 5 (74°), Carioca Precoce (61°), Gen TS 4-7 (59°), Gen P5-4-3-1 (56°), Gen TS 3-3 (54°), Gen TS 3-1 (54°), and IAC Sintonia (50°) (Fig. 1). The SEA 5 genotype (tolerant to water deficit) had the highest RGA, as well as GY and HI above the mean for the treatment under water deficit in the two evaluations (2015 and 2016).

Table 5. Mean squares of analysis of variance of 12 bean genotypes evaluated in regard to root growth angle.

Analysis variances	DF	Mean squares RA
Block	4	19.1
Genotype	11	701.4**
Residue	44	34.9
Total	59	
C.V.(%)		11.68

**significant at 1% probability by the F test, respectively.

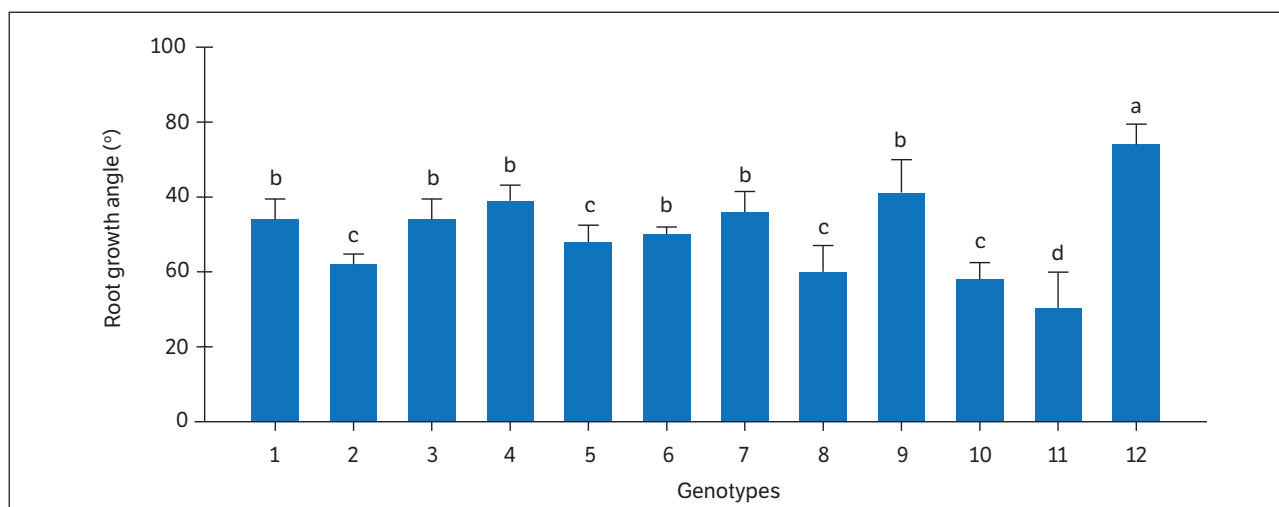


Figure 1. Performance of 12 bean genotypes with regard to root growth angle. Genotypes: 1 = Gen TS 3-1; 2 = Gen TS 3-2; 3 = Gen TS 3-3; 4 = Gen TS 4-7; 5 = H96A31-P2-1-1-1-1; 6 = IAC Sintonia; 7 = Gen P5-4-3-1; 8 = IAPAR 81; 9 = Carioca Precoce; 10 = IAC Carioca Eté; 11 = IAC Apuã (susceptible control); and 12 = SEA 5 (tolerant control).

Similar results were observed by Polania et al. (2016), who showed that the genotype SEA 5 had higher performance under drought stress and was associated with better canopy biomass that could be related to deeper root system, favoring the grain yield. The authors also emphasized that the genotype SEA 5 have mechanisms that can maintain a competitive level of water balance, allowing more effective use of water and the grain formation and filling during stress. The genotypes IAC Apuã (susceptible to water deficit) and H96A31-P2-1-1-1 had lower RGA, GY and HI below the overall mean in the two evaluations (Fig. 1). The Carioca Precoce genotype had RGA above the overall mean (Fig. 1) and stood out for TDM, HI, and GY in the two evaluations (Tables 3 and 4), emphasizing the importance of evaluation of these characteristics for selection of genotypes tolerant to water deficit. A similar result was presented by Polania et al. (2017), who identified the genotypes SEA 15, NCB 280, SCR 16, SMC 141, BFS 29, BFS 67, and SER 119 as possible parent lines for improvement of the drought tolerance trait for common bean, as they had a deeper root system, greater biomass, and ability to remobilize photoassimilates to grain production. The authors emphasized that common bean yield under water deficit conditions is directly related to root length and vigor, allowing access to water from deeper soil layers. In the present study, in the 2015 evaluation the genotype Gen TS 4-7 stood out in regard to TDM, HI, GY, and RGA; in 2016, the genotypes Gen TS 3-1 and Gen TS 3-3 stood out. In the 2015 and 2016 evaluation the genotypes SEA 5 and Carioca Precoce stood out.

According to Müller et al. (2014), success in selection of drought tolerant genotypes occurs through evaluation of the root system, CO₂ absorption, biomass accumulation, harvest index, and grain yield, making selection more reliable and efficient for development of cultivars with better performance under these conditions. In this study, evaluations of TDM, GY, HI, and RGA proved to be essential for selection of genotypes tolerant to water deficit. Thus, considering these variables, the cultivars SEA 5 and Carioca Precoce stood out in relation to the other genotypes under water deficit conditions because it had a larger root growth angle, providing for better utilization of deeper soil, higher biomass production, and higher harvest index, favoring mobilization of biomass for pod and grain formation, allowing crop production under unfavorable conditions.

CONCLUSION

Induction of water deficit was effective in discriminating genotypes in the two crop years, resulting in significant differences in development of plants in regard to water treatments for all the traits evaluated and between the genotypes for leaf area, leaf dry matter, total shoot dry matter, plant height, first pod height, 100 seed weight, and grain yield.

Evaluation of root growth angle indicated genetic variability, making genotype discrimination possible.

The traits of shoot dry matter, harvest index, grain yield, and root growth angle were effective for selection of genotypes tolerant to water deficit.

The cultivars Carioca Precoce and Sea 5 exhibited better performance than the other genotypes under water deficit conditions. The superior performance of these genotypes under drought stress could be associated with better canopy biomass accumulation and a vigorous root system providing better utilization of deeper soil, associated with effective remobilization of photosynthates from vegetative structures for pod production and grains.

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