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Drought tolerance evaluated in common bean genotypes

Tolerância à seca avaliada em genótipos de feijoeiro comum

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ABSTRACT

Given the impact of climate issues and their direct influence on agricultural production, the aim of this study was to identify superior genotypes of dry edible common bean under water deficit. Thus, 30 common bean genotypes were evaluated under controlled greenhouse conditions in a randomized block experimental design with split plots and four replications; the plots consisted of the water treatments (irrigated and water deficit) and the split plots consisted of the genotypes. The results showed genetic variability among the accessions evaluated, and in spite of significant reduction in grain yield and stomatal conductance under water deficit, these two traits showed significant, positive correlation and are able to be applied in early selection of genotypes under this stress condition. Another important response was in relation to the genotypes SER-16, SEN 92, FT Paulistinha, Carioca Precoce, IAC Imperador, and SXB 410, which showed the best yield performances in the two water treatments applied. They can be widely used in breeding programs for development of new cultivars, especially aiming at drought tolerance.

Index terms: *Phaseolus vulgaris*; genetic variability; plant selection; water deficit.

RESUMO

Frente ao impacto das questões climáticas e sua influência direta sobre a produção agrícola, o objetivo desse trabalho foi identificar genótipos superiores de feijoeiro comum submetidos ao déficit hídrico. Dessa forma, trinta genótipos de feijoeiro comum foram avaliados em condições controladas de casa de vegetação, sob delineamento experimental de blocos casualizados com parcelas subdivididas e quatro repetições, sendo as parcelas constituídas pelos tratamentos hídricos (irrigado e déficit hídrico) e as subparcelas, pelos genótipos. Constatou-se variabilidade genética entre os acessos avaliados e, apesar da redução significativa da produtividade de grãos e da condutância estomática sob deficiência hídrica, as duas características apresentaram correlações significativas e positivas, podendo ser aplicadas na seleção precoce de genótipos neste tipo de condição de estresse. Outra importante resposta foi com relação aos genótipos SER-16, SEN 92, FT Paulistinha, Carioca Precoce, IAC Imperador e SXB 410 que apresentaram os melhores desempenhos produtivos nos dois tratamentos hídricos aplicados, podendo ser amplamente utilizados em programas de melhoramento para o desenvolvimento de novas cultivares, visando principalmente a característica de tolerância à seca.

Termos para indexação: *Phaseolus vulgaris*; variabilidade genética; seleção de plantas; déficit hídrico.

INTRODUCTION

Abiotic stresses characteristic of dry land environments, such as water deficit and high temperature, are factors that have an important impact on world agriculture through limiting the yield of important crops (Fahad et al., 2017). These factors affect the growth and development of plants, especially in tropical and subtropical areas. Therefore, adapting crops to environments with limited water and improving plant yield under these conditions is a crucial aspect in achieving food security worldwide (Mutava et al., 2015).

To improve crop performance under water deficit, it is necessary to understand plant response to limiting conditions. Drought tolerance involves diverse adaptive mechanisms of plants in morphological, physiological, cellular, and metabolic aspects for the purpose of ensuring survival and reproduction (Basu et al., 2016). Activation and extending the action of these mechanisms depend on the quantity and the rate of water loss, the duration of the stress, and the stage of plant development. In addition, the simultaneous occurrence of other stresses or unfavorable climate conditions, such as low relative humidity and high solar radiation, can exacerbate the effects of water deficit (Kumar et al., 2015).

Under water deficit conditions, a series of modifications occur in plant development processes such as photosynthesis, respiration, water transport, nutrient uptake, and partitioning of photo assimilates, as well as changes in biomass accumulation. These diverse processes are highly correlated, and each one has a complex and versatile regulatory system, allowing the plant to adapt to and resist large environmental variations (Lambers, 2008). Drought tolerance is a complex trait, that is controlled by many genes and its full expression is affected by the environment. Investigations from a physiological perspective assist understanding of the attributes linked with water deficit and of the complex mechanisms involved (Mwadzingeni et al., 2016; Barlett et al., 2016).

Drought stress on reproductive stages constitute a major problem for common bean (*Phaseolus vulgaris* L.) because it affects flowering and pod-filling processes which are highly drought-sensitive (Dipp et al., 2017). Yield reduction from 40% to 87% have been reported, especially because it is a species also grown on small properties, which mostly have low fertility soils and seasonal occurrence of drought periods. Around 80% of common bean production is in developing countries in Latin America and Africa, where common bean is an important source of nutrition (Farooq et al, 2016; Beebe et al., 2013).

Breeding for drought tolerance has proved challenging, at least partly because tolerance mechanisms are often environment-specific, and screening methods that integrate the multiple spatial and temporal variations that are relevant to this stress are difficult to establish. Thus, analysis of accessions from germplasm banks is an important step in choosing the best genotypes, considering that a cache of genetic diversity is accessible for the improvement of yield stability resides in the germplasm of crops and their wild relatives. The use of adequate screening tools facilitates and refines the work, allowing plant performance to be predicted, making choices more effective and the breeding process more rapid, and reducing production costs as much as possible (Mickelbart et al., 2015; MacCouch et al., 2013).

Phenotypic evaluation of germplasm banks in environments with more realistic conditions is an important factor, and is considered decisive in breeding programs for obtaining superior genotypes for adaptation to drought. The use of physiological parameters is relatively simple and they have been applied in evaluation of plants under water deficit conditions. However, there are controversies in regard to correlation with yield, and, thus, phenotyping remains a great challenge. The aim of this study was to evaluate 30 common bean accessions under water deficit in a greenhouse, considering evaluations of physiological, morphological, and yield traits.

MATERIAL AND METHODS

From an initial collection of 100 genotypes from the Germplasm Bank of the Instituto Agronômico de Campinas - IAC, thirty accessions were selected for this study (Table 1). The accessions were selected in accordance with previous analyses regarding performance under water deficit conditions using grain yield as a criterion. SEA 5 and SER 16 were used as drought tolerant controls and IAC Milênio as a susceptible control due to its lower yield performance under this condition. Water deficit was applied beginning at the R5 stage, according to the method adapted from Gonçalves et al. (2015). The thirty genotypes selected were reevaluated under water deficit conditions with the aim of selecting superior genotypes that may contribute to development of drought tolerant lines.

The experiment was set up in a greenhouse, using 10 L capacity plastic pots filled with a mixture of soil and cured cattle manure in a 4:1 proportion. In accordance with the chemical characteristics of the soil (Table 2), considered to be of medium to high fertility, only one application of nitrogen fertilizer was made at sowing, consisting of 100 kg N ha^{-1}, which corresponds to application of 1.13 g of urea per pot. The seeds used in the study were first germinated for a period of three days in filter paper in a germination chamber, and they were then transplanted in pots.

The experimental design used was randomized blocks with split plots and four replicates. The plots corresponded to the water treatments (irrigated and water deficit), and the split plots consisted of the genotypes. The treatments received two applications of 140 ml each of irrigation daily through distribution lines and one drip tube per pot. Matric potential of the soil was maintained at around -40 Centibars/kPa, monitored daily by moisture sensors set up in the pots.

Water deficit was intermittent and began at the R5 stage. Short periods of water deficit were applied, alternating with periods of irrigation, which was determined by monitoring the sensors (Watermark® measuring device.) at readings near -199 Centibars/kPa, showing water scarcity in the soil. The first cycle of water deficit remained for five days, when the plants showed a severe wilt due to the scarcity of water in the soil, at that time the irrigation was resumed for two days to avoid permanent wilting, equally two more cycles of water deficit were applied. In the third period of water deficit applied, physiological evaluations were made and, after that, irrigation was resumed.

Table 1: Common bean genotypes selected for evaluation under water deficit.

No.	Genotype	Seed coat	Origin	No.	Genotype	Seed coat	Origin
1	IAC Aysó	Carioca	IAC	16	Campeão II	Carioca	Landrace
2	IAC Votuporanga	Carioca	IAC	17	CV 48	Carioca	UFLA
3	Carioca Comum	Carioca	IAC	18	BRSMG Talismã	Carioca	UFLA/Embrapa/UFV/ EPAMIG
4	IAC Apuã	Carioca	IAC	19	BRSMG Majestoso	Carioca	UFLA/Embrapa/UFV/ EPAMIG
5	IAC Alvorada	Carioca	IAC	20	Aporé	Carioca	Embrapa
6	IAC Milênio	Carioca	IAC	21	Pérola	Carioca	Embrapa
7	IAC Imperador	Carioca	IAC	22	CNFP 10794	Black	Embrapa
8	IAC Una	Black	IAC	23	SXB 746	Carioca	CIAT
9	H96A31 P2-1-1-1-1	Carioca	IAC	24	SXB 410	Carioca	CIAT
10	IAPAR 81	Carioca	IAPAR	25	A 449	Carioca	CIAT
11	LP0940	Carioca	IAPAR	26	SXB 415	Carioca	CIAT
12	LP0890	Black	IAPAR	27	BAT 477	Cream-colored	CIAT
13	IPR Uirapuru	Black	IAPAR	28	SEA 5	Brown	CIAT
14	Carioca Precoce	Carioca	CATI	29	SER 16	Red	CIAT
15	FT Paulistinha	Carioca	Sementes FT	30	SEN 92	Black	CIAT

Table 2: Chemical analysis of the soil used.

OM	pH ($CaCl_2$)	Macronutrients					Al	SB	H+Al	CEC	V
		P	S	K	Ca	Mg					
g dm^{-3}		mg dm^{-3}		mmol$_c$ dm^{-3}							%
23	6.1	127	135	3.2	81	40	0	135.7	11	146.7	93

Micronutrients				
B	Cu	Fe	Mn	Zn
mg dm^{-3}				
1.4	3.0	5.0	12.8	2.4

- Relative Chlorophyll Index (RCI) - readings performed with the SPAD-502Plus device (Konica Minolta Sensing, Inc., Japan) on completely expanded leaves from the middle part of the plant.
- Stomatal conductance (SC) - readings performed with a porometer (AP4 - Delta T Devices) in a state of dynamic equilibrium on the abaxial surface of completely expanded leaves from the middle part of the plants two days after rehydration.

While the experiment was being carried out, the mean temperature in the greenhouse was 33 °C, and the crop treatments were performed according to crop needs. At physiological maturity of the plants, evaluation was made of shoot dry matter (obtained in a forced air laboratory oven at a temperature of 60 °C until reaching constant weight), grain yield (GY), and water stress intensity index (*IIE*) (Fischer; Maurer, 1978) which was calculated by the following formula:

$$IIE = 1 - \frac{Xd.h.}{Xi}$$

Xd.h.-mean yield of all the genotypes under water deficit; *Xi.*-mean yield of all the genotypes under irrigated conditions.

Analyses of variance were carried out, and mean values were determined for the physiological, morphological, and yield variables, which were compared by the Tukey test at 5% probability using the Genes statistical program.

RESULTS AND DISCUSSION

The results of analysis of variance (Table 3) indicate that there was a significant difference between the water treatments for the traits SC, GY, and shoot dry matter (SDM), since there was reduction of the mean values of all the characteristics under the condition of water deficit. For the genotype factor, a significant difference was found for the traits RCI, GY, and SDM, which reveals genetic variability among the genotypes studied, facilitating the selection process. There was also a significant effect for the genotype x water treatment interaction for the GY and SDM traits, showing that some genotypes had different behavior under the two treatments.

Under a water stress intensity index of 69%, reductions of 4.62% for RCI, 24.01% for SDM, 68.51% for GY, and 74.16% for SC were found, compared to the irrigated treatment. When the genotypes were under the irrigated condition, they had differential behavior for the GY and SDM traits, while under the water deficit treatment, they showed differences for the RCI and GY traits (Table 4).

When plants are subjected to prolonged periods of water deficit, moisture content in the plant is reduced, leading to lower cell turgidity and, consequently, cell expansion stops, causing reduction and/or lack of formation of new branches and leaves (Tenhaken, 2015). The results of SDM show that in spite of the significant difference among the genotypes for the irrigated treatment, IAC Milênio (8.39 g) had the highest SDM, differing statistically only from the genotypes Carioca Comum (4.90 g) and SXB 746 (4.54 g), which had the lowest mean values. For the treatment under water deficit, there was no significant difference among the genotypes; nevertheless, the highest mean value was for Campeão II (6.38 g) and the lowest mean was for the genotype SXB 746 (3.09 g).

Reduction in leaf area of plants under water deficit and, consequently, reduction in dry matter production, results in a decrease in the plant photosynthetic rate. Nevertheless, this event is considered an important line of defense of plants against water deficit. According to Emam et al. (2010), the intensity of reduction in dry matter of common bean plants under water deficit occurs from exposure to stress. The genotypes H96A31-P2-1-1-1-1, BRSMG Talismã, Pérola, SXB 415, CV 48, A449, BRSMG Majestoso, BAT 477, SXB 746, Carioca comum, IAC Una, IAC Imperador, IAPAR 81, Campeão II, IAC Votuporanga, IAC Alvorada, IPR Uirapuru, LP 0890, and Carioca Precoce remained stable, that is, they did not exhibit significant difference between the two water treatments, showing signs of adaptation to environments with water limitation (Table 4).

Table 3: Mean squares of analysis of variance of the relative chlorophyll index (RCI), stomatal conductance (SC), grain yield (GY), and shoot dry matter (SDM) in regard to 30 common bean genotypes under two water treatments (irrigated and water deficit).

Source of Variation	D.F.	RCI	SC[1]	GY[1]	SDM
Blocks	3	699.338	14.853	0.126	1.978
Water Treatment (WT)	1	253.998	1310.351*	24.627**	117.194**
Error a	3	166.918	53.366	0.053	0.593
Genotypes (G)	29	103.388**	21.366	0.934**	2.731*
WT x G Interaction	29	29.037	12.459	0.228**	2.247*
Error b	174	43.556	18.498	0.078	1.662
Total	239				
Mean		43.560	8.083	1.752	5.133
CV (%) plot		29.66	90.38	13.17	15.00
CV (%) split plot		15.15	53.21	15.98	25.12

[1]Transformed data ($\sqrt{x} + 1$). *Significant at 5% probability. **Significant at 1% probability.

Table 4: Mean values of shoot dry matter (SDM), relative chlorophyll index (RCI), stomatal conductance (SC), and grain yield (GY), in reference to 30 common bean genotypes under two water treatments (irrigated and water deficit).

Genotypes	SDM (g)		RCI (SPAD units)		SC (mmol m^{-2} s^{-1})		GY (g)	
	Irrigated	Deficit	Irrigated	Deficit	Irrigated	Deficit	Irrigated	Deficit
IAC Aysó	5.87abA	3.79 aB	44.90 aA	43.10 abA	265.85 aA	20.03 aB	0.79 f-hA	0.00 bB
H96A31-P2-1-1-1-1	4.94abA	5.28 aA	45.85 aA	45.18 abA	112.60 aA	41.20 aA	5.80 a-d A	1.46 abB
BRSMG Talismã	5.14abA	4.85 aA	49.75 aA	49.73 abA	144.10 aA	33.93 aA	5.27 a-dA	0.50 abB
Pérola	6.78abA	5.24 aA	42.15 aA	38.83 abA	103.95 aA	35.19 aA	1.98 e-hA	0.52 abB
SXB 415	5.17abA	5.48 aA	43.43 aA	44.93 abA	71.13 aA	15.75 aA	2.59 d-gA	1.30 abB
CV 48	5.11abA	4.97 aA	46.75 aA	48.98 abA	83.20 aA	21.45 aA	0.94 f-hA	0.00 bB
SXB 410	5.72abA	3.22 aB	47.70 aA	46.60 abA	74.58 aA	51.35 aA	5.88 a-cA	1.64 abB
A449	5.83abA	4.60 aA	43.70 aA	35.50 bA	93.40 aA	47.48 aA	0.55 ghA	0.98 abA
BRSMG Majestoso	5.95abA	4.66 aA	45.95 aA	43.10 abA	46.95 aA	36.45 aA	4.10 a-eA	1.58 abB
IAC Apuã	7.21abA	4.82 aB	44.43 aA	36.40 bA	148.75 aA	16.88 aB	0.54 ghA	0.82 abA
BAT 477	6.31abA	5.03 aA	40.20 aA	38.68 abA	75.63 aA	41.10 aA	2.77 c-gA	0.00 bB
SXB 746	4.54bA	3.09 aA	44.75 aA	35.73 bA	115.50 aA	36.35 aA	2.90 b-gA	1.04 abB
Carioca Comum	4.90bA	4.31 aA	46.20 aA	43.08 abA	147.20 aA	42.80 aA	4.41 a-eA	1.35 abB
IAC Una	5.06abA	3.70 aA	41.70 aA	45.93 abA	40.63 aA	34.48 aA	4.53 a-eA	1.23 abB
IAC Imperador	5.85abA	4.10 aA	46.20 aA	37.58 abA	109.75 aA	48.00 aA	6.08 abA	1.83 aB
IAPAR 81	6.07abA	4.82 aA	46.18 aA	43.38 abA	115.25 aA	34.70 aA	2.84 c-gA	0.56 abB
Campeão II	6.06abA	6.38 aA	46.98 aA	48.40 abA	101.08 aA	41.53 aA	2.55 c-gA	0.83 abB
IAC Milênio	8.39aA	4.68 aB	50.38 aA	54.93 aA	165.00 aA	33.03 aB	0.00 hA	0.00 bA
IAC Votuporanga	5.37abA	4.95 aA	43.10 aA	43.30 abA	97.95 aA	30.90 aA	3.57 a-fA	0.93 abB
IAC Alvorada	5.36abA	4.23 aA	44.40 aA	42.90 abA	76.58 aA	17.23 aA	2.93 b-gA	1.13 abB
SEN 92	5.38abA	3.44 aB	43.18 aA	43.33 abA	120.18 aA	46.33 aA	6.71 aA	2.28 aB
CNFP 10794	6.68abA	3.63 aB	46.55 aA	38.80 abA	240.00 aA	28.85 aB	3.33 a-fA	1.00 abB
IPR Uirapuru	5.57abA	4.49 aA	39.90 aA	38.93 abA	152.25 aA	20.73 aB	4.24 a-eA	1.28 abB
LP 0940	6.90abA	3.81 aB	41.65 aA	36.40 bA	88.98 aA	27.83 aA	3.36 a-fA	0.88 abB
FT Paulistinha	6.43abA	3.74 aB	44.68 aA	45.28 abA	262.00 aA	39.98 aB	5.24 a-dA	2.32 aB
Aporé	6.69abA	4.52 aB	43.48 aA	46.75 abA	267.33 aA	38.48 aB	2.78 c-gA	1.26 abB
LP 0890	5.00abA	4.78 aA	51.80 aA	46.10 abA	137.25 aA	36.85 aA	4.58 a-cA	1.74 aB
Carioca Precoce	5.18abA	4.74 aA	39.00 aA	36.28 bA	288.25 aA	80.00 aB	6.94 aA	1.69 aB
SER 16	6.03abA	4.18 aB	41.98 aA	36.80 bA	163.18 aA	64.98 aA	5.83 a-cA	2.50 aB
SEA 5	5.40abA	3.44 aB	40.78 aA	41.08 abA	296.28 aA	45.30 aB	4.49 a-eA	1.48 abB
Mean	5.83A	4.43B	44.59A	42.53A	140.16A	36.22B	3.62A	1.14B

*Mean values followed by different lowercase letters in the column and uppercase letters in the row differ among themselves at 5% probability by the Tukey test for genotypes and for water treatment, respectively.

This statistical similarity for dry matter between the water treatments represented by the genotypes highlighted above was not observed for the controls SEA 5 and SER 16, which had reductions of 36.3% and 30.7%, respectively, when under water stress. Polania et al. (2016a), found a similar decrease (31.22%) in shoot dry matter of common bean plants in the treatment under water deficit in comparison to the irrigated treatment.

Leaf rolling, abscission, and senescence characterize some of the most expressive visual symptoms in the plants under water restriction. Under critical conditions of water deficit, accelerated yellowing of leaves is observed, and this can be monitored by evaluation of the RCI (relative chlorophyll index). In the present study, a significant difference was not found in the effect of the water treatment for RCI, indicating that, both in the irrigated condition and under water deficit, plants did not exhibit an evident change in leaf color. According to Shah, Houborg and Mccabe (2017), the SPAD mean values are widely used to measure chlorophyll content in an indirect manner. Nevertheless, the effects of the diverse abiotic stresses on the estimate of this parameter require greater investigation. However, among the genotypes, a significant difference was found only under water deficit, with variation from 54.95 (IAC Milênio) to 35.50 (A449) SPAD units. The genotypes SER 16, A449, IAC Apuã, SXB 746, LP0940, and Carioca Precoce exhibited the lowest mean values for this trait, which differed from IAC Milênio (Table 4).

The higher values for SC, registered in the irrigated treatment (140.16 mmol m^{-2} s^{-1}) in relation to water deficit (36.22 mmol m^{-2} s^{-1}) (Table 4), are owing to the greater matric potential of the soil that affected this response and shows the effectiveness of the water deficit treatment in evaluation of plants under stress. Oliveira, Fernandes and Rodrigues (2005) aimed to determine indicators of water stress, as well as their effect on the common bean crop, by means of stomatal conductance. They confirmed that the lowest values were found, in nearly the entire cycle, for the treatment under water deficit, ranging from 14 to 165 mmol $m^{-2}s^{-1}$, whereas the highest values were in the irrigated treatment, with lower maximum accumulated evapotranspiration, ranging from 48 to 183 mmol m^{-2} s^{-1}at the end of the cycle. Thus, reduction in growth in response to the decrease in water availability in the soil can be attributed to a decline in photosynthetic activity through stomatal closing (Chaves; Oliveira, 2004).

For Traub, Kelly and Loescher (2017), stomatal conductance is an important parameter for determination of the degree of drought tolerance of a common bean genotype. According to Bragg et al. (2004), measurements obtained by the porometer assist in analysis of the physiological status of the plants. In the irrigated treatment, although there was no significant statistical difference among the genotypes, the SC ranged from 296.28 mmol m^{-2} s^{-1} for the genotype SEA 5 to 40.63 mmol $m^{-2}s^{-1}$ for IAC Una. The same occurred for the genotypes under the water deficit condition, with values ranging from 80.00 mmolm^{-2} s^{-1} for Carioca Precoce to 15.74 mmol m^{-2} s^{-1} for the genotype SXB 415 (Table 4). According to Blum (2015), under dry land conditions, the concentration of abscisic acid can increase in a significant manner, which causes closing of the stomata and results in decline in the gas exchange rate of the leaf. Furthermore, the accumulation of ABA in the leaves can reduce the rate of cell expansion, which results in a decrease in total biomass of the plant. This reduction plays an important role in reducing water loss by transpiration under water stress conditions. For this trait, a reduction of 74.16% was found in the treatment under water deficit.

The expressive mean of stomatal conductance exhibited by the irrigated treatment in relation to water deficit, according to Traub, Kelly and Loescher (2017), occurs because stomatal conductance is closely correlated with soil water status. According to Oliveira, Fernandes and Rodrigues (2005), stomatal conductance can be considered a serious factor that indicates water stress in common bean. The lower values for SC observed under water deficit characterize partial closing of the stomata as a way of avoiding water loss through the leaves in critical periods of stress. The controls SEA 5 and SER 16, as well as the genotypes H96A31-P2-1-1-1-1, SXB 410, A449, BRSMG Majestoso, BAT 477, SXB 746, Carioca Comum, IAC Imperador, Campeão II, SEN 92, FT Paulistinha, Aporé, LP 0890, and Carioca Precoce, exhibited average performance superior to the others under this condition (Table 4).

Around 60% of the common bean production areas have prolonged periods of water scarcity, and drought is the factor that has the biggest impact on grain yield after diseases; losses can range from 10% to 100% (Rao, 2014). Nevertheless, there is vast variability to be exploited (Assefa et al., 2015; Darkwa et al., 2016) given the different response of common bean plants to water deficit. In general, reduction in matric potential of water in the soil reduced grain yield by 68.5% (Table 4). This yield reduction under restrictive water conditions in the soil occurs in accordance with a series of physiological and morphological modifications in plants, in which they need to adjust to survive and ensure grain production. Other authors found reduction in common bean grain yield under water restriction of 42.4% (Lanna et al., 2016), 44.8% (Mideksa, 2016) and 31.42% (Sofi et al., 2017).

Para GY, the genotypes FT Paulistinha (2.32g), SEN 92 (2.28g), IAC Imperador (1.83g), LP 0890 (1.74g), and Carioca Precoce (1.69g) stood out with the best yield performances when under the water deficit treatment, together with the control SER 16 (2.50 g), compared to the other genotypes and with the control SEA 5 (1.48 g).

Nevertheless, they differed statistically only from the gentoypes IAC Aysó, CV 48, BAT 477, and the control IAC Milênio (Table 4). Dipp et al. (2017) highlighted IAC Imperador among ten Brazilian genotypes widely grown as tolerant to water deficit, as it exhibited the lowest reduction in grain yield compared to the irrigated condition. Devi et al. (2012) and Polania et al. (2016b) highlighted SER 16 and SEA 5 as important sources of drought tolerance. Dipp et al. (2017) evaluated ten genotypes of common bean in the reproductive phase subjected to two water treatments (irrigated and water deficit) and they found a reduction of 63.9% in yield and 74.3% in stomatal conductance under water deficit. Those results are similar to the results obtained in this study, which exhibited reduction of 74.2% in SC and 68.5% in GY.

Together with drought tolerance, genotypes should have satisfactory yield under the most diverse conditions so as to ensure the food security necessary to meet the demand caused by constant increase in population. Results show that 43% of the genotypes stood out in the two treatments applied (Figure 1), namely, SEN 92, FT Paulistinha, H96A31-P2-1-1-1-1, SXB 410, BRSMG Majestoso, Carioca Comum, IAC Imperador, Carioca Precoce, LP 0890, IAC Una, IPR Uirapuru, and the controls SEA 5 and SER 16. The phenotypical plasticity shown by these genotypes is of utmost importance in plant breeding programs for development of potentially high-yielding lines. Moreover, it is noteworthy that the genotype SER 16 had the highest mean value for GY in the treatment under water deficit and Carioca Precoce had the highest mean value in the irrigated treatment. In contrast, the genotypes IAC Aysó, CV 48, BAT 477, and the susceptible control IAC Milênio obtained the lowest mean values for GY under both water treatments and were not promising for use in breeding programs for drought tolerance.

Correlation between traits allows evaluation of the magnitude and direction of the relationship between two traits and, that way, if the traits show favorable correlation, it is possible to obtain gains for one of them by means of indirect selection in the other one that is associated (Cruz; Regazzi; Carneiro, 2004). Observing the results of the treatment under water deficit shown in Table 5, the SC and GY traits show significant and positive correlation. Early selection can be made of those genotypes that exhibit higher values of stomatal conductance after the period of water deficit. These results are similar to those presented by Polania et al. (2016a) in evaluation of 36 genotypes of common bean under water deficit. This physiological trait indicates that, even under water deficit, the plants exchange gases in a satisfactory manner to carry out photosynthetic processes and, thus, tend to show higher yield capacity. This is an important strategy for use within a breeding program with the aim of increasing yield under the condition of water deficit. It provides for selection of genotypes that carried the best mean values for these two traits and insertion of the genotypes in crosses blocks. For Beebe et al. (2013 and 2014), the development of superior genotypes should be a process that involves evaluation of adaptive traits because they are closely connected with high yield in environments with water restriction.

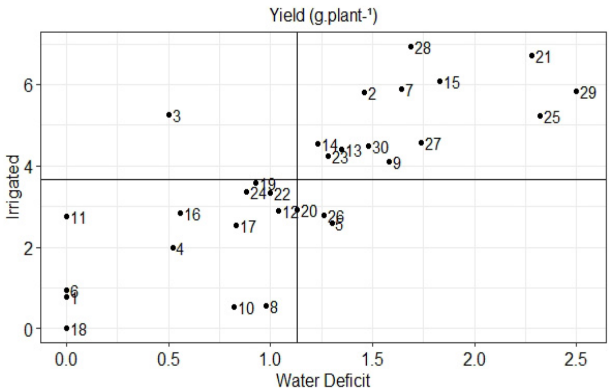

Figure 1: Yield performance of 30 common bean genotypes under two water treatments: 1 - Water deficit, applied in the pre-flowering stage (abscissa axis), and 2) Irrigated (ordinate axis). Genotypes: 1- IAC Aysó, 2- H96A31-P2-1-1-1-1, 3- BRSMG Talismã, 4- Pérola, 5- SXB 415, 6- CV 48, 7- SXB 410, 8- A449, 9- BRSMG Majestoso, 10- IAC Apuã, 11- BAT 477, 12- SXB 746, 13- Carioca Comum, 14- IAC Una, 15- IAC Imperador, 16- IAPAR-81, 17- Campeão II, 18- IAC Milênio, 19- IAC Votuporanga, 20- IAC Alvorada, 21- SEN 92, 22- CNFP 10794, 23- IPR Uirapuru, 24- LP 0940, 25- FT Paulistinha, 26- Aporé, 27- LP 0890, 28- Carioca Precoce, 29- SER 16 and 30- SEA5.

Table 5: Values and significance of the phenotypic correlation coefficients (r_f) between the traits evaluated in the 30 genotypes of common bean in relation to the treatment under water deficit.

Traits	RCI	SC	GY	SDM
RCI	-	-0.221	-0.227	0.348
SC		-	0.458*	-0.098
GY			-	-0.322
SDM				-

* Significant at 5% probability, by the t test.

In Figure 2, the performance of the genotypes in relation to stomatal conductance and grain yield under water deficit exhibits almost the same ranking of the genotypes highlighted in Figure 1, once more reinforcing the positive correlation observed between these traits. The genotypes SER-16, SEN 92, FT Paulistinha, Carioca Precoce, IAC Imperador, and SXB 410 were those that once more most stood out in relation to performance for SC and GY under water deficit compared to the other genotypes evaluated. They are prominent in selection for drought tolerance and can assist common bean breeding programs in development of lines with superior drought tolerance.

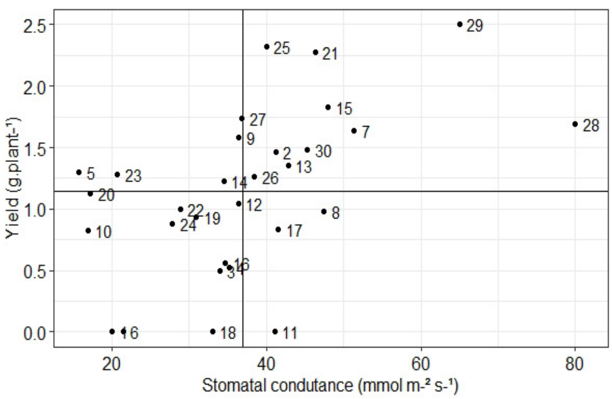

Figure 2: Performance of grain yield and stomatal conductance regarding 30 accessions of the common bean germplasm bank of IAC under water deficit, applied in the pre-flowering stage. Genotypes: 1- IAC Aysó, 2- H96A31-P2-1-1-1-1, 3- BRSMG Talismã, 4- Pérola, 5- SXB 415, 6- CV 48, 7- SXB 410, 8- A449, 9- BRSMG Majestoso, 10- IAC Apuã, 11- BAT 477, 12- SXB 746, 13- Carioca Comum, 14- IAC Una, 15- IAC Imperador, 16- IAPAR-81, 17- Campeão II, 18- IAC Milênio, 19- IAC Votuporanga, 20- IAC Alvorada, 21- SEN 92, 22- CNFP 10794, 23- IPR Uirapuru, 24- LP 0940, 25- FT Paulistinha, 26- Aporé, 27- LP 0890, 28- Carioca Precoce, 29- SER 16 and 30- SEA5.

CONCLUSIONS

Water deficit significantly affected all the traits evaluated. This study showed significant and positive correlation between the traits of grain yield and stomatal conductance, and this fact is of great importance for breeding programs that seek to obtain high-yielding genotypes under water deficit conditions. The genotypes SER 16, SEN 92, FT Paulistinha, Carioca Precoce, IAC Imperador, and SXB 410 stood out with higher yield potential in both water treatments, indicating superiority in composing crosses blocks in breeding programs, especially for the drought tolerance trait.

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