Physiological and Biochemical Responses of Common Bush Bean to Drought

Alefsi David SÁNCHEZ-REINOSO, Gustavo Adolfo LIGARRETO-MORENO, Hermann RESTREPO-DÍAZ*

Universidad Nacional de Colombia, Facultad de Ciencias Agrarias, Departamento de Agronomía, Carrera 30 No 45-03 Edificio 500, Bogotá, Colombia; adsanchezre@unal.edu.co; galigarretom@unal.edu.co; hrestrepod@unal.edu.co (*corresponding author)

Abstract

Agriculture has been adversely affected by the low water availability resulting from climate change, creating environmental stress for the common bean (Phaseolus vulgaris L.). A growth room experiment was performed to evaluate the physiological and biochemical responses of the several bush bean genotypes to water deficit conditions. Plants in soil with 20 g∙L⁻¹ polyethylene glycol 6000 (PEG) were subjected to drought for 15 d. The levels of photosynthesis, stomatal conductance and transpiration in all genotypes decreased by approximately 65% under water deficit conditions compared with the corresponding values in the controls. Water use efficiency was enhanced by water deficit conditions, with ‘Bianca’ plants exhibiting the highest values (28.08 µmol∙mol⁻¹), followed by ‘NUA35’, ‘Bachue’ and ‘Cerinza’ (20.46, 20.11 and 18.21 µmol∙mol⁻¹, respectively). The ‘Bianca’ plants exhibited a lower relative tolerance index (50%), and water deficit increased the levels of leaf photosynthetic pigments, chlorophyll and carotenoids in this genotype by approximately 100%. The photosynthetic efficiency, which was evaluated using the F_v/F_m ratio and rapid light-derived parameters (the maximum electron transport rate and a light saturation parameter), decreased due to water deficit conditions, particularly in the ‘Bianca’ plants, in which these parameters were reduced by approximately 60%. The proline and malondialdehyde (MDA) contents were increased by the addition of PEG, primarily in the ‘Bacatá’ and ‘Bianca’ plants. In conclusion, our results suggest that rapid light-response curves can be useful for characterizing genotypes because they represent an easy and non-destructive tool for understanding acclimatization mechanisms under water deficit conditions. In addition, all genotypes exhibited susceptibility to water deficit conditions, and the most susceptible genotype was ‘Bianca’, as reflected by a significant reduction in the electron transport rate and the presence of oxidative damage (high MDA content and electrolyte leakage), suggesting that this cultivar could not adapt well to landscaping situations in which periods of extreme water deficit can be expected.

Keywords: lipid peroxidation; photosynthesis; proline; rapid light-response curves; relative tolerance index

Introduction

The common bean (Phaseolus vulgaris L.) is a traditional crop of the neotropics and a primary source of protein in the diets of populations in developing countries (Beebe et al., 2012). A significant production constraint of common bean crops is water deficit, which affects up to 60% of bean-producing regions (Beebe et al., 2012). In the Andean region, P. vulgaris is mainly grown by small holder farmers, often under unfavorable conditions due to drought and heat (Beebe et al., 2008; Omae et al., 2012).

Climate change adversely affects food production due to increased drought in production areas (Dai, 2011). Global warming can generate changes in rainfall patterns in the Andean countries, affecting the availability of water for agriculture (Bradley et al., 2006). By 2050, climate change will affect 80% of crops in Colombia, causing changes in crop phenology and ultimately the product chain of common beans (Ramírez-Villegas et al., 2012). Plants display adverse effects in growth, development and yield in response to water deficit (Lobell and Gourdji, 2012). Knowledge of plant physiology has helped identify strategies used by drought-resistant genotypes to cope with water deficits (Polania et al., 2016). P. vulgaris plants under water deficit conditions adopt higher water use efficiency (WUE) (De Laat, 2014; Polania et al., 2016). Polania et al. (2016) also stated that a characteristic of bean genotypes
with drought tolerance is the ability to mobilize photosynthates to pods and seeds. Others have reported that a greater root length under water deficit conditions contributes to improved drought resistance of the common bean (White and Castillo, 1992; Polania et al., 2009).

The chlorophyll fluorescence technique has become important in plant ecophysiological studies because photosystem II (PSII) is sensitive to water deficit (Lu and Zhang, 1999; Maxwell and Johnson, 2000). Consequently, chlorophyll fluorescence parameters are used to screen for tolerance to abiotic stress (Sayed, 2003). Rapid light-response curves allow measurement of the effective quantum yield as a function of irradiance. This technique provides complete information on the saturation characteristics of electrons and is a powerful tool for assessing photosynthetic activity (Ralph et al., 2002). The rapid light curve-derived parameters (the maximum relative electron transport rate (ETRmax), minimum saturating irradiance (Ek) and initial slope of the curve (α)) indicate photosynthetic efficiency in plants under stress (Xu et al., 2013).

Plants exposed to water deficit exhibit other acclimation mechanisms, such as (i) decreased leaf chlorophyll content (Chavez et al., 2002), (ii) increased proline production (Rosales et al., 2012), and (iii) cell membrane damage due to lipid peroxidation, causing the generation of peroxide ions and malondialdehyde (MDA) (Sánchez-Rodríguez et al., 2010). Biochemical parameters are important markers for categorizing susceptible and/or tolerant genotypes with respect to responses to water deficit (Ghanbari et al., 2002), (ii) increased proline production (PanReac, Barcelona, Spain) to the nutrient solution at a rate of 20 g L^{-1} (De Laat et al., 2014). The plants were exposed to the solution containing PEG from 40 to 55 DAT.

Physiological measures

The relative water content (RWC) in fully expanded leaves from the upper part of the canopy was determined. The leaves were collected at 55 DAT for all genotypes. The RWC was calculated according to the equation described by Clavijo-Sánchez et al. (2015) using fresh and turgid weights after submergence in distilled water for 24 h at 4 °C in the dark.

The levels of photosynthesis (Pn), stomatal conductance (g) and transpiration (E) in a fully expanded trifoliate leaf from the upper half of the plants were measured at 54 and 55 DAT between 10:00 and 15:00 using a portable photosynthesis meter (LSPro-SD, ADC BioScientific Ltd., UK). The chamber conditions during leaf gas exchange measurements were the following: PAR, 800 µmol·m^{-2}·s^{-1}; leaf temperature, 25 ± 2 °C; and CO₂ concentration, 400 ± 10 µmol·mol^{-1}. The extrinsic water use efficiency (WUE) was calculated as the Pn/E ratio.

The plants were harvested at 55 DAT and dried in a compressed air oven at 70 °C for 48 h to obtain the leaf, stem, root and total plant dry weights. The shoot:root ratio (S/R) was calculated based on the relationship between the dry weight of the aerial parts (leaves and stem) to that of the roots. Additionally, the relative tolerance index (RTI) was obtained using the equation described by Dutta Gupta et al. (1995).

The F_v/F_m ratio and rapid light-response curves (RLCs) at 54 and 55 DAT were determined using a modulated chlorophyll fluorescence meter (MINI-PAM, Walz, Effeltrich, Germany). After measurement of the leaf-gas exchange, the same leaves were adapted to the dark for 15 min. The F_v/F_m measurements were performed by applying a pulse with a maximum light intensity of up to 2,600 µmol·m^{-2}·s^{-1} to the surface of leaf samples. The RLCs were constructed by plotting the electron transport rate (ETR) versus the increasing actinic irradiance (from 1 to 1.795 µmol·m^{-2}·s^{-1}) with 10-s intervals between the irradiance levels. The parameters α (initial slope), ETR max (maximum ETR) and I_s (a light-saturation parameter) were estimated using the model described by Xu et al. (2014).
The leaf photosynthetic pigments were measured at 55 DAT, and approximately 30 mg of the second fully expanded trifoliate leaf was homogenized in 4 mL of 80% acetone. Subsequently, the samples were centrifuged (Model 420101, Becton Dickinson Primary Care Diagnostics, MD, USA) at 3000 g to remove particles. The supernatant was diluted to a final volume of 6 mL by adding acetone. The leaf chlorophyll content was measured at 663 and 646 nm, and the carotenoid levels were determined at 470 nm using a spectrophotometer (Spectronic BioMate 3 UV-VIS, Thermo, WI, USA). The equations described by Wellburn (1994) were used to calculate the leaf photosynthetic pigment contents.

**Electrolyte leakage, lipid peroxidation and proline content**

Damage to the plasma membrane was estimated as the percentage of electrolyte leakage at 55 DAT following the method described by Sanchez-Reinoso et al. (2014). Five discs (0.5 cm diameter) from the second fully expanded trifoliate leaf were extracted in 50-mL Falcon tubes using 25 mL of deionized water as the medium. The initial electrical conductivity of the samples (CE) was recorded with a conductivity meter (Model P700, Oakton Instruments, Vernon Hills, IL, USA). The samples were placed in a water bath (Model B-480, Büchi Labortechnik AG, Switzerland) at 30 °C for 2 h, and the final electrical conductivity (CEf) was then measured after 20 min in a water bath at 90 °C.

The thiobarbituric acid (TBA) method described by Hodges et al. (1999) was used to assess lipid oxidation based on the MDA concentration. Approximately 0.3 g of homogenized plant material was collected at 55 DAT and stored in liquid nitrogen. The samples were centrifuged at 3000 g, and the absorbance values at 440, 532 and 600 nm were estimated using a spectrophotometer (Spectronic BioMate 3 UV-VIS, Thermo, WI, USA). An extinction coefficient was used (157 M·mL⁻¹) to calculate the MDA concentration.

Approximately 0.3 g of homogenized plant material was collected from the second fully expanded trifoliate leaf at 55 DAT and stored in liquid nitrogen. The absorbance was measured at 520 nm using a spectrophotometer (Spectronic), and the proline concentration was determined using a standard curve and the equation described by Bates et al. (1973).

**Experimental design and statistical analysis**

A factorial design, in which the first factor was the water stress treatment and the second factor was the cultivars evaluated, resulting in a total of 10 treatments with four replicates (40 seedlings in total), was adopted. Percentage values were transformed using the arcsin function. A variance analysis followed by the comparative Tukey’s test was performed. The data were analyzed using Statistix (ver. 9.0, Analytical Software, Tallahassee, FL, USA), and SigmaPlot (version 10.0; Systat Software, San Jose, CA, USA) was used to draw three-dimensional plots and to perform cluster analysis.

**Results and Discussion**

**Physiological measures**

Most of the variables were affected by the water treatment or genotype and their interaction (Table 1); however, the relative water content was affected by the water treatment but not the genotype or their interaction, and stomatal conductance was not affected by genotype. The plants under water deficit conditions had a lower RWC compared with the control plants (Fig. 1). RWC is an important physiological measurement that helps quantify a plant’s water status under normal or drought conditions.

**Table 1. Effects of water stress on the physiological behavior of Phaseolus vulgaris L. genotypes based on ANOVA**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Abbreviation</th>
<th>Variance source</th>
<th>Water treatment (W)</th>
<th>Genotype (G)</th>
<th>Interaction (W × G)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative water content</td>
<td>RWC</td>
<td>***</td>
<td>NS</td>
<td>NS</td>
<td>NS</td>
</tr>
<tr>
<td>Photosynthesis</td>
<td>Pn</td>
<td>***</td>
<td>**</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Stomatal conductance</td>
<td>gsc</td>
<td>***</td>
<td>NS</td>
<td>***</td>
<td></td>
</tr>
<tr>
<td>Transpiration</td>
<td>E</td>
<td>***</td>
<td>***</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Water use efficiency</td>
<td>WUE</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td></td>
</tr>
<tr>
<td>Aerial dry weight</td>
<td>ADW</td>
<td>**</td>
<td>***</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Root dry weight</td>
<td>RDW</td>
<td>***</td>
<td>***</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Total dry weight</td>
<td>TDW</td>
<td>***</td>
<td>***</td>
<td>**</td>
<td></td>
</tr>
<tr>
<td>Shoot/root ratio</td>
<td>AR/R</td>
<td>NS</td>
<td>***</td>
<td>***</td>
<td></td>
</tr>
<tr>
<td>Chlorophyll a</td>
<td>Chl a</td>
<td>**</td>
<td>***</td>
<td>***</td>
<td></td>
</tr>
<tr>
<td>Chlorophyll b</td>
<td>Chl b</td>
<td>*</td>
<td>***</td>
<td>***</td>
<td></td>
</tr>
<tr>
<td>Total chlorophyll content</td>
<td>Chl total</td>
<td>*</td>
<td>***</td>
<td>***</td>
<td></td>
</tr>
<tr>
<td>Carotenoids</td>
<td>Cx+c</td>
<td>*</td>
<td>***</td>
<td>***</td>
<td></td>
</tr>
<tr>
<td>Maximum efficiency of PSII</td>
<td>Fv/Fm</td>
<td>***</td>
<td>*</td>
<td>**</td>
<td></td>
</tr>
<tr>
<td>Electrolyte leakage</td>
<td></td>
<td>***</td>
<td>*</td>
<td>**</td>
<td></td>
</tr>
<tr>
<td>Malondialdehyde</td>
<td>MDA</td>
<td>***</td>
<td>**</td>
<td>*</td>
<td></td>
</tr>
<tr>
<td>Proline</td>
<td></td>
<td>***</td>
<td>***</td>
<td>***</td>
<td></td>
</tr>
<tr>
<td>Initial slope</td>
<td>a</td>
<td>***</td>
<td>***</td>
<td>**</td>
<td></td>
</tr>
<tr>
<td>Maximum relative electron transport rate</td>
<td>ETRmax</td>
<td>***</td>
<td>*</td>
<td>***</td>
<td></td>
</tr>
<tr>
<td>Light saturation parameter</td>
<td>E</td>
<td>***</td>
<td>***</td>
<td>***</td>
<td></td>
</tr>
</tbody>
</table>

NS, *, **, and *** indicate not significant at P ≤ 0.05 or significant at probability levels of 0.05, 0.01 and 0.001, respectively.
conditions (Keyvan, 2010). Reduced RWC values indicate that plant-water relationships might be affected by adverse abiotic conditions, which could reduce the photosynthetic rate (Costa-França et al., 2000).

The interaction between water treatment and genotype affected $P_n$ (Table 1). In response to water deficit, the $P_n$ level in ‘Bachue’ decreased by approximately 60%, whereas that in ‘Bacatá’, ‘Bianca’, ‘Cerinza’ and ‘NUA35’ decreased by approximately 80% (Fig. 2A). The water deficit condition caused the greatest $g_s$ reduction in ‘Bianca’ (Fig. 2B). Additionally, $E$ decreased by approximately 70% across all genotypes in response to the imposed water deficit (Fig. 2C). Lanna et al. (2016) and Mathobo et al. (2017) found that a moderate water deficit led to a severe reduction ($\geq 45\%$) in photosynthesis. Water deficit can inhibit leaf photosynthesis due to alterations in the photosynthetic apparatus, a reduced stomatal aperture, decreased transpiration, changes in light absorption, and alterations of the biochemical pathways associated with CO$_2$ fixation (Farooq, 2009).

WUE was significantly affected by the interaction between water treatment and genotype (Table 1). In general, differences were not observed between genotypes under control conditions. However, when the plants were subjected to water deficit, the WUE of all the genotypes increased. ‘Bianca’ had the highest values, followed by the ‘NUA35’, ‘Bachue’ and ‘Cerinza’ cultivars (Fig. 3). Increased WUE in *P. vulgaris* genotypes has been reported to occur as a physiological response to water-stress conditions.
conditions (Munoz-Perea et al., 2007; Lanna et al., 2016), suggesting that greater WUE under water deficit conditions can likely lead to reductions in seed production and resistance to water stress (Polania et al., 2016).

The interaction also affected the plants’ aerial parts and roots, the total plant dry weights and the shoot:root ratio (Table 2). In general, the ‘Cerinza’ plants under the water deficit conditions had the lowest aerial part dry matter compared with the other genotypes. The root dry weights of ‘Bianca’, ‘Bacatá’, ‘Cerinza’ and ‘NUA35’ were reduced by the water deficit, whereas the root dry weight of ‘Bachue’ plants increased. The total plant dry weights of ‘Bianca’, ‘Bacatá’ and ‘Cerinza’ accumulated less biomass under the water deficit conditions, but the biomass of ‘Bachue’ and ‘NUA35’ did not vary between treatments. The ‘Cerinza’, ‘Bianca’, and ‘Bachue’ plants had lower shoot:root ratios compared with the ‘Bacatá’ and ‘NUA35’ plants. It has been reported that a water deficit results in less biomass accumulation in P. vulgaris genotypes (Munoz-Perea et al., 2007; Lanna et al., 2016, Mathobo et al., 2017). However, Polania et al. (2016) reported that a higher root dry weight under drought conditions is an important physiological trait that could be used to characterize a tolerant genotype. ‘Bachue’ produces a vigorous root system, suggesting that this genotype might be tolerant to drought.

Stress indices, such as the RTI, have been used to screen genotypes in response to water deficits. Tolerant genotypes exhibit the highest RTI scores (Fernandez, 1993). The RTI results revealed different drought-tolerant responses among the genotypes and in response to the water treatment. The ‘Cerinza’ and ‘Bianca’ plants had the lowest values, indicating that these genotypes are susceptible to drought (Fig. 4). Susceptible genotypes have been reported to exhibit lower biomass accumulation, as reflected by a lower RTI (Darkwa et al., 2016).

In general, the chlorophyll a and b and the total chlorophyll contents of the plants subjected to water deficit did not vary compared with the corresponding values in the control plants, except for ‘Bianca’. In ‘Bianca’, the leaf chlorophyll contents (a, b and total) were 2-fold higher than those in the control plants (Fig. 5 A, B, C). ‘Bianca’ plants exposed to water deficit exhibited a higher leaf carotenoid content than the control plants (Fig. 5D).

The ability to maintain the leaf chlorophyll content under abiotic stress has been used as a parameter in the selection of tolerant cultivars (Kiani-Pouya and Rasouli, 2014). The leaf carotenoid content (another leaf photosynthetic pigment) also plays a role in tolerance to drought (Faroq et al., 2009). The levels of leaf photosynthetic pigments were favorable under moderate water deficit, particularly in ‘Bianca’. An increase in the contents of these pigments can be considered a response mechanism to reduce the adverse effects of water deficit-induced photo-inhibition (Silva et al., 2007).

‘Bianca’ plants had a lower Fv/Fm ratio than the ‘Cerinza’, ‘Bachue’, ‘NUA35’ and ‘Bacatá’ under water deficit conditions (Fig. 6). The RLCs showed differences between water treatments (Fig. 7). The ETR values of all genotypes under water deficit conditions generally decreased due to an increase in actinic irradiance. Higher α values were obtained for all genotypes under water deficit conditions, whereas ETRmax and Ic decreased. Similar results have been found for bush clover (Lespedeza davurica (Lax.) Schindl) (Xu et al., 2014). RLCs represent a tool for estimating photosynthetic activity because these measures provide complete information on the saturation characteristics of electrons (Ralph et al., 2002), and decreases in ETRmax and Ic indicate a reduction in the photosynthetic efficiency of plants under abiotic stress (Song et al., 2013). ‘Bianca’ plants consistently exhibited lower rapid light-derived parameters (ETRmax and Ic) and Fv/Fm ratios compared with the other genotypes, indicating that the photosynthetic activity was severely affected by the water deficit.

Table 2. Effects of the interaction between water deficit and genotype on the initial slope of the curve (α), the maximum electron transport rate (ETRmax) and minimum saturation irradiance (Ic)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>α (µmol·m⁻²·s⁻¹)</th>
<th>ETRmax (µmol·m⁻²·s⁻¹)</th>
<th>Ic (µmol·m⁻²·s⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cerinza × Control</td>
<td>0.45 c</td>
<td>74.80 abc</td>
<td>210.07 c</td>
</tr>
<tr>
<td>Bachue × Control</td>
<td>0.36 c</td>
<td>88.07 ab</td>
<td>249.85 b</td>
</tr>
<tr>
<td>NUA35 × Control</td>
<td>0.72 b</td>
<td>64.88 bc</td>
<td>131.58 d</td>
</tr>
<tr>
<td>Bacatá × Control</td>
<td>0.31 c</td>
<td>73.54 abc</td>
<td>303.15 a</td>
</tr>
<tr>
<td>Bianca × Control</td>
<td>0.32 c</td>
<td>91.90 a</td>
<td>302.44 a</td>
</tr>
<tr>
<td>Cerinza × Stress</td>
<td>1.19 a</td>
<td>30.03 c</td>
<td>24.23 e</td>
</tr>
<tr>
<td>Bachue × Stress</td>
<td>1.02 a</td>
<td>29.30 c</td>
<td>32.73 e</td>
</tr>
<tr>
<td>NUA35 × Stress</td>
<td>1.10 a</td>
<td>53.84 de</td>
<td>32.51 e</td>
</tr>
<tr>
<td>Bacatá × Stress</td>
<td>0.73 b</td>
<td>57.66 cd</td>
<td>97.82 d</td>
</tr>
<tr>
<td>Bianca × Stress</td>
<td>1.04 a</td>
<td>18.42e</td>
<td>16.90 e</td>
</tr>
</tbody>
</table>

** and *** refer to interaction data analyzed using the least squares means and means separated at P < 0.05 and P < 0.01, respectively.

* The data represent the average of four plants per treatment (n = 4). The means followed by the same letter are not significantly different according to Tukey’s test at P ≤ 0.05.
were obtained in the ‘Bianca’ and ‘Bacatá’ plants (Fig. 7B). Additionally, the leaf proline content increased under water deficit conditions: ‘Cerinza’ and ‘Bianca’ had the highest values of this osmolyte, followed by ‘Bacatá’, ‘NUA35’ and ‘Bachue’ (Fig. 7C). Water deficits have been reported to enhance the proline and MDA contents of common bean and faba bean (*Vicia faba*) (Ghanbari *et al*., 2013; Siddiqui *et al*., 2015).

Increases in the proline content under water deficit conditions help maintain hydration in cells and prevent damage. This amino acid acts as an osmolyte and as a storage source for carbon and nitrogen, which are subsequently used to stabilize macromolecules, proteins and cell membranes in plant tissues (George *et al*., 2015). Proline has been proposed as a biochemical marker to determine the tolerance of a genotype to water deficit conditions (Naser *et al*., 2010). Higher MDA accumulation indicates greater damage at the cellular level due to increased membrane lipid peroxidation (Sanchez-Reinoso *et al*., 2014). It has been reported that a higher proline content, a lower MDA production and electrolyte leakage under water deficit conditions are useful indicators of plant tolerance, and these features can be used for the selection of tolerant genotypes (Liu *et al*., 2013; Sanchez-Reinoso *et al*., 2014). The results obtained from the analyses of the leaf proline content, electrolyte leakage and MDA content plots indicate that ‘Bacatá’ and ‘Cerinza’ are drought-susceptible genotypes based on (Fig. 8). The cluster analysis identified ‘Bianca’ as a drought-susceptible genotype, ‘Cerinza’, ‘Bacatá’ and ‘NUA35’ as moderately susceptible genotypes, and ‘Bachue’ as moderately tolerant to water deficit conditions (Fig. 9).

**Electrolyte leakage, lipid peroxidation and proline content**

Electrolyte leakage and the MDA and proline contents were affected by the interaction between water treatment and genotype. Electrolyte leakage in the ‘Cerinza’, ‘NUA35’, ‘Bacatá’ and ‘Bianca’ genotypes increased under water deficit conditions, and ‘Bachue’ plants maintained levels similar to those measured in the controls (Fig. 7A). A higher MDA content was observed in all the genotypes subjected to water deficit conditions, and the highest values

---

**Fig. 4.** Effects of the interaction between genotype and water deficit on the total chlorophyll (A), chlorophyll *a* (B), chlorophyll *b* (C) and total carotenoid (D) contents in the leaves of common bush bean (*Phaseolus vulgaris* L.). The data represent the average of four plants per treatment (n = 4). The means followed by the same letter are not significantly different according to Tukey’s test at P ≤ 0.05.

**Fig. 5.** Effect of the interaction between genotype and water deficit on the PSII efficiency (*F*<sub>p</sub>*F*<sub>∞</sub>) in leaves of common bush bean (*Phaseolus vulgaris* L.). The data represent the average of four plants per treatment (n = 4). The means followed by the same letter are not significantly different according to Tukey’s test at P ≤ 0.05.
Phaseolus vulgaris according to Tukey’s test at P ≤ 0.05 followed by the same letter are not significantly different. The means of four plants per treatment (n = 4). The mean of four data points ± standard errors.

Fig. 6. Rapid light-response curves of ‘Cerinza’ (A), ‘Bacatá’ (B), ‘Bianca’ (C), ‘Bachue’ and ‘NUA35’ (D) genotypes due to water deficit. The data represent the mean of four data points ± standard errors.

Fig. 7. Effects of the interaction between genotype and water deficit on electrolyte leakage (A), MDA content (B) and proline content (C) measured in the leaves of common bush bean (Phaseolus vulgaris L.) genotypes. The data represent the average of four plants per treatment (n = 4). The means followed by the same letter are not significantly different according to Tukey’s test at P ≤ 0.05.

Fig. 8. Three-dimensional plot (proline content, MDA content and electrolyte leakage) for common bush bean (Phaseolus vulgaris L.) genotypes under water deficit conditions. The data represent the mean of four data points.

Fig. 9. Dendrogram using the Euclidean distance to characterize common bush bean (Phaseolus vulgaris L.) genotypes under control and water deficit conditions.
Conclusions

‘Biana’ was identified as the most susceptible genotype to water deficit, and ‘Bachue’ can be considered moderately tolerant to short periods of water deficit and can adapt to arid regions or to situations in which periods of moderate drought can be expected. Our results indicate that physiological variables such as Pn, the E efficacy, and RLCs and the MDA and proline contents can be used to characterize genotypes that are tolerant to water deficit conditions.

References


