

Full Length Research Paper

## Effect of water deficit on carbon metabolism in *Spondia mombin* L. plants

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In Brazil, hog plum trees are found mainly in the North and Northeast regions; they are considered to be under plant domestication and extractive exploitation. Therefore, it is economically important for those regions. In order to evaluate physiological and biochemical aspects of carbon metabolism in young hog plum plants (*Spondia mombin* L.) under full irrigation and water deficit conditions, an experiment was conducted in a greenhouse at the Federal Rural University of the Amazon, Belém, PA. The experimental design was completely randomized with two irrigation water conditions: full irrigation water (control) and water stress, with 20 repetitions, totaling 40 experimental units. As a result of water deficit, there were significant decreases in water potential, stomatal conductance, transpiration and starch content, and a significant increase in the levels of total soluble carbohydrates and sucrose. Water stress directly affected the levels of carbon cycle compounds.

**Key words:** Water deficit, osmoregulators, full irrigation, hog plum, carbohydrate content.

### INTRODUCTION

In Brazil, the hog plum is one of the tropical, native fruit species that belong to the genus *Spondia* and the family Anacardeacea. Native to tropical America, the hog plum (*Spondia mombin* L.) is found mainly in the North and Northeast regions. It is considered to be under plant domestication and extractive exploitation, which makes it very economically important in those regions (Soares et al., 2008).

Agriculture currently involves about 80% of water usage, with 65% of this water used for dryland farming

and the remaining 35% used for irrigation (Wiener et al., 2010; Thenkabail et al., 2010). The agricultural system and irrigation management in Asia and Oceania may cause a decline in water availability through irrigation extraction which when the renewable limits is exceeded, it causes negative impacts on water quality, resulting in problems downstream (Wiener et al., 2010).

Agricultural growth in Asia-Pacific has been stagnated in resources, and parallel to this, there has been increasing population growth. The benefits achieved with

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the green revolution have been conducted, and currently there are no revolutionary technologies to sustainably quicken the reinvigoration in agriculture. Climate change impacts agriculture in many ways, especially in areas vulnerable to natural disasters (FAO-IFAD, 2015). According to the United Nations World Report on Development of Water Resources, about 70% of the total amount of water used by the group of agricultural activities is represented by agriculture. With the continually increasing demand for water use, it is estimated that by 2050 the global demand for food will grow to about 70% (World Water Development Report (WWDR), 2015).

It is predicted that in 2030, parts of South Asia and Southern Africa will battle with questions about food shortages caused by climate change. The increase in demand for food will lead to increased use of water resources, affecting about 44 million people by 2070 (WWDR, 2015).

Water deficit is a major constraint on agriculture, as it may cause reductions in agricultural productivity and compromise the anatomical, physiological and biochemical aspects of plants. The magnitude of its effects depends on the behavior of plants in their growth cycle (Silva et al., 2013).

Thus, under water deficit conditions, there is a reduction of intercellular CO<sub>2</sub> concentration, which causes a decrease in CO<sub>2</sub> assimilation, because of stomatal closure; it can be predicted that, during periods of drought, there is major constraint on transpiration, with decreases in photosynthetic activity (Mariano et al., 2009).

When water stress starts in plants, there is a series of physiological, biochemical and morphological changes, which act as a plant defense mechanism. The objective of this study was to evaluate physiological and biochemical aspects of carbon metabolism in young hog plum (*Spondia mombin* L.) plants under full irrigation and water deficit conditions.

## MATERIALS AND METHODS

### Experimental setup and location

The experiment was conducted in a greenhouse at the Institute of Agricultural Sciences (ICA) of the Federal Rural University of the Amazon (UFRA), in Belém, PA, Brazil (01° 27'S and 48° 26'W). Before the start of treatment, all plants were placed under 50% shade cloth, irrigated daily for a month to keep them at field capacity and acclimatized (Fernande and Sykes, 1968).

### Plants

Young hog plum plants grown from seeds were supplied by AIMEX (Federation of Timber Export Industries from the State of Pará). Hog plum seedlings were transplanted to 10 kg pots with substrate containing a mixture composed of black soil, manure and

earthworm humus at a ratio of 3:1:1 (v:v:v), respectively, on a 0.02 m layer of crushed stones to facilitate soil drainage. Before transplanting, tests were made to check the field capacity of the pots; liming was performed to correct soil pH, and macro and micronutrients were supplemented, based on chemical soil analysis, by applying 600 ml of the nutrient solution of Hoagland and Arnon (1950), modified at the Laboratory of Biodiversity Studies on Higher Plants (EBPS), UFRA.

### Experimental design

The experimental design was completely randomized with two irrigation water conditions: full water irrigation (control) and water deficit, with 20 repetitions, totaling 40 experimental units. Where each experimental unit consisted one plant/pot.

### Statistical analysis

Analysis of variance was applied to the results and when there was significant difference, the means were compared by Tukey's test at 5% significance level. Moreover, standard deviations were calculated for each treatment, and statistical analyses were performed with the software program (SAS-Institute, 1996).

### Plant training

A preliminary experiment was performed to simulate moderate/severe water deficit by suspending irrigation on the seedlings, respectively, for 15 days. During the experiment period, the control plants were irrigated daily to replace water loss. Watering was performed individually for each pot, taking into account daily weighings, forming a set (pot + plant + soil); weed control was also done manually without causing nutritional deficiency, pests and pathogens.

The soil was sieved, and then the pots were and the average weight of the vessels when the soil was at field capacity was determined. The average weight of the plants in clod was also made from each treatment. Therefore prior planting of each seedling in a respective vessel, the average weight of each pot at field capacity was already known. The vessels were weighed at every turn of irrigation, determining the average weight with the soil in the current humidity. This was followed up shortly with irrigation, with the aim of obtaining the same weight of the vessel that of a vase with irrigated soil, thus keeping the field capacity. This procedure was determined following the recommendations of Melo et al. (1998).

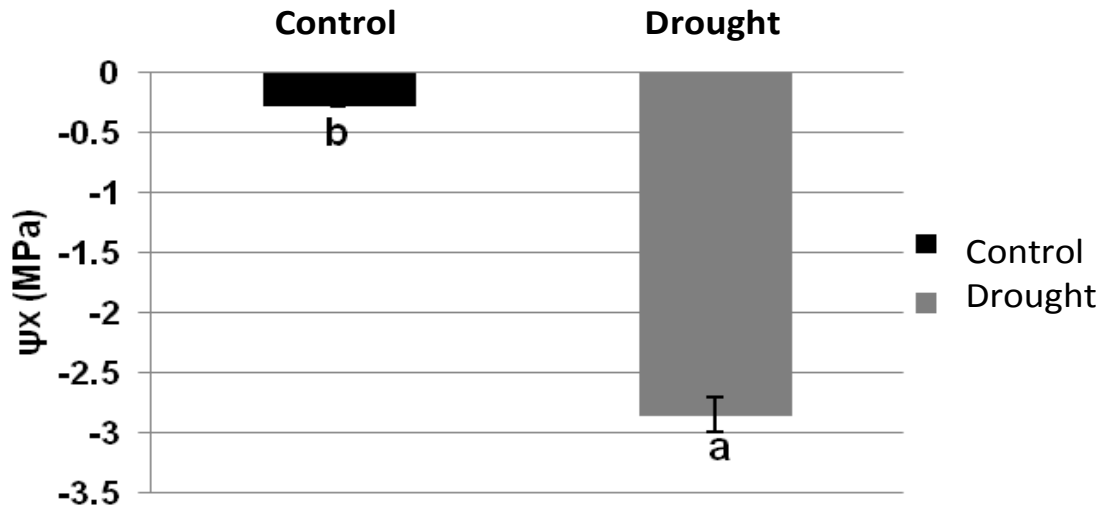
### Predawn water potential

Predawn water potential ( $\Psi_{am}$ ) was determined between 4:30 and 5:30 am, by means of a pressure pump type Scholander (M670, PMS Instrument Co., Albany, USA) as described by Pinheiro et al. (2007).

### Determination of the biochemical variables

#### Determining starch concentrations

The starch concentration was determined according Dubois et al. (1956).



**Figure 1.** Water potential in young plants of *Spondia mombin* L. under drought. The letters a and b did not differ statistically at 5% probability, by the Tukey test.

#### Total soluble carbohydrates (TSC)

This was determined by using the spectrophotometric method described by Dubois et al. (1956).

#### Determination of sucrose

This was determined according to the method described by Van Handel (1968).

#### Determination of gas exchange

The stomatal conductance to water vapor ( $g_s$ ) and the transpiration rate ( $E$ ) were determined by a portable parameter of dynamics balance (mod. Li 1600, LiCor, Nebraska, USA). The measurements were made at 9:00 a.m. As samples, mature leaflets, completely expanded were selected from leaves of second or third pair, with counts starting from the apex. After gas exchange, leaves samples were collected and immediately taken to a forced air circulation glasshouse at 65°C until the drought for the flour preparation.

## RESULTS AND DISCUSSION

### Water potential

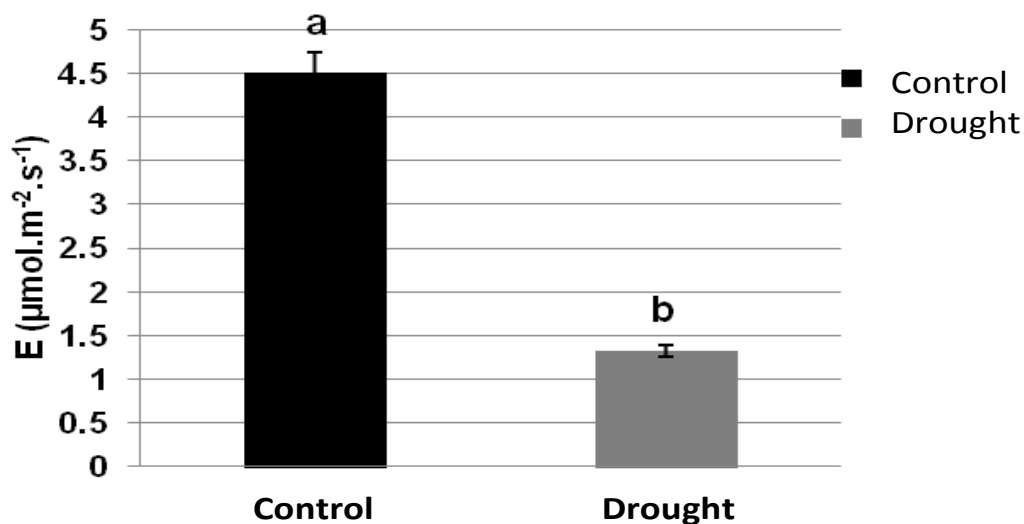
The results showed significant reduction in water potential ( $\Psi_w$ ) from -0.28 MPa with control plants to -2.855 MPa under water stress conditions (Figure 1), which represents a decrease of 919% in water potential when compared with the control plants. This negative increase of water potential is relative to low water availability in the soil, as it occurs during the dry season in some regions. Plants need to reduce the water potential of their cells to maintain cell turgidity, and this

adjustment takes place, especially, through the accumulation of organic substances that help in osmoregulation. Marenco et al. (2014) mentioned that this may also occur because leaf transpiration rate is greater than absorption capacity (roots) or greater than transportation capacity along the tree trunk and branches. These results are similar to those obtained by Guedes et al. (2013) who found a water potential of -0.6 MPa with *Apeiba tibourbou* when exposed to water stress. Also, Almeida et al. (2014), on tonka, found that the water potential was from -0.2 to -0.4 MPa under water deficit conditions.

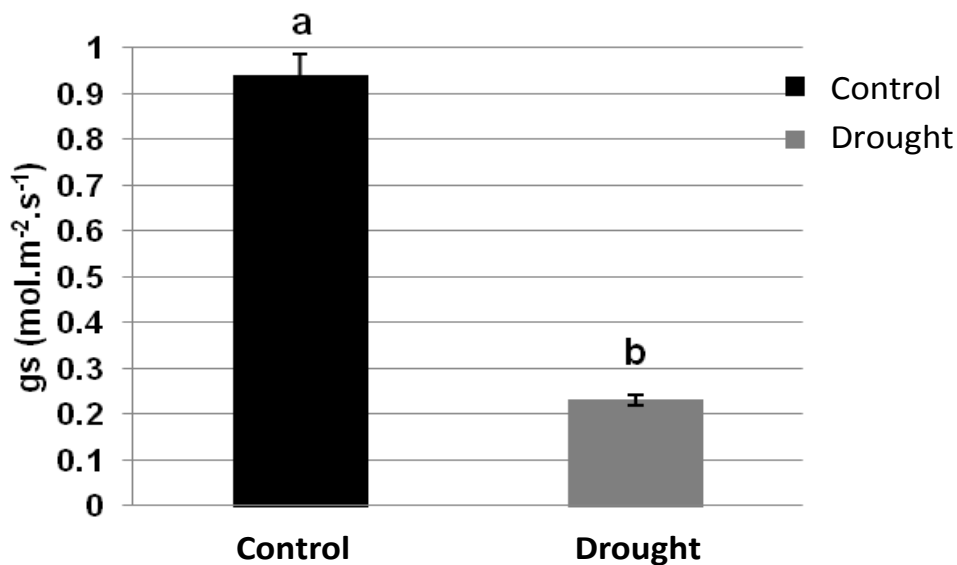
### Transpiration rate

There was a significant decrease in the transpiration rate of the hog plum seedlings (Figure 2). The values were  $1.321 \mu\text{mol}/\text{m}^2 \cdot \text{s}^{-1}$  for plants under the water stress and  $4.509 \mu\text{mol}/\text{m}^2 \cdot \text{s}^{-1}$  for well irrigated plants. Thus, the treatment that caused water deficit showed a percentage equivalent to 70.7% reduction in the transpiration rate compared with the control treatment. The treatment directly influenced the reduction of the transpiration rate, affecting the cellular mechanism and stomatal behavior of the plant.

These processes are directly associated with the variation of water availability in the plant (Mariano et al., 2009). Such process, according to Aïdar et al. (2013), can make water balanced between the root and the shoot of the plant, thus keeping water potential in leaves despite water deficit conditions in the soil. However, Azhar et al. (2011) pointed out that the reduction in soil moisture may reduce nutrient availability in plants,



**Figure 2.** Transpiration in young plants of *Spondia mombin* L. under drought. The letters a and b did not differ statistically at 5% probability, by the Tukey test.



**Figure 3.** Stomatal conductance in young plants of *Spondia mombin* L. under drought. The letters a and b did not differ statistically at 5% probability, by the Tukey test.

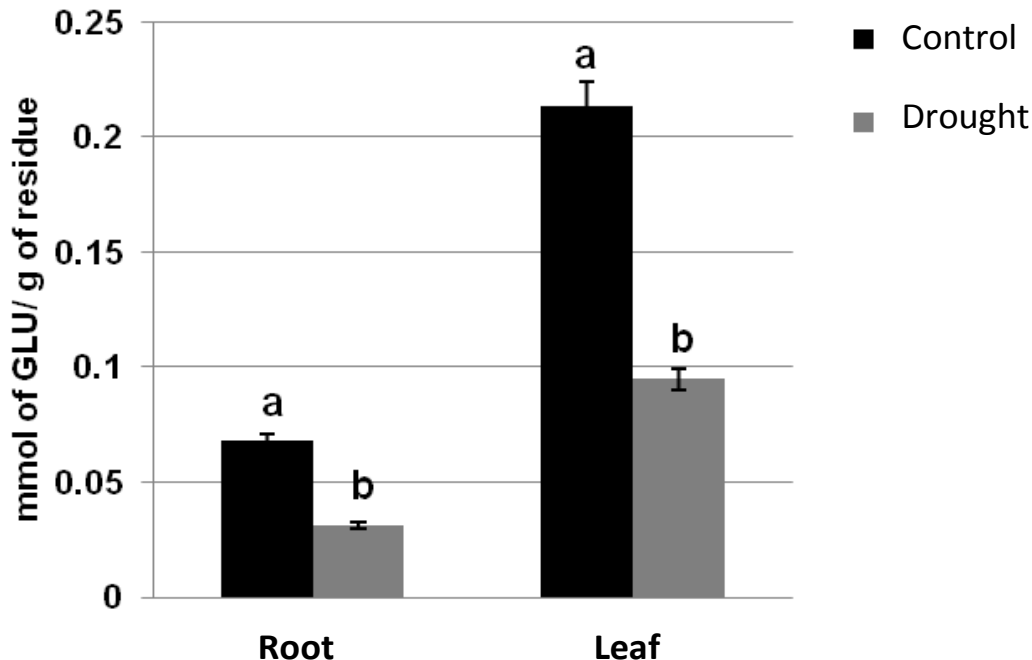
negatively affecting plant growth and productivity. Silva et al. (2008) study on rose pepper (*Schinus terebinthifolius* Raddi) plants observed a drastic reduction in the transpiration rate of the seedlings when under water deficit.

#### Stomatal conductance

The values of stomatal conductance (gs) for plants under water deficit was  $0.23 \text{ mmol m}^{-2} \text{ s}^{-1}$ , which represents a

decrease of 75.54% when compared with the well irrigated plants ( $0.94 \text{ mmol m}^{-2} \text{ s}^{-1}$ ), as shown in (Figure 3).

The reduction of water potential in soil makes the plants develop several mechanisms to control transpiration; one of them is stomatal closure; reduction of stomatal conductance (gs) is the leading cause of photosynthesis inhibition, given the reduced supply of  $\text{CO}_2$  for the intercellular space (Singh and Reddy, 2011). These results were consistent with the findings of Silva et



**Figure 4.** Starch concentration in young plants of *S. mombin* L. under drought. The letters a and b did not differ statistically at 5% probability, by the Tukey test.

al. (2008), who studied seedlings of *Schinus terebinthifolius* Raddi, a species belonging to the same family of hog plums (Anacardiaceae).

They observed that stomatal closure after 11 days of water deficit in plants subjected to treatment with more severe water stress was  $0.46 \text{ mmol m}^{-2} \text{ s}^{-1}$ . Scalon et al. (2011) studied bay cedar (*Guazuma ulmifolia* Lam.) seedlings under different water regimes, and they noted the reduction in stomatal conductance. This implies, in turn, a decrease in transpiration and possibly  $\text{CO}_2$  assimilation, since both of them are diffusive processes, which lead, however, to a reduction in the production of photosynthates.

### Starch

The *S. mombin* plants, after a period of 15 days under water deficit, showed a decrease of 0.031 and 0.094 mmol GLU/g.Res when compared with the control plants, and 0.067 and 0.213 mmol GLU/g.Res, for root and leaf tissues (Figure 4), which corresponds to a percentage of 53.73 and 55.86%, respectively. Similar results were obtained by Pereira et al. (2012), who reported that a decrease in starch concentration is followed by an increase in the concentration of carbohydrates. Melo et al. (2007) also stated that a decrease in starch content, when not followed by an increase in the levels of soluble

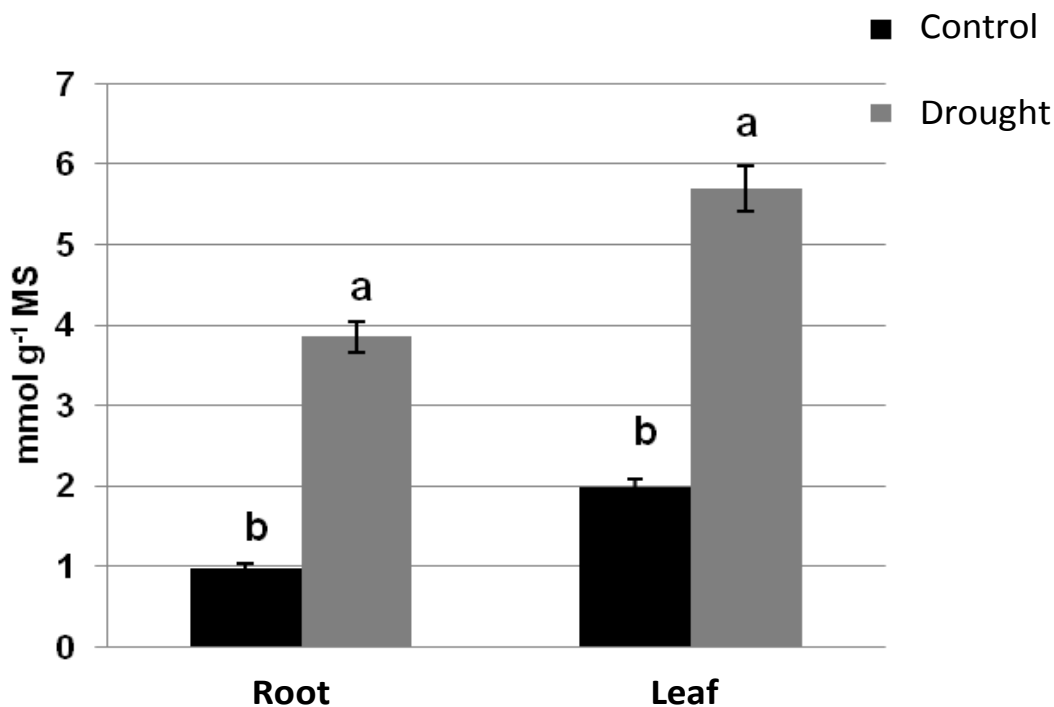
sugars, may indicate that the immediate uptake of sugars is occurring to maintain the survival of plants, a fact that was not observed in the present study.

According to Kakani et al. (2011), starch consumption would be an initial response to drought, allowing the maintenance of the carbon supply in a condition of reduced atmospheric  $\text{CO}_2$  fixation. Similar results were obtained by De Paula et al. (2013), who evaluated Brazilian mahogany seedlings in two periods (dry and wet); the plants subjected in the dry period was decreased by 30.3% when compared with plants during the rainy season.

Sales et al. (2012) also found a reduction in starch content in leaf tissue when sugarcane plants were subjected under water deficit conditions.

### Total soluble carbohydrates

The results revealed that there was an increase in the amount of soluble carbohydrates in the roots and leaves, when they were subjected under water stress. Carbohydrates content in roots was increased from  $0.98 \text{ mmol g}^{-1} \text{ MS}$  (control) to  $3.85 \text{ mmol g}^{-1} \text{ MS}$  (water deficit), while in leaves, it was increased from  $1.978 \text{ mmol g}^{-1} \text{ MS}$  (control) to  $5.7 \text{ mmol g}^{-1} \text{ MS}$  (water deficit). Figure 5 shows an increase of 29.2 and 18.8%, respectively. de Paula et al. (2011) evaluated mahogany (*Swietenia*



**Figure 5.** Total soluble carbohydrates concentration in young plants of *S. mombin* L. under drought. The letters **a** and **b** not differ statistically at 5% probability, by the Tukey test.

*macrophylla* King) plants in two periods (dry and rainy), and found that the mean total soluble carbohydrates content in the leaves analyzed during the dry period was 20.85% higher ( $P \leq 0.05$ ), compared with the means of plants assessed during the rainy season. They also reported that the increase in carbohydrates content is due to the fact that carbohydrates act as osmotic regulators, maintaining water levels in the leaves, as well as the osmotic balance of the cells, even during water deficit. Silva et al. (2009) analyzed four genotypes of Brazilian plum, where there were variations of carbohydrates content between genotypes in leaves in response to drought and evaluation times. The reduction in soluble carbohydrates in Brazilian plum under drought stress suggests breakdown or translocation to the roots, which should be important to maintain water absorption.

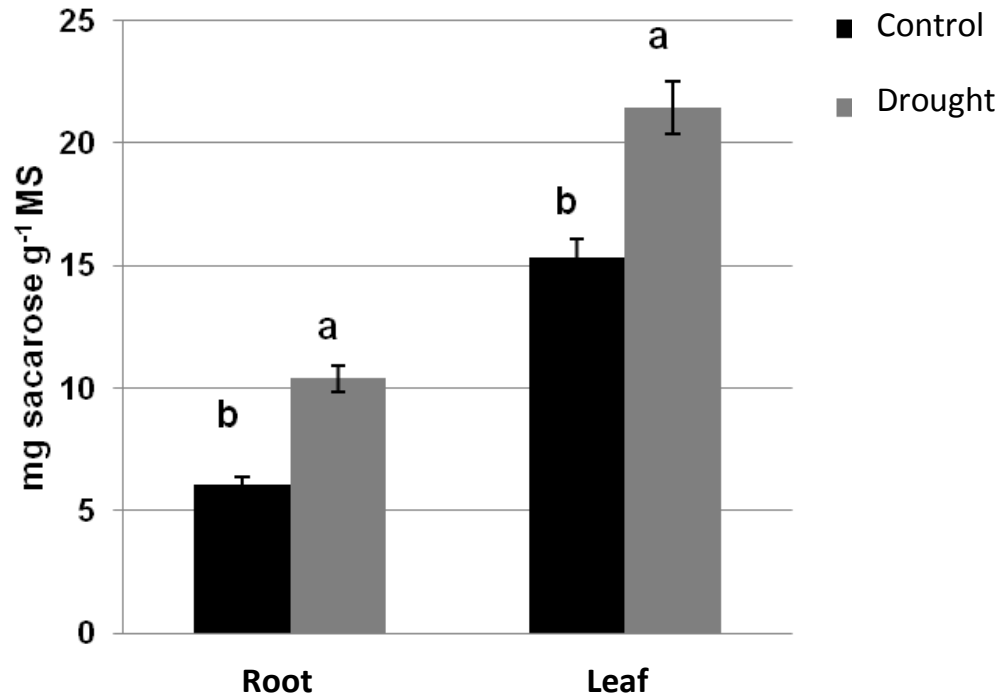
### Sucrose

Sucrose levels in the hog plum tree seedlings subjected under water deficit conditions in the present study were 10.37 mg sucrose g<sup>-1</sup> MS at the root, while for the leaves, it was 21.45 mg sucrose.g<sup>-1</sup> MS, which represents an increase of about 71 and 40%, respectively (Figure 6). Plants subjected under water deficit showed an increase in sucrose content as a strategy to prevent leaf

dehydration (Vieira et al., 2013). Because sucrose is extremely soluble, it can be accumulated in the cells, improving plant resistance to water deficit (Fioreze et al., 2011). The decrease in stomatal conductance (Figure 3) and in gas exchange showed that the photosynthetic rate was lower.

By lowering the supply of photoassimilates produced through photosynthesis, the plant accumulates sucrose to ensure the availability of sugars to be used for osmotic adjustment (Lobo et al., 2011). This is because water stress inhibits growth, causing the plant to accumulate sucrose rather than use it as an energy source for their growth. The accumulation of these molecules in the vacuole enables the reduction of water potential, affects the release of cytoplasmic water and keeps tissue swelling.

Similar results were found by Filho et al. (2008) on 'Valencia' orange trees on two types of rootstocks. They observed that sucrose content was increased in plants under water deficit compared to well irrigation water (control plants). After suspension of irrigation during a period of 15 days, it was noted that time was sufficient to cause a decrease in water potential of young plants of taperebá (*Spondia mombin* L.), reduction in transpiration rate, stomatal conductance and starch concentrations, but an increase in levels of total soluble carbohydrates and sucrose. Water stress directly affects the levels of



**Figure 6.** Sucrose concentration in young plants of *S. mombin* L. under drought. The letters **a** and **b** not differ statistically at 5% probability, by the Tukey test.

carbon cycle compounds.

### Conflict of Interests

The authors have not declared any conflict of interests.

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