Photochemical efficiency of photosystem II (PSII) and Water Potential of *Cnidoscolus quercifolius* Pohl in areas of Caatinga Paraibana[1]

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ABSTRACT – We conducted a study on the ecophysiological parameters of natural populations of *Cnidoscolus quercifolius* Pohl in the municipalities of Santa Luzia and São Mamede. The research was undertaken between 2009 and 2011, and photochemical quantum efficiency of photosystem II and water potential in seasonal wet and dry periods were analyzed. In the study of photosynthetic efficiency, we used fluorescence measurements, and to study the water potential, we used the Scholander pump. There was a decrease in photosynthetic efficiency related to photosystem II, with values of 0.591 and 0.616, and mean values of water potential that were negative during dry months, -1.3714 MPa (July/August 2009, Population 1), and -1.52 MPa (September/October 2010, Population 2). *C. quercifolius* presented related determinant physiological conditions of water stress, with low mean photosynthetic quantum efficiency values, indicative of damage in photosystem II, associated with low levels of osmotic potential, revealing an osmotic adjustment to limiting environmental conditions

Keywords: *Cnidoscolus*, ecophysiology, faveleira, phytochemical, semiarid

RESUMO – Realizou-se um estudo de parâmetros ecofisiológicos em populações naturais de *Cnidoscolus quercifolius* Pohl nos municípios de Santa Luzia e São Mamede. A pesquisa foi desenvolvida nos anos de 2009 a 2011, abordando a análise da eficiência quântica fotoquímica do fotossistema II e potencial hídrico em períodos chuvoso e seco. No estudo de eficiência fotossintética foi utilizado um medidor de fluorescência, e para o estudo do potencial hídrico utilizou-se a bomba de Scholander. Houve redução da eficiência fotossintética relacionada ao fotossistema II, com valores médios de 0,591 e 0,616, e valores médios de potencial hídrico negativo nos meses de estiagem, -1,3714 MPa (Jul/Ago-2009, População 1), e -1,52 MPa (Set/Out-2010, População 2). *Cnidoscolus quercifolius* apresentou condições fisiológicas determinantes de estresse hídrico com valores médios de eficiência quântica fotossintética muito baixos, indicativos de danos ao fotossistema II, associados a baixos índices de potencial osmótico, revelando um ajuste osmótico às condições limitantes do ambiente.

Palavras-chave: *Cnidoscolus*, ecofisiologia, faveleira, fotoquímica, semiárido

INTRODUCTION

The Caatinga is one of the five major Brazilian biomes, and is endemic to the semi-arid Northeast, characterized by a significant but poorly studied biodiversity (Albuquerque *et al.* 2007). *Cnidoscolus quercifolius* Pohl., popularly known as *faveleira, faveleiro* or *favela*, belongs to the family Euphorbiaceae and is distributed in several spots throughout the semi-arid area of the Caatinga. Until recently, the factors that regulate its dispersion were not known. *C. quercifolius* grows in dry and rocky soil, without humus or protective covering, exposed to strong radiation, and with a mean temperature of 25 °C (Duque 1980a, Amorim et al. 2005, Melo & Sales 2008). The West of Pernambuco and the central north regions of Paraíba, extending to the central south of Rio Grande do Norte, are areas where the populations have the highest density.

Data submitted by the Banco do Nordeste Report (BNB – *Northeast Bank*) in 2004 lists some potential uses of *C. quercifolius*, such as the use of its wood, which is characterized by being very brittle, tortuous, and light. The wood of *C. quercifolius* burns easily as firewood of low calorific value, in addition to being used in the manufacturing of coffins and other small job, for example small boxes and benches. Moreover, this wood is also used in medicine, forage, oil production for human consumption, hay for feeding cattle, goats, sheep, beef production, and more recently for producing biodiesel (Silva et al. 2007, Conceição *et al.* 2007).

Unplanned rural development of the Caatinga, notably in the semi-arid, and the consequent use of natural resources in a disorderly manner, caused profound changes in vegetation types and biodiversity, especially due to the type of developmental proscess. The use of extensive livestock without the appropriate management of the relationship between vegetation cover and density of livestock, inappropriate forms of land management and agricultural crops, forest fires and deforestation for planting exotic species and public policies implemented without a study about the probable environmental impacts, are all significant examples of these profound changes (Araujo-Filho 1989, Duarte 2003, BNB 2004, Pereira 2006, Trovão 2010). The research on native species of the semiarid tropical areas, for example *C. quercifolius*, is characterized as highly relevant for the implementation of projects that provide the sustainable use of natural resources, especially for the semi-arid state of Paraiba, especially the micro-region of West Seridó which has the highest concentrations of *C. quercifolius*. Thus, analysis of native species has received increased attention mainly by plant physiologists. This data may provide evidence for further research in the semi-arid tropics.

Measurements of the photochemical quantum efficiency and water potential are important ecophysiological parameters (Govindejee 1995), which account for adaptive behavior, reflecting the environmental conditions in which the plant grows, thus providing an understanding of the species ecology adapted to growth limiting conditions. The photosynthetic rate is an important variable for understanding plant physiology (Krause &Weiss 1984, Ogren & Oquist 1985, Nogueira & Silva Jr. 2001).

Water stress causes different physiological, biochemical and molecular responses in plants, which depend on the rate and the intensity of the stress (Keck & Boyer 1974); for example, the plants' physiological state, their stability and full efficiency in water use. Less negative levels of the water potential reflect water availability in the soil or successful adaptations to the stressful conditions. Knowing the variations in water potential of the plant species that comprise the Caatinga, we are able to analyze the changes related to this factor and evaluate its influence on other physiological factors.

In this context, measurements of ecophysiological parameters of water potential and photosystem II photosynthetic efficiency were made in natural populations of *C. quercifolius*, inhabiting the semi-arid regions of West Seridó in Paraíba State, located in the municipalities of Santa Luzia and São Mamede, in 2009 and 2011, considering seasonal rainy and dry periods.

MATERIAL AND METHODS

The study was conducted on *C. quercifolius* populations occurring in the municipalities of Santa Luzia and São Mamede. The municipalities of Santa Luzia (6º 52' 19" S and 36º 55' 08" O) and São Mamede (6º 55' 19" S and 37º 05' 45" O) are located in the middle-region of Borborema, Western Seridó micro-region of Paraiba. In these regions, temperatures range between 25°C and 30°C with mean annual rainfall around 550 mm, concentrated from January to April. In the last few decades there were periods with great irregularity in rainfall across Western Seridó (Duarte 2003). According to the Köppen classification, this region presents a hot semi-arid climate (BSw'h, i.e. Low-latitude steppe/ deserts). The Western Seridó micro-region has a high susceptibility to desertification, according to studies by the Ministry for the Environment, which is characterized as one of the centers of extreme desertification in the Northeast (Duarte 2003).

Photosystem II Photochemistry Quantum efficiency

Four populations of the *C. quercifolius* were studied: two populations located in Santa Luzia (Barra and Yayu Farms, hereon populations 1 and 2, respectively) and two in São Mamede (Promissão Farm, hereon population 3 and 4). In order to assess the photosynthetic efficiency, we followed the methodology described by Trovão et al., (2007). Three individuals per population were used, randomly arranged in the populations and fully exposed to light intensity. Three leaves per individual were taken from the middle portion, with N = 36 measurements (N = total number of experimental units). During the procedure, in each leaf, one *leaf clip* was placed retaining a portion of leaf area covered, free of light intensity, after approximately 90 minutes (Kautsky effect) held to the measurements of fluorescence emission via a fluorescence detector PEA (Plant Efficiency Analyzer) determining F0 (minimal or initial fluorescence), Fv (increase fluorescence from F0 to Fm), Fm (maximum fluorescence), and the Fv/ Fm ratio that allows the quantum yield determination of the photochemical phase of photosynthesis, with subsequent statistical analysis.

In statistical analysis we used the complete randomized block design, with four blocks, analyzed with Assistat software Version 7.6 beta. Analyses were carried out in the rainy (April 2010) and dry (September 2010) seasons, which are considered as treatments, and considered populations sampled as blocks, using ANOVA and the Tukey test with p = 0.05 to comparison of means.

Water potential

Two populations were studied to assess water potential, one located in Yayu Farm (population 1) and another located in Promissão Farm (population 2). Stems with 10 cm were removed from plants and placed in a Scholander pressure chamber, and the reading being taken after the first liquid expulsion from the cut. Seven individuals from each population sampled were used, randomly chosen, with three measurements from the same individuals, with a total of 21 measurements per population, with N = 42 measurements (N = total number of experimental units).

The water potential measurements always occurred in the early hours of the morning. In statistical analysis we used the same treatments and statistical program described in the chrolophyll fluorescence study. Here, each individual was considered a block. Sampling was conducted in dry and wet seasonal periods between the years 2009, 2010 and 2011 with a periodicity of 60 days between each collection.

RESULTS AND DISCUSSION

Photochemistry Quantum efficiency of Photosystem II

Statistical analysis of the results of photochemical quantum efficiency of the photosystem II in *Cnidoscolus quercifolius* populations in the municipalities of Santa Luzia and São Mamede, revealed a significant difference among the treatments using the F test. The blocks presented no significant statistical differences according to the test applied (Table 1).

Table 1. Analysis of variance (ANOVA) in a randomized block design, with four blocks. Each block corresponding to a population analyzed. Mean values are taken from three different measurements on each block, in order to compare the photosynthetic quantum efficiency of *Cnidoscolus quercifolius* in both rainy and dry periods. The means were compared by the F test with three replicates and N = 36.

Source of variation	Degrees of freedom	Sum of Squares	Mean square	F
Treatments	1	0.012042	0.12042	44.3653 **
Blocks	3	0.02281	0.00760	2.8018 ns
Treatments x Block	3	0.00463	0.00154	0.5687 ns
Error	16	0.04343	0.00271	
Total	23	0.19129		

** significant at 1 % probability ($p < .01$) * significant at 5 % probability ($.01 \leq p < .05$) ns-not significant ($p \geq .05$)

Table 2 shows mean values of photochemistry quantum efficiency of photosystem II for the species *Cnidoscolus quercifolius* in four populations studied during seasonal wet and dry seasons. The values indicated that C. quercifolius is affected by drought and reduced the photosynthetic efficiency related to photosystem II.

Table 2. Populations of *Cnidoscolus quercifolius* analyzed, with their respective photosynthetic quantum efficiency mean values, in relation to the rainy (April 2010) and dry (September 2010) periods compared by ANOVA followed by the Tukey test with three replicates and N = 36.

Populations	Periods	
	Rainy	Dry
Barra Farm – Pop. 1 (Santa Luzia)	0.792 A	0.616 B
Yayu Farm – Pop. 2 (Santa Luzia)	0.751 A	0.591 B
Promissão Farm – Pop. 3 (São Mamede)	0.812 A	0.667 B
Promissão Farm – Pop. 4 (São Mamede)	0.790 A	0.691 B
General mean	0.786 A	0.641 B

*Means followed by distinct letters are statistically different.

The data in table 2 indicate a strong tendency to decrease in photosynthetic activity as a result of situations of water stress during drought. It is important to remember that *C. quercifolius* is a deciduous species, and thus goes over experiencing a limitation of the dry season water potential, culminating in a falling leaf phenology that peaks of increased activity in the dry season of the year.

Values of 0.800 ± 0.05 correspond to maximum efficiency in energy use in the photochemical process (Torres, Neto *et al.* 2002, Trovão et al. 2007), since values lower than 0.750 indicate stress conditions, thus reducing plant photosynthetic potential according to Maxwell and Johnson (2000) and Araújo *et al.* (2004).

Photochemical damage to photosystem II under drought conditions were analyzed by Silva *et al.* (2010a). Studies of the quantum efficiency of PSII performed by Santos *et al.* (2013) showed that *Jatropha curcas* L. revealed a decrease in F_v/F_m in the semiarid region of northeastern Brazil during the driest months of the year, with values of quantum efficiency of 0.51 for the hottest hours of the day. In these stressful conditions, the species also showed an increase in the concentration of proline and soluble amino acids.

The accumulation of metabolites may be an important mechanism in the plants for tolerance to water stress conditions. The accumulation of proline acts as a mediator for osmotic adjustment, protecting the integrity of the plasma membrane as a source of carbon and nitrogen and promotes the reduction of reactive oxygen species (Johari-Pireivatlou et al. 2010).

Sapeta *et al.* (2013) studied the water stress impact on growth and physiology of two accesses of *Jatropha curcas* to different climatic origins, one area of wet tropical climate and a semiarid climate, observed that even conditions of stress both accesses maintained high leaf relative water content between 70-80 %. There was a reduction in plant growth, without significant differences between accesses in conditions of water stress. Photosynthetic rates were not affected when the stress conditions were moderate, and a decline in stomatal conductance under severe stress conditions in two accesses wererecorded. Drought stress did not reduce chlorophyll contents however, a reduction in the ratio of chlorophyll *a/b* was observed. Even under water stress the specie showed good tolerance to adverse conditions to which was subjected.

Similar results were found by Diaz-López et al. (2012) analyzed the behavior of *Jatropha curcas* L. seedlings under water stress, when they showed a decrease in rates of leaf growth and decline in stomatal conductance, as an adaptation strategy the condition of low water potential.

Changes in morphology and physiology resulting from water stress were also evaluated by Lobet et al. (2014), in a study addressing the absorption of water in the soil-plant system, focusing on the development of the rhizosphere. The authors noted that transient situations of water deficiency, affecting the conductivity of water in the soil, may interfere with the distribution of the roots to points of greater availability of water, changing the hydraulic architecture of the plant root system. Being further observed that the hydraulic architecture of root system accounts for better absorption of water in the soil-plant system with great impact on the hydraulic conductivity of the water in the plant.

The difference between the values of quantum efficiency of photosynthesis for the periods analyzed showed a considerable decrease between them, ranging from 12.55% (individuals in the population 4, Promissão Farm) to 22.22% (individuals in the population 1, Barra Farm). For individuals of the population 2, Yayu Farm and population 3, Promissão Farm, there were differences of 21.3% and 17.85%, respectively.

In a study done with species of the Caatinga occurring in Cariri, Paraiba, Trovão *et al.* (2007) found no significant differences between the two seasons (wet and dry) related to photochemical quantum efficiency for ten species analyzed. The species *Commiphora leptophloeoes* Mart. recorded the highest percentage difference between the seasons, showing 9.55%.

Water Potential

The statistical analysis of water potential for the two periods considered in this study revealed that the mean values of water potential reached by individuals in population 1 during the rainy season and dry season were significant at 1% probability by the F test (Tab. 3).

Table 3. Analysis of variance (ANOVA) in a randomized block design, with seven blocks. Each block corresponding to a individual analyzed. Mean values are taken from three different measurements on each block, in order to compare both rainy and dry periods for the population 1 (Yayu Farm, Santa Luzia – PB), 2009-2011. The means were compared with the F test with seven replicates and N = 21.

Source of variation	Degrees of freedom	Sum of Squares	Mean square	F
Treatments	1	747.479	747.479	53,6982 **
Blocks	6	0.08707	0.01451	0.0010 ns
Treatments x Block	10	0.65485	0.06548	0.0047 ns
Error	59	821.671	13.9266	
Total	76			

** significant at 1 % probability ($p < .01$) * significant at 5 % probability ($.01 \leq p < .05$) ns-not significant ($p \geq .05$)

Table 4 presented statistical analysis of water potential for population 2. This analysis showed that the values for the water potential in the population were significant at 1% probability for the F test.

Table 4. Analysis of variance (ANOVA) in a randomized block design, with seven blocks. Each block corresponding to an individual analyzed. Mean values are taken from three different measurements on each block, in order to compare both rainy and dry periods for population 2 (Promissão Farm, São Mamede – PB), 2009-2011. The means were compared with the F test with seven replicates and N = 21.

Source of variation	Degrees of freedom	Sum of Squares	Mean square	F
Treatments	1	10.56035	10.56035	51.66487**
Blocks	6	0.00906	1.76005	8.61039**
Treatments x Block	10	1.44693	0.14469	0.70787 ns
Error	59	12.06072	0.20441	
Total	76			

** significant at 1 % probability ($p < .01$) * significant at 5 % probability ($.01 \leq p < .05$) ns-not significant ($p \geq .05$)

Tables 5 and 6 present the results of water potential and their statistical analysis by Tukey test for *C. quercifolius* in the Santa Luzia population (Yayu Farm, population 1) and the São Mamede population (Promissão Farm, population 2), respectively. The data revealed a decrease in water potential during the dry months, and indicate an establishment of water stress as the drought condition is established in the environment, becoming low with increasing intensity of drought, registering -1.1857 (MPa) and -1.3714 (MPa) in July/August and September/October 2009, respectively, for individuals of population 1 (Table 5). Considering the year 2010, the same period reported higher values of water potential in the plant, in this population, although these values are still low, -0.8776 (MPa) and -0.9785 (MPa) for July/August and September/October 2010, respectively, even considering that the year 2010 had rainfall rates lower than those recorded in 2009 in Santa Luzia and São Mamede.

Table 5. Tukey test preceded by ANOVA with seven replicates (N = 21), mean water potential values (MPa) of *Cnidoscolus quercifolius* in both rainy and dry periods for population 1 (Yayu Farm, Santa Luzia – PB), 2009-2011. Data were not taken separately, they were only presented separately in the table to facilitate comparison between the rainy and dry periods.

Population 1 - (Yayu Farm, Santa Luzia – PB), 2009-2011					
Year	Month	Rainy period	Year	Month	Dry period
2009	May/Jun.	-0.5558 B	2009	Jul./Aug.	-1.1857 C
2010	Jan./Feb.	-0.5671 B		Sep./Oct.	-1.3714 C
	Mar./Apr.	-0.4114 B		Nov./Dec.	-0.8271 C
	May/Jun.	-0.5961 B	2010	Jul./Aug.	-0.8776 C
2011	Jan./Feb.	-0.3474 A		Sep./Oct.	-0.9785 C
				Nov./Dec.	-0.5361 B

*Means followed by distinct letters differ between themselves.

Table 6. Tukey test preceded by ANOVA with seven replicates (N = 21), mean water potential values (MPa) of Cnidoscolus quercifolius in both rainy and dry periods for population 2 (Promissão Farm, São Mamede – PB), 2009-2011. Data were not taken separately, they were only presented separately in the table to facilitate comparison between the rainy and dry periods.

Population 2 - (Promissão Farm, São Mamede – PB), 2009-2011					
Year	Month	Rainy period	Year	Month	Dry period
2009	May/Jun.	-0.7771 B	2009	Jul./Aug.	-1.4571 C
2010	Jan./Feb.	-0.5300 B		Sep./Oct.	-1.5285 C
	Mar./Apr.	-0.4185 A		Nov./Dec.	-0.7471 B
	May/Jun.	-0.6142 A	2010	Jul./Aug.	-0.8842 C
2011	Jan./Feb.	-0.3442 A		Sep./Oct.	-0.9714 D
				Nov./Dec.	-0.5857 B

*Means followed by distinct letters differ between themselves.

Population 1 presented a higher water potential in the rainy period, and the lowest water potential was observed between the months of March/April 2010 (-0.4114 MPa) and January/February 2011 (-0.3474 MPa). The analysis of water potential in the populations studied showed that *C. quercifolius* performs an osmotic adjustment triggered by water stress, a consequence of the seasonal dry period.

Plants subjected to water stress conditions may develop osmotic adjustment induced by the accumulation of the amino acid proline, which was observed by Silva et al. (2004) in Paraiba semiarid with *Poincianella pyramidalis*, which showed marked accumulation of free proline, which can be associated with survival under conditions of water deficit. According to Coll et al. (1995), plants performing osmotic adjustments are truly xerophilous and, moreover, the amino acid proline influences this adjustment.

Johari-Pireivatlou et al. (2010) in a study to evaluate the effect of water stress in wheat, found increased rates of proline and total soluble sugars and also a 25% decrease in the production of seeds and stems when stress occurred after anthesis.

Sharma et al. (2011) analyzed the role of proline tissue-specific mutants of Arabidopsis thaliana, both for synthesis (p5cs1) and for blocking proline catabolism (*pdh1*), observing that the mutant not synthesizing proline had decreased root growth, similar to the mutant that did not produce abscisic acid (*aba2-1*) while the mutant blocking reactions continued to catalyse proline to some extent, and had a good development of the root and shoot meristem in conditions of low water potential, suggesting the need for an active metabolism of proline for continued growth in water deficit conditions. The authors suggest that the proline metabolism can act as a mediator of abscisic acid protection growth in water stress conditions. Both mutants also showed a greater decrease in the rates of NADP/NADPH compared with the wild type under drought stress.

Seasonal variations in water potential in semiarid regions have been described by San José (1977), who found values of -1.4 MPa for *Curatella americana* L. during the dry season in savanna areas; Moraes, Perez and Carvalho Jr. (1989), who recorded values below -3.0 MPa for tree species in the savanna during the dry season; Trovão et al. (2007) reported values of -1.49 MPa and -2.2 MPa for the species *Commiphora leptophloeoes* Mart. and *Bumelia sartorum* Mart., respectively, in areas of Paraiba Cariri during the dry season.

Population 2, located in São Mamede (Promissão Farm) showed similar behavior to that found in population 1. The water potential values range according to the periods analyzed, showing a more pronounced acclimation in the driest periods of the year, with values of -1.4571 MPa and -1.5285 MPa, between July/August and September/October 2009, respectively, and July/August - September/October 2010, with values of -0.8842 MPa and -0.9714 MPa, respectively (Tab. 6). The wet period coincides with less negative water potential values, as environmental conditions favor the absorption of water available and the species retains the necessary water reserve for the physiological development adjusted to climate conditions, particularly precipitation. The average values of water potential in the wet season were low for periods of March/April 2010 (-0.4185 MPa) and January/February 2011 (-0.3442 MPa).

CONCLUSIONS

Cnidoscolus quercifolius presented determinant physiological conditions of water stress, with low photosynthetic quantum efficiency mean values in the dry season, corresponding to low levels of water potential for the populations analyzed in the drier periods of the year. The water potential in *C. quercifolius* changed seasonally, which is a fact that confirms the need to modify itself physiologically, adjusting to water stress conditions. In the rainy season, the populations of *C. quercifolius* analyzed presented a less negative mean values of water potential, which corresponds to better quantum efficiency indices for the same period. There are significant differences in photosynthetic efficiency in *C. quercifolius* in the seasons with water availability and in water absence, possibly because of drought adaptation.

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