Scientific Electronic Archives
Issue ID: Sci. Elec. Arch. Vol. 12 (6)
December 2019
DOI: http://dx.doi.org/10.36560/1262019963
Article link
http://www.seasinop.com.br/revista/index.php?journal=SEA&page=article&op=view&path%5B%5D=963&path%5B%5D=pdf
Included in DOAJ, AGRIS, Latindex, Journal TOCs, CORE, Discoursio Open Science, Science Gate, GFAR, CIARDRING, Academic Journals Database and NTHRYS Technologies, Portal de Periódicos CAPES.

ISSN 2316-9281

Does *Allium sativum* L. tolerate water deficit?

T. F. Marostica[1,2], L. H. Cazarolli[1,2], G.S. Moura[1,2], V. C. D. Luz[1], E. A. C. M. Guimarães[1], D. Cargnelutti[1,2]

Post-Graduate Program in Agroecology and Sustainable Rural Development

Universidade Federal da Fronteira Sul

Author for correspondence: denise.cargnelutti@uffs.edu.br

Abstract: The objective of this work was to evaluate the effect on the physiological and biochemical aspects of garlic submitted to water deficit, knowing that popular garlic Allium sativum L. is a culture worldwide known for its medicinal, culinary and ecological properties of agricultural pests. Treatments were constituted with water condition of 100; 75; 50 and 25% pot capacity (CP). Three bulbs were planted per pot (5 L) containing Plantmax® substrate, irrigated every two days, according to pot capacity. Chlorophyll index was evaluated during the first and last weeks of greenhouse treatments. At 45 days after treatments, garlic plants were harvested to evaluate physiological and biochemical parameters. Garlic plants showed to be sensitive to water deficit, resulting in lower leaf length and fresh biomass. Water stress induced APX enzyme activity in leaves and POD activity in roots, as well as protein increase in bulbs as biochemical mechanisms of adaptation.

Keywords: Climate change, water deficit, adaptation.

Introduction

Garlic (*Allium sativum L.*) is a culture currently used in world cuisine and highly known for its medicinal benefits due to the high chemicals concentrations including essential oils, sulfur compounds, carbohydrates, proteins, vitamins and minerals. In addition, some reports in the literature showing the effects of garlic extracts as well as their essential oils on ecological management of agricultural pests. (LOZANO et al., 2015).

According to Ankri and Mirelman (1999), garlic is one of the edible plants that have generated much interest throughout human history as a medicine against a wide range of microorganisms. The same authors also attributed this antimicrobial biological activity to the allicin metabolite, composed of oxygenated sulfur, extracted from the bulbs.

In Guarani indigenous villages located in the Rio das Cobras village of Nova Laranjeiras, Paraná, garlic is grown among other crops or its extracts are used to eliminate different pathology-causing flies. Such empirical evidence further reinforces the scarce scientific evidence regarding garlic's potential in agricultural pests ecological management and their therapeutic functions through traditional knowledge.

Thus, this plant is a lucrative option in family farming and, as a worldwide crop, could suffer with climate change future consequences. Climate change is one of the most serious challenges facing humanity. According to Marengo (2011), Nobre (2008), Guetter (1998), and Dias et al. (2005) earth temperature, as well as gases emission and agrochemicals misuse will result, in the future, in climate events worsening, such as excessive rainfall and lack thereof as well (BERLATO, 2013).

In Brazil, some changes are already observed, as climate extremes (direct changes in hydrological cycle and fluctuations in temperature frequencies, storms, frosts) (GUETTER, 1998, VALE et al., 2009). Nobre (2008) pointed out that, with temperature increase, surface water availability decreases. Thus, less rainfall periods combined with high temperatures become a threat to ecosystems biodiversity, as stated by Vale et al. (2009) especially for agriculture across the country, which could have a strong socioeconomic impact (MARENGO, 2011). Abusive agrochemicals use in conjunction with climate change can undermine the water available in soil.

Plants, in general, when exposed to stress situations such as salinity, temperature extremes, water deficit, among others (OSAKABE et al., 2014), undergo an imbalance of its normal metabolism and, in addition, they need to react by activating endogenous defense responses to ensure their survival. Among the defense responses is reactive species production and removal (ERs). To do so, plants have an antioxidant defense system composed of enzymatic antioxidants, such as guaiacol peroxidase (POD), ascorbate peroxidase (APX) and catalase (CAT), as well as non-enzymatic antioxidants, capable of removing ERs. However, if complete removal does not occur, ERs may trigger an oxidative stress situation, leading to damage in biomolecules as lipids, proteins and nucleic acids (Mittler et al., 2004; Silva et al., 2012; Pyngrope et al., 2013).

Under these conditions, plants need to alter their defense system to tolerate stress. Otherwise, the water restriction to which plants are subjected to may induce oxidative stress on crops resulting in yield losses. Due to climate change and inadequate soil management, drought periods will be frequent, in which the farmer must be prepared to keep his agricultural production in balance with the environment.

In this context, it is important to know the physiological and biochemical responses of *Allium sativum* L. to water deficit. Thus, the present study aimed to investigate the water deficit effect on garlic crop and its biochemical and physiological responses triggered by water stress.

Methods

Experiments were conducted in the laboratories of Federal University of Fronteira Sul - UFFS, Laranjeiras do Sul Campus, PR and Erechim campus, RS, as well as in UFFS experimental areas of Laranjeiras do Sul campus - PR. Garlic seeds were all acquired as garlic-heads in the same place (same access), from farmers of Nova Laranjeiras-PR, and then bulbs were separated (garlic cloves) (EMBRAPA, 1993), which were propagated in a greenhouse.

Three bulbs were planted in each pot filled with Plantmax® substrate, which is rich in organic matter, with ten pots for each treatment at a 2 to 3 centimeters depth (EMBRAPA, 1993). Each pot contained four kilograms of substrate, all weighed on a precision scale. After one acclimation month, treatments began for a further forty-five (45) days. Treatments were determined from the laboratory definition of substrate water retention capacity, substrate density, solids and pore volume, and substrate volume in each pot and aeration space. Pot capacity (CP) was determined by assuming the weight of soil saturated with water by capillarity plus pot weight. From water amount retained by substrate in CP, 25%, 50% and 75% were omitted, giving a weight for these pots. Pots without plants were weighed every two days to know the evapotranspirated water amount, previously being known the weight of these. Evapotranspirated water replacement in the period was performed using a bucket with ml calibration, keeping pots without plants and 0% CP water deficit treatment and omitting irrigation in 25%, 50% and 75% pot capacity in those treatments under stress.

During the water stress period, plants were subjected to chlorophyll analysis using the chlorophyll meter (SPAD, model Falker ClorofiLog CFL 1030) according to the methodology described by Leonardo et al. (2013). At 45 days after the beginning of treatments, plants were harvested, separated in root, shoot and bulbs and then analyzed.

Root system (main root length), shoot and bulb lengths were measured using a ruler. To determine biomass, the organs were weighed using an analytical scale and fresh mass was registered. For dry mass, shoot, root and bulbs were oven dried at 70 ° C until a constant mass was obtained.

To determine antioxidant enzymes activity (ascorbate peroxidase, APX, and guaiacol peroxidase, POD), leaf, root and bulb samples were macerated in liquid nitrogen and stored at -20ºC. To one gram of samples was added 3 ml of 0.05 M sodium phosphate buffer (pH 7.8) containing 1 mM EDTA, 2% polyvinylpyrrolidone and Triton X-100 (10 ml L^{-1}). The homogenate was centrifuged at 13,000 x g for 20 min at 4 ° C and resulting supernatant was used for antioxidant enzymes activity analysis.

APX activity was determined according to the method described by Zhu e *cols*. (2004). The H_2O_2-dependent ascorbate oxidation recorded at 290 nm using the 2.8 mM cm-¹ molar extinction coefficient, with a total time of 120 seconds and reading interval every 15 seconds on a spectrophotometer. Final volume of reaction mixture was 2 ml, which was composed of NaH_2PO_4 / Na_2HPO_4 sodium phosphate buffer (25 mM) (pH 7.0), 0.1 mM EDTA, ascorbate (0.25 mM), H_2O_2 (1 mM) and enzymatic extract (30 µl). Activity was expressed as µmol oxidized AsA min^{-1} mg^{-1} protein.

The POD enzyme activity was determined according to Zeraik et al. (2008), using guaiacol as a substrate. Reaction mixture contained 1.0 mL potassium phosphate buffer (100mM, pH 6.5), 1.0 mL guaiacol (15 mM) and 1.0 mL H_2O_2 (3 mM). After homogenization, 50µL plant extract was added to this solution. Enzyme activity was measured by guaiacol oxidation to tetraguaiacol at 470 nm. Results were expressed in enzyme unit per mg protein (U mg^{-1} protein). For calculation, the molar extinction coefficient of 26.6 mM^{-1} cm^{-1} was used. In all enzyme preparations protein concentration was measured by Coomassie Blue method (BRADFORD, 1976) using bovine serum albumin (BSA) as standard.

A completely randomized design was used, consisting of 5 replications with two plants for each repetition equivalent to 25%, 50%, 75% and 100% treatments respectively. Data were subjected to variance analysis by SISVAR software, and means compared by Tukey test at 0.05% significance.

Results and discussion

Data regarding chlorophyll content of apex, median and basal regions of *Allium sativum* L. leaf submitted to different water deficit concentrations are shown in Table 1. The 50% water deficit treatment induced a 46% reduction in chlorophyll levels from *A. sativum* basal leaf region when compared to control treatment (100% pot capacity).

Moreover, in the 50% water concentration treatment, it was observed the yellowing of some evaluated leaves. This observed yellowing may be associated with garlic's adaptability to temperature and humidity in the greenhouse.

Table 1 - Chlorophyll concentration index of apex, median and basal regions of *Allium sativum* leave growing under different water deficit concentrations.

Pot capacity (%)	Chlorophyll concentration index (Spad)			
	Apex	Median	Basal	Mean
25	45,64 abB	42,02 abB	27,80 abA	38,48 a
50	42,56 aB	45,56 abB	18,66 Ab	35,59 a
75	52,65 bB	48,63 aA	32,13 Ba	44,47 b
100	46,73 abB	36,05 bA	34,44 Ba	39,07 ab
Mean	46,90 B	43,06 B	28,26 A	
C.V. (%)	15,15			

* Means followed by same lowercase letter in column and uppercase in row do not differ by Tukey test at 0.05% probability.

These differences in leaf color observed throughout the experiment influenced the chlorophyll concentration index variation linked to nutrient uptake by plant, as well as the higher temperature inside the greenhouse due to the acclimation period itself, once garlic is a winter crop, and was grown in a milder, shady environment.

Dutra et al. (2012) obtained similar results to the present study, when studying sunflower during water stress, in which leaf chlorophyll content of the plants was reduced due to low water availability. In the present study, it was found that in 25% and 50% CP treatment there was a decrease in chlorophyll index in leaf basal portion compared to apex and median regions of garlic leaf, respectively (Table 1). The observed chlorophyll variation in garlic leaf basal part is associated to a thicker leaf blade, which probably contributed to the lower efficiency of the chlorophyll meter.

Uddling et al. (2007) and Jesus and Marenco (2008), justify the lack of linearity between chlorophyll contents, observed in their studies, in which the chlorophyll distribution on leaf surface presents some unevenness, especially in well greenish leaves which can lead to underestimation of index values in leaves with high chlorophyll content. Despite this information, it is known that a plant during stress decreases its photosynthetic rates to save energy expenditure, an explanation that corroborates the data observed in the present study.

Observing *A. sativum* growth, it was possible to verify a reduction (1.2 and 1.3 times greater when compared to control, 100%, respectively) in leaves length only when treated with 25% and 50% CP, and an increase (1.2 times greater when compared to control, 100%, respectively) in length in this same organ when *A. sativum* was treated with 75% CP.

This may have been due to the fact that *A. sativum* cycle is early, and therefore, the bulb did not grow completely, as garlic's life cycle takes approximately 30 weeks (7 months) according to Resende et al. (2004). However, in leaf, these differences were remarkable considering the existence of more complex physiological processes as transpiration and photosynthesis among others, when compared to processes that occur in the root system.

Table 2 - Total length (cm) mean values of *Allium sativum* bulb, leaf and root regions growing under different water deficit concentrations.

Pot capacity (%)	Bulb	Leaf	Root
25	2,10 aA	32,9 bC	10,90 aB
50	2,37 aA	28,4 aC	13,80 aB
75	3,70 aA	44,9 dC	12,50 aB
100	2,50 aA	38,2 cC	13,30 aB
Mean	2,66 A	36,10 C	12,62 B
C.V (%)	10,67		

* Means followed by same lowercase letter in column and uppercase in row do not differ by Tukey test at 0.05% probability.

Teixeira et al. (2011) when evaluating *Crambe abyssinica* seeds as potential for biodiesel production, observed a reduction in plant growth at lower water concentrations as observed in the present study. Sesame (*Sesamum indicum*), evaluated by Taveira et al. (2016), showed a higher growth in stages in which water deficit was moderate and severe, also similar results to the findings of the present study (Table 2).

On the other hand, Brito et al. (2013) and Sanches (2012) obtained significant results with increased growth for other plant species exposed to water deficit. For *A. sativum*, growth increase was observed in the 75% CP treatment (1.3 to 1.4 times greater than control), in which conditions were not of total water deficit. If this condition occurs at plant's growth stage, it may affect productivity, as this is the most resource-demanding phase (DARIANTO et al., 2015; HE et al., 2017). Some plants are able to adjust itself in order to tolerate stressful conditions, allowing them to maintain their growth and development, but for cultivated plants tolerance is related to maintaining productivity (ROSA, 2017).

The fact that *A. sativum* plants reduce growth when exposed to soil water levels below 50% is probably related to water deficit effects on plant growth. Water deficit can cause changes in leaf water relations, which in turn affect chemical and physiological processes and, consequently, the growth and development of plant aerial part (ROSA, 2017).

According to Scalon et al. (2011), water deficit in plants occurs in situations where cells and tissues are not fully turgid. As a result, stomata close, causing a reduction in photosynthesis and, consequently, in the development. Root system development in deeper layers of soil profile enables plants to better explore soil moisture and fertility, according to plant morphological and genotypic characteristics (OSAKABE et al., 2014). *A. sativum* did not obtain a significant root system length (Table 2), as, according to literature data, water content in this phase should be maintained around 70 to 90% field capacity, according to Csiszár et al. (2007).

Table 3 shows fresh biomass data for *A. sativum*. For roots and bulbs no significant results were observed. However, for shoot, significant changes were observed. For *A. sativum* treated with 25% and 50% CP, biomass was 1.4 and 1.7 times smaller when compared to control treatment (100% CP), which did not differ from witness (Table 3). Dutra et al. (2012) obtained similar results when evaluating sunflower plants in different water concentrations. According to the same authors, 60% water restriction treatment affected both shoots and roots biomass production. Water lack can lead to reduced cell expansion, stomata closure and reduced photosynthesis, severely affecting shoot and root biomass production. (GÓMEZBELLOT et al., 2013; HSIE et al, 2015).

In addition, Sobrinho et al. (2011) studying Sunflower under water deficit conditions found that fresh mass accumulation may be a reflection of a reduction in soil nutrient absorption, a reduction in photosynthesis, and a reduction in photoassimilates redistribution.

Carvalho et al. (2003) observed in their water deficiency study with Artemisia, at 90% water level, similar responses to the data obtained in the present study with 50% CP. Moreover, Carvalho et al. (2003) points out that water deficiency disrupts the growth process, not only decreasing fresh and dry mass accumulation, but also altering the growth process, and accelerating catabolic processes.

In the present study, it was observed a reduction in *A. sativum* leaf fresh mass, precisely because the plant biomass production is linked to photosynthetic activity, thus, under stress conditions, the relative growth rate is also reduced, being more tolerant at 75% CP as shown in Table 3.

Table 3 - Fresh biomass mean values of *Allium sativum* bulb, leaf and root growing under different water deficit concentrations

Pot capacity (%)	Bulb	Leaf	Root
25	0,96 aA	4,31 aB	0,50 Aa
50	0,94 aA	3,57 aB	0,60 aA
75	1,27 aA	6,06 bB	0,74 aA
100	1,28 aA	6,05 bB	0,71 aA
Mean	1,11 A	5,00 B	
C.V (%)	33,57		

* Means followed by same lowercase letter in column and uppercase in row do not differ by Tukey test at 0.05% probability.

Shoot dry mass mean values in 100% CP treatment did not differ from 25% CP treatment, being lower under less water availability. Root and bulb dry mass did not differ significantly in relation to the treatments. Morales et al. (2015) obtained similar results to those observed in the present study when studying tomato strains under water stress. The same authors observed a reduction in fresh and dry mass of leaves, stem and root system in the strains, where tomato root system dry mass had no difference between strains.

As the water deficit increased, no significant changes were observed in the dry biomass of *A. sativum* organs (Table 4), with only a 40% increase in leaf biomass of plants treated with 75% CP. Some authors such as Bernier et al. (2008), Morales et al. (2015), Sousa et al. (2015) Mendes et al. (2007), Silva et al. (2007) and Macêdo et al. (2006) obtained similar results with those obtained in the present study. The same authors stated that water lack affects practically all physiological processes, including dry matter accumulation, which is mainly responsible for productivity, in which the most vigorous plants, when subjected to water deficit, have physiological mechanisms that allow its development even under drought conditions.

Thus, excessive biomass requires more water in the soil due to increased plant transpiration. Such effect may have influenced biomass reduction in control treatment. Allied to this, the temperature present in greenhouse could also have led to higher energy expenditure, consequently intervening in this parameter.

Plants with flooding roots, according to Belo (2011), also have reduced dry matter production, as saturated soil impairs water and nutrients absorption by roots, as well as negative effects on the photosynthetic apparatus leading to reductions in photosynthetic rate and root death. *A. sativum* is a plant sensitive to water restriction, as evidenced by data obtained in the 25% CP treatment. However, this same plant also does not tolerate saturation situations, as observed in control treatment with 100% CP.

Table 4 - Biomass mean values of *Allium sativum* bulb, leaf, root and total dry weight (g) growing under different water deficit concentrations.

Pot capacity (%)	Bulb	Leaf	Root
25	0,21 aA	0,51 aB	0,06 aA
50	0,14 aA	0,44 aB	0,08 aA
75	0,19 aA	0,86 bB	0,09 aA
100	0,14 aA	0,61 aB	0,05 aA
Mean	0,17 B	0,61 C	0,07 A
C.V (%)	37,43		

* Means followed by same lowercase letter in column and uppercase in row do not differ by Tukey test at 0.05% probability.

However, Csiszár et al. (2007) reported that a decrease in water for *A. sativum* (a 40% decrease in soil water content) during growing season might cause significant changes in antioxidants and antioxidant enzyme activities such as peroxidase (POD) and ascorbate peroxidase (APX). Thus, according to Macedo and Cargnelutti (2016) for plants adaptation to adverse conditions, biochemical and physiological changes are necessary to adapt the plant to the stress condition. Water deficit triggers changes in growth parameters, photosynthesis, stomata opening and closing, leaf expansion and triggers oxidative stress.

Among the parameters affected by water stress are soluble protein levels, many of which are enzymes responsible for ERs metabolism. Thus, specific enzymes such as POD and APX are important biomolecules for the removal of toxic compounds generated during stress. In the present study, protein levels were altered only in *A. sativum* bulbs treated with 50% CP (Table 5), a 1.3 times increase when compared to control treatment (100% CP).

Table 5 - Protein content (mg/L) of *Allium sativum* bulbs, leaves and roots growing under different water deficit concentrations.

Pot capacity (%)	Protein Content (mg L^{-1})			
	Bulb	Leaf	Root	Mean
25	2,78 aC	2,67 aB	0,75 aA	2,21 ab
50	3,57 bC	2,71 aB	0,97 aA	2,42 b
75	2,95 aC	2,43 aB	0,71 aA	2,03 a
100	2,78 aC	2,21 aB	0,76 aA	1,92 a
Mean	3,12 C	2,50 B	0,75 aA	
C.V (%)	14,30			

* Means followed by same lowercase letter in column and uppercase in row do not differ by Tukey test at 0.05% probability.

The change in protein concentration pattern is completely linked to water restriction (PARIDA et al., 2007). When a plant is exposed to stress for a time period, there is an increase in protein content that is intended for stress defense pathways, sweeping ERs and other oxidants that tend to damage structural compounds and cellular metabolic machinery. Thus, data observed in the present study corroborate data found in the literature for other plant species exposed to different levels of water deficit. (FUMIS e PEDRAS, 2002; MELO, 2012; QUEIROZ et al., 2002; SOUSA et al., 2015).

Evidence suggests that drought leads to oxidative stress in several plants where ERs as superoxide radical ($O^{2\bullet-}$), hydroxyl radical (OH), hydrogen peroxide (H_2O_2) and singlet oxygen ($1O_2$) are produced (CARNEIRO et al., 2011). The ERs synthesis appears to be a dynamic event during plant development, as well as a plant response to biotic and abiotic stresses (APEIL e HIRT, 2004). According to Carneiro et al. (2011), to eliminate these reactive species, plants have antioxidant enzyme systems that constitute an important primary defense against free radicals generated under stress conditions, such as APX, that can break H_2O_2 into H_2O and O_2, and POD, that also acts breaking H_2O_2. The APX is responsible for eliminating H_2O_2 toxic power in chloroplast and cytosol, while peroxidases (POD) are present in almost all vegetable compartments (ZANETTI 2013).

Results of the present study for POD activity are shown in Table 6. According to data, significant changes were only observed in roots from plants treated with 50% CP, and the activity was 2.1 times higher when compared to control treatment. Enzymes play a defensive role, acting when the plant is producing many toxic substances. On water deficiency, POD promotes maintenance of cell membrane stability (SHARIFI et al., 2012; GE et al., 2006).

Mitller (2002) states that antioxidant system enzymes are very sensitive to environmental stress conditions and act as stress signals. Thus, antioxidant enzymes role in stressful situations is to control ROS accumulation limiting oxidative damage.

In the present study, due to ideal cultivation in a greenhouse and because it is a winter crop, already resistant to extremes, no changes in POD activity were observed for most A. sativum organs, also suggesting that, in water deficit conditions, or the plant did not increase ERs production or such species were produced, but they were removed through secondary compounds activity, present in abundance in this plant species (BARBOSA et al., 2010).

Table 6 - Peroxidase (POD) activity of *Allium sativum* bulb, leaf and root submitted to different water deficit concentrations.

Pot capacity (%)	POD activity (U mg^{-1} protein)			
	Bulb	Leaf	Root	Mean
25	83,28 aAB	42,63 aA	170,93 abB	98,95 a
50	88,61 aA	46,45 aA	279,22 bB	138,09 a
75	88,53 aA	44,79 aA	208,89 ab	148,71 a
100	105,82 aA	65,44 aA	132,25 aA	101,17 a
Mean	91,56 A	51,50 A	197,92 B	
C.V (%)	63,49			

* Means followed by same lowercase letter in column and uppercase in row do not differ by Tukey test at 0.05% probability.

For ascorbate peroxidase enzyme (APX), the highest activities were observed in 75% CP treatment, only in leaves, when compared to control (100% CP) (Table 7). Literature data show that when plants are exposed to water deficit there is a significant increase in antioxidant enzymes activity, POD, APX and SOD (CARNEIRO et al., 2011; SILVA, 2014; CRUZ, 2015; MITTLER, 2002). In the present study, APX and POD enzymes activity seem to be relational, once, while POD showed high root activity, APX showed high activity in shoots (Tables 6 and 7). When Zanetti (2013) studied cocoa plants, he realized that in non-irrigated plants, POD enzyme seems to be the main defense system, whereas in irrigated plants it would be APX. Peroxidases are responsible for polymers synthesis (lignin) in the cell wall as well as prevention of membrane lipid oxidation. Increased peroxidase activity in stressed plants would allow greater stress tolerance (MITTLER, 2002). Cell damage caused by free radicals and lipid peroxidation can be reduced or prevented by antioxidant system metabolism involving antioxidant enzymes such as peroxidase. (ZANETTI, 2013).

Both APX and POD have forms distributed in the various cellular compartments. Literature data have shown increased activity of this enzyme when plants are exposed to water deficit (CIA, 2010; DEUNER et al., 2011), high temperatures (HU et al., 2008), although enzyme inactivation or reduced activity is also reported (MAIA et al., 2012; PEREIRA et al., 2010).

Enzymes are proteins that catalyze chemical reactions and mediate virtually every biochemical reaction constituting life, so they are essential for the proper maintenance of any organism. Hendges et al. (2015) evaluated corn oxidizing enzymes in drought periods, and did not observe changes in POD and APX activities. APX is one of the major enzymes involved in H_2O_2 rapid elimination, as it has a high affinity for this molecule, even removing it at low concentrations (micromolar). Unlike catalase, which works by removing hydrogen peroxide excess (millimolar) (MITTLER, 2002).

Table 7 - Ascorbate peroxidase (APX) activity of Allium sativum leaf and root growing under different water deficit concentrations.

Pot capacity (%)	APX activity (μmol oxidized AsA min^{-1} mg^{-1} protein)	
	Leaf	Root
25	256,00 aA	71,40 aB
50	396,00 abA	65,50 aB
75	642,20 cA	153,80 aB
100	434,20 aB	183,80 aB
Mean	432,10 B	118,62 A
C.V (%)	29,95	

* Means followed by same lowercase letter in column and uppercase in row do not differ by Tukey test at 0.05% probability.

Resende et al. (2004) states that garlic cultivation is very sensitive to water lack, but water excess is as harmful as its lack. In this way, proper irrigation management is a determining factor for good bulb production and conservation after harvest. While water lack can lead to drastic productivity reductions, excess favors the onset of disease, stimulates pseudo-tillering and reduces bulb conservation during storage.

Conclusion

Despite the significant changes observed in antioxidant defense system, this system was not effective in eliminating reactive species excess, leading to a reduction in growth and biomass of *A. sativum* exposed to water deficit. Thus, it is concluded that *A. sativum* plants are sensitive to water deficit and, when grown under this condition, there will be significant yield losses.

References

ANKRI S. MIRELMAN D. Antimicrobial properties of allicin from garlic. Microbes and Infection, 2, 125−129.Elsevier, Paris. 1999.

APEL, K.; HIRT, H. Reactive oxygen species: metabolism, oxidative stress, and signal transduction. Annual Review of Plant Biology, v.55, p.373-399. 2004. http:// www.annualreviews.org/doi/abs/10.1146/annurev. arplant.55.031903.141701.

BARBOSA M. R., SILVA M. M. A., WILLADINO L., ULISSES C., CAMARA T. R. Geração e desintoxicação enzimática de espécies reativas de oxigênio em plantas. Ciência Rural, Santa Maria, v.44, n.3, p.453-460, mar, 2010.

BELO E. S. Efeito do Estresse Hídrico no Metabolismo de Gabirobeira. Dissertação (Mestrado) – Universidade Federal de Goiás, Programa de Pós-Graduação em Agronomia, 2011. 131 pag. Disponível em: < file:///C:/Users/Usuario/Downloads/CAPA%20DISSERTA%C3%87%C3%83O.pdf >. Acesso em: 20/01/2018.

BERNIER, J. et al. Breeding upland rice for drought resistance. Journal of the Science of Food and Agriculture, Ox-ford, v. 88, n. 6, p. 927-939, 2008.

BLUM, A. Osmotic adjustment is a prime drought stress adaptive engine in support of plant production. Plant; Cell e environment. 40: 4-16; 2016.

BRADFORD, M. M. A. Rapid and Sensitive Method for the Quantitation of Microgram Quantities of Protein Utilizing the Principle of Protein- Dye Bending. Analytical Biochemistry 72: 248-254, 1976.

BOTREL N, OLIVEIRA VR. Cultivares de cebola e alho para processamento. In: Congresso Brasileiro de Olericultura, 52. Horticultura Brasileira 30. Salvador: ABH. Ano 2012. S8420-S8434.

CARNEIRO C. L. M. M., DEUNER S., OLIVEIRA P. V., TEIXEIRA S. B., SOUSA P. C., BACARIN M. A., MORAES M. D.; Atividade antioxidante e viabilidade de sementes de girassol após estresse hídrico e salino. Revista Brasileira de Sementes, vol. 33, nº 4 p. 000 - 000, 2011.

CARVALHO, L.M.; CASALI, V.W.D.; SOUZA, M.A.; CECON, P.R. Disponibilidade de água no solo e crescimento de artemísia. Horticultura brasileira, Brasília, v. 21, n. 4, p. 726-730, outubro-dezembro, 2003.

CRUZ F. J. R. Respostas bioquímicas e fisiológicas de plantas jovens de canade-açúcar sob diferentes concentrações de NaCl no solo. Tese (doutorado) - Universidade Estadual Paulista, Faculdade de Ciências Agrárias e Veterinárias, Jaboticabal, 2015.

CSISZÁR, J., LANTOS, E., TARI, I., MADOŞĂ, E., WODALA, B., VASHEGYI, Á., HORVÁTH, F., PÉCSVÁRADI, A., SZABÓ, M., BARTHA, B., GALLÉ, Á., LAZĂR, A., CORADINI, G., STAICU, M., POSTELNICU, S., MIHACEA, S., NEDELEA, G., e ERDEI, L. Antioxidant enzyme activities in Allium species and their cultivars under water stress. Plant Soil and Environment, 53, 517-523, 2007.

DIAS N. S., S. N.DUARTE, HANS R G., J. F D. MEDEIROS, T. M. SOARES. Manejo da fertirrigação e controle da salinidade do solo sob ambiente protegido, utilizando-se e ando-se e ando-se extratores de solução do solo e de solução do solo._Revista Brasileira de Engenharia Agrícola e Ambiental, volume 9, edicao 4, páginas 496-504, 2005.

DIAS F., M. BERNADINO D. F., LOPES S. J. M. Triagem de forrageiras para tolerância ao excesso de água no solo. Belém, PA: Embrapa Amazônia Oriental, 2012. 29 p.; 15 cm x 21 cm. – (Documentos / Embrapa Amazônia Oriental, ISSN 1983-0513; 381). Disponível em: < https://www.infoteca.cnptia.embrapa.br/bitstream/doc/925639/1/Doc381.pdf>. Acesso em: 25 de março de 2017.

EMBRAPA: EMPRESA BRASILEIRA DE PESQUISA AGROPECUARIA, CENTRO NACIONAL DE PESQUISA DE HORTALICA. Cultura do alho. Ministério da agricultura, do abastecimento e da reforma agrária. Brasília, DF. SPI. Edição 1. 1993. 50 pág.

FERREIRA, D. F. SISVAR – sistema de análise de variância. Versão 3.04. Lavras: UFLA, 2000.

FUMIS, T.F.; PEDRAS, J.F. Proline, diamine and polyamines accumulation in wheat cultivars submitted to water deficits. Pesquisa Agropecuária Brasileira 37: 449-453 (in Portuguese with abstract in English). Ano 2012.

GE, T. et al. Effects of Water Stress on the Protective Enzyme Activities and Lipid Peroxidation in Roots and Leaves of Summer Maize. Agricultural Sciences in China, Haidian District, Beijing, v.5, n.4, p. 291-298, 2006.

GÓMEZ-BELLOT, M.J.; ÁLVAREZ, S.; BANON, S.; ORTUNO, M.F.; SÁNCHEZBLANCO, M.J. Physiological mechanisms involved in the recovery of euonymus and laurustinus subjected to saline waters. Agricultural Water Management. 128: 131-139; 2013.

GUETTER, A. K. Associação entre a temperatura mínima no Paraná e o Niño-3. In: CBMET, 10, 1998, Brasília. Anais... Brasília, DF, 1998.

HASEGAWA P.M., BRESSAN R.A., ZHU J.K., BOHNERT H.J. Plant cellular and molecular responses to high salinity. Annu. Rev. Plant Physiol. Plant Mol. Biol., 51: 463–499. 2000.

HENDGES, M. V.; STEFFENS, C.A.; ESPINDOLA , B.P.; AMARANTE, C.V.T.; NEUWALD , D.A.; KITTEMANN, D. 1-MCP treatment increases internal browning disorders in 'Alexander Lucas' pears stored under controlled atmosphere. Acta Horticulturae, Trani, v.1071, p.511-517, 2015.

HSIE, B.S.; MENDES, K.R.; ANTUNES, W.C.; ENDRES, L.; CAMPOS, M.L.O.; SOUZA, F.C.; SANTOS, N.D.; SINGH, B.; ARRUDA, E.C.P; POMPELLI, M.F. Jatropha curcas L. (Euphorbiaceae) modulates stomatal traits in response to leaf-to-air vapor pressure deficit. Biomass ans Bioenergy. 81: 273-281; 2015

JESUS S. V., MARENCO R. A. O SPAD-502 como alternativa para a determinação dos teores de clorofila em espécies frutíferas. Editora Acta Amazônia. VOL. 38. 2008: 815 – 818.

LEONARDO F. A. P., PEREIRA W. E., SILVA M. S., COSTA J. P; Teor de clorofila e índice spad no abacaxizeiro cv. vitória em função da adubação nitrogenada. Rev. Bras. Frutic., Jaboticabal - SP, v. 35, n. 2, p. 377-383 Junho 2013.

LOZANO A. F. Q.; BAGNE L.; HORA D. C. B.; An approach thetherapeuticeffectsof*alliumsativum* (garlic) ontheimmune system. Revista Científica da FHO|UNIARARAS v. 3, n. 1/2015. Disponível em <http://www.uniararas.br/revistacientifica/_documentos/art.3-009-2015.pdf>. Acesso em: 21/10/2016.

MACEDO F. F.; CARGNELUTTI D., ROVARIS G. Efeito do déficit hídrico em parâmetros bioquímicos e fisiológicos de Baccharis trimera (Less.). Anais da VII Jornada de Iniciação Científica e Tecnológica - VII JIC ISSN 2526-205x, 2015.

MACEDO F. S., SOUZA J. R., PEREIRA M. G., Control of secondary bulb growth and productivity of vernalized garlic under water stress. Pesquisa e agropecuária brasileira, Brasília, v.41, n.4, p.629-635, abr. 2006.

MARENGO J. A; Mudanças climáticas, condições meteorológicas extremas e eventos climáticos no Brasil. Produção Executiva: Fundação Brasileira para o Desenvolvimento Sustentável - FBDS, 2011. Disponivel em: <http://www.fbds.org.br/cop15/FBDS_MudancasClimaticas.pdf > Acesso em 17/01/2017.

MENDES, R. M. DE S.; TÁVORA, F. J. A. F.; PITOMBEIRA, J. B.; NOGUEIRA, R. J. Relações fonte-dreno em feijão-de-corda submetido à deficiência hídrica. Revista Ciência Agronômica, v.38, p.95-103, 2007.

MITTLER, R. Oxidative stress, antioxidants and stress tolerance. Plant Science, Limerick, v.7, n.9, 2002.

MITTLE, R.; VANDERAUWERA, S.; GOLLERY, M.; BREUSEGEM, F.V. Reactive oxygen gene network of plants. Abiotic Stress Series. 9: 417-422; 2004.

MORALES R. F. G., RESENDE L. S., BORDINI I. C., GALVÃO A. G., REZENDE F. C.; characterization of tomato plants subjected to water deficit. Scientia Agraria, Curitiba, v.16, n.1, p.09-17, Jan/Fev. 2015.

NOBRE A. F.; Mudanças climáticas, no Brasil porque devemos nos preocupar. Revista Plenarium, v. 5, n. 5, 12 pág, ano de 2008.Disponível em: <file:///D:/Meus%20Documentos/Desktop/mudancas_climaticas_globais.pdf>. Acesso em: 12/02/2017.

NORWOOD M., TOLDI O., RICHTER A., SCOTT P. Investigation into the ability of roots of the poikilohydric plant Craterostigma plantagineum to survive dehydration stress. Journal of Experimental Botany, Vol. 54, No. 391. Society for Experimental Biology, 2003.

OSAKABE, Y.; OSAKABE, K.; SHINOZAKI, K.; TRAN, L.S.P. Response of plants to water stress. Plant Science. 2014. Htpp://doi: 10.3389/fpls.2014.00086.

PARIDA A.K. Alterations in photosynthetic pigments, protein and osmotic components in cotton genotypes subjected to short-term drought stress followed by recovery. J. Plant Biol., 45: 28–36. 2007.

PEREIRA, E.P.L. Marcadores bioquímicos da atividade antioxidante em sementes de Amburana cearenses (fr. allemão) A. C. Smith submetidas a estresse hídrico. 2010. 102f. Dissertação (Mestrado em Processos Interativos dos Órgãos e Sistemas) – Programa de Pós-graduação em Processos Interativos dos Órgãos e Sistemas, Universidade Federal da Bahia, Salvador, 2010.

PYNGROPE, S.; BHOOMIKA, K.; DUBEY, R.S. Reactive oxygen species; ascorbateglutathione pool; and enzymes of their metabolism in drought-sensitive and tolerant indica rice (Oryza sativa L.) seedlings subjected to progressing levels of water deficit. Protoplasma. 250: 585-600; 2013.

RESENDE F. V., HABER L. L., PINHEIRO J. B. A cultura do Alho. 2004. Disponível em <https://www.embrapa.br/documents/1355126/9124396/Sistema+de+Produ%C3%A7%C3%A3o+de+Alho/64258d94-6bb8-4826-a0e9-ece47aa434ff.pdf.>Acesso em: 19/01/2017.

RIGOTTO R.; Agrotóxicos, trabalho e saúde vulnerabilidade e resistência da modernização agrícola no baixo Jaguaribe/CE. Edição 02, editora Expressão Popular, Fortaleza, UFC, 2011. ISBN: 9788572824828. 612 pag.

ROSA V. R.; Alterações fisiológicas induzidas pelo déficit hídrico no estádio reprodutivo da soja com reflexo sobre a produtividade. Tese de mestrado. Universidade Federal de Viçosa. 46 páginas. 2017.

SCALON, S. P. Q., MUSSURY R. M., EUZÉBIO V. L. M., KODAMA F. M., KISSMANN C.; Estresse hídrico no metabolismo e crescimento inicial de mudas de mutambo (Guazu maulmifolia Lam). Ciência Florestal, Santa Maria, v. 21, n. 4, p. 655-662, out.-dez., 2011.

SILVA, N.E.; RIBEIRO, R.V.; SILVA, LF.; VIEIRA, S.A.; PONTE, L.F.A.; SILVEIRA, J.A.G. Coordinate changes in photosynthesis; sugar accumulation and antioxidative enzymes improve the performance of Jatropha curcas plants under drought stress. Biomass and Bioenergy. 45: 270-279; 2012.

SOBRINHO S. P., TIEPPO R. C., SILVA T. J. A. Desenvolvimento inicial de plantas de girassol em condições de estresse hídrico. ENCICLOPÉDIA BIOSFERA, Centro Científico Conhecer - Goiânia, vol.7, N.12; 2011 Pág.

SHARIFI, P. Relationship between drought stress and some antioxidant enzymes with cell membrane and chlorophyll stability in wheat lines. African Journal of Microbiology Research, v.6, n.3, p. 617-623, 2012.

SOUSA, C. C. DE; OLIVEIRA, PEDROSA E. M. R., ROLIM M. M., FILHO R. A. O., SOUSA M. A. L. M. Crescimento e respostas enzimáticas do feijoeiro caupi sob estresse hídrico e nematoide de galhas. Revista Brasileira de Engenharia Agrícola e Ambiental, v.19, n.2, p.113–118, 2015.

TAVEIRA M. R. D., SUASSUNA J. F., FILHO R. C. J., CARNEIRO R. F., ARAUJO E. D. Crescimento de plantas de gergelim sob déficit hídrico induzido e tratamento com ácido salicílico. I congresso nacional do semiárido, ano de 2010.

TAIZ, L; ZEIGER, E. Fisiologia Vegetal. Tradução: Armando Molina Divan Junior. 5. ed. Porto Alegre: Artmed, 2013.

TEIXEIRA, R.N.; TOLEDO, M.Z.; FERREIRA, G.; CAVARIANI, C; JASPER, S.P. Crambe seeds germination and vigor under water stress. Brazilian jornal of irrigation and drainage. Volume 16, n. 01, ano 2011.

UDDLING, J.; GELANG-ALFREDSSON, J.; PIIKKI, K.; PLEIJEL, H. Evaluating the relationship between leaf chlorophyll concentration and SPAD-502 chlorophyll meter readings. *Photosynth.* Res., 91: 37-46. 2007.

VALE M. M., ALVES M. A. S., LORINI M. L. Mudanças climáticas: Desafios e oportunidades para a conservação da biodiversidade Brasileira. Revista O ecologia brasiliensis. Departamento de ecologia, instituto de Biologia Roberto Alcântara Gomes, Universidade do Estado do Rio de Janeiro (UERJ). Setembro de 2009, doi:4257/oeco.2009.1303.07.

ZANETTI L. V. Efeitos da pulverização foliar com silício na tolerância de Theobroma cacao L. (Malvaceae) ao défice hídrico. Dissertação (Mestrado em Biologia Vegetal) – Universidade Federal do Espírito Santo, Centro de Ciências Humanas e Naturais, 2003.