



Effect of water stress on some morphophysiological and biochemical parameters at the juvenile and adult stages under glass in *Lavandula dentata*. L

M. Chetouani, I. Mzabri, S. Otouya, K. Charif, and A. Berrichi

Laboratory for Agricultural Production Improvement, Biotechnology and Environment, Faculty of Science. Mohammed Premier University, BP717, 60000 Oujda, Morocco.

E-mails: chetouanimohammed@gmail.com

Received 07 December 2021, Revised 26 February 2022, Accepted 28 February 2022

Abstract

Water stress is a limited factor affecting agricultural production worldwide, especially in the Mediterranean regions. It is estimated that over 800 million hectares of land worldwide are affected by abiotic stress. As part of the evaluation of the effect of water stress on the morphophysiological and biochemical behavior of the plant, we are interested in *dentata lavender* given its medicinal, aromatic and socio-economic interests in order to assess its tolerance to water stress by applying three water treatments: 100, 60 and 20% ET₀.

Keywords: water stress, morphological, physiological, biochemical parameters, water treatments 100, 60 and 20% ET₀.

*Corresponding author.

E-mail address: chetouanimohammed@gmail.com

1. Introduction

Water stress is a serious problem in many arid and semi-arid environments, where precipitation is irregular due to climate change, which will become increasingly frequent and persistent in the future [1]. The combination of summer droughts and erratic precipitation make water one of the most frightening

resources [2, 3], so arid and semi-arid areas need further study for better water use efficiency [4]. Indeed, the effects of drought on some species have been studied for many years. However, information on the relationship between plant and ecophysiological performance in response to drought is still relatively scarce [5]. Understanding the behavior and how plants respond to water stress is necessary for the implementation of vegetation management practices under a changing climate [6].

[7] Classified the Mediterranean region as particularly sensitive to global warming, and allows the development of a rich flora of medicinal and aromatic plants adapted to the climate such as lavender known for its therapeutic values and can constitute an economic alternative for the inhabitants of landlocked regions.

In this study, we will focus on the behavior of toothed lavender at the juvenile and adult stages with respect to the intensity of water stress in order to evaluate its morphophysiological and biochemical performance under water stress.

2. Materials and methods

In this study, we will focus on the behavior of toothed lavender at the juvenile and adult stages in relation to the intensity of water stress by studying morphophysiological and biochemical parameters.

2.1 Experimental site.

The tests were conducted under glass greenhouse at the experimental station of the Faculty of Science of Oujda at an altitude of 661 m, a latitude of 34 ° 39 '07' 'North and a longitude of 01 ° 53' 01 'West (GPS Back Track Bushnell),

A Min-Max thermometer was fixed to determine the minimum and maximum daily temperature inside the greenhouse. The average temperature was 24.5 ± 0.2 during the test periods.

2.2. Plant material.

The 10 cm head cuttings were taken in July 2015 for plants in the juvenile stage and in April 2016 for plants in the adult stage from lavender mother plants planted at the experimental station of the Faculty of Science in Oujda.

2.3. Test procedure.

Three water regimes T0, T1 and T2 corresponding respectively to 100, 60 and 20% of ET0 were used in this experiment.

All the plants in the trial were irrigated with 100% of the ET₀ (reference evapotranspiration) calculated with reference to the values of the city of Oujda [8].

ET₀= reference evaporation.

The tests were installed in a glass greenhouse of dimensions 3 x 10 x 2.8m at the experimental station, during the whole period of the trial from 01/12/2015 to 30/3/2016 (4 months) for juvenile plants and from 01/11/2016 to 30/04/2017 (6 months) for adult plants. Juvenile plants are transplanted individually into cups, filled with a peat/sand mixture (2V/V).

T₀: Control treatment (water pumped from the well of the Faculty of Science of Oujda) with an electrical conductivity EC₀ = 0.57 ms/cm.

a. Chemical analysis of the irrigation water used.

Each value represents an average of tree samples ± standard deviation. (Source: Oriental Center of Water Sciences and Technologies of the Faculty of Sciences of Oujda).

Table I: Chemical analysis of the irrigation water used.

pH	7.18±0,12
Electrical conductivity (ms/cm)	0.57±0.012

2.5. Morphological parameters.

2.5.1 Growth in height (in cm).

The growth in height of the aerial part is evaluated each month using a tape graduated in centimeters (cm) from the base of the collar to the top.

2.5.2. Leaf area (cm²).

The leaf area is measured directly using AUTOCAD 2010 software by carefully digitizing the leaf edges. The leaf area is determined each month by taking three leaves from each treatment.

2.5.3. Determination of root biomass Br, aerial biomass Ba and the root biomass to aerial biomass ratio BR/BA.

The ratio of dry root biomass to dry aerial biomass BR/BA is considered a good indicator of the action of water stress on plants [9]. Cumulative aboveground and root biomass expressed in grams were determined by weighing using a precision balance type AND GF300.

2.6. Physiological and biochemical parameters.

2.6.1. Relative water content (TRE %).

Carried out once a month the relative water content of the leaf was determined by the method described by Barrs.

The relative water content is calculated by the formula: $RWC = (FP - S) / (TP - S) * 100$

RWC: Relative water content (%), FF: Fresh weight (g), SW: Turgid weight (g)

PS: Dry weight (g).

2.6.2. Baseline leaf water pressure.

Leaf water potential measurements are made using the Scholander pressure chamber [10] with a compressed nitrogen source, a flow regulator and an electronic pressure gauge with an accuracy of 0.025 MPA. The progressive increase in pressure causes the first drop to exit, expressed in MPA, and corresponds to the opposite of the water potential of the leaf. Measurements were made with three replicates per treatment.

2.6.3. Measurement of PSII quantum yield (Φ_{PSII}).

The quantum yield of PSII is measured using a portable Fluorometer model FMS (FMS2 Pulse-Modulated Chlorophyll Fluorescence Monitoring System, Hansatech, England).

The leaf of each seedling is directly attached to the FMS head with a clip. The chlorophyll fluorescence of the leaves is measured at morning room temperature.

2.6.4. Determination of Chlorophyll.

Chlorophyll is extracted according to the procedure described by [11]. It consists in grinding in a mortar 100 mg of fresh material taken from the leaf blade of the middle part of the leaf in acetone diluted to 80%. After determining the total volume of the extract, the optical density of the supernatant obtained is measured at 663 and 646 nm using a standard spectrophotometer (RAYLEIGH VIS-7220G).

The total chlorophyll expressed in mg/g of fresh matter is determined by the following formula:

Total Chlorophyll = $(7.15 \times OD_{663} + 18.71 \times OD_{646}) \times V/M$; where V is the volume of the total extract in liter and M is the mass of the freshly ground material in grams.

2.6.5. Determination of proline.

The determination of this amino acid is determined by the method [12].

Two phases are separated, the upper phase is recovered and its optical density is determined at a

wavelength $\lambda = 528$ nm using a typical spectrophotometer (RAYLEIGH VIS-7220G). A standard range previously established and the contents are expressed as μg of proline / g of MF.

2.6.6. Determination of soluble sugars.

The assay was carried out with reference to the method [13] reported by [14]. The principle of the reaction is based on the condensation of the products of degradation of neutral oses by sulfuric acid. The latter is very concentrated and transforms the oses into furfural derivatives, which give a blue-green coloration with anthrone. After cooling for 30mn in the dark, read the OD at $\lambda = 530\text{nm}$ with a spectrophotometer (RAYLEIGH VIS-7220G).

The soluble sugar content of the leaves ($\mu\text{g/gMF}$) was calculated with reference to a standard glucose range from a stock solution.

2.6.7. Experimental setup for water stress.

The experiment includes 3 blocks with a total of 45 plants at the juvenile stage, 5 plants/treatment * 3 treatments * 3 replications. For the adult stage, the trial includes 45 plants, 5 plants/treatment * 3 treatments * 3 replicates. The blocks indicate the repetitions and the sub-blocks represent the treatments.

2.7. Statistical analysis

The results obtained were subjected to the one-factor analysis of variance (ANOVA). In the case of significant differences, multiple comparisons were made using the Tuckey test at a probability level of (5%, 1% and 0.1%). Each mean is assigned a letter, with means followed by the same letter not being significantly different.

3. Results and discussion

3.1. Morphological parameters.

3.1.1. Height of the plant.

➤ *Juvenile stage*

The results of the variation of the growth in height of the plants according to the different hydric treatments are represented in [Figure 1](#). With the exception of the first month of the trial, i.e. December, where there was no difference between the treatments in relation to the control, the other months showed that as the water stress became more severe, the length of the main stem of the young seedlings decreased, thus affecting the growth of the plant.

Indeed, the most important decrease in apical height was recorded during the month of March with a rate of 16% for the moderate treatment with exhaustion of the plants from February for the severe treatment compared to the control. The single criterion analysis of variance showed that the difference between the treatments recorded was significant at the threshold of $p \leq 0.05$.

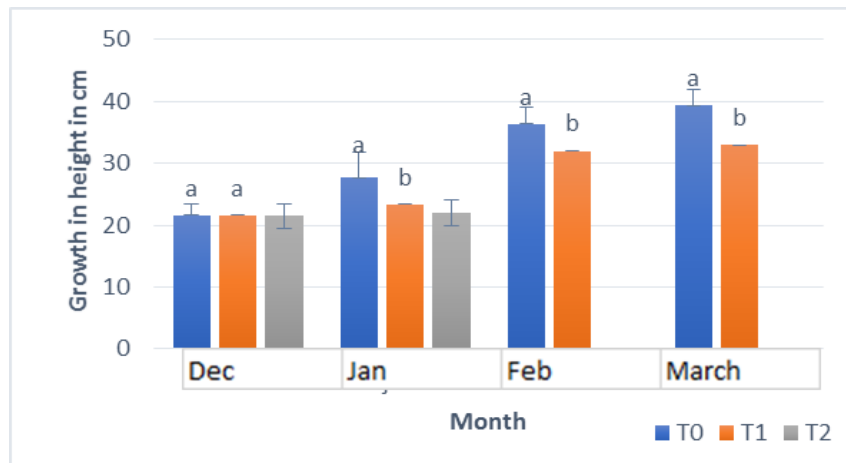


Figure 1: Effect of different levels of water stress (100, 60 and 20% ET₀ on mean stem height growth of juvenile lavender.

➤ *Adult stage.*

Histogram 2 shows the effect of water stress on the apical height growth of adult lavender plants, from the results, it can be seen that the severe treatment induced plant depletion from the month of February, while the lowest values of moderate treatment were observed during the months of February, March and April respectively with 40, 41 and 43cm. decreases of 19%, 20% and 19% compared to the control. The analysis of variance showed that the difference recorded in the month of February was significant $p \leq 0.05$.

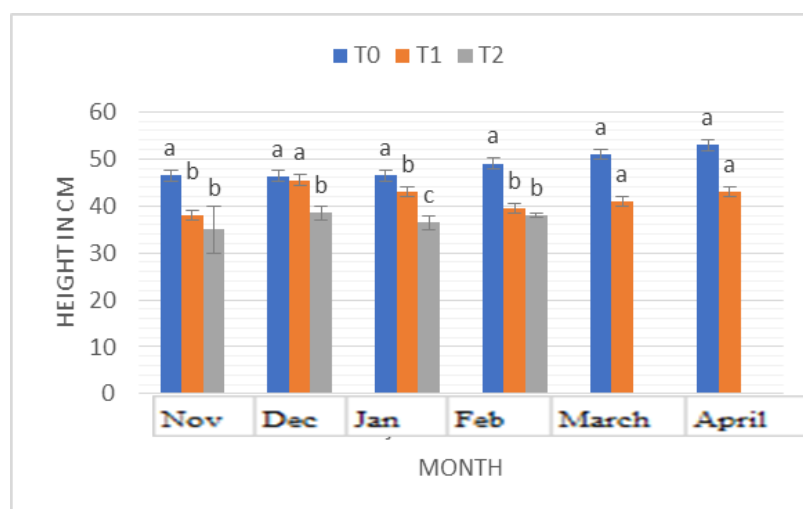


Figure 2: Effect of different levels of water stress (100, 60 and 20% ET₀ on mean stem height growth of adult lavender.

3.1.2. Effect on leaf area

➤ *Juvenile stage.*

The results of the effect of different irrigation levels on leaf area of juvenile lavender were summarized in Figure 3. Applied water stress resulted in a decrease in leaf area for all treatments studied. Indeed, the most significant reductions in applied water levels (60% and 20% of ET₀) were recorded in the months of February with a decrease of 16% for the moderate treatment and a total destruction of the plant for the severe treatment. Single-criterion analysis of variance showed that the recorded differences were significant between treatments during the last two months ($p \leq 0.05$).

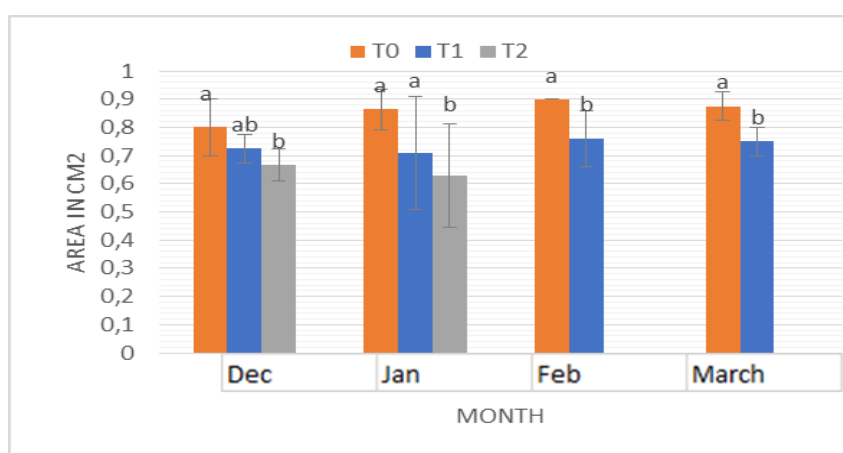


Figure 3: Effect of different levels of water stress (100; 60 and 20% ET₀) on leaf area in juvenile lavender.

➤ *Adult stage*

The results in Figure 4 show the effect of water stress on the leaf area of adult lavender. It can be seen that the plant followed the same decreasing rhythm as that of the juvenile stage where the most striking decreases were observed respectively for the moderate treatment during the month of March and April, which was confirmed by the one-criteria analysis of variance.

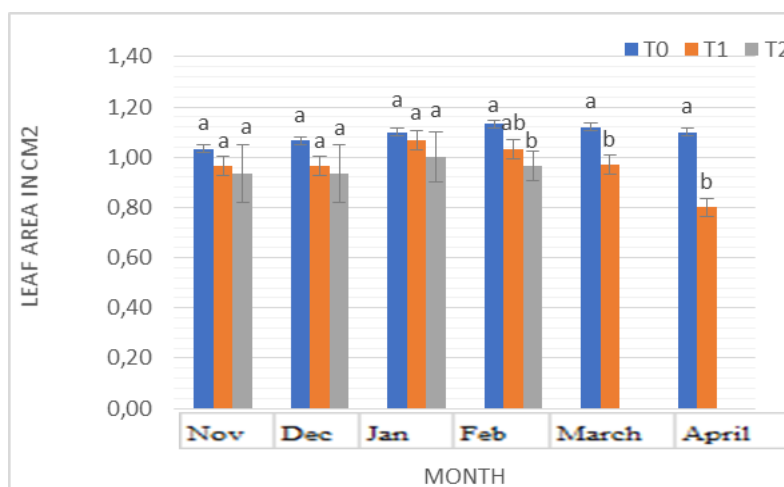


Figure 4: Effect of different levels of water stress (100; 60 and 20% ET₀) on leaf area in adult lavender

3.1.3. The ratio of root biomass to aboveground biomass Br/Ba.

The results of the change in the ratio of root biomass to aboveground biomass under different water treatments are shown in Figures 5 and 6.

According to these results, dent lavender in the juvenile stage showed an increase in the Br/Ba ratio by 9% for the moderate treatment compared to the control, while the application of severe water stress resulted in a reduction of this ratio by 5%.

Similarly, in adulthood, the Br/Ba ratio showed a reduction of 3 and 19% for the moderate and severe treatment, respectively.

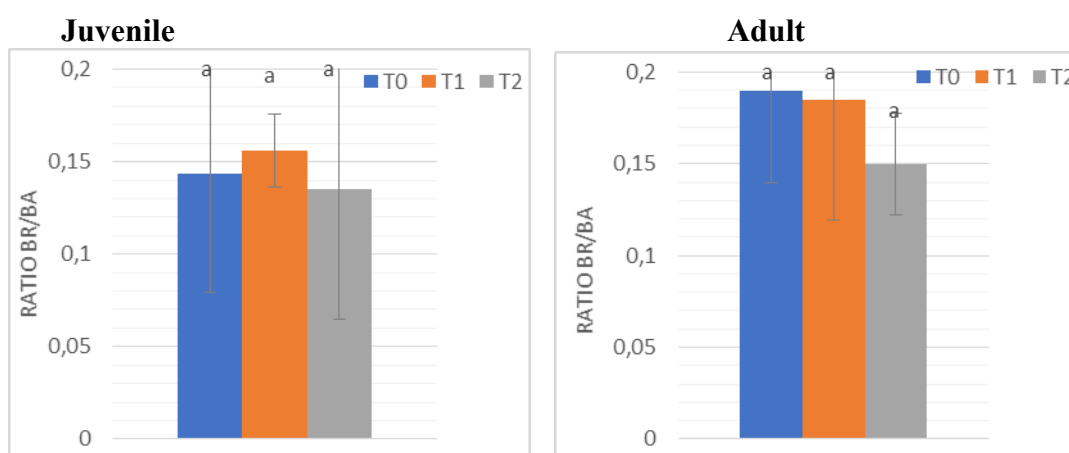


Figure 5, 6: Effect of water stress (100, 60 and 20% ET0) on the ratio of root biomass to aboveground biomass Br/Ba for lavender in the juvenile and adult stages.

3.2. Physiological and biochemical parameters.

3.2.1. The relative water content TRE

➤ *Juvenile stage.*

Analysis of the results in Figure 7 illustrates that the levels of water stress applied induce a decrease in ERR. The highest values were recorded for the control treatment (100% ET0), while the lowest values were recorded for the 60 and 20% ET0 treatments, with the most significant decrease observed during the month of March with a reduction of 24% for the moderate treatment. However, this reduction was not statistically significant.

➤ *Adult stage.*

Histogram 8 illustrates the effect of water stress on plant TER of adult lavender. It can be seen that the dentate lavender kept the same trend as the juvenile stage where the most important decreases started from February accompanied by a destruction of the plant following the deficit irrigation of 20% ET0.

The moderate treatment recorded reductions during the months of February, March and April with values

of 13, 18 and 21% respectively. The single criterion analysis of variance confirmed that the differences recorded between the treatments studied were significant for the moderate treatment ($p \leq 0.05$).

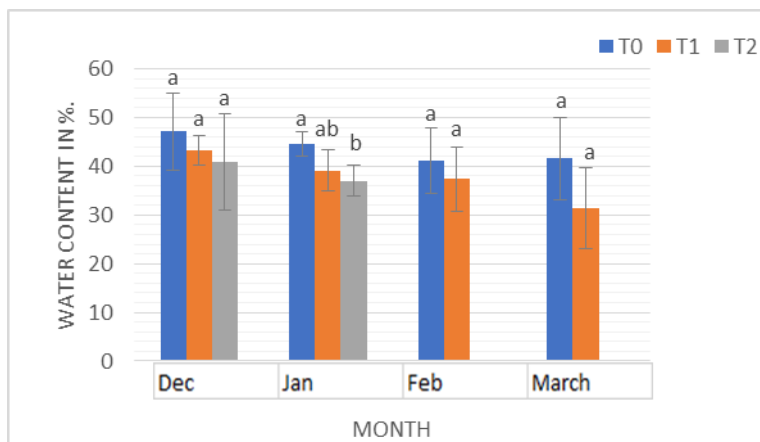


Figure 7: variation of relative water content according to the different water treatments (100, 60, 20% ET₀) in juvenile lavender.

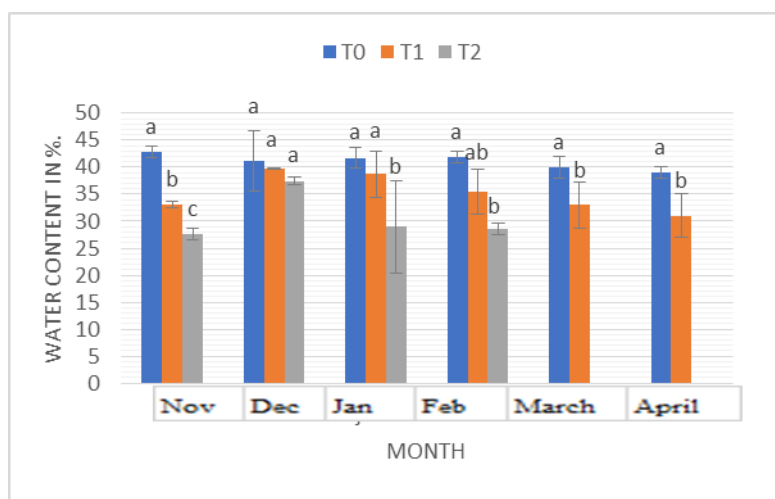


Figure 8: variation of relative water content according to the different water treatments (100, 60, 20% ET₀) in adult lavender.

3.2.2. The water potential

➤ *Juvenile stage*

The variation of water potential with different water treatments in juvenile lavender is shown in [Figure 9](#). The results showed a decrease in water potential with increasing water stress intensity relative to the control. In fact, the largest decrease in water potential relative to the control was recorded in the months of February and March for the moderate treatment (19%) and for the severe treatment (34%), respectively, relative to the controls. The single-criterion analysis of variance confirmed that the differences recorded between the treatments studied were significant $p \leq 0.05$.

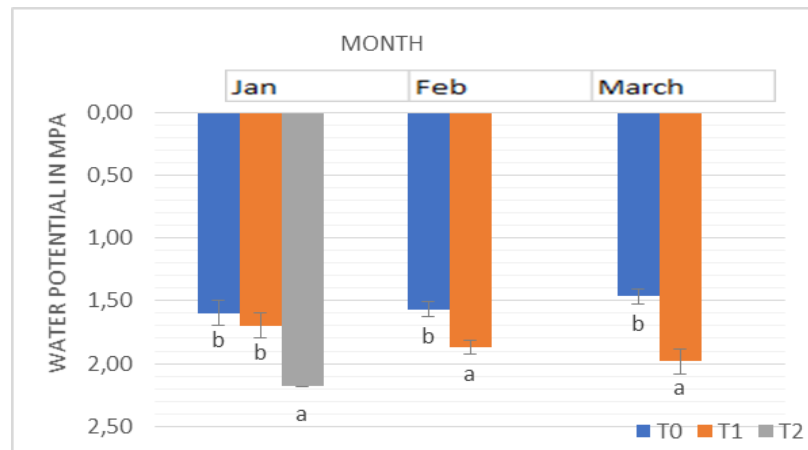


Figure 9: Variation in leaf water potential as a function of different water treatments (100, 60, 20 % ET₀) in juvenile lavender.

➤ **Adult stage**

From the results of Figure 10 which illustrates the effect of water stress on the water potential of the adult lavender plant, it can be seen that the plant did not undergo any change during the first month of the trial, thereafter, it kept the same trend as that of the Juvenile Stage where the most significant decreases were observed in the month of April of 21% for the moderate treatment with destruction of the plant for the severe treatment.

The single criterion analysis of variance confirmed that the difference recorded was significant for the treatment applied ($p \leq 0.05$).

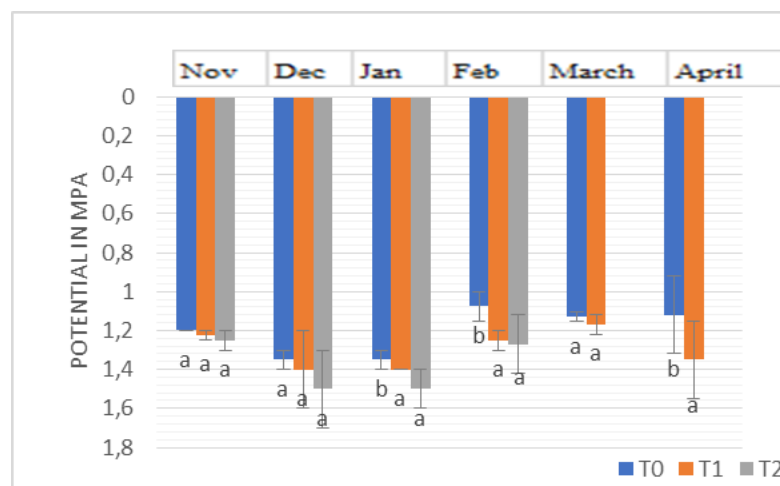


Figure 10: Variation in leaf water potential as a function of different water treatments (100, 60, 20 % ET₀) in adult lavender.

3.2.3. Chlorophyll fluorescence.

➤ **Juvenile stage.**

Figure 11 represents the effect of different levels of water stress on the quantum yield of PSII of young lavender seedlings. As the water stress becomes severe, the Φ_{PSII} of young seedlings decreases. Indeed,

the largest decrease in chlorophyll fluorescence relative to the control was recorded in January 28% for the severe treatment. The single criterion analysis of variance confirmed that the difference recorded between the studied treatments is significant for the severe treatment $p \leq 0.05$.

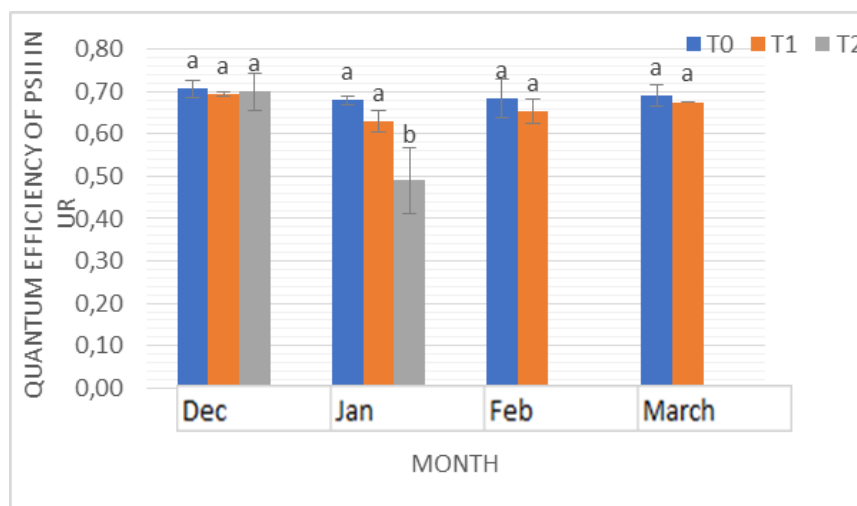


Figure 11: Effect of different levels of water stress (100%, 60% and 20% ET₀) on quantum yield of juvenile lavender PSII.

➤ **Adult Stage.**

According to the results of Figure 12 which summarizes the effect of water stress on chlorophyll fluorescence of adult lavender, it can be said that lavender kept the same behavior as that of the Juvenile Stage where the most significant decreases were observed (12%) for the moderate treatment during February and 28% for the severe treatment in January.

The one-way analysis of variance confirmed that the recorded differences were significant for the treatments applied ($p \leq 0.05$).

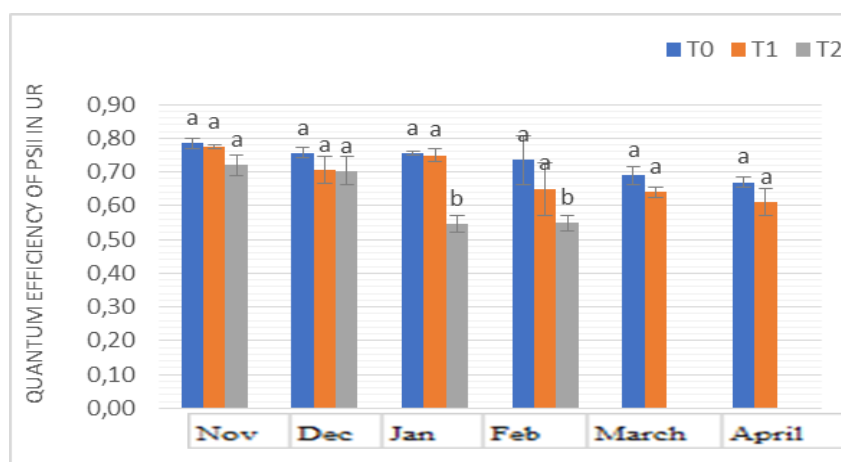


Figure 12: Effect of different levels of water stress (100%, 60% and 20% ET₀) on quantum yield of adult lavender PSII.

3.2.4. Chlorophyll content (TCT).

➤ *Juvenile stage.*

The results of the effect of the different levels of water stress on the total chlorophyll content have been represented in the figure below. The TCT decreases proportionally with the increase of the degree of water stress applied to the lavender plants. Indeed, the most important decrease in total chlorophyll content was recorded in January, i.e. 28% for the severe treatment, followed by the total disappearance of the seedlings from February onwards.

The single criterion analysis of variance confirmed that the recorded difference was significant for the severe treatment $p \leq 0.05$.

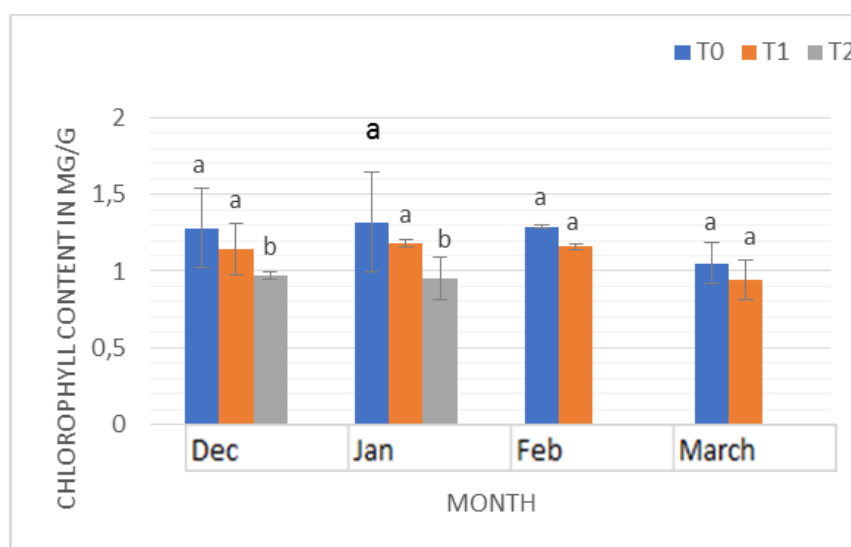


Figure13: Effect of different levels of water stress (100; 60 and 20% ET₀) on chlorophyll content of juvenile lavender.

➤ *Adult Stage.*

According to the results of Figure 14 which illustrates the effect of water stress on the chlorophyll content of adult lavender plants, it can be seen that the species kept the same trend as that of the Juvenile Stage where the most dramatic decreases were observed for the moderate treatment during February i.e. 11% and 17% for the severe treatment in January. The single criterion analysis of variance confirmed that the recorded difference was not significant for the studied treatments ($p \leq 0.05$).

3.2.5 Sugar content in lavender

➤ *Juvenile stage*

According to the results in Figure 15, an increase in sugar content was observed in parallel with the increase in the intensity of water stress. The sugar content remains low and stable in the control plant, under conditions of water stress, the accumulation of sugars is gradual and regular depending on the

severity of the treatment, an increase 38% was recorded for the moderate treatment in March and 74% for the severe treatment during the month of January. Statistical analysis showed that these variations were statistically significant for the applied treatment ($p \leq 0.05$).

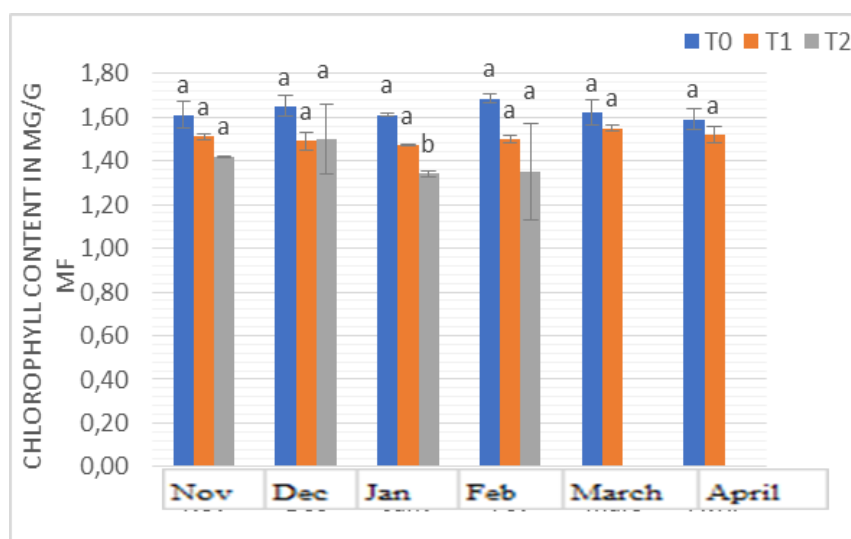


Figure 14: Effect of different levels of water stress (100; 60 and 20% ET₀) on chlorophyll content of adult lavender.

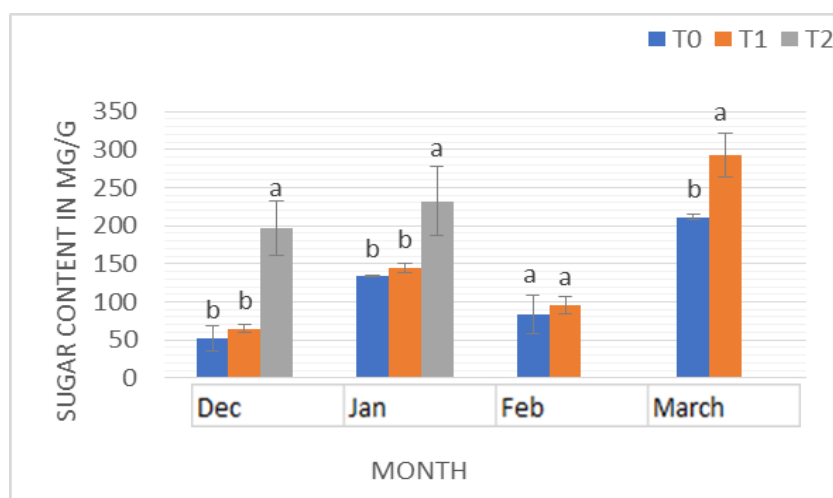


Figure 15: Effect of different levels of water stress (100; 60 and 20% ET₀) on the soluble sugar content of juvenile lavender.

➤ *Adult Stage.*

From the results in Figure 16 showing the effect of water stress on adult lavender plants, it can be seen that this species followed the same pattern as that of the Juvenile Stage where the largest increases were recorded during the month of February i.e. 98% in the moderate treatment and 306% for the severe treatment in the month of January culminating in total plant destruction in the month of March. Statistical analysis revealed a significant difference from the control ($p \leq 0.05$).

3.2.6. Leaf proline content.

➤ *Juvenile stage.*

The results below showed an increase in leaf proline content with increasing water stress intensity with stable values in the control along the experiment. Indeed, the largest increase in leaf proline was observed during March, which was 58% for the moderate treatments and 82% for the severe treatment in January. The single criterion analysis of variance confirmed that the differences recorded between the treatments studied were significant $p \leq 0.05$.

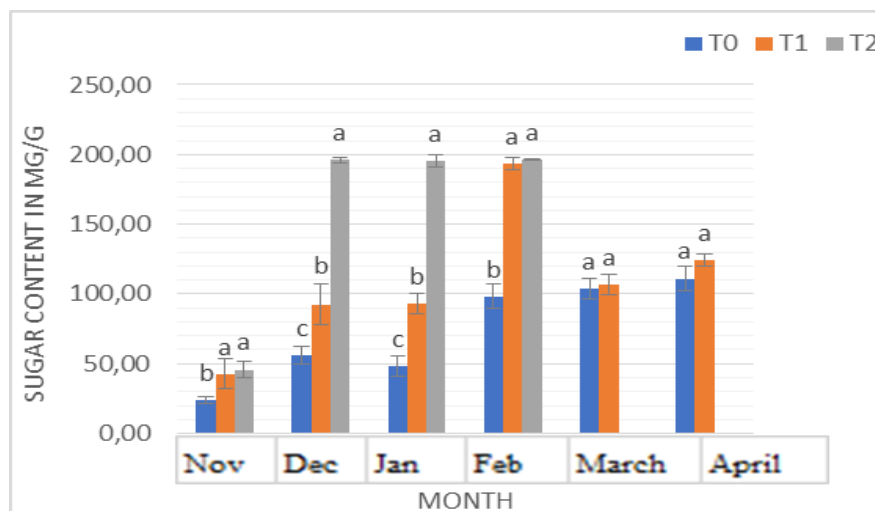


Figure 16: Effect of different levels of water stress (100; 60 and 20% ET₀) on the soluble sugar content of adult lavender

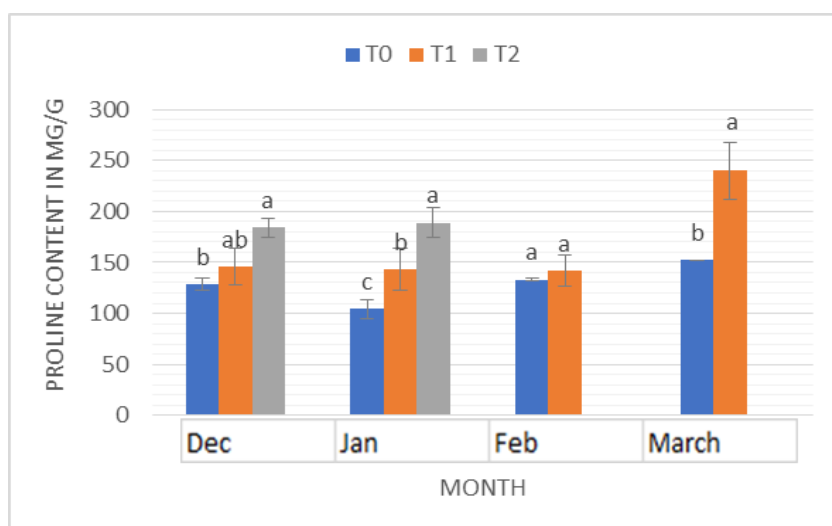


Figure 17: Effect of different levels of water stress (100; 60 and 20% ET₀) on leaf proline content of juvenile lavender.

➤ *Adult stage.*

Analysis of the results shows that adult lavender behaved similarly to the juvenile stage where the largest increases were observed for the moderate and severe treatment during the month of February,

respectively 67% and 71% for the moderate and severe treatment followed by plant death. The one-way analysis of variance showed that these variations were statistically significant between the different water regime treatments ($p \leq 0.05$).

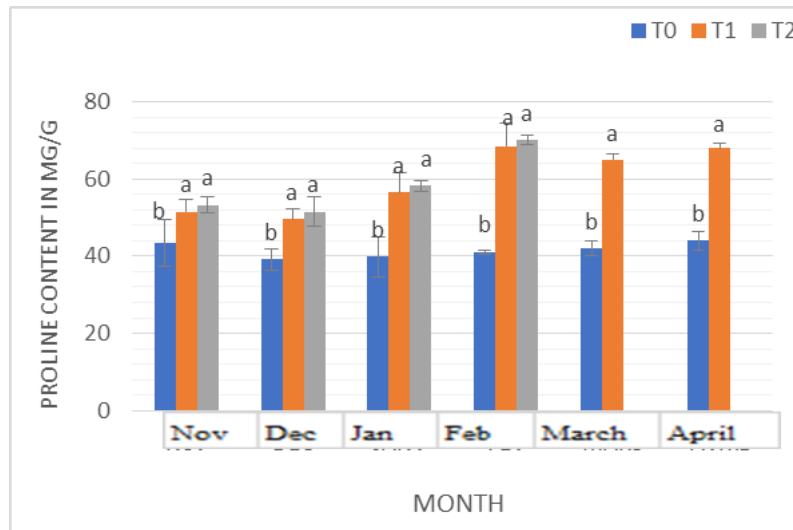


Figure 18: Effect of different levels of water stress (100; 60 and 20% ET₀) on leaf proline content of adult lavender.

4. Discussion

The effect of water stress can lead to morphological changes aimed at increasing water uptake, decreasing transpiration and reducing competition between organs for assimilates, thus affecting both the aboveground and belowground parts of the plant [15].

In this study, toothed lavender was subjected to two situations of water stress (moderate stress imposed by an irrigation of 60% ET₀ and severe stress by an irrigation of 20% ET₀), was evaluated by measuring the changes recorded in some of their morphophysiological and biochemical parameters.

All plants experienced a decrease in their morphological development capacities resulting in a reduction of their leaf surfaces, their growth in height up to the complete wilting of the plants for the severe treatments from the third month. These plants also experienced a change in the ratio between their aerial and underground biomass and this according to the intensity of the water stress and according to the age. These results seem to confirm some results obtained by previous work done in *Melissa officinalis* (L.) [16], *Matricaria recutita* (L.) [17], *Satura hortensis* (L.) [18], lavender and Greek sage [19].

We also noticed that the ratio of root biomass to aboveground biomass indicates a shift from aboveground to root biomass in the juvenile stage, suggesting that our plants favored the belowground developmental pathway in the juvenile stage. The plants thus adopted a strategy of balance between aboveground and root biomass, which is considered by several authors as a criterion of drought resistance [20, 21] to optimize their resistance to water stress and to allow a better availability of water.

The reduction in developmental parameters could, therefore, result from the preferential allocation of plants at juvenile age for root biomass production despite the development of the aboveground part, which is in agreement with work already carried out on some Lamiaceae (sage) [22].

However, the reduction of BR/BA ratios, recorded in adult plants, can be explained by the fact that the underground part of the stressed plants, having benefited from the allocation of root biomass during the juvenile period, became able to offer a more sustained production of aerial biomass than before. These results add to those reported by [23,24] who suggested that lack of water would modulate root biomass in order to maintain a maximum rate of aboveground growth, similar results have been reported in *Casuarina glauca* [25], *Pinus ponderosa* [24] and *Quercus robur* and *Fagus sylvatica* [26].

We noted that the relative water content underwent the same trend of reductions either in moderate or severe mode recording significant maximum decreases in juvenile and adult age, accompanied by a reduction in water potentials, which will undoubtedly prompt the biosynthesis of osmoticums to safeguard a vital minimum of water resources. According to [27], a decrease in leaf water potential from -0.4 to -2 MPA, is the cause of a significant increase in amino acid concentration in *alfalfa (Medicago sativa)*.

The water stress caused chlorophyll losses through stomatal closure resulting in decreased CO₂ uptake and thus decreased net photosynthetic uptake, which is consistent with the work of [28] in wheat. This decrease in chlorophyll can be explained by the excess synthesis of enzymes such as chlorophyllase, responsible for the degradation of chlorophyll that can damage the photosynthetic apparatus [29] and stimulates the increase of osmoticums (proline) which suggests the presence of a competition between the two compounds on their common precursor [28].

The biochemical evaluation through the determination of sugars and proline allows us to note that the application of moderate or severe water stress caused maximum increases in the content of soluble sugars and proline. This increase is considered to be a distress signal emitted by plants to allow protection of membranes and enzyme systems especially at the juvenile age under severe stress, and which could also play a role in the regulation of cytoplasmic pH and in the constitution of a nitrogen reserve for the cell [28] Several studies have shown that proline content increases during water stress, and that its accumulation is associated with improved drought tolerance [30].

Conclusion

Stress tolerance from morphophysiological and biochemical point of view in lavender was discussed in this study and showed that this species is relatively tolerant to water stress at moderate doses in the adult stage.

Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

- [1] G. H. William. *Physiologie végétale*. Editeur De Boeck, 408 p (2003).
- [2] R. Joffre, S. Rambal, C. Demesin, Functional attributes in Mediterranean-type ecosystems, In: *Handbook of functional plant ecology*, Marcel Dekker, Inc. Francisco I. Pugnaire and Fernando Valladares, New York, pp 347–380 (1999).
- [3] A. Iglesias, L. Garrote, F. Flores, M. Moneo, Challenges to manage the Risk of Water Scarcity and Climate Change in the Mediterranean. *Water Resour Manag* 21:775–788 (2006).
- [4] B. Du, H. Rennenberg. Physiological responses of lavender (*Lavandula angustifolia* Mill.) to water deficit and recovery, *South African Journal of Botany* 119 212–218 (2018).
- [5] Z. Xu, G. Zhou, H. Shimizu. Are plant growth and photosynthesis limited by pre-drought following rewatering in grass? *Journal of Experimental Botany* 60: 3737–3749 (2009).
- [6] Z. Xu, G. Zhou, H. Shimizu, Plant responses to drought and rewatering. *Plant Signaling & Behavior* 5: 649–654 (2010).
- [7] W. Thuiller, S. Lavorel, MB. Araújo, Climate change threats to plant diversity in Europe. *Proc Natl Acad Sci U S A* 102: 8245–8250 (2005).
- [8] Mara (Ministère de l’Agriculture et de la réforme Agraire). Le pouvoir d’évapotranspiration du climat Marocain, Rabat, Maroc (1978).
- [9] M. O. LY, Effet de la salinité sur la croissance et la production de biomasse de deux provenances de *Jatropha curcas* L. cultivés en serre, *Int. J Biol. Chem. Sci.* 8(1): 46-56, (2014).
- [10] P.F. Scholander, H.J. Hammel, A. Brad Street and Hemmingsen E.A. Sap, pressure in vascular Plants. *Science*, 148, 339-346 (1965).
- [11] H. Tran, H. Vu, A. Mahunu, D. Chien. Chlorophyll formation in flowers and fruits of *Phalaenopsis* (Orchidaceae) species and hybrids following pollination. *American J. Bot.*, 82: 1089–94 (1995).
- [12] W. Troll, G. Lindsley, A photometric method for the determination of proline. *J. Biol. Chem.* 215: 655-660 (1955).
- [13] Ew. Yemn. Aj. Willis, The estimation of carbohydrates in plants extracts by anthrone. *Biochem J.*, 57: 508-514 (1954).
- [14] M. Sidari, Carmelo Mallamaci, Adele Muscolo, Drought, salinity and heat differently affect seed

- germination of *Pinus pinea*. Journal of Forest Research. 13 : 326-330. [10.1007/s10310-008-0086-4](https://doi.org/10.1007/s10310-008-0086-4) (2008).
- [15] M. Bajji, Étude des mécanismes de résistance au stress hydrique chez le blé dur : caractérisation de cultivars différant par leurs niveaux de résistance à la sécheresse et de variantes somaclonales sélectionnés In vitro. *Thèse de doctorat*. Univ Louvain (1999).
- [16] A. Ozturk, A. Unlukara, A. Ipek, B. Gurbuz, Effects of salt stress and water deficit on plant growth and essential oil content of lemon balm (*Melissa officinalis* L.). *Pak. J. Bot.* 34: 787–792 (2004).
- [17] K. Baghalian, S. Abdoshah, F. Khalighi-Sigaroodi., F. Paknejad, Physiological and phytochemical response to drought stress of German chamomile (*Matricaria recutita* L.). *Plant Physiol. Biochem.* 49 (2): 201–207 (2011).
- [18] Z.F. Baher, M. Mirza, M. Ghorbanli, M. Bagher Rezaii, The influence of water stress on plant height, herbal and essential oil yield and composition in *Satureja hortensis* L. *Flavour Frag. J.* 17: 275–277 (2002).
- [19] A. Chrysargyris, C. Panayiotou, Nitrogen and phosphorus levels affected plant growth, essential oil composition and antioxidant status of lavender plant (*Lavandula angustifolia* Mill.). *Industrial Crops and Products.* 83. [10.1016/j.indcrop.2015.12.067](https://doi.org/10.1016/j.indcrop.2015.12.067) (2016).
- [20] J. Bakht, M. Shafi, Y. Jamal, H. She. Response of maize (*Zea mays* L.) to seed priming with NaCl and salinity stress. *Span J. Agri. Res.*, 9: 252-261 (2011).
- [21] K. Yoshida, Plant biotechnology genetic engineering to enhance plant salt tolerance. *J. Biosci. Bioeng.* 94: 585–590 (2002).
- [22] I. Bettaieb, N. Zakham, W. A. Wannas, M. E. Kchouk, B. Marzouk, Water deficit effects on *Salvia officinalis* fatty acids and essential oils composition. *Scientia Horticulturae* 120:271–275 (2009).
- [23] A. Monroy-Ata, Ch. Floret, R. Pontanier, S. Rambal, Rapport entre la biomasse racinaire et aeriennne de plantes pérennes de la zone aride pendant la période d’installation. In : di Castri F, Floret Ch, Rambal S, Roy J, eds. *Time Scales and Water Stress*. Paris: UIBS pub, 247-53 (1988).
- [24] JD. Mc millin., MR. Wagner effects of water stress on biopartitioning of ponderosa pine seedlings during primary root growth and shoot periods. *For Sci*; 41:594-610 (1995).
- [25] A. Allouchi, B. Zoubeir, M. Hedi El Aouni, Influence d’un stress hydrique sévère sur la croissance de jeunes plants de *Casuarina glauca* sied. Sécheresse n°3, vol 14, septembre. Nutritional Status in Maize Plants. *Env. & Exp. Botany* 62(1) : 1-9 (2003).
- [26] AFM .Van Hees. Growth and morphology of pedunculate oak (*Quercus robur* L) and beech (*Fagus sylvatica* L) seedling in relation to shading and drought. *Ann Sci*; 54:9-18 (1997).
- [27] C. Girousse, R. Bournoville., J.L. Bonnemain., Water deficit induced changes in concentration in

- proline and some other amino acids in phloem sap of *Alfalfa*. *Plant Physiol*, 111:109-113 (1996).
- [28] E.H. Tahri, A. Belabed, K. Sadki, Effet d'un stress osmotique sur l'accumulation de proline, de chlorophylle et des ARNm codant pour la glutamine synthétase chez trois variétés de blé dur (*Triticum durum*). *Bull. Inst. Sci., Rabat*, n°21 (1997-1998), pp. 81-87 (1998).
- [29] A. Levent Tuna, C. Kaya, M. Dikilitas. D. Higgs. The Combined Effects of Gibberellic Acid and Salinity on some Antioxidant Enzyme Activities, Plant Growth Parameters and Nutritional Status in Maize Plants. *Env. & Exp. Botany*, 62(1): 1-9 (2008).
- [30] M. Seki. T. Umezawa, K. Urano., K. Shinozaki. Regulatory metabolic networks in drought stress responses. *Curr. Opin. Plant Biol.* 10 : 296–302 (2007).
-

(2022) ; www.mocedes.org/ajcer