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Water status of cork oak seedlings (*Quercus suber* L.) in Tunisia

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Abstract

The Mediterranean forest constitutes a fragile ecosystem subjected to various aggressions closely linked to the conditions of the physical and human environment. A comparative study of the water and physiological responses of young cork oak plants which was carried out on the nursery of twelve sites of cork oak from the North West and North East of Tunisia. In nurseries in Tunis, seedlings were subjected to water stress. The analyzes focus on adapting to physiological water stress in *Quercus suber* L. show that osmotic adjustment increases considerably in Méjen Essef populations; Dj khroufa and Hammam Bourguiba, which explains why these populations have an important capacity for osmo-regulation allowing the tissues to develop a higher turgor and a strategy of resistance to water stress. Similarly, for populations of Keff El Rand; Oued Zeen; Bellif and Ain Zana; but this is limited in time. A greater decrease in the population of Hammam Jdidi; Dar Fatma, Djebel Zouza; El Feidja and Beni Mtir , indicating that they therefore exhibit stress sensitivity water. The differences revealed between the twelve provenances show that the importance of monitoring the physiology of young cork oak seedlings under semi-controlled conditions in order to control better their characteristics with respect to water stress.

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Introduction

The area of Tunisian subarea increased from 127,000 hectares in 1950 (Boudy, 1952) to 69,933 hectares in 1995 (General Directorate of Forests, 2005). The regression of these forests, which can be estimated at 1.22% of the area per year, is due to the mortality of the stands by aging (100 to 150 years) and their difficulty of regeneration. The cork oak's regeneration encounters big difficulties to reconstitute naturally by sowing and rejection of stumps. These problems are mainly at intermediate growth stages (thicket, saplings and perchis) (Hasnaoui, 1998): The course of Tunisian subarea shows the existence of two strata: a tree stratum, comprising adult individuals and a younger stratum, including seedlings of the year and older plants, but not more than forty centimeters in height. Between the two, one encounters only rare subjects, belonging to the intermediate stages (Hasnaoui, 1992; Ksontini, 1996). The absence of these intermediate stages is mainly due to predation, anthropogenic factors and particularly difficult environmental conditions that characterize the mediterranean environment: significant and recurrent drought in summer, high luminous radiation affecting open-seeded seedlings and high temperatures that accompany it. The tolerance' limitations of cork oak seedlings against constraints aren't still understood despite the studies devoted to this species in the mediterranean basin (Hasnaoui 1992, Ksontini 1996, Ghouil, 2004). This understanding is nevertheless essential for the implementation of new forest management plans, especially for the crucial phase of regeneration. The aims of this work is studying the effect of water stress on the physiology of cork oak seedlings and the physiological characterization of population's seed in Tunisia and to compare their behavior towards water stress.

Plant materials

The study was performed on seedlings of *Quercus suber* L. in Tunisia aged 2 years old and from 12 study sites: Hammam Bourguiba [HB], Dar Fatma [DF], Oued Zeen [OZ], Ain Zana [AZ], Mejen Essef [ME], Béni Mtir [BM], Jebel zouza [DZ] (Ain Draham), El Feidja [EF] (Gar Dimaou), Bellif [B] (Nefza), Jebel Khroufa [DK] (Tabarka), Keff El Rand [KR] (El Haouaria) and Hammam Jdidi [HJ] (Hammamet). The experiment was conducted in semi-controlled nursery of INRGREF in Ariana's conditions (semi-arid bioclimatic higher). Two water regimes were applied: control plants (NS) were watered daily and will stressed plants (S) underwent two cycles of 14 days drying by blackout separated by an intermediate rehydration watering. The choice of sites was performed according to geographical distribution, the bio-climate and relief. The substrate of breeding plants is characterized by moisture to the field capacity is about 26% and its texture is in Table 1.

Methodology

P–V curves were determined using the Scholander pressure chamber technique (Scholander *et al.*, 1965). The P–V curves of each leaf were obtained by expressing the relationship between relative water content (RWC) values and the reciprocals of the measured water potentials ($-1/\Psi w$). Osmotic potential at full turgor ($\Psi\pi$ 100) was estimated via linear regression of data in the straight-line region of the P–V curve (Mguis *et al.*, 2012). Osmotic potential at the turgor loss point ($\Psi\pi$ 0) was derived from the RWC and $-1/\Psi w$ coordinates respectively of the first point in the straight-line region of the P–V curves (Patakas and Noitsakis, 1999). The osmotic adjustment (OA) was defined as the difference in $\Psi\pi$ 100 between stressed and control plants:

$$OA = (\Psi 100\ \pi)\ stressed - (\Psi 100\ \pi)\ control$$

The apoplastic water content (AWC) or intercellular water is estimated from the extension of the linear part to the axis (OX). The relative water content at the turgor loss point (RWC0) was obtained from the extension of the intersection of curve and linear portions. The volumetric modulus elasticity (ε) was calculated as the slope of the relationship between turgor pressure and RWC:

$$\varepsilon max = (\Psi 100\ \pi - \Psi 0\ \pi)\ (1 - AWC/(\ 1 - RWC0)$$

Concentrations of organic solutes as well as inorganic ions were calculated for the symplastic water volume at full turgor, according to the different fractions in control and stressed leaves estimated by pressure–volume technique (Patakas *et al.*, 2002). These concentrations were used to estimate the contribution of each solute to osmotic adjustment, assuming that 40 μmol·g−1 of symplastic water corresponds to 0.1 MPa (Hessini *et al.*, 2008). The contribution of each solute (s) to the total osmotic adjustment (OAt) was calculated using the formula:

OA(s) in % = (((s) stressed−(s) control) x 0.1 x 100)/40)/Oat.

The estimated osmotic contribution of each measured solute Ψs to the leaf osmotic potential at full turgor Ψπ 100 was obtained using the van't Hoff equation according to Meloni *et al.* (2001).

Implementation of the technique of the pressure volume curve: Section in leaf water to avoid possible embolism, rehydration samples overnight in the dark in a laboratory environment. After taring, we proceed to the bag sheet (to prevent water loss during the pressure-mounted) and determining its weight. Is the measurement Ψh then up to 2.5 Bar pressure in the chamber and the sap that comes from the section is wiped, when the sap out more gently releases the pressure and leaves the sheet.

Then weigh the sheet and measures were continued by increasing the pressure of 2.5 bars at each measurement up to 36 Bars. The samples are placed in an oven at 80 ° C for 24 hours to obtain their dry weight. The Measurements of parameters of the pressure volume curve were performed on 6 samples/population/treatment at the end of the first and second cycle of drought.

Analysis of the pressure volume curve: From the representation 1/ψh = f (RWC %) we draw a pressure volume curve which shows the characteristics of a relationship of two parts: a curvilinear portion corresponds to potential positive turgor and at low water and a linear portion with zero potential of turgidity and water at elevated values.

1/ψh = 0 gives no water is displaceable ie bound water (The water fraction appoplastique) membrane, etc... The walls extrapolation RWC (%) = 100 gives us the value of the reverse osmotic potential at full turgor (Ψ100π).

The osmotic potential at zero turgor (ψπ0): It is estimated by projection on the y-axis of the point of intersection of the line with the Bend Kansas. This parameter is used to find the lower limit of the water potential at which the turgor potential may exist.

The relative water content at zero turgor (RWC0): The value is determined by projection on the x-axis at the intersection of the straight line with the curve.

We can calculate the modulus of elasticity ε defined by the following relationship (Nabil and Coudret, 1995): (ε max) = (ΨΠ100 - ΨΠ0) × (1 - EL) / (1 - RWC 0).

The Adjustment osmotic Δψs100: Osmotic adjustment is determined indirectly from the pressure volume curve and is calculated from the difference between the osmotic potential at full turgor ψ100π stressed and the controls.

The osmotic adjustment = ψπ100 stressed - ψπ100 control.

Osmotic Adjustment for: It determines the degree of adjustment: AOR = (ΔΨ $_{\pi}$ 100 S / Ψ $_{\pi}$ 100 T) × 100.

Statistical analysis

The statistical analyzes were carried out by the SPSS 20 software. For the first cycle of water stress, the 5% Duncan test discriminates 5 groups for the zero-turgid osmotic potential, bone amplitude, and relative osmotic adjustment; 3 groups for osmotic potential at full turgor; Osmotic adjustment and bound water and 2 groups for relative water continuity and volume elasticity.

For the second cycle of water stress, the 5% Duncan test discriminates a single group for bound water; Three homogeneous groups for the osmotic potential at full turgor, the osmotic potential at zero turgidity and for the relative continuum in water; Five groups for relative osmotic adjustment; Six groups for osmotic amplitude; Seven groups for osmotic adjustment and nine groups for volume elasticity;

Results

Full turgor osmotic potential (ψ100π)

The highest reduction is recorded in the populations of Béni Mtir (-1.76 MPa) and Djebel Zouza (-1.67 MPa), to a lesser extent in populations of Oued Zeen; Keff El Rand; Hammam Jdidi; Dar Fatma; Aîn Zana; Hammam Bourguiba; El Feidja and Bellif (-1.28 to -1.57 MPa) and lower in the populations of Djebel khroufa (-1.15 MPa) and Méjen Essef (-1.18 MPa) at the end of the first cycle.

Table 1. Characteristics of soil.

Materiel	Clay (%)	Silt (%)	Fine sand (%)	Coarce sand (%)	Coarce lime stone (%)	MO (g)	PH	P2 O5	K2 O
Soil composition	12	12	30	43	3	3.2	7.5	4	0.17

At the end of the second cycle, the highest reduction was recorded in the populations of Méjen Essef (-1.69 MPa) and to a lesser extent in the populations of Keff El Rand, Hammam Jdidi, Ain Zana and Djebel khroufa (-1.39 At -1.57 MPa), lower in the populations of Oued Zeen, Dar Fatma, Djebel Zouza, Hammam Bourguiba, El Feidja, Beni Mtir and Bellif (-1.25 to -1.38 MPa) (Fig. 1).

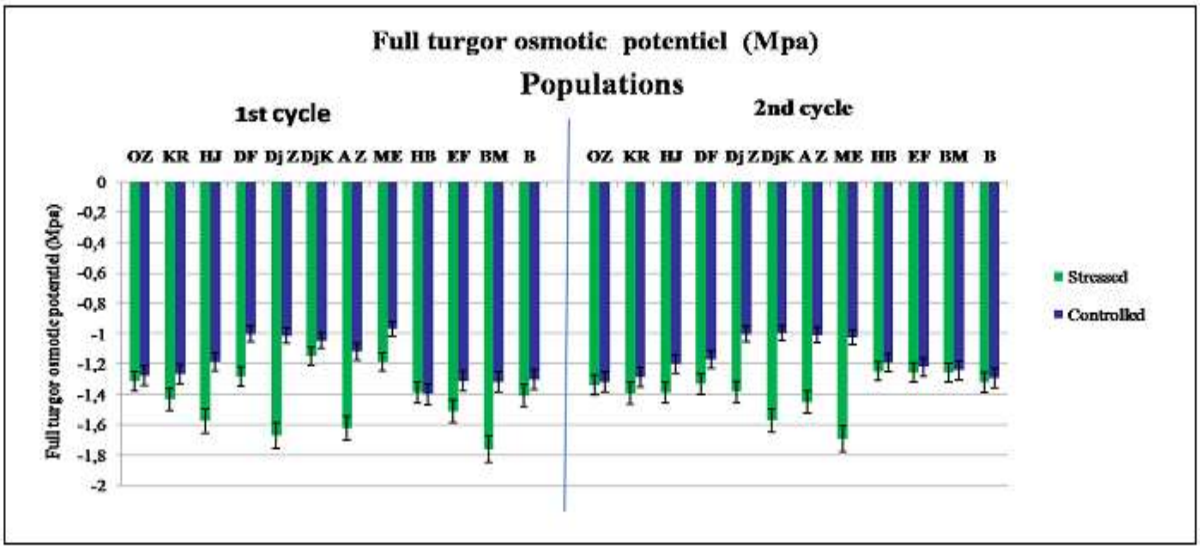

Fig. 1. Variation of osmotic potential at full turgor in the control (T) and stressed (S) of different populations of cork oak (*Quercus suber*. L) in Tunisia: during the two cycle water stress.

Osmotic potential at zero turgor (ψ0π)

The most negative values at the end of the first cycle of water stress are recorded in the populations of Djebel Zouza (-3.15 MPa) and Béni Mtir (-2.90 MPa), to a lesser extent in the Keff El Rand, Hammam Jdidi, Dar Fatma, Djebel Khroufa, Ain Zana and Mejen Essef (-2.28 to -2.72 MPa) and lower in populations of Oued Zeen, Keff El Rand, Hammam Bourguiba and El Feidja (-2.17 to -2.30 MPa).

At the end of the second cycle, the greatest reduction is in the populations of Méjen Essef (-3.13MPa), to a lesser degree in the populations of Dar Fatma, Djebel Zouza, Djebel Khroufa and Aîn Zana (-2.58 to -2.73 MPa) and lower in the populations of Oued Zeen, Keff El Rand, Hammam Jdidi, Hammam Bourguiba, El Feidja, Béni Mtir and Bellif (-2.03 to -2.13 MPa) (Fig. 2).

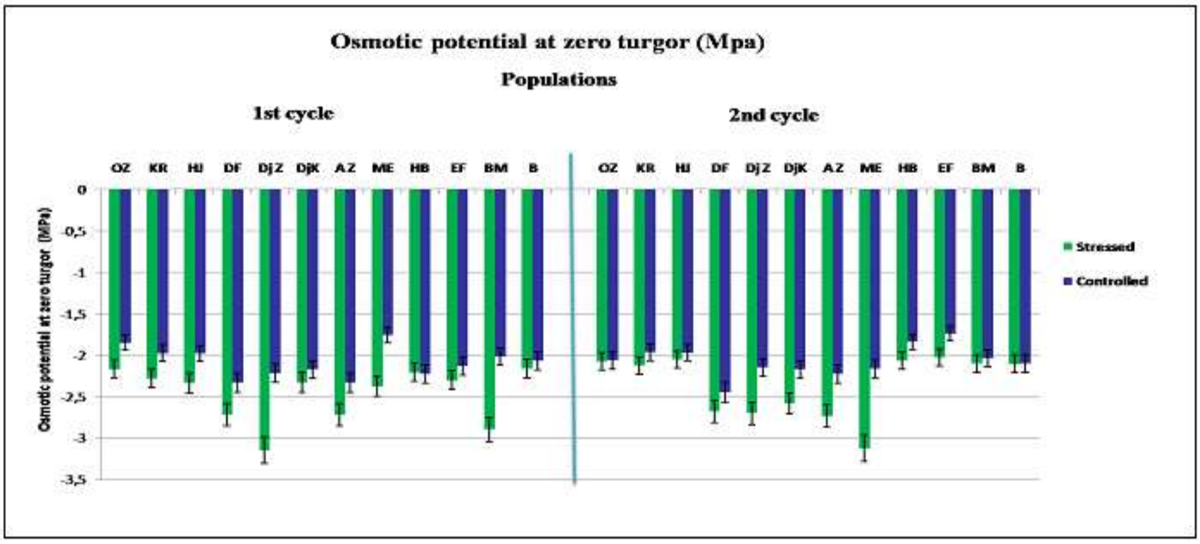

Fig. 2. Variation of osmotic potential at zero turgor in the control (T) and stressed (S) of different populations of cork oak (*Quercus suber*. L) in Tunisia: during the two cycle water stress.

Osmotic amplitude

At the end of the first cycle of stress; the highest reduction is recorded among the population of Djebel Zouza, Dar Fatma, Mejen Essef, Djebel Khroufa and Béni Mtir (1.48, 1.43, 1.20, 1.18 and 1.14 MPa), to a lesser extent in the populations of Aîn Zana (1.10 MPa), and lower in the populations of Keff El Rand, Oued Zeen (0.85 MPa), Hammam Bourguiba (0.82 MPa), El Feidja (0.79 MPa), Bellif and Hammam Jdidi (0.76 MPa). At the end of the second cycle, the highest reduction was recorded in the populations of Méjen Essef (1.43 MPa), Dar Fatma (1.35), Djebel Zouza (1.32) and Ain Zana (1.28 MPa) Of Djebel Khroufa (1.01 MPa); Béni Mtir (0.85 MPa) and Hammam Bourguiba (0.82 MPa) and lower in the populations of Bellif, El Feidja, Keff El Rand, Oued Zeen and Hammam Jdidi (0.66 to 0.78 MPa) (Fig. 3).

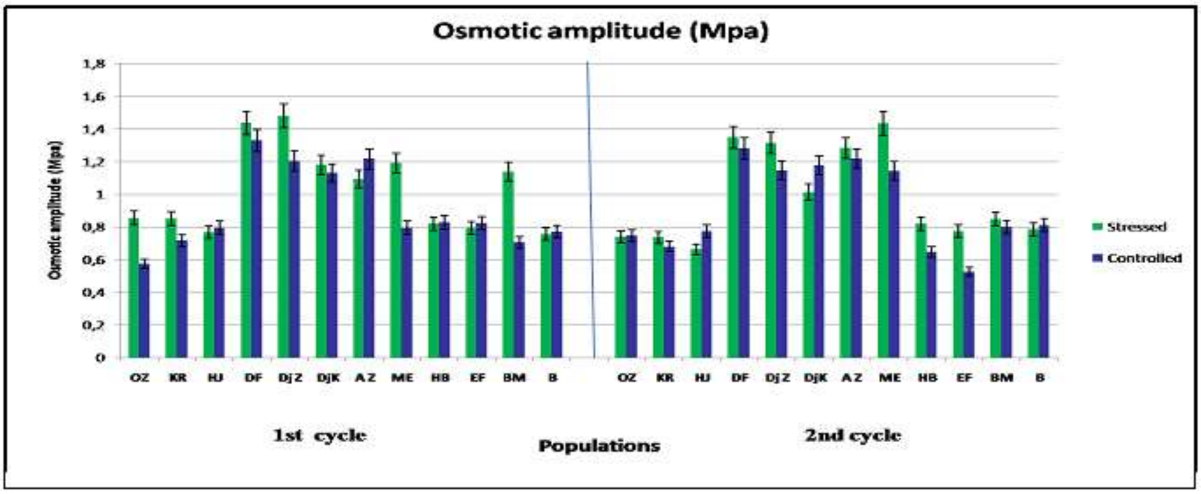

Fig. 3. Variation of osmotic amplitude in the control (T) and stressed (S) of different populations of cork oak (*Quercus suber*. L) in Tunisia: during the two cycle water stress.

Osmotic adjustment

At the end of the first cycle of stress; The highest reduction is recorded in the populations of Djebel Zouza, Ain Zana, Beni Mtir, Hammam Jdidi (0.39 to 0.66 MPa), to a lesser extent in the populations of Dar Fatma, Mejen Essef and Keff El Rand (0.17 to 0.28 MPa) and lower in the populations of Djebel Khroufa, Bellif, El Feidja, Oued Zeen and Hammam Bourguiba

(0.01 to 0.10 MPa). At the end of the second cycle, the highest reduction was recorded in the populations of Méjen Essef, Djebel Khroufa, Aîn Zana and Djebel Zouza (0.38 to 0.67 MPa), to a lesser extent in the populations of Dar Fatma, Hammam Jdidi and Keff El Fe (0.10 to 0.16 MPa) and lower in populations of Hammam Bourguiba, El Feidja, Bellif, Beni Mtir and Oued Zeen (0.02 to 0.06 MPa). (Fig. 4).

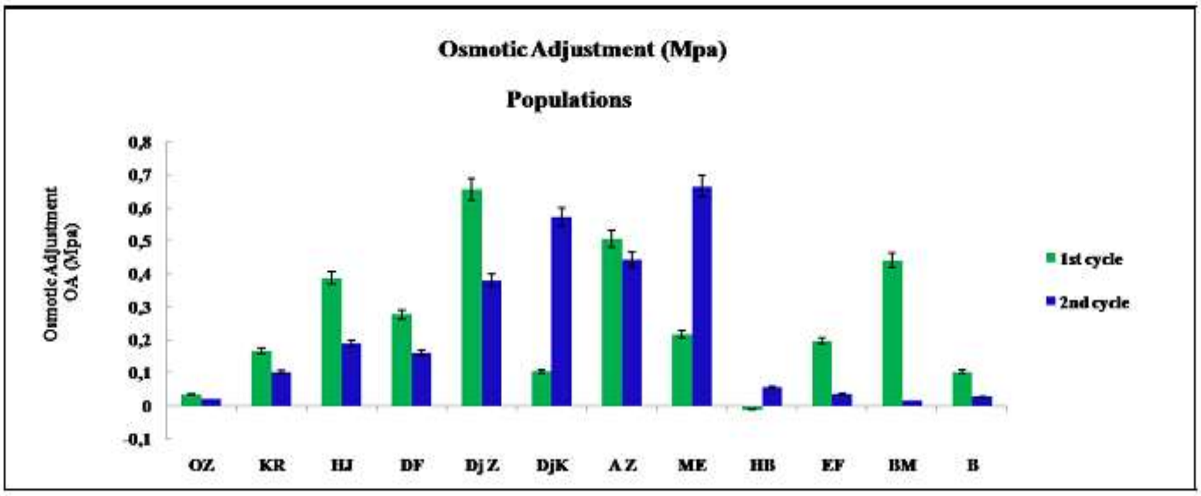

Fig. 4. Variation of osmotic adjustment in the control (T) and stressed (S) of different populations of cork oak (*Quercus suber*. L) in Tunisia: during the two cycle water stress.

On relative osmotic adjustment

At the end of the first cycle of stress; the highest reduction is recorded in the population of Djebel Zouza (64.79%), to a lesser degree in the populations of Aîn Zana, Beni Mtir, Hammam Jdidi, Dar Fatma and Méjen Essef (22.49 to 45.32%) and lower in populations of El Feidja, Keff El Rand, Djebel Khroufa, Bellif, Oued Zeen and Hammam Bourguiba (0.74 to 15.05%).

At the end of the second cycle, the highest reduction was recorded in the populations of Méjen Essef and Djebel Khroufa (57.37 to 64.99%), to a lesser extent in the populations of Aîn Zana and Djebel Zouza (37.99 to 43.95%) and lower in populations of Hammam Jdidi, Dar Fatma, Keff El Rand, Hammam Bourguiba, El Feidja, Bellif, Oued Zeen and Beni Mtir (1.33 to 15.83%). (Fig. 5).

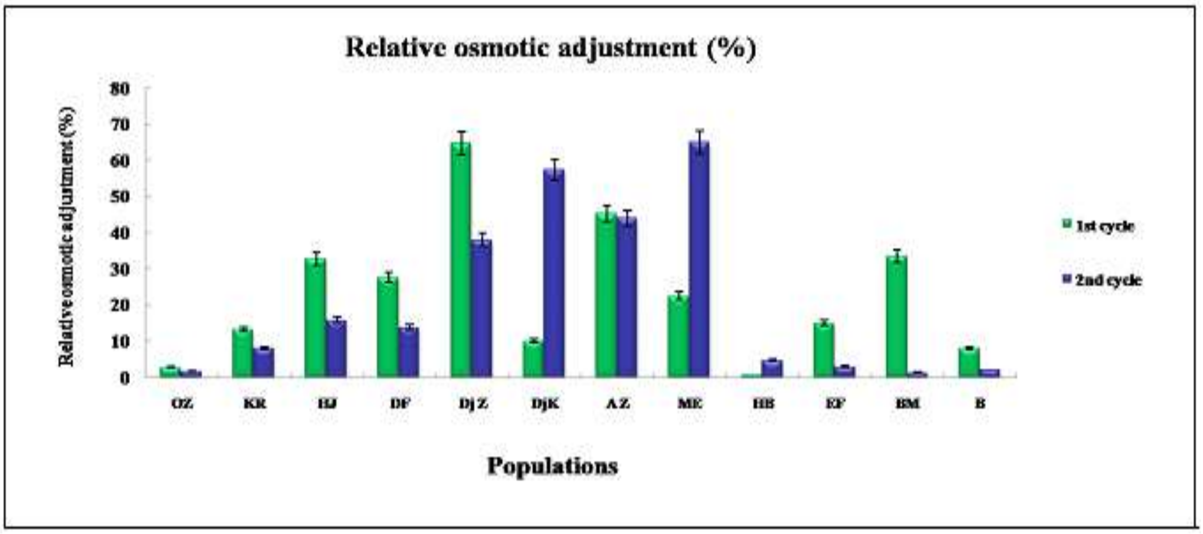

Fig. 5. Variation of the osmotic adjustment relative in the control (T) and stressed (S) of different populations of cork oak (*Quercus suber*. L) in Tunisia: during the two cycle water stress.

Relative water content at zero turgor (RWC0)

At the end of the first cycle of stress; The highest values are recorded in populations of Dar Fatma, Mejen Essef, Ain Zana, Bellif, Hammam Jdidi, Jebel Khroufa, Keff El Rand, Hammam Bourguiba, Jebel zouza, Oued Zeen and El Feidja (90.53 to 94.92%), to a lesser degree among populations of Beni Mtir (82.98%). At the end of the second cycle, the highest values are recorded in populations of Jebel zouza, Bellif, Beni Mtir, Hammam Jdidi, Hammam Bourguiba, Keff El Rand, Oued Zeen (92.09 to 95.00 MPa), to a lesser extent in populations of El Feidja (89.07%) and Djebel Khroufa (79.27%); and lower in the populations of Dar Fatma, Ain Zana, Mejen Essef (57.90 to 63.54%) (Fig.6).

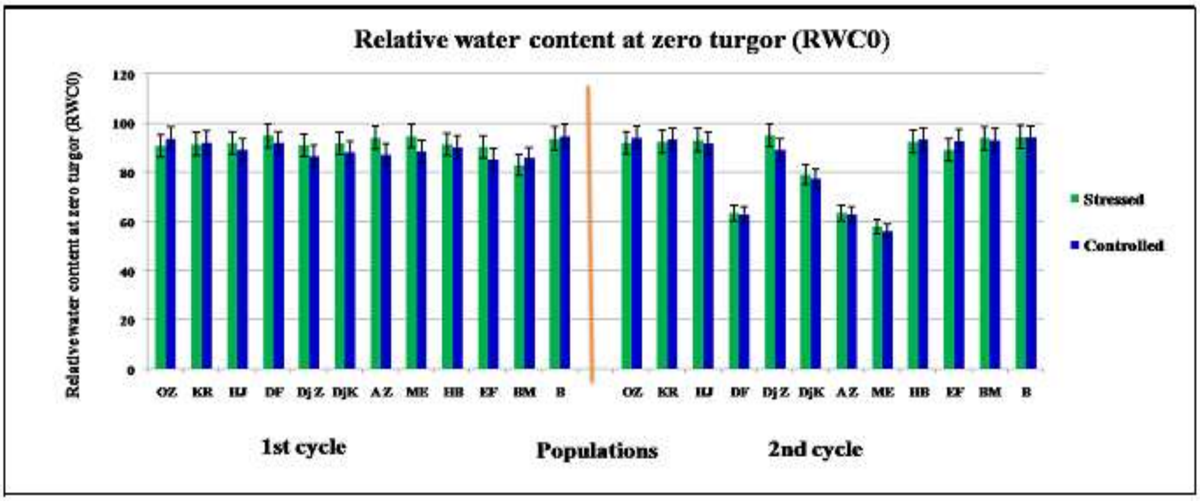

Fig. 6. Variation of relative water contained at zero turgor in the control (T) and stressed (S) of different populations of cork oak (*Quercus suber*. L) in Tunisia: during the two cycle water stress.

Water fraction apoplastic: bound water (BW)

At the end of the first cycle of stress; The highest values were recorded in the populations of Bellif, Mejen Essef and Dar Fatma (80.82 to 82.57%), to a lesser extent in the populations of Hammam Bourguiba, Keff El Rand, Ain Zana, Hammam Jdidi, El Feidja, Oued Zeen, Djebel Khroufa and Djebel Zouza (72.22 to 77.15%) and lower in the populations of Beni Mtir (55.60 MPa) (Fig. 7).

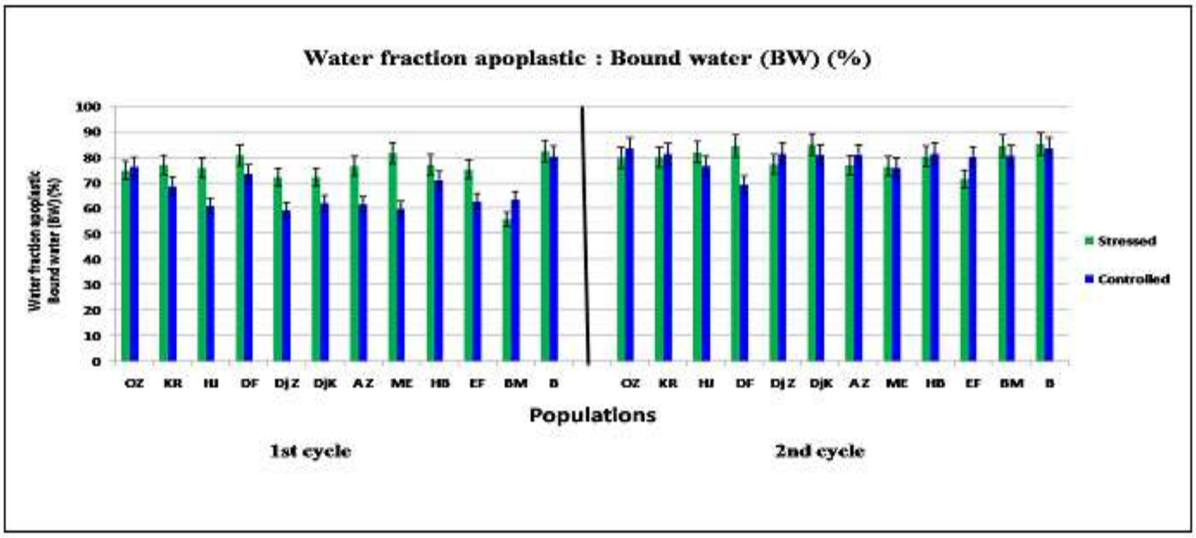

Fig. 7. Variation of the fraction of apoplastic water bound water in the control (T) and stressed (S) of different populations of cork oak (*Quercus suber*. L) in Tunisia: during the two cycle water stress.

At the end of the second cycle, the highest values are recorded in populations of Bellif; Djebel Khroufa; Dar Fatma; Beni Mtir; Hammam Jdidi; Hammam Bourguiba; Keff El Rand (80.00 to 85.22%), to a lesser degree among the populations of Oued Zeen; Djebel Zouza; Aîn Zana and Méjen Essef (76.43 to 79.83%); and lower in the population of El Feidja, (71.51%) (Fig.7).

Bulk modulus of elasticity (εmax)

At the end of the first cycle of stress; The highest values are recorded in the populations of Djebel Zouza, Mejen Essef Djebel Khroufa Dar Fatma, Ain Zana, (0.89 to 1.16 MPa), to a lesser degree in populations of Beni Mtir (0.76 MPa) and lower in populations of Hammam Bourguiba, El Feidja, Bellif, Keff El Rand, Oued Zeen and Hammam Jdidi, (0.64 to 0.69 MPa). At the end of the second cycle, the highest values were recorded in the populations of Mejen Essef, Djebel Zouza, Dar Fatma and Ain Zana (1.06-1.18 MPa), to a lesser degree in the populations of Djebel Khroufa, Beni Mtir, Hammam Bourguiba, Bellif, Oued Zeen, El Feidja, Keff El Rand (0.62 to 1.18 MPa) and lower in the Hammam Jdidi populations (0.58 MPa). (Fig.8).

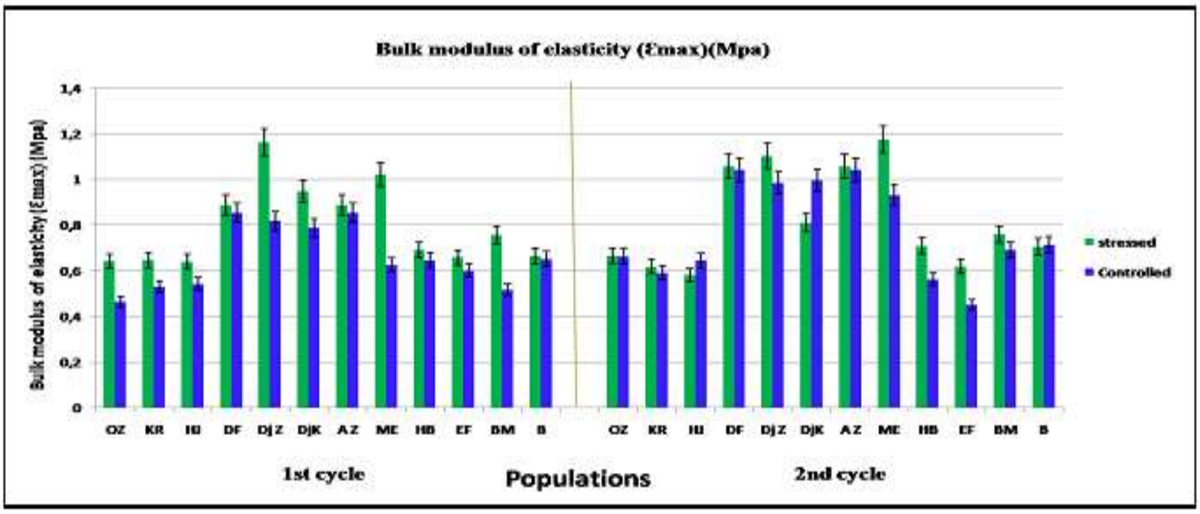

Fig. 8. Variation of bulk modulus of elasticity in the control (T) and stressed (S) of different populations of cork oak (*Quercus suber*. L) in Tunisia: during the two cycle water stress.

Discussion

Stressed plants need a positive turgor, compatible with physiological activities (Bejaoui *et al*, 2008). This process is the main physiological form of adaptation to water deficit. The osmotic potential is generally retained at two points: the osmotic potential at full turgor (Ψπ100), the osmotic potential at zero turgidity (Ψπ0) Where a more negative osmotic potential indicates an increased capacity of plants to absorb water from the soil (Yaakoub, 1997), the fraction of apoplastic water or bound water (EL) and the relative content of water with zero turgor (RWC). The osmotic properties of cells reflect the intrinsic state of plant tissues in response to environmental factors, and indicate the ability of trees to respond to water stress.

The osmotic potential at full turgor showed a significant reduction in the stressed plants compared to the controls during the two cycles of stress but there are not significant differences between the populations. These estimated values for the controls and the constraints are higher than those found for *Quercus coccifera* which are -1.22 MPa and -1.34 MPa respectively, as well as for *Quercus suber* which are of -1.35 MPa and -1.45 MPa (Ksontini, 1996). While they are lower than those found for *Ceratonia siliqua* for controls (-2.1 MPa) and for stressed (-2.3 MPa) individuals, (Rejeb, 1992).

The values of Osmotic potential with zero turgor (Ψπ°) are kept lower towards the end of the second cycle than towards the end of the first cycle in the stressed populations of Oued Zeen, Keff El Rand, Hammam Bourguiba and El Feidja, contrary to the Méjen Essef, Djebel Zouza and Beni Mtir populations, This demonstrates an ability to withstand dehydration since pre-conditioned plants maintain a positive turgor potential for relatively lower osmotic potentials than controls (Henchi, 1987). This is probably due to increased solute concentrations in the tissues (Ksontini, 1996). However, they are higher than those found for *Eucalyptus occidentalis* which are -2.5 MPa for the controls and -2.65 MPa for the stressed (Haddad, 2002), as well as those found by ksontini (1996) for *Quercus suber* which are -2.38 MPa for the controls and -2.63 MPa for the stressed.

At the end of the second cycle, the values of Osmotic amplitude is higher in the populations of Mejen Essef , Dar Fatma, Djebel Zouza and Ain Zana, to a lesser extent in the populations of Djebel Khroufa; Beni Mtir and Hammam Bourguiba and lower in the populations of Bellif, El Feidja, Keff El Rand, Oued Zeen and Hammam Jdidi. This does not seem to be the case for *Eucalyptus gomphocephala*, which has an osmotic amplitude of (0.31MPa) for the controls and (0.17MPa) for the stressed (Haddad, 2002). Another comparison showed that the osmotic amplitudes of *Quercus suber* are similar to those found for the kermes oak, which are of the order of (1.11MPa) for the controls and (1.16MPa) for the stressed (Ksontini, 1996).

Osmotic adjustment is considered as an important criterion, determining the capacity of osmo-regulation that it allows the maintenance of a turgor which is compatible with the physiological activities in limiting water conditions. Our results show that osmotic adjustment increases considerably at the end of the second cycle in populations of Méjen Essef; Dj khroufa and Hammam Bourguiba, which explains why these populations have an important capacity for osmo-regulation allowing the tissues to develop a higher turgor and a strategy of resistance to water stress. Similarly, for populations of Keff El Rand; Oued Zeen; Bellif; Ain Zana; But this is limited in time. A greater decrease in the population of Hammam Jdidi; Dar Fatma; Djebel Zouza; El Feidja and Beni Mtir at the end of the second cycle, indicating that these populations therefore exhibit stress sensitivity water.

The osmotic adjustment allows the maintenance of a turgor which is compatible with the physiological activities under limiting water conditions (Turner *et al*., 1980). These values are higher than that recorded for the Kermes oak which has a relative osmotic adjustment of 9.83 % (Ksontini, 1996). Similar results were found by Hireche (2006) for two *dessica* and *moapa* varieties.

The relative osmotic adjustment is higher in the populations of Djebel Zouza, to a lesser extent in the populations of Aîn Zana, Beni Mtir, Hammam Jdidi, Dar Fatma and Méjen Essef and lower in the populations of El Feidja, Keff El Rand, Djebel Khroufa, Bellif, Oued Zeen and Hammam Bourguiba.

At the end of the second cycle, it is higher in the populations of Méjen Essef and Djebel Khroufa , to a lesser degree in the populations of Aîn Zana and Djebel Zouza and lower in the Hammam Bourguiba, El Feidja, Bellif, Oued Zeen and Beni Mtir . The $\Delta\Psi$ of *Quercus suber* are lower than those found for the kermes oak, which are 1.11MPa for the controls and 1.16MPa for the stressed (Ksontini, 1996). Whereas they are higher than those found for *Plantago albicans* which are 0.23MPa for the controls and 0.37MPa for the stressed (Henchi, 1987). This parameter provides even more information on the adaptive capacity of plants to water stress.

RWC0 It seems that the populations of Djebel Zouza, Bellif, Hammam Jdidi, Hammam Bourguiba, Keff El Rand and Oued Zeen, support the water stress since the relative content of water with zero turgor is high and between 89 and 95% at the end of the two cycles of water stress. According to Rejeb (1992) the cancellation of turgescence at high water content presupposes a good water supply at the foliar level and seems to indicate a preferential reaction of avoidance of the drought or this can only happen with a good rooting, Low osmotic potentials, and significant elasticity of the walls and vessels of large diameter.

These values are similar to those found in *Pinus pinaster* (81.5-88.2%), Rejeb, 1992 on carob, Haddad, 2002 on *Eucalyptus camaldulensis* and *Eucalyptus. microtherca*, but are higher than those found by Fernandez *et al* 1999, Those obtained by Ksontini 1996 in *Quercus suber* (62%) and *Quercus faginea* (65%), *Quercus coccifera* (60%) and by Chouchane 2003 Weatherley and Slatyer (1957) indicate that in tolerant plants, a large changes in water potential lead to small variations at RWC level and conversely for sensitive species.

Bound water plays an important role during water stress because it protects the tissues against the loss of water of the symplasm. It is probably responsible for maintaining turgor by its buffering effect under limiting water conditions. In our study, values ranged from 59.32% to 80.46% for controls and from 55.60% to 82.57% for stresses at the end of the first cycle for the twelve populations. At the end of the second cycle of water stress, the values are between 69.32% and 83.55% for the controls and between 71.51% and 85.22% for the stressed ones. Our values are higher than those found in cork oak by Chouchane (2003) and *Quercus coccifera* by Ksontini (1996). Values of bound water in leaf and stem tissue can range from 50 to 75% but physiological significance of these values remains unknown according to Ritchie and Dunham (1979) in Ksontini (1996). Ritchie and Shula (1981) reported that low values of $\Psi\pi o$ and bound water values indicate resistance to drought in some forest species such as *Pinus taeda*.

The modulus of elasticity characterizes the degree of rigidity of the cell walls, it plays an important role because it protects the tissues and maintains the turgor by its buffering effect (Roy, 1980). The fact of having a more pronounced modulus of elasticity in the constrained individuals already inspires us that there has been a modification of the intrinsic state of the plant. This modification results, by thickening of the walls or by reduction of the size of the cells (Chouchane, 2003). The elasticity's modulus is greater in the stressed plants than in the controls for the first and second cycles except for the provenances of Hammam Jdidi, Djebel Khroufa and Bellif.

The increase in elasticity's modulus is a form of adaptation to drought. Indeed, the provenances of Hammam Bourguiba; Dj Khroufa, and Méjen Essef, showed resistance to water stress, while the provenances of Hammam Jdidi, Dar Fatma, Djebel Zouza, El Feidja and Beni Mtir showed sensitivity to water stress but the provenances of Keff El Rand, Oued Zeen, Bellif And Aîn Zana have shown resistance to water stress but limited in time. This parameter reflects the effect of water regimes on the elasticity of the cell walls in the studied plants. Its increase reflects a lower elasticity of the walls generally concomitant with an increase in the content of apoplasmic water (Ennajeh, 2004).

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Indeed, this factor confers on the plant the possibility of undergoing significant variations of the water content without losing the turgor. Maier *et al.* (1992) reported that in drought conditions, the maintenance of a positive turgor which is compatible with the physiological activities in the adapted species requires the development of a regulation by accumulation of the solutes.

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References

Abid H, Selmi K. 1998. Tunisian suberia: Importance and orientation for sustainable management. In: Proceedings Mediterranean seminar on the regeneration of cork oak forests. Annals of INRGREF (National Institute of Research in Engineering, Rural, Water and Forestry), special issue 63-72.

Bejaoui Z, Albouchi A, Lamhamdi MS, El Aouni MH. 2008. Effect of soil drying on growth, biomass allocation and water relationships in *casuarina glauca*. Botany **86** 1242-1251.

Boudy P. 1952. A Guide for Foresters in North Africa. The Rustic house. Ed. Paris.

Chouchane S. 2003. Comparative study of the resistance to water stress of two provenances of cork oak (altitude and plain). FST (Faculty of Science, Tunis). P 58.

Department of Agriculture and Forest of the Eastern Pyrenees. 1992. Proceedings of the symposium "Mediterranean subarea".

Ennageh A. 2004. Influence of sampling conditions on water parameters determined by the volume pressure curve technique, Mastère, FST (Faculty of Science, Tunis). P 106.

Fernandez G, Effern A, Grunwald T, Pezer N, Lehnertz K, Dumpelmann M, Van Roost D, Elger CE. 1999. Real-time tracking of memory formation in the human *rhinal cortex* and *hippocampus*. Science.

Ghouil H. 2004. Response of the cork oak to the constraints of the environment (Temperature, light and lack of water) Application to the problems of regeneration of the suberia, Doctoral thesis.

Haddad I. 2002. Water status in the drought adaptation of 5 species of Eucalyptus most used in reforestation in Tunisia. University of Tunis El Manar. 62 p.

Hasnaoui B. 1992. Northern oak groves of Tunisia. Ecology and Regeneration. Doctoral Thesis, Univ. From Provence to Aix-en-Provence.

Hasnaoui B. 1998. Natural regeneration of cork oak: difficulties and proposals for solutions, Ann. INRGREF (National Institute of Research in Engineering, Rural, Water and Forestry), Special issue.

Henchi B. 1987. Effects of water stress on the ecology and ecophysiology of *Plantago albicans* L. Thesis Doc. State. Univ. Tunis. P 314.

Hessini K, Ghandour M, Albouchi A, Soltani A, Koyro HW, Abdelly C. 2008. Biomass production, photosynthesis, and leaf water relations of Spartina alterniflora under moderate water stress. Journal of Plant Research **121,** 311–318.

Hireche Y. 2006. Response of alfalfa (*Medicago Sativa* L) to water stress and seeding depth. Al HadJ Lakdar University Hubac, C., Vieira, Da Silva, J. Metabolic indicators of mesological stresses. Vegetable Physiology, **18,** 45-53.

Ksontini M. 1996. Eco-physiological studies of the responses to the water stress of the cork oak (Quercus suber) in Northern Tunisia: Comparison of the oak Kermès (*Quercus coccifera*) and the oak Zeen (*Quercus canariensis*), Thesis doctor of the University, 157.

Maier CE, Newton RJ, Puryear JD, Sen S. 1992. Physiological responses of loblolly pine (*Pinus taeda* L.) Seedling to drought stress, osmotic adjustment and tissue elasticity. Journal of plant physiology **140**, 754-760 p.

Meloni DA, Oliva MA, Ruiz HA, Martinez CA. 2001. Contribution of proline and inorganic solutes to osmotic adjustment in cotton under salt stress. Journal of Plant Nutrition **24,** 599–612.

Mguis K, Albouchi A, Khadhri A, Abassi M, Yakoubi-Tej M, Mahjoub A, Ouerghi Z, Ben Brahim N. 2012. Adjustments in leaf water relations of wild wheat relative Aegilops geniculata Roth. and wheat (Triticum durum Desf.) plants grown in a salinity gradient. Australian Journal of Crop Science **6,** 768–776.

Mougou A. 1984. Evaluation of drought resistance by morphological, eco - physiological and biochemical parameters in several Tomato species, Ph.D Thesis. University of Gent, Belgium.

Nabil M, Coudret A. 1995. Effects of sodium chloride on growth tissue elasticity and solute adjustment in two: *Acacia nilotica* sub species. Physiology plant **93,** 217-224.
http://dx.doi.org/10.1111/j 1399-3054.1995tb 0222 o.x.

Patakas A, Noitsakis B. 1999. Mechanisms involved in diurnal changes of osmotic potential in grapevines under drought conditions. Journal of Plant Physiology **154**, 767–774.

Patakas A, Nikolaou N, Zioziou K, Radoglou K, Noitsakis B. 2002. The role of organic solute and ion accumulation in osmotic adjustment in drought-stressed grapevines. Plant Science **163,** 361–367.

Rejeb MN. 1992. Study of the drought resistance mechanisms of carob (*ceratonia siliqua* L.). Doctoral Thesis in Natural sciences Faculty of Sciences of Tunis. P 199.

Ritchie GA, Dunham DL. 1979. Pressure volume curves. In: Theory, methods interpretation. Western Forestry Research center, Centralia, Washington.

ROY G. 1980. Rue Des Chambault, Montreal, Stanké, 303 p.

Scholander PF, Hammel HT, Bradstreet ED, Hemmingsen EA. 1965. Sap pressure in vascular plants. Science **148,** 339–346.

Turner NC, Jones MM. 1980. Turgor maintenance by osmotic adjustment. A review and evaluation. In: Adaptation of plants to water and high temperature (Turner N.C. and Kramer P.J. Eds) **87** and 454 New York John Wiley and Sons.

Weatherley PE, Slatyer RO. 1957. Relationship between relative Physiol. 120: 391–399. Turgidity and diffusion pressure deficit in leaves. Nature (London). **179**. 1080-1087 p.

Yaakoub B. 1997. Hydric relations and formation of caulinary adventitious roots in black spruce seedlings (*Picea mariana* (Mili) Plant biology.

YESSAD SA. 2000. Cork oak and oak in the countries of the Western Mediterranean. Edition ASBL Forest Wallonne. P 190.