GROWTH STATUS OF SOME SELECTED *EUCALYPTUS* SPECIES IN THE ENVIRONMENTAL CONDITIONS OF RIYADH, SAUDI ARABIA

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ABSTRACT:

Six introduced species of *Eucalyptus* were studied to point out their growth status and adaptability potentials in the environmental conditions of Riyadh area. *Eucalyptus camaldulensis* and *E. microtheca* were characterized with high degree of drought resisting characters like significantly high saturated water deficit, short narrow vessel segments with thicker wall, high vessel pore frequency per mm^2 of sapwood, low vulnerability of water conducting system and thicker bark. *E camaldulensis* was detected having a strong wood as it possessed lesse vessel lumen area/ mm^2 and thicker fibers. *E dandasii, E melanophloia* and *E sideroxylon* had a combination of drought resistant and drought susceptible traits. High vulnerability of water conducting system in *E dandasii* and *E melanophloia* was associated with the high relative water content of leaf. Positive and significant correlations were obtained between/among anatomical traits of wood and morph-functional features of leaves of *Eucalyptus* species: Water content of leaf / leaf specific mass (LSM), vessel wall thickness and saturated water deficit (SWD); SWD / LSM and vessel wall thickness; relative water content (RWC) / leaf area and vulnerability factor (Vf); vessel pore frequency / bark thickness. Negative and significant correlations were observed in these combinations of parameters: water content of leaf / vessel pore diameter and Vf ; vessel pore diameter / LSM, vessel wall thickness and SWD; Vf / LSM, SWD, vessel wall thickness and bark thickness ; RWC / vessel pore frequency and bark thickness.

Key Words: Sapwood - Water deficit - Leaf specific mass - Water stress - Bark - Relative water content - Vulnerability factor - Drought – Correlation.

INTRODUCTION

Water is the most limiting environmental factor for growth of most trees and forest sites. Effect of water deficits on plant productivity and water use efficiency has been extensively reviewed (Farquhar et al. 1989; Osoria and Pereira 1994). At the whole plant level, limited soil water supply may have a strong effect on dry matter accumulation (Li, 1998). Demand by the forest industry for improved productivity and the introduction of plantation trees into marginal areas have created a need for a detailed understanding of the water relations of commercially grown *Eucalyptus* clones (Mulin and Park 1992). Battaglia *et al.* (2002) while working on *Eucalyptus globulus* proposed a model which may be used to develop silvicultural prescription and management regimes to reduce the risk of drought death in plantations.

Water stress is a major factor limiting terrestrial plant productivity. Growth related processes such as respiration, dark reaction of photosynthesis and formation of chlorophyll, stomatal conductance and biomass partitioning are affected by water deficits (Tyree and Jarvis 1982). The hydraulic properties of a tree influence the supply of water to the leaves and hence possibly growth (Tyree and Ewers 1991). The ability of water in the xylem to withstand the tensions developed by high rates of transpiration, or brought about by soil water deficits, can also have significant bearing on the susceptibility of trees to drought (Boyer 1982). Cavitation is influenced by the structure of the xylem. The ability of the xylem to prevent or at least limit cavitation could have a marked influence on the response of a tree to drought. The importance of vulnerability to cavitation must be understood in relation to the ability of plant to conduct water. Trees on the xeric sites did not show the excess conducting capacity and thus were susceptible to water stress. To prevent catastrophic embolism cycles (Tyree and Sperry 1988), trees at the xeric site have had to reduce transpiration, by decreasing stomatal conductance which in turn could lead to reduce carbon assimilation.

The inter provenance variation in regards to total biomass, height, specific leaf area and water use efficiency of *Eucalyptus microtheca* has been found to be more pronounced in water stressed treatment than in well watered one (Li *et al.* 2000). The ability of trees to utilize ground water decreases with increasing ground water salinity and the deepening of the water table (Thorburn *et al.* 1995). In studies where trees have been shown to utilize saline ground water, low transpiration rates have been recorded. Thornburn *et al.* (1993) found that highly saline ground water was an important water source in *Eucalyptus largiflorens* and *Eucalyptus camaldulensis,* although they considered that high ground water and soil salinity were limiting factor for water uptake and transpiration. In another study the low NaCl salt concentration has been found to stimulate growth, biomass production and rate of photosynthesis in *Eucalyptus camaldulensis* (Rawat and Banerjee 1998). Stem diameter (Diameter at breast height or DBH) is highly correlated with a number of other plant variables. Among *Eucalyptus* DBH which have served as an independent variable in studies of physiological behavior (Vertessy et al. 1995), population dynamics (Fensham and Bowman 1992) and ecosystem (O' Grady et al. 2000).

Under certain conditions moderate water deficits or stress can improve the quality of plant products, though it reduces vegetational growth. Fruit characteristics of cultivar Hilwa of date palm is reported to be found better under moderate to high water stress treatments (40 to 60% depletion of total soil moisture content) in Saudi Arabia (Hussain et al. 1993). It is argued that increased amount of thick walled element produced in trees subjected to water stress is sometimes beneficial because it results in wood of higher quality (Zahner 1968). Vessel lumen diameter and vessel frequencies per cross sectional area of xylem are heritable traits that are extremely variable from species to species. However the field of ecological wood anatomy has, to date, centered on the relationship of xylem anatomy to drought tolerance and water transport efficiency (Tyree *et al.* 1994).

Many *Eucalyptus* species are well adapted to growth in dry condition, that is one of their great values, but it is becoming clear that they are not drought-evaders; minimizing leaf water loss by early stomatal closure, but drought-tolerant and capable of transpiring even under considerable moisture stress. However, Zotz *et al.* (1994) *Eucalyptus* could be classified as 'drought-evaders', exhibiting high leaf specific conductivity and thus low xylem pressure potentials and high vulnerability to conductivity loss.

So far no study has been undertaken on the growth status of introduced species of *Eucalyptus* in the desert of Saudi Arabia. These species were screened for a set of selected variables to test the hypothesis that drought survival is related to vulnerability of xylem to embolism and to know the degree of adaptability potential of each species under investigation.

MATERIALS AND METHODS

Six species of Eucalyptus were selected out of fifteen species introduced in Riyadh area (latitudes 15° 45' N and 34° 34'N and longitudes 34° 40'E and 55° 45'E, altitude 591 m) with varying degrees of salt tolerance by Desert Research Centre, King Saud University, Riyadh (Al- Zught, 1997).

1. *Eucalyptus camaldulensis var.* Obtusa (Dehn) Blackley: fast growing, tolerates strong wind, salinity (4000-10000 ppm), extreme range of temperature (45 to - 5 °C), and dry desert climate for long time. This species is grown extensively in other parts of the world for fuel wood, timber and pulp (Midgley *et al.* 1986).
2. *Eucalyptus dandasii* Maiden: slow growing, tolerates salinity up to 7000 ppm, temperature (45 to - 3°C), and dry condition.
3. *Eucalyptus melanophloia* F. Muell.: fast growing, tolerates strong wind, salinity up to 6000 ppm, excessive heat but not cold, accept desert environment.
4. *Eucalyptus microtheca* F. Muell.: fast growing, tolerates strong wind, temperature 45 to 0°C, dry condition and salinity. It has been planted successfully in a number of countries in Africa and Middle East (NAS 1980).
5. *Eucalyptus siderophloia*: small tree, tolerates wind and heat, salinity up to 6000 ppm .
6. *Eucalyptus sideroxylon* A. cunn ex Wolls: slow growing, exhibits excessive transpiration, wind and salinity accepted, difficult to survive beyond 40°C, many trees die.

Ten trees of each species were selected and tagged. Care was taken to select the trees of approximately same age. All the samples were collected at 10:00 am during hot and dry season of June and July 2002 and 2003. On random basis 50 leaves were taken from each individual tree of each species. Leaves were collected in plastic bags, taken immediately to laboratory for refrigeration before taking fresh weight. Leaf area was measured using a leaf area meter (CI-203 laser area meter. CID, Inc. Washington, USA). Fresh weight; turgid weight and oven dry weight at 80°C for 48 hours, of leaves were taken for all samples. The entire set of samples was brought to full turgor by enclosing them in a moist chamber for 12 hours. Full turgid weight was obtained by re-weighing them. Later on saturated water deficit (SWD) and relative water content (RWC) were calculated using the formula given by Weatherly (1950).

Leaf specific mass (dry matter/ cm^2 of leaf) and water content/cm^2 of leaf were calculated for each species. Circumference of the tree axis was measured 1.3-1.4m above the ground and later diameter was calculated (Diameter at breast height or DBH).

Blocks of about $4cm^3$ with sapwood and bark were taken out from the trunk at breast height using a chisel and hammer. Bark thickness was measured from the cut end of blocks. The collected blocks were fixed on the spot in FAA (formaldehyde aceto alcohol), (Johansen, 1940). The fixed blocks were cut into small pieces and preserved in alcogylcerol solution. For the study of fibers, samples were macerated by using the method given by Ghouse and Yunus (1972). The samples were made into thin tangential slices. These slices were treated with hot 30% HNO_3 until the tissue elements got separated from each other. They were washed several times with a distilled water and stained with safranin and mounted in 5% glycerol. In each sample 100 fiber elements were observed at random basis and measured using ocular scale. Thus 1000 elements were taken for each species.

Thin transverse and tangential longitudinal sections of sapwood were cut at 8-12 μm thickness on AO 860 sliding microtome, NY, USA. These sections were stained in haematoxylin and Bismark brown, mounted in euperol after dehydrating in ethanol series (Johansen, 1940).The sections were studied under Nova Vision Series Brightfield microscope. Data were collected on vessel dimension and vessel pore frequency /mm^2 of sapwood to determine the vulnerability factor (Vf) of water conducting media following the method devised by Carlquist (1977).

Electrical conductivity and pH of the soil was tested from the different locations of the study site (EC = 4.24 mS/cm $\pm$ 1.46, pH = 7.95 $\pm$ 0.012). Obtained data were analyzed statistically for standard deviation (SD), least significant difference (LSD) and correlation coefficient according to Snedecor and Cochran (1973). Computed mean values for all parameters of each tagged tree of each species were used as replicate for analysis.

RESULTS

Ecalyptus camaldulensis, E. microtheca and *E. melanophloia* were fast growing recording a mean of 1.5 m per year for extension growth *E. camaldulensis* and 1 m per year for E. *microtheca* and *E. melanophloia*. *E. camaldulensis* was the tallest among all the six species. *Eucalyptus dandasii, E. siderophloia* and *E.sideroxylon* showed a slow growth of less than a meter per year. Because of this differential rate of growth of *Eucalyptus* species a wide range of variation was recorded in DBH (Table, 1).

Many trees of *E. sideroxylon* died during 2003 summer because of unbearable heat (slightly above 45°C) of July and August (Fig, 1).All the old leaves shed very fast after showing burning symptoms. Trees were naked for some times before new leaves came up, but all the affected trees died during August when still new leaves were of 2 cm size.

Table 1: DBH, Bark thickness and dimensional variation in the sapwood components of *Eucalyptus* species in the environmental conditions of Riyadh (2002/2003)

Species	DBH (cm)	Bark thickness (cm)	Vessel length (µm)	Mean vessel Diameter (µm)	Vessel wall thickness (µm)	Vessel pore frequency/ mm2 of Sapwood	Fiber length (µm)	Fiber width (µm)	Vf
Eucalyptus camaldulensis	31.18 d ±3.74	1.80 d ±0.21	264.04 a +67.11	121.16 a +48.59	9.50 c ±2.59	10.87 c ±2.54	800.12 a ±105.18	19.16 c ±2.39	11.13 a ±1.70
Eucalyptus dandasii	24.62 b ±2.58	1.10 a ±0.13	358.14 cd ±91.55	183.67 c ±39.29	7.16 a ±1.51	5.14 a ±1.04	1125.27 d ±176.81	15.46 a ±3.65	35.73 c ±5.43
Eucalyptus melanophloia	27.00 c ±2.63	1.30 b ±0.19	383.14 d ±82.34	195.14 c ±32.90	6.66 a ±1.77	4.81 a ±1.01	1147.17 d ±191.38	15.51 a ±4.94	40.54 d ±5.91
Eucalyptus microtheca	28.22 c ±2.85	1.60 c ±0.19	314.61 b +58.09	153.00 b +39.19	9.97 c +3.26	9.33 b +1.87	978.91 b +138.36	17.32 b +3.53	16.42 b +2.46
Eucalyptus siderophloia	22.53 a ±2.09	1.20 ab ±0.17	342.25 bc ±64.86	162.15 b ±46.34	7.70 ab ±1.97	8.73 b ±1.69	1084.76cd ±161.39	16.15 ab ±3.75	18.51b ±2.77
Eucalyptus sideroxylon	23.26 ab ±2.15	1.30 b ±0.17	330.03 bc ±60.34	150.00 b ±41.45	8.99 cb ±2.93	9.04 b ±1.85	1057.68 c ±115.15	14.91 a ±2.98	16.58 b ±2.32
LSD at 5% level	1.67	0.11	34.58	20.54	1.41	1.44	65.34	1.77	3.58

DBH: Diameter at Breast height
Vf: Vulnerability factor
Values having same letter are not significantly different

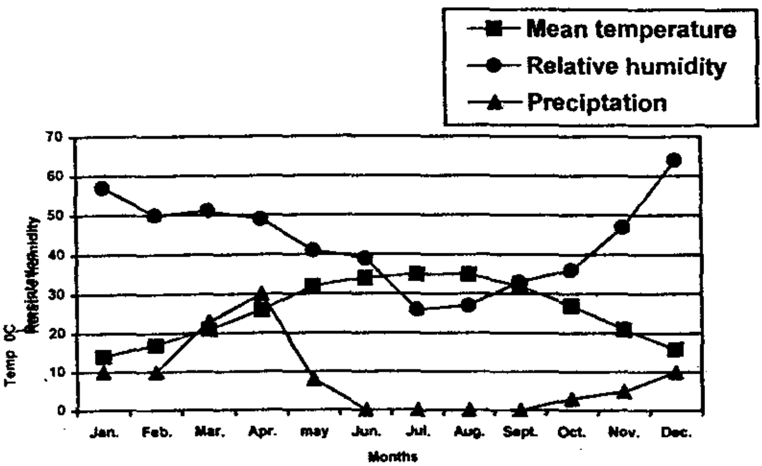

Figure 1: Meteorological data (mean of two years) of the study area for the year 2002 and 2003

E. camaldulensis and *E. microtheca* were found to be more tolerant to deficient water than other four species as they showed a high value of SWD, a drought resisting character. Due to this fact these two species conserve more water in their leaf and were more capable to resist any drought situation. *E. camaldulensis* was detected as most deficient in the water and *E. melanophloia* as the most saturated species and showed a difference of 11.75% in their RWC and SWD (Fig, 2). A significantly higher amount of 10.00 mg of water was found in unit area of leaf in *E. camaldulensis* followed by *E. microtheca* and *E. siderophloia*. A significantly lower value of 5.64 mg was recorded for *E. melanophloia*. A significantly higher value of 20.64 mg of leaf specific mass (dry matter accumulation/$cm^2$of leaf) was recorded for *E. camaldulensis* and a lowest value of 7.05 mg for *E. melanophloia* (Fig, 3). Leaf specific mass followed the same trend as that of water content / cm^2, exhibited a high degree of positive correlation ($r=0.8588$, $p> 0.01$) between the two parameters (Table,2).

Sapwood of six *Eucalyptus* species was studied to evaluate the impact of environments on vessels differentiation involved in the water conduction and fibers meant for mechanical support and determining the wood quality. *E.camaldulensis* showed a poor growth in the fiber length having a mean value of 800.12 µm which is significantly shorter than the other species. *E. siderophloia* and *E. sideroxylon* did not show any significant difference in their fiber length. The significantly longer fibers were found in *E. dandasii* and *E. melanophloia*. *Eucalyptus camaldulensis and E. microtheca* showed a significantly higher value for mean fiber width than the other species. A minimum length of vessel segment (264.04 µm) was recorded in *E. camaldulensis*. *E melanophoia* showed a much better growth of vessel segment than the other species. A minimum vessel pore expansion was observed in *E. camaldulensis*. The vessel pore of *E. microtheca* , *E. siderophloia* and *E. sideroxylon* did not differ significantly from each other. *E. melanophloia* and *E. dandasii* possessed significantly broader pores than the other species. An analysis of vessel wall thickness showed that *E. camaldulenis* and *E. microtheca* were having a significantly thicker wall than other species. A significantly lower value of 6.66 µm of vessel wall thickness was recorded for *E. melanophloia* (Table, 1)

The analysis of number of vessels differentiated in mm^2 of sapwood showed a significantly higher value for *E. camaldulenses* followed by *E. microtheca.* The significantly lowest number of vessel pores was observed in *E. melanophloia*. The vessel pore frequency of *E. microtheca*, *E. siderophloia* and *E. sideroxylon* did not differ significantly from each other .The mean area of vessel pores present in

Table 2: Correlation studies on the inter-specific variation among the selected growth variables of *Eucalyptus* in the environmental conditions of Riyadh (2002/2003).

		Water content /cm² of leaf	Mean vessel diameter	Vessel wall thickness	Vulnerability factor (Vf)	Saturated water deficit (SWD)
Leaf specific mass	r	0.8588**	-0.8608**	0.5704	-0.8070**	0.8946**
	d	73.75	74.09	32.53	65.12	80.03
Water content /cm² of leaf	r	x	-0.7956**	0.7614*	-0.8647**	0.7691*
	d		63.29	57.97	74.77	59.15
Mean vessel diameter	r	x	x	-0.8557**	0.9409**	-0.9449**
	d			73.22	88.52	89.28
Vessel wall thickness	r	x	x	x	-0.8735**	0.9718**
	d				76.30	94.43
Vulnerability factor (Vf)	r	x	x	x	x	-0.9122**
	d					83.21

r = Coefficient of correlation
d = Coefficient of determination
* Significant at 5% level** Significant at 1% level,

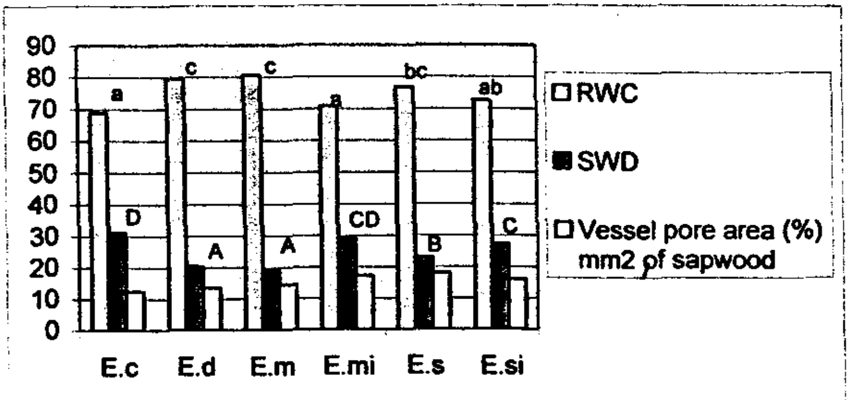

Figure 2: Comparing the six *Eucalyptus* species for RWC and SWD in the environmental conditions of Riyadh.

Ec= *E. camaldulensis*, *Ed= E. dandasii*, Em= *E. melanophloia*, Emi= *E. microtheca*, Es= *E. siderophloia*, Esi= *E. sideroxylon*.
RWC = Relative water content.
SWD = Saturated water deflect.
Bars having same superscript are not significantly different separated on LSD ($p<0.05$) analysis.

mm^2 of sapwood showed a significantly higher value of 18.03% in *E. siderophloia* followed by *E. microtheca* and a lowest of 12.50% in *E. camaldulensis* (Fig, 2).

Vulnerability factor (Vf) was considered a suitable index for the ratio between the mean vessel diameter and vessel pore frequency / mm^2 of sapwood. It determined the degree of xeromorphy/ mesomorphy of taxa. Vf calculated for the six species showed a range of 11.13 to 40.54, *E. camaldulensis* having a significant lowest value and *E. melanophloia* a significant highest value. A low value of Vf obtained for *E. camaldulensis, E. microtheca* and *E. sideroxylon* indicated the degree of safety against drought for these tree species growing in the desert of Saudi Arabia. Besides its physiological function bark also functions as a protective device against adverse environmental conditions. *E. camaldulensis* possessed the significantly thickest bark of 1.8cm followed by *E. microtheca.* A lowest value of 1.10cm was recorded for *E. dandasii.* A thick bark of 1.80cm coupled with lowest value of Vf (11.13) obtained for *E. camaldulensis* showed a tendency towards xeromorphy (Table, 1).

Correlation of interspecific variation among the selected growth variables of ***Eucalyptus***

An analysis of correlation between inter specific variation in the water content and leaf specific mass (LSM) of six *Eucalyptus* species showed a highly significant positive correlation up to 73.75 % ($r = 0.8588$ $p<0.01$). The variation in vessel pore diameter was negatively correlated with the dry matter accumulation in leaf up to highly significant level in the six species of *Eucalyptus* species. LSM was found to favour vessel wall development but not up to a significant level (Table, 2).

Variation in the vulnerability factor of water conducting system of the six *Eucalyptus* species was significantly correlated but negatively with LSM (-0.8070). It was indicative of a fact that a plant species with low Vf like *E. camaldulenis* and *E. microtheca* were efficient having comparatively low photosynthetic activity than those having high Vf like *E. dandasii* and *E. melanophloia.* The inter-specific variation in SWD was positively and significantly correlated with the dry matter accumulation in the leaf. Thus, it may be concluded that narrow vessel pores coupled with low Vf resulted in the high SWD / low RWC and high water retaining capacity of leaf which favor a manageable photosynthetic activity for better growth in *E. camaldulensis and E microtheca* (Tables 1 & 2, Figs,2 & 3).

The variation in vessel pore diameter exhibited negative but significant correlation with the water content /cm^2 of leaf. The amount of

Table 3: Correlation studies on the inter-specific variation among the selected growth variables of *Eucalyptus* in the environmental conditions of Riyadh (2002/2003).

		Vessel pore frequency/mm² of sapwood	Relative water content (RWC)	Vulnera bility factor (Vf)	Bark thickness
Leaf area	r	-0.4433	0.6937*	0.4127	-0.6120
	d	19.65	48.12	17.03	37.45
Vessel pore frequency/mm² of sapwood	r	x	-0.9322**	-	0.8286**
	d		86.89	0.9912** 98.24	68.65
Relative water content (RWC)	r	x	x	0.9122**	-0.8980**
	d			83.21	80.64
Vulnerability factor (Vf)	r	x	x	x	-07544*
	d				56.91

r = Coefficient of correlation
d = Coefficient of determination

* Significant at 5% level,
** Significant at 1% level,

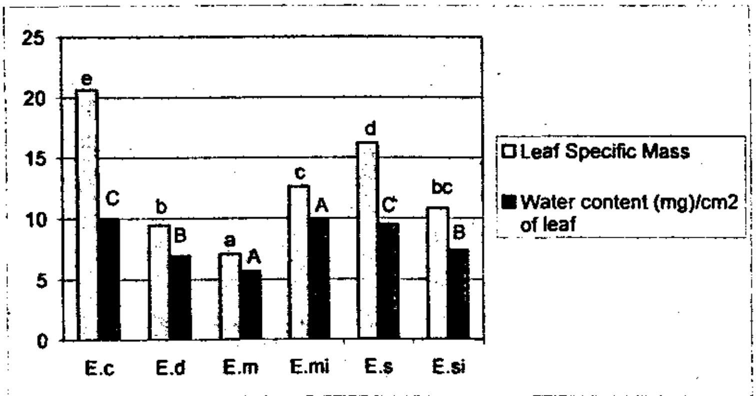

Figure 3: Inter-specific variation and correlation (r = 0.8588, p< 0.01) of water contents and specific mass of leaves of the *Eucalyptus* species.

Ec= *E. camaldulensis*, Ed= *E. dandasii*, Em= *E. melanophloia*, Emi= *E. microtheca*, Es= *E. siderophloia*, Esi= *E. sideroxylon*. Bars having same superscript are not significantly different separated on LSD (p<0.05) analysis.

water present in leaf favoured the development of vessel wall thickness in all species. The vulnerability factor of water conducting system badly affected the water accumulation in leaf as a negative and highly significant correlation was obtained for these two variables ($p < 0.01$). A variation in water deficit showed a positive and significant correlation with the amount of water accumulation /cm^2 of leaf. A variation in vessel pore diameter had a negative but highly significant correlation with the development of vessel wall thickness ($p<0.01$). However a positive and highly significant correlation existed between vessel pore diameter and vulnerability factor of investigated species ($r = 0.9409$). The vessel pore diameter affected the water accumulating capability of leaf (SWD) as a significant but negative correlation was obtained for this pair of parameters (Table, 2).

The vulnerability factor of water conducting system was found to affect adversely the development of vessel wall ($r = -0.8735$). However, SWD of leaf favoured the vessel wall development in the investigated species ($r = + 0.9718$). Low Vf (tending towards xeromorphy) which caused high water deficiency percentage ($r = -0.9122$) and led to more water accumulation in the leaf of *E. camaldulensis* and *E. microtheca* than *E. dandasii* and *E. melanophloia* (Fig, 3).

Leaf area did not show a significant correlation with any anatomical parameters. It showed a positive and significant correlation with its own RWC. The vessel pore frequency of sapwood had highly significant but adverse effect on the relative water content (RWC) of leaf ($r = -0.9322$) and Vf of water conducting column ($r = -0.9912$) in the investigated species.On the other hand, narrow and high vessel pore frequency favored the bark development up to a high level of significance. A positive and significant correlation existed between Vf of water conducting column and the relative water content of leaf. But RWC was inversely proportional to the thickness of bark up to highly significant level ($d = 80.64$ %). Similarly Vf was found to affect the bark development adversely as a negative and significant correlation was obtained for this pair of parameters (Table, 3). The species like *E. camaldulensis* and *E. microtheca* with low Vf favored bark development as a protective device while *E. dandasii* and *E. melonophloia* with high Vf possessed thin bark (Table,1).

DISCUSSION

Besides age, DBH is also dependent on the rate of growth. Radial growth is fully dependent on extension growth (Alvim 1964 and Reinders-Gouwentak 1965) for the supply of growth hormone. The role of auxins has been suggested for the initiation and continuation of cambial activity (Digby and Wareing 1966 a, b). This was the reason the DBH of fast growing species of *Eucalyptus* was significantly higher than those of slow growing species of the same age.

The result obtained on 21 *Eucalyptus* species from Australia through remote sensing showed a comparable but slightly higher mean value of leaf specific mass of 0.017g cm^{-2} with a range of 0.008-0.031 than our findings on six species of *Eucalyptus* recording a mean value of 0.012g cm^{-2} with a range of 0.007-0.020. A strong positive correlation was found between leaf specific mass and water content of leaves ($r = 0.8588$ $p > 0.01$) in the present investigation as has also been reported ($r=0.67$) for 21 Australian species (Datt 1999). James and Bell (2001) reported a quite high value of leaf specific mass and leaf water content for *Eucalyptus globulus* from Australia. These observations reflect the sclerophyllic and drought resistant nature of *Eucalyptus* leaves where the increase in dry matter content with leaf development is accompanied by a proportionately smaller increase in water content (Datt 1999, James and Bell 2001).

E. camaldulensis and *E. microtheca* were found to be well adapted to resist drought or any water stress situation as they possessed significantly lower Relative Water Content (RWC) to maintain cell turgidity for their normal growth. A decrease in RWC and leaf water potential has been cited by Morgan (1984) as an important adaptation to water stress.

Eucalyptus camaldulensis has significantly shorter and thicker fiber than other species. Similarly vessel segment exhibited also a significantly narrow pore with short length having a thicker wall in *E. camaldulensis* than the other species. *E. melanophloia* showed the longest fiber together with the longest vessel segment and widest vessel pore having thin wall. A significant increase in the growth of vessel segment length (1.96 times) and vessel pore diameter (2.45 times) were noted while comparing the findings of the present investigation on *E. sideroxylon* with the one reported from semi arid region of India (Ajmal *et al.* 1985). The fiber length showed also a significant increase (1.85 times) but fiber width exhibited a significant decrease.

In the present study, two species namely *E. camaldulensis* and *E. microtheca* had short and narrow vessels segment coupled with high frequency of vessel pore in mm^2 of wood. Thus these species offered a high degree of safety under water stress condition by resisting tension in the water column (Zimmermann 1983; Bass *et al.* 1983). The thick walled xylem element produced in trees due to water stress is beneficial because it results in the production of better quality of wood (Zahner 1968). The wood of *E. camaldulensis* and *E. microtheca* was found to be better in quality than other four species on account of possessing significantly short, narrow and thick walled vessels and fibers. The lesser area occupied by vessel lumen/ mm^2 of sapwood made them stronger The same conclusion has been drawn by Wagner *et al.* (1998) while working on four chaparral shrubs of Southern California. A similar result has also been obtained for *Bombax costatum* (Tongtok 1995) and *Eucalyptus torelliana* (Danbwarang 1995) growing elsewhere under water stress condition.

The lowest Vf (11.13) was observed for *E. camaldulensis* followed by *E. microtheca* (16.42), *E. sideroxylon* (16.58) and *E. siderophloia* (18.51). The Vf. values calculated for *E. dandasii* and *E. melanophloia* were found to be 3.21 and 3.64 times more than *E. camaldulensis*. A quite high value of Vf. (101.29) has been noticed for *Bombax costatum* growing under extreme water stress condition of Jos plateau, Nigeria (Tongtok,1995). While two year old twig of *Eucalyptus torelliana* from the top of tree showed an extremely low value of Vf. (0.63) than two year old sapling collection (Danbwarang 1995). A significantly high correlation ($r= 0.9122$, $p<0.01$) was recorded between inter-specific variation in vulnerability factor and water storage capacity (RWC) of leaf belonging to six *Eucalyptus* species. A significantly higher Vf value of 40.54 of *E. melanophloia* and 35.73 of *E. dandasii* was associated with significantly higher RWC value of 80.65 and 79.57% respectively. The same relationship between vulnerability to embolism and RWC of wood is reported for softwood species. Late wood is more vulnerable to embolism than early wood (Domec and Gartner 2002). In hard wood species, the small diameter late wood vessels and the small-diameter vasicentric tracheids near the larger vessels are thought to provide water transport once the early wood and/ or wider vessels have become air- filled (Carlquist 1985 and Cochard *et al.* 1997). Growth is more sensitive to sites than the genetic make up of a tree. Vulnerability of xylem to cavitation differed among clones but not between the sites as observed for four closely related *Eucalyptus* clones. Hydraulic conductivity is determined predominantly by environmental conditions whereas vulnerability to cavitation is more closely associated with genotype. The vulnerability factor of sapwood did not show any intra-specific significant variation with respect to collection site of material in the present investigation. However inter-specific significant difference in vulnerability was recorded for *Eucalyptus* indicating that this character was species specific. Our studies and that of Al-Zught (1997) have revealed that *Eucalyptus sideroxylon* possessed a combination of drought resistant and drought susceptible traits. Probably the cause of death of too many plants of this species may be due to high rate of transpiration, inability to tolerate dry condition and salinity (Al-Zught 1997) although it has low vulnerability factor and manageable thick bark to resist drought. The clone of *Eucalyptus* most vulnerable to cavitation shows considerable aboveground die-back (Willigen and Parameter,1998). The exact reason behind the death of many *E. sideroxylon* trees in the present study is yet to be investigated.

E camaldulensis with the lowest value of Vf. (11.13) has developed the thickest bark of 1.8 cm among the six species. A significant but negative correlation existed between Vf. and thickness of bark. It appeared that gibberellin / auxin balance has been affected to produce thicker bark as a protective device against drought in *E camaldulensis* and *E microtheca*. ***Bombax costatum*** appears to be more sensitive than any one of the *Eucalyptus* species investigated as the thickness of bark has gone up to 3.6 cm from 1.2cm with slight decrease in Vf. from 135.22 to 101.29 (Tongtok, 1995). The bark thickness of certain arid zone Acacias and *Prosopis* could reach the level of *E. camaldulensis* (Ghouse and Iqbal, 1979).

CONCLUSIONS

Plant water status is governed by complex interactions involving soil water, plant and atmosphere. Also, because water stress affects every physiological process, drought is the environmental factor that most often limits tree growth and development.

All the investigated species with varying degree of salt tolerance were found to be performing well except *E. sideroxylon* in the climatic conditions of Riyadh located in the rocky desert. *E. camaldulensis* and *E. microtheca* had better drought resisting traits and adaptability potentials. *E. dandasii* and *E. melanophloia* were discovered as potentially weak species because of high vulnerability to drought.

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الملخص العربي

سلوك نمو بعض أنواع الكافور المختارة للزراعة تحت الظروف البيئية لمنطقة الرياض بالمملكة العربية السعودية

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مدينة الملك عبد العزيز للعلوم والتقنية

ص.ب. ٦٠٨٦ – الرياض ١١٤٤٢ – السعودية

درست ستة أنواع مستوردة من جنس الكافور Eucalyptus من ناحية النمو والقابلية للأقلمة تحت ظروف منطقة الرياض. ولقد وجد أن النوعين *E. microtheca, E. camaldulensis* كانا يتصفان بدرجة عالية من مقاومة الجفاف مثل تحمل نقص المياه بدرجة عالية المعنوية مع قصر وضيق عناصر الأوعية الخشبية وزيادة سمك جدرها وزيادة عدد المسام في المليمتر المربع للخشب العصاري وانخفاض قابلية أوعية التوصيل المائية للألتئام من الجروح مع زيادة سمك القلف. ولقد وجد أن *E. camaldulensi* ذو خشب قوى حيث كانت به مساحة أقل من الأوعية/م٢ مع ألياف أكثر سمكا.

أما الأنواع *E. Sideraphylon, E. melanephloia, E. dandasic* فكانت تتصف بمزيج من صفات مقاومة الجفاف والقابلية للإصابة والقابلية العالية لالتئام جروح أوعية توصيل الماء في الأنواع *E. melanophloia, E. dandasic* كانت مصحوبة بدرجة عالية من محتوى الأوراق النسبي من الماء. ولقد وجد تلازم عالى معنوى بين الصفات التشريحية للخشب والصفات الظاهرية والتطبيقية لأوراق أنواع الكافور مثل محتوى الورقة من الماء/كتلة الورقة – سمك جدار الأوعية/قدرة التشبع لنقص الماء، قدرة التشبع لنقص الماء/كتلة الورقة وسمك جدر الأوعية، المحتوى النسبي من الماء/مساحة الورقة ومعامل القابلية لالتئام الجروح، عدد مسام الوعاء/سمك القلف. ولقد وجدت تلازمات معنوية سالبه بين هذه القياسات مثل محتوى الورقة من الماء/سمك مسام الأوعية ومعامل القابلية لالتئام الجروح، سمك مسام الأوعية/كتلة الورقة، سمك جدار أوعية وتشبع نقص المياه، مقابل القابلية لالتئام الجروح/كتلة الورقة، تشبع نقص المياه. سمك جدر الأوعية وسمك القلف، المحتوى النسبي للمياه/عدد مسام الأوعية وسمك القلف.