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Research Article:

Comparative evaluation of the biomass, chemical, and anatomical characteristics of wastewater-irrigated *Eucalyptus camaldulensis* and *Corymbia citriodora*

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Abstract

Eucalyptus camaldulensis and *Corymbia citriodora* are economically valuable trees due to their fast-growth and role in producing wood and raw materials. This study evaluated their anatomical structure, biomass productivity, and wood properties under conditions of wastewater irrigation. These two tree species were grown in the Serapeum plantation forest, Ismailia Governorate, Egypt. Results showed that *E. camaldulensis* had higher and wider stem and leaf epidermal cells with a thicker cuticular covering layer: 7.88 µm for the stem cuticle and 8.25 µm for the foliar one, compared to 5.78 µm and 6.40 µm for *C. citriodora* stem and leaf, respectively. *C. citriodora* had a larger overall stem sector size of 1.75 × 2.13 µm and larger xylem vessels, measuring 40.16 µm in the stem and 26.36 µm in the leaf vascular system. Secretory glands and druses were observed in both stems and leaves. *E.* camaldulensis had higher biomass characteristics, such as fresh weight of biomass/tree (250.00 kg/tree), dry weight of biomass/tree (120.00 kg/tree), fresh weight of biomass/ha (277.75 ton/ha) and dry weight of biomass/ha (133.32 ton/ha), as well as volume per tree. *C. citriodora* wood had a higher average density and lower average moisture content. Holocellulose percentage was higher in *E. camaldulensis* wood, while the lignin and ash content decreased. The study also found a significant difference in chemical parameters between the two species.

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1. Introduction

Concerning the observed increase in atmospheric concentrations of greenhouse gases and global climate troubles, one primary leading choice is to enhance forest biomass. This can be accomplished by planting previously unforested land or increasing the productivity of existing forests to reduce the amount of greenhouse gases (FAO, 2025). Egypt has planted fast-growing tree species to meet the country's growing needs, and instead of using irrigation water to water food crops, sewage effluent has been utilized to water forest trees. After primary treatment, wastewater can be safely used for irrigation in tree plantations, forest areas, green belts around towns, and non-food crops (Nasser, 2008)

Plantation woody trees in arid regions can significantly contribute to regulating the climate and reducing atmospheric greenhouse gas emissions, as rapid carbon storage occurs on sufficiently available and unused desert lands. The ideal approach to managing this afforestation could be to focus on producing timber and sequestering carbon, respectively (El Kateb et al., 2022).

Selecting suitable species for such environmental conditions requires a comprehensive understanding of their physiological and structural traits. Anatomical studies provide critical insights into species' adaptability, growth performance, and wood quality. Researchers can evaluate a tree's ability to transport water, provide mechanical support, and withstand environmental stressors by examining characteristics including fiber size, vascular architecture, and parenchyma distribution (Venegas-González et al., 2015). These anatomical characteristics are closely linked to biomass accumulation and industrial suitability, especially for pulp and paper production. Moreover, anatomical markers can serve as sensitive indicators of environmental conditions, offering valuable data for species selection and forest management under changing climates (Salimath et al., 2025).

Eucalyptus (Myrtaceae) trees are valued for their active nutrient recycling, their ability to preserve soil against erosion, and their contribution to biodiversity by providing shelter for wildlife. In addition, sustainability must be considered when establishing short-rotation *Eucalyptus* plantations (Stape et al., 2010). Their rapid progress and healthy growth under irrigation with wastewater make them particularly suitable for expanding cultivation in afforestation programs. *Eucalyptus* species are economically important in producing wood, paper, cellulose, essential oils, and honey (Birtchnell and Gibson, 2006; Balbino et al., 2011). Moreover, different species of Eucalyptus have been reported to be tolerant to heavy metals, improving phytotoxicity symptoms and can be significantly used in restoration and phytoremediation programs (Soares et al., 2005; Gomes et al., 2012).

Eucalyptus species exhibit intraspecific variation in gross wood density, which closely reflects variations in the transverse dimensions of fibers, such as the double wall thickness to lumen diameter ratio (Wilkes, 1988). Xylem structures change along the tree with age (Gartner, 1995) and contain essential inclusions for tree functions (Zanne et al., 2010). In angiosperm xylem, in addition to their primary function of upholding water, fibers may indirectly contribute to water transmission by reducing vessel implosion impedance under negative pressure (Jacobsen et al., 2005) or by extending water to decrease tension in the xylem (Pratt et al., 2007). Despite the scarcity of unanimity (Charrier et al., 2016), many authors argue that parenchyma may also play a pivotal role in embolism repair by providing the necessary solutes to induce an osmotic gradient (Salleo et al., 2006; Brodersen et al., 2010). On the other hand, Santos et al. (2008) studied the foliar anatomy of seven *Eucalyptus* species and demonstrated anatomical differences among the tested species.

In addition, Del Piero et al. (2022) revealed that *Eucalyptus* species possess inducible chemical defense strategies against certain pest infestations, achieved through the concentration and variability of terpenes, the presence of specific compounds (Silveira et al., 2021), and the amounts of epicuticular wax in leaves. Faria et al. (2014), in their study on some Myrtaceae members, considered that anatomical characterizations and morphological features contributed to identifying the family's plants. The chemical composition of Myrtaceae leaves has been reported to contribute to a wide range of biological activity (Oussalah et al., 2006; Marzouk et al., 2007; Oussalah et al., 2007; Faria et al., 2014).

Orwa et al. (2009) introduced *Corymbia citriodora* (Myrtaceae) as a fast-growing plantation tree in Asia, Australia, Europe, and the United States, suitable for fuel wood, poles, timber, lumber, biomass, essential oil, and as an excellent source of nectar for honeybees. This tree was recommended by Ghorab et al. (2017) for afforestation with irrigated primary treated wastewater, as it showed the highest significant increment in tree parameters.

Wood's chemical structure and composition consist of cellulose, hemicelluloses, lignin, small proportions of ash, and extractives. Regarding the chemical characterization of wood designed to produce cellulosic pulp, low levels of extractives, lignin, and ash are desired, along with high levels of cellulose and hemicellulose (Segura et al., 2017). However, each chemical composition shows variations in quality and composition, which affects the potential for cellulosic pulp production, necessitating a deep chemical analysis (Santos et al., 2016). Lopes et al. (2023) studied wood's chemical and physical properties from *Eucalyptus* and *Corymbia*. They indicated that *Eucalyptus* showed higher levels of lignin and cellulose, while hybrid clones of *Corymbia* showed the highest values of basic density and energy density of wood. The species effect was detected for the levels of hemicelluloses and ash in the wood.

In the forest, apart from trees left for visual purposes, all merchantable trees in the same area are harvested at once in clear-cutting. Regeneration of the tree species develops from sprouting in the clear-cut area. This regeneration method supports the establishment and development of various tree species, including eucalypts, aspen, and jack pine (Smith, 1986). Biomass estimation has become essential worldwide and is vital in implementing emerging carbon credit mechanism (Mugasha et al., 2013). Measurable tree characteristics strongly connected to biomass, such as height, canopy spread, and diameter at breast height (DBH), are used to calculate biomass (Chave et al., 2014). DBH is the most essential variable for predicting biomass (Verma et al., 2014). Tree productivity, measured in terms of the volume of standing and felled Eucalyptus trees (1 to 5 years old), exhibited exponential growth with increasing tree age, according to Divya et al. (2022).

Therefore, given the increasing need for wood production and raw materials for the pulp and paper, charcoal, fiberboard, plywood, veneer, and particleboard industries, plantings of desirable species such as *Eucalyptus camaldulensis* and *Corymbia citriodora* in Egypt should be considered. In light of the aforementioned, this study aims to assess the anatomical, chemical, and biomass traits of *E. camaldulensis* and *C. citriodora* trees that were irrigated with wastewater during their second 5-year rotation.

2. Materials and methods

2.1. Study site and experimental design: The present study was conducted at the Serapeum plantation forest in Ismailia Governorate, Northeastern Egypt (N 30 ° 28'49.14

"E 32°13'29.86"), in 2023, on *Eucalyptus camaldulensis* Dehnh. and *Corymbia citriodora* (Hook.) K.D.Hill & L.A.S. Johnson trees are irrigated with municipal wastewater treated by drip irrigation. Table (1) shows the chemical analysis of wastewater used at the Soil and Water Agriculture Directorate laboratory, Qena Governorate, Egypt. These trees were planted in 2008 in an area totaling 27.3 hectares; the original planting density was 1111 trees per hectare. Analysis showed that the soil is sandy, with 90.48% sand, 6.31% silt, and 3.21% clay, an electrical conductivity of 1.27, and a pH of 7.88. The 1st rotation age was taken ten years later in 2018 using a clear-cutting method, retaining two stems per stump (the stump height is 10-12 cm above ground). Regeneration of the two tree species develops from sprouting in a clear-cut area. The stump survival rate of these trees was 97%, and they were then irrigated and cared for. Selected shoots were monitored for five years until the 2nd rotation age in 2023. The experimental design was a randomized complete block; the plot consisted of 5 plants in three rows, totaling 15 trees per plot, with two tree species at a 3 m x 3m tree density and three replications. Each plot was specified before harvesting.

2.2. Plant material: Fresh samples of stem and leaves from the two tree species were fixed in a formalin: acetic acid: alcohol solution (FAA, 5:5:90) for 24 hours and stored in 70% ethanol until use. The last author checked and authenticated the scientific names and synonyms according to 0POWO (2024).

2.3. Anatomical investigations: Delicate leaves and stems were chosen for the anatomical studies. The plant parts were selected from the fifth upper node. The previous 70% of alcohol-preserved specimens were used to carry out the anatomy of the stem and leaves. Anatomical sections were cut using a rotary microtome and mounted in Canada balsam according to the method by Johansen (1940). Light microscopy [Leica DM1000] was used to investigate sections of permanent slides at magnifications of 4, 10, and 40 to provide the best possible clarity. A ToupView digital camera was attached to the light microscope for microphotography. Table (2) lists various anatomical quantitative and qualitative characteristics that are examined.

Table 1. Chemical analysis of the treated wastewater used for irrigation in the current study

Parameter	***Value***	***Parameter***	***Value***
pH	7.81	Pb (mg/l)	0.007
Temp (^{0}C)	28.3	Cd (mg/l)	0.001
TSS (mg/l)	28.3	Cr (mg/l)	0.024
TDS (mg/l)	640.0	Ni (mg/l)	0.019
BOD_5 (mg/l)	50.0	Zn (mg/l)	0.064
COD (mg/l)	75.3	Fe (mg/l)	0.374
Amm-N (mg/l)	25.1	Cu (mg/l)	0.019
T-P (mg/l)	2.49		

TSS=Total soluble solids, TDS= Total dissolved solids, BOD= Biochemical Oxygen Demand, COD= Chemical Oxygen Demand, Amm-N= Ammonia-N and T-P= Total phosphorus

2.4. Aboveground biomass estimation: The total height of the two tree species and merchantable tree height were measured by a measuring tape and expressed in meters (m). All tested trees were marked at 1.30 m from ground level using a 1 cm band of red paint around the stem. Root collar diameter (RCD cm) and diameter at breast height (DBH cm) of trees were measured and expressed in centimeters. The diameters of the two shoots/stumps were measured and then summed to give the diameter per tree. Trees are felled at ground level using a mechanical chainsaw, and the aboveground portion is processed into stem wood and branches with foliage. Fresh weights of all the aboveground tree components were measured immediately after falling using appropriate spring scales. Green weights were measured using a digital scale (0.1 kg) for stems and branches with foliage (Kg/ tree). A sample (50 cm long) of wood, branches, and leaves was immediately carried to the laboratory in double-sealed polythene bags. The collected samples were dried at 70 °C for the foliage and at 103±2 °C for the stem and branches until a constant weight was obtained, and the tree biomass's dry weight was estimated. The stem volume of each tree was measured using a measuring tape, and the stem diameter and length between these points were recorded at certain point intervals along the tree stem. The volume of felled trees was calculated by using the Samilian׳s formula (De Gier, 2003) and expressed in m^3. The basal area of the trees (m^2/tree) was calculated for the two main branches of each tree and then summed.

2.5. Physical wood analysis:

2.5.1. Wood density (g/cm3): Wood density was determined based on an air-dried weight (12-14% MC) and air-dried volume of wood (Haygreen and Bowyer, 1996). Ten samples (2×2×5 cm) from the sapwood and heartwood, sampled from the butt and crown regions of each tree species, were weighed and sealed in air-tight plastic foil, and their volume was recorded using the water displacement method. The weight of wood density was measured by dividing the conditioned air-dried weights by the volume of water it displaced in the formula: $D\ (g/cm^3) = W/\ (Vb\text{-}Va)$, where *W*= air-dried weight of wood sample at 12-14% MC, *Va*= volume of the sample after immersion, *Vb*= volume of water before immersion.

2.5.2. Moisture content (%): For measuring moisture content, wood samples were weighed to an accuracy of 0.001 g in a weighing balance (digital scale), then dried in an oven-dry till a constant weight at a temperature of 103 ±2°C. The final weight was taken as the oven-dry weight. The samples' moisture contents (%) were recorded using the formula described by Desch and Dinwoodie (1996). Moisture content (%) = (Mi-Mo/Mo) ×100, where Mi= Initial weight of the sample (g), Mo= Oven-dried weight of the sample (g).

2.6. Chemical wood analysis: Chemical properties of the wood were determined for the tree species using pooled sampling. Wood disks obtained along the tree's stem were subsampled, then pooled and tested in a single vial. Cellulose was determined as reported by Sadasivam and Manikam (2005). Holocellulose was estimated in oven-dried samples pre-extracted with a 1:2 (v/v) mixture of benzene and alcohol, according to Anonymous (1959). Lignin contents in an oven-dry sample were pre-extracted with alcohol-benzene (1:2 v/v) as the method described by Anonymous (1959c), Hemicellulose content was calculated by subtracting the cellulose content from the holocellulose content, determination of extractives was done according to Anonymous (1959b), and ash content was recorded according to the Instituto Adolfo Lutz (2008). The analysis of C, N, and H as wood elements was conducted according to the methodology described by Paula et al. (2011), while the oxygen values were determined in accordance with Ascough et al. (2010). The procedure used for Pentosans (%) analysis is described by the Technical Association Pulp and Paper Industry (1950).

2.6. Statistical analysis: The results obtained in the present investigation were subject to statistical analysis, like Mean ($\bar{x}$) and standard error (SE) by Zar (1984). Mean $\bar{x} = \Sigma\ x\ /n$, where $\bar{x}$ is the summation of values, n is the total number of observations. SE = Sx $/\sqrt{n}$, where Sx is the standard deviation, and n is the total number of observations. The statistical analysis of the present data was carried out according to Snedecor and Cochran (1980). Averages were compared using the T-test at a 5% level (Steel and Torrie, 1980).

3. Results and discussion

3.1. Anatomical study: The dermal tissue characteristics revealed significant differences between the epidermal cells of the two species on the stem and leaf surfaces. However, the epidermal cells in the stem and leaf surfaces of *Eucalyptus camaldulensis* were higher and broader than those of *Corymbia citriodora* (Table 2). The cuticular covering layer was also thicker in *E. camaldulensis* than in *C. citriodora*. Cuticle thickness was 7.88 μm and 8.25 μm in the stem and leaf of the first species, while 5.78 μm and 6.40 in the epidermis of the second species.

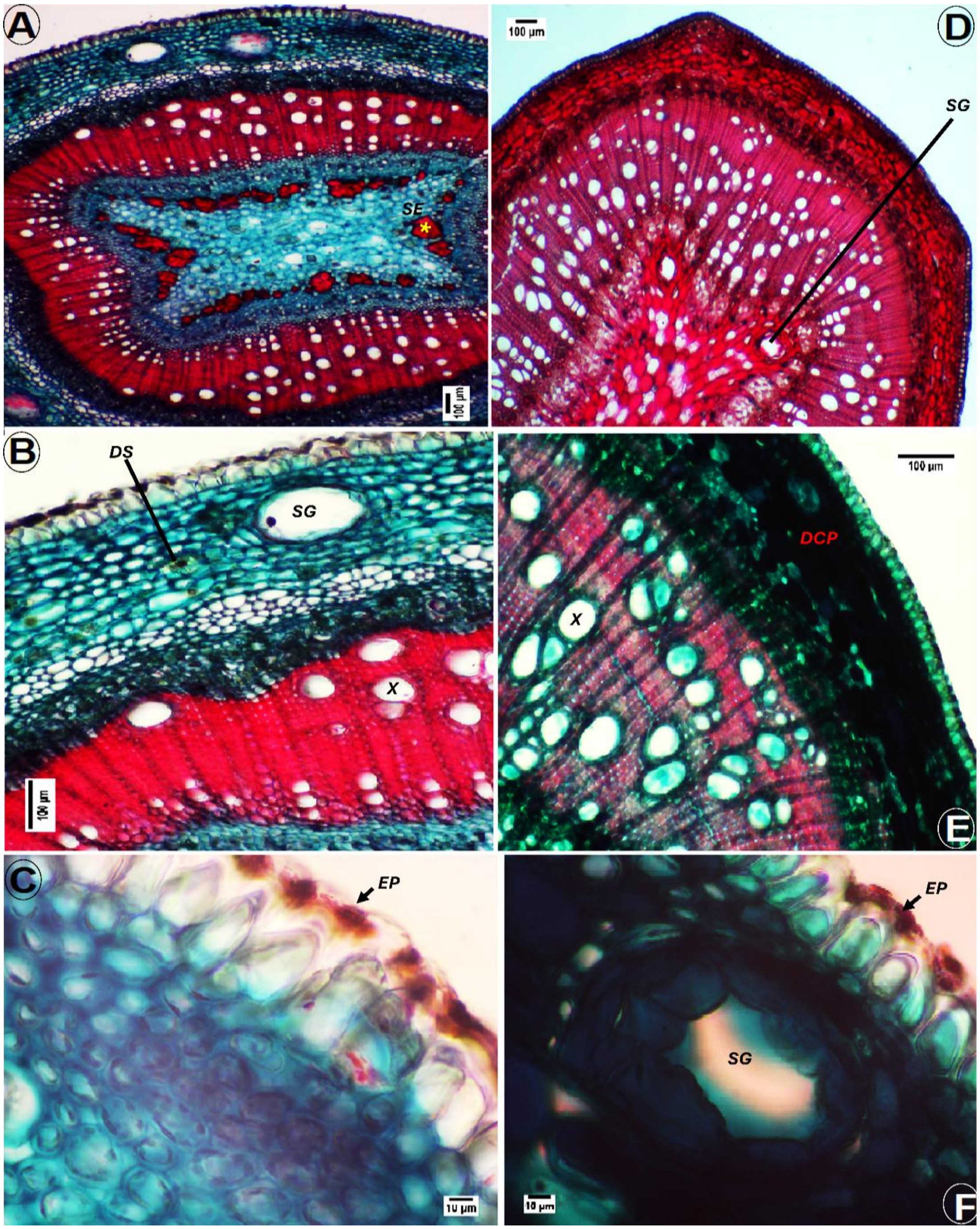

Figure 1: Light micrographs of cross sections in stems of *Eucalyptus camaldulensis* [A-C] and *Corymbia citriodora* [D-F]. (A & D) The general view of the stem sector. (B & E) enlarged part of the vascular structure. (C & F) enlarged part of the epidermis. *SE: Sclereids; SG: Secretory glands; X: Xylem; DS: Druses; DCP: Dark color particles; EP: Epicuticular depositions.

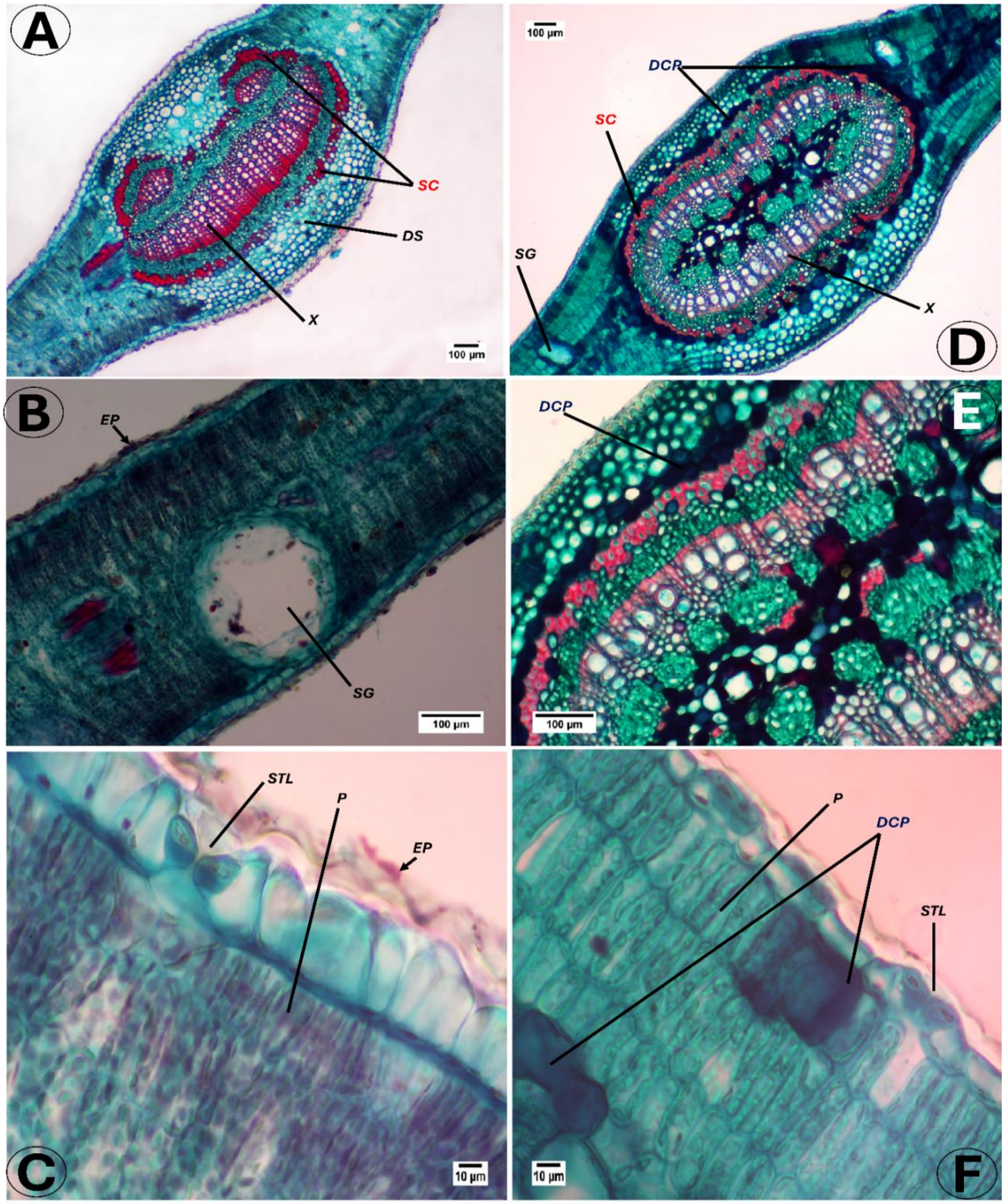

Figure 2: Light micrographs of leaves in *E. camaldulensis* [A-C] and *C. citriodora* [D-F]. (A & D) The general view of the leaf sector. (B & E) enlarged part in the blade (B), and the midrib (E). (C & F) enlarged part of the epidermis and palisade layers. SE: Sclereids; X: Xylem; DS: Druses; SG: Secretory glands; DCP: Dark color particles; EP: Epicuticular depositions; STL: Stomata level; P: Palisade tissue cells.

The main structural plant parts in the stems of *E. camaldulensis and C. citriodora* were similar (Figure 1). Significant differences were detected among the main structural plant parts of the two species studied. The overall size of the stem sector was larger in

C. citriodora, measuring 1.75 mm in length and 2.13 mm in width, compared to *E. camaldulensis* (Table 2). This investigation revealed that the mesophyll thickness was higher in *E. camaldulensis*, *at* 1.02 mm, and in *C. citriodora*, at 0.93 mm. The lamina of *C. citriodora* tree had 3-5 layers of palisade layers, which were 2-3 or a maximum of 4 layers in *E. camaldulensis*. The palisade tissue layers were taller and broader in *E. camaldulensis* than those of *C. citriodora* (Table 1). Santos et al. (2008) also reported variations in the thickness of the palisade layer in *Eucalyptus pyrocarpa* and *E. pilularis*.

Meanwhile, these assimilatory cells were more compact and juxtaposed in *C. citriodora* than in *E. camaldulensis* (Figure 2 C & F). Metcalfe and Chalk (1979) adopted the anatomical layout of *Eucalyptus*. We agree with Santos et al. (2008) in recording the presence of palisade tissue on both adaxial and abaxial leaf surfaces in the species under study. Retamales and Scharaschkin (2015) and Pauzer et al. (2021) reported that Myrtaceae plants usually have palisades on both adaxial and abaxial surfaces. The palisade parenchyma has been considered an adaptive strategy to mitigate the effects of environmental factors, such as high levels of light intensity (Doley, 1978; Gutschick, 1999), which is expected to result in a higher photosynthetic rate in leaves with thicker palisade layers (Bolhar-Nordenkampf and Draxler, 1993).

The vascular system: The characteristics of the vascular system significantly differed between the two tree species. Stem and leaves xylem vessels were larger in number and larger in diameter (40.16 µm, 26.36 µm respectively) in *C. citriodora* than in *E. camaldulensis* (11.72 µm, 16.49 µm respectively) (Figure 1 A & D). We adopted Bryant and Trueman (2015) in the anatomical construction of other eucalypt taxa and *C. citriodora* stems. Each plant part, i.e., stems and leaves, of the two species investigated, had vascular rays intermixed among the vascular tissues. Rays, however, were more in the stem than in the leaves' vascular cylinder (Figures 1 B & E; 2A & D). The findings in this study align with the anatomical structure of the stem and leaves of *E. cinerea* as revealed by Pauzer et al. (2021). Our findings agreed with the results of *E. saligna* by Saulle et al. (2018).

Idioplasts, secretory glands/cavities, and druses were observed in both stems of the two investigated species and in the leaf of *E. camaldulensis* only. The glands were observed within the cortical ground tissue in *the E. camaldulensis* stem (Figure 1 B), while appearing at the outline of the pith in the *C. citriodora* stem (Figure 1E). The secretory cavities have also been investigated in the stem and leaf of *E. cinerea* (Pauzer et al., 2021). Previous studies analyzing this secretory system indicated that volatile oils were present in the secretory cavities of stem and midrib tissues (Saulle et al., 2018; Pauzer et al., 2021).

Druses have been scattered within the cortex of *E. camaldulensis, C. citriodora* stems, and the midribs of *E. camaldulensis*. Cystolith had appeared in the leaf blade of *C. citriodora* only (Figure 2 D). Calcium salts appeared in different morphotype of crystals, one being the druse shape. These insoluble calcium salts revealed the plant species' ability to detoxify soluble oxalic salts (Pauzer et al., 2021). The different shapes and types of insoluble calcium salts have been reported to be valuable for diagnostic purposes (Machado et al., 2019; Almeida et al., 2020; D'Almeida et al., 2021; Brustulim et al., 2020). Weiner and Dove (2003) and Pauzer et al. (2021) revealed that excess calcium precipitates in various calcium salts, including oxalate, carbonate, phosphate, silicate, sulfate, citrate, and/or malate.

The deep dark color is deposited within the stem cortex and peripheral to the vascular cylinder in the leaves of *C. citriodora* (Figure 1B & E). Epicuticular deposits/waxes were observed as covering the epidermal cells of the stem and leaves of *E. camaldulensis*, and the stem only in *C. citriodora* Figure (1 C & F). Sclerenchyma sclereids were deposited at the outline of the pith in the stem of *E. camaldulensis* (Figure 1 A) and surrounding its leaf vascular cylinder (Figure 2 A). They were primarily deposited surrounding the vascular bundle of *C. citriodora* mesophyll (Figure 2 D). Sclerenchyma cells were also found to be present in the stem and midrib of *E. cinerea* (Pauzer et al., 2021).

Table 2. Comparison between stem and leaf structural traits in *Eucalyptus camaldulensis* Dehnh. and *Corymbia citriodora* (Hook.) K.D.Hill & L.A.S.Johnson:

Quantitative Traits	***E. camaldulensis***			***C. citriodora***			**LSD 5%**
	Min	**Max**	**Mean**	**Min**	**Max**	**Mean**	
1. Stem Section Length **SL (mm)**	1.50	1.70	1.61	1.60	1.90	1.75	0.10
2. Stem Section Width **SW (mm)**	1.80	2.10	1.96	2.00	2.30	2.13	0.21
3. Mesophyll Thickness **MT (mm)**	1.01	1.03	1.02	0.90	0.95	0.93	0.01
4. Height of Palisade **HP (μm)**	65.13	141.58	104.04	88.31	207.21	141.16	87.01
5. Number of Palidsade Layers **NP**	2-3(-4)			3-5			
6. Height of Epidermal Cells **HE (μm)**							
Stem	27.75	51.48	39.37	15.42	27.68	21.01	2.38
Leaf	29.84	31.69	30.88	6.73	19.93	12.69	5.40
7. Diameter of Epidermal Cells **DE (μm)**							
Stem	15.56	31.20	21.42	8.75	21.38	13.81	1.91
Leaf	11.65	29.97	21.16	6.28	35.67	19.80	9.88
8. Cuticle Layer Thickness **CT (μm)**							
Stem	6.54	9.02	7.88	4.04	7.61	5.78	3.14
Leaf	3.70	12.06	8.25	3.67	9.19	6.40	5.49
9. Xylem Vessels Diameter **XD (μm)**							
Stem	9.22	13.53	11.72	29.15	49.18	40.16	8.45
Leaf	10.41	21.08	16.49	18.85	32.11	26.36	11.96
Qualitative Traits							
10.Stomata Level **STL**	**Leveled**			**Sligh elevated**			
11.Idioplasts **IDP**	***Stem***		***Leaf***	***Stem***		***Leaf***	
- *Secretory glands* **SG**	+		+	+		-	
- *Druses* **DS**	+		+	+		-	
- *Epicuticular deposits* **EP**	+		+	+		-	
- *Scelereids* **SC**	+		+	-		+	
- *Dark color deposits* **DCP**	-		-	+		+	
- *Cystolith* **CY**	-		-	-		+	

Later, Wilkes (1988) pointed out that *Eucalyptus* species are characterized by substantial genetically predetermined variation in wood and leaf anatomical features within and between trees. Additionally, the results of Santos et al. (2008) and Ramirez et al. (2009) revealed significant differences in vessel coverage of the wood among *E. globulus* clones. Fernández et al. (2019) suggested that the wood/xylem characteristics in *Eucalyptus* species can contribute to widening the knowledge about the role of wood anatomy in angiosperms in adapting to drought cases.

Table 3: Mean height, merchantable height, root collar diameter, and diameter at breast height in the 2nd 5-year rotation of *Eucalyptus camaldulensis* and *Corymbia citriodora* trees

Characters	*E. camaldulensis*			*C. citriodora*			LSD 5%
	Mean	Min	Max	Mean	Min	Max	
Total height of tree (m)	13.00	14.00	13.50	11.00	12.00	11.43	1.50
Merchantable height (m)	12.00	13.50	12.57	10.00	11.00	10.50	3.20
Root collar diameter (cm)	32.00	36.00	34.00	26.00	28.00	27.00	2.48
Diameter at breast height (cm)	26.00	30.60	28.27	19.00	23.00	21.00	5.26

Table 4: Basic area, fresh weight of branches with foliage, dry weight of branches with foliage, and fresh and dry weight of stem per tree in the 2nd 5-year rotation of *Eucalyptus camaldulensis* and *Corymbia citriodora*

Characters	*Eucalyptus camaldulensis*			*Corymbia citriodora*			LSD 5%
	Mean	Min	Max	Mean	Min	Max	
Basal area (m^2)	0.05	0.07	0.06	0.03	0.04	0.03	0.02
Branches with foliage fresh weight (kg)	50.00	53.30	51.77	24.00	26.00	25.10	5.74
Branches with foliage dry weight (kg)	22.00	24.10	23.03	12.00	13.00	12.53	3.29
Stem fresh weight (kg)	200.00	210.30	205.10	150.00	155.00	152.67	6.67
Stem dry weight (kg)	98.00	103.00	100.33	88.00	96.00	91.33	4.30

3.2. Aboveground biomass: Significant variations in minimum and maximum Mean, total height, merchantable height, root collar diameter, and diameter at breast height were observed in the *E. camaldulensis* and *C. citriodora* trees in the second rotation at age 5-years (Table 3). Higher values of mean total height of tree (13.50 m), merchantable height (12.57 m), root collar diameter (34.00 cm) and diameter at breast height (28.27 cm) were consistently detected in *E. camaldulensis* than for *C. citriodora* trees where the mean total height (11.43 m), merchantable height (10.50 m), root collar diameter (27.00 cm) and diameter at breast height (21.00cm).

Getachew et al. (2024) indicated that significant variations were observed between *Eucalyptus* species, i.e., *E. viminalis*, *E. saligna*, and *E. grandis*, in terms of height, volume, survival rate, and mean annual increment. They noted that growth rates varied significantly depending on the *Eucalyptus* species. *E. viminalis* emerged as the thickest in root collar diameter at 33 months after planting. *E. viminalis*, *E. saligina*, and *E. grandis* exhibited different root collar diameters (Leif *et al.*., 2006). Getachew *et al.* (2024) implied that *E. viminalis* and *E. saligina* had comparable growth performance in terms of diameter at breast height, mean height and volume compared to *E. globulus*. These results were from Tesfaye et al. (2002), Tesfaye et al. (2007), and Mengist et al. (2011).

There existed significant differences in basal areas, fresh weight of branches with foliage, dry weight of branches with foliage, and fresh and dry weight of stem per tree in the second rotation at age 5-years for *E. camaldulensis* and *C. citriodora* trees (Table 4). The higher basal area (0.063 m^2/tree), fresh weight of branches with foliage (51.77 kg), dry weight of branches with foliage (23.03 kg), fresh weight of stem (205.10 kg), and stem dry weight (100.33 kg) in *E. camaldulensis* than that in the *C. citriodora* (basal area (0.034 m^2/tree), fresh weight of branches with foliage (25.10 kg), dry weight of branches with foliage (12.53 kg), fresh weight of stem (152.67 kg) and stem dry weight (91.33 kg).

As shown in Table 5, tree species significantly affected aboveground biomass characters. Biomass characters for *E. camaldulensis* i.e. fresh weight of biomass/tree (256.87 kg), dry weight of biomass/tree (123.37 kg), fresh weight of biomass/ha (285.38 ton), dry weight of biomass/ha (137.06 ton), and volume per tree (0.105 m^3) was higher than that in the *C. citriodora* trees (fresh weight of biomass/tree 177.77 kg, dry weight of biomass/tree 103.87 kg, fresh weight of biomass/ha 197.50 ton, dry weight of biomass/ha 115.40 ton, and volume per tree 0.087 m^3). The results revealed that *E. camaldulensis* produced significantly more aboveground biomass than *C. citriodora* in the second rotation. Branches with fresh and dry foliage contribute to the explanation of aboveground biomass, stem fresh and dry weight, and the total volume of aboveground biomass in both fresh and dry forms. The biomass measurements obtained in our study were higher than those reported by Brito et al. (1983) for 10-year-old *Eucalyptus grandis* and *Eucalyptus pilularis* plants. The higher accumulated biomass in *E. camaldulensis* over *C. citriodora* plantations can be explained by the genetic variations among the studied species (Nardini *et al.*, 2020). Fang et al. (1999) evaluated growth and biomass production in short-rotation poplar plantations and found variations in the tested parameters for the three studied poplar clones. Our findings confirm that the growth performance and biomass production of the plantations are influenced by clones and planting practices (Swamy et al., 2006; Nelson et al., 2018; Tun et al., 2018).

3.3. Physical and chemical wood properties:

3.3.1. Physical properties: Results in Figure 3 present the average values of the wood density and moisture content in the second rotation cycle of *E. camaldulensis* and *C. citriodora* wood; the average density of *C. citriodora* (0.70 g/cm.^{3}) and was higher than that of *E. camaldulensis* (0.59 g/cm.^{3}). On the other hand, *C. citriodora* wood had an average moisture content of 38.62% and was lower than E. *camaldulensis* (48.43%). It is noticeable that the density and moisture content of wood differ in the two tree species, while the density is higher in *C. citriodora* than in *E. camaldulensis*. This may be due to the growth speed of *E. camaldulensis* being higher than that of *C. citriodora*, resulting in a decrease in wood density with a higher moisture content in *E. camaldulensis*. These results were assured by De Jesus and Rossmann (1988), who reported that *Eucalyptus* had lower wood density than *Leucaena* and had higher moisture content. In this respect, Lopes et al. (2023) evaluated the physical wood properties of *Eucalyptus* and *Corymbia* clones, indicating that the *Corymbia* clone had the highest average basic density compared to *Eucalyptus* clones. On the other hand, Segura and Silva Júnior (2016) explained that Corymbia clones exhibit longer fibers, greater wall thickness, smaller lumen width, and a higher wall fraction compared to Eucalyptus clones, which directly contributes to the higher wood density of *Corymbia.*

3.3.2. Chemical properties: A significant difference existed among the mean values of the tested chemical parameters (Figure 4). Across the two tree species, the lignin percentage in *C. citriodora* wood was consistently higher than that of *E. camaldulensis*. Lignin % was 30.0% in *C. citriodora*, while 28.20% for *E. camaldulensis* Cellulose (%) in *E. camaldulensis* wood was consistently higher than *C. citriodora*. Cellulose % was

47.26% in *E. camaldulensis*, and 46.23 % in *C. citriodora*. Hemicellulose % in *E. camaldulensis* wood was consistently higher than those of *C. citriodora*. Hemicellulose % was 24.5 in *E. camaldulensis*, while 23.75% for *C. citriodora*. Holocellulose % in *E. camaldulensis* wood was higher than that of *C. citriodora*. Holocellulose % 71.8% in *E. camaldulensis*, while 70.00 % for *C. citriodora*. Pentosans percentage in E. camaldulensis wood was higher than that of *C. citriodora*. The pentosan percentage was 14.0% in E. camaldulensis, while it was 13.30% for *C. citriodora*. The extractive percentage in *C. citriodora* wood was higher than that of *E. camaldulensis*. Extractive % was 3.60% in *C. citriodora*, and 4.20% for *E. camaldulensis*.

The ash percentage was 0.20% in C. citriodora, and it was also 0.2% for *E. camaldulensis*. Regarding the elemental contents, the percentages of nitrogen and carbon increased in *C. citriodora* wood compared to *E. camaldulensis* wood. On the contrary, the oxygen and hydrogen content in *E. camaldulensis* wood is higher than that of *C. citriodora.* The relative percentages of these chemical constituents of wood are essential determinants for cellulose yield and processing efficiency in the pulping process. Generally, high holocellulose contents are considered desirable, while extractives and lignin can conflict with the pulping process, resulting in lower-quality pulp.

Table 5: Aboveground biomass fresh and dry weight, and total volume in the 2nd 5-year rotation of *Eucalyptus camaldulensis* and *Corymbia citriodora*

Characters	*E. camaldulensis*			*C. citriodora*			LSD 5%
	Mean	Min	Max	Mean	Min	Max	
Aboveground biomass FW (kg/tree)	250.00	263.60	256.87	176.00	180.30	177.77	11.71
Aboveground biomass DW (kg/tree)	120.00	127.10	123.37	101.00	108.60	103.87	3.29
Aboveground biomass FW (ton/ha)	277.75	292.86	285.38	195.54	200.31	197.50	12.98
Aboveground biomass DW (ton/ha)	133.32	141.21	137.06	112.21	120.65	115.40	3.55
Total volume (m^3/tree)	0.10	0.11	0.10	0.08	0.09	0.09	0.01

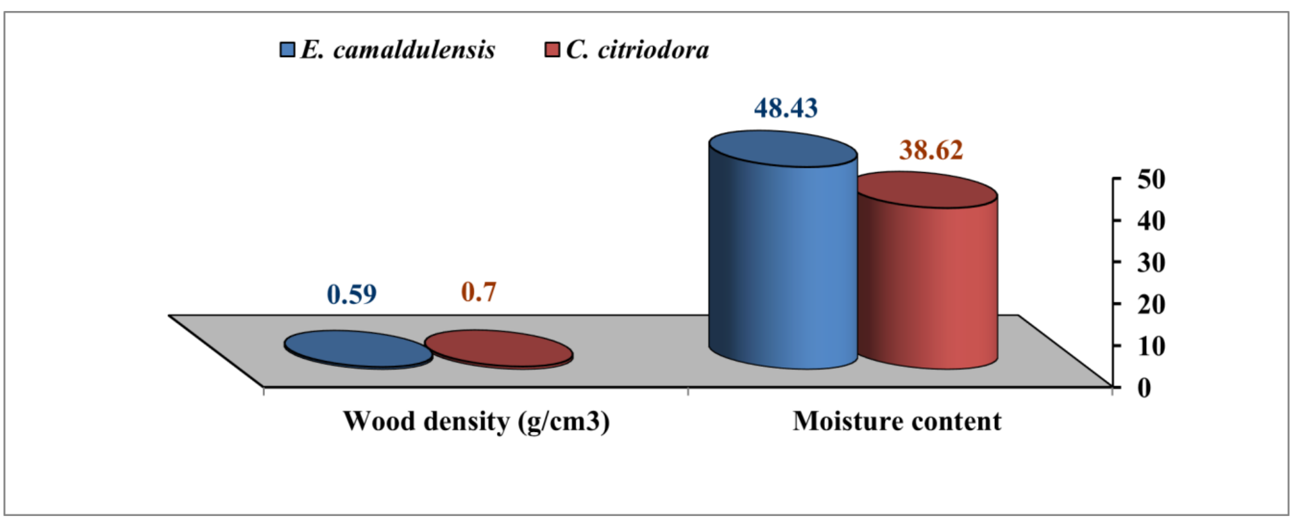

Figure 3: Average values of the wood density (g/cm^3) and moisture content (%) in the 2nd 5-year rotation of *Eucalyptus camaldulensis* and *Corymbia citriodora*

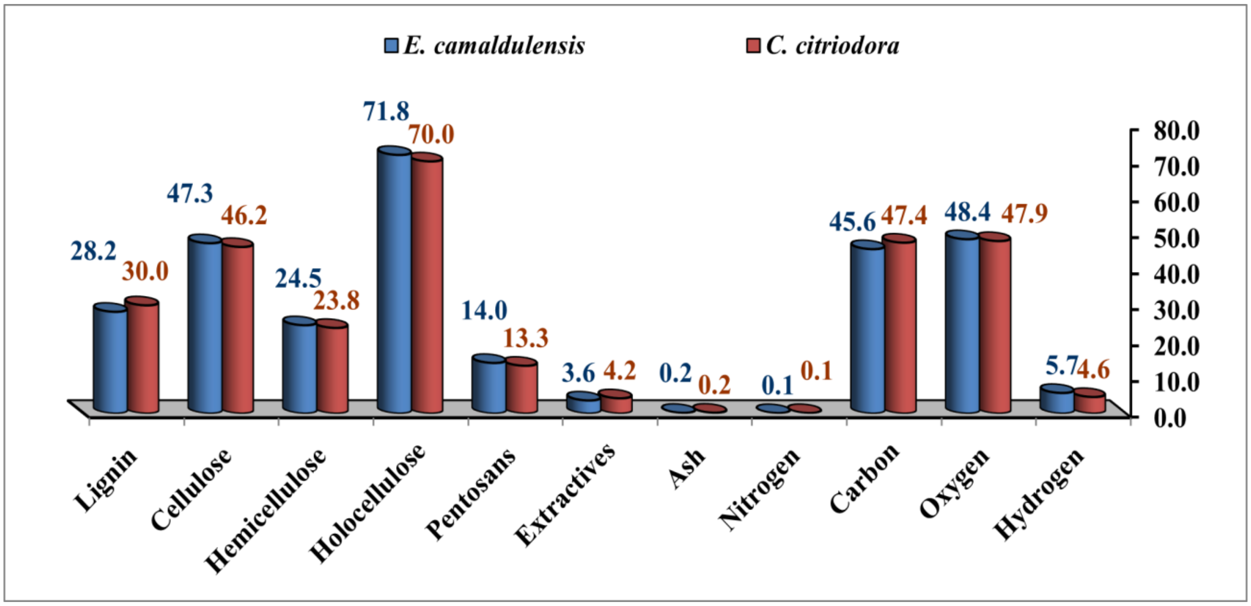

Figure 4: Average values of the chemical composition in the 2nd 5-year rotation of *Eucalyptus camaldulensis* and *Corymbia citriodora*

Our results in this study revealed that the holocellulose percentage was higher in *E. camaldulensis* wood compared to *C. citriodora*. Meanwhile, the lignin and ash content of *E. camaldulensis* wood decreased relative to *C. citriodora*. These results are consistent with those of others (Moulin et al., 2015; Segura and Silva Júnior, 2016; Lopes et al., 2023). Hsing et al. (2016) estimated the lignin content to be between 20.41% and 22.93% in five Eucalyptus tree hybrids over 27 months.

Garcia et al. (2016) studied hybrid clones of Eucalyptus trees at 24 months and found that the lignin content ranged from 21.16 to 23.64%. In contrast, the present study indicated that the lignin level in Eucalyptus trees was higher than these values. The values of cellulose percentage in the present study are similar to those reported by Hsing et al. (2016), who suggested that the cellulose content in Eucalyptus trees at 27 months ranged between 46.04% and 50.12%. At the same time, Morais et al. (2017) reported that the mean values of wood cellulose in Eucalyptus trees at 36 months were 42.4%.

4.Conclusions

This study concluded that using treated wastewater for tree irrigation resulted in valuable tree biomass and good chemical and anatomical characteristics, as represented by *Eucalyptus camaldulensis* and *Corymbia citriodora*. These trees can be expanded because they produce good biomass in a short-cutting cycle compared to slow-growing trees. This highlights the importance of planting other woody trees irrigated with treated wastewater and evaluating their anatomical and growth attributes. The difference in biomass production and chemical properties of *E. camaldulensis* compared to *C. citriodora* provides a broader range of choices depending on the required wood industry. These two species are recommended for inclusion in various afforestation programs in Egypt to contribute to sustainable development.

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