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WOOD ANATOMY OF *FLUEGGEA ANATOLICA* (PHYLLANTHACEAE)

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SUMMARY

Wood anatomy of *Flueggea anatolica* Gemici, a relictual endemic from southern Turkey, is described and compared with wood of its presumed relatives in Phyllanthaceae (formerly Euphorbiaceae subfamily Phyllanthoideae). Wood of this critically endangered species may be characterized as semi-ring porous with mostly solitary vessels bearing simple perforations, alternate intervessel pits and helical thickenings; imperforate tracheary elements include helically thickened vascular tracheids and septate libriform fibers; axial parenchyma consists of a few scanty paratracheal cells; rays are heterocellular, 1 to 6 cells wide, with some perforated cells present. Anatomically, *Flueggea anatolica* possesses a syndrome of features common in Phyllanthaceae known in previous literature as *Glochidion*-type wood structure; as such, it is a good match for woods from other species of the genus *Flueggea*.

Key words: *Flueggea anatolica*, Euphorbiaceae, Phyllanthaceae, wood anatomy, Turkey.

INTRODUCTION

The current concept of the genus *Flueggea* Willdenow stems from the work of Webster (1984) who succeeded in disentangling the genus from a welter of other Euphorbiaceae (*sensu lato*). Although previously recognized as distinct by a few botanists (Baillon 1858; Bentham 1880; Hooker 1887), most species of *Flueggea* had been confounded with the somewhat distantly related genus *Securinega* Commerson *ex* Jussieu in the seminal classifications of Euphorbiaceae (*sl*) published by Mueller (1866) and Pax & Hoffmann (1931). Webster (1984) accepted 13 species scattered through the tropics and extending to temperate latitudes in the Old World. Subsequently, the rare Hawaiian endemic *Neowawraea* Rock was recognized as an overlooked member of the genus (Hayden & Brandt 1984; Hayden 1987) and *Flueggea anatolica* Gemici, another rare species and the subject of this paper, was discovered in southern Turkey (Gemici 1993; Gemici & Leblebici 1995), bringing the species tally to 15. If united with *Richeriella* Pax & Hoffmann, as suggested by recent molecular data (Kathriarachchi *et al*. 2006), the number of species classified in *Flueggea* could increase to 17.

Flueggea anatolica is known only from the type locality, a c. 1 hectare region in the Cilician Toros Mountains (Gemici 1993; Gemici & Leblebici 1995; Gemici 2000). Morphologically it closely resembles *F. virosa* (Roxb. *ex* Willd.) Voigt, the most wide-

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spread species in the genus, ranging (as two subspecies) from western Africa through tropical Asia, Indonesia, and tropical Australia (Webster 1984). *Flueggea anatolica* and *F. virosa* may be separated on the basis of small differences in leaf surface luster, degree of pistillode division, length of fruiting pedicels, and seed surface texture. Not only is *F. virosa* similar morphologically to *F. anatolica*, it is also close geographically, being present in the Nile River valley in Egypt.

Flueggea anatolica has been interpreted as a relict from Tertiary times when warm and moist conditions prevailed throughout the northern hemisphere (Zachos *et al.* 2001) and when, presumably, *Flueggea* species were more widely distributed north of their current ranges. As the Pleistocene brought cooler and drier conditions to northern regions, elements of their Tertiary floras responded by extinction or range contraction to the south. Some plants found refuge among the south-facing valleys and gorges of southern Turkey in sites with warmth and moisture suitable to their physiological requirements. Other Tertiary relicts of southern Turkey include species like *Ajuga postii* Davis and *Liquidambar orientalis* Mill. (Gemici & Leblebici 1995).

To understand better the biology and relationships of this obscure, rare shrub, we undertook this first study of its wood anatomy.

MATERIALS AND METHODS

Wood samples of *Flueggea anatolica* were collected in the Tarsus–Kadincik valley, Mersin, Turkey, 270 m a.s.l., UTM: 0658567, 4107623 from the southern part of Anatolia. One specimen, *B. Serdar 7503* (with herbarium vouchers at KATO and URV), a stem of 3 cm diameter, was selected for anatomical study. Standard techniques were used in preparation of wood sections which were stained with safranin and alcian blue (Ives 2001) or safranin and hematoxylin (Johansen 1940); macerations were prepared using Schultze's method (Normand 1972) or via Jeffrey's solution (Johansen 1940). In general, quantitative features are based on 25 measurements or counts per character; however, lengths of axial elements are based on 50 measurements of each cell type. Terminology used is in accordance with the list of microscopic features for hardwood identification (IAWA Committee 1989).

Sections of the following woods were consulted for comparison with *F. anatolica*: *F. acidoton* (L.) Webster: *Uw 14649, Uw 18718 – F. flexuosa* Muell. Arg.: *Uw 14650, Uw 24716, Craven & Schodde 530 – F. leucopyrus* Willd.: *Uw 11054 – F. neowawraea* W. J. Hayden: *Degener et al. 4371, St. John et al. 11354, Webster et al. 13889 – F. suffruticosa* (Pallas) Baillon: *Hayden 1897 – F. virosa* (Roxb. *ex* Willd.) Voigt: *Uw 14651*.

Figures 1–4. *Flueggea anatolica* Gemici. – 1 & 2: TS, growth ring boundaries. – 1: Two growth rings, vessels semi-ring porous, and tracheids at growth ring boundary. – 2: Thick-walled and somewhat radially flattened latewood tracheids (below), earlywood vessel (above, left), and somewhat radially elongate fibers (above, right). – 3: RLS, erect ray cells (below), vessel element with partial simple perforation (above, right), tracheids with bordered pits and helical thickenings (above, center), and septate libriform fibers (above, left). – 4: TLS, uniseriate and multiseriate rays among a preponderance of tracheids. — Scale bars of Fig. 1 & 2 = 100 μm; of 3 & 4 = 50 μm.

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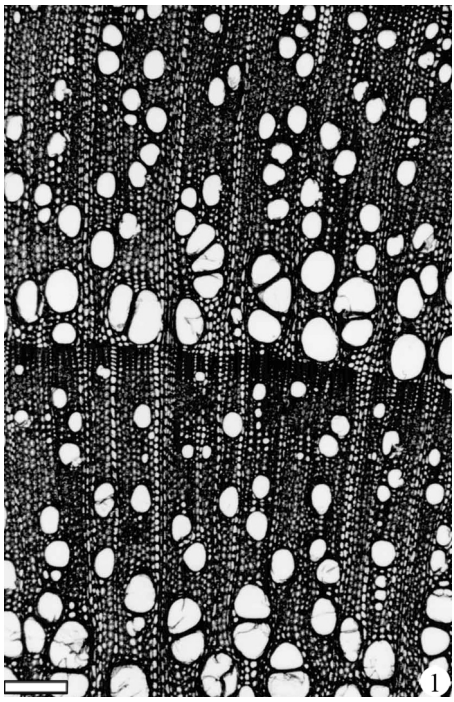

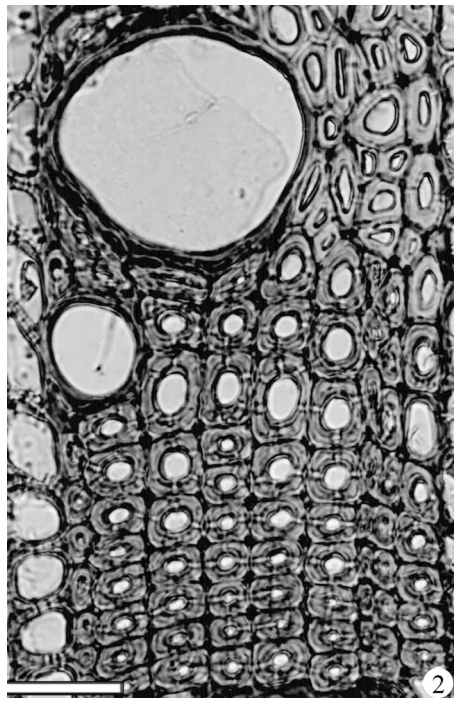

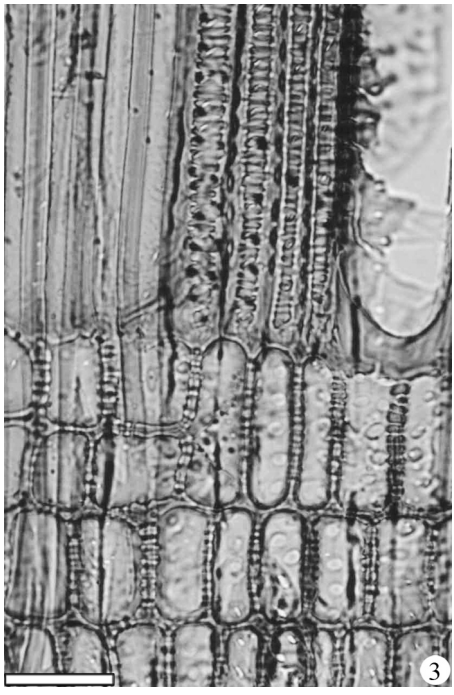

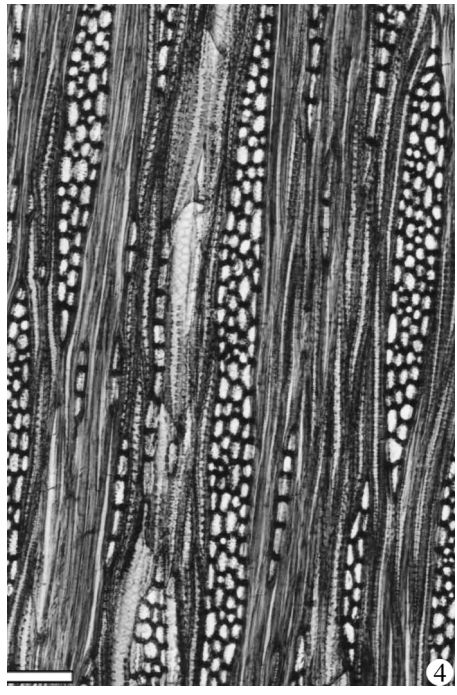

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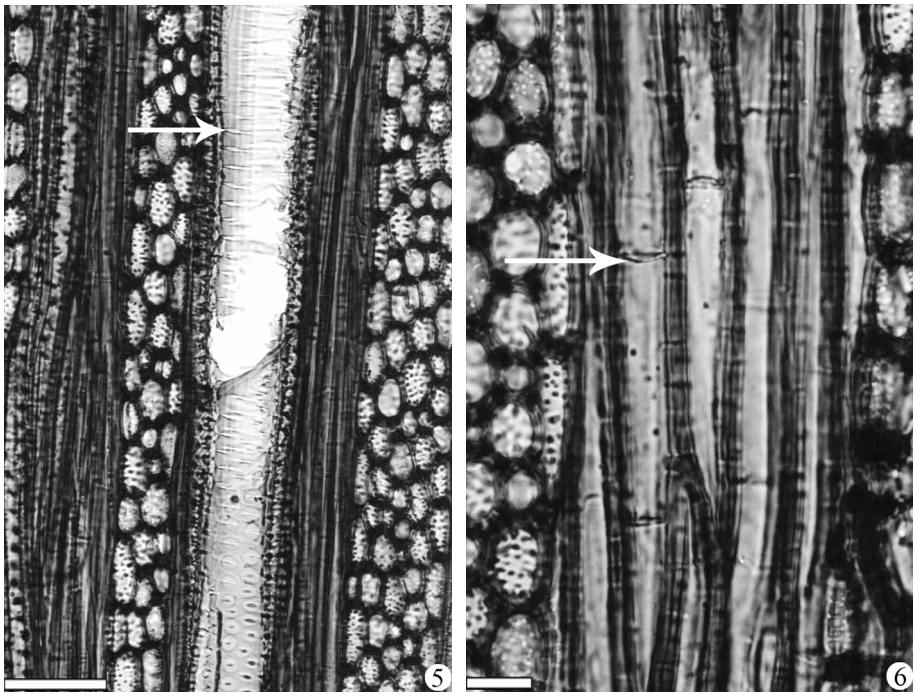

Figure 5 & 6. *Flueggea anatolica* Gemici. – 5 & 6: TLS. – 5: Helical thickening in vessel body (arrow) and tracheids. – 6: Septate libriform fibers (arrow). — Scale bar of Fig. 5 = 50 μm; of 6 = 20 μm.

RESULTS

Wood semi-ring porous, growth ring boundaries distinct, terminal latewood composed of somewhat radially flattened vascular tracheids (Fig. 1 & 2). Vessels mostly solitary, the remainder in radial multiples or, occasionally, clusters of 2–5 cells in the beginning of earlywood (Fig. 1). Vessels many to numerous, 50 (40–59) per mm^2; small, average tangential × radial diameter 81 (62–100) μm × 104 (77–146) μm in the earlywood, 38 (24–53) μm × 49 (29–72) μm in the latewood; outline mostly rounded in cross section. Average vessel element length 270 (180–370) μm; perforation plates predominantly simple in oblique end walls (Fig. 5). Intervessel pits mostly alternate, of medium size (7–10 μm vertical diameter). Vessel walls frequently with faint helical thickenings (Fig. 8). Vessel–ray pits with much reduced borders to apparently simple, pit outline rounded or angular, smaller than the intervessel pits. Thin-walled tyloses present in the heartwood. Vascular tracheids 288 (130–580) μm long; thin- to thick-walled, the lumina distinctly open and about equal to the double wall thickness; pits bordered, on both radial and tangential walls; walls with prominent helical thickenings (Fig. 3–5, 7). Libriform fibers septate (Fig. 6); 612 (410–750) μm long; varying from very thin- to somewhat thick-walled, the lumina generally open (except near the end of cells) and ranging from more than three times wider to about equal to the double wall thickness,

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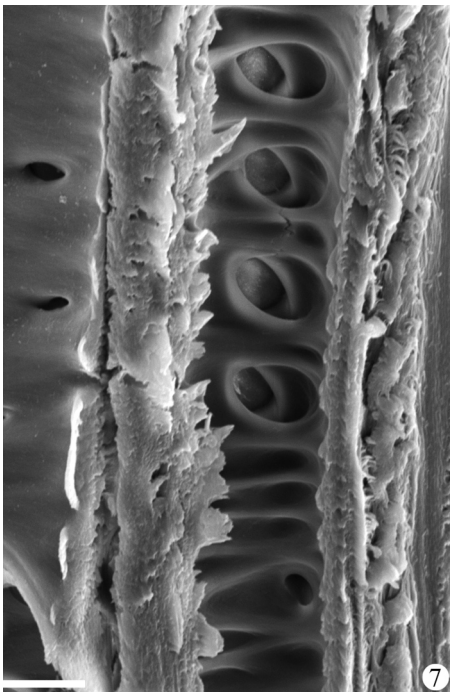

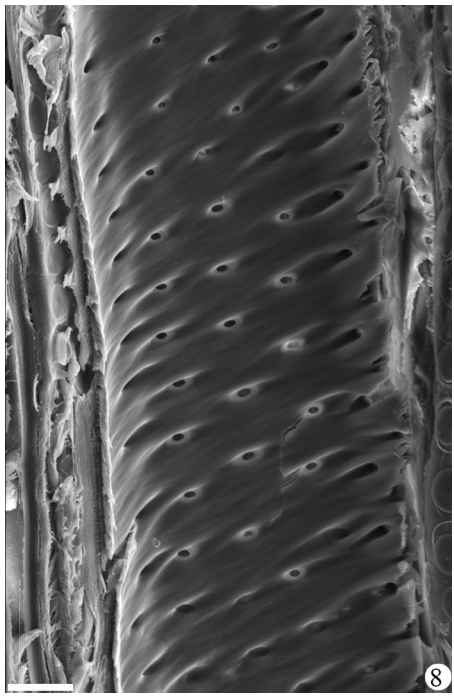

Figure 7 & 8. *Flueggea anatolica* Gemici. – 7: RLS, tracheid, bordered pits and helical thickenings. – 8: RLS, vessel element with contoured inner wall surface, and alternate intervessel pits. — Scale bar of Fig. 7 = 5 μm; of 8 = 10 μm.

somewhat radially elongate in cross section (Fig. 2); helical thickenings absent; gelatinous layers sometimes present. Axial parenchyma infrequent, the few cells present found in scanty paratracheal positions. Rays 10 (9–12) per mm; both uniseriate and multiseriate (Fig. 4); heterocellular, consisting of mostly square cells and erect cells (Fig. 3 & 4), but with a few procumbent cells; uniseriate rays up to 12 cells or about 500 μm tall, almost exclusively composed of square and erect cells; multiseriate rays 786 (369–1515) μm tall and 2–6 cells wide, the multiseriate portion consisting of a few procumbent and many square cells, the uniseriate wings consisting mostly of erect cells; perforated ray cells present; crystals absent; tannin deposits sparse; growth ring boundaries slightly distended by multiseriate rays.

DISCUSSION

Comparison with other woods from the genus Flueggea

From the material available for study, it is evident that woods of the genus *Flueggea* share general similarities but differ in certain details. Of the species studied, *F. suffruticosa* appears most similar to *F. anatolica*; both woods have similarly abundant groups of tracheids with prominent helical thickenings, faint helical thickenings

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in vessel elements, a high percentage of solitary vessels, and paucity of tannin deposits in wood cells (Benkova & Schweingruber 2004). It should be noted that Benkova and Schweingruber (2004) illustrated the tracheids of *F. suffruticosa* but failed to mention them in their description of this species. Noteworthy differences between woods of *F. anatolica* and the other species studied include: presence of numerous vessels in long radial multiples in *F. neowawraea*; absence of tracheids in *F. acidoton*, *F. flexuosa*, and *F. leucopyrus*; very thin-walled fibers in *F. flexuosa*, *F. leucopyrus* and *F. neowawraea*; notably narrow rays with an abundance of uniseriates and tall, well-developed uniseriate wings on multiseriate rays in *F. virosa*; and much more heterocellular rays (more numerous procumbent cells) in *F. flexuosa*. Overall, *F. anatolica* fits well within the range of wood structure exhibited among the species of *Flueggea* available for study.

Comparison with woods of Phyllanthaceae

Metcalfe and Chalk (1950) distinguished three groups of genera among the biovulate Euphorbiaceae (*s.l.*) on the basis of wood structure; they referred to these groups as the *Aporusa*-type, the *Glochidion*-type, and "other genera". Many woods of the "other genera" category were subsequently segregated as elements of subfamily Oldfieldioideae (now Picrodendraceae) (Webster 1975, 1994; Kathriarachchi *et al*. 2005), and are thus of no further concern here. The remaining two wood syndromes found in Phyllanthaceae are starkly distinct (Metcalfe & Chalk 1950; Hayden & Brandt 1984; Mennega 1987). *Aporusa*-type woods are characterized by: scalariform perforations or mixed scalariform and simple perforations; non-septate, thick-walled imperforate tracheary elements; and axial xylem parenchyma that is abundant in diffuse, diffuse-in-aggregates, or short banded patterns. In contrast, *Glochidion*-type woods are characterized by: simple perforation plates; thin-walled septate fibers; and axial parenchyma that is absent or very scarce in a scanty paratracheal pattern. *Flueggea* wood conforms in all respects with the *Glochidion*-type.

Recent classifications of Euphorbiaceae based on traditional (non-molecular) characters, routinely place *Flueggea* among the genera of tribe Phyllantheae subtribe Flueggeinae Muell. Arg. (Webster 1994; Radcliffe-Smith 2001), the 'core' of which may be characterized to include: *Breynia* J.R. & G. Forst., *Flueggea* Willd., *Glochidion* J.R. & G. Forst., *Margaritaria* L. f., *Phyllanthus* L., *Reverchonia* A. Gray, *Richeriella* Pax & Hoffm., and *Sauropus* Blume. These 'core' genera of Flueggeinae all possess *Glochidion*-type wood structure (Metcalfe & Chalk 1950; Mennega 1987; Hayden, unpublished observations for *Reverchonia*). Furthermore, the 'core' genera consistently occupy the same branch in several recently published molecular phylogenies (Wurdack *et al*. 2004; Kathriarachchi *et al*. 2005, 2006). The concordance between molecular and morphological/anatomical data, however, is not complete. *Savia bahamensis*, which possesses *Aporusa*-type wood structure, consistently appears as sister taxon to *Flueggea* and *Richeriella* in the phylogenies cited above and, although somewhat basal in the lineage, *Lingelsheimia*, another *Aporusa*-type wood, also occurs among the genera of Fluegginae in all four cladograms published by Kathriarachchi *et al*. (2005).

The eight genera of Fluegginae (Radcliffe-Smith 2001) constitute just a small portion of the diversity of Phyllanthaceae. Phyllanthaceae is a pantropical family of some 59

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genera and approx. 2,000 species that range from large forest trees to xeromorphic shrubs and ericoid subshrubs. Woods with *Glochidion*-type and *Aporusa*-type structure occur across this diversity. In general, mapping of wood anatomical characters on molecular phylogenies of Phyllanthaceae reveals the same pattern discussed above for Flueggeinae, concordance of wood and molecular data in some branches, and conflict in others.

It is interesting to note that not only is Phyllanthaceae heterogeneous in terms of the wood structure of its constituent genera, but that woods with *Glochidion*-type structure are also commonly encountered in other families, for example, Anacardiaceae, Burseraceae, Flacourtiaceae, and Lauraceae (Wheeler 1991). Indeed, similar fossil woods assigned to the form-genus *Paraphyllanthoxylon* have been recovered from mid-Cretaceous to Paleocene deposits of North America, Europe, and southern Africa (Wheeler 1991). Despite the eponymous allusion to *Phyllanthus*, affinities of *Paraphyllanthoxylon* fossils are not known. It is striking, therefore, to contemplate that within Phyllanthaceae, *Aporusa*-type and *Glochidion*-type woods have diverged so sharply from each other and that the latter have adopted – or converged upon – a structural syndrome found in at least four different orders of extant angiosperms and also known across no less than 100 million years of evolutionary time. The evidence simultaneously suggests that wood structure can be remarkably labile and profoundly stable in the course of evolution.

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