International Journal of Bio-resource and Stress Management 2016, 7(2):229-246 DOI: HTTPS://DOI.ORG/10.23910/IJBSM/2016.7.2.1549

Full Research Article

Comparative Wood Anatomy of 20 Woody Plant Species in Northeastern Mexico and its Significance

Ratikanta Maiti[1], Humberto Gonzalez Rodriguez[2*], Jeff Christofher Gonzalez Diaz[3], HaydeeAlejandra Duenas Tijerina[4], Arturo Allejandro Chavez Flores[5], Aruna Kumari[6] and N. C. Sarkar[7]

[1-5]Universidad Autonoma de Nuevo Leon, Facultad de Ciencias Forestales, Carr. Nac. No. 85 Km. 45, Linares, Nuevo Leon (67 700), Mexico
[6]Dept. of Physiology, Professor Jaya Shankar Telangana State Agricultural University, Agricultural College, Polasa, Jagtial, Karimnagar, Andhra Pradesh (505 529), India
[7]Dept. of ASEPAN, Institute of Agriculture, Visva-Bharati, PO. Sriniketan, Birbhum (Dist), West Bengal (731 236), India

Article History

Manuscript No. AR1549
Received in 28th February, 2016
Received in revised form 30th March, 2016
Accepted in final form 4th April, 2016

Correspondence to

**E-mail*: humberto.gonzlez@uanl.mx

Keywords

Wood anatomy, porosity, vessel characteristics, wood fibres, adaptation

Abstract

A study has been undertaken on wood anatomy of 20 woody species in northeast Mexico. There exists large variation among species in wood anatomical traits such as porosity, vessel diameter, its distribution, parenchyma, compactness of ground tissues and fibre cell characteristics. Most of the species have narrow vessels which help protection against cavitation. Most of the species are ring to semiring porous viz., *Acacia amentacea, Acacia berlandieri, Acacia shaffneri, Acacia wrightii, Cordia boissieri, Helietta parviflora, Condalia hookeri, Xanthoxylum fagara, Celtis pallida, Celtis laevigata, Caesalpinia mexicana, Eysenhardtia polystachya*; only few of them are diffuse porous viz., *Diospyros palmeri, Diospyros texana.* Fibre cell characteristics also showed large variations in morphology, size, lumen breadth and in compactness, these species were soft and hard wood. Most of the species have narrow vessels, *viz*., *Acacia berlandieri, Acacia shaffneri, Acacia wrightii, Helietta parviflora, Cordia boissieri*, *Diospyros palmeri*, *Celtis laevigata*, *Eysenhardtia polystachya, Xanthoxyllum fagara*. *Celtis pallida* contained medium sized vessels, while Celtis *laevigata* and *Caesalpinia mexicana* possessed big sized vessels. Many of the species possess narrow vessels which although impose transport of water but protect the vessels against cavitation during drought and freezing the species with small narrow vessels mentioned have strategy to adapt both to hot and cold climate against cavitation. The species having big vessel diameter may be susceptible to drought such as *Celtis pallida, Caesalpinia mexicana* or they may have deep root system for adaptation to semiarid climates in northeast Mexico. All these wood anatomical traits could be utilized to distinguish species as well as quality determinations of species. The variation in hydraulic systems determine the capacity of water transport among species Statstically significant differences are observed in all wood anatomical parameters among species studied.

1. Introduction

Wood is an important product of woody plants for wood industry. Wood is a hard, fibrous structural tissue present in the stems and roots of woody plants. Its main use is for furniture and building construction (Reid et al., 1990) and also used as firewood for thousands of years. Wood is formed by the secondary growth of cambium which produce secondary xylem vessels, wood fibres and wood parenchyma. The timber having highly lignified fibre cells are expected to contribute strength and produce hard wood useful for the manufacture of furniture, while softwood having thin walled fibre cells and high amount of wood parenchyma are suitable for soft furniture, fencing or paper pulp.

A study on the on anatomy of softwoods and the hardwoods of the world demonstrate a dazzling endgrain patterns and intricate motifs. The decrease in the maximum effective opening diameter with an increase in the thickness of the cross section is greater for the heartwood than for the sapwood (Stamm, 1972). Few studies have been undertaken on ultrastructural and biochemical changes in the development of wood elements.

Increasing concentrations of ions flowing through the xylem of plants produce rapid, substantial, and reversible decreases in hydraulic resistance. Changes in hydraulic resistance in response to solution of ion concentration, pH, and nonpolar solvents are observed with this process being mediated by hydrogels. One of the properties of polysaccharide hydrogels is to swell or shrink due to imbibition. This remarkable control of water movement may allow the plant respond to drought conditions (Zwieniecki et al., 2001). Interlocked grains cause change in the orientation of axial elements. In a study, vessel and fibre orientations in *Acacia mangium* Willd were compared macroscopically and microscopically to analyze the interlocked grain. Fibre orientation manifested on some radial splits also was heterogeneous. They measured the fibre orientation angle with reflecting and polarized light microscopy, respectively, and fast Fourier transform. Both vessel and fiber orientations had a similar radial tendency and distinct inversion of the grain. However, the vessel orientation had a larger amplitude of change than fiber orientation (Ogata et al., 2003).

The seconday wall structure of tension wood of *Laetia procera* Poepp. (Flourtiaceae), revealed alternate arrangement of thick and thin layers with S1+S2+S3 Using UV microspectrophotometry. It was observed that in the thick secondary wall, cellulose microfibril angle is very low (very close to fibre axis) and cellulose microfibrils are well organized but in thin layer the cellulose microfibrils are less organized and oriented with a large angle in the axis of the cell. Thick layers are highly lignified (Ruelle et al., 2007).

Structural heartwood characteristics for *Prosopis laevigata* (Humb. & Bonpl. *Ex* Willd.) M.C. Johnst., using light microscopy coupled with a digitised image analysis system were identified. The average fibre length is 975 μm, the fibres are thick-walled with a single cell wall thickness of 13 μm on average. Average diameter of the vessels which are arranged in non-specific patterns differs significantly between earlywood (116 μm) and latewood (44 μm). The chemical distribution of lignin and phenolic deposits in the tissue was investigated by means of scanning UV microspectrophotometry (UMSP). Monosaccharides were qualitatively and quantitatively determined by borate complex anion exchange chromatography. Holocellulose content ranged between 61.5 and 64.7% and Klason lignin content between 29.8 and 31.4%. Subsequent extraction of the soluble compounds was performed with petrolether, acetone/water and methanol/water by accelerated solvent extraction (ASE). Major compounds in acetone/water extracts were identified as (-)-epicatechin, (+)-catechin and taxifolin, and quantitatively determined by liquid chromatography (Carrillo et al., 2008). Later, a study undertaken on wood anatomy and ultra structure of the 3 species of wood of *Prosopis,* viz.„ *Prosopis vinalillo, Prosopis alba* and *Prosopis nigra* growing in heterogeneous forest dry Chaqueno Park reveal that the 3 species show similarity in the structural features of the subfamily Mimosoideae. However, the number of vessels/mm^2 was quite variable between species and between individuals of the same species. Samples observed under scanning electron microscope the ornaments in pits and striations on the vessels walls were observed. These striations were shown to be characteristics of the 3 *Prosopis* species studied (Bolzon de Muniz et al., 2010). Environments play a great role on wood anatomical characters and measured in tree-rings have proved to be useful in dendrochronology. A study was undertaken on wood anatomical features measured in tree-rings in the East-Ore Mountains, Germany in rings of trees grown under severe stresses. It is observed that environmental changes have caused modifications or adaptations of structural features in dated tree-rings. Overall, wood anatomy reveals clearly that growth and development of trees reflects dynamic processes (Wimmer, 2002). Another study on wood antomy and annual rings of *Prosopis pallida* in the arid and semi-arid lands of the American continent revealed that *P. pallida* has well-differentiated annual growth rings which is related well with precipitation events related to El Nino Southern Oscillation phases (Lopez et al., 2005).

A comparative study undertaken on macroscopic and microscopic anatomical characteristics of five species of the family Rosaceae, *Crateagus mexican*, *Pyrus cummunis*, *Pyrus malus*, *Prunus americana* and *Prunus domestica, s*howed similar macro and microscopic characteristics (Perez Olvera et al., 2008). There exists a large variability in size, cell wall thickness and lumen breadth which may predict the quality and utility of the particular species (Maiti et al., 2015).

Wood anatomical traits are found to be related to the adaptation of woody plants to environmental stresses. A study was undertaken on the anatomical heartwood characteristics viz., fiber length (μm), diameter of vessels (μm), and the area of the vessels (μm^2). It was observed thatin the locality Linares, Nuevo Leon, Mexico, with higher precipitation and lower temperature the wood showed higher fibre length and higher diameter of the vessels than China, Nuevo Leon (Carrillo-Parra et al., 2013).

In addition to the basic studies on the growth and development of wood elements, wood anatomical features play important role in the phylogeny of the species and also the adaptive capacity of the species to environmental stresses. Xylem vessel characteristics (such as length, breadth, perforation plates orientation and pits) predict general ecological and phylogenetic trends in wood anatomy, which suggest possible evolutionary tremds on the basis of the xylem vessel and other traits (Bailey and Tupper, 1918; Carlquist, 1975, 1980; Baas, 1976, 1982; Baas et al., 1983, 2004; Ewers and Fisher, 1991). The hydraulic architecture of woody plants determine the adaptative strategies to adverse climatic conditions of woody plants (Carlquist, 1975, 1983, 1989; Zimmermann, 1978, 1983; Baas and Carlquist, 1985; Baas and Schweingruber, 1987; Tyree and Sperry, 1989; Tyree and Ewers, 1991; Tyree et al., 1994; Hacke and Sperry, 2001; Sperry, 2003; Baas et al., 2004). From a functional viewpoint, few vessel attributes such as narrow pores and pores multiples acts against cavitation and embolism under hot summer and freezing strees, thereby offering mechanical strength (Zimmermann, 1982, 1983; Ewers, 1985; Salleo and Lo Gullo, 1993; Hacke et al., 2006; Jacobsen et al., 2007).

Various authors stated that the presence of narrow vessels and multiple vessels acts against cavitation during summer stress and winter freezing. Sperry, (2005) studied patterns in hydraulic architecture and their implications for transport efficiency.

The stem and root wood anatomy of the shrub-*Phlomis fruticosa* (Labiatae) a malacophyllous Mediterranean drought semi-deciduous species (Psaras and Sofroniou, 2004) has shown that the stem is comprised of diffuse-porous, narrow vessels arranged in tangential bands, vessel elements with oblique simple perforation plates, non-vestured, clustered alternate intervessel pits. It is concluded that though narrow vessels offer high conducting resistance, they are less vulnerable to cavitations, thus providing safety during summer drought and winter freezing. Vessel grouping is a widespread phenomenon in most woody species, especially those from the arid desert flora and Mediterranean species (Fahn et al., 1986; Carlquist 1989).

Veronica De Micco et al. (2009) studied wood anatomy and hydraulic architecture of stems and twigs of some Mediterranean trees and shrubs along a mesic-xeric gradient. This study focuses on the anatomy of juvenile and mature wood of some species representative of continuous sequences of Mediterranean vegetation formations according to gradients of water availability, from xeric to relatively mesic: Although some attributes (i.e. porosity and type of imperforate tracheary elements) were similar in young twigs and older rings, other traits (i.e. vessel frequency and size) revealed the different hydraulic properties of twig and stem wood. The difference between juvenile and mature structures was large in the species of the mesic end of the gradient while it was relatively small in those more xeric. The species showed large variations in wood anatomical traits, most of them are diffuse porous, few semi to ring porous, vessels are narrow resistant to cavitation during drought and freezing.

In Mediterranean-type ecosystems, seasonal dimorphism is an adaptive strategy to save water by developing brachyblasts with xeromorphic summer leaves as opposed to dolichoblasts with more mesomorphic winter leaves. A study was undertaken on the seasonal dimorphism in wood anatomy studied (Veronica De Micco et al., 2009) in Mediterranean subsp *Cistus incanus* has shown that brachyblast wood was safer than dolichoblast and has narrower and more frequent vessels. The measurement of other specific anatomical traits, such as vessel wall thickness, suggested that brachyblast wood has a higher resistance to implosion due to drought-induced embolism.

2. Materials and Methods

2.1. Study site

The study was undertaken in the municipality of Linares, Nuevo Leon in Forest Faculty of Universidad Autonoma de Nuevo Leon (24°47´N; 99°32´O), at sea level of 350 m snm. The type of climate present according to Koppen (1938), modified by Arcia (1981) is subtropical and semiarid condition with hot summer. The average monthly air temperatures oscillate between 14.7 °C in January to 3 °C in August, although the common temperature in summer is 45 °C. The average annual precipitation is approximately 805 mm with a bimodal distribution. This site is situated in soils which are dark brown deep vertisols. The predominant vegetation is Tamaulipan Thorn Scrub or subtropical thorn scrub (COTECOCA-SARH, 1973; SPP-INEGI, 1986).

2.2. Preparation of samples for microscopy

The wood samples were taken from five trees from Tamaulipan Thorn Scrub around the Forest Science Faculty. Wood block of size 2×2 cm^2, are kept in distilled water for several hours or overnight to soften them for cutting sections with the help of wood microtome at 15 to 20 µm thickness. Transverse, radial and tangential sections were cut.

The sections were stained with safranin rapdily for 2 minutes and then washed in distilled water. Then the sections were dehydrated with series of alcohol at 30%, 50%, 70%, 90% and 100%, making two changes of 5 minutes for each treatment. Finally they are placed on glass slides, covered with cover slips and fixed with euparol to make permanent slides.

These sections mounted with Euparol were photographed by a digital camera fixed on to the microscope.

Technique for maceration of wood for observation of wood fibre cells is described by Maiti et al. (2015). A small piece of wood of each species was dipped in concentrated nitric acid and plugged with cotton. Then the test tubes are kept in boiling water bath until the wood pieces started disintegrating. Then the macerated wood elements were washed several times with distilled water. Then, the macerated fiber cells were stained with safranin (1%) and observed under microscope and taken photographs with digital camera fixed with microscope.

2.3. Description of wood anatomical traits

General description are taken on porosity (diffuse porous, semi-ring porous, ring porous), vessel pore size, frequency, diameter, types of perforation plates (straight, inclined). Data were taken on vessel pores mm^{-2}, rays mm^{-2}, diameter of pores (50 pores), length and breadth of pores, vessel length, breadth (50).

Data were taken on different variables, diameter of vessels (µm)), no. of vessels unit area^{-1} (10 X), no. of uniseriate rays (10 X), length of rays (µm) breadth of rays (µm), no. of multiseriae rays (10 X), length of multiseriate rays (µm)), breadth of multiseriate rays (µm).

2.4. Staistical analysis

Data were analysed for various parameters such as diameter of vessels (µm), no. of vessels unit area^{-1} (10 X), no. of uniseriate rays (10 X), length of uniseriate rays (µm) rays breadth of uniseriate rays (µm), no. of multiseriae rays (10 x), length of multiseriate rays (µm), breadth of multiseriate rays (µm). The data were analysed statically for average, ANOVA, correlation, standard deviation using SSSP statistical package.

3. Results and Discussion

3.1. Description of wood anatomy

Microscopic characteristics (transverse section) (N.B. All at 10X except one tangential and fibre cell at 40 X) (Figures 1-20).

3.1.1. Acacia farnesiana (L.) Willd.

Wood semi-ring porous, vessels sparsely scattered, mostly solitary, round to oval in shape, few in radial groups of 2 or 3. very small to medium in size, non-uniform in size in crossection. Axial parenchyma paratracheal to confluent. Apotracheal parenchyma in the form of broad and long band, scalariform, marginal parenchyma, broad band of scalariform parenchyma visible. Medullary rays narrow with dark contents, traverse through wood tissue. Rays stratified, mostly uniseriate, long, very few multiseriate (3 to 4 cells in breadth), spindle form, heterogeneous, cells, angular to rectangular in shape. Vessels medium in length, very broad in breadth more or less with little inclined simple perforation plates, pits round, small, very close, alternate in arrangement. Wood possesses dense contents. Wood tissue compact with mediumly thick walled fibre cells but with profuse parenchymatous tissue, seem to be mediumly soft. The fibre cell with broad lumen and thin cell wall, could be suitable for paper pulp.

3.1.2. Acacia greggii A. Gray.

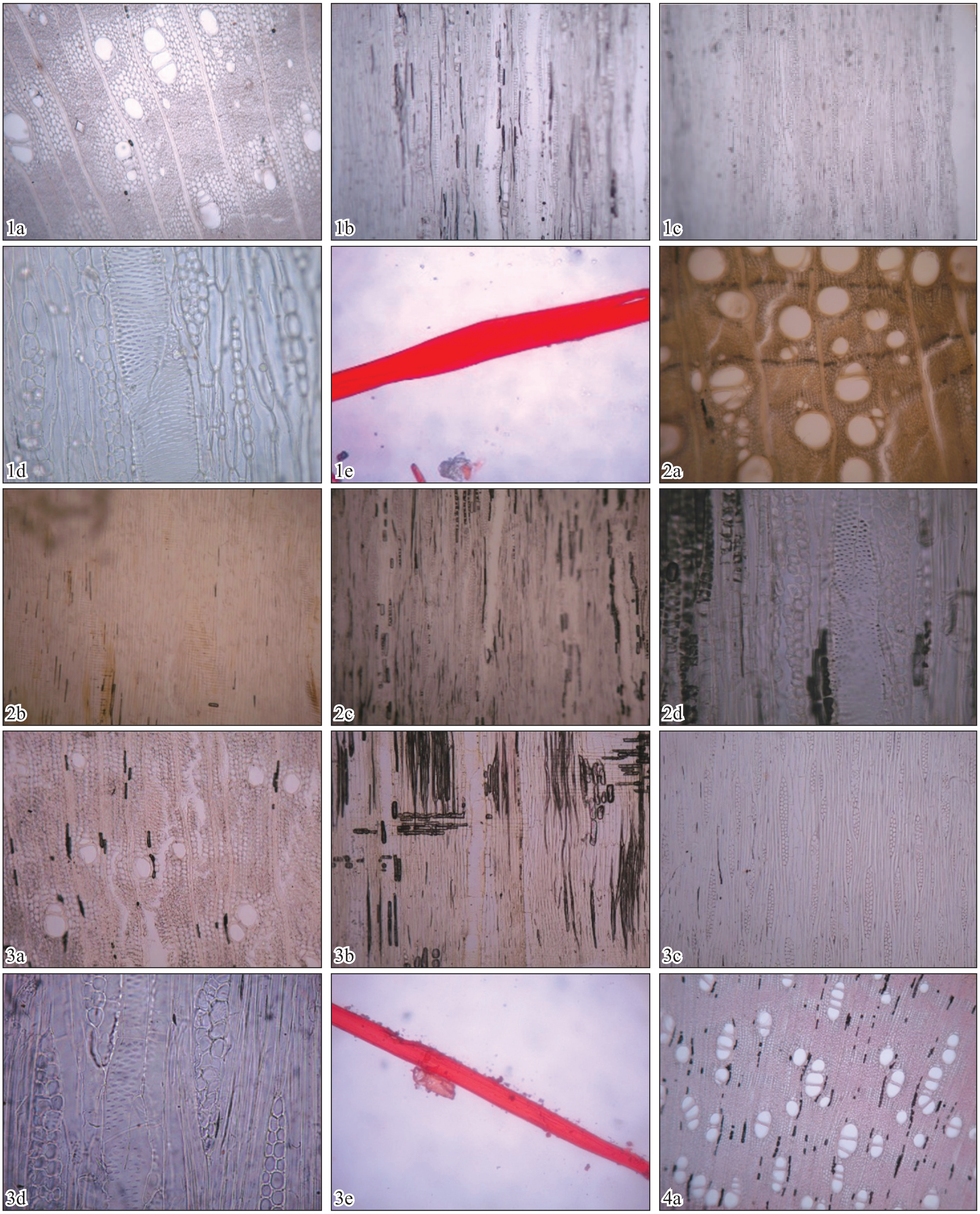
Wood diffuse porous, vessels moderate in number, many are large, few small, mostly solitary, nonuniform, round to oval in shape, few in radial groups of 2 to 3 cells,.mostly big in size, non-uniform in size in crossection. Axial parenchyma confluent to aliform. Apotracheal parenchyma in form of broad and short band, scalariform, compact. Medulary rays mediumly broad, interspersed with wood tissue. Ray cells non-stratified. Rays mediumly long to uniseriate, homogeneous, cells angular to rectangular in shape. Vessels short and broad, truncated to little inclined simple perforation plate, pits small, round, very close, alternate in arrangement. Wood compact with thickwalled fibre, seem to be hard wood.

3.1.3. Caesalpinia mexicana A. Gray

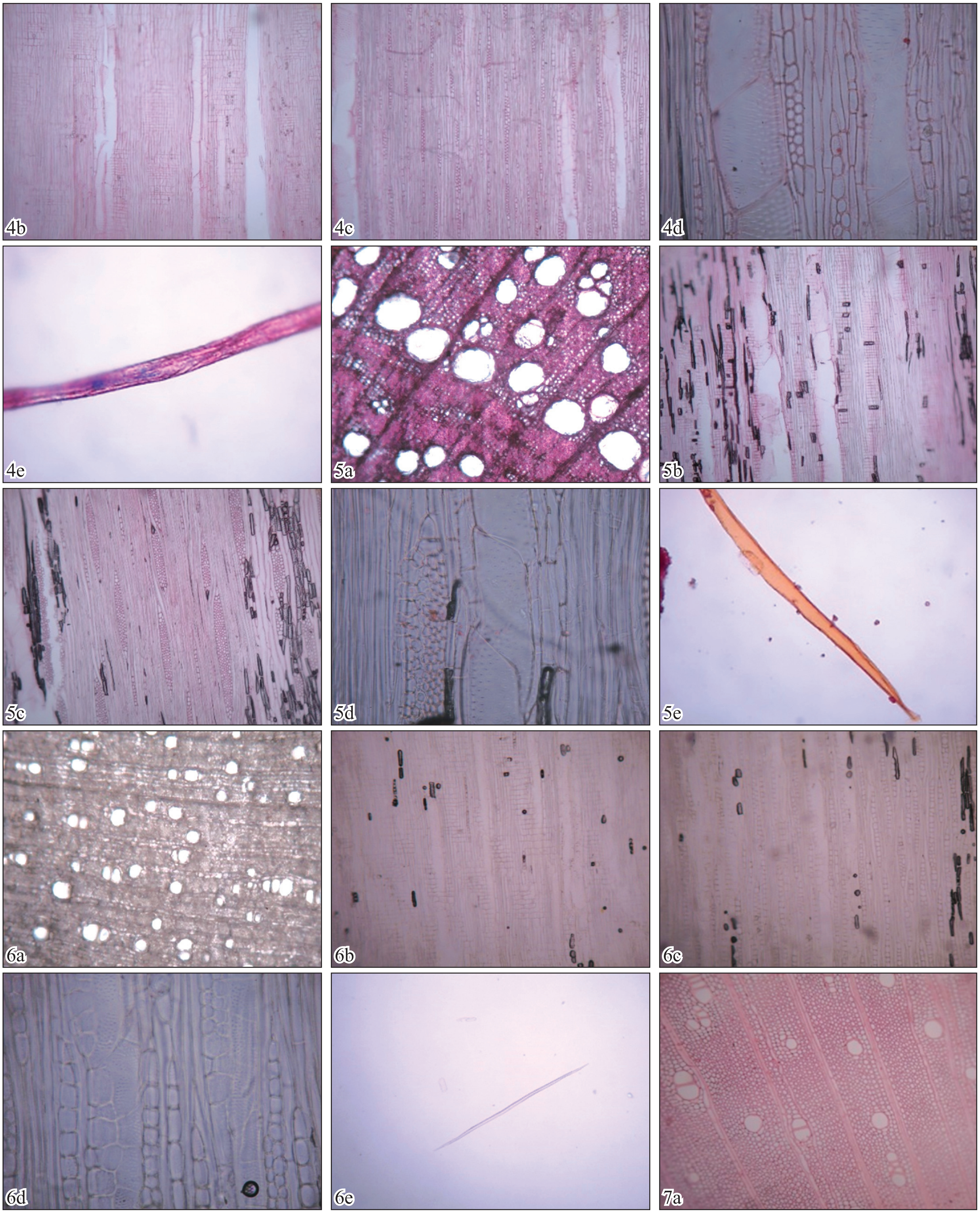
Wood diffuse porous, vessels sparse, mostly solitary, in radial bands of 2-3 cells, round to oval in shape, mostly big and nonuniform in size, small to medium in crossection. Axial parenchyma confluent aliform. Apotracheal parenchyma in the form of short to broad band, scalariform, marginal and terminal parenchyma visible. Medullary rays wavy frequently intercepted by wood tissue, rays narrow, stratified, mostly uniseriate, few multiseriate (2 to 3 cells in breadth), long, numerous, heterogeneous, cells angular to rectangular in shape. Vessels short, broad with inclined perforation plates, pits elliptical, very close, opposite to alternate in arrangement. Wood contains dense exudates. Wood tissue loose with profuse parenchyma and with mediumly thin walled fibre cells. Wood seems to be soft. Fibre cells with broad lumen and medium thick cell wall, could be suitable for paper pulp.

3.1.4. Celtis pallida Torr

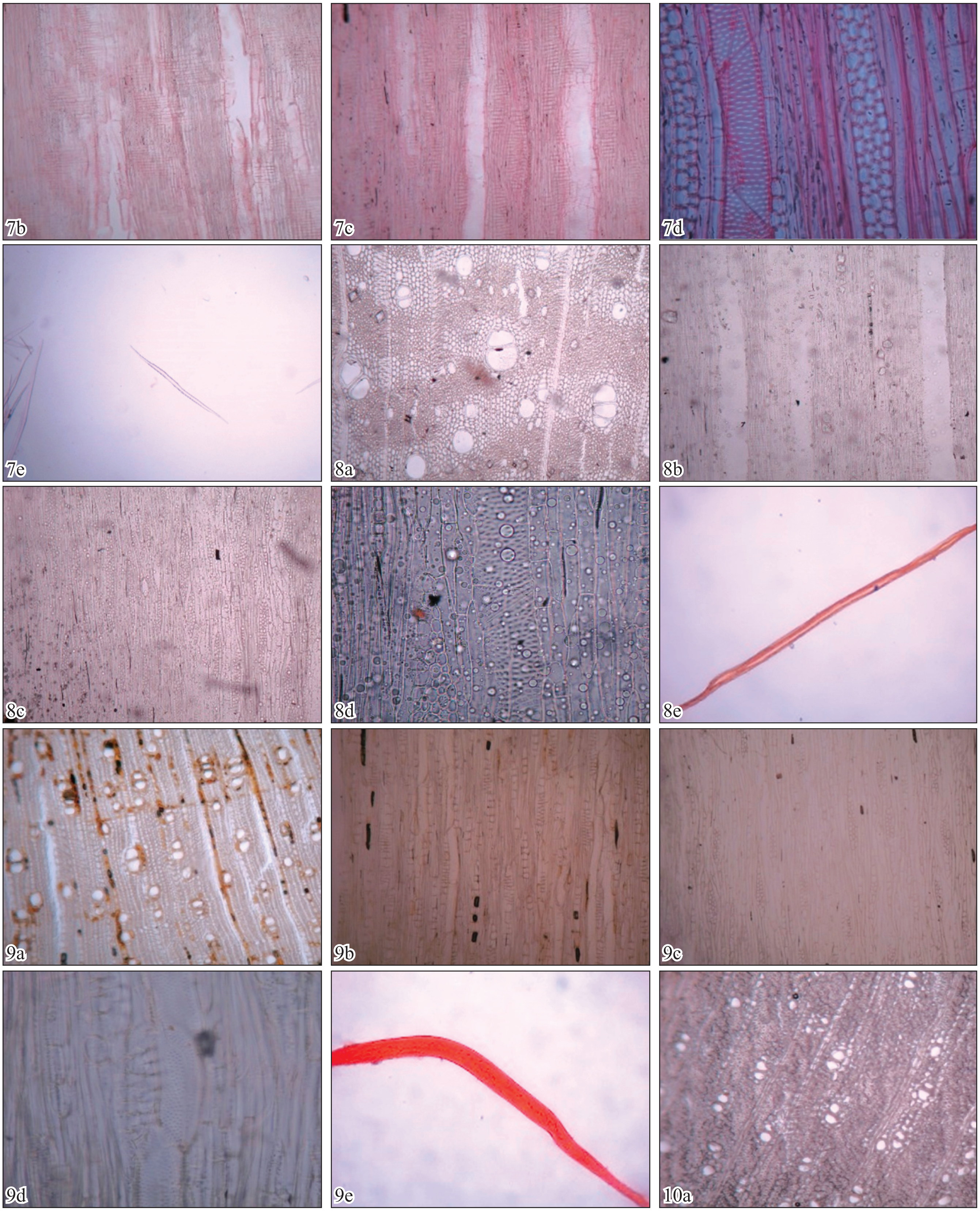
Wood semi-ring porous, vessels numerous mostly in radial rows of 2 to 3 cells, few solitary, round to oval in shape, small to medium in size, non-uniform in size in crossection. Axial parenchyma paratracheal, apotracheal parenchyma in the form of long narrow to broad, scalariform, marginal parenchyma visible. Medullary rays narrow with dense contents, traverse through wood tissue. Rays stratified, profuse, mostly multiseriate (2 cells in breadth), heterogeneous, cells, angular in shape. Vessels short, very much broad with inclined simple perforation plates, pits round, small, very close, alternate in arrangement. Wood possesses dense contents. Wood tissue



1. *Acacia farnesiana* (L) Willd: 1a. Sversal; 1b. Radial; 1c. Tangential; 1d. Tangential (40x); 1e. Fibre 40X; 2: *Acacia greggii* A. Gray.: 2a. Transversal; 2b. Radial; 2c. Tangential; 2d. Tangential 40x; 3. *Caesalpinia mexicana* A. Gray: 3a. Transversal; 3b. Radial; 3c. Tangential; 3d. Tangential 40x; 3e. Fibre 40X; 4. *Celtis pallida* Torr: 4a. Sversal

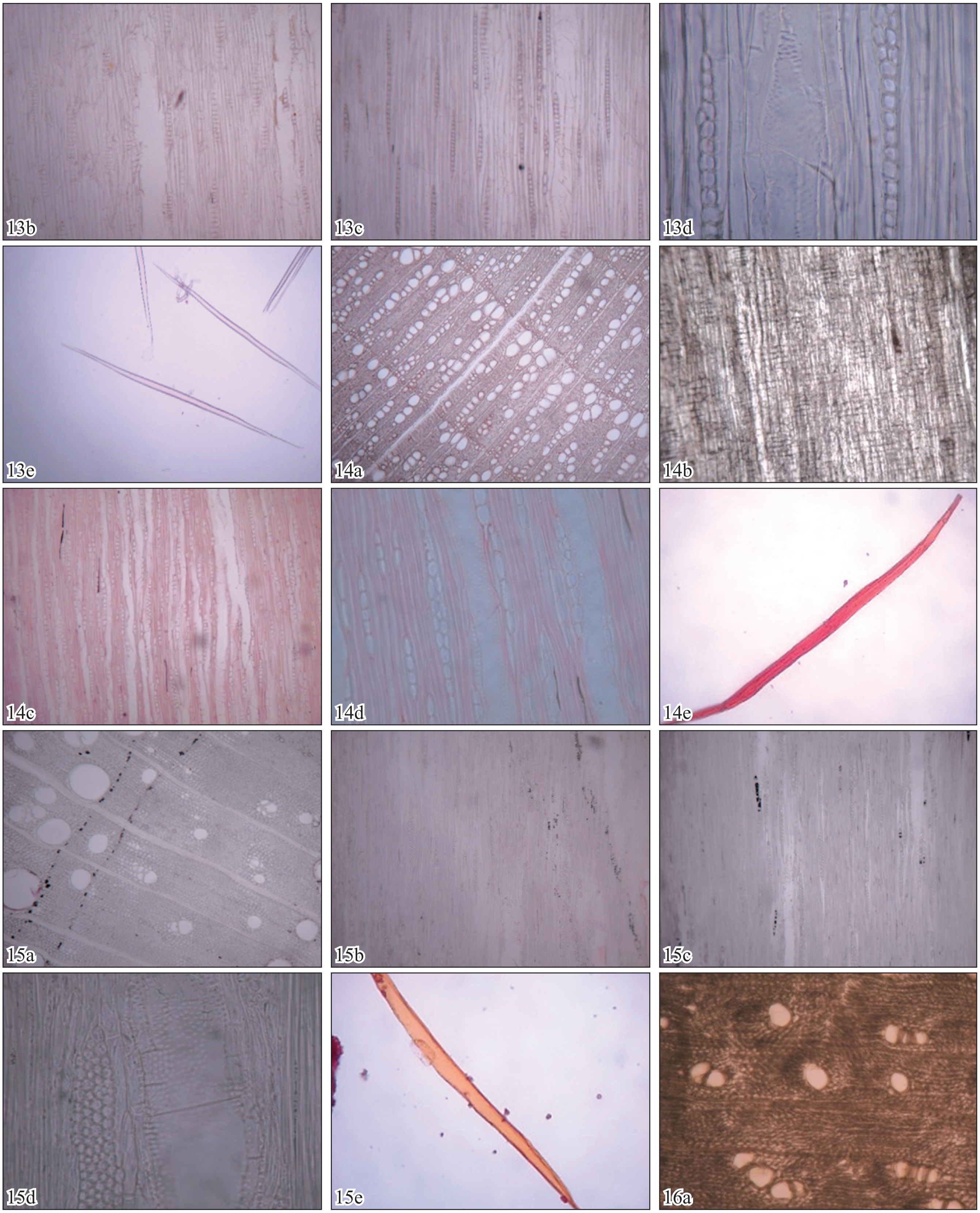


4. *Celtis pallida* Torr: 4b. Radial; 4c. Tangential; 4d. Tangential (40x); 4e. Fibre 40X; 5. *Celtis laevigata* Willd.: 5a. Transversal; 5b. Radial; 5c. Tangential; 5d. Tangential (40x); 5e. Fibre 40X; 6. *Diospyros texana* Scheele: 6a. Transversal; 6b. Radial; 6c. Tangential; 6d. Tangencial 40x; 7. *Cercidium macrum* I.M. Johnst: 7a. Ansversal



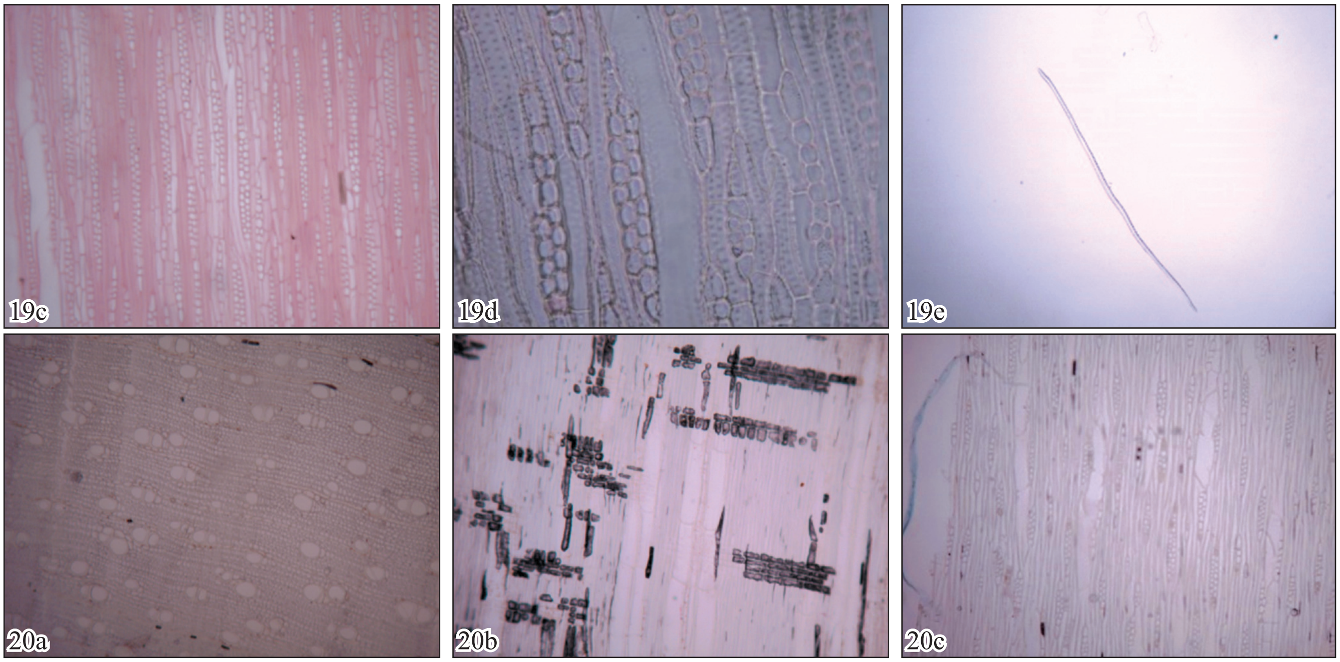
7. *Cercidium macrum* I.M. Johnst: 7b. Radial; 7c. tangential (40x); 7d. tangential (40x); 7e. Fibre 40X; 8. *Condalia hookeri* M.C. Johnst.: 8a. Transversal; 8b. Radial; 8c. Tangential; 8d. Tangencial 40x; 8e. Fibre 40X; 9. *Forestiera angustifolia* Torr.: 9a. Transversal; 9b. Radial; 9c. Tangential; 9d. Tangential 40x; 9e. Fibre 40X; 10. *Gochnatia hypoleuca* (DC.) A. Gray.: 10a. Transversal

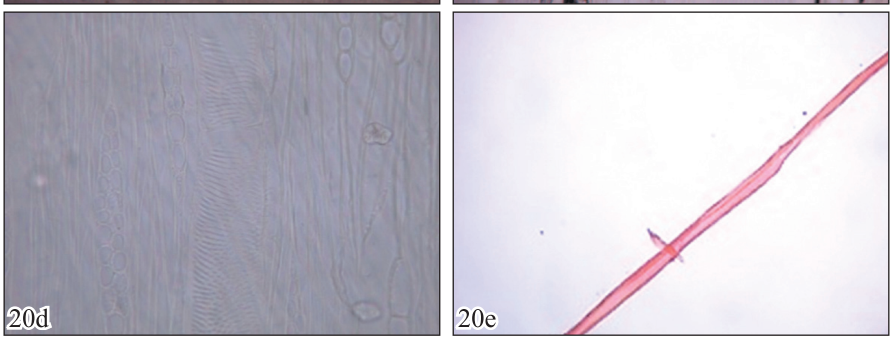
10. *Gochnatia hypoleuca* (DC.) A. Gray.: 10b. Radial; c. tangential; d. tangential 40x; e. Fibres 40X; 11. *Havardia pallens* (Benth.)Britton & Rose: 11a. transversal; 11b. radial; 11c. tangential; 11d. tangential (40x); 11e. Fibre 40X; 12. *Karwinskia humboldtiana* (Schult.) Zucc.: 12a. transversal; 12b. radial; 12c. tangential; 12d. tangential (40x); 12e. Fibre 40X; 13. Leucaena leucocephala (Lam.): 13a. transversal



13. *Leucaena leucocephala* (Lam.): 13b. Radial; 13c. Tangential; 13d.Tangential 40x; 13e. Fibres; 14. *Leucophyllum frutescens* (Berland.) I. M. Johnst: 14a. Transversal; 14b. Radial; 14c. Tangential; 14d. Tangential (40x); 14e. Fibre 40X; 15. *Prosopis laevigata* (H. & B.) Jonhst: 15a. Transversal; 15b. Radial; 15c. Tangential; 15d. Tangential (40x); 15e. Fibre 40X; 16. *Retama sphaerocarpa* L.) Boiss.: 16a. Transversal

16. *Retama sphaerocarpa* L.) Boiss.: 16b. Radial; 16c. Tangential; 16d. Tangential 40x; 17. *Salix humboldtiana* Willd: 17a. Transversal; 17b. Radial; 17c. Tangential; 17d. Tangential 40x; 17e. Fibre 40X; 18. *Sargentia greggii* S. Watson: 18a. Transversal; 18b. Radial; 18c. Tangential; 18d. Tangential 40x; 18e. Fibre; 19. *Sideroxylon celastrinum* (Kunth) .D. Penn: 19a. Transversal; 19b. Radial





19. *Sideroxylon celastrinum* (Kunth) .D. Penn: 19a. Transversal; 19b. Radial; 19c. Tangential; 19d. Tangential (40x); 19d. Fibre; 20. *Zanthoxylum fagara* (L.) Sarg 20a. Transversal; 20b. Radial; 20c. Tangential; 20d. Tangential (40x); 20e. Fiber 40X

compact with mediumly thick walled fibre cells and profuse parenchyma. Wood seems to be semi-hard. Fibre cells with broad lumen and medium cell wall thickness, could be suitable for paper pulp.

3.1.5. Celtis laevigata Willd.

Wood semi-ring porous, vessels few, mostly solitary, very few in multiples of 3 cells or more, round to oval in shape, mostly big in size, non-uniform in size in cross section. Axial parenchyma paratracheal, vescicentric. Apotracheal parenchyma in the form of long narrow to broad, scalariform, marginal and terminal parenchyma visible. Medullary rays mediumly broad narrow with dense contents, traverse through wood tissue. Rays non-stratified, mostly multiseriate (few cells in breadth), very few uniseriate, heterogeneous, cells, angular in shape. Vessels short, very much broad with inclined simple perforation plates, pits round, small, very close, alternate in arrangement. Wood contains dense materials. Wood tissue not compact with mediumly thinwalled walled fibre cells and profuse parenchyma. Wood seems to be mediumly soft. Fibre cells with broad lumen and medium thick cell wall, could be suitable for paper pulp.

3.1.6. Diospyros texana scheele.

Wood diffuse porous, vessels numerous, mostly solitary, few in radial band of 2-3 cells , round to oval in shape, non-uniform in size, small in size in crossection. Axial parenchyma paratracheal, vascicentric. Apotracheal parenchyma loose, sparse, marginal parenchyma visible. Medullary rays narrow, rays numerous, uniseriate, long, homogeneus, cells large, rectangular in shape. Vessels medium in size, broad with slightly inclined perforation plates, pits round, small, alternate in arrangement. Rays uniseriate, homogenous Wood possesses dense contents.Fibre cell with mediumly broad lumen and moderately thickened cell wal. Wood tissue not compact with mediumly thickwa cell wall fibre cells and parenchyma, seems to be semi-hard wood.

3.1.7. Cercidium macrum I.M. Johnst

Wood semi-ring porous, vessels sparse, mostly solitary or very few in radial rows of 2 cells, round to oval in shape, very small to medium in size, non-uniform in size in crossection. Axial parenchyma paratracheal, vascicentric. Apotracheal parenchyma in the form of narrow to broad, scalariform, marginal parenchyma visible. Medullary rays narrow, traverse through wood tissue. Rays stratified, profuse, mostly multiseriate (2 to 4 cells in breadth), heterogeneous, cells, angular to rectangular, elongated in shape. Vessels short, broad with inclined simple perforation plates, pits round, small, very close, alternate in arrangement. Fibre cell with slightly broader lumen and mediumly thick cell wall. Wood tissue compact with mediumly thick walled fibre cells and profuse parenchyma. Wood seems to be semi-hard.

3.1.8. Condalia hookeri M.C. Johnst.

Wood diffuse porous, vessels sparse, mostly solitary, very few in radial bands of 2-3 cells, round to oval in shape, large to small in size, mostly big in size, non-uniform in size in crossection. Axial parenchyma confluent aliform. Apotracheal parenchyma in the form of short to broad band, scalariform, marginal and terminal parenchyma visible. Medullary rays narrow, intersepted by wood tissue. Rays mostly uniseriate, few multiseriate (2 to 3 cells in breadth), numerous, heterogeneous, cells, round in shape. Vessels short, broad with truncated simple perforation plates, pits reticulate to scalariform. Wood tissue compact with mediumly thickwalled fibre cells. Wood seems to be semi-hard. Fibre cells with thick cell wall and narrow lumen could impart strength and suitable for strong furniture.

3.1.9. Forestiera angustifolia Torr.

Wood semi-ring porous, vessels numerous, mostly in radial bands of 2 or few of 3 vessel poressolitary, round to oval in shape, few in radial groups of 2 or 3, very small in size, narrow, non-uniform in size in crossection. Axial parenchyma paratracheal. Apotracheal parenchyma in the form of long tiers, scalariform. Medulary rays narrow, traverse through wood tissue. Wood contains dense contents. Ray cells stratified. Rays mediumly long, profuse, mostly uniseriate long, few biseriate profuse in number, heterogeneous, cells are rectangular in shape. Vessels short and broad, more or less with little inclined simple perforation plates, pits round, very close, small, alternate in arrangement. Wood tissue is compact with mediumly thick walled fibre cells, seem to be mediumly hard. Fibre cells thinwalled, broad lumened, suitable for paper pulp.

3.1.10. Gochnatia hypoleuca (DC.) A. Gray.

Wood diffuse porous, vessels sparse, few solitary, in radial bands 3 or 3 cells, very small in size, narrow, non-uniform in size in crossection. Axial parenchyma paratracheal to confluent Apotracheal parenchyma diffuse. Medullary rays narrow, interrupted. Wood contains dense contents.Ray cells stratified. Rays mediumly long, not profuse, mostly uniseriate long, few biseriate heterogeneous, cells are rectangular in shape. Vessels long, narrow more or less with little inclined simple perforation plates, pits round, very close, small, alternate in arrangement. Wood tissue not compact with mediumly thick walled fibre cells, seem to be mediumly hard. Fibre cells thinwalled, broad lumened, suitable for paper pulp.

3.1.11. Havardia pallens (Benth.) Britton & Rose

Wood semi-ring porous, vessels sparsely scattered, mostly solitary, round to oval in shape, few in radial groups of 2 or 3, small in size, non-uniform in size in crossection. Axial parenchyma paratracheal vascicentric. Apotracheal parenchyma in the form of broad and long band, scalariform, marginal parenchyma, broad band of scalariform parenchyma visible. Medullary rays narrow with dark contents, traverse through wood tissue. Wood possess dense contents. Rays mediumly long, uniseriate long, heterogeneous, cells, angular to rectangular in shape. Vessels medium in length, broad in breadth more or less with little inclined simple perforation plates, pits elliptical, scalariform, very close, big, alternate in arrangement. Wood tissue is compact with mediumly thick walled fibre cells but with profuse parenchymatous tissue, seem to be mediumly hard.

3.1.12. Karwinskia humboldtiana (Schult.) Zucc.

Wood diffuse porous to semi-ring porous, vessels numerous, mostly solitary, round to oval in shape, few in radial groups of 2 or 3, small to medium in size, non-uniform in size in crossection. Axial parenchyma paratracheal, vascicentric. Apotracheal parenchyma in the form of broad and long band, scalariform, marginal parenchyma, broad band of scalariformm parenchyma, terminal parenchyma visible. Medullary rays narrow with dark contents, traverse through wood tissue. Rays, stratified, mostly uniseriate, long, very few multiseriate (2 to 3 cells in breadth), heterogeneous, cells, angular to rectangular in shape. Vessels long with medium in breadth, inclined simple perforation plates, pits round, small, very close, and alternate in arrangement. Wood possesses dense contents. Wood tissue compact with mediumly thick walled fibre cells. Wood seems to be hard. The fibre cells with broad lumen and medium thick cell wall could be suitable for paper pulp.

3.1.13. Leucaena leucocephala (Lam.)

Wood ring porous, vessels sparse mostly solitary, few in radial band of 2–3 cells, round to oval in shape, non-uniform in size, small to big in crossection. Axial parenchyma paratracheal, vascicentric. Apotracheal parenchyma in the form of short to broad band, scalariform, marginal parenchyma visible. Medullary rays intercepted by wood tissue. Rays numerous, mostly uniseriate, long, homogeneus, cells large, angular to rectangular in shape. Vessels medium in size, medium in breadth with stightly inclined perforation plates, pits round, small, alternate in arrangement. Fibre cell with broad lumen and thin cell wall, suitable for paper pulp. Wood tissue not compact with mediumly thin walled fibre cells. Wood seems to be soft.

3.1.14. Leucophyllum frutescens (Berland.) I. M. Johnst

Wood ring porous, vessels numerous, mostly in radial rows of many cells (3 to 10), in dendrite pattern, round to oval in shape, very small to medium in size, non-uniform in size in crossection, annual ring distinct. Axial parenchyma paratracheal, partial vascicentric. Apotracheal parenchyma in the form of broad and long band, scalariform, marginal parenchyma, terminal parenchyma visible. Annual ring distinct. Medullary rays narrow, Rays stratified, profuse, mostly multiseriate long, very few multiseriate (2 to 4 cells in breadth), heterogeneous, cells, angular to rectangular, elongated in shape. Distic annual rings visible. Vessels long, narrow with inclined simple perforation plates, pits round, small, very close, alternate in arrangement. Wood tissue compact with mediumly thick walled fibre cells. Wood seems to be semi-hard. Fibre cells with broad lumen and thin cell wall could be suitable for paper pulp.

3.1.15. Prosopis laevigata (H. & B.) Jonhst

Wood ring porous, vessels infrequent, mostly solitary, round to oval in shape, few in radial groups of 2 or 3, non-uniform in size, some are big in crossection. Axial parenchyma confluent. Apotracheal parenchyma in the form of broad band, scalariform, not clearly distiNct, marginal parenchyma is visible. Medulary rays mediumly broad, traverse through wood tissue. Rays short, spindle shaped, broad, several cells (5-6) in breadth very few uniseriate heterogeneous, cells oval in shape. Vessels longer, slightly broad, more or less with little inclined simple perforation plates, pits elongated elliptical, alternate in arrangement. Wood tissue is compact with mediumly thick walled fibre cells, seem to be mediumly hard hard. Fibre cells with pointed apex, lumen broad with medium thick cell wall could be suitable for paper pulp.

3.1.16. Retama sphaerocarpaL) Boiss.

Wood diffuse porous, vessels infrequent, few solitary, few in a multiple of 2 to 3 vessels, round to oval in shape, non-uniform in size. Axial parenchyma confluent. Apotracheal parenchyma diffuse, not clearly distict. Medulary rays intercepted. Rays uniseriate, short, profuse in numbers. Vessels broad, medium in length, more or less with little inclined simple perforation plates, pits round to elliptical, alternate in arrangement. Medulary ray cells non-stratified. Wood tissue is not compact with profuse parenchyma probably leading to soft wood.

3.1.17. Salix humboldtiana Willd

Wood diffuse porous to semi-ring porous, vessels, numerous, mostly solitary, very few in multiple of 2 3 cells, round to oval in shape, non-uniform in size, small to medium in crossection. Axial parenchyma paratracheal, vascicentric. Apotracheal parenchyma in the form of short to broad band, scalariform, marginal parenchyma visible. Medullary rays narrow, frequently intersepted by wood tissue. Ray cells stratified. Rays uniseriate, long, homogeneus, cells angular to rectangular in shape. Vessels medium, broad with inclined perforation plates, pits round, small, alternate in arrangement. Wood tissue not compact with mediumly thin walled fibre cells. Wood seems to be soft. Fibre cells with broad lumen and medium thick cell wall could be suitable for paper pulp.

3.1.18. Sargentia greggii S. Watson

Wood diffuse porous, vessels numerous, mostly in radial bands of 2-3 cells, very few in multiples, round to oval in shape, mostly big in size, non-uniform in size. Axial parenchyma confluent aliform. Apotracheal parenchyma in the form of short to broad band, scalariform, marginal and terminal parenchyma visible. Medullary rays narrow, intersepted by wood. Rays non-stratified, mostly uniseriate, short, few multiseriate (3 to 4 cells in breadth) leading to one cell at the tip, not numerous, heterogeneous, cells round in shape. Vessels short, broad with inclined perforation plates, pits round to elliptical, very close, opposie in arrangement. Fibre cell with broad lumen and thin cell wall suitable for paper pulp.Wood tissue mediumly compact with mediumly thickwalled fibre cells. Wood seems to be semi-hard.

3.1.19. Sideroxylon celastrinum (Kunth). D. Penn

Wood semi-ring porous, vessels numerous present scattered like groups of stars spaced from another groups, mostly solitary, round to oval in shape, few in radial groups of 2 or 3, very small in size, narrow, non-uniform in size in crossection. Axial parenchyma confluent. Apotracheal parenchyma in the form of broad band, scalariform, marginal parenchyma, broad band of scalariform parenchyma visible. Medullary rays narrow, traverse through wood tissue. Wood contains dense contents. Rays mediumly long to profuse, mostly uniseriate long, few 2 celled in breadth profuse in number, heterogeneous, cells rectangular in shape. Vessels longer, medium in breadth more or less with little inclined simple perforation plates, very close, small, alternate in arrangement.Fibre cell with broad lumen and thin cell wall, suitable for paper pulp. Wood tissue is compact with thin walled fibre cells but with profuse parenchymatous tissue, seem to be mediumly hard.

3.1.20. Zanthoxylum fagara (L.) Sarg.

Wood semiring porous, vessels moderate in numbers mostly solitary, round to oval in shape, few in radial groups of 2 or 3, non-uniform in size, mostly small. Axial parenchyma paratracheal confluent. Apotracheal parenchyma in the form of broad band, scalariform, not clearly distinct, marginal parenchyma is visible. Medullary rays thin traverse through wood tissue. Rays in radial section stratified with dense contents. Rays short, mostly uniseriate, few multiseriate, mostly 2-3-cells in breadth, heterogeneous, cells oval in shape. Vessels long, slightly broad, more or less with straight simple perforation plates, pits elongated scalariform alternate in arrangement. Medullary ray cells stratified, multilayered, stratified, pits scalariform, evolutionary slightly less advanced. Wood tissue is compact with mediumly thick walled fibre cells, profuse vessels, seem to be mediumly hard. The apex of fibre cells is pointed to round, the lumen is some what broad, the cell wall is thin, but little lignified. Wood is semi-hard for fabrication of furniture, this may be suitable for paper pulp.

The anatomical studies of these twenty woody tree species of north eastern Mexico, has shown the existence of wide variability with respect to wood porosity, intensity of vessels, their diameter, orientation, and type of wood parenchyma, paratracheal and apotracheal, as well as fibre cell characteristics. Species may be distinguished on the basis of various wood anatomical traits which coincide with other studies (Perez Oliviera et al., 2008; Maiti et al., 2015). The woody plant species showed variability in xyem vessel characteristics such as length, vessel, perforation plate inclination and types pits which determine the evolutionary trend as suggested by Carlquist and others mentioned already. In addition, Wood anatomy could predict the adaptation of woody plants to environmental stresses and quality of timbers (Maiti and Rodriguez, 2015).

3.2. Classification of wood anatomy

3.2.1. On the basis of porosity

3.2.1.1. Ring porous

Prosopis laevigata, semiring porous: *Acacia farnesciana, Celtis pallida, Cercidium macrum, Havardia pallens, Leucophylum frutescens, Sideroxylon celastrinum, Zanthoxylum fagara.*

3.2.1.2. Diffuse porous

Caesalpinia mexicana, Celtis laevigata, Condalia hookeri, Karwinskia humoldtiana, Salix humoldtiana, Sargentia greggii.

3.2.1.3. Narrow pore size

Most of the species possess narrow vessels viz. *Acacia farnesciana, Celtis pallida, Cercidium macrum, Diospyros texana, Caesalpinia mexicana, Condalia hookeri, Havardia pallens, Leucophyllum frutescens.* Few species possess medium pore size viz. *Acacia farnesciana, Celtis pallida, Caesalpinia mexicana, Havardia pallens, Prosopis laevigata*

3.2.1.4. Big pore size

Celtis laevigata, Leucaena leucocephala possess big pore size. These species have capacity of resistance to cavitation and embolism exposed to hot summer and cold winter in semiarid Northeastern Mexico, similar to those in Mediterranean climates as discussed by several authors (Zimmermann, 1982, 1983; Ewers, 1985 and others). Similar to the present study the variability in wood anatomical traits have been reported by other authors (Alejandra Quintanar Isaias et al., 1998., Carillo et al, 2008, Carillo Paraa et al., 2013; Veronica De Micco et al., 2009; Rebollar-Dominguez and Tapia-Torres, 2010).

3.2.2. On the basis of fibre cell characteristics

Fibre cell characteristics of different species studied also showed large variations in morphology, size, lumen breadth on the basis of which the species are recommended for its utility such as furniture (Maiti et al., 2015). In this respect, woody plant species having wood fibre cells with broad lumen and thin cell wall could be related to good paper pulp quality such as *Acacia farnesciana, Caesalpinia Mexicana, Celtis laevigata, Forestieria angustifolia, Prosopis laevigata*. Therefore wood anatomical traits could predict the quality and utility of the timbers and also adaptation of the species to adverse environments (Maiti and Rodriguez, 2015).

3.2.3. On the basis of compactness

We recommended species as soft and hard wood.

The variations of hydraulic architecture may be related to the adaptive strategies to adverse climatic conditions of woody plants, suggested by various authors (Carlquist, 1975, 1983, 1989; and others2001; Baas et al., 2004). From a functional viewpoint, various studies have discussed vessel pore size affecting conductivity, vulnerability to cavitation and mechanical strength (Zimmermann, 1982, 1983; Ewers, 1985; Salleo and Lo Gullo, 1993; Hacke et al., 2006; Sperry et al., 2006; Jacobsen et al., 2007). The present study coincides with the observation with these authors that many of the species possess narrow vessels which although impose transport of water but protect the vessels against cavitation during drought and freezing. This has been observed in the Mediterranean climates where plants were exposed to hot dry climate separated by hard winter as have been reported by few authors

(Psaras and Sofronieu, 2004, De Micco and Aronne, 2008; De Micco et al., 2006). Similar to the climatic conditions in the Mediterranean regions the climatic condition in Northeast Mexico where the trees are exposed to hot dry summer with temperature raising to more than 40 °C separated cold climate of winter season with temperature going below to 5 °C. It has been reported that vessel grouping is a widespread phenomenon in most woody species, especially those from the arid desert flora and Mediterranean species (Fahn et al., 1986; Carlquist, 1984, 1989). Therefore the species with small narrow vessels, solitary or in groups mentioned have strategy to adapt both to hot and cold climate against cavitation and embolism as mentioned by various authors. The species having big vessel diameter may be susceptible to drought such as *Celtis pallida, Caesalpinia mexicana* or they may have deep root system for adaptation to semiarid climates in northeast Mexico.

It is observed from the Table 1, that there exist a large variability in different variables, diameter of vessels (µm), no. of vessels unit area^{-1} (10X), no. of uniseriate rays, length of rays (µm), breadth of uniseriate rays (µms), no. of multiseriate rays, length of multiseriate rays (µm), breadth of multiseriate rays (µm) showing specific characteristics of each species. For example, the species that have large vessel diameter (µm) are *C. laevigata* (112.7), *L. leucophyllum* (111.9), *C. hookeri* (104.86), *A. gregii* (102.9), *A. farnesciana* (99.76). *C. mexicana* (85.26) which shows that these species are evolutionary advanced. On the other hand the speies having low vessel diameter are *H. pallens* (34.8), *D. texana* (44.1), *F. angustifolia* (44.94), *Z. Fagara* (45.27). *R. sphaerocarpa* (60.90). These species seem to act against cavitation during hot summer and cool winter. On the other hand, species showing higher vessels are *L. frutescens* (562,4), *S. gregii* (169.4), *S. celastrinun* (139.6), *C. pallida* (114.2).

The analysis of variance (ANOVA) is shown in Table 2. It is observed that all the variable, as diameter of vessels (uni), no. of vessels unit area^{-1}, no. of rays, length of rays (uni breadth

Table 1: Wood characteristics showing different variables

Species	Diameter vessels (µm)	No. of vessels	No. of rays unit^{-1} area	Length of rays, (uniseriate) (µm)	Breadth of rays (uniseriate) (µm)	No. of multiseriate ray unit^{-1} area	Length, multiseriate rays (µm)	Breadth of multiseriate rays (µm)
Z. fagara	45.27±1.58	180±10.83	39±6.09	133.28±9.25	10.29±0.49	63.4±3.29	185.22±10.49	25.48±1.10
H. pallens	78.98±2.24	34.8±2.08	141±4.77	146.02±9.15	10.78±0.67	. .	..	..
L. frutescens	37.63±2.41	562.4±34.32	150.4±10.27	176.4±18.38	11.27±0.80	25.4±5.74	238.14±16.26	18.62±0.67
C. boissieri	66.44±4.16	67.8±9.20	. .	. .	. .	27±1.37	778.61±77.13	79.38±5.59
F. angustifolia	41.94±1.50	85.2±7.60	44.4±6.66	187.67±9.43	16.66±1.25	44.8±2.37	153.86±9.85	20.09±1.50
R. sphaerocarpa	60.95±2.90	49.6±3.77	27.2±4.22	98.49±5.48	16.17±1.28	42.6±2.94	263.13±21.78	33.32±1.49
D. texana	44.1±1.59	92.6±3.20	33.4±1.50	196.49±15.88	19.6 0.001	47±3.30	400.82±32.74	33.32±1.31
S. celastrinum	41.55±1.64	108.2±8.24	21.6±2.01	123.97±11.35	10.29±0.49	88.4±5.92	293.51±20.75	23.03±1.07
L. leucocephala	111.91±2.71	22.8±2.26	15.6±0.74	248.43±23.67	16.66±1.03	16.6±0.92	343.49±34.32	26.46±1.43
S. humboldtiana	58.8±2.20	137.6±13.42	84.8±11.86	139.65±7.68	16.66±1.03	6.8±1.28	118.58±17.34	15.68±1.10
C. pallida	52.33±2.25	114.2±7.37	22.6±1.46	214.05±21.82	11.34±0.84	76.4±2.54	306.37±33.93	19.6±0.001
P. aculeata	62.13±2.26	58.8±4.21	23.8±3.02	101.43±8.17	11.76±0.89	81.2±5.75	441.49±24.36	49.49±2.06
P. laevigata	101.52±4.71	38.2±4.15	8±1.67	67.13±5.18	9.8±0.001	58.8±2.8	310.66±27.75	36.75±1.99
C. laevigata	112.7±5.11	52±1.58	14±2.56	156.31±10.74	11.76±0.89	36.8±1.59	538.51±63.16	42.14±3.70
K. humboldtiana	46.06±1.48	270.8±14.60	13±3.04	165.13±10.50	12.74±1.03	120±3	293.51±21.07	23.03±1.28
C. hookeri	104.86 ±4.84	42.6±6.94	16.8±2.65	119.56±10.72	11.76±0.89	71.4±6.43	285.18±30.89	28.42±1.57
A. farnesciana	99.76±3.28	46.4±2.24	17±1.61	103.39±9.88	10.29±0.49	59.6±4.80	287.63±27.14	36.75±1.72
A. greggii	102.9±6.81	45±12.52	7.8±1.82	103.88±11.92	10.78±0.67	61.2±3.42	285.18±34.60	33.81±1.94
S. greggii	52.52±2.05	169.4±18.21	21.8±2.43	114.66±4.27	13.23±1.07	63.2±4.47	450.8±43.46	46.55±2.92
C. mexicana	85.26±3.40	25.8±3.12	5.4±1.69	91.63±7.08	15.68±1.10	72.6±3.29	303.31±33.42	32.83±1.47
Total	n=1000	n=100	n=95	n=379	n=379	n=95	n=379	n=379

Table 2: Analysis of variance (ANOVA) of variables (wood characteristics)

Variable	MSS	F	P value
Diameter, (µm)	35439.549	65.539	0.001
No. of vessels unit^{-1} area	76416.115	118.598	0.001
No. of uniseriate rays unit^{-1} area	8900.013	79.156	0.001
Length, uniseriate rays, (µm)	43918.221	14.86	0.001
Breadth, uniseriate rays	170.454	11.445	0.001
No. of multiseriate rays	3713.635	51.368	0.001
Length, multiseriate rays (µm)	440700.221	18.468	0.001
Breadth, multiseriate rays (µm)	4313.519	46.901	0.001

of rays, no. of multiseriae rays, length of multiseriate rays (uni), breadth of multiseriate rays (uni) show highly significant differences among species (p>0.001).

Table 3 shows correlation among different variables. It is observed that vessel diameter shows highly significant negative correlation with the number of vessels unit area^{-1}, breadth of uniseriate cells, breadth of multiseriate rays (p=001), but only significant negative correlation with the length of uniseriate rays and length of multiseriate rays (p>0.005). Number of vessels shows highly significant correlation with the number of uniseriate rays unit area^{-1}, but only negative correlation with the breadth of multiseriate rays. The number of uniseriate rays shows negative correlation with the number of multiseriate rays and breadth of multiseriate rays.

Table 3: Correlation among different variables

	Diameter (µm)	No. of vessels unit^{-1} area	No. of rays (uniseriate) unit^{-1} area	Length, uniseriate rays (µm)	Breadth, uniseriate rays (µm)	No. of multiseriate rays unit^{-1} area	Length, multiseriate rays (µm)	Breadth, multiseriate rays (µm)
Diameter	1	-.464**	-.300**	-.116**	-.133**	-0.108	.116*	.190**
No. of vessels	0.001	1	.537**	0.198	-0.058	-0.025	-0.173	-.277**
No. of uniseriate rays	0.003	0.001	1	0.152	0.137	-.482**	-.262*	-.397**
Lenght of uniseriate rays (µm)	0.024	0.055	0.141	1	.173**	-.246*	-0.058	-.246**
Breadth of uniseriate rays (µm)	0.009	0.576	0.185	0.001	1	-.312**	-.119*	-0.091
No. of multiseriate rays	0.299	0.811	0.001	0.019	0.003	1	-0.105	-.209*
Length, multiseriate rays (µm)	0.024	0.094	0.013	0.276	0.024	0.31	1	.748**
Breadth, multiseriate rays (µm)	0.001	0.007	0.001	0.001	0.087	0.042	0.001	1

**Significant at p=0.01; and * at p=0.05

4. Conclusion

Characterization of 20 species in Northeastern Mexico revealed large variability in wood anatomical structures that could be used in taxonomic delimitation of the species as well as in the adaptation of the species in xeric habitats in summer and cool environments in winter. Research inputs need to be directed to relate wood anatomical traits with their adaptations to hot summer and cool winter in Northeastern Mexico. Besides, the variations in wood anatomical traits could be related to the wood quality and its utilization. In this respect, the trees having highly lignified cell wall could be recommended for strong furniture, similarly the species having the fibre cells with broad lumen and thin cell could be recommended for paper pulp. Research needs to be addressed in this aspect.

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