INFORMATION TO USERS

This manuscript has been reproduced from the microfilm master. UMI films the text directly from the original or copy submitted. Thus, some thesis and dissertation copies are in typewriter face, while others may be from any type of computer printer.

The quality of this reproduction is dependent upon the quality of the copy submitted. Broken or indistinct print, colored or poor quality illustrations and photographs, print bleedthrough, substandard margins, and improper alignment can adversely affect reproduction.

In the unlikely event that the author did not send UMI a complete manuscript and there are missing pages, these will be noted. Also, if unauthorized copyright material had to be removed, a note will indicate the deletion.

Oversize materials (e.g., maps, drawings, charts) are reproduced by sectioning the original, beginning at the upper left-hand corner and continuing from left to right in equal sections with small overlaps. Each original is also photographed in one exposure and is included in reduced form at the back of the book.

Photographs included in the original manuscript have been reproduced xerographically in this copy. Higher quality 6" x 9" black and white photographic prints are available for any photographs or illustrations appearing in this copy for an additional charge. Contact UMI directly to order.

UMI

A Bell & Howell Information Company
300 North Zeeb Road, Ann Arbor MI 48106-1346 USA
313/761-4700 800/521-0600

STEM WOOD STRUCTURE OF FOUR GHANAIAN *KHAYA* SPECIES

By

Ben N. Donkor ©

A Graduate Thesis Submitted
In Partial Fulfilment of the Requirements
for the Master of Science in Forestry Degree

Faculty of Forestry
Lakehead University
1997

A CAUTION TO THE READER

This MScF thesis has been through external examiner's review and and comment by at least two faculty members.

It is made available for loan by the faculty for the purpose of advancing the practice of professional and scientific forestry.

The reader should realise that opinions expressed in this document are the opinions and conclusions of the student and do not necessarily reflect the opinions of either the supervisor, the faculty or the university.

ABSTRACT

Donkor, B. N. 1997. Stem wood structure of four Ghanaian *Khaya* species. Lakehead University, Faculty of Forestry, Thunder Bay, Ontario, Canada. 92 pp.

Keywords : Mahogany, Ghana, Identification, Khaya species, qualitative, quantitative

Four closely related Ghanaian Khaya woods were studied for differences in anatomical, chemical and physical properties to enable clear identification of the species. The species were *Khaya anthotheca* (Ka), *Khaya ivorensis* (Ki), *Khaya grandifoliola* (Kg) and *Khaya senegalensis* (Ks). Samples for the study were obtained from identified standing trees from eight Forest Districts in Ghana. Macroscopic, microscopic and ultrastructural features including physical and chemical features were examined qualitatively and quantitatively.

Qualitative description of anatomical features indicated that the four species possess similar features with only a few differences in ray appearance of Ks and Ki. Ks rays were relatively more rounded and rich in gum deposits while Ki contained more of smaller rays (uniseriate, biserite and triseriate) compared to the other species. Chemical test for colour reaction in sapwood and heartwood of the four species failed to show differences except with Bromcresol green. Ks heartwood at 12% m.c was stained yellowish-green by Bromcresol green whereas the other species were only stained by the green colour of the chemical. Some quantitative anatomical data further confirmed the close relationship of the species since reliable differences could hardly be found using features such as sapwood width and percentage; vessel diameter, length, and density. Also included were fibre length, diameter, lumen size and single wall thickness as well as ray frequency, height, width and height/width ratio. These features were either not significantly different with t-test of 95% confidence level, or varied considerably from juvenile to mature wood with extensive overlap between compared ranges. Hence these features were unsuitable for identification of the four species. However, fibre lumen/wall ratio, percentage multiseriate rays and relative density of the four species showed significant differences with negligible variation from juvenile to mature wood and no overlaps.

It was found that the mean fibre lumen/wall ratio in Ks, Kg, Ki and Ka were 0.4, 2.4, 4.5 and 4.8 respectively. Ki had the lowest of percentage multiseriate rays averaging 64% while the other species ranged from 80-87%. Relative density range of Ka and Ki, i.e., 0.4-0.6 was classified as medium while that of Kg and Ks, i.e., 0.6-0.8 was in the high density group. Therefore, a key for differentiating the four Ghanaian Khaya woods with a confidence level of 99% was postulated based on fibre/lumen wall ratio, percentage multiseriate rays, relative density and ray appearance.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACKNOWLEDGEMENT

I wish to express my sincere appreciation to Dr. K. C. Yang, the major advisor under whose guidance this study was conducted. I am also thankful to the members of the advisory committee, Dr. R. Pulkki and Professor C. A. Benson for their invaluable suggestions.

I should be grateful to the Canadian International Development Agency and the Government of Ghana for funding the Ghana/CIDA Project, through which this study became possible. I am also grateful to my employers, the Management and staff of Forest Products Inspection Bureau (FPIB), Ghana for releasing me to undertake this programme and for their immense contribution to this work.

Thanks are due to Dr. G. Hazenburg and Mr. Kevin Ride for translating literature from German and French to English. Among those who deserve special thanks are Mr. S. Elliott for his assistance in my laboratory work., the Faculty of Forestry and the staff of Graduate Studies and Research of Lakehead University, for their co-operation and understanding. My felicitations are extended to all the graduate students on the Ghana/CIDA Project for their support and encouragement and also to all others who helped in diverse ways to make this work a success.

1. INTRODUCTION

In Ghana, the genus *Khaya* occurs as four species namely *Khaya ivorensis* (A. Chev.), *Khaya anthoteca* (Welw.) C. DC., *Khaya grandifoliola* (C. DC.), and *Khaya senegalensis* (A. Juss). These are among the most important commercial woods in the Ghanaian timber industry, especially on the export market.

In 1995, out of 40 commercial species Khaya accounted for 3% of the total volume, and 5% of the value of lumber and other finished and semi-finished wood products exported from Ghana (FPIB[1] Permit Report, 1995). All four species of Khaya are highly valued due to their aesthetic value, stability in service and workability (Pleydell 1994). Examples of Khaya products exported are square-edge lumber, boules, curls, furniture parts, veneer lay-ons, mouldings, profile boards, plywood, rotary veneer and sliced veneer.

Identification of standing trees of these species is possible in view of differences in crown and leaf characteristics (Hawthorne 1990). After conversion into logs, lumber and other finished and semi-finished wood products, identification of the individual species becomes very difficult even for very experienced wood workers. The wood may have slight colour differences depending on the location. For example, the heartwood of

[1] Forest Products Inspection Bureau (FPIB)

K. anthotheca may appear in a lighter shade of the usual reddish-brown colour of all the species, but in most cases separation by colour differences is unreliable.

Due to the similarity of wood properties, the timber industry groups them under the common trade name "Mahogany". Hence, over the years these woods have been marketed and used indiscriminately in large volumes. In the event of dwindling global supply of high quality wood raw material, especially the tropical 'redwoods', and the subsequent increased awareness of effective wood usage, i.e., as dictated by their mechanical properties, the trend of inefficient wood use is being reversed. There is evidence that the four Khaya species exhibit some differences in mechanical properties that have effects on end use of the individual species. To this end the Forest Products Inspection Bureau (FPIB) of Ghana was urged to properly identify the individual species instead of grouping them when collecting data on wood products (FRMP[2] - Discussion paper I, 1994).

Recent records from FPIB indicate high cost of these species that is still rising. The high cost coupled with differences in mechanical properties of these woods is compelling buyers to use the wood effectively. In the past, orders for Khaya woods were made in the bulk trade name "African Mahogany", but nowadays specific orders, notably *K. ivorensis* and *K. anthotheca* are made. As a result there is a steady rise in disputes between buyers and sellers over true identity of Khaya wood supplies. An attempt to reverse this situation by monitoring the identity of the species from standing trees through production lines at the sawmills has proved futile. Buyers and sellers

[2] Forest Resources Management Project (FRMP)

continue taking advantage of each other for profit, knowing that identification of the processed wood is difficult.

A number of Khaya wood studies, mostly carried out in the 1960's resulted in only a few differences among the species that are useful for identification. Thus separation of the individual species is still difficult. It is my presumption that another study using the reviewed standard properties for hardwood identification (IAWA 1989), besides new unlisted procedures, may show more differences among the species. It is therefore imperative that an extensive study of the stem wood properties of the four Khaya species be made.

The objectives of this study therefore are:

(1) to carry out a study of stem wood structural differences among the four Khaya species; and

(2) to assess the suitability of using any differences found to develop a method for separating the species.

Limitation in the study

All samples used in this study were wholly obtained at breast height. Therefore, variation due to tree height can be a potential factor to influence the results, notwithstanding numerous reports recognising breast height sampling.

2. LITERATURE REVIEW

2.1 DISTRIBUTION OF THE KHAYA SPECIES

Khaya species is reportedly found in all timber producing areas of West Africa and parts of East Africa (Figures 2.1 and 2.2) (WCMC[3]1992, Kline 1981, HMSO[4]1981, Titmus 1965, Kribs 1959). In Ghana, Hawthorne (1995) outlines the above distribution pattern of the species by forest types as follows.

2.1.1 *Khaya anthotheca*[5] (Welw.) C. DC.

K. anthotheca (henceforth referred to as Ka) occurs in the lower rainfall regions of Africa. These regions can be located from Sierra Leone to south-eastern Nigeria, and then to Democratic Republic of Congo and Uganda. The species' distribution in Ghana is more or less restricted to the moist semideciduous-northwest (MSNW)[6] forest subtype.

---

[3] World Conservation Monitoring Centre

[4] Her Majesty's Stationery Office (HMSO)

[5] K. anthoteca and grandifoliola have a little overlap in distribution and therefore can present problems in identifying especially young trees. Synott (1985) even reported evidence for hybridisation of the two species. However, the adult trees can be separated as K. grandifoliola has a darker, rougher bark.

[6] Forest classification after Hall and Swaine (1976, 1981)

2.1.2 *Khaya ivorensis* (A. Chev.)

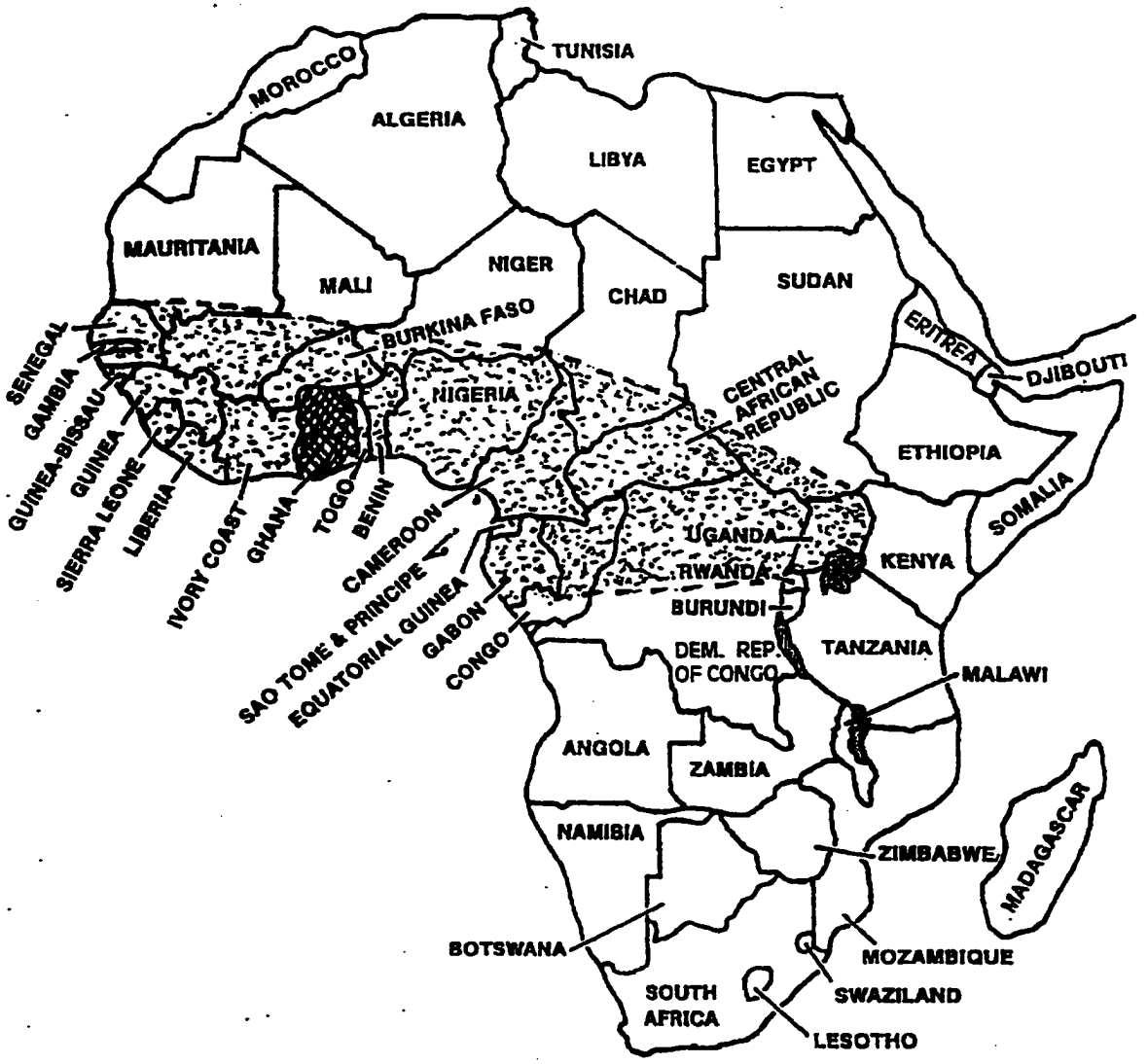
Khaya ivorensis (Ki) prefers the high rainfall zones in high forests: i.e., from Ivory Coast to Gabon. It is widespread in Ghana with particular preference for moist evergreen (ME) and moist semideciduous-southeast (MSSE) forest types.

2.1.3 *Khaya grandifoliola* (C. DC.)

Occurring in more or less the transitional zone between savanna and closed forests, *K. grandifoliola* (Kg) trees are predominant in the Ivory Coast, Ghana and Nigeria. In Ghana, *K. grandifoliola* is in drier forests of the dry semideciduous (DS) forest type and in rocky, hilly parts of moist semideciduous (MS) forests.

2.1.4 *Khaya senegalensis* (A. Juss)

K. senegalensis (Ks) has a very wide distribution and occurs in almost all areas of the savanna stretching from Senegal to Uganda. These areas cover Benin, Burkina Faso, Cameroon, Central African Republic, Chad, Gabon, Gambia, Ghana, Guinea and Guinea Bissau. Others are Ivory Coast, Mali, Niger, Nigeria, Sierra Leone, Sudan, Togo and Democratic Republic of Congo. In Ghana, *K. senegalensis* is prevalent in the Guinea savanna zone mostly in use for amenity planting.



Legend : - Location of Khaya species

- Study area

Figure 2.1 Distribution of Khaya species in Africa

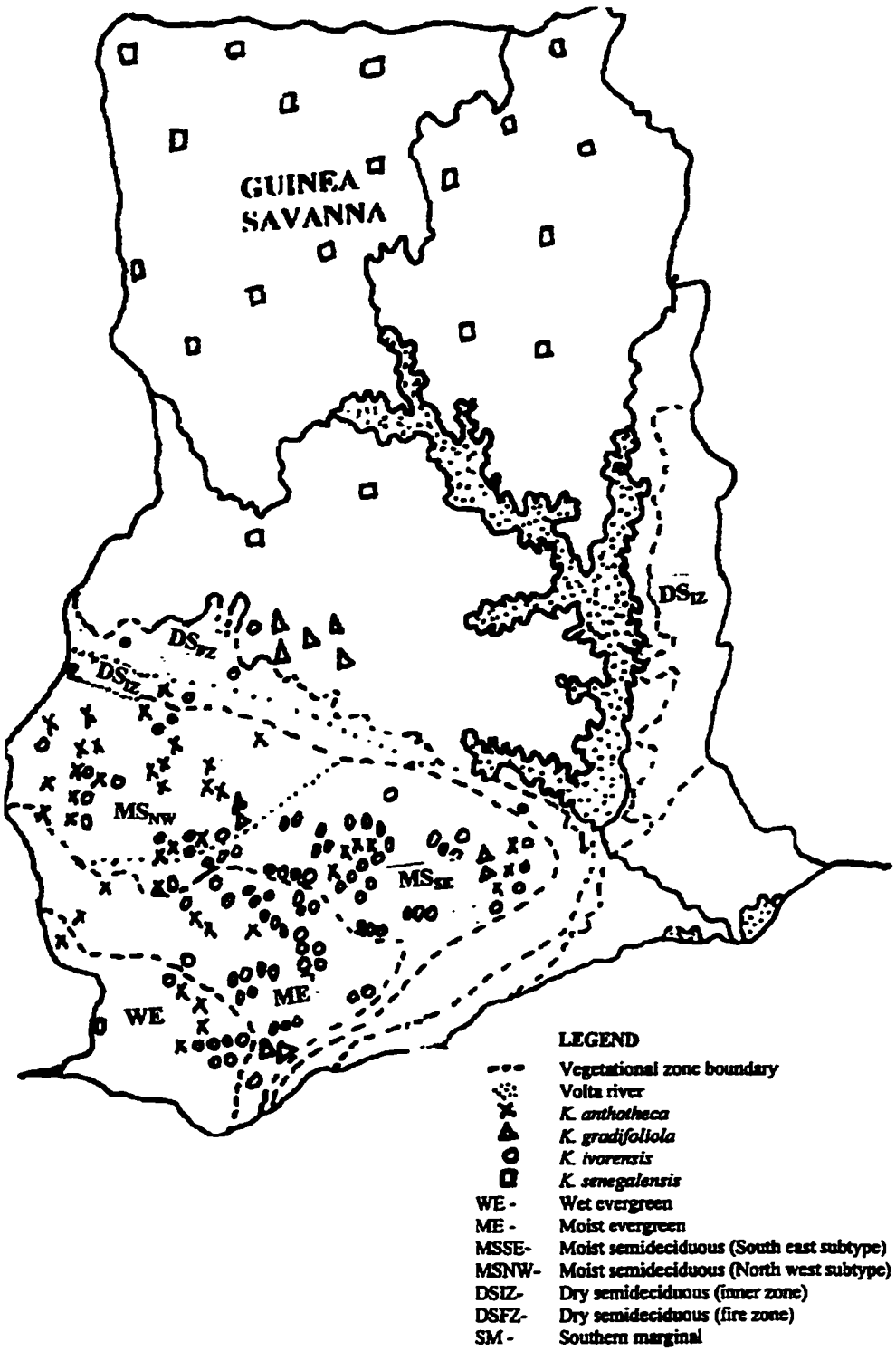


Figure 2.2 Distribution of Khaya species and vegetational zones in Ghana.

2.2 IDENTIFICATION OF KHAYA TREES

The following general descriptions of Khaya trees were made by Hawthorne (1990, 1995) and HMSO (1956).

2.2.1 K. anthotheca (Ka)

The tree has 2-4 pairs of leaflets with 6-8 pairs of lateral nerves and poorly defined veins. The lower surfaces of dry leaves appear leathery with more or less larger veins. The bark is normally smooth and pale, with red to orange, soft, fibrous and gummy inner bark. The fruits are found with 4-5 thin valves. Tree heights and diameters at breast height reach 55 m and 1.2 m respectively, with buttresses of up to 2.7 m high. Boles are often straight but not generally as good as Ki.

2.2.2 K. grandifoliola (Kg)

Leaflets of this tree are in 3-5 pairs, sometimes with 12-15 pairs of well-defined lateral nerves and thread-like inter-lateral veins that appear more prominent on the lower surface. The scented inner bark is red with white streaks and viscous exudate. The fruits have 5 thick valves. The tree is generally smaller than Ki and Ka with heights 30-40 m and diameters (dbh) 0.9-1.2 m. The bole is normally twisted or leaning near the top with rough, scaly and dented bark.

2.2.3 K. ivorensis (Ki)

Mature tree has 4-7 (saplings have 5-7) oblong or oblong-elliptic leaflets, 5-9 lateral nerves and less than 6 mm long petiolule with pronounced drip tips. The older

bark is thick, dark with deep dents where scales have fallen. The outer bark is deep red, while the paler red inner bark is often scented, fibrous and extremely bitter. The fruits are seen with 5 thin valves. The tree reaches a height of 55-60 m with usually 25-27 m of clear and cylindrical bole. Diameters range from 1.5-1.8 m with buttresses (often larger on one side of tree) extending 1.2-1.5 m.

2.2.4 K. senegalensis (Ks)

The tree has 4-6 paired leaflets. The outer bark is greyish and the inner bark is reddish and gummy. The fruits have 4 thick valves. This species attains a height of up to 30 m and diameters of 1.0-1.5 m, but are not as well shaped as the other Khayas.

2.3 USES

Khaya species are widely used for paneling, furniture parts and joinery, interior fittings, boat building, decorative veneer and mouldings. The denser species of Kg and Ks have additional uses such as carvings, flooring, light construction, musical instruments and dowels. The less dense species of Ka and Ki are suitable for peeling and are used in rotary veneer and plywood manufacturing (GTMB 1969, Bolza & Keating 1972, ITTO 1986, Kline 1981).

2.4 GENERAL WOOD IDENTIFICATION PROCEDURES

Wood can be identified by three main methods, namely, macroscopic, microscopic and ultrastructural studies (Hoadley 1990, Miller and Baas 1981, Hart 1960).

2.4.1 Macroscopic Features

This category embraces all observable gross features seen either with the unaided eye or with a hand lens. The hand lens has been a remarkable but very simple tool in separating even very closely related species. This has been demonstrated by Ilic (1990), Wiemann (1987), Brunner *et al.* (1994), Outer *et al.* (1988), Wong and Kochumen (1973) and Mainieri (1972). The IAWA (1989) identifies 130 detailed descriptions of major gross wood features for macroscopic identification (Appendix I). Among these, major groups include growth rings, pores, wood parenchyma, rays and cell inclusions. Also included are physical and chemical properties e.g., colour, lustre, relative density, weight, hardness, flourescence, etc., and physical/chemical tests e.g., splinter burning, extractive content, froth test, aluminium in wood, colour reaction, etc.

Hoadley (1990) summarised steps for examining gross features in wood. He suggested the preparation of samples in the three dimensional planes of wood, i.e, transverse, tangential and radial before taking note of the following features:

1. *Sapwood* and *heartwood* for absence or presence of colour difference,
2. *Growth rings* for the width, percentage of early and latewood, evenness of grain and transition from earlywood to latewood, and

3. Rays for visibility on transverse and tangential surfaces and ray fleck on radial surfaces.

Sapwood width varies from species to species (Lassen and Okkonen 1969, Panshin and De Zeuuw 1980) and by colour (Hoadley 1990). Ayensu and Bentum (1974) described the sapwood of Ki as yellowish brown in colour measuring 50 mm in width. Kg sapwood/heartwood junction was reportedly indistinct when freshly felled. A study to compare sapwood/heartwood width and colour in the four Khaya species could be a useful means for separation.

The use of physical or chemical properties in wood identification has been reported by a number of workers. These include relative density (Sumarliani 1992, Chu 1974), extractive content (Imamura *et al.* 1968, Maekawa and Kitao 1970), colour reaction (Panshin and de Zeuuw 1980, Kutscha *et al.* 1978, Barton 1973, Steiger 1972, Morgan and Orsler 1967), splinter burning (FPRI 1961), flourescence and aluminum test (Dyer 1988).

2.4.2 Microscopic Features

Microscopic method for identifying woods is believed to be most dependable and effective. Hoadley (1990) discussed limitations in the use of a hand lens in wood identification and granted that "... it may take a little more time to prepare sections for microscopic viewing, but features viewed are far more definitive and more easily judged than the more arbitrary features seen without magnification or with a hand lens. You can get accurate results with samples ranging from tiny slivers to painted furniture that would otherwise defy identification."

The IAWA (1989) states 163 minute or microscopic wood features that could be used in identifying hardwoods (Appendix II). Among the main groups are growth rings, vessels, fibres/fibre tracheids, axial parenchyma, rays, secretory elements, cambial variants and mineral inclusions.

Considering the aforementioned, several detailed studies to identify various wood species have evolved. Li *et al.* (1995) characterised the Sapindaceae genera of China with diffuse-porous vessel distribution, simple perforations, alternate inter-vessel pits, and commonly septate libriform fibres. Other observed features of the genus were the usual occurrence of scanty paratracheal parenchyma, mainly uniseriate rays and prismatic crystals common in chambered parenchyma and/or fibres. Baretta-Kuipers (1979) showed that ray type (homocellular or heterocellular, storeyed ray, and uniseriate or multiseriate) was an important feature in wood identification. Parenchyma cells were reported more useful for distinguishing the leguminous genera and species. Other recent works on microscopic wood identification include the following: Chen *et al.* (1993) characterised the Magnoliaceae of China with diffuse porosity, pits, scalariform perforation plates, parenchyma, ray structure, vessel structure, oil cells, and helical thickening. Dong and Baas (1993) developed anatomical key for identification of 11 genera of the Anarcadiaceae. Oteng Amoako (1992) identified woods of Papua New Guinea based on IAWA (1989) standard characters. Yang and Yang (1987) microscopically identified Taiwanese woods. Lyashenco (1984) compared and separated *Gnetum* and *Coffea excelsa*. Gottwald and Parameswaran (1980) detected silica and calcium phosphate in *Tectona grandis*. Sieber and Kucera (1980) outlined the

anatomy of *Clematis vitalba*. Gregory (1980) described general microscopic wood identification characteristics.

In each of these works, wood samples were sectioned using either razor blade or microtome sledge on the three dimensional planes of wood. The sections produced (stained or unstained) were mounted in either water or resin (depending upon whether temporary or permanent slides were required) and viewed under light microscope for anatomical description.

2.4.3 Ultrastructural Features

The term 'ultrastructure' applied in wood structure concerns studies on single cells and/or cell wall building units, orientation of microfibrils and distribution of chemical constituents in the cell wall (Côté 1967).

Identification of chemical constituents and close study of very minute structures in wood could be best achieved by analysis with Scanning and/or Transmission Electron Microscope (SEM/TEM) with Energy Dispersive X-ray Analysis (EXDA) (Carlquist 1988). SEM is capable of viewing objects to a high depth of field (about 300 times that of light microscope) and resolutions down to 20 nm. This enables a three dimensional study of wood cells over a considerable magnification (Meylan and Butterfield 1972). According to Carlquist (1988), although TEM involves tedious preparations and can only view a small area at a time, no other method surpasses it in studying the nature of minute structures in wood. Carlquist also pointed out that SEM-EDX study has the advantage of obtaining photographs that show the distribution pattern of chemical elements in wood cells. SEM/TEM and SEM-EDXA analysis is

reported to eliminate uncertainty about the identity of minute cellular structures, cellular inclusions and presence of inconspicuous deposits such as silica granules, cystolyths, etc. (Parameswaran *et al.* 1985, Parameswaran and Richter 1984, Nair *et al.* 1983, Wheeler (1981, 1983), Furuno *et al.* 1983, ter Welle 1980, and Gray and Cote 1974)

In a SEM study, Meylan and Butterfield (1972) obtained good results with cubes from air-dried wood cut with a razor blade in the three dimensional planes. The cubes measured 3-4 mm per side. Wood samples that were too hard to cut were softened in boiling water before cutting. The cubes were mounted on standard stubs and transferred to a high vacuum evaporation unit for drying and coating with carbon followed by another light coating (about 40 nm) of gold palladium. Collet (1970) in a similar study suggested the use of fractured, split or microtomed samples whereas Carlquist (1988) recommended macerated samples to facilitate a 3-dimensional viewing of indvidual cells. For TEM analysis, Robards (1970) 'fixed' the samples. The samples were placed in a fixing solution, washed and dehydrated with acetone or alcohol and embedded with plastic. The embedded specimen were then polymerised or hardened by heating in an oven before sectioning on an ultra microtome with a glass or diamond knife.

2.5 INFLUENCE OF WOOD VARIATION ON IDENTIFICATION OF SPECIES

Wood is known to be a variable material even if sampled from the same tree. Thus features used in identifying a species (especially in quantitative data) may be different in different positions or sections of the same tree (Panshin and de Zeeuw, 1980, Harzman and Koch 1982). A major factor hampering Wood Anatomists in clearly separating some species, has been variation in wood. Barefoot and Frank (1982)

realised that "Such a failure in classification of a wood to its species may be due to the overlapping nature of the variation in wood elements of many species .... Further studies ... might lead to discovery of a new character (though still biologically variable) that will be useful in their differentiation. These new characteristics might well be defined statistically." Unfortunately, financial and logistical problems would not permit exacting statistical information necessary for identification. Therefore, the averages and ranges of data for certain wood properties are at best taken from only a few trees.

Wood variation may be considered in three main forms, within-tree, between-tree and environmental and genetic variations (Wilkes 1988). The features of importance in discussing wood variation include cell dimensions (length, diameter and wall thickness), relative density and proportions of various cell types.

2.5.1 Within-tree Variation

Variations of anatomical features or of physical properties in a tree stem can be described with changes that occur from pith to bark (radial) and changes that occur with height in stem (axial).

Radially, from the centre of a stem (pith) to bark, a zone of juvenile wood can be defined where rapid anatomical changes occur. This region usually occupies the first 10-20 rings (or higher depending on species) where marked changes are observed in the diameter, wall thickness and length of wood cells. Depending on age of a tree, there may be a zone of mature wood after the juvenile wood where cell dimensions are observed to have relatively stabilised (Panshin and de Zeeuw 1980, Thomas 1985, Bamber and Curtin 1974, Wilkes and Heather 1982). Zobel and Buijtenen (1989) noted

that a number of researchers use only mature wood for comparison among species, rather than using samples from the full cross-section of the stem. The reason for this is to offset the effect of extensive variation of juvenile wood. In various studies of Eucalyptus (probably the most extensively studied hardwood), increases in fibre diameter, wall thickness and length over the first 10-20 years of growth e.g., 10%, 30% and 50%, respectively were reported (Santos and Nogueria 1971, Brasil and Ferreira 1972). Similar increases e.g., of 50% occurred in the diameter and length of vessel elements while vessel frequency declined e.g., by 50%. The proportions of the various cell types changed relatively little (Nicholls and Phillips 1970, Malan 1985). Sapwood width increases with tree diameter have been reported (Smith *et al.* 1966, Nelson 1975, 1976).

Panshin and De Zeeuw (1980) classified the genaral patterns of radial variation in relative density in softwoods and hardwoods, into three main types:

1. Mean relative density increases from pith to bark. The relative density curve may show linear or curvilinear increase or may flatten in the mature wood. The outer parts of the trunk in old trees may show a decrease.
2. Mean relative density decreases outward from the pith, then increases towards the bark. The relative density at the bark may be higher or lower than that near the pith.
3. Mean relative density is higher at the pith than at the bark decreasing either in a straight line or in a curve.

In a study of 11 tropical Indian hardwoods, Bhat *et al.* (1989) found relatively little variation in density from pith to bark. However, the tendency for minimum

density to occur near the bark was more common in tropical hardwoods than in softwoods. In a similar study of *Triplochiton scleroxylon* K. Schum., a diffuse-porous wood from Ghana, Oteng-Amoako *et al.* (1983) found only a slight increase in relative density from pith to bark. Fibre length increased by 30% from juvenile to mature wood.

In the axial direction, fibre lengths increase from the base of the tree to a point up the trunk and then decrease to the top of the crown (Bamber *et al.* 1969, Santos and Nogueria 1974, Bhat *et al.* 1989). Density in hardwoods commonly increases with height, sometimes after an initial decline before increasing towards the crown (Harris and Young 1980, Crawford *et al.* 1972, Hamilton 1961). Although, the trend of axial variation is evident in hardwoods, some diffuse-porous woods were reported with little or no axial variation in relative density. The species include *Platanus occidentalis* (Land and Lee 1981, Taylor 1969), *Acer rubrum* (Saucier and Taras 1966), *Nyssa silvatica* (McElwee and Faircloth 1966), *Eucalptus camaldulensis* (Chudnoff 1961) and *Populus japonigigas* (Inokuma *et al.* 1956). Fibre length patterns varied but the most common was to have slightly longer fibres at the tree base than in the top or for the fibres to be essentially of the same length at all heights.

Panshin and de Zeuuw (1980) generally noted sapwood width increases from base upward in a tree. However, Yang and Hazenberg (1985) found no correlation between the two variables in *Pinus banksiana* and *Larix lariciana.*

2.5.2 Between-tree Variation

Zobel and Buijtenen (1989) noted that tree to tree variation which is mostly genetic controlled is so large for all wood properties and species that it makes studies of wood difficult and utilisation inefficient. Therefore, if tree to tree variation is ignored in wood studies, great errors could be made in predicting properties like strength and wood quality . In most tree to tree variation studies, relative density and fibre length seem to be the greatly affected properties. Some diffuse-porous woods reported with such variations include *Populus tremuloides* (Yanchuk *et al.* 1983a), *Platanus occidentalis* (Land *et al.* 1983), *Acacia mearnsii* (Palmer *et al.* 1982b), *Eucalyptus* species (Doran 1974, Taylor 1973, Skolman 1972, Hans *et al.* 1972), and *Celtis occidentalis* (Taylor 1971). Between-tree variation of sapwood width was mentioned by Panshin and de Zeuuw (1980).

2.5.3 Enviromental and Genetic Variation

Enviromental factors such as climate, soil and topography, and genetic features cause variation in wood properties. Zobel and Talbert (1984) found that trees with similar genetic background often grow differently in contrasting environments, although some features that are strongly genetically controlled e.g., cell length do experience minimal environmental effect. Jayne (1958) suggested a probable link between environment and relative density and recommended that variation in wood density needs to be studied in regard to specific environmental factors. This assertion was confirmed by Zobel and Talbert (1984) when they found that in the U.S.A, relative

density is less in the north and in the Piedmont, but tree to tree differences within a stand are the same in both provenances. In recognition of relative density variation due to environmental effects within the United States, wood density surveys were carried out with the following objectives (Maeglin and Wahlgren 1972, USDA 1965a,b):

1. obtaining systematic sampling, adequate data on average wood density and related wood quality characteristics for each of the sampled species, the magnitude of the differences between species, and the range of variation within each species.
2. determining the extent to which wood density varies with age, tree volume, tree growth rate, climate, longitude, latitude, altitude, aspect and other growth factors.

Chudnoff (1976) found that the tropical dry zones contained species with a large variation in relative density. It has been reported that site (Nelson 1976), climate (Chalk 1951) and elevation (Lassen and Okkonen 1969) affect sapwood width.

Despite all forms of variation affecting the use of anatomical features in identifying some species, many workers have made headway in quantitatively determining values, frequencies, dimensions and proportions of some anatomical features as a means for identifying species (Luxmi-Chauhan *et al.* 1994, Agarwal and Luxmi-Chauhan 1988, Li 1988, Wagenfur and Steiger 1986, Gasson 1987, Swart and Walt 1985, Wheeler and Pearson 1985, Ifju *et al.* 1984, Giraud 1977, Steele *et al.* 1976, Jain and Jain 1976, Brazier 1976).

Chimello and Ifju. (1978) found from a study of 22 diffuse porous woods that large differences existed between the species studied in practically all quantitative properties studied. It was suggested that a 'quantitative' databank of many species be

established, against which unknown woods may be tested for purposes of identification and characterisation.

2.6 ANATOMY OF KHAYA WOOD SPECIES

2.6.1 Macroscopic Features

A study of descriptions made by Hoadley (1990), Kribs (1968), Wagenfürh and Steiger (1963), Streets (1962), Kloot and Bolza (1961), Spalt and Stern (1956) Johnston (1955) and Hart (1960) revealed that the Khaya species have closely related gross features. Thus, most of the available literature have described the species together and in studies where they are described separately, clear differences are not made.

The work of the above authors indicated that the sapwood/heartwood junction is not clearly or easily demarcated, although, the sapwood is usually observed to be lighter in colour with a width of 12-60 mm. The heartwood is pink in colour when freshly sawn but darkens to reddish brown on exposure to air. Ks often appears to be darkest among the Khaya species. Upon visual inspection, i.e., without the aid of a hand lens, pores could be observed to be medium to medium large, relatively few to numerous in number, and evenly distributed. Also, the pores occur in both solitary and radial multiples of two to eight in all the species. The growth ring is often found to be indistinct but may sometimes be seen with increased fibre density in outer latewood or by occasional presence of terminal parenchyma. Axial parenchyma cells may show up, but are usually not visible without a hand lens; these may take either paratracheal or vasicentric forms. Ks may sometimes show banded parenchyma. Deposition of gum is prolific in the pores of the Khaya species. It occurs as a red substance filling the pores

in especially the heartwood region. Traumatic ducts are sometimes seen in Ks. Ripple mark is a rare feature in the Khayas and it is indistinct or irregular when it occurs. The coarse textured species are also known to exhibit interlocked grain that may reach acute levels in the denser woods of Kg and Ks.

Mechanical properties of the species have been extensively studied due to heavy utilisation of these woods (ITTO 1986, Chudnoff 1980, Bolza and Keating 1972, Lavers 1969, and Kloot and Bolza 1961.). A comparison and perusal of the data obtained from these workers (Table 2.1) clearly separates the species into two groups, Ka and Ki on one hand, and Kg and Ks on the other.

Table 2.1. Mechanical properties of four Khaya species (Chudnoff 1980,Bolza and Keating 1972, Lavers 1969,Kloot and Bolza 1961)

Property	Ki		Ka		Kg		Ks	
	Green	12%mc	Green	12% mc	Green	12% mc	Green	12% mc
Bending strength (psi)	7410	10735	7790	11447	9500	13395	8250	12550
Crushing strength(psi)	3734	6460	3744	6283	4992	7680	4112	7225
Impact strength (psi)	26	23	26	23	29	25	-	-
Stiffness (1000 psi)	1155	1391	1177	1412	1412	1648	1435	1675
Hardness(psi)	-	830	-	895	-	1370	-	1350
Shearing strength(psi)	-	1505	-	1685	-	2209	-	1800
Relative density	0.45	0.5	-	0.55	-	0.73	0.6	0.74
Density (kg/m^3)	-	513	-	553	-	720	-	737
Tangential shrinkage (%)	-	5.0-6.5	-	6.5-8.0	-	5.0-6.5	-	6.6-8.0
Radial shrinkage (%)	-	3.0-4.0	-	4.0-5.0	-	3.0-4.0	-	4.1-5.0
Volumetric shrinkage (%)	-	11.2	-	10.5	-	9.5	-	10.9

Chemical properties of the species have rarely been investigated. According to Morgan and Orsler (1967), Ka can be positively identified with ferric chloride-chloroform-pyridine spray reagent if the concentration of anthothecol (an extractive constituent) in the wood is greater than 0.03%. Tests carried out using spots (on filter paper) of pure anthothecol solution extracted with light petroleum showed that, with ferric chloride-chloroform-pyridine spray reagent, an intense reddish brown spot which does not disappear on drying is produced (Soloway and Wilen 1952). This effect was not observed in the other species.

2.6.2 Microscopic Features

Some descriptions of microscopic features have been done by Ayensu and Bentum (1974) on Ki and Kg and by Johnston (1955) on Ks (Table 2.2). Another detailed study of comparative importance on all the Khaya species was undertaken by Wagenführ and Steiger (1963) (Table 2.3). Species from diverse locations that might have obviously been under completely different environmental influences were compared. Therefore, the differences observed in their study could possibly be due to enviromental effects and not features related to the species *per se*. It is therefore necessary that a study with samples collected from closer locations for all the species be conducted to compare their results.

Table 2.2. Summary of microscopic features in three Khaya species (Ayensu and Bentum 1974, and Johnston1955)

Feature	Ki	Kg	Ks
Growth ring	-indistinct -diffuse porous	-indistinct -diffuse porous	-moderately distinct -diffuse porous with traumatic ducts
Vessels	-solitary with few radial multiples of 2-3 small pores	-mainly paired, but 1-4 range	-solitary and radial multiples of up to 7 and occassional clusters, deposits present
	-circular outline, rarely angular	-oval in outline, sometimes circular	-
	-pore size 80-130, averaging 100 µm	-50-90 averaging 71.5 µm	-
	-pore length 388-588 (ave.511 µm)	-350-763 averaging 564 µm	-
	-perforation plate - simple	-simple	-simple
	-endwall inclination almost transverse	-slightly oblique	-
	-intervascular pits alternate	-no intervascular pitting	-
Imperforate tracheary element	-septate fibres present	-septate fibres present	-septate fibres present
	-length 1250-1650 averaging 1488µm	-1638-2250 averaging 1893µm	-
	-pits simple and on tangential walls	-pits numerous	-
	-	-	-medium thick to thick walled
Rays	-heterogenous	-homogenous	-heterogenous
	-mainly mutiseriate	-mainly multiseriate	-mainly multiseriate
	-5 cells wide	-3-5 cells high	-up to 8 cells wide
	-	-	-crystal deposits
Axial parenchyma	-	-paratracheal	-paratracheal
	-	-cells containing amorphous deposits, no crystals present	-

Table 2.3. Summary of microscopic features in four Khaya species (Wagenführ and Steiger 1963)

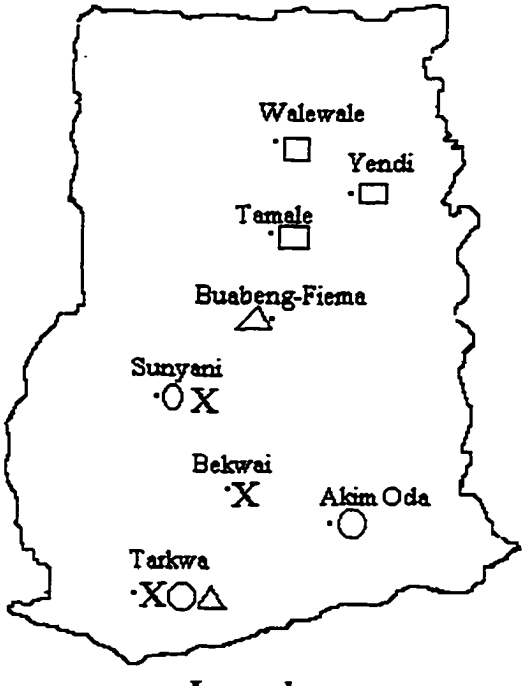
Feature		Ka	Ki	Kg	Ks
Vessel:					
-density	minimum	2	3	3	3
(per mm^2)	average:	3	7	7	6
	maximum:	7	11	10	10
-diameter:		82	122	100	100
(μm)		149	169	189	170
		185	225	275	200
Ray (Heterogenous):					
-organisation		-2different widths and heights	-2 different widths and heights	-2 different widths and heights	-2 different widths and heights
-marginal rows		-1 or more rows with crystals	-1 or more rows with crystals	-1 or more rows with crystals	-1 or more rows with crystals
-width		1	1	1	1
(cells)		4	5	4	5
		7	7	6	8
-density		11	8	12	13
(per mm^2)		15	10	16	17
		20	13	19	20
-height in cells:					
1 and 2 layers:		3	3	2	7
		5	6	6	9
		8	8	10	12
more than 2:		8	7	11	15
		16	21	16	22
		32	37	30	33
-height in microns:					
1 and 2 layers:		235	176	121	186
		333	325	274	254
		423	400	356	400
more than 2:		310	360	300	331
		570	648	464	482
		941	1055	638	820
Parenchyma:		-paratracheal(rare) -occasionally, vasicentric, apotracheal, concentric	-paratracheal(rare) -occasionally, vasicentric, apotracheal, concentric	-paratracheal(rare) -occasionally, vasicentric, apotracheal, concentric	-paratracheal(rare) -apotracheal, terminal
Fibres:		-thin walled	-thin walled	-thin walled	-thick walled
Origin of sample:		-Ghana	-Nigeria	-Nigeria	-Guinea

3. MATERIALS AND METHODS

3.1 SAMPLE COLLECTION

3.1.1 Location

All samples used in the study were collected from eight forest districts in Ghana (Figure 3.1). Three areas of about 2 km^2 each were randomly located within the range of distribution for each species. For Kg, only two locations were selected due to the limited range of distribution.



Legend

O - *Khaya ivorensis*
X - *Khaya anthotheca*
Δ - *Khaya grandifoliola*
□- *Khaya senegalensis*

Figure 3.1 Selected areas for sample collection in Ghana.

3.1.2 Species

Samples were collected from identified standing trees of *Khaya anthotheca* (Ka), *Khaya ivorensis* (Ki), *Khaya grandifoliola* (Kg) and *Khaya senegalensis* (Ks).

3.1.3 Type and Number of Samples

Two sets of samples, *incremental cores* and *wood strips* were collected

Core samples of about 10 mm diameter and 100 mm long were removed at breast height (bh) using an increment borer. Ten trees were selected per diameter class ranging from 1-10 cm, 11-20, ..., 91-100 to 100+. Thus a total of 440 trees were sampled in the 11 diameter classes for all the species. Immediately after collection, each sample was labeled by species name and dbh with masking tape wrapped around the heartwood end of the core.

A strip sample constituted a strip of wood radially cut from pith to bark from a disc removed at breast height. Only one strip was taken per species, measuring 25 mm thick along the grain, 100 mm wide on the endgrain and length covering the distance from pith to bark.

3.1.4 Handling and Transportation of Samples

To avoid moulding and discolouring, all samples were air-dried for about two weeks before packaging. Safe transportation of the core samples was achieved by securing them in place with dry foam pads in a wooden box chambered according to species.

3.2 DATA COLLECTION

Data collection was organised according to the standard description of wood features (IAWA 1989) and was grouped into qualitative or quantitative depending on whether the data were descriptive or measurable. Almost all the gross features including some physical and chemical tests and a greater part of minute and ultrastructural features came under the qualitative category as the data were mainly descriptive. On the other hand, all features that required some form of linear measurement, weighing and/or counting were classified as quantitative.

3.2.1 Qualitative Studies

3.2.1.1 Macroscopic (or Gross) Features

Gross features of the species were investigated by visual and/or handlens examination and by simple physical and chemical tests.

3.2.1.1.1 Visual/Handlens examination

Endgrain portions of the samples were smoothened with a single-edged razor blade to obtain a fresh surface of wood. Distribution, size and arrangement of pores, parenchyma and rays were examined visually or with the aid of a 10x hand lens. The pores were also observed for any deposits in the lumen. Other features investigated included the existence of vasicentric tracheids, normal axial canals, traumatic canals, oil cells and tanniniferous tubes as outlined by IAWA (1989).

3.2.1.1.2 Physical appearance and tests

Various physical examinations and simple tests were carried out on samples of the species as follows.

(a) *General wood appearance*: - Heartwood samples were inspected for any differences regarding colour, odour and taste, weight and hardness, texture, and grain direction.

(b) *Splinter test*: - Splinters (of match-stick size) were prepared from samples of the four species and lighted in an area of still air to observe whether they would burn to full ash or to charcoal. The splinters were also observed for sparkles when in flames. In situations where the splinter burned to ash, the colour of ash produced was also recorded.

(c) *Flourescence test*: - Freshly cut surfaces of heartwood samples of the species were held under longwave ultra violet (UV) light for any indication of flourescence. Heartwood extracts with water and ethanol were also tested for flourescence. The water extraction was done by preparing heartwood shavings enough to cover the bottom of a 20 mm x 70 mm vial. Approximately 5 ml of distilled water buffered at pH of 6.86 was added. The vial was then corked and shaken vigorously for 10-15 seconds and immediately held under longwave U.V light to observe if any flourescence would occur. The ethanol extract followed the same procedure but by replacing distilled water with 95% ethyl alcohol.

(d) *Froth test*: - During water extraction in (c), the vial was allowed to stand for about a minute after the flourescence test to observe if froth (or foamy bubbles) remained

completely covering the surface of the extract or not. This would indicate positive or negative froth test.

(e) *Colour of extract*: - The colours of water and ethanol extracts described in (c) were also recorded to find out any differences among the species. The water extract was heated to boil before carrying out this observation.

Some chemicals used by Kutscha and Sachs (1962) in differentiating heartwood and sapwood (by colour reaction) in certain softwood species were tried on the Khaya species to find out if the species would react differently to any of the chemicals. Details of preparation of the chemicals are shown in Appendix III. Small wood strips measuring 5 mm x 5 mm x 100 mm were cut from the outer portions, i.e., bark end of the main strip samples such that each contained half sapwood and half heartwood. The main strip samples had been air-dried to about 12% moisture content. The small strips were dipped in freshly prepared chemical solutions and the resultant colours produced in sapwood and/or heartwood zone(s) were noted after five minutes.

3.2.1.2 Microscopic Features

Sections of 20 micron thickness were cut from the three dimensional planes of wood using microtome sledge. These sections were dehydrated in serial dilutions of 30%, 50%, 70%, 80%, 90% and 95% ethanol after staining for 24 hours in 1% aqeous safranin. Permanent slides were prepared by mounting the sections in resin medium using toluene as the mounting medium. Weights were placed on the cover slips overnight to ensure flatness of sections as drying procceeded. Any excess resin which spilled over the cover slips was cleaned off using toluene and a soft mounting brush

after drying was completed. The slides were then viewed under a Zeiss light microscope for description of anatomical features (IAWA 1989). Photographs of observed features were taken under various magnifications using camera lucida mounted on the Zeiss light microscope.

3.2.1.3 Ultrastructural Studies

This study was carried out on three types of samples. These included small cubes of wood (with a side of 4 mm prepared in the three dimensional planes), fully macerated and partially macerated samples. The cubes were prepared by smoothing all planes on a microtome sledge. Macerated samples were prepared by cooking small chips of samples in 1:1 mixture of glacial acetic acid and hydrogen peroxide at 60 $^{\circ}$C for 48-72 h (Franklin 1945). In the case of partial maceration, the cooking time was well below the stated range (about 24 h) whereas fully macerated samples were well cooked and shaken into individual wood cells after rinsing in distilled water.

Prepared samples were mounted on stubs using double-sided tape. The base was glued with conventional carbon paint. Small amounts of fully macerated samples of several hundred wood cells (mainly fibres) were scooped onto the stubs. The samples on stubs were placed in a sputtering coater for drying and subsequently light coated with gold before being transferred into a Hitachi 570 scanning electron microscope for viewing. The purpose of coating was to protect samples from charging under electron bombardment. Under high magnifications, photographs were taken of features that were not clearly observed under light microscope, concentrating mainly on pitting of cell walls and cellular contents.

3.2.2 Quantitative Studies

Quantitative data in the study covered juvenile/mature wood width, sapwood width and percentage, relative density, and vessel characteristics (diameter, length and density). Other cell characteristics measured include those of ray (height, width, number per mm, height/width ratio, percentage of multiseriate rays) and fibre (length, diameter and wall thickness).

There was an initial survey study with only the strip sample from each species to determine features that would exhibit significant differences among the species using the Student t-test. The initial study was also for observing the variation patterns in cell characteristics from pith outwards. This was followed by further investigations of features that showed significant differences using 10 core samples per species from the 100+ cm class[7]. In each quantitative assessment, the minimum sample size, n_c (Appendix IV) needed to determine the magnitude of each feature was calculated with the formula:

$$n_c = \frac{(t_{(\alpha)}^2 . s^2)}{E^2}$$

where;

n_c = the calculated sample size,

$t_{(\alpha)}$ = student t-value at probability level of 95%,

s = standard deviation, and

E = allowable error set at 10% of the mean.

[7] Specifically chosen because it is the felling diameter limit approved by Forestry Department in Ghana

3.2.2.1 Juvenile/Mature wood width

The strip samples were smoothened using fine sand paper to reveal the indisdinct terminal parenchyma boundaries. Smaller strips measuring 15 x 15 mm were cut and every fifth annual ring from the pith to bark was removed. Each ring sample obtained was divided into two; one half for determining juvenile/mature wood boundary and the other for relative density determination.

Samples for juvenile/mature wood boundary were further split into minute chips and macerated into individual wood cells as described in 3.2.1.3. The macerated material was stained and gradually dehydrated in serial dilution of alcohol for preparation of permanent slides as shown in 3.2.1.2.

Cell lengths were measured with a Houston Instruments HIPAD digitizer after fibre images were projected from a microscope to the pad. The digitizer was connected to an Apple microcomputer through an interface. The microcomputer recorded fibre length data. Mean fibre length and corresponding standard deviation were generated by the computer and printed.

Determination of juvenile/mature wood boundary was based on the Yang *et al.* (1986) method of using cell length. The initial boundary was taken as the ring number at which fibre lengths stopped increasing on a plot of fibre length against ring number. At the initial boundary the data became separated into two parts, pith to boundary and bark to boundary. A linear regression model was used to fit a line to three-quarters of both sets of data. Intersection of the two regression lines was considered to be the secondary boundary. The secondary boundary separated the data again, but this time

100% of the data was used to determine the regression lines. The resultant intersection point was taken as the final boundary of juvenile/mature wood.

3.2.2.2 Relative Density

Smith's (1954) maximum moisture content method was used to determine relative density of the annual ring samples described above. Samples were placed in a beaker and submerged in water under 65 cmHg dessicator. To obtain maximum moisture content (W_m), samples were taken out of the dessicator, dried of excess water and weighed every other day untill the last three weights remained constant. It took about 35 days to attain this condition in all the species. The wet samples were then transferred to an oven set at 100°c ± 5 for the determination of oven-dry weight (W_o). Relative density was calculated as:

$$G = \frac{1}{[(W_m - W_o)/W_o] + (1/G_o)}$$

where;

G = relative density, and

G_o = density of wood substance, i.e., 1.53.

3.2.2.3 Sapwood Width and Percentage

The point of separation between sapwood and heartwood (usually indistinct) was determined under microscope as the point at which light coloured wood cells suddenly turned deep coloured, i.e., reddish brown. Sapwood widths on 10 core samples per diameter class for all the 11 classes were measured and the corresponding estimation of percentage sapwood of whole diameter was calculated as:

$$\% \text{ sapwood width} = \frac{\text{sapwood width}}{\text{1/2 diameter}} \times 100$$

3.2.2.4 Vessel Frequency and Dimensions

3.2.2.4.1 Density

Vessel density expressed as the number of vessels per mm^2 was determined on the transverse section at low magnification. The section was projected to a screen and a quadrat made of paper was used in assessing vessel density. The quadrat had a side equivalent to a 1 mm scale projected under the same magnification as the wood section. It was placed on the image of the projected section and number of vessels appearing within it (quadrat) were counted. Ten different fields of the same wood section were assessed and averaged. Both solitary and multiple vessels were considered as single in all counts.

3.2.2.4.2 Diameter (μm)

Vessel diameter was determined from macerated samples. Full outside diameter of 25 vessels per species were measured and the average calculated.

3.2.2.4.3 Length (mm)

As in the case of diameter, vessel element lengths including tails were measured on 25 macerated vessels and the mean determined.

3.2.2.6 Fibre Dimensions

Fibre length was measured with a Houston Instruments HIPAD digitizer as in 3.2.2.1. Diameter was linearly measured on images of projected macerated samples at the widest point of fibre. Tangential cell wall thickness and lumen size were measured on cross sections under light microscope. In order to offset the extensive variation in fibre dimensions, only uniform fibres with majority occurrence in a section were selected for measurement. The average of measurements done on 20 individual fibres per section was used.

3.2.2.5 Ray Frequency and Dimensions

3.2.2.5.1 Ray frequency

Ray frequency, i.e., ray per mm was determined at low magnification on the tangential section. The section was projected as in 3.2.2.4.1. A strip of paper, 3 mm wide with length equivalent to a projected 1mm scale under the same magnification as the section was used in determining ray frequency. The paper strip was placed perpendicular to the vertical ray axis and the number of rays crossing it were counted. Average number of rays per mm from 10 different fields on the same image was calculated as ray frequency.

3.2.2.5.2 Height, Width and Height/Width Ratio

Ray height and maximum width in microns were determined directly on projected images from tangential sections. Ten multiserate rays of uniform sizes per

section were selected for linear measurements using a ruler graduated in millimetres. Height/width ratios were simultaneously calculated.

3.2.2.5.3 Percentage of Multiseriate Rays

Proportion of rays with more than 3 cells in width, i.e., multiseriate rays was determined as the percentage of the total number of rays counted. This was carried out with the quadrat described in 3.2.2.4.1 on tangential sections. The mean of five quadrat counts per section was used to indicate percentage of multiseriate rays.

3.3 DATA ANALYSIS

3.3.1 Qualitative Studies

All described features were compared among the four Khaya species to find out any differences that could be used either as unique features or in combined state to separate the species.

3.3.2 Quantitative Studies

The quantitative data were analysed using student t-tests at probability level of 99%. Besides being significantly different between the species, features should not have overlapping confidence limits to enable their use for separating the species.

4. RESULTS

4.1 QUALITATIVE DATA

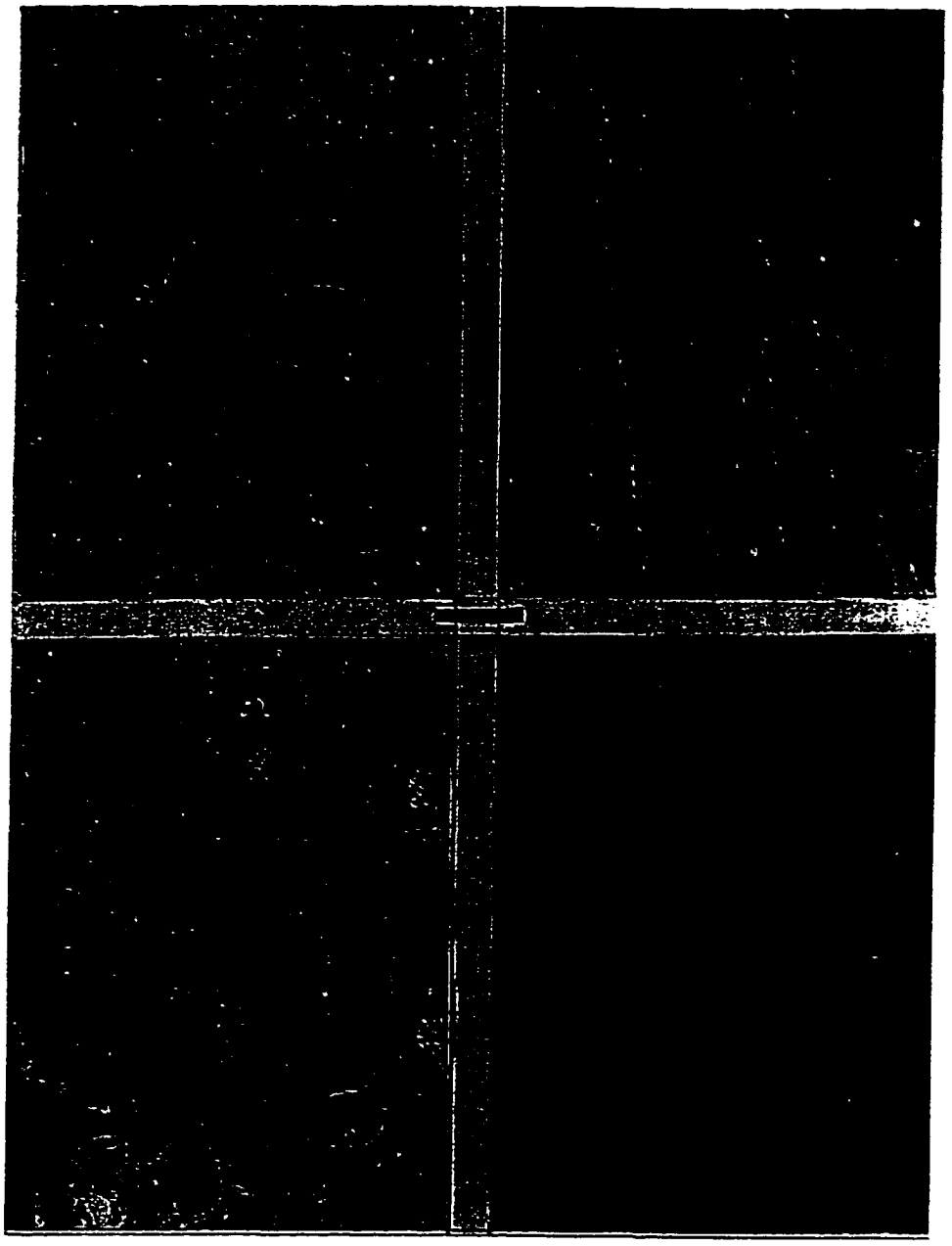
4.1.1 Macroscopic Features

Comparison of macroscopic features observed in the four species showed a few differences among the species (Appendix I). It was found that only Ks had occassional horizontal (traumatic) gum canals (Figure 4.1). On weight and hardness, Ka and Ki were found to be of medium weight and fairly hard while Kg and Ks were heavy and hard. The grain direction in both Ka and Ki could be straight, wavy or interlocked whereas in most cases Kg and Ks were found to be interlocked. In the chemical trials, only Bromcresol green stained Ks differently, i.e., yelowish-green from the other species, i.e., green, in the heartwood region. However, considering the originally intended use for sapwood/heartwood differentiation, a number of the chemicals clearly showed the indistinct sapwood/heartwood boundary of the Khaya species (Table 4.1).

The following macroscopic features were found in all the the species.

- *Physical features* - heartwood colour pinkish-brown or reddish-brown, coarse textured, splinter burns to full ash (white or whitish-grey), water/ethanol extract brown.
- *Growth rings* - indistinct or absent.

- *Pores* - diffuse porous, few, large, partially solitary, mostly radial multiples/clusters of 4 or more (Figure 4.1), diagonal and/or radial pattern, brown/pinkish deposits,



Top left - Ka, Top right - Ki, Bottom left - Kg, Bottom right - Ks

Figure 4.1 Cross sections of Khaya species showing diffuse porosity, gum deposits in pores and traumatic canals (only in Ks). Bar = 250 microns.

Table 4.1. Colour reaction to selected chemicals (Kutscha & Sachs 1962) in four Khaya species.

Chemical	Colour reaction							
	Heartwood				Sapwood			
	Ka	Ki	Kg	Ks	Ka	Ki	Kg	Ks
Alizirine - iodine	--no effect--				--no effect--			
Alizirine Red S	red	red	red	red	red	red	red	red
Ammonium bichromate	Brown	Brown	Brown	Brown	light brown	light brown	light brown	light brown
Benedict's soluton	Brown	Brown	Brown	Brown	light brown	light brown	light brown	light brown
Bromcresol green	green	green	green	yellowish-green	green	green	green	green
Bromphenol blue	blue	blue	blue	blue	blue	blue	blue	blue
Fehling's solution	Brown	Brown	Brown	Brown	light brown	light brown	light brown	light brown
Ferric chloride	Dark green	Dark green	Dark green	Dark green	light green	light green	light green	light green
Ferric nitrate	green	green	green	green	light green	light green	light green	light green
Ferrous sulphate	green	green	green	green	light green	light green	light green	light green
Hydrochloric acid - methanol	--no effect--				--no effect--			
Iodine	--no effect--				--no effect--			
Methyl orange	--no effect--				yellow	yellow	yellow	yello w
Perchloric acid	Purple	Purple	Purple	Purple	Purple	Purple	Purple	Purple
Phenol - HCl + U.V light	--no effect--				--no effect-			
Pottasium - iodide - iodine	Brown	Brown	Brown	Brown	light brown	light brown	light brown	light brown

4.1.2 Microscopic features

Viewing thin sections under a light microscope revealed a clearer view of the unique feature of traumatic (horizontal) canals in Ks (Figure 4.2). Observation of fibre wall thickness indicated dramatic differences among the Khaya species (Figure 4.3). Fibre wall thickness in Ks was much greater than the lumen. In a cross-sectional view, Ks fibres were so thick-walled that the lumen appeared to be almost closed. Kg fibre lumen was about the same size or up to three times the wall thickness indicating thin-to-thick walled fibres. In Ka and Ki, fibre lumen greatly exceeded wall thickness hence indicating thin walled fibres. It was also observed on tangential sections that Ks rays were relatively more rounded and rich in gum deposits while Ki appeared to have more of smaller rays, i.e., uniseriate, biseriate and triseriate rays (Figure 4.4). Details of the microscopic study are indicated in Appendix II.

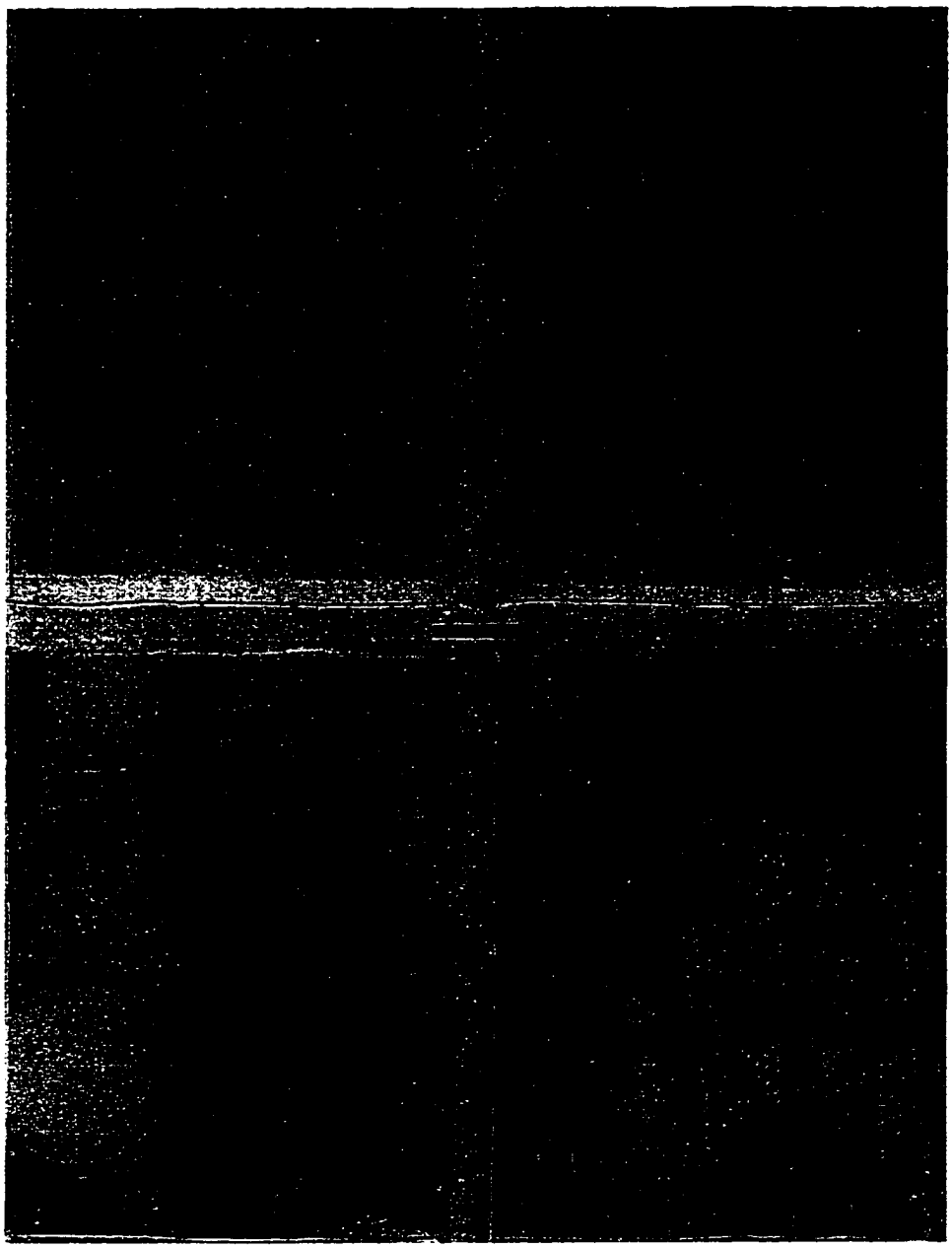
The underlisted microscopic features were found common to all the Khaya species.

- *Vessels* - simple perforation plates, intervessel pits: alternate, minute and occassionally vestured; vessel/ray pits similar to intervessel pits in size and shape.
- *Axial parenchyma* - extremely rare, vascicentric, occassionally marginal.
- *Fibres* - simple to minutely bordered pits, septate fibres present.
- *Rays* - two distinct widths (Figures 4.4 and 4.5), larger rays commonly 4-10 seriate in width, partially aggregate, body ray cells procumbent with mostly 2-4 rows of upright and/or square marginal cells i.e., heterogenous (Figure 4.6), sheath cells present, perforated cells, irregularly storeyed.

- *Mineral Inclusions* - prismatic crystals present in upright and/or square ray cells (Figure 4.7).

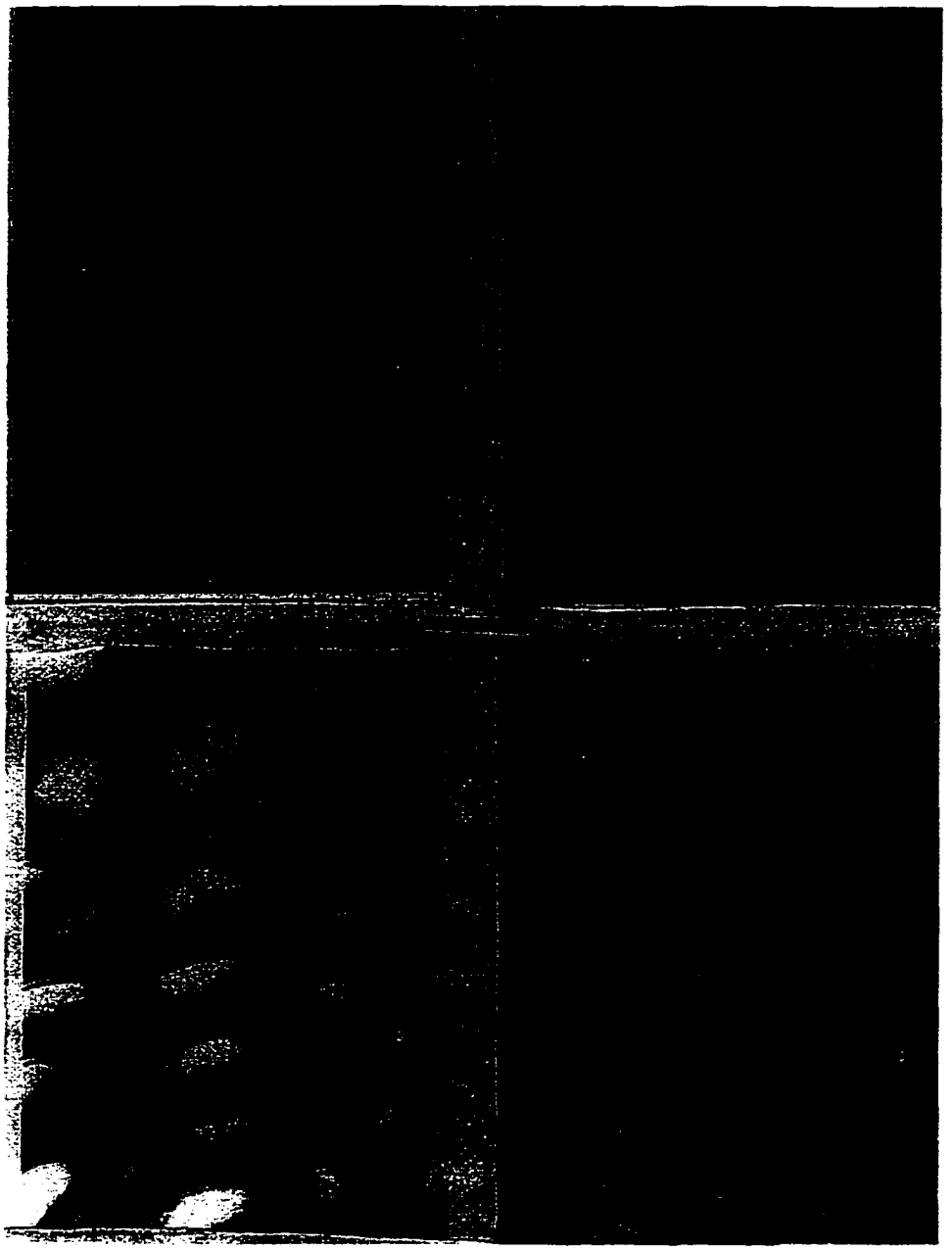
4.1.3 Ultrastructural study

This study provided magnification of features already observed under a light microscope for clearer viewing but no specific differences among the species could be revealed using the Hitachi 570 scanning electron microscope. However, some important features common to all the species that could not be properly seen under a light microscope were examined. These features are indicated in Appendix II with asterisks.



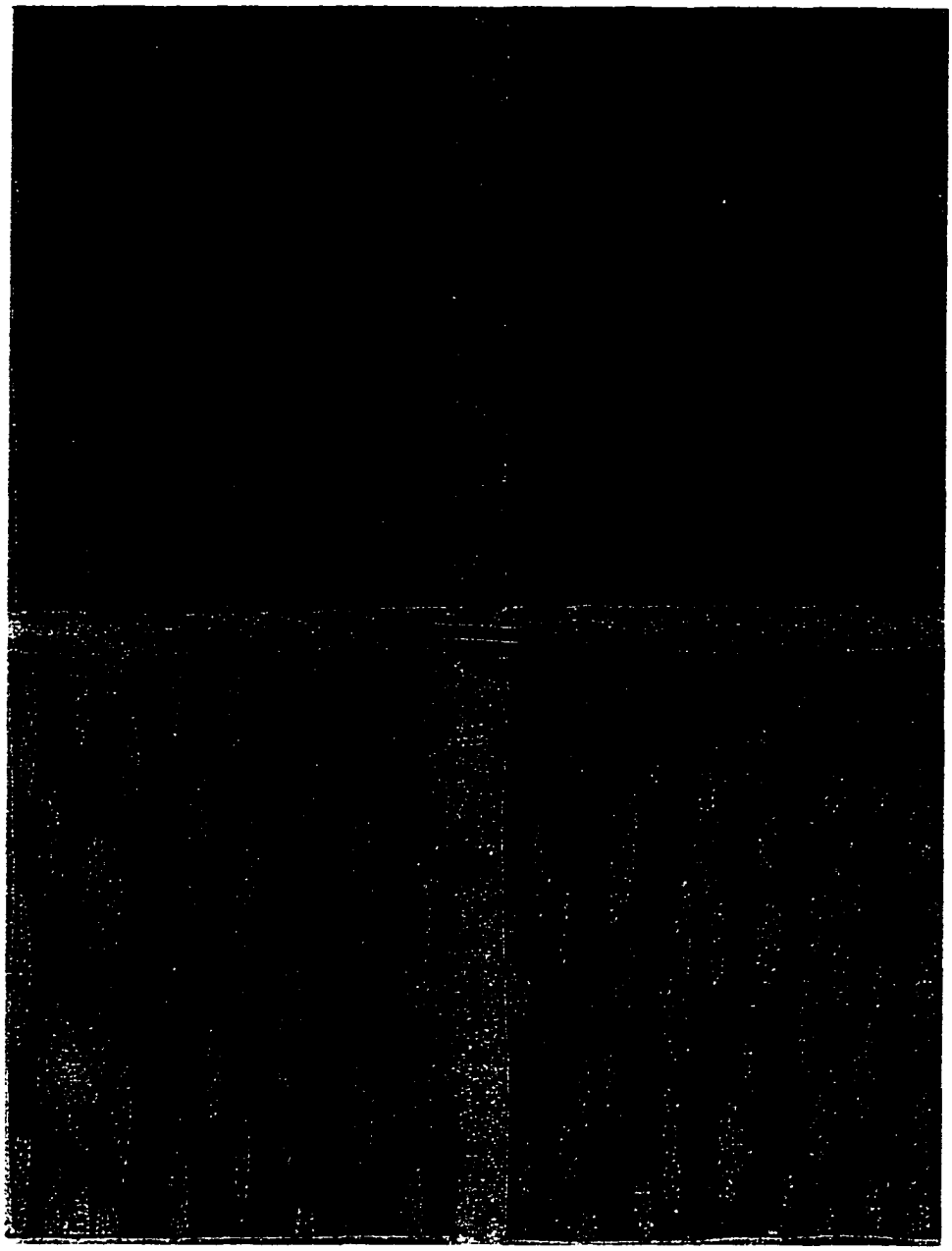
Top left - Ka, Top right - Ki, Bottom left - Kg, Bottom right - Ks

Figure 4.2 Cross sections of Khaya species showing vessel grouping, vascicentric axial parenchyma distribution and rays of two widths. Bar = 125 microns.



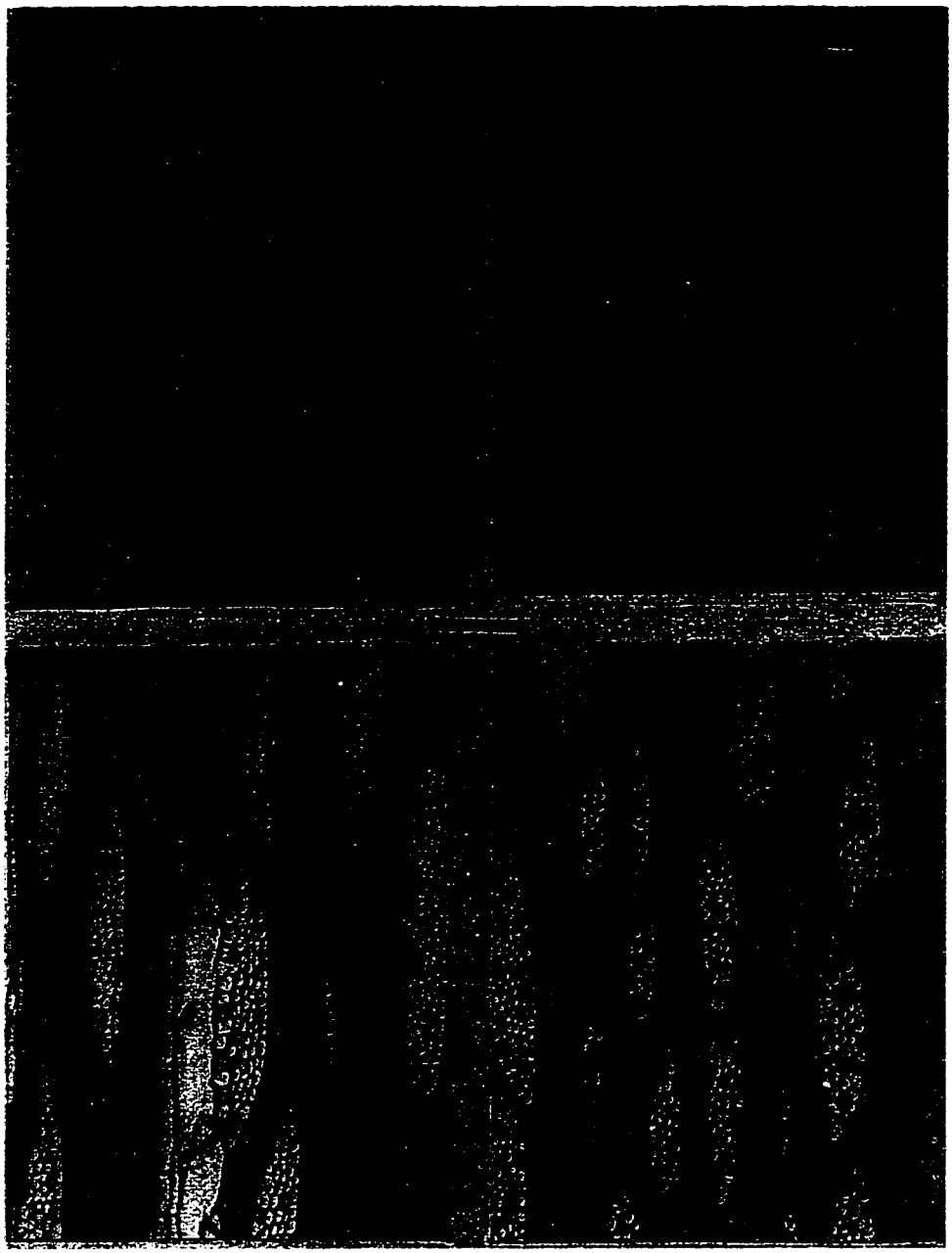
Top left - Ka, Top right - Ki, Bottom left - Kg, Bottom right - Ks

Figure 4.3 Cross sections of Khaya species indicating relative fiber wall thickness. Bar = 15 microns



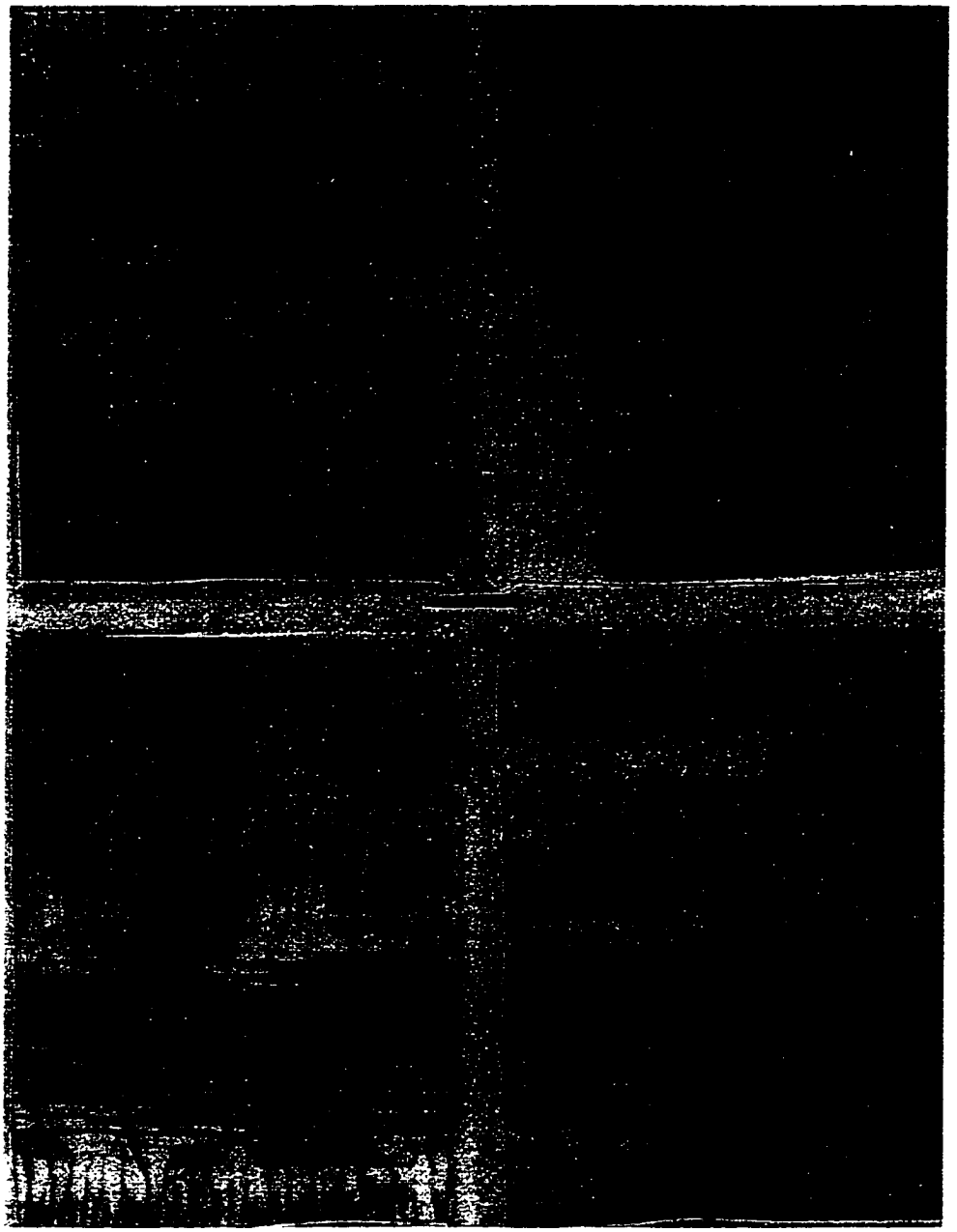
Top left - Ka, Top right - Ki, Bottom left - Kg, Bottom right - Ks

Figure 4.4 Tangential sections of Khaya species showing proportions of small (uni-, bi-, and triseriate) to multiseriate rays. Bar = 260 microns



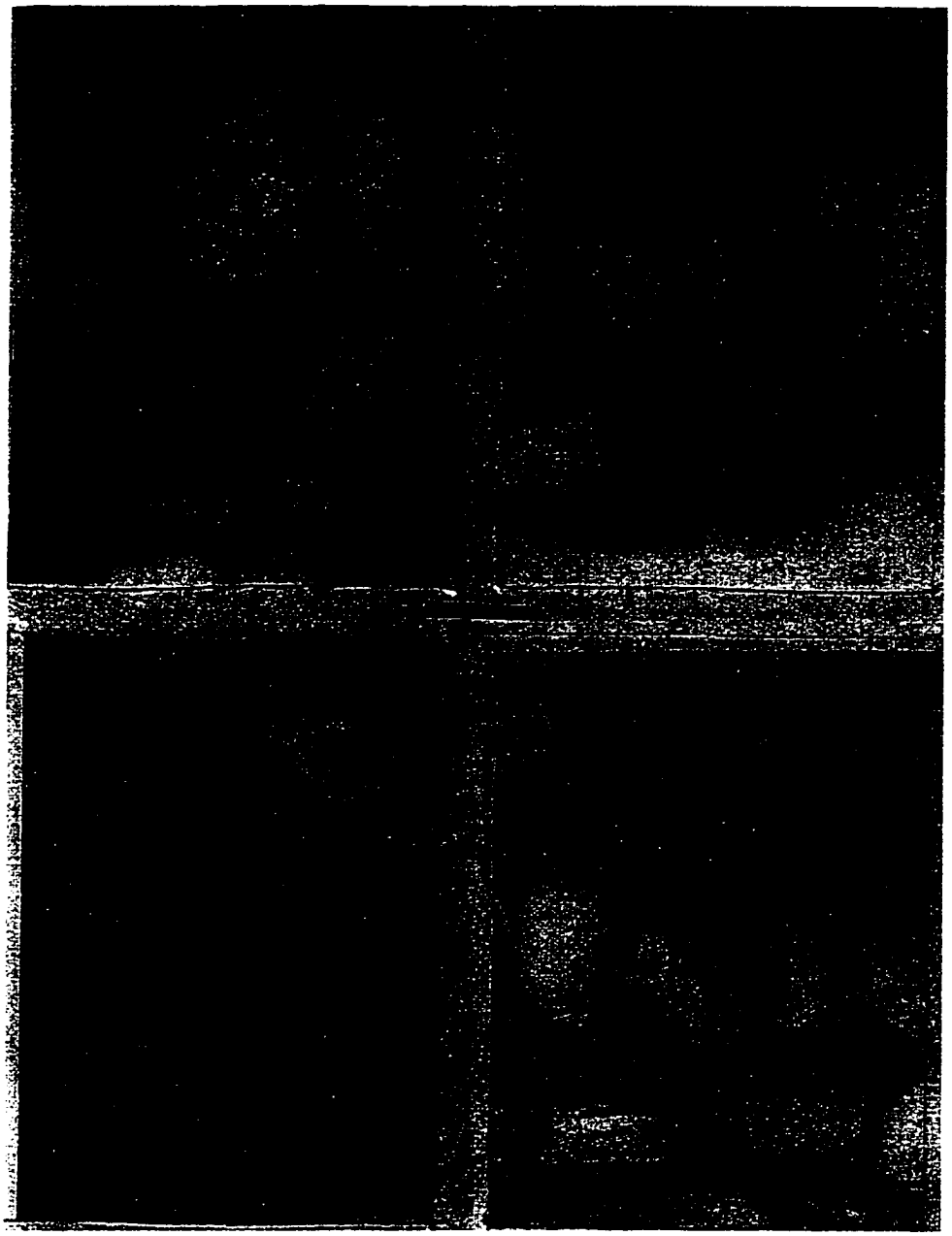
Top left - Ka, Top right - Ki, Bottom left - Kg, Bottom right - Ks

Figure 4.5 Tangential sections of Khaya species showing ray structure (sheath cells, aggregate rays, heterogeneity, size etc.) and fibre septation. Bar = 160 microns.



Top left - Ka, Top right - Ki, Bottom left - Kg, Bottom right - Ks

Figure 4.6 Radial sections of Khaya species showing mainly procumbent ray cells and few upright cells in marginal rows (about 2-4). Bar = 125 microns.



Top left - Ka, Top right - Ki, Bottom left - Kg, Bottom right - Ks

Figure 4.7 Radial sections of Khaya species showing prismatic crystals in upright ray cells. Bar = 30 microns.

4.2 QUANTITATIVE DATA

4.2.1 Juvenile/mature wood width

As shown in Table 4.2, Figure 4.8 is the result of fitting a linear regression model, Y=A+BX (Yang *et al.*, 1986) to the initial data on fibre lengths. This was done to enable the determination of juvenile/mature wood boundary. The pattern of variation in fibre lengths as shown in Figure 4.8 comprised a zone close to the pith with increasing lengths (juvenile wood) and a zone with approximately constant lengths towards the bark (mature wood). Table 4.3 indicates fibre lengths, ring numbers and distances from pith of the juvenile/mature wood boundary in the four Khaya species.

Table 4.2 Linear regression equation and correlation coefficient between fibre length and growth ring number counted from the pith in juvenile and mature wood of four Khaya species

Species and wood zone	Linear Equation	r^2 value
KaJ	Y = 1.110 + 0.0150X	0.903*
KaM	Y = 1.500 + 0.0005X	0.297^{ns}
KiJ	Y = 1.090 + 0.0180X	0.931*
KiM	Y = 1.530 + 0.0014X	0.075^{ns}
KgJ	Y = 1.050 + 0.0260X	0.860*
KgM	Y = 1.806 + 0.0001X	0.002^{ns}
KsJ	Y = 1.120 + 0.0100X	0.466^{ns}
KsM	Y = 1.340 + 0.0008X	0.030^{ns}

(...J) and (...M) are juvenile and mature wood zones respectively. Y is fibre length and X is growth number counted from the pith. * - significant at 95% probability level, ns - not significant at 95% probability level

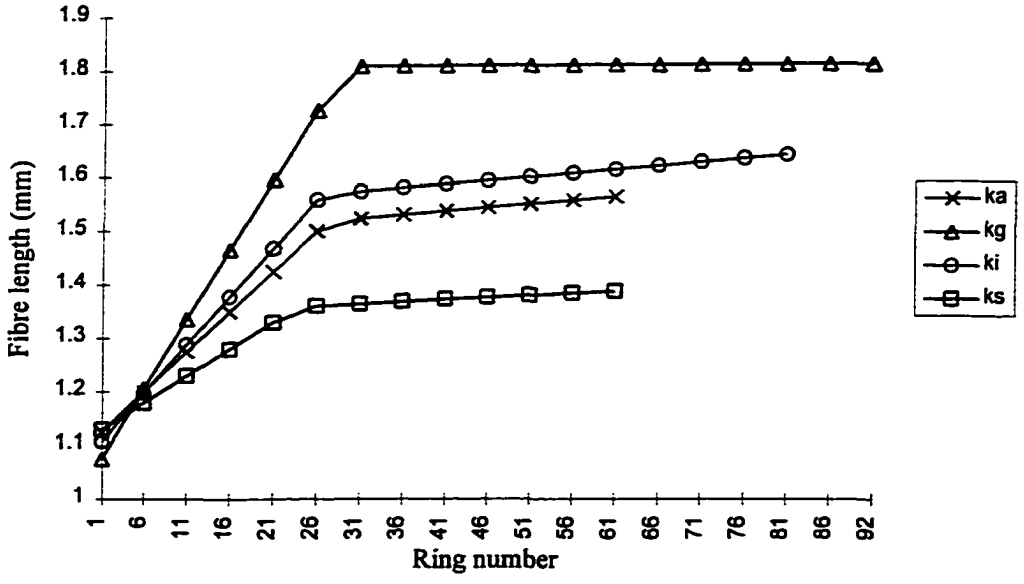


Figure 4.8 Fibre length versus ring number in four *Khaya* species.

Table 4.3 Fibre lengths, ring numbers and distances from pith of juvenile/ mature wood boundaries in four Khaya species.

Species	Fibre length at boundary (mm)	Ring number at boundary	Boundary distance from pith (cm)
Ka	1.51	27	17
Ki	1.57	26	14
Kg	1.81	29	15
Ks	1.36	24	18

4.2.2 Relative Density

In the initial study with strip samples it was observed that apart from the first few rings, i.e., the first five rings, almost all of the species demonstrated only a fair amount of variation in relative density from pith outward. The only exception was in Ks where relative density in heartwood zone increased continuously from 0.70 to 0.80 followed by a sharp drop in the sapwood zone, from 0.80 to about 0.50. Kg varied

within 0.60 and 0.70 whereas Ka and Ki ranged between 0.40 and 0.55 (Fig. 4.9). Averages of relative density for the four species shown in Table 4.4 were obtained from further studies of 10 core samples per species.

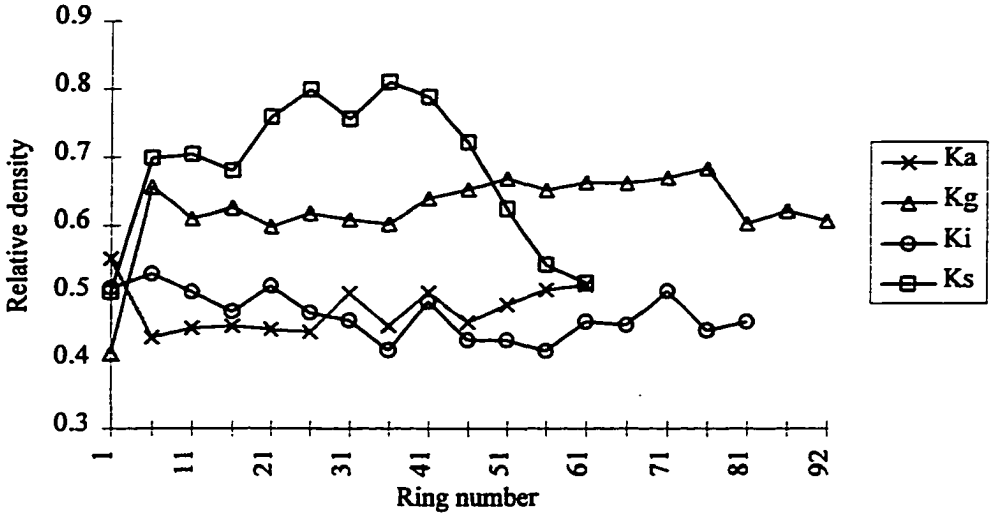


Figure 4.9 Relative density versus ring number in four *khaya* species.

Table 4.4 Mean relative densities in mature wood of four Khaya species

Relative density	S P E C I E S			
	Ka	Ki	Kg	Ks
Mean	0.56	0.53	0.68	0.72
S.d	0.04	0.05	0.03	0.03

4.2.3 Sapwood width and percentage

Generally, sapwood width increased sharply up to the 41-50 cm diameter (dbh) class followed with a gradual rise up to about 81-90 cm diameter class and then somewhat flattened out with 40-50 mm of sapwood (Figure 4.10). The percentage sapwood chart (Figure 4.11) showed approximately a mirror image of the widths chart, dropping steeply from the small diameters to the large ones up to the 41-50 cm diameter

class. Thereafter, a gradual decrease was evident in all the species until about the 81-90 cm diameter class where the % sapwood became constant at 8-10 %. Table 4.5 shows mean sapwood widths and corresponding standard deviations for each diameter class.

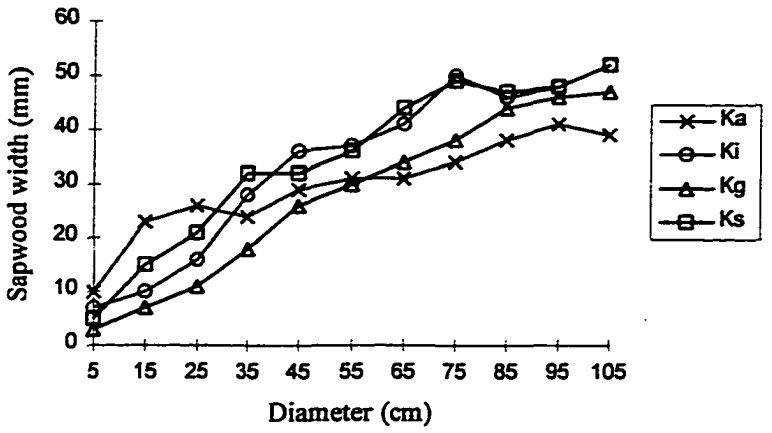


Figure 4.10 Sapwood width versus diameter class in four Khaya species.

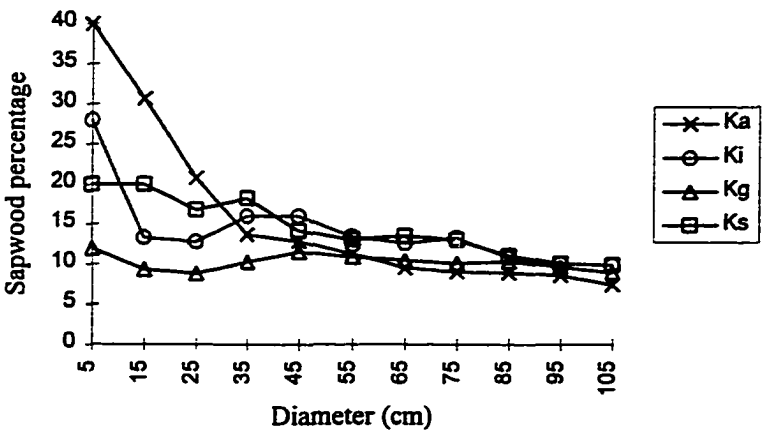


Figure 4.11 Sapwood percentage versus diameter class in four Khaya species.

Table 4.5 Mean sapwood widths and percentages in four Khaya species.

Class (cm)	MEAN / STANDARD DEVIATION							
	Ka		Ki		Kg		Ks	
	width	%	width	%	width	%	width	%
1-10	10.4	**42**	7.1	**28**	3.0	**12**	5.1	**20**
	1.9	**7.6**	2.2	**8.7**	1.2	**4.6**	2.6	**10.4**
11-20	23.0	**31**	9.6	**13**	7.4	**10**	15.4	**21**
	4.7	**6.3**	1.6	**2.2**	2.8	**3.7**	6.0	**8.0**
21-30	25.5	**20**	16.4	**13**	10.7	**9**	20.6	**17**
	5.9	**4.8**	1.6	**1.3**	3.9	**3.2**	5.4	**4.3**
31-40	28.0	**14**	28	**16**	17.9	**10**	32.4	**19**
	6.3	**3.6**	3.3	**1.9**	4.0	**2.3**	6.6	**3.8**
41-50	28.9	**13**	35.5	**16**	26.4	**12**	32.1	**14**
	6.2	**2.7**	4.9	**2.2**	4.5	**2.0**	6.7	**3.0**
51-60	31.3	**11**	36.5	**13**	30.2	**11**	35.5	**13**
	6.4	**2.3**	3.2	**1.2**	5.7	**2.1**	4.6	**1.7**
61-70	30.6	**9**	41.4	**13**	33.8	**10**	44.1	**14**
	5.5	**1.7**	3.1	**1.0**	5.9	**1.8**	9.9	**3.1**
71-80	34.2	**9**	50.3	**13**	37.9	**10**	48.5	**13**
	3.6	**1.0**	2.7	**0.7**	6.6	**1.7**	9.1	**2.4**
81-90	38.4	**9**	45.7	**11**	43.6	**10**	46.8	**11**
	7.6	**1.8**	6.1	**1.4**	5.7	**1.3**	9.3	**2.2**
91-100	41.3	**9**	47.6	**10**	45.8	**10**	47.9	**10**
	6.8	**1.4**	5.3	**1.1**	5.9	**1.2**	7.2	**1.5**
100+	38.9	**7**	52.0	**10**	46.5	**9**	51.9	**10**
	7.3	**1.4**	3.2	**0.6**	4.4	**0.8**	9.0	**1.7**

4.2.4 Vessel frequency and dimension

Results of initial measurements on Khaya wood vessels, i.e., density, diameter and length are shown in (Appendix V). Most of these initial vessel data did not show significant differences among the Khaya species. The few significant cases were largely overlapping, thus no further investigation with core samples was carried out on vessels.

4.2.5 Fibre dimensions

In the initial study, marked variation in fibre length and diameter was observed from juvenile to mature wood zones within each of the species (Appendix VI). Other fibre dimensions such as lumen size, single wall thickness and lumen/wall ratio did vary but not significantly (Appendix VI). Further studies of fibre dimensions with core samples revealed differences among the species (Table 4.6).

Table 4.6 Mean fibre characteristics in mature wood of four Khaya species.

Fibre characteristic	MEAN/STANDARD DEVIATION			
	Ka	Ki	Kg	Ks
Length (mm) - mean	1.6	1.7	1.9	1.3
- s.d	0.20	0.29	0.24	0.24
Diameter (μm)	24	25	20	16
	3.78	4.89	3.29	2.93
Lumen size (μm)	12.3	10.1	8.7	1.9
	1.80	1.80	1.80	0.70
Wall thickness (μm)	2.6	2.3	3.7	5.2
	0.40	0.30	0.50	0.90
Lumen/wall ratio	4.8	4.5	2.4	0.4
	0.90	1.00	0.50	0.10

4.2.6 Ray frequency and dimension

4.2.6.1 Rays per mm

As in the case of vessels, some initial ray frequency data indicated significant differences but could not be further investigated due to pronounced overlaps among species' ranges.

4.2.6.2 Dimensions (height, width and height/width ratio)

Ray dimensions measured from the juvenile wood zone varied considerably from those of mature wood in the initial survey study (Appendix VI). Juvenile rays were mostly found shorter and thinner than mature ones. In the mature wood core samples, average ray heights, widths and height/width ratios showed some differences among the Khaya species (Table 4.7).

Table 4.7 Mean ray characteristics in mature wood of four Khaya species.

Ray characteristic	MEAN/STANDARD DEVIATION			
	Ka	Ki	Kg	Ks
Height (mm)	0.57	0.55	0.59	0.50
	0.04	0.05	0.06	0.06
Width (μm)	88	100	89	104
	15.20	13.87	17.52	21.47
Height/width ratio	6.6	5.7	6.9	5.0
	1.41	1.19	1.40	1.22

4.2.3.3 Percentage Multiseriate Rays

Preliminary ray counts on tangential sections prepared from juvenile and mature wood zones showed fairly equal proportions of multiseriate rays in both zones within a

species (Appendix V and VI). Among the species, mean values obtained from the 10 core samples revealed large differences (Table 4.8). Ki had the lowest percentage of multiseriate rays, averaging 64%, followed by Ka, Kg and Ks with respective values of 80%, 85% and 87%.

Table 4.8 Mean percentage multiseriate rays in mature wood of four Khaya species.

Multiseriate rays	S P E C I E S			
(%)	Ka	Ki	Kg	Ks
Mean	80	64	85	87
s.d	3.45	5.18	5.51	5.01

5. DISCUSSION

5.1 SUITABILITY ASSESSMENT OF IDENTIFICATION FEATURES

5.1.1 Qualitative descriptions

In most wood identification undertakings, qualitative descriptions of anatomical features are preferred due to speed and accuracy achieved by assigning special features to species. In situations where species to be identified bear very close resemblance to each other, over-reliance on mere descriptive features may elude clear identification. As observed in this study, the species exhibited characteristics so similar that it was impossible to separate all the four species based on qualitative descriptions alone. However, there were some qualitative differences that enabled separation of Ks.

5.1.1.1 Macroscopic features

As reported by Hart (1960) and Johnston (1955), only Ks was observed with occasional traumatic canals in this study (Figure 4.1). Therefore, the detection of such canals in a Ghanaian Khaya wood sample could be very well associated to Ks. However, the absence of this feature does not preclude a given Khaya wood from being Ks, due to its occasional nature. Hence this is a weakness in its suitability for identifying the species.

Results obtained from the chemical tests indicated Bromcresol green as effective in differentiating Ks (at 12% moisture content) from the other Khaya species (Table 4.1). This observation needs to be further investigated considering the following factors (as outlined by Kutscha and Sachs 1962) before being applied. The factors include presence of preservatives, immersion in sea water, presence of extractives, moisture content, freshly exposed surface, environmental conditions e.g., soil pH, time of felling, abnormal wood e.g., wound, false heartwood and presence of decay.

5.1.1.2 Microscopic features

Chattaway (1932) classifies fibres with lumen size less than double wall thickness as 'thick-walled', those with lumen much greater than double wall thickness 'thin-walled', and intermediate cases as 'thin-to-thick-walled'. From Figure 4.3, only Ks fibres were observed as thick-walled. Similar observation was made by Wagenführ and Steiger (1963) and Johnston (1955). This unique feature confers an unmistakable identity on the species. The 'thin-to-thick walled' description of Kg fibres seem too ambiguous to distinguish it from the thin-walled Ka and Ki. However, following Chattaway's (1932) description, relative fibre wall thickness can be quantitatively expressed in terms of lumen/wall ratio in order to overcome the problem of ambiguity.

The relatively more rounded and gum-enrinched rays in Ks and higher incidence of smaller rays in Ki could be useful as supporting features in identifying the species.

5.1.2 Quantitative data

Suitability of a quantitative feature in this study was based on significant Student t-test with no overlap of compared confidence limits. This was done to ensure that a defined confidence limit is really confined to a species.

5.1.2.1 Juvenile/mature wood width

There is no reported use of this feature for wood identification in the literature. Its determination in this study was just for gaining an indication of the 'pith- outward' variation pattern of quantitative data on wood cells. However, its importance in wood utilisation cannot be overemphasised due to the profound effect it has on wood in service. Therefore, it is necessary as a concomitant data in wood studies but not in species identification.

5.1.2.2 Relative density

In listing the standard characters suitable for computerised hardwood identification, Miller and Baas (1981) recognised the usefulness of relative density in identification and as the most important of all the physical properties.

In the diffuse-porous Khaya species, the slight variation observed in relative density from pith outward was expected (Zobel and Buijtenen 1989, Bhat *et al.* 1989, Oteng-Amoako *et al.* 1983). The relatively higher variation observed in Ks might be due to the harsh environmental conditions of growth in an area of extreme dryness and high frequency of bush fires (Chudnoff 1976). Since the biggest change in relative density in Ks occurred in the sapwood zone, comparison among heartwood samples was

still possible with resultant highly significant differences shown in Table 5.1. The data obtained in this study closely related to the averages reported on the species (ITTO 1986, Chudnoff 1980, Bolza and Keating 1972, Lavers 1969, GTMB 1969, Kloot and Bolza 1961). Relative density in the Khaya species can be used to group the four species into two with Ka and Ki in the medium density range of 0.4 - 0.6, and Kg and Ks in the high densities of 0.6 - 0.8.

Table 5.1 Comparison of significance levels of mature wood relative density in four Khaya species.

Wood property	Degrees of freedom	Calculated t-values/Levels of significance					
		Ka/Ki	Ka/Kg	Ka/Ks	Ki/Kg	Ki/Ks	Kg/Ks
Relative density	9	1.41^{ns}	7.20**	9.60**	5.91**	7.49**	2.83*

* - 95% probability level, ** - 99% probability level, ns - not significant

5.1.2.3 Sapwood width and percentage

The continuous variation in Khaya sapwood widths with tree diameter (Figure 4.10) rendered it difficult to compare species for any significant differences within a reasonable range of tree diameters. As seen from Table 5.2 there was an interplay of 'significant' and 'non-significant' differences among the species from one diameter class to the other. However, from 80-100 cm diameters, where sapwood widths were noted to be somewhat constant, all the species tested insignificantly different. Thus sapwood width was considered not suitable for identification of the species.

Table 5.2. Comparison of of significance levels of sapwood widths in four Khaya species.

Diameter class	Deg. of freedom	Calculated t-values/ Levels of significance					
		Ka/Ki	Ka/Kg	Ka/Ks	Ki/Kg	Ki/Ks	Kg/Ks
1-10	9	3.41**	9.88**	4.94**	4.91**	1.76^{ns}	2.20^{ns}
11-20	9	8.10**	8.56**	2.99*	2.05^{ns}	2.80*	3.63**
21-30	9	4.46**	6.28**	1.84^{ns}	4.06**	2.24^{ns}	4.46**
31-40	9	1.65^{ns}	2.49*	2.73*	5.84**	1.79^{ns}	5.64**
41-50	9	2.51*	0.98^{ns}	1.05^{ns}	4.10**	1.23^{ns}	2.12^{ns}
51-60	9	2.18^{ns}	0.39^{ns}	1.60^{ns}	2.89*	0.54^{ns}	2.17^{ns}
61-70	9	5.13**	1.19^{ns}	3.588**	3.42**	0.78^{ns}	2.68*
71-80	9	10.73**	1.48^{ns}	4.38**	5.22**	0.57^{ns}	2.83*
81-90	9	2.25^{ns}	1.64^{ns}	2.10^{ns}	0.76^{ns}	0.30^{ns}	0.88^{ns}
91-100	9	2.19^{ns}	1.50^{ns}	2.00^{ns}	0.68^{ns}	0.10^{ns}	0.68^{ns}
100+	9	4.93**	2.68*	3.36**	3.03*	0.03^{ns}	1.62^{ns}

5.1.2.4 Vessel frequency and dimensions

Initial quantitative data, i.e., density, diameter and length collected on Khaya wood vessels did not establish any appreciable differences among the species (Appendix V), thus vessel data were considered unsuitable for use in separating the species. However, Wagenführ and Steiger (1963) found some differences (though with overlap) in vessel density between Ka from Ghana and Ki from Nigeria. This presupposes a posssible influence of differing locations.

5.1.2.5 Fibre dimensions

Miller and Baas (1981) reported that, although fibre length is used in standard wood description and phylogenetic studies, its use in wood identification is only occassional. On quantitative measurements of fibre wall thickness, Miller and Baas (1981) noted it as time consuming and not useful in identification.

Comparative studies of mature wood fibre lengths indicated highly significant differences among the species (Table 5.3), but the use of fibre lengths for identifying

Khaya species was impaired by the high degree of variation from juvenile to mature wood zones (Figure 4.8 and Appendix VI). This resulted in large overlaps between compared ranges of the fibre data. Fibre lumen size and single wall thickness also showed significant differences with overlaps, but when lumen/wall ratio was considered, Kg and Ks tested significantly different from all other species without overlaps.

5.1.2.5 Ray frequency and dimensions

Quantitative assessment of rays for identification of species has taken various forms such as height, width and volume (Carlquist 1988), rays per mm or ray frequency (Miller and Bass 1981), frequency of broad rays (Luxmi-Chauhan *et al.* 1995), numbers of biseriate and triseriate rays (Agarwal and Luxmi-Chauhan 1988), and percentage areas of rays (Giraud 1977). The choice of percentage multiseriate rays for comparative examination in this study was prompted by the relatively high incidence of small rays (i.e., uni-, bi-, and triseriate) on tangential sections of Ki (Figure 4.4). This resulted in reduced proportion of the more functional multiseriate rays. The initial study indicated approximately equal percentages of multiseriate rays in juvenile and mature wood zones within a species (Appendix VI). A further study also indicated significant differences among species at the 99% probability level (Table 5.3). Therefore, percentage mutiseriate ray was considered useful in separating the species.

Data collected on ray height, width and height/width ratio from mature wood samples were significantly different in most comparative tests. Like fibre dimensions, considerable variations were seen between juvenile and mature wood samples within a

species (Appendix VI). Thus ray data, such as height, width, and height/width ratio were considered unsuitable for identifying the Khaya species from Ghana due to extensive overlaps.

Table 5.3 Comparison of significance levels of mature wood cell characteristics in four Khaya species.

Description of Measurement	Degree of freedom	Calculated t-values/Levels of significance					
		Ka/Ki	Ka/Kg	Ka/Ks	Ki/Kg	Ki/Ks	Kg/Ks
Fibre:							
- Length	149	3.47**	11.72**	11.72**	6.49**	12.97**	21.58**
- Diameter	49	1.13^{ns}	5.59**	9.46**	5.94**	9.28**	4.34**
- Lumen size	49	3.77*	11.57**	23.47**	7.03**	18.51**	16.05**
- Wall thickness	49	2.62*	4.33**	11.51**	6.30**	13.32**	6.88**
-Lumen/wall ratio	49	0.97^{ns}	12.87**	21.18**	10.44**	17.78**	22.05**
Rays:							
- % multiseriate rays	49	18.00**	5.38**	8.05**	19.44**	22.34**	1.73^{ns}
- height	99	2.76**	3.11**	9.66**	5.10**	5.86**	11.47**
- width	99	5.32**	0.14^{ns}	5.67**	4.90**	1.56^{ns}	5.39**
- height/width ratio	99	4.85**	1.50^{ns}	8.54**	6.50**	4.09**	10.18**

* - 95% probability level, ** - 99% probability level, ns - not significant

5.2 PROPOSAL FOR IDENTIFICATION KEY

From the suitability assessment, it was clear that Ghanaian Khaya species can be separated from each other. Identification of the individual species should be possible by combined use of features such as fibre lumen/wall ratio and percentage multiserite rays including other supporting features like relative density and ray appearance.

In Ks, the fibre lumen/wall ratio of less than 1 and the relatively more rounded and gum-enriched rays were considered unique. Therefore, it was inferred that the species could be separated without any interference from the others. Distinction of Kg from the remaining three was also possible with its lumen/ wall ratio less than 3, i.e.,

ranging from 1.8- 2.8 and relative density more than 0.6. Average percentage multiseriate rays in Ki, i.e., 64% tested significant at the 99% probability level against all other species without overlaps. In the case of Ka and Ki, percentage multiseriate rays showed the best difference between the two. Based on the combination of the above features, Figure 5.1 is being proposed as the identification key for separating Ghanaian *K. anthotheca* (Ka), *K. ivorensis* (Ki), *K. grandifoliola* (Kg) and *K. senegalensis* (Ks)

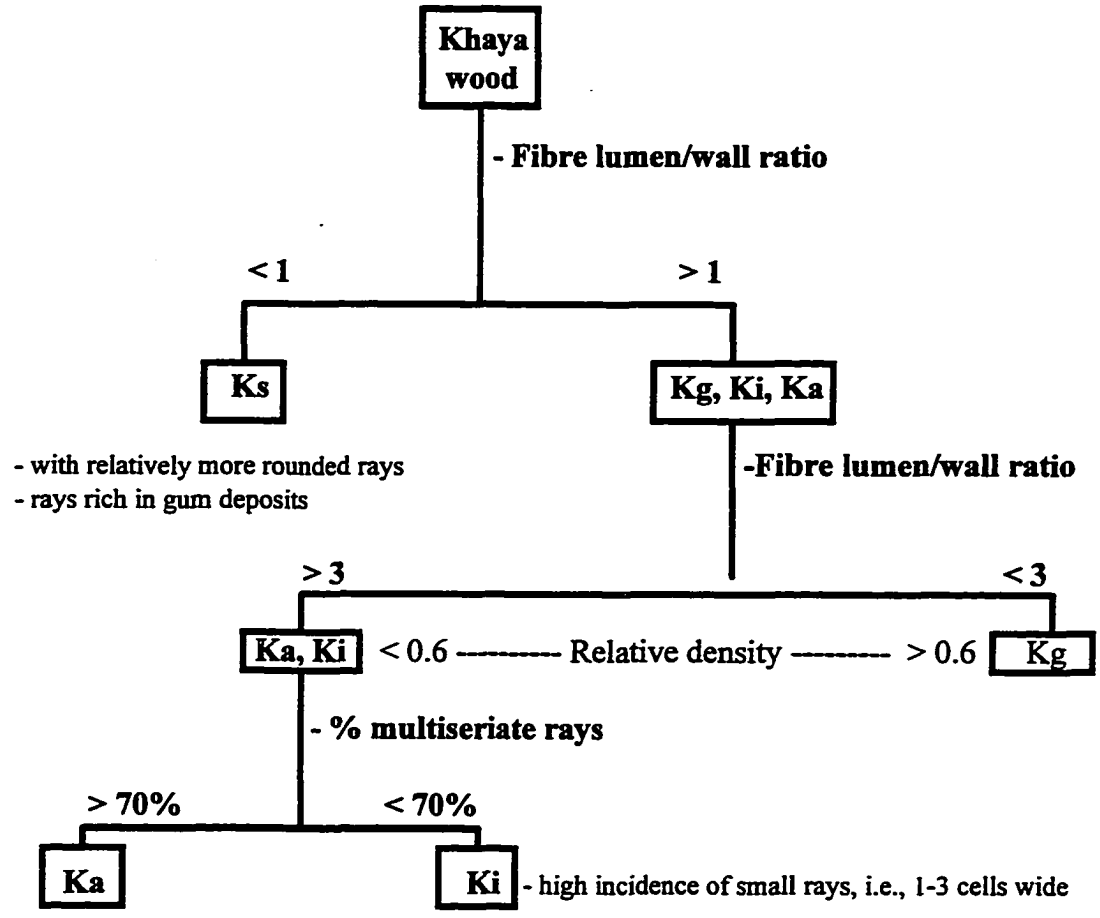


Figure 5.1 Proposed identification key for Ghanaian Khaya species.

CONCLUSIONS

Stem wood structure of four Ghanaian Khaya species were studied. Some features were very similar while others showed significant differences which can be used for identification of the four species.

Qualitative description of anatomical features alone failed to show clear differences among the four species studied. However, Ks had relatively more rounded, gum-enriched rays while Ki had high incidence of smaller rays, i.e., uniserite, biseriate and triserite rays.

Chemical tests for colour reaction in sapwood and heartwood gave off similar reactions in all the species. However, the heartwood of Ks at 12% m.c was stained yellowish-green by Bromcresol green with all others being stained by just the green colour of the chemical.

Some quantitative anatomical features of the four studied species were very similar. The overall ranges of these features in mature wood were sapwood width and percentage (39-52 mm and 7-10 % respectively); vessel diameter (247-292 μm), length (0.40-0.54 mm), and density (4-5). Others were fibre length (1.3-1.9 mm), diameter (16-25 μm), lumen size (8.7-12.3 μm) and single wall thickness (2.6-5.2 μm) in addition to ray frequency (7-8), height 0.50-0.59 mm), width (88-104 μm) and height/width ratio (5.0-6.9).

Other quantitative anatomical features showed significant differences. It was found that mean fibre lumen/wall ratio in Ks, Kg, Ki and Ka were 0.4, 2.4, 4.5 and 4.8 respectively. Ki had the lowest of percentage multiseriate rays averaging 64% while the other species ranged from 80-87%. Relative density of Ka and Ki ranged from 0.4-0.6 while that of Kg and Ks was 0.6-0.8. Based on the features which showed significant differences, an identification key to differentiate the four Ghanaian Khaya species was proposed.

LITERATURE CITED

Agarwal, S. P. and Luxmi-Chauhan 1988. On the structure and identification of Eucalyptus species. Indian Forester 114(3): 145-151

Ayensu, E. S. and A. Bentum 1974. Commercial timbers of West Africa. Smithsonian Contributions to botany No. 14. 69pp.

Bamber, R. K. and R. A. Curtin 1974. Some properties of wood in blackbutt trees of two ages. Aust. For. 36: 226-234.

Bamber, R. K., A. G. Floyd and F. R. Humphreys 1969. Wood properties of flooded gum. Aust. For. 33: 3-12.

Barefoot, A. C. and W. H. Frank 1982. Identification of modern and tertiary woods. Clarendon Press, Oxford. 189 pp.

Baretta-Kuipers, T. 1979. The wood structure of leguminous tribes - their characterisation by ray and parenchyma features. IAWA Bull. No. 2(3): 34.

Barton, G. M. 1973. Chemical colour tests for Canadian woods. Can. For. Ind. February 1973, 57-62.

Bhat, K. M., K. V. Bhat, and T. K. Dhamodaran 1989. Radial patterns of density variation in eleven tropical Indian hardwoods. Holzforschung 43(1): 45-48.

Bolza, E. and W. G. Keating 1972. African timbers - the properties, uses, and characteristics of 700 species. Div. Bld. Res. (CSIRO), Melbourne, Australia. 699pp.

Brazier, J. D. 1976. Observations on some anatomical features used in identification and taxonomy. Leiden Botanical Series No. 3. 102-106

Brasil, M. A. M. and M. Ferreira 1972. Viriacao da densidade basica e das caracteristicas das fibras em *Eucalyptus grandis* Hill ex Maiden, ao nivel do DAP. IPEF 5: 81-90.

Brunner, M.; L. J. Kucera and E. Zurcher 1994. Major timbers of Guyuna - a lens key. Backhuys Publishers, Leiden, Netherlands. 184 pp.

Carlquist, S. 1988. Comparative wood anatomy: systematic, ecological, and evolutionary aspects of dicotyledon wood. Springer-Verlag, N.Y. 436 pp.

Chalk, L. 1951. Water and growth of Douglas-fir. Q. J. For. 45: 237-242

Chattaway, M. M. 1932. Proposed standards for numerical values in describing woods. Trop. Woods 29: 20-28

Chen, B. L., P. Baas; E. A. Wheeler and S. M. Wu 1993. Wood anatomy of trees and shrubs from China VI - Magnoliaceae. IAWA J. 14(4): 391-412.

Chimello, J. P. and G. Ifju 1978. A qualitative approach to wood anatomy. IAWA Bull. 2(3): 48-49.

Chu, F. F. T. 1974. Anatomical features of the Dipterocarp timbers of Sarawak. Gardens' Bull. 27(1): 95-119.

Chudnoff, M. 1961. The physical and mechanical properties of *Eucalyptus camaldulensis*. Isr. J. Agr. Res. 66, 39pp.

Chudnoff, M. 1976. Density of tropical timbers as influenced by climatic life zones. Commonwealth For. Rev. 55: 203-217

Chudnoff, M. 1980. Tropical timbers of the world. United States Dept. Agric., USDA, For. Serv., Agric. Handbook No. 607, F. P. L., Madison, Wisconsin. 439-442.

Collet, B. M. 1970. Scanning electron microscopy: a review and report of research in wood science. Wood Fibre 2(2): 113-133.

Côté, W. A. Jr. 1967. Wood Ultrastructure: an atlas of electron micrographs. University of Washington Press, Seattle.

Crawford, I. A., F. J. Prentice and C. H. Turner 1972. Variation in pulping quality within two trees of *Eucalyptus delegatensis*. Appita 25: 353-358.

Dong, Z. M. and P. Baas 1993. Wood anatomy of trees and shrubs from China V - Anarcadiaceae. IAWA J. 14(1): 87-102.

Doran, J. C. 1974. Genetic variation of wood density in *Eucalyptus regnans*. Res. Work Group. Aust. For. Commonwealth For. Gen. Melbourne, Australia, 99-101

Dyer, S. T. 1988. Wood flourescence of indigenous South African trees. IAWA Bull. 9(1): 75-87.

FPIB 1995. Annual permit report. Forest Products Inspection Bureau, Takoradi, Ghana (Unpublished).

FPRI 1961. Differentiation of Red Luan (*Shorea negrosis* Foxw.) and Tangile (*Shorea polysperma* [Blco.] Merr.). Tech. Note For. Prod. Res. Inst. Phillipines No. 23: 4

FRMP 1994. Discussion paper I. Forest Resources Management Project, Forestry Department, Ghana (Unpublished).

Franklin, C. L. 1945. Preparing thin sections of synthetic resin and wood resin composites, and a new maceration method for wood. Nature (London) 155: 51.

Furuno, T., W. Côté and W. A. Côté 1983. Observation of cell inclusions in Papua New Guinea woods by means of SEM/EDXA. IAWA Bull. 4(4): 219-236.

Gasson, P. 1987. Interpretation and choice of vessel characters in the IAWA standard list. IAWA Bull. 8(3): 233-235

Giraud, B. 1977. Statistical analysis of wood structure variation as related to distance from the pith in *Entandrophragma utile* (Meliaceae). IAWA Bull. 4: 71-75

Gottwald, H. and N. Parameswaran 1980. Anatomy of wood and bark of Tectona (Verbanaceae) in relation to taxonomy. Botanische Jahrbucher fur systematik, Pflanzengeschicte und Pflazengoegraphie 101(3): 363-384.

Gray, R. L. and W. A. Côté 1974. SEM/EDXA as a diagnostic tool for wood and its inclusions. IAWA Bull. 3: 6-11.

Gregory, M. 1980. Wood identification: an annotated bibliography. IAWA Bull. 1 (n.s): 3-41.

GTMB 1969. Ghana hardwoods. Ghana Timber Marketing Board, Takoradi, Ghana. 109pp.

Hall, J. B. and M. D. Swaine 1976. Classification and ecology of closed canopy forest in Ghana. J. Ecol. 64: 931-951.

Hall, J. B. and M. D. Swaine 1981. Distribution and ecology of vascular plants in a tropical rain forest vegetation: Forest vegetation in Ghana. Junk, the Hague. 383pp.

Hamilton, J. R. 1961. Variation of wood properties in southern red oak. For. Prod. J. 11: 267-271.

Hans, A. S., J. Burley and P. Williamson 1972. Wood quality in *Eucalyptus grandis* grown in Zambia. Holzforschung 26: 138-141.

Harris, J. M. and G. D. Young 1980. Wood properties of some New Zealand-grown Eucalyptus. Proc. Conf. Aust. - New Zealand Inst. For., Rotorua: 200-212.

Hart, G. 1960. The structure of hardwoods with terms, definitions and drawings: Part I - macroscopic structure. Information Bull. B/IB/3, TRADA. 11pp.

Harzman, L. and H. Koch 1982. Structural development of tropical hardwoods. Holztechnologie 23(1): 8-13

Hawthorne, W. D. 1990. Field guide to the forest trees of Ghana. Natural Resources Institute, Chatam, Kent. 278pp.

Hawthorne, W. D. 1995. Ecological profiles of Ghanaian forest trees. Nuffield Press, Oxon, Gt. Britain. 182-188.

HMSO 1956. A handbook of hardwoods. Dept. Sci. Ind. Res., London.

HMSO 1981. Ahandbook of hardwoods. Dept. Env. Bld. Res. Est., PRL, Princess Ribourough, Ayeslesbury, Buckinghamshire.

Hoadley, R. B. 1990. Identifying wood - Accurate results with simple tools. The Taunton Press, Newtown, CT. 223pp.

IAWA 1989. IAWA list of microscopic features for hardwood identification. IAWA-Bulletin 10: 3, 219-332

Ifju, G., J. P. Chimello and S. Sudo 1984. Can quantitative anatomy be useful for probability-based wood identification? Poceedings, Pacific Regional Wood Anatomy Conference, Tsukuba, Ibaraki, Japan. 141-143

Ilic, J. 1990. The CSIRO macro key for hardwood identification. CSIRO Div. For. & For. Prod., Highett, Victoria, Australia. 125pp.

Imamura, H.; Y. Tanno and T. Takahashi 1968. The chemistry of wood extractives. XIX. Isolation and identification of four isoflavone dervatives form Eurosian Teak (*Pericopsis spp.*). J. Jap. Wood Res. Soc. 14(5): 295-7.

Inokuma, T., K. Shimaji and T. Hamaya 1956. Studies on Poplars (I). Measurement of fibre-length and specific gravity of Japanese giant poplar (*Populus japano-gigas*). Misc. Infor. Tokyo Univ. For 11: 77-86

ITTO 1986. Tropical timber atlas, Vol. 1 - Africa. International Tropical Timber Organisation (ITTO) and Centre Technique Forestier Tropicale (CTFT), France.

Jain, K. K. and S. Jain 1976. Wood structure and statistical identification in the east Himalayan junipers. Journal of the Indian Academy of Wood Sciences 7(2): 79-86

Jayne, B. A. 1958. Effect of site and spacing on the specific gravity of wood of plantation-grown red pine. Tappi 41: 161-166.

Johnston, D. R. 1955. Structure drawings to 'Specimen woods' 48-51. Wood 20(6-9):230, 280, 321, 358.

Kline, M. 1981. Khaya species - African Mahogany. In a guide to useful woods of the World. King Philip Publishing Co. Portland, Maine. 201-202.

Kloot, N. H. and E. Bolza 1961. Properties of timbers imported into Australia. Technol. Pap. 12. Div. For. Prod., CSIRO, Australia. 79 pp.

Kribs, D. A. 1959. Commercial foreign woods on American market. Penn. State Coll., USA. 241pp.

Kribs, D. A. 1968. Commercial foreign woods on the American market. Dover Publications Inc., N.Y. 241 pp.

Kutscha, N. P. and I. B. Sachs 1962. Colour tests for differentiating heartwood and sapwood in certain sotwood tree species. Report No. 2246, FPL, USDA. 13pp.

Kutscha, N. P., J. T. Lomerson and M. V. Dyer 1978. Separation of Eastern spruce and Balsam fir by chemical methods. Wood Sci. & Tech. 12: 293-308.

Land, S. B. and J. C. Lee 1981. Variation in sycamore wood specific gravity. Wood Sci. 13: 166-170.

Land, S. B., S. G. Dicke, G. A. Tuskan and P. E. Patterson 1983. Genetic, site and within-tree variation in specific gravity and moisture content in young sycamore trees. Tappi 66: 149-155.

Lassen, L. W. and E. A. Okkonen 1969. Sapwood thickness of Douglas-fir and five other western softwoods. USDA For. Serv. For. Prod. Lab. Res. Pap. FPL 124

Lavers, G. M. 1969. The strength properties of timbers. F. P. R. L., Bull. 50, HMSO, London.

Li, B., B. J. H. ter Welle and R. K. W. M. Klaassen 1995. Wood anatomy of trees and shrubs from China VII - Sapindcaeae. IAWA J. 16(2): 191-215

Li, Z. M. 1988. On the application of the analysis of variance in the identification of Dadoxylon woods. Acta Botanica Sinica 30(2): 187-195

Luxmi-Chauhan, R. D. Raturi, R. V. Rao, R. Dayal and L. Chauhan 1995. Wood anatomy of Indian Flacourtiaceae. Indian Forester 121(9): 824-837

Lyashenco, N. I. 1984. Anatomical structure of the wood in *Gnetum gnemon* (Gnataceae) and some dicotyledonous plants. Botanicheskii Zhurnal 69(7): 940-943

Maeglin, R. R. and H. E. Wahlgren 1972. Western wood density survey - Rep. No. 2. USDA For. Serv. Res. Pap. FPL - 183.

Maekawa, E. and K. Kitao 1970. Isolation of pterocarpanoid compounds as heartwood constituents of *Maackia amurensis* (Rupr. et Maxim. var. buegri Schneid). Wood Res. No. 50, 29-35.

Mainieri, C. 1972. Contribution to the anatomical study of the timbers of Eastern Region of Paraguay. Forestry and Forest Industries Development Programme. FAO Report No. FAO: SF/PAR 15, Documento de Trabajo No. 14.

Malan, F. S. 1985. Wood property variation in South African grown *Eucalyptus grandis* trees of varying growth stress intensity. Proc. Int. Symp. 'Forest Products Research International - Achievements and the Future', Pretoria. Vol. 1, Topic 16-19.

McElwee, R. L. and J. P. Faircloth 1966. Variation in wood properties of water tupelo in the southeastern coastal plain. Tappi 49: 538-541

Meylan, B. A. and B. G. Butterfield 1972. Three dimensional structure of wood. A scanning electron microscope study. Syracuse Univ. Press. 80 pp.

Miller, R. B. and P. Baas 1981. Standard list of characters suitable for computerised wood identification. IAWA Bull. 2(2-3) n.s: 99-145

Morgan, J. W. W. and R. J. Orsler 1967. A simple test to distinguish *Khaya anthotheca* from *Khaya ivorensis* and *Khaya grandifoliola*. Inst. Wd. Sci. J. 18: 61-4.

Nair, M. N. B., J. J. Shah, and S. V. Subramanyam 1983. Ultrastructure and histochemistry of traumatic gum canals in the wood of *Azadirachta indica* A. Juss. IAWA Bull. 4 (n.s): 103-112.

Nelson, H. D. 1975. Important influence on heartwood formation and heartwood-sapwood proportions in black walnut. Annual Report of the Nut-Growers Association Inc., Southwest Missouri State University, Springfield, MO, August 10-13, 1975. 156-160.

Nelson, H. D. 1976. Gross influence on heartwood formation in black walnut and black cherry trees. USDA For. Res. Pap. FLP 268.

Nicholls, J. W. P. and F. H. Phillips 1970. Preliminary study of coppice-grown *Eucalyptus viminalis* as a source of chip material. CSIRO (Aust.) Div. For. Prod. Tecnol. Pap. No. 58.

Oteng-Amoako, A., C. H. de Zeuuw, and R. W. Meyer 1983. Variation of selected anatomical properties and specific gravity in the stem of naturally grown and plantation-grown Triplochiton scleroxylon from Ghana. IUFRO Conf. Div. 5, Madison, Wisconsin. 45-46.

Oteng-Amoako, A. 1992. The wood anatomy of Papua New Guinea timbers based on the 'IAWA list of microscopic features of hardwood identification'. IAWA Bull. 13(3): 261

Outer, R. W. den; W. L. H. van Veenendaal and C. Versteegh 1988. Determination keys for important West-European woods and tropical commercial timbers. Agricultural Univ., Wageningen Papers, No. 88-1. 89pp.

Palmer, E. R., J. A. Gibbs and A. P. Dutta 1982b. Pulping trials of wood species in plantations in Kenya. Trop. Prod. Inst. L61 London, 58pp.

Panshin, A. J. and C. De Zeuuw 1980. Textbook of woodtechnology. Vol. 1. McGraw-Hill, N. Y. 722pp.

Parameswaran, N. and H. G. Richter 1984. The ultrastructure of crystalliferous cells in some Lecythidaceae with a discussion of their terminology. IAWA Bull. 5 (n.s): 229-236.

Parameswaran, N. and H. Knigge and W. Liesse 1985. Electron microscope demonstration of a suberised layer in the tylosis wall of Beech and Oak. IAWA Bull. 6 (n.s): 269-271

Pleydell, G. 1994. The tropical timbers of Ghana. Timber Export Development Board, Takoradi, Ghana. 87pp.

Robards, A. W. 1970. Electron microscopy and plant ultrastructure. McGraw-Hill, N.Y. 298 pp.

Santos, C. F. O. and I. R. Nogueria 1971. A idade adulta do *Eucalyptus sligna* Smith em Rio Claro Estado de Sao Paulo, determinada pelas dimensoes das fibras. Anais da Escola Superior de Agricultura 'Luiz de Queiroz' 28: 165-175.

Santos, C. F. O. and I. R. Nogueria 1974. Differencas entre as dimenseos das fibras nos aneis de crescimento determinados no D. A. P. e em niveis diferentes do fusto de arvores adultas de *Eucalyptus saligna* Smith. Anais de Escola Superior Agricultura 'Luis de Queiroz' 31: 269-287.

Saucier, J. R. and M. A. Taras 1966. Specific gravity and fibre length variation within annual height increments of red maple. For. Prod. J. 16: 33-36

Sieber, M. and L. T. Kucera 1980. On the anatomy of *Clematis vitalba* L. IAWA Bull. 1(n.s): 49-54.

Skolman, R. G. 1972. Specific gravity variation in *Eucalyptus robusta* grown in Hawaii. US For. Serv. Res. Pap. PSW - 12, 7pp.

Smith, D. M. 1954. Maximum moisture content method for determining specific gravity of small wood samples. USDA, F. P. L. Rep. 2014. 8pp.

Smith, J. H. G., J. Walters and R. W. Wellwood 1966. Variation in sapwood thickness of Douglas-fir in relation to tree and section characteristics. For. Sci. 12: 97-103.

Soloway, S. and S. H. Wilen 1952. Improved ferric chloride test for phenols. Anal. Chem. 24: 979-983.

Spalt, H. A. and W. L. Stern 1956. Survey of African woods. Tropical woods, New Haven, Conn. USA. 105-107.

Steele, J. H., G. Ifju and J. A. Johnson 1976. Quantitative characterization of wood microstructure. Journal of microscopy 107(3): 297-311

Steiger, A. 1972. Rapid identification of some African veneer woods by simple physical and chemical methods. Holztechnologie 13(3): 175-179.

Streets, R. J. 1962. Exotic forest trees in the British Commonwealth. Clarendon Press, Oxford. 765pp.

Swart, J. P. J. and J. J. A. Walt 1985. Systematic wood anatomy of the southern African Lauraceae. Proceedings volume I. Symposium on forest products research international - achievements and the future, Pretoria, South Africa. Paper No. 16-9, 13pp.

Synott, T. J. 1985. A checklist of the flora of Budongo Forest Reserve, Uganda, with notes on ecology and phenology. Commonwealth For. Inst. Occassional Papers 27, Oxford.

Taylor, F. W. 1969. Variation in wood properties of sycamore. For. Prod. Utiliz. Lab. Mississippi State Univ. Res. Pap. 7, 18pp.

Taylor, F. W. 1971. Variation of wood properties in sugarberry. For. Prod. Utiliz. Lab. Mississippi State Univ. Res. Rep. 11, 17pp.

Taylor, F. W. 1973. Variation in the anatomical properties of South African grown *Eucalyptus grandis*. Appita 27: 171-178.

Thomas, R. J. 1985. The characteristics of juvenile wood. Symp. Util. Chang wood Res. South U. S., North Carolina State Univ., Raleigh, North Carolina. 18pp.

Titmus, F. H. 1965. Commercial timbers of the World. The Technical Press, London.U. K. 585 pp.

USDA 1965a. 1965 Status Report - Southern wood density survey. USDA For. Serv. Res. Pap. FPL - 26.

USDA 1965b. Western wood density survey - Rep. No. 1. USDA For. Serv. Res. Pap. FPL - 27.

Wagenführ, R. and A. Steiger 1963. Mahagoni und mahagoniähnliche Hölzer: probleme identifizierung. Holztechnologie, Dresden 4(2): 137-146.

Wagenführ, R. and A. Steiger 1986. Comparative studies on wood anatomy of *Entandrophragma cylindricum* of diverse provenance. Holztechnologie 27(5): 258-259

WCMC 1992. Conservation status listing - Trees and timbers of the World. World Conservation Monitoring Centre - Plants Programme, Cambridge, CB3 ODL, U. K. 585pp.

Welle, B. J. H. ter 1980. Cystolyths in the secondary xylem of Sparattanthelium (Hernandiaceae). IAWA Bull. 1 (n.s): 43-48.

Wheeler, E. A. 1981. Intervascular pitting in *Fraxinus americana* L. IAWA Bull. 2 (n.s): 169-174.

Wheeler, E. A. 1983. Intervascular pit membranes in Ulmus and Celtis native to the United States. IAWA Bull. 4 (n.s): 79-88.

Wheeler, E. A. and R. G. Pearson 1985. A critical review of the IAWA standard list of characters formatted for the IDENT programs. IAWA Bull. 6(2): 151-160

Wiemann, M. C. 1987. Keys for the identification of various woods from Costa Rica. Turrialba 37(4): 381-403.

Wilkes, J. 1988. Wood anatomy of Eucalyptus. IAWA Bull. 9(1): 16-23.

Wilkes, J. and W. A. Heather 1982. Detection of decay with a pulsed-current resistance meter, and radial variation in some wood properties in tallowwood. Aust. For. Res. 12: 63-70.

Wong, T. M. and K. M. Kochumen 1973. The identification of common commercial logs in Peninsular Malaysia. Malaysian-Forester 36(3): 164-184.

Yanchuk, A. D., B. P. Dancik and M. M. Micko 1983. Intraclonal variation in wood density of trembling aspen in Alberta. Wood Fibre Sci. 15: 8pp.

Yang, K. C. and Y. H. Yang 1987. Minute structure of Taiwanese woods: a guide to their identification with micrographs. Huang Shian Yuan Publishing Co., Taipei, Taiwan. 172 pp.

Yang, K. C., C. A. Benson and J. K. Wong 1986. Distribution of juvenile wood in two stems of Larix lariciana. Can. J. For. Res. 16: 1041-1049

Yang, K. C., G. Hazenberg, G. E. Bradfield and J. R. Maze 1985. Vertical variation of sapwood thickness in Pinus banksiana Lamb. and Larix lariciana (Du Roi) K. Koch. Can. J. For. Res. 15: 822-828.

Zobel, B. and J. P. van Buijtenen 1989. Wood variation: its causes and control. Springer-Verlag, N.Y. 363pp.

Zobel, B. and J. Talbert 1984. Applied forest tree improvement. Wiley, N.Y. 505pp.

APPENDICES

Appendix I. Macroscopic features of four Khaya species (Ka, Ki, Kg and Ks)

Feature	Ka	Ki	Kg	Ks
Pores:				
1. Diffuse porous	+	+	+	+
2. Ring or semi-ring porous	-	-	-	-
3. Few	+	+	+	+
4. Moderately numerous	-	-	-	-
5. Numerous	-	-	-	-
6. Small	-	-	-	-
7. Medium (intermediate	-	-	-	-
8. Large	+	+	+	+
9. Solitary pores	-	-	-	-
10. Pore chain (oblique or radial flares)	-	-	-	-
11. Short radial multiples	+	+	+	+
12. Long radial multiples	-	-	-	-
13. Tangential pores	-	-	-	-
14. Pore clusters	+	+	+	+
15. Tyloses distinct	-	-	-	-
16. Black, brown, pinkish deposits	+	+	+	+
17. White or yellowish deposits	-	-	-	-
Parenchyma:				
20. Parenchyma absent or indistinct	-	-	-	-
21. Marginal	±	±	±	±
22. Diffuse	-	-	-	-
23. Diffuse-in-aggregate (Recticulate)	-	-	-	-
24. Surrounding pores (Vasicentric)	+	+	+	+
25. Aliform or confluent	-	-	-	-
26. Fine bands	-	-	-	-
27. Broad	-	-	-	-
28. Regular bands	-	-	-	-
29. Irregular bands	-	-	-	-
Rays:				
30. Very narrow	-	-	-	-
31. Narrow	-	-	-	-
32. Broad	-	-	-	-
33. Two distinct widths	+	+	+	+
34. Ripple marks				
Miscellaneous:				
35. Vasicentric tracheids	-	-	-	-
36. Normal axial canals	-	-	-	-
37. Horzontal (Traumatic) gum canals	-	-	-	+
38. Oil cells	-	-	-	-
39. Latex traces, latex tubes (tanniferous tubes)	-	-	-	-

Physical features:				
Colour:				
40. Cream, pale yellow, straw or white	-	-	-	-
41. Yellow-brown	-	-	-	-
42. Brown, grey-brown or pale brown	-	-	-	-
43. Orange-brown	-	-	-	-
44. Pinkish-brown or reddish-brown	+	+	+	+
45. Black	-	-	-	-
46. Chocolate-brown	-	-	-	-
47. Streaks of colours or greenish-brown	-	-	-	-
48. Tinge, Mauve tint	-	-	-	-
49. Bright-yellow, Dark-yellow	-	-	-	-
Odour and taste:				
50. Aromatic, fragrant	-	-	-	-
51. Foetid	-	-	-	-
52. Spicy, Peppery, Onion, Camphor	-	-	-	-
53. Leathery,Greasy	-	-	-	-
54. Iodine	-	-	-	-
55. Resinous, tannin	-	-	-	-
56. Fruity, sweet	-	-	-	-
57. Bitter	-	-	-	-
58. Salty	-	-	-	-
59. Toxic	-	-	-	-
Weight and Hardness:				
60. Light	-	-	-	-
61. Medium	+	+	-	-
62. Heavy	-	-	+	+
63. Soft	-	-	-	-
64. Fairly hard	+	+	-	-
65. Hard	-	-	+	+
Texture:				
66. Fine	-	-	-	-
67. Moderately coarse	-	-	-	-
68. Coarse	+	+	+	+
Grain:				
69. Straight	±	±	-	-
70. Cross	-	-	-	-
71. Wavy	±	±	-	-
72. Interlocked	±	±	+	+
Miscellaneous tests:				
73. Splinter burns to full ash	+	+	+	+
74. Splinter burns to charcoal	-	-	-	-
75. Ash black	-	-	-	-
76. Ash brown	-	-	-	-
77. Ash grey	-	-	-	-
78. Ash white or whitish-grey	+	+	+	+
79. Splinter sparkles when in flame	-	-	-	-

80. Heartwood flourescent	-	-	-	-
81. Froth test positive	-	-	-	-
82. Water extract flourescent	-	-	-	-
83. Water extract colourless	-	-	-	-
84. Water extract brown or red	+	+	+	+
85. Water extract yellow	-	-	-	-
86. Ethanol extract flourescent	-	-	-	-
87. Ethanol extract colourless	-	-	-	-
88. Ethanol extract brown or red	+	+	+	+
89. Ethanol extract yellow	-	-	-	-
90. Chrome azurol-S test positive	x*	x	x	x

* - not studied
+ - present
- - absent

Appendix II. Microscopic and ultrastructural features of four Khaya species.

Feature	Ka	Ki	Kg	Ks
Growth rings:				
1. Growth ring boundaries distinct	-	-	-	-
2. Growth ring boundaries indistinct or absent	±	±	±	±
Vessels:				
Porosity:				
3. Wood ring-porous	-	-	-	-
4. Wood semi-ring porous	-	-	-	-
5. Wood diffuse- porous	+	+	+	+
Vessel groupings:				
6. Vessels in tangential bands	-	-	-	-
7. Vessels in diagonal and/or radial pattern	+	+	+	+
8. Vessels in dendritic pattern	-	-	-	-
Vessel arrangement:				
9. Vessels exclusively solitary (90% or more)	-	-	-	-
10. Vessels in radial multiples of 4 or more common	+	+	+	+
11. Vessel clusters common	+	+	+	+
Solitary vessel outline:				
12. Solitary vessel outline angular	-	-	-	-
Perforation plates:				
13. Simple perforation plates	+	+	+	+
14. Scalariform perforation plates	-	-	-	-
15. Scalariform perforation plates with ≤ 10 bars	-	-	-	-
16. Scalariform perforation plates with 10-20 bars	-	-	-	-
17. Scalariform perforation plates with 20-40 bars	-	-	-	-
18. Scalariform perforation plates with ≥ 40 bars	-	-	-	-
19. Reticulate, foraminate, and/or other types of multiple perforation plates	-	-	-	-
Intervessel pits: arrangement and size *				
20. Intervessel pits scalariform	-	-	-	-
21. Intervessel pits opposite	-	-	-	-
22. Intervessel pits alternate	+	+	+	+
23. Shape of alternate pits polygonal	-	-	-	-
Range of intervessel pit size (μm):				
24. Minute - ≤ 4μ	+	+	+	+
25. Small - 4-7μ	-	-	-	-
26. Medium - 7-10μ	-	-	-	-
27. Large - ≥ 10μ	-	-	-	-
Vestured pits *:				
28. Vestured pits	±	±	±	±

Vessel-ray pitting *				
29. Vessel-ray pits with distinct borders; similar to intervessel pits in size and shape throughout ray cell	+	+	+	+
30. Vessel-ray pits with much reduced borders to apparently simple: pits rounded or angular	-	-	-	-
31. Vessel-ray pits with much reduced borders to apparently simple: pits horizontal (scalariform,gash-like) to vertical	-	-	-	-
32. Vessel-ray pits of two distinct sizes or types in the same ray	-	-	-	-
33. Vessel-ray pits unilaterally compound and coarse	-	-	-	-
34. Vessel-ray pits restricted to marginal rows	-	-	-	-
Helical thickenings:				
35. Helical thickenings in vessel elements present	-	-	-	-
36. Helical thickenings throughout body of vessel element	-	-	-	-
37. Helical thickenings only in vessel elements tails	-	-	-	-
38. Helical thickenings only in narrower vessel elements	-	-	-	-
Tangential diameter of vessel lumina:				
Mean tangential diameter of vessel lumina				
39. ≤ 50 microns	-	-	-	-
40. 50-100 microns	-	-	-	-
41. 100-200 microns	-	-	-	-
42. ≥ 200 microns	+	+	+	+
43. Vessels of two distinct diameter classes, wood not ring porous	-	-	-	-
Vessels per square millimetre:				
44. ≤ 5 vessels per square millimetre	+	+	+	+
44. 5-20 vessels per square millimetre	-	-	-	-
46. 20-40 vessels per square millimetre	-	-	-	-
47. 40-100 vessels per square millimetre	-	-	-	-
48. ≥ 100 vessels per square millimetre	-	-	-	-
Mean vessel element length:				
49. ≤ 350 microns	-	-	-	-
50. 350-800 microns	+	+	+	+
51. ≥ 800 microns	-	-	-	-
Tyloses and deposits in vessels:				
52. Tyloses common	-	-	-	-
53. Tyloses sclerotic	-	-	-	-
54. Gums and other deposits in heartwood vessels	+	+	+	+
Wood vesselless:				
55. Wood vesselless	-	-	-	-
Tracheids and Fibres:				
56. Vascular/vasicentric tracheids	-	-	-	-
Ground tissue fibres:				
57. Fibres with simple pits *	+	+	+	+
58. Fibres with distinctly bordered pits	-	-	-	-
59. Fibre pits common in both radial and tangential walls	-	-	-	-
60. Helical thickenings in ground tissue fibres	-	-	-	-
Septate fibres and parenchyma-like fibre bands:				

61. Septate fibres present	+	+	+	+
62. Non-septate fibres present	-	-	-	-
63. Parenchyma-like fibre bands alternating with ordinary fibres	-	-	-	-
Fibre wall thickness:				
64. Fibres very thin-walled	+	+	-	-
65. Fibres thin- to thick-walled	-	-	+	-
66. Fibres very thick-walled	-	-	-	+
Mean fibre lengths:				
67. ≤ 900 microns	-	-	-	-
68. 900-1600 microns	±	±	-	+
69. ≥ 1600 microns	±	±	+	-
Axial parenchyma:				
70. Axial parenchyma absent or extremely rare	-	-	-	-
Apotracheal axial parenchyma:				
71. Axial parenchyma diffuse	-	-	-	-
72. Axial parenchyma diffuse-in-aggregate	-	-	-	-
Paratracheal axial parenchyma				
73. Axial parenchyma scanty paratracheal	-	-	-	-
74. Axial parenchyma vasicentric	±	±	±	±
75. Axial parenchyma aliform	-	-	-	-
76. Axial parenchyma lozenge-aliform	-	-	-	-
77. Axial parenchyma winged- aliform	-	-	-	-
78. Axial parenchyma confluent	-	-	-	-
79. Axial parenchyma unilateral paratracheal	-	-	-	-
Banded parenchyma:				
80. Axial parenchyma bands more than three cells wide	-	-	-	-
81. Axial parenchyma in narrow bands or lines up to three cells	-	-	-	-
82. Axial parenchyma reticulate	-	-	-	-
83. Axial parenchyma scalariform	-	-	-	-
84. Axial parenchyma in marginal bands	±	±	±	±
Axial parenchyma cell type/strand length:				
85. Fusiform parenchyma cells	-	-	-	-
86. Two cells per parenchyma strand	-	-	-	-
87. 3-4 cells per parenchyma strand	+	+	+	+
88. 5-8 cells per parenchyma strand	-	-	-	-
89. Over 8 cells per parenchyma strand	-	-	-	-
90. Unlignified parenchyma	-	-	-	-
Rays:				
Ray width				
91. Rays exclusively uniseriate	-	-	-	-
92. Ray width 1-3 cells	-	-	-	-
93. Larger rays commonly 4- to 10-seriate	+	+	+	+
94. Larger rays commonly more than 10-seriate	-	-	-	-
95. Rays with multiseriate portion(s) as wide as uniseriate portions	-	-	-	-
Aggregate rays:				
96. Aggregate rays	+	+	+	+

Ray height:				
97. Ray height more than 1 mm	-	-	-	-
Rays of two distinct sizes:				
98. Rays of two distinct sizes	+	+	+	+
Rays: cellular composition:				
99. All rays procumbent	-	-	-	-
100. All rays upright and/or square	-	-	-	-
101. Body ray cells procumbent with one row of upright and/or square marginal cells	-	-	-	-
102. Body ray cells procumbent with mostly 2-4 rows of upright and/or square marginal cells	+	+	+	+
103. Body ray cells procumbent with over 4 rows of upright and/or square marginal cells	-	-	-	-
104. Rays with procumbent, square and upright cells mixed throughout the ray	-	-	-	-
Sheath cells:				
105. Sheath cells	+	+	+	+
Tile cells:				
106. Tile cells	-	-	-	-
Perforated ray cells:				
107. Perforated ray cells	+	+	+	+
Disjunctive ray parenchyma cell walls:				
108. Disjunctive ray parenchyma cell walls	-	-	-	-
109. ≤ 4/mm	-	-	-	-
110. 4-12/mm	+	+	+	+
111. ≥ 12/mm	-	-	-	-
Wood rayless				
112. Wood rayless	-	-	-	-
Storied structure:				
113. All rays storied	-	-	-	-
114. Low rays storied, high rays non-storied	-	-	-	-
115. Axial parenchyma and/or vessel elements storied	-	-	-	-
116. Fibres storied	-	-	-	-
117. Rays and/or axial elements irregularly storied	+	+	+	+
Secretory elements/cambial variants:				
Oil and mucilage cells:				
119. Oil and/or mucilage cells associated with ray parenchyma	-	-	-	-
120. Oil and/or mucilage cells associated with axial parenchyma	-	-	-	-
121. Oil and/or mucilage cells present among fibres	-	-	-	-
Intercellular canals:				
122. Axial canals in long tangential lines	-	-	-	-
123. Axial canals in short tangential lines	-	-	-	-
124. Axial canals diffuse	-	-	-	-
125. Radial canals	-	-	-	-
126. Intercellular cannals of traumatic origin	-	-	-	±
Tubes/tubules:				
127. Laticifers or tanniniferous tubes	-	-	-	-

Cambial variants:				
128. Included Phloem,concentric	-	-	-	-
129. Included phloem, diffuse	-	-	-	-
130. Other cambial variants	-	-	-	-
Mineral Inclusions:				
Prismatic Crystals:				
131. Prismatic crystals present	+	+	+	+
132. Prismatic crystals in upright and/or square ray cells	+	+	+	+
133. Prismatic crystals in procumbent ray cells	-	-	-	-
134. Prismatic crystals in radial allignment in procumbent ray cells	-	-	-	-
135. Prismatic crystals in chambered upright and/or square ray cells	+	+	+	+
136. Prismatic crystals in non-chambered axial parenchyma	-	-	-	-
137. Prismatic crystals in chambered axial parenchyma cells	-	-	-	-
138. Prismatic crystals in fibres	-	-	-	-
*Druses**				
139. Druses present*	±	±	±	±
140. Druses in ray parenchyma cells	-	-	-	-
141. Druses in axial parenchyma cells	-	-	-	-
142. Druses in fibres	-	-	-	-
143. Druses in chambered cells	-	-	-	-
Other crystal types:				
144. Raphides	-	-	-	-
145.Acicular crystals	-	-	-	-
146. Styloides and/or elongate crystals	-	-	-	-
147. Crystals of other shapes (mostly small)	-	-	-	-
148. Crystal sand	-	-	-	-
Other diagnostic crystal features:				
149. More than one crystal of about the same size per cell or chamber	-	-	-	-
150. Two distinct sizes of crystals per cell or chamber	-	-	-	-
151. Crystals in enlarged cells	-	-	-	-
152. Crystals in tyloses	-	-	-	-
153. Cystoliths	-	-	-	-
Silica:				
154. Silica bodies present	-	-	-	-
155. Silica bodies in ray cells	-	-	-	-
156. Silica bodies in axial parenchyma cells	-	-	-	-
157. Silica bodies in fibres	-	-	-	-
158. Vitreous silica	-	-	-	-

* - *Features that were observed with scanning electron microscope;*

(+) - *present;* (-) - *absent*

Appendix III. Colour tests for heartwood and sapwood -Preparation of chemicals (Kutscha & Sachs 1962)

1. **Alizarine-iodine**[*]
   69.40ml. methanol
   0.30g iodine crystals
   0.10g Alizarine Red S indicator
   0.50ml. conc. sulphuric acid
   29.70ml. water

Mix iodine with methanol, add acid to this mixture; mix alizarine with water and add iodine-methanol-acid mixture; resultant solution is stable.

2. **Alizarine Red S** (0.75%) (USFPL 1954)
   99.25ml. water
   0.75g Alizarine Red S indicator

3. **Ammonium bichromate** (0.6%) (Eades 1958)
   6.00g ammonium bichromate
   94.00ml. water

4. **Benedict's solution** (Eades 1958)
   10.00g sodium carbonate
   17.38g sodium citrate
   1.73g copper sulphte [$CuSO_4.5H_2O$]
   Enough water to make 100ml.

With aid of heat dissolve 17.38g of sodium citrate and 10g of sodium carbonate in 80ml. of water. Filter if necessary, and dilute to 85ml. Dissolve 1.73g of copper sulphate in 10ml. of water. Pour this solution, with constant stirring, into the carbonate-citrate solution, and make up to 100ml. total volume.

5. **Benzidine** (USFPL 1954)
Solution A:
   1.00g Benzidine
   5.00ml. of 25% Hydrochloric acid (5ml. conc. acid + 2.5ml. water = 25% acid)
   194.00ml. water
Solution B:
   20.00g sodium nitrite

---

[*] Described in personal communication to R. M. Lindgren, USFPL, from L. J. Wildes, Atlantic Coast Line Railroad Company, Jacksonville, Fla.

180.00g water

Solutions A and B must be stored in separate bottles; A gradually deteriorates and forms a precipitate. When ready to make test, mix solutions together in equal amounts. Mixture is stable for only 2-3 hours, after which reaction to it becomes slower.

6. **Bromcresol green** (0.0413%) (Lund & Sciascia 1956)
   0.0413g Bromcresol green
   100.00ml. water

7. **Bromphenol blue** (0.0413%) (Eades 1958)
   0.0413g Bromphenol blue
   100.00ml water

8. **Fehling's solution** (Eades 1958)
   3.50g copper sulphate
   17.30g pottassium sodium tartarate
   6.00g sodium hydroxide
   100.00ml. water

9. **Ferric chloride** (10%) (Brown 1948)
   10.00g Ferric chloride
   90.00ml. water

10. **Ferric nitrate** (0.1N) (Eades 1958)
    1.346g Ferric nitrate [$Fe(NO_3)_3.9H_2O$]
    100.00ml. water

11. **Ferrous ammonium sulphate** (0.1N) (Eades 1958)
    1.96g Ferrous ammonium sulphate [$Fe(NH_4SO_4)2.6H_20$]
    0.10ml. sulphuric acid
    100.00ml. water

12. **Ferrous sulphate** (0.1N) (Eades 1958)
    1.39g Ferrous sulphate [$FeSO_4.7H_2O$]
    0.10ml. sulphuric acid
    100.00ml. water

13. **Harlco indicator** [universal wide range pH indicator]

14. **Hydrchloric acid-methanol** (Isenberg & Buchanan 1945)
    2.50ml. hydrochloric acid
    100.00ml. methyl alcohol

15. **Iodine** (2-2.5%) (Eades 1937)

1.25g iodine
48.75ml. ethyl alcohol

16. **Methyl orange** (0.1%) (Eades 1958)
    0.10g methyl orange
    99.90 ml. water

17. **Perchloric acid** (40%) (Eades 1958)
    100.00ml. of 70% perchloric acid
    75.00ml. water
- very caustic, degrades wood.

18. **Per-Osmic acid** (1%) (Wahlberg 1922)
    1.00g Per-Osmic acid
    99.00ml. water
- very caustic, degrades wood.

19. **Phenol-Hcl-Ethanol + U.V light** (American Wood Preservers Assoc. 1959)
    10.00ml. phenol
    5.00ml. hydrochloric acid
    45.00ml. 95% ethanol

Melt phenol by heating in a water bath. Add mixture of acid and ethanol to phenol. After application of chemicals to wood, the wood must be exposed to direct sunlight or to rays of an ultraviolet lamp for 2-4 minutes to bring about reaction.

20. **Pottassium iodide-iodine** (Eades 1958)
    0.50g pottassium iodide
    24.50ml. water
    0.50g iodine
    24.50 ml. ethanol

Dissolve pottassium iodide in water, dissolve iodine in ethanol, mix both solutions together.

21. **Triplex Soil Indicator** (Samuels & Glennie 1959)
    Triplex indicator solution No. 697-27, Reagent N

Appendix IV. Minimum sample size required in determining average values of realative density, cell dimensions and ratios of cell dimensios in four Khaya species

Cell characteristic	Degree of freedom	$t_{(\alpha=0.05)}$	mean	Standard deviation	C.V (%)	Samples required
Relative density:						
Ka	9	2.26	0.56	0.04	7	3
Ki	9	2.26	0.53	0.05	9	5
Kg	9	2.26	0.68	0.03	4	2
Ks	9	2.26	0.72	0.03	4	2
Fibre length (mm):						
Ka	149	1.98	1.6	0.20	13	6
Ki	149	1.98	1.7	0.29	17	12
Kg	149	1.98	1.9	0.24	13	7
Ks	149	1.98	1.3	0.24	18	14
Fibre diameter (μm):						
Ka	99	2.00	24	3.78	16	11
Ki	99	2.00	25	4.89	20	16
Kg	99	2.00	20	3.29	16	12
Ks	99	2.00	16	2.93	18	14
Fibre lumen (μm):						
Ka	99	2.00	12.3	1.80	15	9
Ki	99	2.00	10.1	1.80	18	15
Kg	99	2.00	8.7	1.80	21	19
Ks	99	2.00	1.9	0.70	37	57
Fibre wall thickness (μm):						
Ka	99	2.00	2.6	0.40	15	9
Ki	99	2.00	2.3	0.30	13	10
Kg	99	2.00	3.7	0.50	14	9
Ks	99	2.00	5.2	0.90	17	12
Lumen/wall ratio:						
Ka	99	2.00	4.8	0.90	19	15
Ki	99	2.00	4.5	1.00	22	21
Kg	99	2.00	2.4	0.50	21	19
Ks	499	2.00	0.4	0.10	25	55
% multiseriate rays:						
Ka	49	2.02	80	3.45	4	2
Ki	49	2.02	64	5.18	8	3
Kg	49	2.02	85	5.51	6	2
Ks	49	2.02	87	5.01	6	2
Ray height (mm):						
Ka	99	2.00	0.57	0.04	7	3
Ki	99	2.00	0.55	0.06	11	5

Kg	99	2.00	0.59	0.05	8	3
Ks	99	2.00	0.50	0.06	12	6
Ray width (μm):						
Ka	99	2.00	88	15.20	17	12
Ki	99	2.00	100	13.87	14	8
Kg	99	2.00	89	17.52	20	16
Ks	99	2.00	104	21.47	21	18
Ray height/width ratio:						
Ka	99	2.00	6.6	1.41	21	19
Ki	99	2.00	5.7	1.19	21	18
Kg	99	2.00	6.9	1.40	20	17
Ks	99	2.00	5.0	1.22	24	24

Appendix V Preliminary[8] measurement of cell characteristics and their significance status in paired comparison of four Khaya species in juvenile and mature wood zones.

CELL CHARACTERISTIC		JUVENILE Ka	Ki	Kg	Ks	MATURE Ka	Ki	Kg	Ks	SIGNIFICANCE STATUS K(a,i)*	K(a,g)	K(a,s)	K(i,g)	K(i,s)	K(g,s)
Vessel :															
- No./mm^2	mean-	5	5	5	5	5	4	5	4	nn**	nn	nn	nn	nn	nn
	s.d -	0.79	0.52	0.48	0.74	0.63	0.82	0.52	0.48						
- diameter (µm)		250	260	244	189	292	276	284	247	nn	nn	ss	nn	sn	sn
		22.35	38.57	41.35	29.83	48.92	52.63	29.65	49.08						
- length (mm)		0.51	0.48	0.50	0.33	0.54	0.52	0.48	0.40	nn	ns	ss	nn	ss	ss
		0.04	0.06	0.07	0.05	0.08	0.08	0.07	0.06						
Ray:															
- No./mm		9	8	8	9	7	8	7	8	ss	sn	ns	ns	nn	ss
		0.67	1.10	0.71	0.85	0.79	0.79	0.42	0.52						
- height (mm)		0.45	0.42	0.45	0.43	0.56	0.53	0.45	0.38	nn	nn	ns	sn	ns	ns
		0.06	0.04	0.03	0.06	0.05	0.05	0.20	0.06						
- width (µm)		55	45	52	83	69	70	60	79	sn	ns	ss	ss	ss	ss
		5.97	6.14	3.85	7.77	8.91	5.36	5.00	5.36						
- height/width ratio		8.2	9.5	8.7	5.2	7.6	7.6	8.0	4.8	sn	nn	ss	nn	ss	ss
		0.75	1.10	0.78	0.94	0.73	1.09	0.94	0.63						
- % multiseriate rays		75	64	94	92	76	65	89	93	ss	ss	ss	ss	ss	nn
		8.69	6.18	8.38	7.62	12.87	0.73	8.94	9.91						
Fibre :															
- diameter (µm)		22	20	14	14	29	25	18	19	ns	ss	ss	ss	ss	nn
		6.34	3.30	3.04	2.84	3.60	3.91	2.71	4.20						

[8] Preliminary measurements based on 11th (juvenile) and 46th (mature) growth rings in all species.

- Fibre lumen (μm)	13.0	10.2	7.2	1.9	12.3	10.1	6.7	1.9	ss	ss	ss	ss	ss	ss
	1.93	2.40	1.60	1.1	1.80	1.80	1.10	0.70						
- wall thickness (μm)	2.7	2.5	3.2	5.3	2.6	2.3	3.4	5.2	ns	ss	ss	ss	ss	ss
	0.41	0.50	0.50	0.60	0.40	0.30	0.70	0.90						
- Lumen/wall ratio	4.9	4.3	2.3	0.4	4.8	4.5	2.0	0.4	nn	ss	ss	ss	ss	ss
	0.95	1.07	0.50	0.20	0.90	1.00	0.30	0.10						
- Fibre length (μm)	1.25	1.26	1.32	1.21	1.60	1.69	1.86	1.40	ns	ns	ns	ns	ns	ns
	0.29	0.30	0.29	0.16	0.20	0.21	0.21	0.23						

* - K(a,i),...K(i,s) - Paired comparison of species.

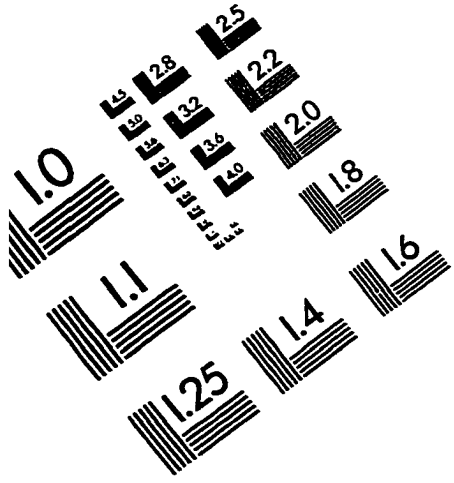
** - First letter indicates significance status in juvenile wood comparison (n - not significant, s - significant)
- Second letter indicates significance status in mature wood comparison (n - not significant, s - significant)

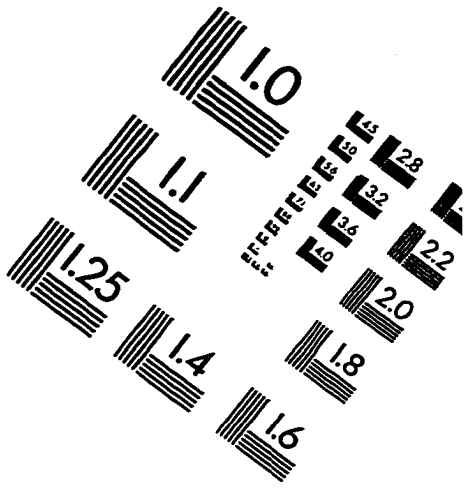
Appendix VI Differences in juvenile and mature of four Khaya species in terms of cell characteristics

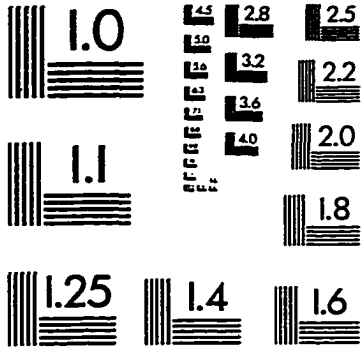
Cell characteristic	Wood zone	SPECIES MEAN Ka	Ki	Kg	Ks	Deg. of freedom	Calculated t-value/Significant level KaJ/KaM	KiJ/KiM	KgJ/KgM	KsJ/KsM
Vessel diameter (μm)	J	250	260	244	189					
	M	292	276	284	247	24	3.83**	1.20^{ns}	3.85**	4.95**
Vessel length (mm)	J	0.51	0.48	0.50	0.33					
	M	0.54	0.52	0.48	0.40	24	1.64^{ns}	1.96^{ns}	0.99^{ns}	4.39**
Vessel density	J	4.8	4.6	4.7	4.9					
(No./mm^2)	M	4.8	4.3	4.6	4.3	9	0.31^{ns}	0.98^{ns}	0.45^{ns}	2.15*
Fibre length (mm)	J	1.25	1.26	1.32	1.21					
	M	1.60	1.69	1.86	1.40	24	4.97**	5.87**	7.54**	3.39**
Fibre diameter (μm)	J	22	20	14	14					
	M	29	25	18	19	19	4.80**	4.89**	4.91**	4.93**
Fibre wall thickness (μm)	J	2.7	2.5	3.2	5.3					
	M	2.6	2.3	3.7	5.2	19	0.76^{ns}	1.50^{ns}	1.01^{ns}	0.40^{ns}
Fibre lumen size (μm)	J	13	10.2	7.2	1.8					
	M	12.3	10.1	6.7	1.9	19	1.16^{ns}	0.14^{ns}	1.12^{ns}	0.43^{ns}
Fibre lumen/wall ratio	J	4.9	4.3	2.3	0.38					
(μm)	M	4.8	4.5	2.4	0.4	19	0.33^{ns}	0.60^{ns}	0.62^{ns}	0.33^{ns}
Ray per mm	J	9.3	7.9	7.5	8.5					
	M	6.8	8.2	7.2	8.4	9	7.42**	0.66^{ns}	1.09^{ns}	0.30^{ns}
Ray height (mm)	J	0.45	0.42	0.45	0.38					
	M	0.56	0.53	0.45	0.43	24	7.04**	8.59**	2.57*	2.95*
Ray width (μm)	J	55	45	52	79					
	M	69	70	60	83	24	6.53**	16.22**	6.34**	2.12*
Ray height/width ratio	J	8.2	9.5	8.7	5.2					
	M	7.6	7.6	8.0	4.8	24	2.87**	6.14**	2.87**	1.77^{ns}
% mutiseriate rays	J	75	64	94	92					
	M	76	65	89	93	9	0.20^{ns}	0.51^{ns}	1.29^{ns}	0.25^{ns}

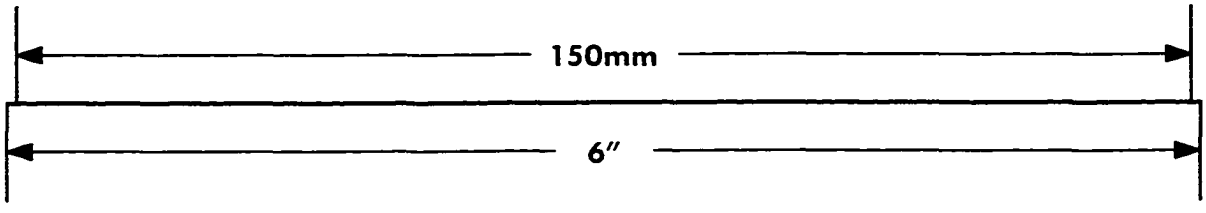
* - 95% probability level; ** - 99% probability level; ns - not significant. Comparison based on 11th (juvenile) and 46th (mature) growth rings.

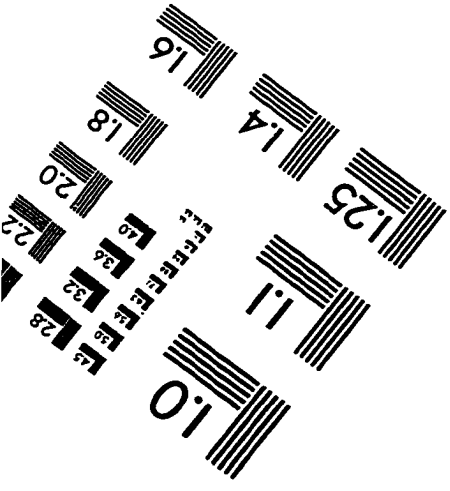
IMAGE EVALUATION TEST TARGET (QA-3)

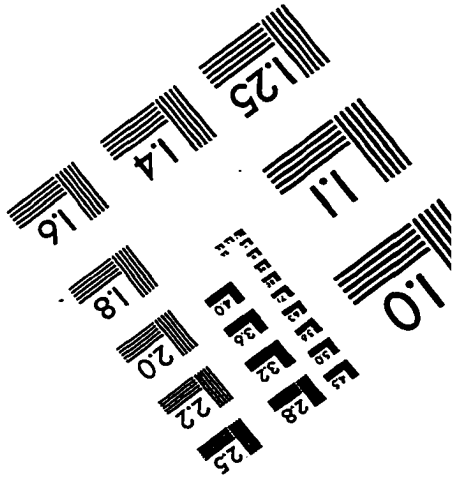












APPLIED IMAGE, Inc
1653 East Main Street
Rochester, NY 14609 USA
Phone: 716/482-0300
Fax: 716/288-5989