Leaflet No. 12/85-86

Government of the Union of Myanmar
Ministry of Forestry
Forest Department

An Investigation of the Relationship Between Certain Anatomical Characteristics and Basic Physical Properties in Three Burmese Woods

U Thein Kywe, M.Sc. [Rgn.], M.S [SUNY, CESF],
Research Officer,
Forest Research Institute.
1986

မြန်မာသစ်မျိုး(၃)မျိုး၏သစ်အင်္ဂါဗေဒလက္ခဏာများနှင့် သစ်ဂုဏ်သတ္တိများ နှီးနွှယ်ဆက်စပ်မှုကို လေ့လာခြင်း

ဦးသိန်းကြွယ်f M.Sc. (Rgn,), M.s. (SUNY CESF) okawoerSL:
သစ်တောသုတေသနဌာန

စာတမ်းအကျဉ်းချုပ်

မြန်မာနိုင်ငံတွင် သစ်တောများ၌ စီးပွားရေးတွင်အသုံးမပြုသေးသော ဒုတိယတန်းစား သစ်မျိုးများနှင့် လူသိနည်းသစ်မျိုးများ အကျိုးရှိရှိတိုးချဲ့အသုံးပြုရန် လိုအပ်နေပေသည်။ နောင်အနာဂတ်တွင် ၎င်းသစ်မျိုးများ တွင်ကျယ်စွာ အသုံးပြုနိုင်ရန်အတွက် သစ်အင်္ဂါဗေဒလက္ခဏာနှင့် သစ်ဂုဏ်သတ္တိများနှီးနွှယ် ဆက်စပ်မှုကို သိရှိထားရမည့်အပြင်၊ အချိန်နှင့်ငွေကို အသုံးပြုပြီးများစွာသော သစ်မျိုးများ၏ သစ်အင်အားကိုသိရှိရန် စမ်းသပ်ရပေဦးမည်။ ဤစာတမ်းတွင် ရေမနေ (*Gmelina arborea* Roxb.)၊ ထောက်ကြံ့ (*Terminalia tomentosa* Weight. L. Arn) နှင့် ပျဉ်းကတိုး (*Xylia dolabriformis* Benth.) တို့၏ သစ်အင်္ဂါဗေဒလက္ခဏာများကို ဖော်ပြထားပြီး အစိုဓါတ်ပါဝင်မှု၊ သိပ်သည်းဆ၊ တစ်သျှူး အမျိုးမျိုးတို့၏ ပါဝင်မှုအချိုးအစားနှင့် ကျုံ့ခြင်းတို့အား တိုင်းထွာ၍၎င်း၊ လက္ခဏာများအကြား နှီးနွှယ်ဆက်စပ်မှုများကို ဆွေးနွေးတင်ပြထားပါသည်။ ထို့အပြင် ဒုတိယတန်းစား သစ်မျိုးများနှင့် လူသိနည်း သစ်မျိုးများအား လက်တွေ့ကျကျတိုင်းထွာ စမ်းသပ်မှုများ မပြုလုပ်မီ မည်သည့်သစ်မျိုးသည် အဆောက်အဦး အတွက်သော်၎င်း၊ မည်သည့်သစ်မျိုးသည် အခြားသော လုပ်ငန်းများအတွက်သော်၎င်း၊ အသုံးပြုရန် သင့်လျော်သည်ဟု ကြိုတင်ဆုံးဖြတ်နိုင်သည့် နည်းလမ်းတခုအား တင်ပြထားပါသည်။

An Investigation of the Relationship Between Certain

Anatomical Characteristics and Basic Physical Properties in Three Burmese Woods.

U Thein Kywe, M.Sc.[Rgn.], M.S.(SUNY,CESF),
Research Officer,
Forest Research Institute.

Abstracts

Burma is faced with the need to extend the utilization of its forests by exploition of many secondary species and lesser known species which now are unused commercially. In order to improve the utilization of these species, it is necessary to explore the relationship between anatomy and wood properties and the various species must be subjected to many tests for strength which are both time consuming and expensive. In this paper the anatomical features of the secondary xylem of *Gmelina arborea* Roxb., *Terminalia tomentosa* Wight. & Arn. and *Xylia dolabriformis* Benth. are described as initial steps towards this end. Moisture content, specifics gravity, proportions of different tissues and shrinkage are measured and relationships between these characteristics are discussed. Furthermore, a method is also presented for screening the secondary and lesser known timbers, prior to full scale testing, to determine which will be suitable for construction and other purposes.

Contents

1. Introduction

It is a well known fact that the forests of Burma contribute significantly to the economic welfare of the country as timber and other forest products being used locally and exported in large quantities. In particular, Burma possesses about 75 percent of the word's supply of Teak, other indigenous tree species produce valuable timbers which remain to be developed. Additionally, the forests contain a variety of species that are less known, but have considerable potential importance for both local use and export.

A detailed analysis of the anatomical structure of wood, moisture content, specific gravity and shrinkage is the best way. However, knowledge of the wood anatomy and certain physical properties plays only a limited part in the understanding and performance of wood in use. In view of the improved utilization of lesser known species in the near future, it is necessary to explore the relationship between the anatomy and wood properties in a limited number of hardwood species must be subjected to many tests for strength. Specifically, samples of *xylia dolabriformis* Benth., *Terminalia tomentosa* Wight. & Arn. and *Gmelina arborea* Roxb. are selected for study of wood structure and moisture content, specific gravity, proportion of different tissues and shrinkage. A comparative studies of this type using Burmese species have not been carried out previously.

The present investigation is designed as a preliminary survey and a pilot study to form the basis for a long term research project.

2. Literature Review

Yemane (*Gmelina arborea* Roxb.), Taukkyan (*Terminalia tometosa* Weight. & Arn.) and Pyinkado (*Xylia dolabriformis* Benth.) were selected to study as representative of the species gravity range for Burmese woods.

Yemane (*Gmelina arborea* Roxb.) is a member of the family Verbenaceae. There are many location names, 38 of which were listed by Pearson and Brown (1932) for India and Burma alone. It is one of the commercially important timber and it is characteristically found growing in deciduous as well as in the moisture forests through out Burma. This species is also indigenous to India and several neighbouring countries.

Pearson & Brown (1932) gave a detailed account of the anatomy of Gmelina wood based on microscopic examination of two Indian samples. These feature were, in general, in agreement with Krib's finding (1968). Chowdhury (1935) examined a wider-ranging material comprising of 34 from India, Thailand and Sri Lanka.

Esan (1966) reported that the relative density and fibre length were highly and positively corellated. Data have been published for the mechanical properties of *G. arborea* timber growing in Bangladesh (Yacub et al., 1972), Burma (Sekhar & Gulati, 1972), India (Limaye & Sen, 1956, Sekhar & Rajput, 1972) and Malaysia (Lee Yew Han & Chu Yue Pun, 1965). Sono (1974) investigated the shrikage and the mechnical properties of Thai trees.

Taukkyan (*Terminalia tomentosa* Wight. & Arn.) is placed in the family Combretaceae. There are many local names, 35 of which are listed by Pearson & Brown, (1932). It is well known as 'Laurel' or Indian Walnut in the international trade. This tree is one of the commonest in Burma and occurs in considerable quantities everywhere in the country except the Northern Shan States, Arakan State and South of Tenasserim where it is scarce.

Pearson & Brown (1932), Rao & Purkayastha (1972) have discussed the anatomical characteristics, physical and mechanical properties of this species. Kribs (1968) agreed with their findings of the anatomical structure. Mottet (1963) noted that, in nature forest trees of *Terminalia superba*, the density of the wood increases regularly with age and this increase in density is accompanied by a corresponding reduction in the fibre flexibility coefficient. In other words, the increase in density is related to a reduction of the exterior diameter of the fibre and an increase in the thickness of their walls.

It is generally assumed that a wood will become denser if the proportion of the fibre is increased. Such a positive relationships has been reported by Clarke (1930). The increase in density must imply an increase in the proportion of cell wall, and the percentage of cell wall in the fibres are mainly responsible for that increase.

The most obvious cause of such an increase in density due to the increase in the proportion of the cell wall thickness does not appear to apply to the case of Shorea species (Ferrieinha, 1965).

Pyinkado (*xylia dolabriformis* Benth.) is one of the species of the family Leguminosae. It is known in trade as 'Pyinkado'. Seven local names were listed by Pearson & Brown (1932). It is a very large tree and is found growing at its best in the Pegu Yoma, where the boles of the trees are straight and fairly cylindrical. They are found in association with Teak in all the lower hill forests of Burma and certain localities in the Arakan State. Pyinkado is, a part from Teak, the most important timber in Burma for constructional purposes, especially as posts for bridges and houses.

Bennet and Bahadur (1978) stated that xylia trees were found in India, Burma, Indo-China, Singapore and the Philippines. Rao and Purkayastha (1972) offered a description of the wood, which is, in general in agreement with Lecomte (1925) and Pearson & Brown (1932).

To a very large extent, many of the physical proporties of hardwoods are related to the relative proportions of vessels, fibres and parenchyma present in the wood. The anatomical characteristics of fibre length, cell diameter, cell wall thickness and proportion of cell type vary in accordance with the environmental forests such as temperature, precipitation and wide, In addition, such factors as age and position of the material in the stem influence these anatomical characteristics (Wangaard, 1981).

The amount of cell wall substance obtained in a given volume of clear wood is an important criterion for its quality and serviceability, because it effects all wood properties, physical, mechanical and chemical. This characteristics may be measured approximately by density which is mass for a given volume of wood or by specifics gravity (Tsoumis, 1964).

Generally the specific gravity increases as the vessel elements primarily with small diameter fibres increase the amount of cell wall and thus increases the specific gravity (Wangaard, 1981). Mottet (1965) indicated that the fibres appear to play a part in the differences of wood density, not only by their presence in various amounts but also by the amount of substance they contain.

Strong relationship of the specific gravity of wood to fibre diameter was reported by Ferreirinha (1953) in a study on tropical hardwood species from 28 different genera. Gudim (1963) reported that fibre wall thickness is the probable principal factor of the variation in density. As a matter of fact, wood density and wood structure relationships have been extensively investigated in softwoods but much less information is available for hardwoods.

Wood responds to changes in atmospheric humidity and losses bound water as the relative humidity drops, regaining bound water as the relative humidity increases. For a given relative humidity, a balance is eventually reached at which the wood is no longer gaining or losing moisture. Most of the strength properties of wood increase repidly as it dries beyond the fibre saturation point. This increment is due to the actual strengthening and stiffening of the cell walls as they dry out. In addition, these properties are increased by the compacting of the amount of wood substance in a given volume because of the shrinkage that accompanies drying below the fibre saturation point.

Actually all the strength properties are not affected to the same degree by changes in moisture content. Espenas (1947) pointed out that crusing strength and bending strength increase greatly as wood dries, but stiffness is only moderately improved, while shock resistance may even decline slightly. He also indicated that the shrinkage that accompanies drying of wood below the fibre saturation point is directly proportional to the extent of the drying. Therefore, on the volumetric basis, shrinkage or swelling is approximately equal to the volume of the water, gained or lost. Wood shrinkage most in the direction of the annular growth rings (Tangentially) about one-half as mush as this across the rings (radically) and very little as a rule, along the grain (longitudinally). As a matter of fact, shrinkage is responsible for the decrease in dimension, distortion in cross section, warping, surface and end checking, honey combing and case-hardening.

A knowledge, therefore, of the relationship between wood and water is helpful to an understanding of the behaviour of wood, not only in drying the wood, but also in its behaviour in service.

3. Materials and Methods

The materials for this study consists of wood samples collected from single mature trees of *Gmelina arborea* Roxb., *Terminalia tomentosa* Wight & Arn, and *xylia dilabriformis* Benth. growing naturally in moist upper deciduous forests of Burma. These samples were removed from each merchantable trunk of each species at breast height above the ground. Measurements were made for each species of wood for fibre length, vessel member length, fibre diameters, vessel member diameters, widths of rays and parenchyma, proportions of different tissues, moisture content of the wood, species gravity or basic density, and shrinkage at a series of point from fibre saturation to oven dry.

For anatomical observations, sections were prepared adopting the usual microtechnique procedure as given by Jeffrey, 1917. About 20-25 micrometer thick sections were cut on a sliding microtome, after evacuating the samples. The sectioning blocks of *Gmelina arborea* required no softening except evacuation in water. In contrast, the samples of *Terminalia tomentosa* and *xylia dolabriformis* required additional softening. They were places in a 4 percent solution of ethlenediamene in small beakers evacuated in vacuum, releasing the vacuum three times, then held under vacuum for a period of 12 hours. Following this evacuation, the samples were heated slowly to a temperature of 70˚ - 75˚C for one-half hour according to a modification of Kukachka's method (1977). After this heating, sections were cut directly from ethylenediamene.

The sections were stain with haematoxylin using from alum as a mordant and then with safranin. The wood was macerated for study of individual elements by treatment with a mixture of equal volume of 30 percent hydrogen peroxide and glacial

acetic acid using Franklin's method (1964). The anatomical features of the wood were measured from transverse, radial and tangential sections and from maceration. Fifty measurements were made for each feature for each species. fibre length and vessel member lengths, diameters of fibres, vessel members, rays and axial parenchyma, wall thickness of the wood, total height and numbers of cells in rays, widths of rays, diameter of intervascular pits and ray-vessel pits. For microscopic descriptions, the terminology used in this work was given in the international glossary of terms used in wood anatomy (1964). The terms for numerical values used in describing wood were determined in accordance with proposed standards (Chittawy, 1932), standard terms of length of vessel members and wood fibres (Anon, 1937), and standard terms of size for vessel diameter and ray width (Anon, 1939). Photomicrographs were taken with an aid of Nikon Optiphot biological microscope.

3.1. Determination of tissue proportion

The percent of different tissue types is traditionally measured on a percent volume basis. The proportional volume of tissue types can be determined by the test point method, the line integration method, the photographic cutout, or the planimetric method.

Measurements of cellular proportions were made according to the test point method indicated by Taylor (1971), Ezell (1979) and Maeglin and Quirk (1984), which involves a point counting technique using a zeiss integrating eyepiece graticule that superimposes a grid system of dots on the magnified cross section surface of the sample block examined.

A method for calculating tissue proportions by weight from proportions by volume was presented by Maeglin and Quirk (1984). To determine the proportions of tissue by weight, data on the proportion of tissue by volume and cell measurements were used in the following sequence.

(1) The percent area of cell wall material for each tissue type was calculated as follows:

$$\% \text{ CWA} = \frac{(\text{CA} - \text{LA})}{\text{CA}} \times 100$$

where % CWA is percent cell wall area: CA is cell area: and LA is lumen area.

To calculate cell and lumen area, a circular cross section was assumed and average cell and lumen diameters used.

(2) The specific gravity of each tissue was calculated as follows:

$$\text{TSG} = (\% \text{ CWA} \times 1.25 \text{ g/cm}^3) \div 100$$

where TSG is tissue type specific gravity and 1.25 g/ cm^3 is the specific gravity of cell wall substance (Jayme and Krause, 1963).

(3) The contribution to tissue type to total wood specific gravity was calculated as follows:

$$\text{CSG} = (\text{TSG} \times \% \text{ TV}) \div 100$$

where CSG is the contribution to wood specific gravity and % TV is the percent tissue by volume.

(4) The percent tissue type by weight was calculated as follows:

$$\% \text{ TW} = (\text{CSG} \div \text{WSG}) \times 100$$

where % TW is the percent tissue type by weight and WSG is the total wood specific gravity, i.e. the sum of CSG for all tissue types.

In this study, a uniform 100 dot grid was employed to determine tissue proportion because a systematic arrangement of dots are easier to count than a random arrangement of dots on an asymmetric dot grid eyepiece graticule. The number of test points on the grid that fall on a tissue type are recorded and expressed as a proportion of the total points counted for all tissue types.

3.2. Determination of moisture content

Measurement of the moisture content of wood can be made in various ways by the oven drying method, the distillation method, electrical method, relative humidity method and chemical method. The last two are generally not of practical importance in the wood-using industries.

In this study, the oven drying method was used for moisture content determination. The material to be tested was chosen as representative of the sample material. The moisture content of the wood is calculated by using the following formula:

$$\text{Moisture content percent} = \frac{\text{original weight} - \text{ovendry weight}}{\text{ovendry weight}} \times 100$$

3.3. Determination of specific gravity

Physical properties of wood have been related to strength, quality, uniformity and yields of pulps. The most commonly measured property is specific gravity determined from green volume and oven dry weight of the samples.

$$\text{Basic specific gravity} = \frac{\text{ovendry weight}}{\text{weight of water = to the volume of the wood in green condition}}$$

3.4. Determination of shrinkage

Shrinkage occurs when moisture is removed from between the chain molecules of the cell wall. The molecular structure of the cell wall is oriented more less parallel to the axis of the cell. When water is removed, the molecules approach each other and the wall decreases in thickness and in circumference (Peck, 1947).

In point of fact, wood does not begin to shrink util moisture content in the walls has been deduced below the fibre saturation point. Such dimensional changes are traditionally expressed as a percentage of the maximum dimension of the wood

and it is believed that the green size is a condition at which no reduction in dimension has occurred (Panshin & dezeeuw, 1980). The shrinkage is expressed as a percentage of the green volume or size and can be calculated using the following formula:

$$\text{Shrinkage} = \frac{\text{Change in dimension from green size}}{\text{green size}} \times 100$$

All the samples in this study were based 1" x 1" x 4" sizes for shrinkage examination. At the beginning of this study, transverse, radial, and tangential green dimension of the sample were measured accurately to the nearest 0.001" using a dial guage. At the same time, weight and volume of the samples were recorded. These samples were then placed successively in four chambers maintained at different moisture conditions (18 percent, 12 percent, 6 percent and oven dry). The conditioning chambers were prepared using the series of saturated salt solutions suggested by Hoadley (1980) for controlling relative humidity at a constant temperature. Final chamber was a standard oven maintained at 102 $^\circ$C $\pm$ 3 $^\circ$.

When the samples came into equilibrium weight with the desired environment, the measurement of the dimensions, weights and volume of the woods were recorded. Then the samples were moved to the next conditioning chamber in the series. Finally after oven drying the measurements of the final dimensions of each sample were determined and the longitudinal, radial, tangential and volumetric shrinkage percentage were calculated.

4. Results and Discussion

4.1. Anatomical Characteristics

4.2.2. *Gmelina Arborea* Roxb.

4.1.1.1. General Description

A moderate sized, unarmed, unbutressed, diciduous tree, with a clear bole of 9 -15 m., on favourable sites, attaining 21 - 30 m. height and 2.1 – 4.5 m in girth. The corky bark is 10 – 20 mm. thick, light grey to brownish grey in colour. It is longitudinally shallowly furrowed, relatively smooth, without fissures. When old, it exfoliates in irregularly shaped flakes leaving lighter coloured patches beneath.

4.1.1.2. General characteristics and properties of the wood

Colour yellowish white, greyish white, or reddish white turning light yellowish brown with increasing age; heart wood not distinct; lustrous; odour and taste not distinct; very light to light in weight, (specific gravity 0.41 green, 0.46 oven dry) soft; straight – grained or more or less irregular and interlocked – grained, medium coarse textured, sometimes showing a curly figure; semiring to ring porous wood; growth rings fairly distinct by narrow bands of parenchyma.

4.1.1.3 Microscopic characteristics

Vessel elements: Semi-ring to ring porous with increments marked by greater concentrations of pores moderately small to very large; mean tangential diameter 207 um (range 60-320 um); number per sq. mm. very few to very numerous range 2-12; pores solitary, or as radial pore multiples of 2-4 and sometimes as pore clusters; circular or oval in cross section; thin-walled; lumen with thin-walled tyloses; perforation plates simple; end walls of elements oblique or transverse; inter-vascular pitting alternate, crowded, pentagonal, chambers mean diameters 7 um; vessel parenchyma pitting alternate, 7-10 um in diameter, circular or oval in outline; vessel elements extremely short to moderately long, mean length 394 um (range 170-620 um).

Fibres: Non-libriform extremely short to moderately long mean length 989 um (range 340 1880 um), medium fine with mean tangential diameter 22 um (range 15-30 um): septate, very thin to thin-walled, 2.5-5 um thickness, inter-fibre pits numorous, small, simple, slit-like.

Rays: Heterocelluar, 1-5 cells wide, usually biseriate to tetraseriate, 2-6 per mm. tangentially; very find to moderately find, mean width 29 um (range 17-42 um) mean height of uniseriate rays is 93 um (range 50-180 um) and 2-5 cells high, the multiseriate rays have a mean height of 387 um (range 190-810 um) and are 5-32 cells high; yellow gum sparse in the ray tissue; ray vessel pitting opposite or alternate, round, oval or mostly angular in shape, simple to half-bordered, 7-10 um in diameter; similar to inter-vascular pitting; no crystals, starch deposits or silica in the ray cells.

Axial parenchyma: Moderately abundant, typically paratracheal, usually vasicentric, forming a narrow uniseriate sheath around the vessel, or more rarely uniting adjacent vessels laterally, or confluent connecting 2-5 pores forming tangential bands resembling marginal parenchyma, no crystals in the axial parenchyma.

4.1.2. *Terminalia tomentosa* Wight &Arn

4.1.2. General description

A large, deciduous tree with a long clear bole, spreading branches and a heavy crown, attains 24-34 m. in height and 3.6-4.5 m. in girth. The corky bark is 8-12 mm. thick, light gray or blackish gray to dark brown often longitudinally fissures, exfoliating in flaky ridges.

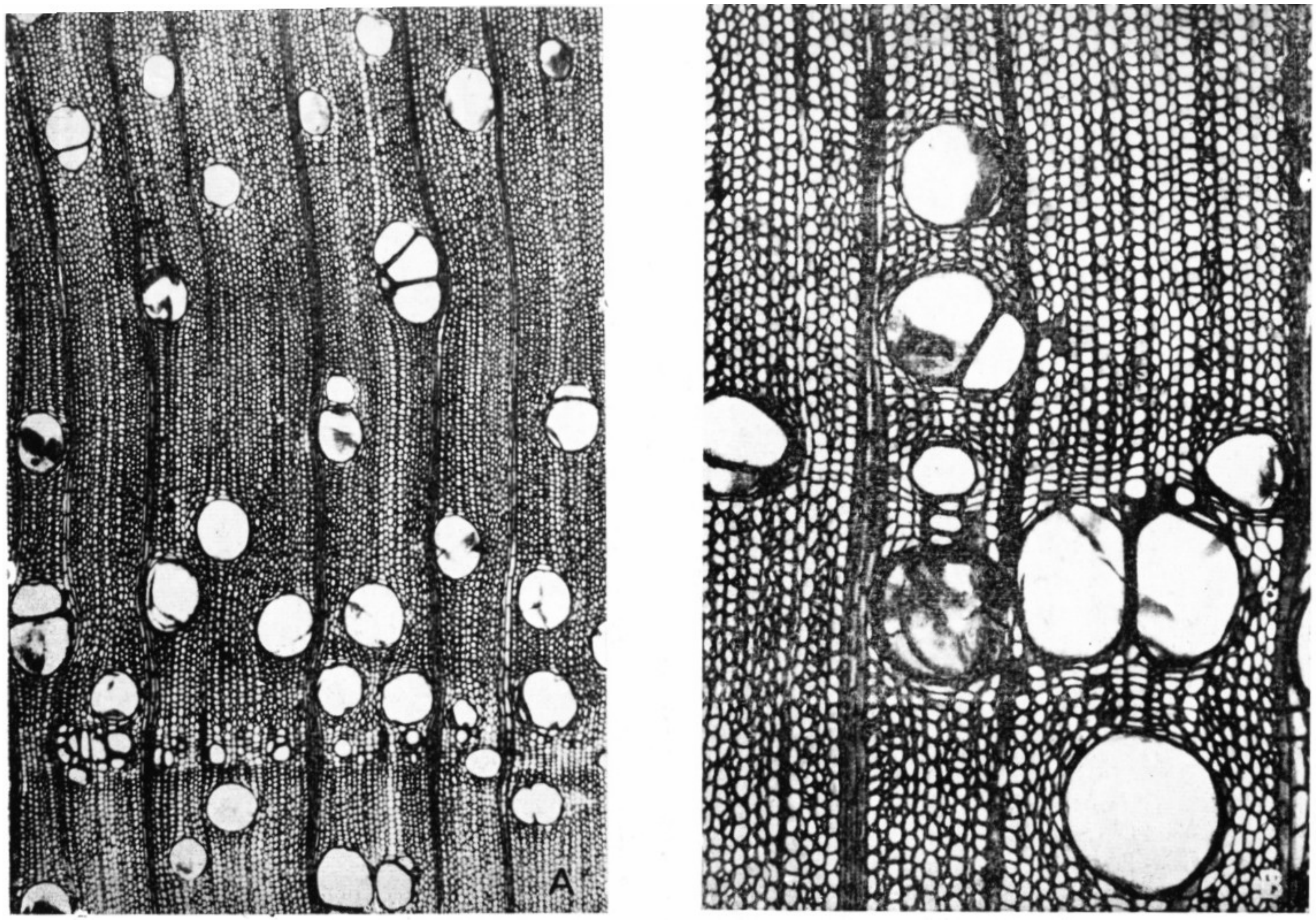


Fig.4.1. Photomicrographs of a cross section of *Gmelina arborea* to show distribution of vessels and a marginal parenchyma zone (A) Magnification 35 X. (B) Magnification 100 X.

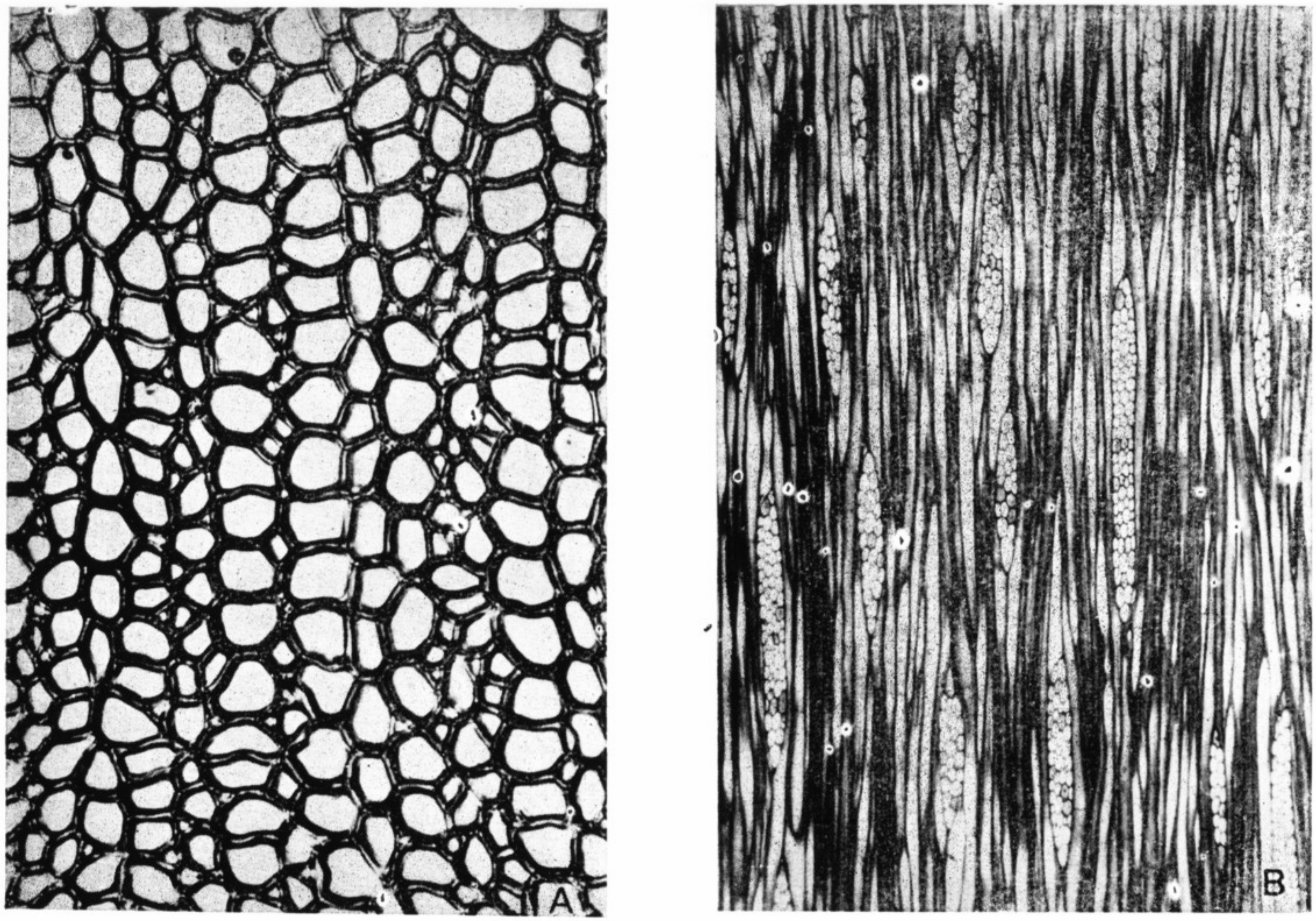


Fig.4.2. Photomicrographs of *Gmelina arborea* (A) a cross section to show fibre wall thickness, magnification 400 X. (B) a tangential section to show type of rays, magnification 100 X.

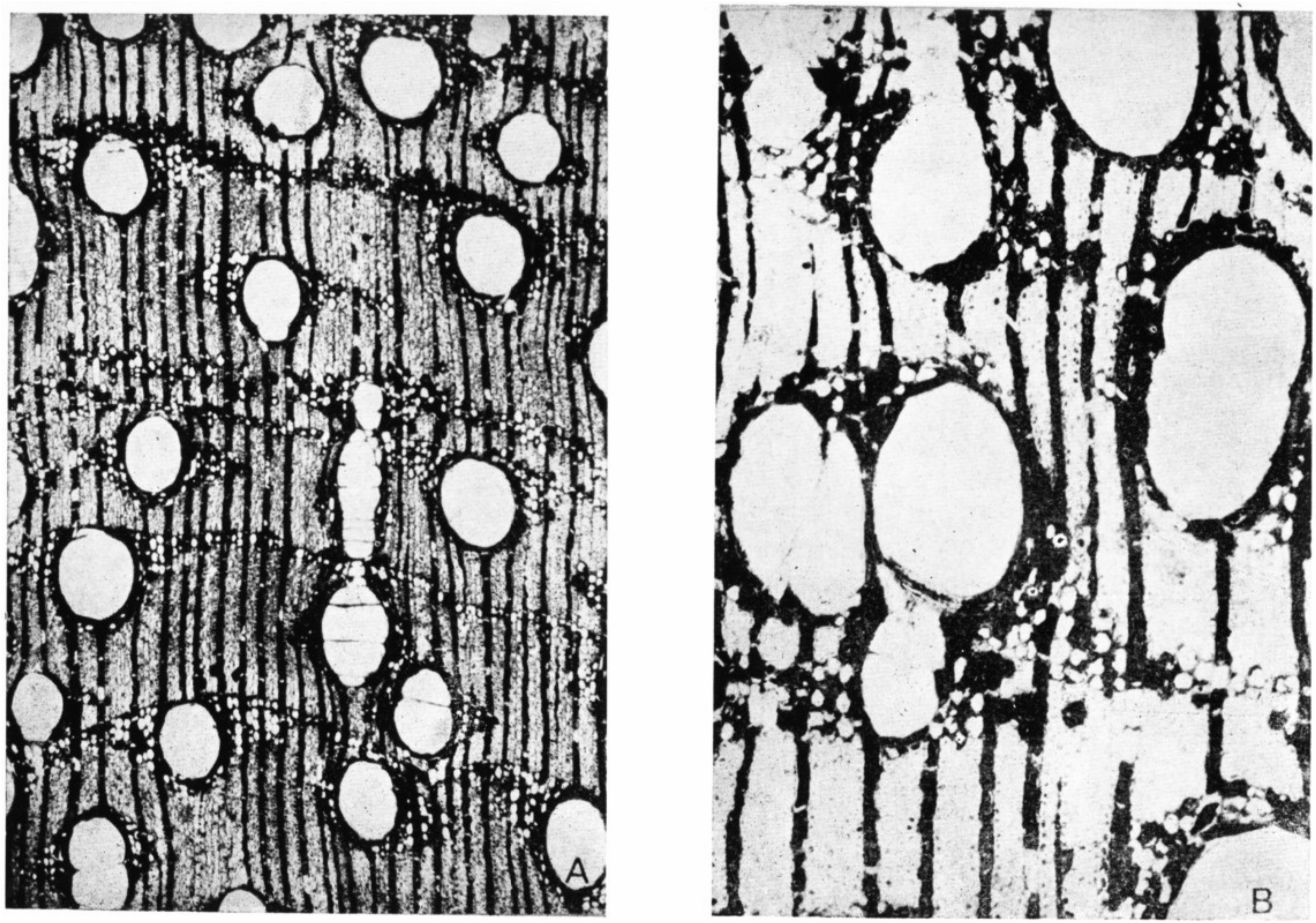


Fig.4.3. Photomicrographs of a cross section of *Terminalia tomentosa* to show distribution of vessels and confluent parenchyma (A) Magnification 35 X. (B) Magnification 100 X.

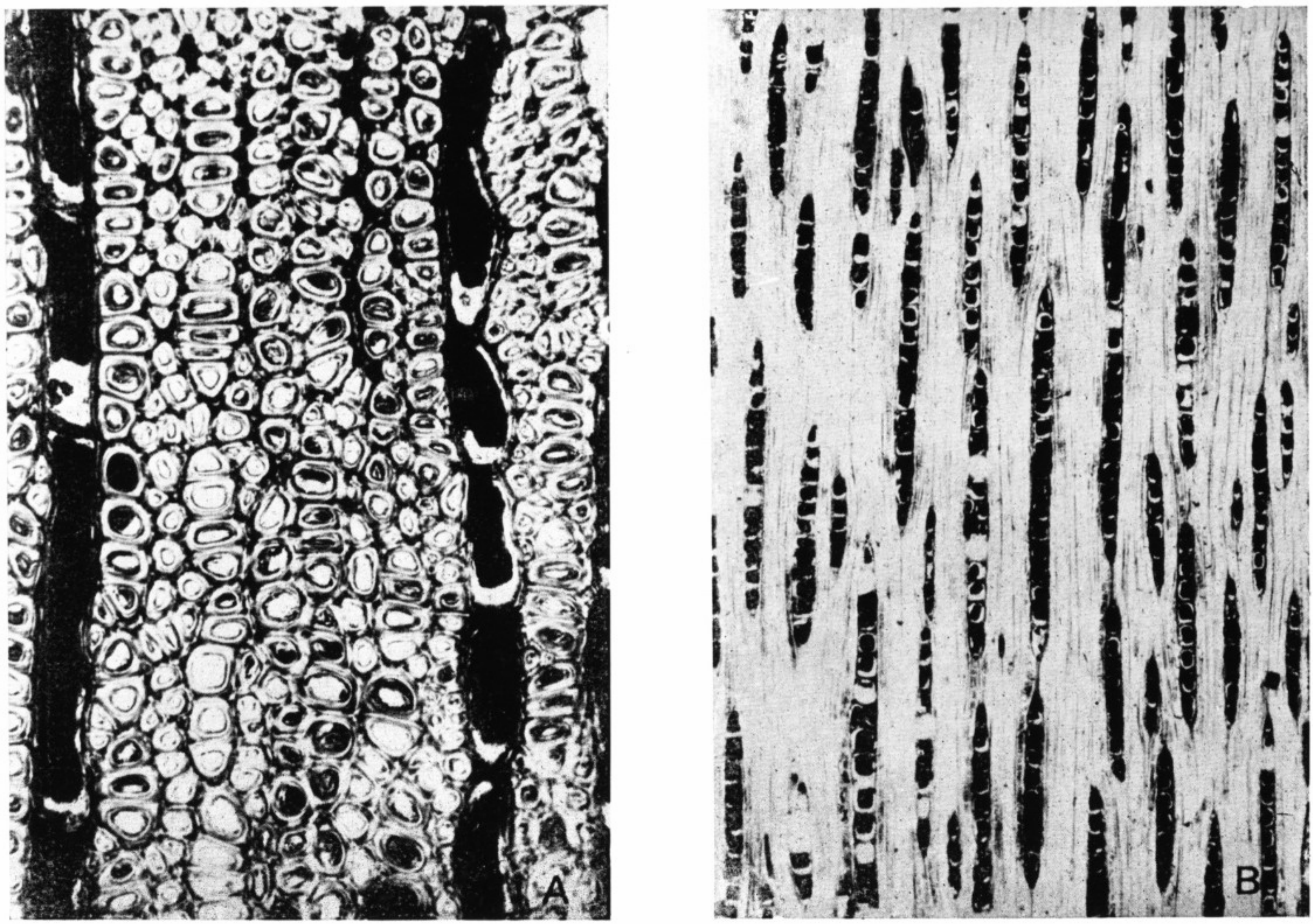


Fig.4.4 Photomicrographs of *Terminalia tomentosa* (A) a cross section to show fibre wall thickness, magnification 400 X. (B) a tangential section to show type of rays, magnification 100 X.

4.1.2.2 General characteristics and properties of the wood

Sapwood creamy white, heartwood varies considerably in colour ranging from light brown with few markings or finely streaked with darker lines to dark brown bands or brownish black, often banded with streaks of darker colour; dull or lustrous; odour and taste not distinct; moderably heavy to heavy in weight, (specific gravity 0.73 green, 0.84 oven dry); hard and strong; fairly straight-grained; coarse-textured; diffuse porous wood, growth rings distinct but not conspicuous, delimited by the concentric layers of parenchyma occurring at regular intervals.

4.1.2.3. Microscopic characteristics

Vessel elements: Diffuse porous, pores very small to moderately large, mean tangential diameter 184 um (range 50-290 um), number per sq. mm., few to very numerous range 4-12, pores solitary or in radial pore multiples of 2-12 and sometimes in pore clusters, oval or circular in cross section, thick-walled, lumen with tyloses, perforation plates simple; end walls of elements oblique or transverse, inter-vascular pitting alternate, crowded, elliptical in shape, vesture, 7-15 um in diameter, vessel parenchyma pitting alternate, 7-12.5 um in diameter, circular to oval in shape; vessel elements very short to moderately long lumen with gummy deposits, mean length 433 um (range 250-700 um).

Fibres: Non-libriform; very short to moderately long; mean length 1283 um (range 630-1650 um), medium fine with mean tangential diameter 19 um (range 15-25 um); nonseptate, thin to thick-walled, 2.5-5 um thicked, inter-fibre pits sparse, small simple, slit-like. Gelatinous fibres commonly present scattered among the normal fibres, and characterized by a loose inner ring separated from the outer wall of the fibre.

Rays: Homocellular, all uniseriate, occasionally biseriate, 6-16 per mm. trangentially, extremely find to very fine, mean width 16 um (range 7-23 um); mean height of uniseriate, rays is 226 um (range 60-720 um) and 2-24 cells high the mean high of biseriate rays is 265 um (range 180-230 um) and 6-12 cells high ray-vessel pitting alternate, oval or elliptical in outline, simple to half-bordered, 7.7-12.5 um in diameter; similar to inter-vascular pitting dark gum occurs in the lumen, no crystals, starch deposits or silica in the ray cells.

Axial parenchyma: Abundant, paratracheal, vasicentric to aliform and sometimes short confluent in part, forming narrow, short lateral extensions across the rays ending abruptly, or rarely uniting with those from other vessels; marginal parenchyma forming undulate; 1-3 seriate lines, prismatic crystals in short to long chains in the axial parenchyma.

4.1.3. *Xylia dolabriformis* Benth.

4.1.3.1. General description

A very large tree which attains 30-37 m, in height and 2.4-3.7 m. in girth. The corky bark is 8-10 mm. thick, light brown, brownish, gray to reddish gray, longitudinally striated with irregular exfoliating ridges separated by narrow fissures.

4.1.3.2. General characteristics and properties of the wood

Sapwood pale reddish white, narrow heartwood brown, dull; odour and taste not distinct, heavy to very heavy in weight, (specific gravity 0.08 green, 0.92 oven dry), hard and extremely strong; grain straight, wavy or broadly interlocked, medium textured; diffuse porous wood; growth rings not distinct, demarcated by an interrupted line of parenchyma.

4.1.3.3. Microscopic characteristics

Vessel elements: Diffuse porous, pores very small to moderately large; mean tangential diameter 151 um (range 40-210 um), number per sq. mm. very few to very numerous range 2-12, pores arranged in echlon, solitary, in radial pore multiples of 2-9, or occasionally clustered, circular or oval in cross section; end walls of elements oblique or transverse; inter-vascular pitting alternate, crowed, oval in shape, vestured, 5-7.5 um in diameter; vessel parenchyma pitting alternate, 5-7.5 um in diameter, circular in outline, vessel elements very short to medium sized mean length 364 um (range 180-540 um).

Fibres: Libriform; very short to moderately long; mean length 1107 um (range 550-1775 um), fine with mean tangential diameter 15 um (range 10-17 um.), septate, thick to very thick-walled, 5-7.5 um thick, inter-fibre pits sparse, small simple, slit-like.

Rays: Homocellular, 1-2 cells wide, 10-18 per mm. tangentially; extremely fine to moderately fine, mean width 17 um (range 7-28 um); mean height of uniseriate rays is 185 um (range 80-350 um) and 5-19 cells high; the mean height of biseriate rays is 408 um (range 85-180 um) and 5-46 cells high; rays-vessel pitting alternate, circular or oval in outline simple to bordered, 5-7.5 um in diameter, similar to inter-vascular pitting, orange brown gum occurs sparsely in the lumen, no crystals or starch deposits in the ray cells, silica not reported.

Axial parenchyma: Abundant, paratracheal, aliform to vasicetric forming thin to thick sheaths around the vessels, sometimes connecting obliquely and tangentially; marginal parenchyma forming a 1 to 2 seriate interrupted line, cells generally tangentially flattened, prismatic crystals in long crystalliferous chains in the axial parenchyma.

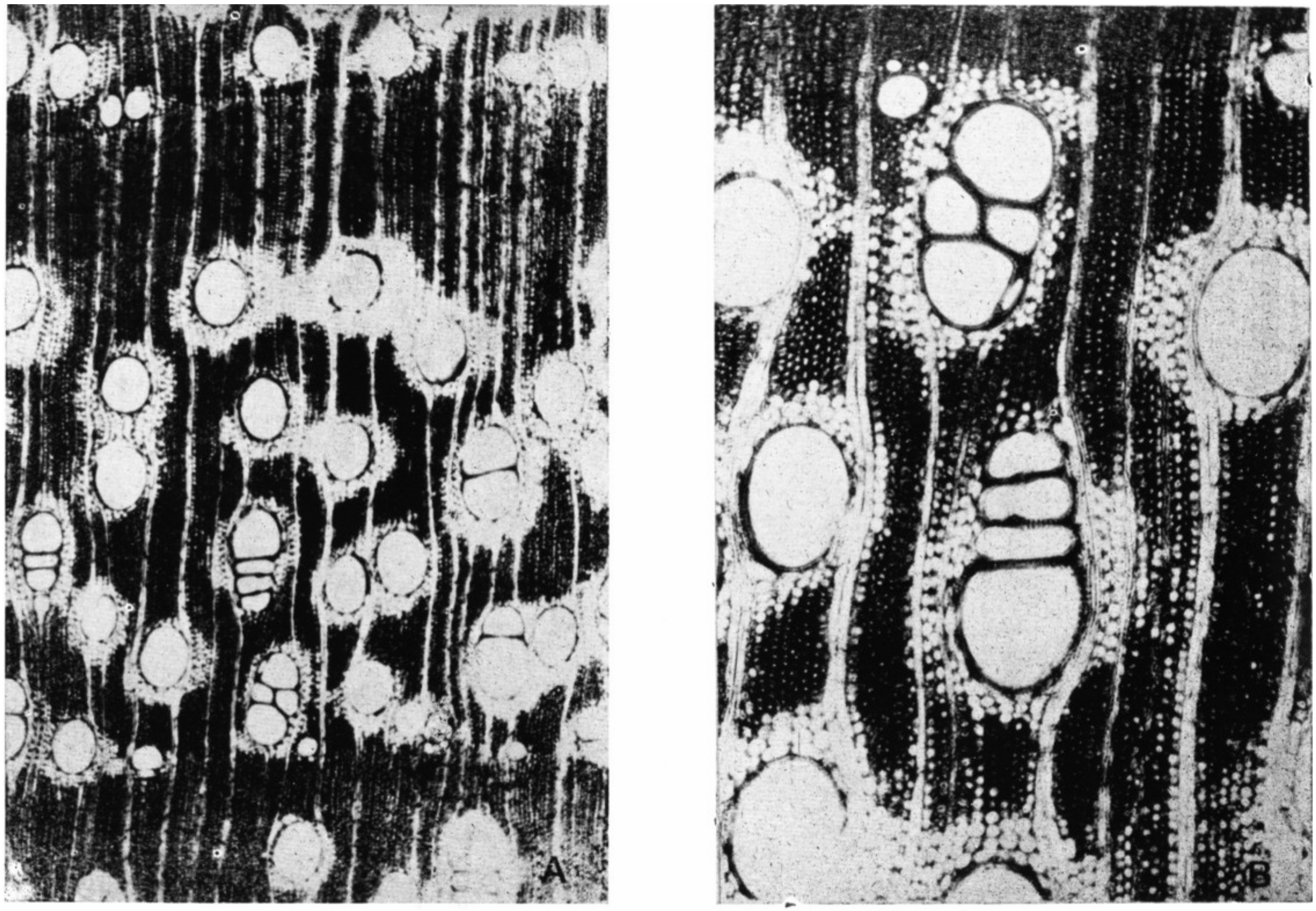


Fig.4.5. Photomicrographs of a cross section of *Xylia dolabriformis* to show distribution of vessels and vasicentric and aliform parenchyma (A) Magnification 35 X. (B) Magnification 100 X.

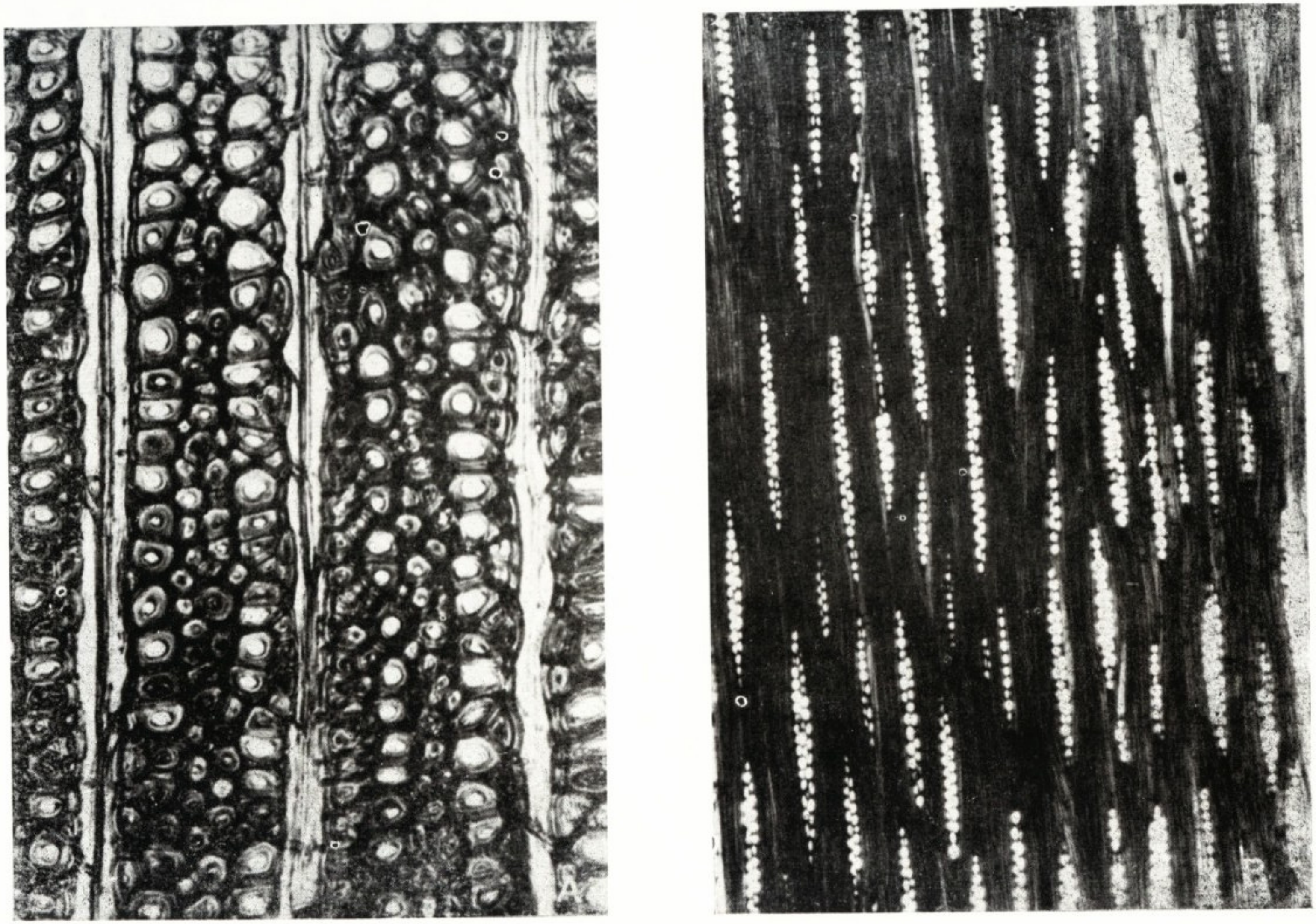


Fig.4.6 Photomicrographs of *Xylia dolabriformis* (A) a cross section to show fibre wall thickness, magnification 400 X. (B) a tangential section to show type of rays, magnification 100 X.

4.1.4. Summary of anatomic characteristics

The observed anatomical characteristics for the three woods studied agree with the description for these species as given in the literature. Growth rings are fairly distinct to inconspicuous for all the samples studied. They may be distinguished by narrow concentric bands of parenchyma in *Gmelina arborea* and *Terminalia tomentosa* or by interrupted lines of parenchyma in *Xylia dolabriformis*.

Vessels distribution among these species varies from diffuse in *T. tomentosa* and *X. dolabriformis* to semi-ring porous and ring porous in *G. arborea*. All these species exhibit radial pore multiples, but *T. tomentosa* has a component of very long radial pore multiples ranging from 2-12, that distinguish it from the other two species. Number of pores per sq. millimeter ranges from 2 to 16 for all these species.

Average vessel element length of these species range from 394 to 433 um, with the largest occuring in *T. tomentosa*. Tangential pore diameters show the usual wide ranges with ranges within species, however, the largest mean and maximum diameter both occur in *G. arborea* and the smallest in *X. dolabriformis* as shown in Table 4.1 Minimum pore diameters show the relationships but on a much smaller scale.

Vessel wall thickness among the three species studied show little difference, in the three species vessel perforations are simple, inter-vessel pitting. Moreover, vestured inter-vessel pits occur in *T. tomentosa* and *X. dolabriformis* but not in *G. arborea*.

G. arborea and *T. tomentosa* showed nonlibriform fibres but *X. dolibriformis* has libriform fibres, Fibre lengths, means as well as meaximum and minimal lengths are largest in *T. tomentosa* shortest in *G. arborea* and intermediate in *X. dolabriformis* as shown in Table 4.2 fibre diameters are largest in *G.arborea*, intermediate in *T. tomentosa* and smallest in *X. dolabriformis*. However, the order is reversed for wall thickness with the thicknest walls and smallest humens in *X. dolabriformis* which shows the smallest fibre diameter. Inter fibre pitting is inconspicuously bordered in all these kinds of wood studied. Septate fibres occur in *G. arborea* and *X. dolabriformis.*

Axial parenchyma patterns as viewed on the transverse section are variable between species. Vasicentric parenchyma forming narrow uniseriate sheaths around the vessels together with narrow bands of marginal parenchyma are usually found in *G. arborea.* In *T. tomentosa* and *X. dolabriformis* abundant vasicentric, and aliform axial parenchyma is present. Additionally, the parenchyma may be confluent in *T. tometosa* prismatic crystals are common in the axial parenchyma for both *T. tomentosa* and *X. dolabriformis* but are absent in *G. arborea*.

Rays vary from low to high, narrow to broad and numerous among those species studies. The number of rays per mm. tangentially is distinctly smaller in *G. arborea* (2-6) than in *T.tomentosa* and *X. dolabriformis* (6 to 16 and 10 to 18 respectively). Rays are commonly homocellular in *X. dolabriformis* and occasionally *T. tomentosa* and homocellular in *G. arborea*. Gum deposits occur in all three kinds of wood. Crystal lacking in woods studied.

4.2. Proportion of tissue types

Based on observation from the wood samples of *G. arborea*, *T. tomentosa* and *X. dolabriformis* the values were calculated from dehydrated sections, as indicated in Table 4.3 and Table 4.4.

4.3. Moisture content

The total amount of water in a green sample piece of wood for each species is measured and it is expressed as a percentage of the oven dry weight of the wood. The results were shown on the following;

Gmelina arborea - 152.84 percent
Terminalia tomentosa - 59.40 percent
Xylia dolabriformis - 48.66 percent

Table 4.1.

Comparison of pore diameters of *Gmelina arborea* *Terminalia tomentosa* and *Xylia dolabrigormis*

Species	**Pore diameters, um**		
	X	**minimum**	**maximum**
Gmelina arborea	207	60	320
Terminalia tomentosa	184	50	290
Xylia dolabriformis	151	40	210

Table 4.2.

Comparision of cell dimensions and length for
Gmelina arborea, Terminalia tomentosa* and *Xylia dolabriformis

Tissue Type	*Gmelina Arborea* um	*Terminalia tomentosa* um	*Xylia Dolabriformis* um
Fibres			
Lumen diameter	15	11	2
Wall thickness (single)	3	4	6
Cells diameter, $\bar{x}$	21	19	14
Vessels			
Lumen diameter	192	169	132
Wall thickness (single)	7	7	9
Cells diameter, $\bar{x}$	206	183	150
Axial parenchyma			
Lumen diameter	18	19	16
Wall thickness (single)	2	2	2
Cells diameter, $\bar{x}$	22	23	20
Ray parenchyma			
Lumen diameter	18	17	10
Wall thickness (single)	2	2	2
Cells diameter, $\bar{x}$	22	21	14
Vessel length	394	433	364
Range	170-620	250-700	180-540
Fibre length	989	1283	1107
Range	340-180	630-650	550-1775

4.4. Specific gravity

In this study, specific gravity of the wood was calculated using oven dry weight as ratio to green volume, and oven dry volume. The results were stated as follows:

Gmelina arborea
Basic specific gravity - 0.41
Oven dry specific gravity - 0.46

Terminalia tomentosa
Basic specific gravity - 0.73
Oven dry specific gravity - 0.84

Xylia dolabriformis
Basic specific gravity - 0.80
Oven dry specific gravity - 0.92

4.5. Shrinkage

The shrinkage is expressed as a percentage of the green volume or size in this study and the following results from green to oven dry were found:

4.5.1 *Gemlina arborea*

	Percent
Volumetric shrinkage -	8.59
Tangential shrinkage -	6.15

Table 4.3.

Tissue contributions to calculated specific gravity of wood and comparisons to empiric specific gravity

Tissue Type	***Gmenlina arborea* um**	***Terminalia tomentosa* um**	***Xylia dolabriformis* um**
Fibres			
Calculated tissue specific gravity	0.64	0.82	1.21
Contribution to wood specific gravity	0.39	0.54	0.71
Vessels			
Calculated tissue specific gravity	0.17	0.19	0.29
Contribution to wood specific gravity	0.03	0.02	0.05
Axial parenchyma			
Calculated tissue specific gravity	0.45	0.42	0.43
Contribution to wood specific gravity	0.03	0.04	0.03
Ray parenchyma			
Calculated tissue specific gravity	0.41	0.37	0.54
Contribution to wood specific gravity	0.04	0.04	0.07
Calculated tissue specific gravity of wood tissue	0.49	0.64	0.86
Basic specific gravity*	0.41	0.73	0.80
Oven dry specific gravity*	0.46	0.84	0.92

* Measured from solid wood samples.

Table 4.4

Comparison of proportion of *Gemlina arborea*, *Terminalia tomentosa*and *Xylia dolabriformis* tissues by weight, by volume and cell wall by volume

Tissue Type	*Gemlina arborea*	*Terminalia tomentosa*	*Xylia dolarbriformis*
Fibres			
Proportion of tissue by weight (%)	79.59	84.37	82.56
Proportion of tissue by volume (%)	60.92	66.13	58.74
Proportion of cell wall by volume (%)	31.60	43.54	56.99
Vessels			
Proportion of tissue by weight (%)	6.13	3.12	5.81
Proportion of tissue by volume (%)	22.15	12.09	18.73
Proportion of cell wall by volume (%)	3.06	1.86	4.45
Axial parenchyma			
Proportion of tissue by weight (%)	6.12	6.25	3.49
Proportion of tissue by volume (%)	6.91	9.82	8.12
Proportion of cell wall by volume (%)	2.51	3.34	2.84
Ray parenchyma			
Proportion of tissue by weight (%)	8.16	6.26	8.14
Proportion of tissue by volume (%)	10.02	11.96	14.41
Proportion of cell wall by volume (%)	3.33	3.60	6.34
Total cell wall volume (%)	40.50	52.34	70.63

Radial shrinkage … 2.34
Longitudinal shrinkage … 0.25

4.5.2 *Terminalia tomentosa*

Volumetric shrinkage … 12.97
Tangential shrinkage … 7.70
Radial shrinkage … 5.42
Longitudinal shrinkage … 0.30

4.5.3 *Xylia dolabriformis*

Volumetric shrinkage … 10.98
Tangential shrinkage … 6.58
Radial shrinkage … 4.93
Longitudinal shrinkage … 0.32

4.6. Relationship between specific gravity and anatomical properties:

Examination of the data in Table 4.4 shows major differences in both volume and weight contribution for the various tissue but relatively small differences among the three species for tissue volume contributions. The major tissue contribution to weight is in the fibres. Among the three species studied, the largest contribution to wood specific gravity is shown by the fibre tissue of *Xylia dolabriformis* which also has the smallest fibre diameter and greatest wall thickness for any of the three species. The contribution of the other tissue to wood specific gravity is much smaller than that for fibres. There is a greater variation in vessel volume than is shown in either ray or axial parenchyma volumes. The latter two are nearly the same for all species.

The proportion of different tissue type for *Gmelina arborea* from this study are, in general, similar to the findings of Akachuku and Buriey (1978), who studied Nigerian *Gmelina arborea* and Isenberg (1963) who recorded for Northern American hardwoods. However, Sosanwo & Linberg (1975) studied the proportions of cell types in *Gnelina arborea* Roxb. and found that fibres predominate and constitute 75.6 percent of the wood. The percentage of vessels and rays are 13.3 and 11.1 respectively and only a few percent of the wood is longitudinal parenchyma. In point of fact, the proportion of fibres values was considerably higher than the others. (Fig. 4.7, 4.8).

It is found that fibre proportion is not correlated with fibre length. This finding is in agreement with the work of Taylor (1971) and Taylor and Wooten (1973), who found a constant negative correlation between fibre length and fibre proportion in sugarberry, but it is contradicted by the observations of Ezell (1979) in sweetgum.

Fibre diameter is negatively correlated with fibre proportion and it is the same statement made by Myint Aung (1962) who studied several of the *Shorea* species.

Limaye & Sen (1956), Gamble (1922), Limaye (1957), Pearson & Brown (1932) and Sehkar & Rajput (1972) indicated that at 12 percent moisture content, the relative density average 0.5 for Indian-grown materials, but Limaye (1957) reported a range from 0.35 to 0.90. The relative density of wood from exotic plantations has been reported to be approximately the of *Gemlina arborea* in this study. However, de Zeeuw & Grey (1972) found that whereas two groups of plantation-grown wood from Nigeria were similar in their density ranges, they were lower than the density of the wood from five trees from Thailand.

Vessel proportion and specific gravity are highly negatively correlated between these specifics. The negative association between the variables is expected because of the fact that the increase in proportion of relatively thin-walled vessel elements will decrease specific gravity since specific gravity is directly related to the amount of cell wall material per unit area. This is similar to the report of Ezell (1979), but this correlation represents a deviation from the work on other specifics of Taylor (1971) and Taylor and Wooten (1973). There is no apparent relationship between parenchyma proportion and specific gravity.

Total cell wall volume, and tangential fibre wall thickness are positively correlated with specific gravity while fibre length, fibre volume, vessel diameter and volume, axial parenchyma diameter and volume, ray parenchyma diameter and volume had negative correlation with specific gravity in all specific studied. It was found that double fibre wall thickness was more influential than fibre volume. This indication is similar to the findings of Stauffer (1892) and Gudim (1963).

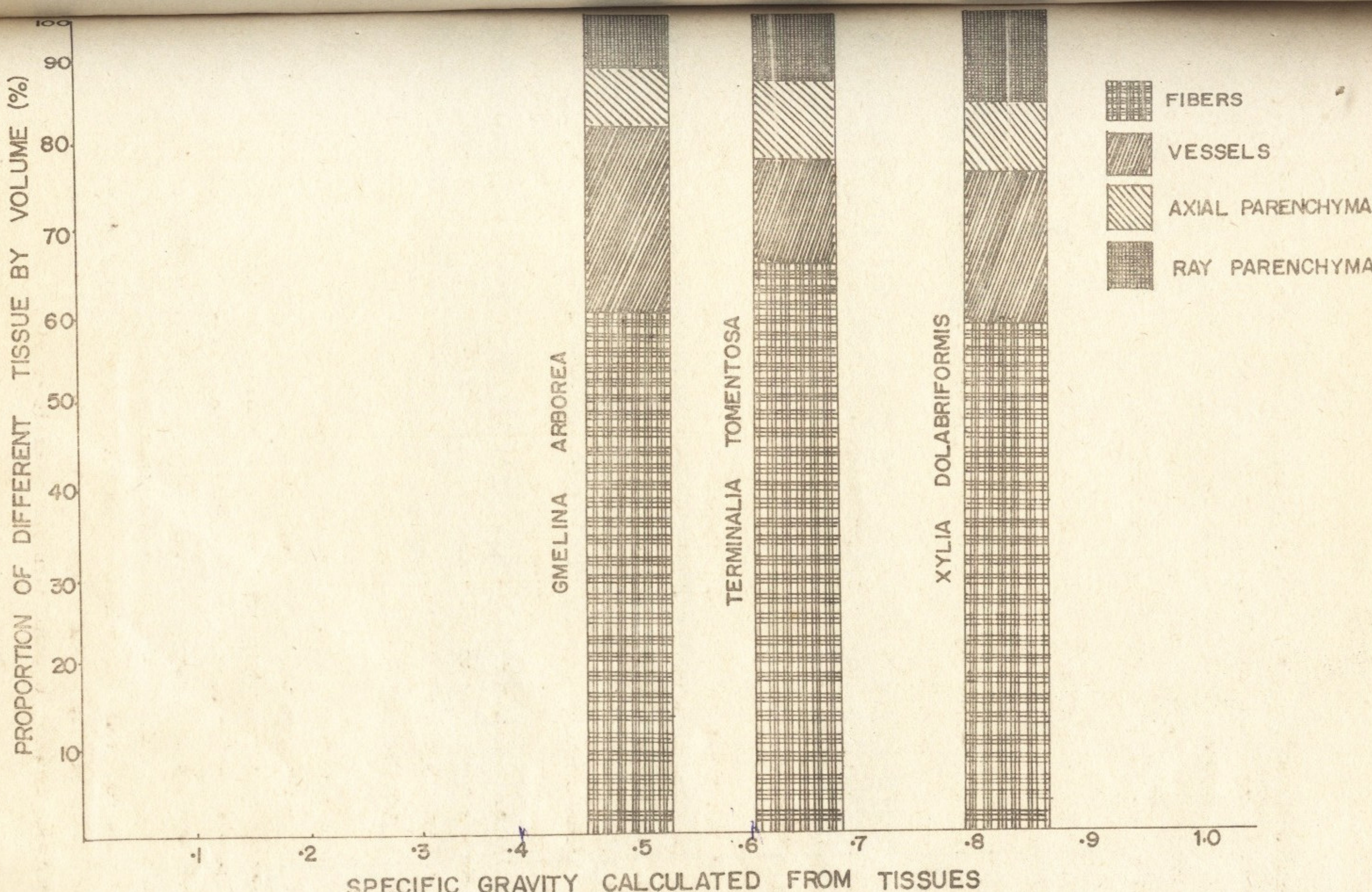


Fig. 4·7· Effect of proportion of different tissue types by volume on specific gravity.

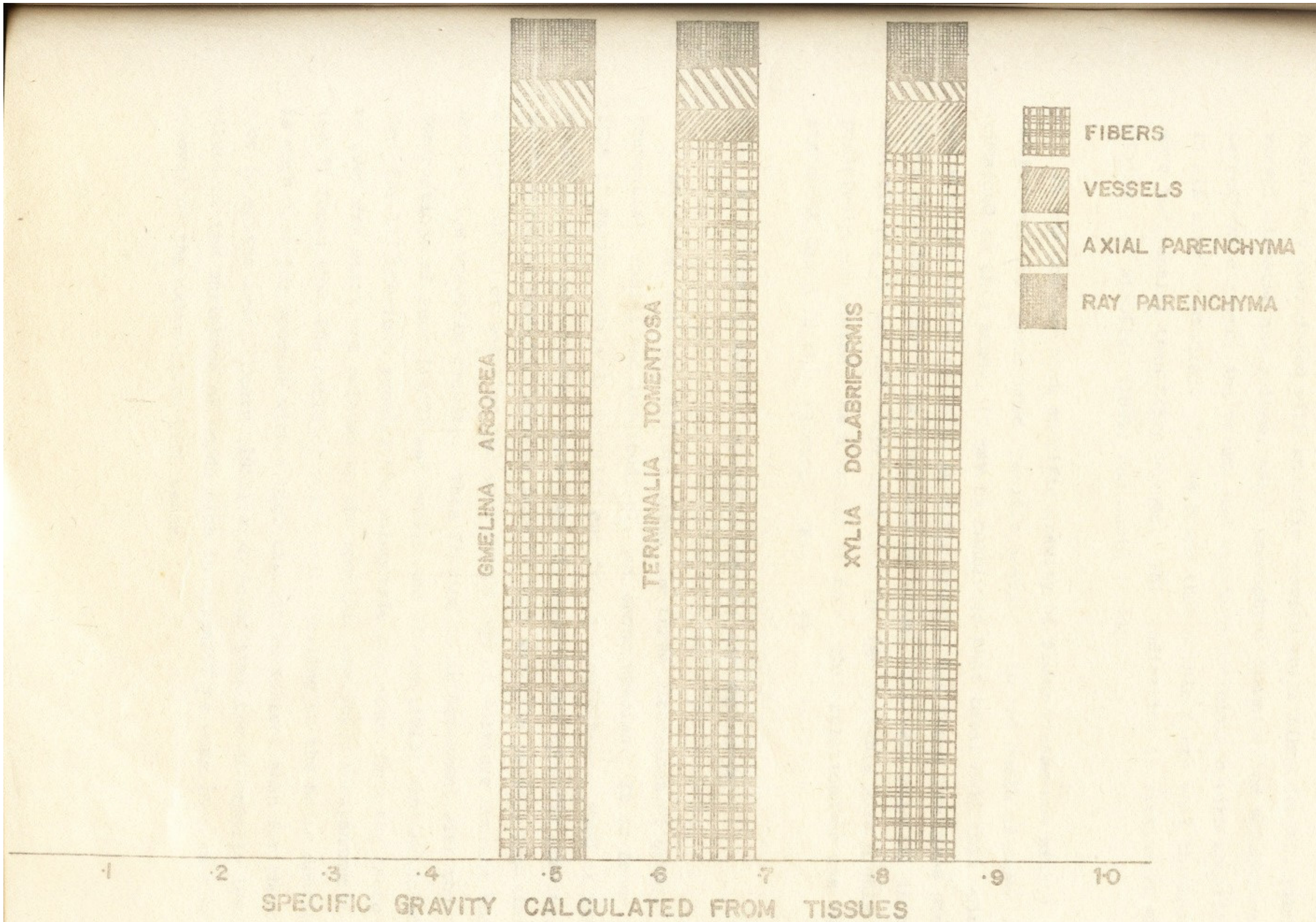


Fig. 4·8· Effect of proportion of different tissue type by weight on specific gravity.

It was obvious that specific gravity of fibre tissue was highly correlated with total wood specific gravity. On the basis of results obtained in this study, it may be concluded that total cell wall volume was strongly correlated with specific gravity for these specimens studied. Since specific gravity is a measure of actual cell wall material in the wood tissue, it was not surprising that the two variable were highly and positively correlated. As a matter of fact, this relationship was the strongest found in this research. (Fig. 4.9)

4.7. Relationship between specific gravity and shrinkage

Shrinkage not only differs along the three directions of grain, tangential, radial and longitudinal, but among species. It is found that it varies widely in material cut from a single tree. Wood of high specific gravity shrinks more than the wood of low specific gravity, which could be expected because wood of high specific gravity contains a great volume of water at the same percentage of moisture content than wood of low specific gravity. This finding is in agreement with the observations of Peck (1947) and Newlin and Wilson (1919) who indicated that for 177 American species the volumetric shrinkage from the green to oven dry state was related to the specific gravity. Narayanmurti (1957) found that the ratio of volumetric swelling to the basic density is much less for specific with a high extractive content than for those poor in extractives. Nearn (1955) also found that the abnormally low values of the shrinkage of woods rich in extractives were increased on removal of the extractives with water.

Although, in general, the woods of high specific gravity possess high shrinkage, there are exceptions. Peck (1947) also mentioned that as for Basswood, a light wood, has a high shrinkage, while black locust, a heavy wood, has a moderates shrinkage.

4.8. Relationship between moisture content and shrinkage

Wood swells and shrinks as its moisture content rises and falls with changes in atmospheric humidity. Therefore the weight of wood varies with the amount of moisture it contains and its volumes changes with the changes in moisture content below the fibre saturation point as shown in Table. 4.5. Its behaviour is, however, more complicated than that of many other materials because of its elaborate structure.

Kelsey (1963) indicated that in the drying of wood from the water-saturated or green condition, little shrinkage normally accompanies the removal of capillaryheld water from the cell lumen. As it is mentioned, all the species in this study, in the oven dry state, when all the moisture has been removed from the cell wall, a marked shrinkage has occurred, between about 6 to 8 percent of green dimensions in the tangential rings and about half this value in the radial directions in the tree. Shrinkage parallel to the grain in this study is small, usually being less than 0.4 percent.. These results are similar to the observations of Kelsey (1963).

The shrinkage characteristics of *Terminalia* measured from the green condition to oven dry was noted in Indian Timbers (1968). Expressed as a percentage of the green dimension, the radial shrinkage was found to be 5.3 percent, the tangential shrinkage to be 12.9 percent respectively with a ratio of tangential to radial of 1.4. Sono (1947) found that the radial shrinkage was 6.5 percent and the tangential shrinkage 8.3 percent, but he did not measure the volumetric shrinkage. The result of radial and tangential shrinkage percentage of *Terminalia* in this study were lower than the values mentioned above and close to the findings of Pearson & Brown (1932).

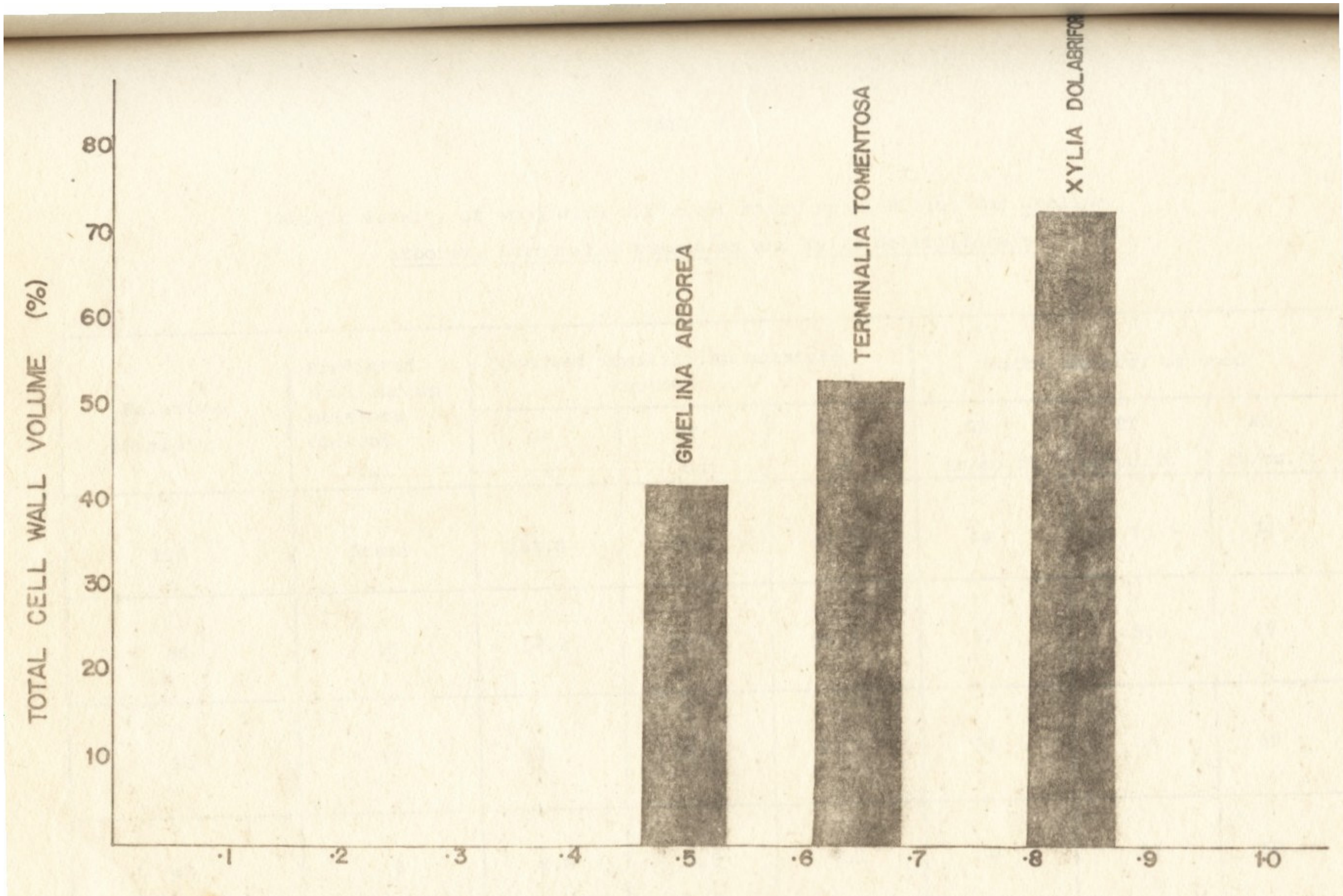


Fig. 4·9· Effect of total cell wall volume percentage on specific gravity.

Most of the sources quoted concur in the fact that the material exhibits a wide range of shrinkage varying from 4.8 to 6.5 percent in the radial dimension and 7.1 to 8.3 percent tangentially.

The shrinkage behaviour for all species from green to oven dry condition are, in general, similar to these given in Chudnoff (1984), Rao & Purkayastha (1972) as shown in Table 4.6. and Anon. (1974) for *Terminalia superba*. In drying wood to a moisture content of 18 percent, two-fifths of the total shrinkage takes place. Further drying to a moisture content of 12 percent and 6 percent, accounts for three-fifths and four-fifths of the total shrinkage respectively as shown in Table 4.7.

Table 4.5.

Weight density of wood with different moisture condition for *Gemlina arborea, Terminalia tomentosa* and *Xylia dolabriformis*

Relative Humidity	Predicted Equilibrium moisture content %	Observed Equilibrium moisture content			Weight density of wood		
		GA (%)	TT (%)	XD (%)	GA lb/cu.ft	TT lb/cu.ft	XD lb/cu.ft
100	Green	152.8	59.4	48.7	64	73	74
86	18	17.2	18.9	16.6	32	56	62
60	12	11.3	13.5	12.7	31	54	60
44	6	6.8	7.5	7.7	30	52	58
0	0	0	0	0	28	50	55

GA = *Gemlina arborea*
TT = *Terminalia tomentosa*
XD = *Xylia dolarbriformis*

Peck (1974) and Espenas (1974) are in agreement with these predictions for shrinkage behaviour in wood. The shrinkage behaviour of wood is modified, if the shrinkage is measured on cross sections less than a fibre length in thickness. The measured shrinkage will be increased since moisture will have free acess to the lumina of the fibres and the only moisture gradients will be those in the individual cell walls and thus severe drying stresses should be eliminated. Green-hill (1936) compared the shrinkage of standard 2.5 x 2.5 x 10 cm. specimens to those which were approximately 12 mm. square in cross section and about a fibre length in thickness. Both tangential and radial shrinkage of the small specimens were about 1.1 times as great as those of the large specimens, the difference being due mainly to the reduction of drying stress.

Kelsey (1974) pointed out that transverse shrinkage generally commences at a moisture content greater than 30 percent. As the moisture content is reduced from 25 to approximately 5 percent, the shrinkage increases more or less linearly. On drying still further, the rate of shrinkage with respect to moisture content decreases as shown in Fig. 4.10; 4.11; 4.12. The longitudinal shrinkage in contrast to the transverse, does not necessarily vary linearly with moisture content over an appreciable part of the moisture content range. This finding was in agreement with the results of all the species studies as shown in Fig. 4.13; 4.14; 4.15.

Table 4.6.

Comparison of shrinkage percentage of observed values and literatures on *Gmelina arborea*, *Terminalia tomentosa* and *Xylia dolabriformis*

Species	Shrinkage percentage	
	Observed value	Source
Gmelina arbores		
Radial	2.3	2.4**
Tangential	6.1	4.9**
Volumetric	8.6	8.8**
Terminal tomentosa		
Radial	5.4	4.8**
Tangential	7.7	7.4**
Volumetric	12.9	13.2**
Xylia dolabriformis		
Radial	4.9	3.3*
Tangential	6.58	6.7*
Volumetric	10.9	11.1*

** Timbers of the world (Chudnoff, 1984)
* Indian Woods (Rao & Purkayastha, 1972)

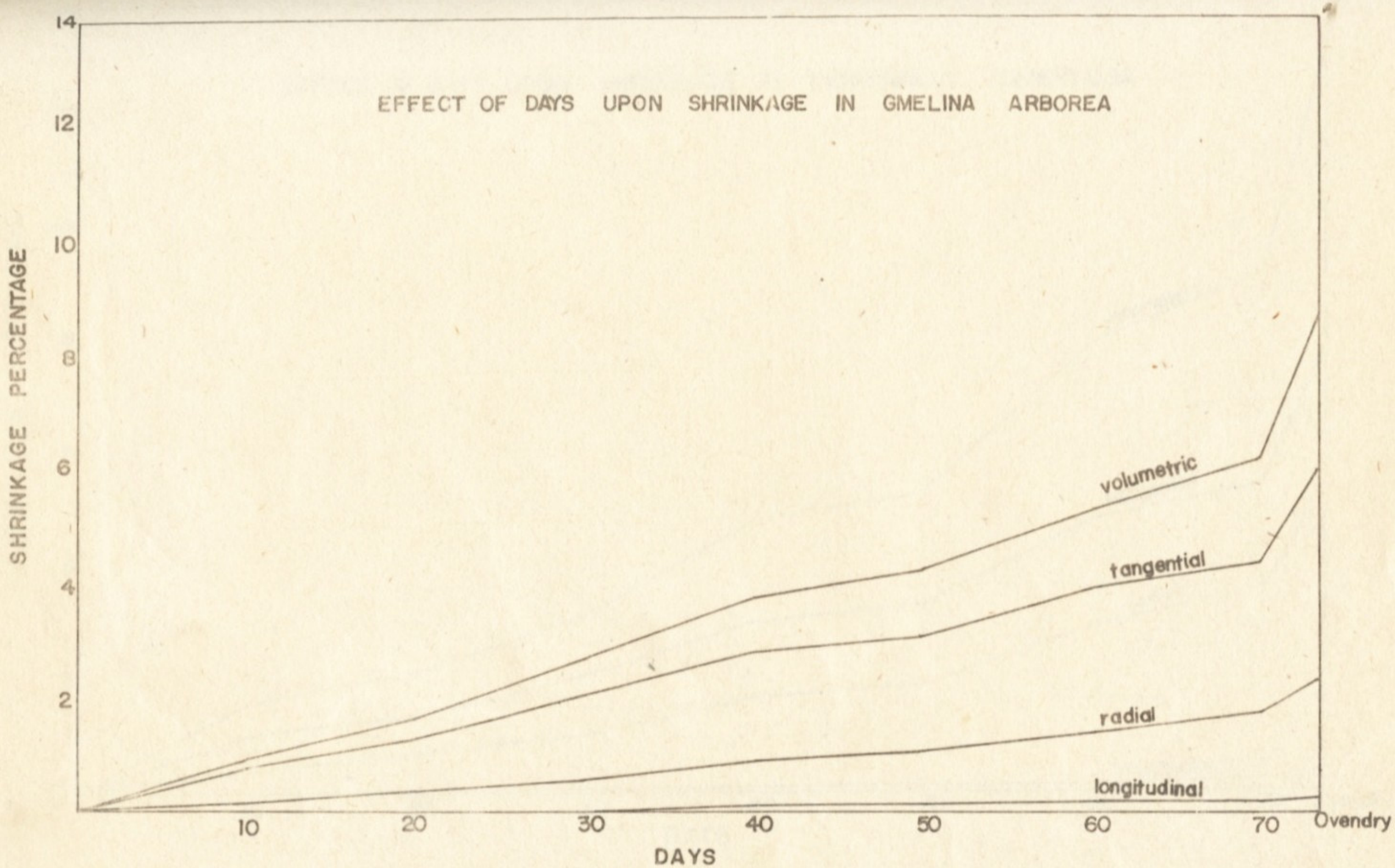
Table 4.7.

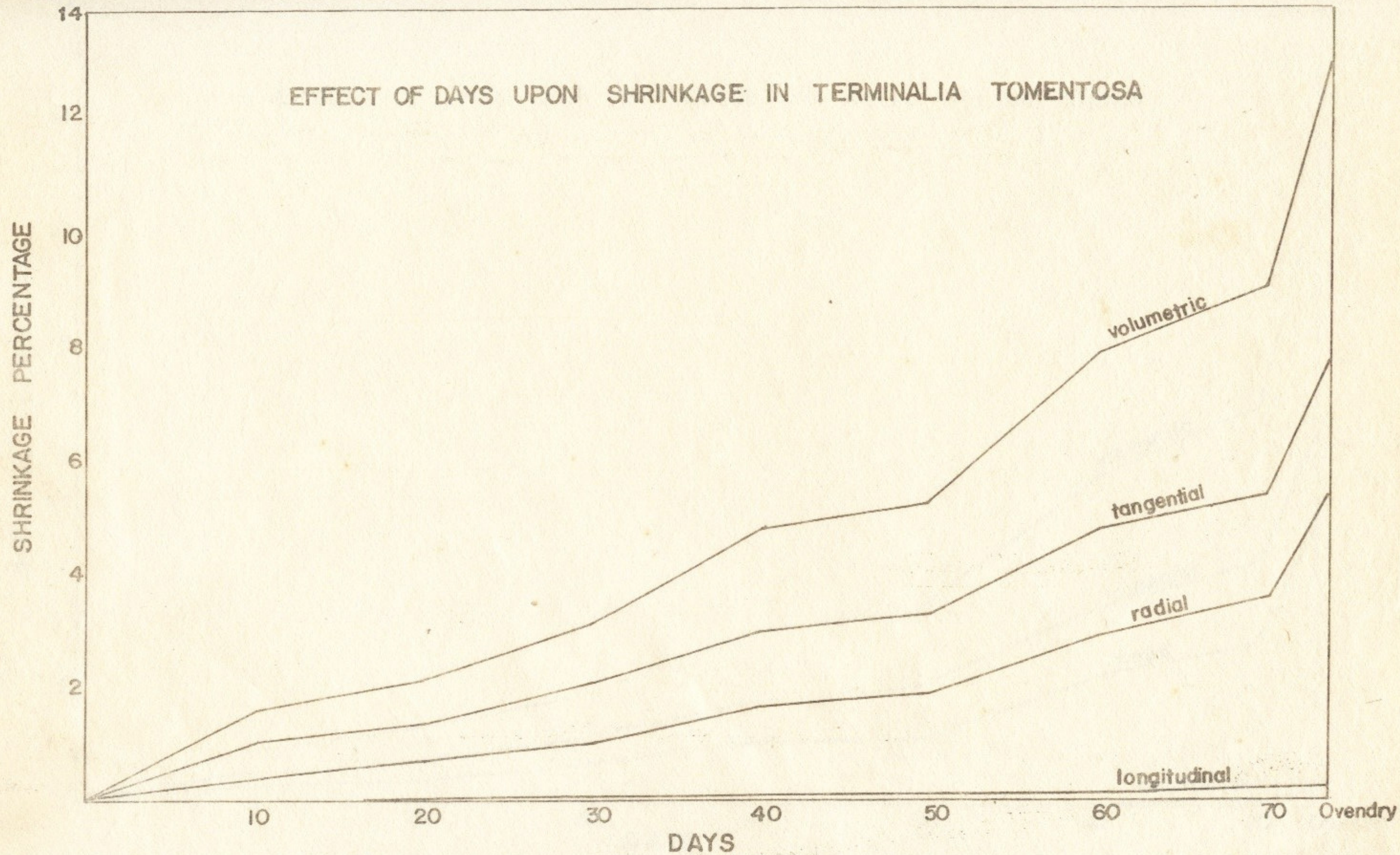
Specific gravity and shrinkage values for Gmelina arborea, Terminalia tomentosa and Xylia dolabriformis with several levels of moisture content

Gmelina arborea					
Levels of moisture content (percent)	**Specific gravity**	**Shrinkage percent**			**T/R**
		Radial	**Tangential**	**Volumetric**	
Green	0.41				
18	0.44	0.58	2.05	2.69	3.5
12	0.45	1.04	3.09	4.22	3.0
6	0.46	1.67	4.43	6.19	2.6
0	0.48	2.34	6.15	8.59	2.6

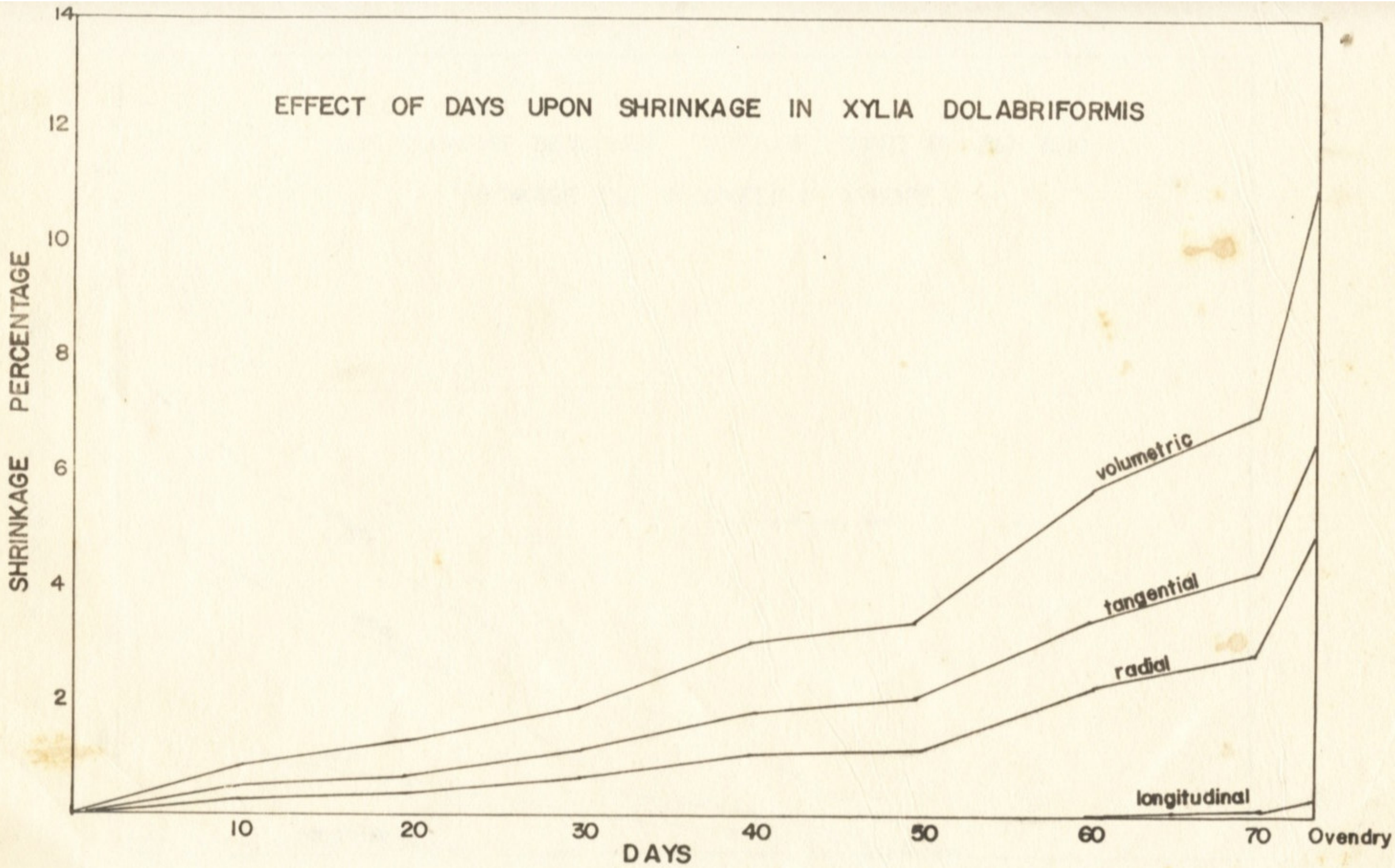
Terminalia tomentosa					
Levels of moisture content (percent)	**Specific gravity**	**Shrinkage percent**			**T/R**
		Radial	**Tangential**	**Volumetric**	
Green	0.73				
18	0.77	1.06	2.07	3.23	1.9
12	0.78	1.88	3.26	5.23	1.7
6	0.80	3.61	5.45	9.05	1.5
0	0.81	5.42	7.70	12.97	1.4

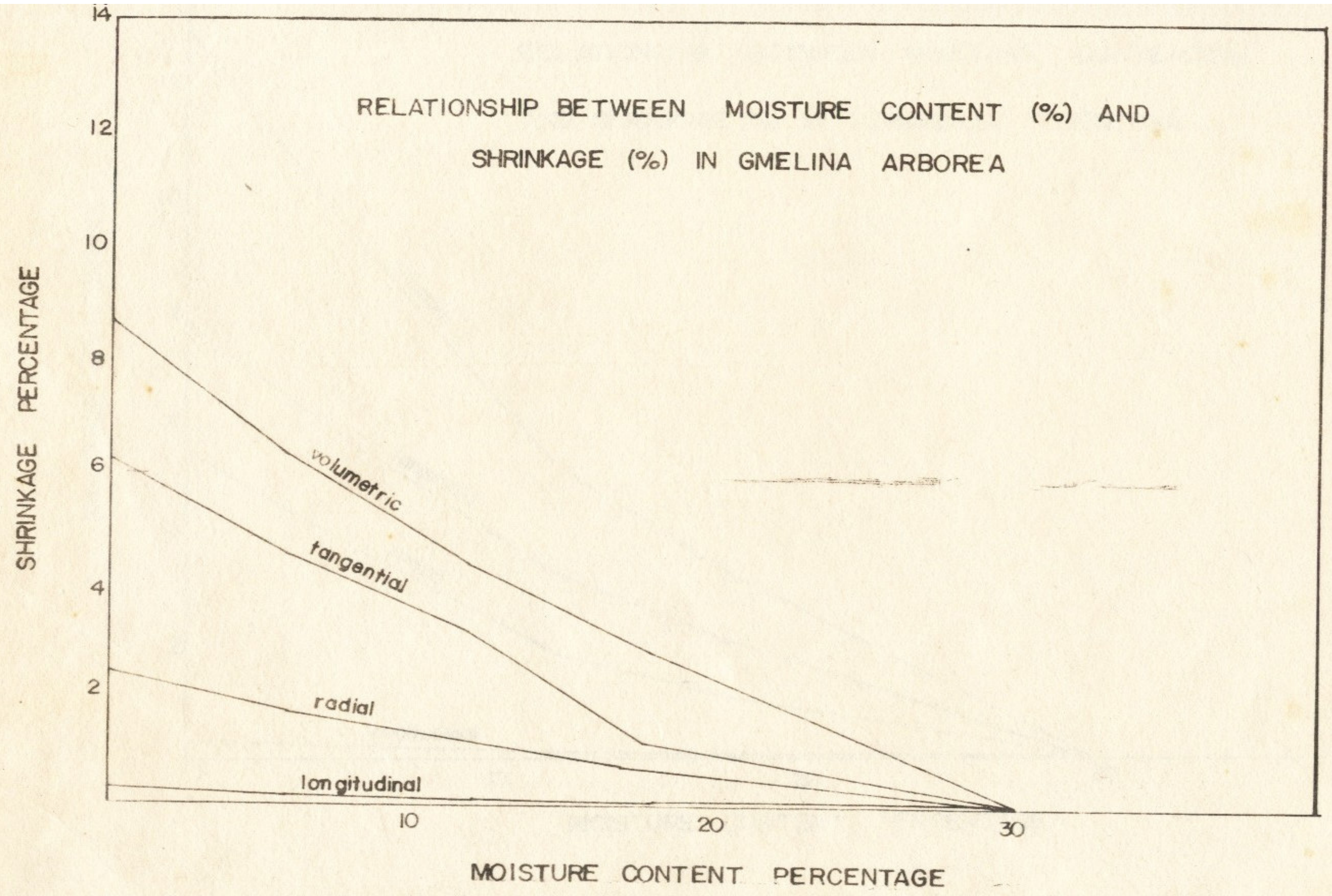
Xylia dolabriformis					
Levels of moisture content (percent)	**Specific gravity**	**Shrinkage percent**			**T/R**
		Radial	**Tangential**	**Volumetric**	
Green	0.80				
18	0.84	0.7	1.15	1.89	1.6
12	0.86	1.27	2.10	3.41	1.7
6	0.88	2.82	4.29	7.05	1.5
0	0.89	4.93	6.58	10.98	1.3

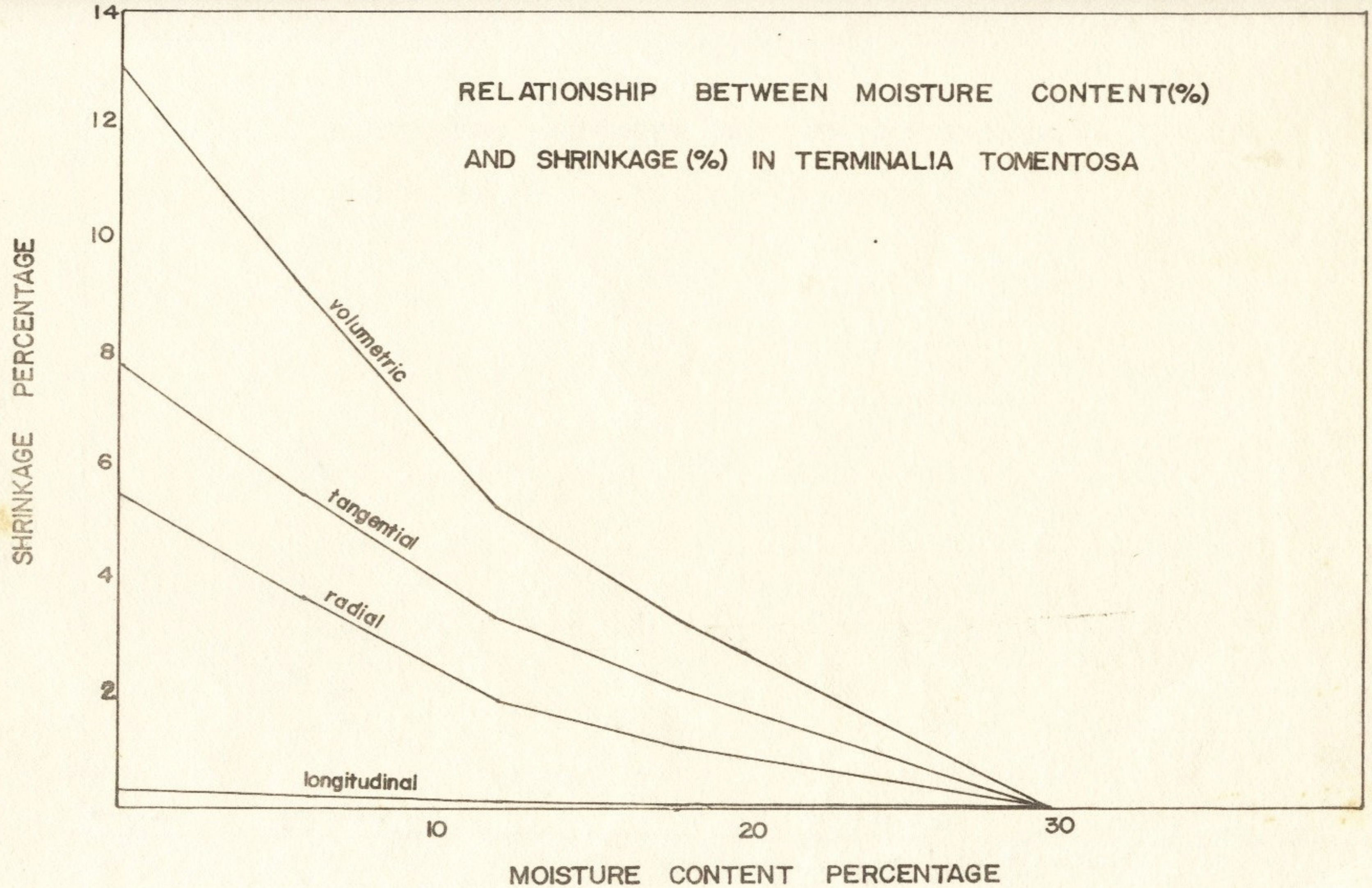

EFFECT OF DAYS UPON SHRINKAGE IN GMELINA ARBOREA
SHRINKAGE PERCENTAGE
14
12
10
8
6
4
2
volumetric
tangential
radial
longitudinal
10
20
30
40
50
60
70
Ovendry
DAYS

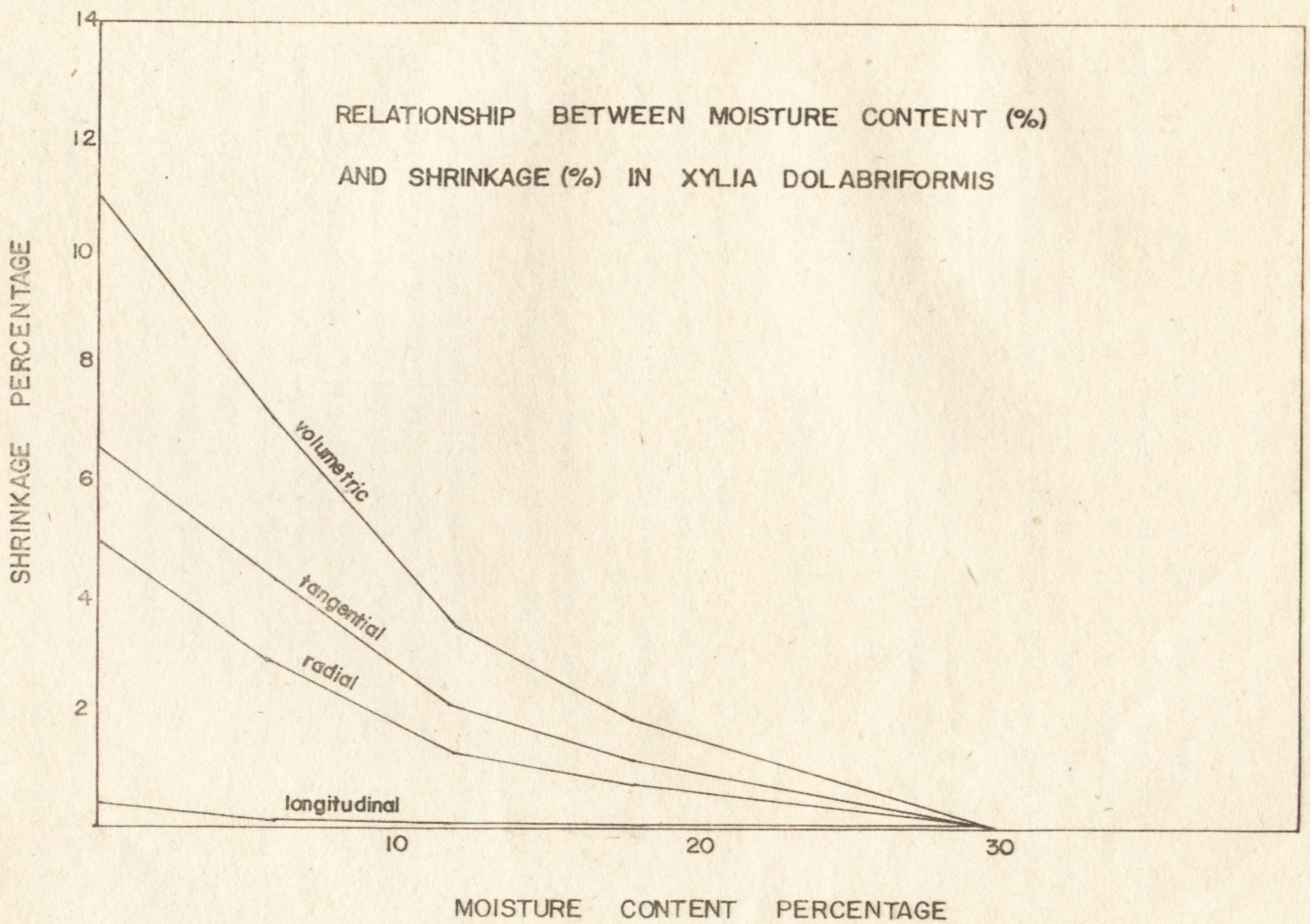


EFFECT OF DAYS UPON SHRINKAGE IN TERMINALIA TOMENTOSA
SHRINKAGE PERCENTAGE
14
12
10
8
6
4
2
volumetric
tangential
radial
longitudinal
10
20
30
40
50
60
70
Ovendry
DAYS


EFFECT OF DAYS UPON SHRINKAGE IN XYLIA DOLABRIFORMIS
SHRINKAGE PERCENTAGE
14
12
10
8
6
4
2
volumetric
tangential
radial
longitudinal
10
20
30
40
50
60
70
Ovendry
DAYS


RELATIONSHIP BETWEEN MOISTURE CONTENT (%) AND
SHRINKAGE (%) IN GMELINA ARBOREA
SHRINKAGE PERCENTAGE
14
12
10
8
6
4
2
volumetric
tangential
radial
longitudinal
10
20
30
MOISTURE CONTENT PERCENTAGE


RELATIONSHIP BETWEEN MOISTURE CONTENT(%)
AND SHRINKAGE (%) IN TERMINALIA TOMENTOSA
SHRINKAGE PERCENTAGE
14
12
10
8
6
4
2
volumetric
tangential
radial
longitudinal
10
20
30
MOISTURE CONTENT PERCENTAGE


RELATIONSHIP BETWEEN MOISTURE CONTENT (%)
AND SHRINKAGE (%) IN XYLIA DOLABRIFORMIS
SHRINKAGE PERCENTAGE
14
12
10
8
6
4
2
volumetric
tangential
radial
longitudinal
10
20
30
MOISTURE CONTENT PERCENTAGE

One could assume that the moisture content shrinkage curve approximates a straight line between 6 percent and 18 percent moisture content, but these datas show an inflection point at about 12 percent for no apparent reason. As a matter of fact, the shape of the moisture content shrinkage curve varies from species to species and from specimen to specimen and also dependent on the method of drying. Because of moisture gradients, large specimens may start shrinkage at a higher average moisture content than small ones, and in cases where severe collapse occurs the shape of the curves may be different.

4.9. Specific gravity as a predictor of strength in wood

Burma is faced with the need to extend the utilization of its forests by exploitation of the many secondary species which now are unused commercially. In order to meet this need the various species must be subjected to many tests which are both time consuming and expensive. A method is available for screening the secondary and unused timbers, prior to full scale testing, to determine those which are suitable for construction

Specific gravity of wood has been shown to be a good index to mechanical properties when expressed as regression equations. Calculations using these regression statements and the easily obtained estimates of specific gravity will give a usable estimate of the strength properties of unknown timbers that can be used in conjunction with the volume data from inventories to set priorities for full scale test programs. These estimates of mechanical properties of wood from specific gravity of the wood can also be useful in assessing the quality of timber produced in tree improvement studies and in studies of the overall variability of wood within species.

Two methods were used for obtaining specific gravity. The first method was direct measurement from solid wood samples to obtain specific gravity on green volume (basic specific gravity) and air dry volume. The second method used was a calculation from tissue volumes measured with a microscope from thin cross sections.

The effect of specific gravity upon modulus of rupture, modulus of elasticity in static bending, and maximum cursing strength in compression parallel to the grain was examined based on three data sets (United states hardwoods; Great Britain hardwoods; Indian) by calculating from regression equations developed by Armstrong et. al., (1984). Estimates of the mechanical properties were calculated for both the green and air dry conditions using specific gravity values determined from both solid blocks and calculated from tissue volume. In this study, air dry was considered to be 12 percent moisture content and green was considered to be at or above fibre saturation point.

Results of the analyses of calculations for green modulus of elasticity in static bending, modulus of rupture and maximum crushing strength in compression parallel to the grain for each species are shown in Tables 4.8, and 4.10. Tables 4.11; 4.12 and 4.13 shown similar tabulations for air dry wood.

The tabulated estimates of mechanical properties do not show completely consistent results in terms of the closed approximations from regressions based on Great Britain data gave the closet approximations with the exception of part of the calculations for *Terminalia tomentosa* which were better approximated by calculation from the regressions based on united States hardwoods. The range of deviation for the best and poorest estimates in each case is shown as percentage in Tables 4.14 and 4.15.

Comparison of results tabulated in Tables 4.8 through 4.13 show that in general the estimates based on specific gravity determined from solid wood are closer to the Burmese data than these made using specific gravity calculated from tissue volumes. However, it must be noted that both sets of estimates are acceptable for the values that are most nearly alike.

It is apparent that the results using data set from Great Britain is closer to the Burmese data than the other two for both green and air dry conditions for each species. It is not surprising that the regressions based on the hardwoods data from Great Britain generally give the best estimates of these mechanical properties since the data set includes tests of hardwoods from the commonwealth and includes all the tropical regions. Furthermore, the regression statements themselves indicated that the Great Britain data produces the best relationship between data and regression equation as indicated by the fact that “r” values were high in all cases.

Table 4.8.

Calculated* And Actual Mechanical Properties for Green Wood in relation to Basic Specific Gravity (*Gmelina arborea*)

Property	Calculated on specific gravity from solid block			Calculated on specific gravity from tissue volume			Burma + data
	U.S. Hard Wood	Great Britain Hard wood	India	U.S. Hard wood	Great Britain Hard wood	India	
Modulus of elasticity	1068	<u>1098</u>	1054	<u>1142</u>	1212	1143	1118
Modulus of rupture	6123	<u>7013</u>	6593	<u>6821</u>	7842	7277	6940
Maximum crushing strength	2653	<u>3354</u>	3237	2922	3790	<u>3592</u>	3300

* Calculated from regression equations in Armstrong et al. (1984).
+ From Rodger, 1963
Underlining indicates the prediction closest to Burma data.

Table 4.9.

Calculated* And Actual Mechanical Properties for Green Wood in relation to Basic Specific Gravity (*Terminalia tomentosa*)

Property	Calculated on specific gravity from solid block			Calculated on specific gravity from tissue volume			Burma + data
	U.S. Hard Wood	Great Britain Hard wood	India	U.S. Hard wood	Great Britain Hard wood	India	
Modulus of elasticity	<u>1618</u>	2025	1742	1319	<u>1500</u>	1361	1662
Modulus of rupture	<u>11957</u>	14014	12152	8610	<u>9977</u>	9001	11290
Maximum crushing strength	4999	7143	<u>6176</u>	3651	<u>4929</u>	4015	5590

* Calculated from regression equations in Armstrong et al. (1984).
+ From Rodger, 1963
Underlining indicates the prediction closest to Burma data.

Table 4.10.

Calculated* And Actual Mechanical Properties for Green Wood in relation to Basic Specific Gravity (*Xylia dolabriformis)*

Property	Calculated on specific gravity from solid block			Calculated on specific gravity from tissue volume			Burma + data
	U.S. Hard Wood	Great Britain Hard wood	India	U.S. Hard wood	Great Britain Hard wood	India	
Modulus of elasticity	1728	2340	1886	1666	2113	1747	2265
Modulus of rupture	13297	15642	13391	12529	14708	12682	15555
Maximum crushing strength	5534	8053	6843	5228	7530	6461	8015

* Calculated from regression equations in Armstrong et al. (1984).
+ From Rodger, 1963
Underlining indicates the prediction closest to Burma data.

Tables 4.11.

Calculated* And Actual Mechanical Properties for Air Dry Wood in relation to Air dry Specific Gravity (*Gmelina arborea*)

Property	Calculated on specific gravity from solid block			Calculated on specific gravity from tissue volume			Burma + data
	U.S. Hard Wood	Great Britain Hard wood	India	U.S. Hard wood	Great Britain Hard wood	India	
Modulus of elasticity	1346	1308	1337	1410	1401	1403	1287
Modulus of rupture	9839	10448	9358	10601	11286	9983	9375
Maximum crushing strength	5314	5811	5220	5635	6253	5543	4850

* Calculated from regression equations in Armstrong et al. (1984).
+ From Rodger, 1963
Underlining indicates the prediction closest to Burma data.

ble 4.12.

Calculated* And Actual Mechanical Properties for Air Dry Wood in relation to Air dry Specific Gravity (*Terminalia tomentosa*)

Property	Calculated on specific gravity from solid block			Calculated on specific gravity from tissue volume			Burma + data
	U.S. Hard Wood	Great Britain Hard wood	India	U.S. Hard wood	Great Britain Hard wood	India	
Modulus of elasticity	<u>2010</u>	2373	2031	1633	<u>1744</u>	1636	1906
Modulus of rupture	1879 1	20415	<u>16401</u>	13444	<u>14435</u>	12268	15380
Maximum crushing strength	8845	10972	<u>8789</u>	6795	<u>7897</u>	6712	8275

* Calculated from regression equations in Armstrong et al. (1984).
\+ From Rodger, 1963
Underlining indicates the prediction closest to Burma data.

Table 4.13.

Calculated* And Actual Mechanical Properties for Air Dry Wood in relation to Air dry Specific Gravity (*Xylia dolabriformis*)

Property	Calculated on specific gravity from solid block			Calculated on specific gravity from tissue volume			Burma + data
	U.S. Hard Wood	Great Britain Hard wood	India	U.S. Hard wood	Great Britain Hard wood	India	
Modulus of elasticity	2152	<u>2627</u>	2182	2028	<u>2405</u>	2050	2530
Modulus of rupture	<u>20983</u>	22886	18048	19063	<u>20722</u>	16607	20580
Maximum crushing strength	9648	<u>12228</u>	9606	8948	<u>11128</u>	8890	11515

* Calculated from regression equations in Armstrong et al. (1984).
\+ From Rodger, 1963
Underlining indicates the prediction closest to Burma data.

Table 4.14.

Percentage deviation of calculated values from Burma data for estimates based on regression equations for three mechanical properties (Green Wood)

(From solid block)

Gmelina arborea	**closest %**	**largest %**
MOE	2 +	5 +
MOR	1 -	11 +
MCS	2 -	20 -
Terminalia tomentosa		
MOE	3 +	22 -
MOR	6 +	24 -
MCS	10 -	28 -
Xylia dolabriformis		
MOE	3 -	24 +
MOR	0.5 -	15 +
MCS	0.5 -	31 +
		(From tissue volume)
Gmelina arborea		
MOE	9 -	10 -
MOR	6 -	20 -
MCS	14 -	29 -
Terminalia tomentosa		
MOE	8 +	14 +
MOR	6 +	20 +
MCS	5 +	19 +
Xylia dolabriformis		
MOE	5 +	20 +
MOR	0.6 -	19 +
MCS	3 +	23 +

MOE = Modulus of elasticity;
MOR = Modulus of rupture;
MCS = Maximum crushing strength

Table 4.15

Percentage deviation of calculated values from Burma data for estimates based on regression equations for three mechanical properties (Green Wood)

(From solid block)

Gmelina arborea	**closest %**	**largest %**
MOE	2 -	4 -
MOR	0.1+	17 -
MCS	8 -	29 -
Terminalia tomentosa		
MOE	5 -	25 -
MOR	7 -	33 -
MCS	6 -	33 -
Xylia dolabriformis		
MOE	4 -	15 +
MOR	2 -	11 -
MCS	6 -	17 +
		(From tissue volume)
Gmelina arborea		
MOE	9 -	10 -
MOR	6 -	20 -
MCS	14 -	29 -
Terminalia tomentosa		
MOE	8 +	14 +
MOR	6 +	20 +
MCS	5 +	19 +
Xylia dolabriformis		
MOE	5 +	20 +
MOR	0.6 -	19 +
MCS	3 +	23 +

MOE = Modulus of elasticity;
MOR = Modulus of rupture;
MCS = Maximum crushing strength

5. Conclusion

Based on the results obtained in this study, the following conclusions may be drawn:

(1) Total cell wall volume and tangential fibre wall thickness are positively correlated with specific gravity while fibre length, fibre volume, vessel diameter and volume, axial parenchyma diameter and volume, ray prenchyma diameter and volume had negative correlation with specific gravity in all species studied. These results are in agreement with studies of hardwoods noted in the literatures.

(2) Total cell wall volume was strongly correlated with specific gravity for these specimens.

(3) Anatomy of three sample species confirms to publish data.

(4) Specific gravity in xylia is highest of these specific as results of the largest cell wall volume plus the influence of the high extractive content (as reported). In spite of this high specific gravity is noteworthy that the volumetric shrinkage in Xylia is lower than that for Terminalia.

(5) The regression equation for hardwoods based on from Great Britain, as developed by Armstrong et.al. (1984), is the best predictor of elasticity in static bending, modulus of rupture and maximum crushing strength in compression parallel to the grain for both green and air dry wood according to the data developed in this study using either specific gravity determined from solid wood or tissue volume estimates.

References

1. Akachuku , A. E. , 1976. A study of variation in wood properties of *Gmelina arborea* Roxb. from Nigeria. Thesis . Oxford University . 186 pp.
2. Akachuku , A. E. , 1978. A study of some wood features of *Gmelina arborea* Roxb . from Nigeria.Thesis Oxford University. 367 pp.
3. Akachuku ,A. E. ,1985. The effects of some extrinsic factors on the proportion of vessels in *Gmelina arborea* Roxb.Wood Sci .Technol.19: 1-12.
4. Akachuku ,A.E , and J. Burley, 1979. Variation of wood anatomy of *Gmelina arborea* Roxb. in Nigerian plantations . I. A. W. A. Bulletin 4:94-99.
5. Anon. , 1937. Standard terms of length of vessel members and wood fibres. Tropical woods. No. 51: 21.
6. Anon., 1939. Standard terms of size for vessel diameter and dry width. Tropical woods. No .59: 51-52.
7. Anon., 1945. Empire timbers, Department of Scientific and Industrial Research. London. His majesty's stationary office. London. 142 pp.
8. Anon., 1956. The wealth of India. Vol. IV. New Delhi, Council of Scientific and Industrial Research, 294 pp.
9. Anon., 1964. Multilingula Glossary of Terms used in Wood Anatomy. International Association of Wood Anatomists. Committee on Nomenclature. Verlagsenstalt Buchdruckerei Konkordia Winterthur, Switzerland, 186 pp.
10. Anon., 1967. Report on a consignment of *Gmelina arborea* Roxb. from Cambia. F. P. R. I. consignment No. 1359. Reports on overseas Timbers, Forest Products Research Laboratory, Princes Risborough. No. 7. 11 p.
11. Anon., 1974. Wood handbook: wood as an engineering material Forest Products Laboratory, Forest Service. U.S. Department of Agriculture. Agriculture Handbook No. 72.
12. Armstring, M., J.P.,C. Skaar and C. de Zeeuw,1984. The effects of specific gravity on several mechanical properties of some world woods. wood Sci. Technol. 18: 137-146.
13. Aung, M., 1962. Density variation outwards from the pith in some species of Shorea and its anatomical Basis. Empire Forestry Review 41 (1): 107, March, 48-56.
14. Bennet, S.S.R. and K.N. Bahadur, 1978. Botanical identity of pyinkado and Irul. Indian Forester. 104(9): 621-624.
15. Chittaway, M.M., 1932. Proposed standards for numerical values used in describing woods. Tropical woods. No. 29: 20-28.
16. Chowdhury, K.A., 1935. The role of initial parenchyma in the transformation of the structure diffuse porous to ring porous in the secondary xylem of the genus *Gmelina* Linn. Proceedings of the National Institute of Science of India. 19 (3): 361-369.
17. Chowdhury, K.A., 1939. "Indian Forest Records". (New Series) Utilization. vol. II. No.1. The formation of growth rings in Indian tree. Government of Indian tree. Government of Indian Press, New Delhi, 39 pp.
18. Chudnoff, Martin, 1984. Tropical timbers of the world, Agriculture Hand book 607, Washington, D.C.U.S. Department of Agriculture, Forest Services, 466 p.
19. Corner, E.J.H., 1940. Wayside trees of Malaya. vol.I. Singapore, Government Printing Office. 777 pp.
20. De Smidt, W.J., 1922. Studies in the distribution and volume of the wood rays of slippery elm, Ulmus fulva Michx. Journal Forestry 20:352-362.
21. Esan, R.F., 1966. A study of Variations in some structural features and properties of *Gmelina arborea* Roxb. Gmelina or Yemane. Thesis. Oxford University. 57 pp.

22. Espenas, L.D., 1947. Some wood moisture relations. United States Department of Agriculture Forest Service. Forest Products Laboratory. Madison, Wisconson. 1-7.
23. Ezell, W.A., 1979. Variation of cellular proportion in sweetgum and their relation to other wood properties. Wood and Fiber II (2): 136-143.
24. Ferreirinha, M.P., 1953. Alguma relacoes entre as caracteristicas anatomicas e fisicas do lenho. Garcia do orta 4 (1): 57-70 (Original paper not seen).
25. Ferreirinha, M.P., 1965. Appraisal of the variation in the micrographic fibre characteristies with and between trees of tropical hardwood species. IUFRO section 41 meeting, Melbourne, Victoria, Australia. 1-11.
26. Franklin, G.L., 1946. A rapid method of soltening wood for microtome sectioning. Tropical woods. No. 88:35.
27. Gamble, J.S., 1922. A manual of Indian timbers. An account of the growth, distribution, and uses of the trees and shrubs of Indian and Ceylon, with descriptions of the their wood structure. 2nd Edition. London, Sampson Law, Marston and Co., Ltd, 522 pp.
28. Greaves, A., 1973. Site studies and associated productivity of *Gmelina arborea* in Nigeria. Thesis. University College of North Wales, Bangor, 183 pp.
29. Greaves, A., 1981. *Gmelina arborea.* Forestry abstracts vol.42. No.6 June. Commonwealth Forestry Bureau. 237-255.
30. Greenhill, W.L., 1936. The shrinkage of Australian Timbers Part 1. A new method of determining shrinkage and shrinkage figures for a number of Australian species. Div. of Forest Products Tech. paper No. 21. Coun. Sci. Industr. Res. Aust. Pamph. No. 67.
31. Gudim, A., 1963. Tidsskr Skogbr. 71:89-120. Original not seen cited from For. Absts. 25: 2727. 1964.
32. Huber, B. and G. Prutz, 1938. Uber den arteil von fasern, Gefassen and Parenchym am Aufbau verchiedener Holz Roh-und Werkstoff. 1: 377-381.
33. Hughes, J.F. and D. Esan, 1969. Variation in some structural features and properties of *Gmelina arborea*. Tropical Science II (1): 23-37.
34. James, W.L., 1954. Electrical moisture meters for wood. United States Department of Agriculture Forest Service. Forestry Products Laboratory. Madison 5. Wisconson. 1-13.
35. Jeffrey, E.C., 1917. The anatomy of woody plants. 1st Edition, Chicago, University of Chicago Press. Illinois. 487 pp.
36. Kellogg, R.M. and G. Ifju, 1962. Influence of specific gravity and certain other factor on the tensile properties of wood. Forest Prod. J. 12 (6): 463-470.
37. Kelsey, K.E., 1963. A critical Review of the Relationship between the Shrinkage and Structure of Wood. Div. of For. Pro. Tech. paper No. 28. Commonwealth Scientific and Industrial Research Organization, Melbourne, Australia. 35 pp.
38. Kribs, D.A., 1968. Commercial foreign woods on the American Market. Dover Publications, New York 241 pp.
39. Kukachka, B.F., 1977. Sectioning refrectory woods for anatomical studies. U.S.D.A. forest service research note. U.S. Department of Agriculture. Forest Service Forest Product Laboratory, Madison, Wisconson.
40. Ladell, J.L., 1959.A method of measuring the amount and distribution of cell wall material in transverse microscopic sections of wood. Journal Inst. Wood Science. 3: 68-69.
41. Lecomte, H., 1925. Les Bois de 1’ Indochine Angence Econmique de 1’ Indochine 20, Rue de la Boetie, Paris: 68-69.

42. Liese, W. and U. Meyer, 1957. Zur quantitativen Bestimmunz der veschiedenen Zellar im Holz. Zeithsch riftfur Woss. Mikrokopie und mikroshopische Technik. 63:269-275. (Original paper not seen).
43. Limaye, V.D. and B.R. Sen, 1956. Weights and specific gravities of Indian woods. Indian Forest Records. (New Series) Timber Mechanic. 1(4) : 107 pp.
44. Limaye, V.D., 1957. Groupings of Indian Timbers and their properties, uses and suitability. Indian Forest Records. (New Series) Timber Mechanics. 1 (2) : 65 pp.
45. Maeglin, R.R. and J.T. Quirk, 1984. Tissue proportions and cell dimensions for red and while Oak groups. Can. J. For. Res. 14 : 101-106.
46. Mcmillen, J.M., 1950. Methods of determining the moisture content of wood. United States Department of Agriculture Forest Service. Forest Products Laboratory. Madison, Wisconson. 1-8.
47. Merrill, E.D., 1923. An enumeration of Philippine flowering Plants. Publication Department of Agriculture and Natural Resources, Bureau of Science, Philippines No. 18 (3) 4 : 127 pp.
48. Metcalfe, C.R. and L. Chalk, 1950. Anatomy of the Dicotyledons. Clarendon Press. Oxford.
49. Meyer, J.E., 1922. Ray volumes of the commercial woods of the United States and their significance. J. For. 20 : 337-351.
50. Mottet, A., 1963.Relation Between the Density of the Wood and the Coefficient of Fibre Flexibility of *Terminalia superba* Engl. and Diels. IUFRO Section 41 meeting, Forest Products, Madison, Wisconson.
51. Mottet, A., 1965. Consideration on the relationship between certain anatomical characteristics and density in tropical woods. IUFRO section 41 meeting, Melbrourne, Australia. 1-14.
52. Nearn, W.T., 1955. Effect of Water soluble extractives on the volumetric shrinkage and equilibrium moisture content of eleven tropical and domestic woods. Pa. Agr. Expt. Sta. B. 598, 38 p.
53. Newlin, J.A. and T.R.C. Wilson, 1919. The relation of shrinkage and strength properties of wood to its specific gravity. Bull. No. 676. U.S.D.A. Forest Service, Forest products Laboratory, Madison, Wisconson.
54. Panshin, A.J. and C. de Zeeuw, 1980. Textbook of Wood Technoligy. Mc Graw Hill. Inc., 722 pp.
55. Pearson, R.S. and H.P. Brown, 1932. Commercial timbers of India. Calcutta, Government of India Central Publication Branch. 600 pp.
56. Pechmann, H.V., 1958. The relationship between the structure and strength of a few hardwoods. Intern. Union Forest Research Organization, 12th Congress, Oxford. 41 (3) : 229-236.
57. Peck, E.C., 1947. Shrinkage of wood. United States Department of Agriculture forest Service. Forest products Laboratory, Madison, Wisconson. 1-6.
58. Peh, T.B., 1964. Pulping studies on Malayan exotic species I. *Gmelina arborea* Rox., Research Pamphlet, Forest Research Institute, Malayan. N.44. 23 pp.
59. Quirk, J.T., 1975. Dot-Grid Intergrating Eyepiece: Two Sampling Technique for Estimating Cell Wall Areas. Wood Science. 8 (2) : 88-91.
60. Quirk, J.T.,1984. Shrinkage and related properties of Douglas-fir cell walls. Wood and Fibre science. 16 (1) : 115-133.
61. Rao, K.R. and S.K. Purkayastha, 1972. Indian woods: Their identification, properties and uses. vol.3. Forest Research Institute Press. Dehra Dun. India. 262 pp.
62. Rodger, A., 1913. Note on Gumhar (*Gmelina arborea* Roxb.) Forest Bulletin No. 16 Superintendent Government Printing, Calcutta, India. 9 pp.

63. Rodger, A., 1913. Note on Sain or Saj (*Terminalia tomentosa* W. & A.) Forest Bulletin No. 18. Superintendent Government Printing, Calcutta, India. 25 pp.
64. Rodger, A., 1963. A handbook of the forest Products of Burma. 2nd Revised edition. Government Printing and Stationaru, Rangoon.
65. Rosiwal, A., 1898. Uber geometriische Gesteinanalysen. Ein einfacher weg zur Ziffermassigen Festellung des Quantitatsiver haltnigses der Mineral bestandth le gemengster gesteine. Verhand lungen der geolog Reichsnstalt, Wien, No. 5 and 6. (Original paper not seen).
66. Saucier, J.R. and M.A. Taras, 1966. Specific gravity and fibre length variation within annual height increments of Red maple. Forest Prod. J. vol. (16) No. (2) : 33-36.
67. Scaramuzzi, G. and G. Ferrari, 1963. Relation of specific gravity to structure in poplar wood. Proceedings of the IUFRO meeting of section 41. Forest Products. Madison, Wisconson.
68. Scaramuzzi, G. and G. Ferrari, 1964. Relation of wood density to wood structure in populus. International Association of wood Anatomists. News Bulletin. 1964/1.
69. Scaramuzzi, G., 1965. The relation of fibre wall thidkness, fibre diameter and percentage of summer wood (late wood) to specific gravity, IUFRO section 41 meeting, Melbourne, Australia. 1-11.
70. Schulz, H., 1957. The proportion of different types of cells in red beech. Holz Roh – u, Werkstoff 15 : 113-118.
71. Sekhar, A.C. and Gulati, 1972. Suitability indices of Indian timbers for industrial and engineering uses. Indian Forest Records. (New Series) Timber Mechanics 2 (1): 92 pp.
72. Sinha, J.N., 1938. A note on Laurel wood. *(Terminalia tomentosa*) and its market in Great Britain. Indian Forester, November: 669-675.
73. Smith, D.M., 1965. Determination of cell diameter and cell wall thickness by analytical method. IUFRO section 41 meeting, Forest Products Proceedings. vol. 1-2, Melbourne, Australia. 1-29.
74. Smith, D.M., 1965. Rapid measurement of tracheid cross-sectional dimensions of Conifers (its application to specific gravity determinations). Forest Prod. J: 325-334.
75. Sono, P., 1974. Merchantable Timbers of Thailand. Forest Products Research Division. Royal Forest Dept. Bangkok. 9., 150 pp.
76. Sosanwo, O. and J.J. Lindberg, 1975. Studies on *Gmelina arborea.* Part II. fiber dimension and some anatomical aspects of Nigerian *Gmelina arborea* wood. Paperija Puu. No. 7. 482-485.
77. Sriburi, T., 1985. Thai reserved timbers. Description of wood of reserved forest species of Siam. Vanasarn 16 (2): 69-72: 17 (2) 31:34 (in Thai).
78. Stauffer, O., 1892. Study of the specific dry weight and the anatomical structure of birch wood. Forest nature. z.1.146:63. orginal paper not seen, cited from Tappi, Monograph No. 24:758, 1962.
79. Stiever, J.E., 1965. Variation in some properties of the turkey oak (*Quercus cerris*). Studies; in quantitativen xylotomy. Drevasky Vyskum. vol. 1,11-23.
80. Taylor, F.W., 1971. Variation in some properties in sugarberry. Forest Prod. Util. Lab. Miss. State University Res. Rep., No.11, 17 pp.
81. Taylor, F.W., and T.E. Wooten, 1973. Wood property variation of Mississippi delta hardwoods. Wood Fibre 5 (1): 2-13.
82. Tonanon, N., 1974. A short introduction for some common timbers of Thailand. Forest Products Research Division, Royal Forest Department. Ministry of Agriculture and cooperative, Bangkok. 9, Thailand, 15 pp.

83. Tsoumis, G., 1964.Microscopic measurement of the amount of cell wall substance in wood and its relationship to specific gravity. Tappi; November, vol. 47, no. 11, 675-677.

84. Wangaard, F.F., 1981.Wood: its structure and properties. vol.1. Clark C. Heritage memorial Series on wood. Material research Laboratory. The Pennsyvania State University. University Park, Pa. 16802. 465 pp.

85. Watson, A.J., 1965. Fiber characteristics and wood properties: Tropical and semitropical hardwoods. IUFRO section 41 meeting, Melbourne, Australia. 1-7.

86. Wedel, K. Von., 1964. Utersuch ungen Eigenchaften, Verwentung and Verwenduny des Ahornholzes. Dissertation zur Erlangurz des Doktorgrades der Forstlichen Fakultat der Geog-August Universitat Zu Gottingen in Hann. Muden. (Original paper not seen).

87. Yacub, M.D. et al., 1972. Strength properties of some Bangladesh timber species. Bulletin (Timber Physics Division) Forest Research Institute, Chittagong, Bangladesh, No. 2, 12 pp.

88. Zeeuw, C. de. and R. L. Gray, 1972. Specific gravity variation in *Gmelina arborea* Roxb. International Association of Wood Anatomist. Bulletin No. 3 : 3-11.