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T 259

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SUBJECT CATEGORY Pulp Properties

RELATED METHODS See "Additional Information"

CAUTION:
This Test Method may include safety precautions which are believed to be appropriate at the time of publication of the method. The intent of these is to alert the user of the method to safety issues related to such use. The user is responsible for determining that the safety precautions are complete and are appropriate to their use of the method, and for ensuring that suitable safety practices have not changed since publication of the method. This method may require the use, disposal, or both, of chemicals which may present serious health hazards to humans. Procedures for the handling of such substances are set forth on Material Safety Data Sheets which must be developed by all manufacturers and importers of potentially hazardous chemicals and maintained by all distributors of potentially hazardous chemicals. Prior to the use of this method, the user must determine whether any of the chemicals to be used or disposed of are potentially hazardous and, if so, must follow strictly the procedures specified by both the manufacturer, as well as local, state, and federal authorities for safe use and disposal of these chemicals.

Species identification of nonwood plant fibers

(Five-year review of Official Method T 259 om-15)

(No changes from previous draft. Standard reaffirmed)

1. Scope

The fibrous elements of the nonwood plant species, which are commonly encountered in papermaking or that are expected to have the potential of being used for this purpose, may be identified on the basis of their morphology as revealed by the microscope. The purpose of this method is to provide some of the details, which are useful in making an identification of an unknown nonwood plant specimen. This method can be used whether a coarse undefibered specimen is present or samples of pulp, paper or other paper products are provided.

2. Apparatus

The only special equipment required for this method is a compound microscope equipped with a calibrated micrometer eyepiece.

3. Significance

To assist an analyst in determining what type of commercially available nonwood fiber is present either in the rough form or present in a pulp, paper or other paper product.

4. Reagents

The majority of the specimens depicted in this method were delignified with an acidified sodium chlorite solution. The required reagents are: 50% acetic acid (CH_3COOH), sodium chlorite ($NaClO_2$), 1.0% NaOH, 0.5*N* HC1, and Graff's C-Stain or Selleger's stain. A second, and more rapid, procedure requires: 1% sodium hydroxide (NaOH) solution and 1% methylene blue solution. The solutions need only be of the approximate strengths indicated. As an additional reference, TAPPI T 401 "Fiber Analysis of Paper and Paperboard" for information on Graff's C-Stain and Selleger's stain. 10% sodium hydroxide (NaOH) solution can be used to defiber specimens of reference fibers.

5. Sample preparation

Caution: Use safe laboratory practices in handling hot chemicals. The sodium chlorite procedure should be handled with extreme care. If the reaction is carried out too rapidly this mixture could react violently. Use of a vented fume hood with sash and a personal protection face shield are necessary.

5.1 A fibrous suspension may be prepared by the acidified sodium chlorite procedure as follows:

5.1.1 Place 1 g of a stalk or coarse specimen in a 170 x 20 mm test tube and wet with 30 mL of H_2O.

5.1.2 Add 5 g of solid $NaClO_2$.

5.1.3 Add 10 mL of 50% CH_3COOH at 60°C and lower test tube into a water bath heated to 60°C.

5.1.4 Lightly swirl the contents, stopper, and allow to react for 1 h.

5.1.5 At the end of 1 h, stir contents with a glass rod and let stand for 24 h at 60°C. The stoppers should be kept in place to prevent the loss of reaction liquor.

5.1.6 At the end of the 24 h period, drain off the reaction liquor, wash the mat three times in distilled water, and shake vigorously to insure uniform fiber separation.

5.1.7 The 24 h reaction period, steps 2 to 6, may have to be repeated as many as three times depending upon the ease of fiber separation of the material.

5.1.8 If the fiber mat was removed for washing, place it back in the test tube. Add 10 mL of 1.0% NaOH, heat to 60°C and hold for 1 h, drain liquor, macerate, and wash pad in water three times.

5.1.9 Treat the fibrous pad with 10 mL of 0.5*N*HCl for 0.5 h at 20°C and wash three times.

5.1.10 Place a few drops of the suspension on a microscope slide, stain in the normal manner with C-Stain or Selleger's stain, cover, and examine. (See TAPPI T 401 for proper staining technique.)

5.2 The rapid hot alkali procedure may alternatively be employed as follows:

5.2.1 A 1 g sample of the specimen pulp or paper is boiled for a few minutes in a 1% NaOH solution.

5.2.2 Wash the sample with water and shake to insure complete separation.

5.2.3 Place a few drops of the fibrous suspension on a microscope slide, stain with a drop of methylene blue, Graff's "C" stain or Selleger's stain solution, cover, and examine.

NOTE 1: The 1941 and 1947 versions of this method contained only the rapid procedure detailed in section 5.2. The more rigorous procedure detailed in 5.1 was added in the 1978 revision of the method. Analysts are referred to Reference 5 and 6 for further information on the use of the stains specified in this method. Depending on the application, analysts may find other stains useful in the identification of fibers.

6. Reference standards

When authentic specimens of commercial fibrous materials are available, it is highly desirable that known fibrous suspensions be prepared for purposes of comparison with tentatively identified samples. A coarse material may be defibered by boiling a small amount of the commercial fiber in 10% NaOH solution for approximately 30 min, followed by washing and vigorous shaking in water. A pulp or paper reference can be defibered and prepared using 5.18 through 5.1.10.

7. Procedure

7.1 A thorough microscopical examination of the fibrous suspension includes an enumeration of the cell types present, their characteristic markings, and a measurement of cell dimensions. The micrographs included in this method have been prepared mostly at the same magnification to facilitate direct comparisons. A tentative identification may be made through the use of the dichotomous key in Table 1. In using the key, select from the pair numbered 1 the description that best fits the material under consideration. If a number is found at the right-hand end of the line, refer next to the pair of descriptions bearing that number and repeat the procedure. By this method of selection, a description will ultimately refer to a species, or group of species, which possesses the required characteristics. Analysts should keep in mind that not all non-woody fibers can be covered in this method. Unknowns will be encountered.

7.2 Reference should next be made to the description, fiber dimensions, and the photomicrographs of this particular species as a further check upon the identification. A final comparison of the unknown with authentic material as previously mentioned should provide conclusive proof as to the identity of the sample.

Table 1. Species identification of nonwood plant fibers; key to nonwood plant papermaking fibers

1.	Fibers long, averaging more than 15 mm in length; complete fibers rarely seen under an ordinary microscope	2
1.	Fibers comparatively short, averaging less than 10 mm in length, complete fibers frequently seen by moving the glass slide about the stage of the microscope	5
	2. Fiber flat, ribbonlike; usually twisted about its longitudinal axis	Cotton
	2. Fiber cylindrical, not twisted; prominent transverse fractures in the cell wall	3
3.	Individual fibers variable in width, up to 80 µm in width at their broadest portions	Ramie
3.	Individual fibers quite uniform in diameter; the broadest fibers not more than 50 µm wide	4
	4. Narrow lumen clearly defined within thick fiber walls; fibers pointed at their ends	Flax
	4. Cell cavity rather obscure but often wider than the fiber wall; fiber ends blunt	Hemp
5.	Fibers isolated or accompanied by occasional cells of other types	6
5.	Vessel segments and parenchyma cells abundant together with fibers	9
	6. Fiber unusually variable in diameter, a central segment averaging about twice as wide as the rest of the fiber	Mitsumata
	6. Diameter of fiber relatively uniform throughout nearly its entire length	7
7.	Fiber lumen irregularly constructed at intervals to an extremely narrow canal	Jute
7.	Fiber lumen uniform in diameter	8
	8. Fiber lumen broad, distinct; cell walls thin to moderately thick	Manila hemp
	8. Fibier lumen narrow; often indistinct; cell walls thick	New Zealand flax
9.	Individual epidermal cells or fragments of epidermal tissue abundant; margins of these cells rather distinctly toothed	10
9.	Epidermal cells infrequent; their margin undulating rather than distinctly toothed	12
	10. Parenchyma cells relatively narrow, none present more than 20.5 µm wide, epidermal cells narrow (less than 14 µm) accompanied by numerous erect trichomas, hooked at their apices	Esparto
	10. Parenchyma cells narrow to barrel-shaped; up to 130 µm in width; epidermal cells usually greater than 14 µm in width occur together with straight trichomes, the latter appressed to the surface of epidermal cells or comparatively spare and erect	11
11.	Trichomes in conspicuous and erect; dermal cells as fattened, spurlike projections; epidermal cells profusely pitted; stomata of the epidermis accompanied by dentate guard cells; fiber diameters 5.1 to 13.6 µm	Rice
11.	Trichomes in conspicuous and erect; epidermal cells rarely pitted; guard cells surrounding the stomata with entire margins; fiber diameters 6.8 to 23.8 µm	Barley, oat, rye, wheat
	12. Fibers relatively long (up to 4.3 mm in length; averaging 2.7 mm) accompanied by thin-walled, ribbon-shaped fibers up to 40 µm in width	Bamboo
	12. Fibers relatively short (up to 2.9 mm in length; broadest fibers not ribbon-shaped (34 µm wide)	13
13.	Vessel segments long (1350 µm); maximum fiber diameter 34 µm, parenchyma cells as long as 850 µm	Sugar Cane
13.	Vessel segments comparatively short (600 µm maximum); maximum fiber diameter 24 µm, parenchyma cells as long as 325 µm	Corn

8. Structure of the plant stem

8.1 Although the pulping process so destroys the original tissue of the plant stem that the individual cells are more or less completely separated and appear as isolated units, a general introduction to the structure of the plant is essential to an understanding of the cell types to be described. The true fiber of the nonwood plant, which is the only cell type contributing in any degree to the strength of the paper, is accompanied by other types of cells which frequently are important aids in identification.

8.2 The plants from which the commercial fibers described herein are obtained may be divided into two general classes according to their botanical characteristics: monocotyledons and dicotyledons. The monocotyledons are the plants having parallel-veined leaves such as the grasses, lilies, and palms. The dicotyledons have net-veined leaves and include such plants as kenaf, hemp, okra, flax, and the common broadleaf trees. The two classes may be separated by an examination of the internal structure of the plant stem.

8.3 The transport of water and food through the plant is accomplished in both monocotyledons and dicotyledons by a system of cells arranged in a long series known as sieve tubes and vessels. The thin walls, frequently modified by openings known as sieve areas and pits, together with the large lumens of these cells, are commonly explained on the basis of their evolutionary adaptation for the conduction of liquids. As though to compensate for these weak conducting cells, they are accompanied by another cell type, the fiber, which contributes strength and rigidity to the plant. Fibers are long, slender cells characterized by relatively thick, infrequently pitted walls and a narrow cell cavity or lumen.

8.4 The arrangement of the conducting or vascular tissue in the plant stem is characteristically different in the monocotyledons and the dicotyledons. In the former group the conducting tissue and the accompanying fibers are arranged in vascular bundles which are generally distributed at random throughout the greater part of the plant stem (Fig. 1). The vascular tissue of the dicotyledons, conversely, are arranged in a definite ring pattern, or frequently an unbroken ring of vascular tissue without distinct bundles may serve for purposes of conduction and mechanical support (Fig. 2). The inner portion of this ring of vascular tissue is the xylem, composed chiefly of xylem fibers and vessels. Just outside of the xylem is a narrow layer of living meristematic cells known as the vascular cambium and beyond this lies the phloem, consisting for the most part of sieve tube elements, parenchyma, and phloem fibers. Surrounding the vascular tissue are successive protective layers known as the pericycle, cortex, and epidermis. The fibers used in papermaking may be vascular bundle fibers from the stem or leaf of the monocotyledons, or, if derived from the dicotyledons, they may be from the phloem, pericycle, cortex, or xylem of the stem. The dicotyledonous phloem fibers are commonly designated as bast fibers.

8.5 The cotton fiber illustrates still another source of commercial fiber. This is the seedhair, a cell that originally was attached to the seed of the plant. In contrast to the structural fibers, which are separated only by disintegration of the plant tissue which they constitute, the seedhairs are individual units in nature.

8.6 The fibers to be described in the ensuing paragraphs may be classified in the following manner:

8.6.1 Structural or stem fibers

8.6.1.1 Vascular bundle fibers - monocotyledons (Gramineae): reed, *arundo donax*; oat, *Avena barbata*; barley, *Hordeum sp.*; rice, *Oryza sp.*; elephant grass, Napier grass, *Pennisetum purpureum*; reed, *Phragmites communis*; rye, *Secale sp.*; Columbum grass, *Sorghum alum*; broomcorn, *Sorghum bicolor*; Piper sudan, *Sorghum sudanense*; esparto, *Stipa tenacissima*; triticale; wheat, *Triticum sp.*; emmer, Russian Wheat, *Triticum dicoccum*; corn, *Zea mays*; bamboo, *Phyllostachys bambusoides*; sugar cane, *Saccharum officinarum.*

8.6.1.2 Bast or bark fibers - dicotyledons: ramie, *Boehmeria nivea* (Urticaceae); hemp, *Cannabis sativa* (Moraceae); Sunn hemp, *Crotalaria juncea* (Fabaceae); cottonstalk, *Gossypium herbeceum* (Malvaceae); kenaf, *Hibiscus cannabinus* (Malvaceae); okra, Hibiscus esculentus (Malvaceae); flax, *Linum usitatissimum* (Linaceae).

8.6.1.3 Seedhair fibers: cotton, *Gossypium sp.* (Malvaceae).

8.6.1.4 Leaf fibers: sisal *Agave sisalina* (Amaryllidaceae); Manila hemp, Abaca, *Musa textilis* (Musaceae).

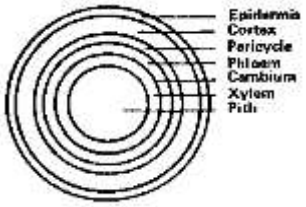

Fig 1. Dicotyledonous stem.

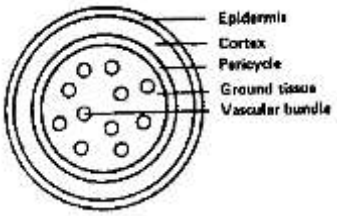

Fig. 2 Monocotyledonous stem.

9. Cell types

9.1 Before proceeding with detailed descriptions of pulp or paper samples from these species, the general features of each type of cell will be outlined.

9.2 Fibers are long, relatively narrow, empty cells with typically thick, usually lignified walls. Most commonly the cell ends are pointed. Pitting is not a characteristic feature of fiber walls, but when present, the pits will appear as simple rounded openings or slits.

9.3 Vessels consist of a series of elements lying end to end to form conducting tubes in the xylem. These cells include large empty cell cavities, and their breadth is greater than that of the fibers. The ends of vessel elements are commonly blunt and, unlike the fiber, the end wall is perforated to permit more ready communication between the individual cells. Vessel walls are usually thin and characteristically marked by numerous pits of various shapes. Annular vessels, which consist of a series of rings, and spiral vessels, the cell wall of which consists of a spiral winding, occur less frequently.

9.4 Parenchyma cells remain alive for a longer period in the plant and consequently retain active protoplasm in the cell cavity. Cells of this type are thin-walled and sparingly pitted; their end walls are complete (not perforated) and more or less right-angled, and their length is often not much greater than their width.

9.5 Epidermal cells are derived from the tissue that forms the outermost layer of the leaf or stem. Their most distinctive feature is a wavy or toothed cell margin. When not completely separated one from another, the cells are clearly shown to interlock. Stomata, openings to provide for the exchange of gases between the plant and the atmosphere, are interspersed over the plant epidermis. Certain cells of the epidermis are variously altered in shape to short spur like projections and even to long tubular hairs. Such cells are known as trichomes, and in as much as the identification of a sample may hinge upon their presence or absence, the necessity for accurate observation and interpretation in microscopic work is apparent.

10. Characteristics of individual species

10.1 *The grasses, Gramineae.* Included in the grass family are sugar cane, the cereal straws, esparto, corn, bamboo, reed, and a number of lesser-known species such as elephant or Napier grass and Columbum grass. Because of the close relationship of these species, a similarity in their cellular elements might be anticipated. The entire stem of these plants, together with the leaves in the case of grasses and straws, is utilized, with a resultant variety of characteristic cell types evident in the pulp. Some of the cells which distinguished this group from others used in the manufacture of paper include: relatively short fibers from the vascular bundle; cells of the ground tissue which are barrel-shaped to narrow-cylindrical; various vessel segments of the annular, spiral, and pitted types; and epidermal cells, either in masses or as individuals, easily recognized because of their more or less irregular margins, especially when characterized by prominent tooth like projections.

10.1.1 *Sugar cane, saccharum officinarum* (Figs. 3, 4, 5, and 6). The vascular bundle fibers of this species vary in cell wall diameter and are with pointed ends (Figs. 4 and 5). Except for occasional small pits, there are no characteristic wall markings. Furthermore, thin-walled, short, fiber like cells with oblique, blunt, or even forked ends may be present. Cells of the parenchyma type, ranging up to 850 μm long, and 140 μm wide, and individual vessel elements as long as 1350 μm and as wide as 150 μm are distinctive due to their large size (Fig. 4). Narrow, rectangular, epidermal cells with slightly undulating margins are present in whole, unfractionated stem material (Fig. 3) but only sparingly present in depithed material. The guard cells accompanying the stomata are smooth walled.

10.1.2 *Cereal straws:* barley, *Hordeum sp.* (Fig. 7); oat, *Avena barbata* (Fig. 8); rye, *Secale sp.* (Fig. 9); wheat, *Triticum sp.* (Fig. 10); triticale, *Triticale sp.* (Fig. 11); emmer, *Triticum dicoccum* (Fig. 12). The fibers of these

cereal straws are somewhat longer and wider than those obtained from esparto. The fiber lumen may be narrow or broad, and the fiber ends are pointed. Cells of the ground tissue, barrel-shaped and cylindrical (Figs. 8, 11, and 12), varying up to 450 μm in length and 130 μm in diameter are abundant. Vessel elements, also, are extremely variable in size, ranging up to 100 μm by 60 μm, but fall considerably short of the maximum diameter attained in corn and sugar cane. Sparsely pitted epidermal cells are frequent and variable. Their margins are characteristically marked with prominent teeth (Figs. 8, 10, and 12), but often these are reduced to exhibit a slightly undulating surface. Epidermal cells vary from 36 to 445 μm in length and from 10 to 41 μm in width on the surface. The guard cells surrounding the stomata are smooth-walled. Although inconspicuous erect trichomes may be present, their occurrence is far less frequent than in esparto or rice.

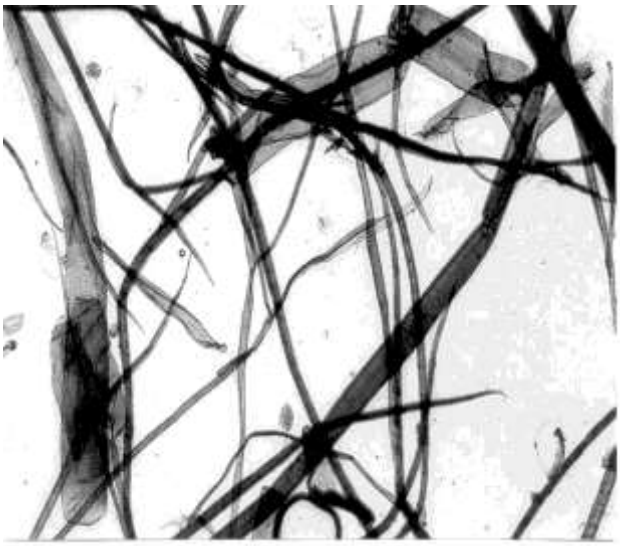

Fig. 3. Sugar cane, whole stem, 100x (*Saccharum officinarum*).

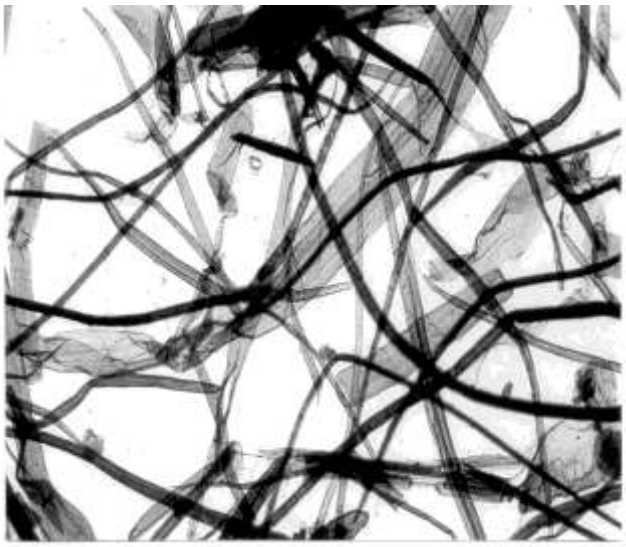

Fig. 4. Sugar cane bagasse, whole, 100x (*Saccharum officinarum*).

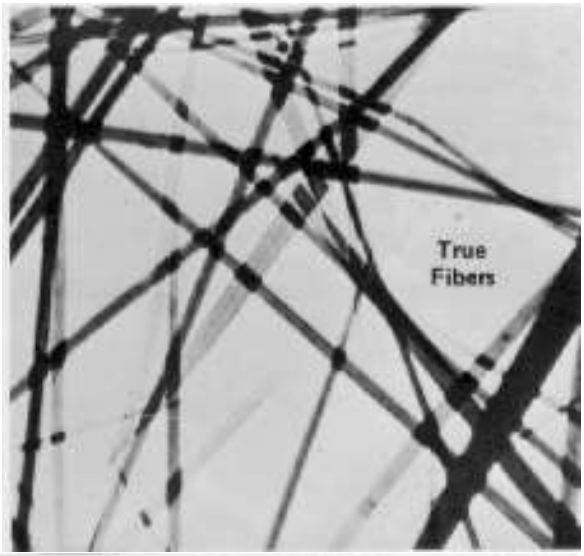

Fig. 5. Sugar cane bagasse, completely depithed, 100x (*Saccharum officinarum*)

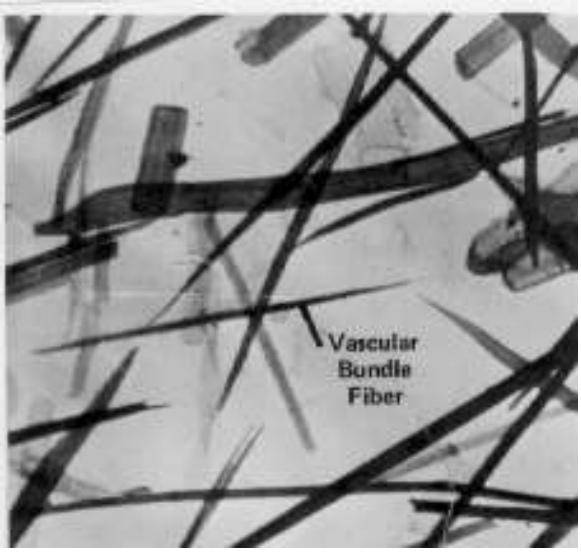

Fig. 6. Sugar cane bagasse, partially depithed, 100x (*Saccharum officinarum*)

10.1.3 *Rice, Oryza sp.* (Fig. 13). Rice straw resembles esparto in the cell types which are present but differs from the preceding species chiefly in size of the elements. The fibers of rice are slightly more slender than those of esparto grass, but their length is greater. Appearing among the larger (10.2 to 20.5 μm wide), heavily pitted epidermal cells (Fig. 13), are prominent appressed trichomes of about the same size as those of esparto. These cells may be distinguished from the trichomes of esparto by their straight tips. The stomata are surrounded by distinctive conspicuously dentate guard cells. Barrel-shaped parenchyma, characteristic of all the grass species except esparto, are accompanied by cylindrical cells of like type and range up to 350 μm long and a maximum of 82 μm wide (Fig. 13). The long, slender vessel segments reach a maximum size of 650 μm by 40 μm .

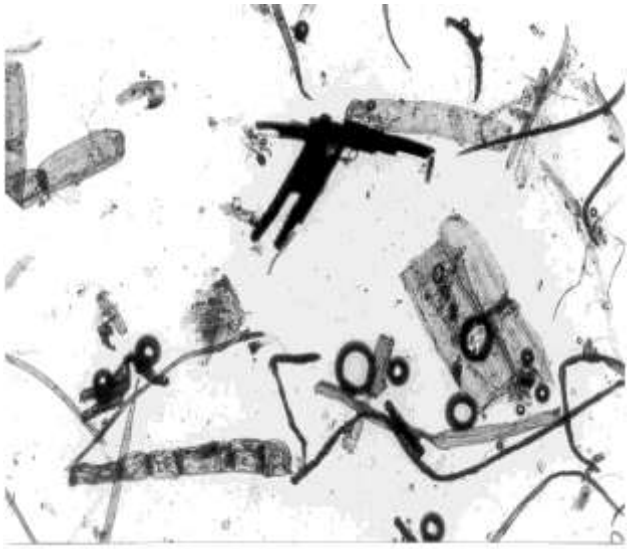

Fig 7 Barley straw, 100x (*Hordeum sp*.).

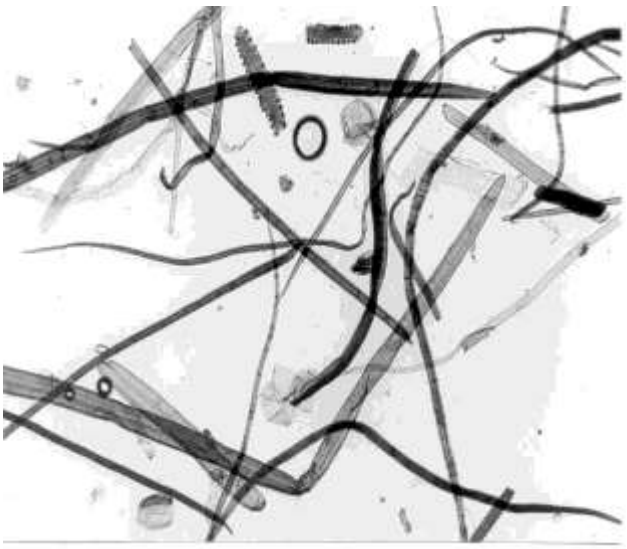

Fig. 8 Oat straw, 100x (*Averna barbata*).

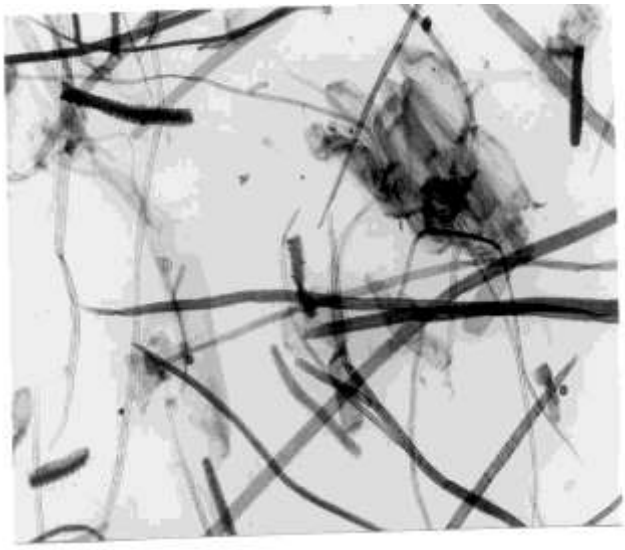

Fig. 9 Rye straw, 100x (*Secale sp*.)

Fig. 10 Wheat straw, 40X (*Triticum sp*.)

10.1.4 *Esparto, Stipa tenacissima* (Fig. 14). The distinctive feature which characterizes this species lies in the presence of abundant pear-shaped trichomes, hooked at the apex (Fig. 14). These may be observed as isolated cells or interspersed among small, sharp-toothed epidermal cells (Fig. 14) which vary in surface width from 6.8 to 13.6 μm and display numerous round pits. The trichomes are about 17 μm wide and from 30 to 50 μm long. The fibers of this grass species are short, thick- or thin-walled, and pointed at the ends (Fig. 14). Parenchyma cells and vessel elements are small, the former ranging up to 350 μm long and 20.5 μm wide, while the latter attained the same maximum width. The guard cells that surround the stomata are smooth-walled.

10.1.5 *Corn, Zea mays* (Fig. 15). Corn and sugar cane are comprised of similar cellular elements but differ in the size of these elements. The corn fibers (Fig. 15) are shorter and more slender; parenchyma cells are shorter, varying up to 325 μm in length and 150 μm in width; the vessel elements (Fig. 15) are shorter, attaining a maximum length and width of 600 μm and 150 μm , respectively.

10.1.6 *Bamboo,* (Fig. 16). The typical fibers are accompanied by very wide, thin-walled fibers (Fig. 16). Measurement of the dimensions of the parenchyma cells serves to separate bamboo from either of the two preceeding species in as much as these cells seldom exceed 250 μm in length or 65 μm in diameter. Bamboo resembles sugar cane except for the frequent occurrence of irregular compressed areas and spiral and transverse checks in the fiber walls. Vessel elements are somewhat smaller than those of sugar cane or corn, attaining a maximum width of about 100 μm.

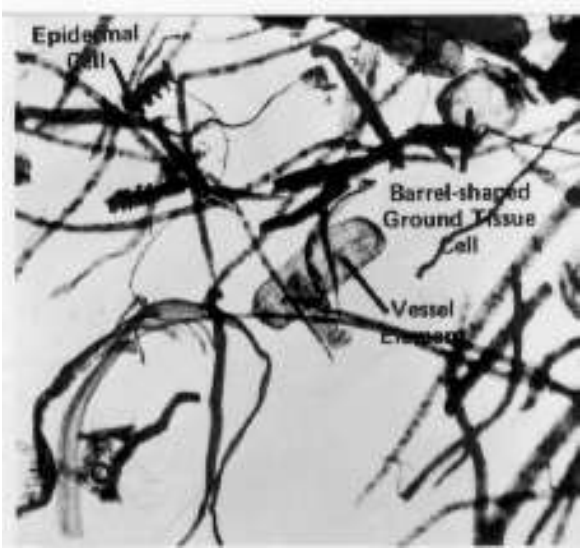

Fig. 11. Tritical (wheat-rye hybrid); 100x (*Triticale sp*.).

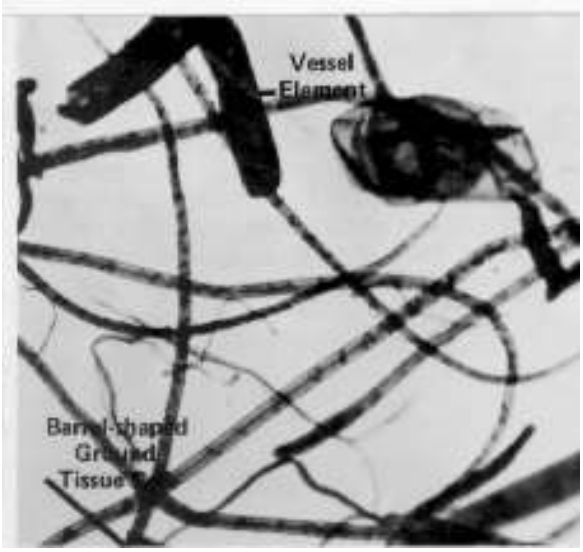

Fig. 12. Emmer, Russian wheat, 100x (*Triticum dicoccum*).

Fig. 13 Rice straw, 40X ~~100x~~ (*Oryza sp*.).

Fig. 14. Esparto, 40X ~~100x~~ (*Stipa tenascissima*).

10.1.7 *Reeds, Arundo donax* (Fig. 17) and *Phragmites communis* (Fig. 18). The principal cellular constituent of the reeds is the long, slender, and pointed true fibers which range from 1.5 to 3.0 mm in length (Figs. 17 and 18). Occasional large diameter vessel elements, 80 to 150 µm, may also be present. The fibers may be distinguished by their elongated tapered ends and lumen-to-cell wall ratio, which may average approximately 1:2.

10.1.8 *Grasses*, elephant grass or Napier grass, *Pennisetum purpureum* (Fig. 19). A wide assortment of fibers, vessel elements, parenchyma cells and epidermal cells may be found in Fig. 19. Areas of nodal thickening and darkening may be observed on the fibers, which tend to give them a segmented appearance.

10.1.9 *Sorghums*, Columbum grass, *Sorghum almum* (Fig. 20), broomcorn, *Sorghum bicolor* (Fig. 21), Piper sudan, *Sorghum sudanense*. Lateral striations may be observed on the fiber cell wa**ll, w**hich tend to be discontinuous and hence do not completely encircle the fiber. The vessel elements appear to be highly perforated and of intermediate sizes, 60 to 100 μm by 0.4 to 0.9 mm. Individual epidermal cells may average 0.1 to 0.2 mm in length.

Fig. 15. Corn, 100x (*Zea mays*).

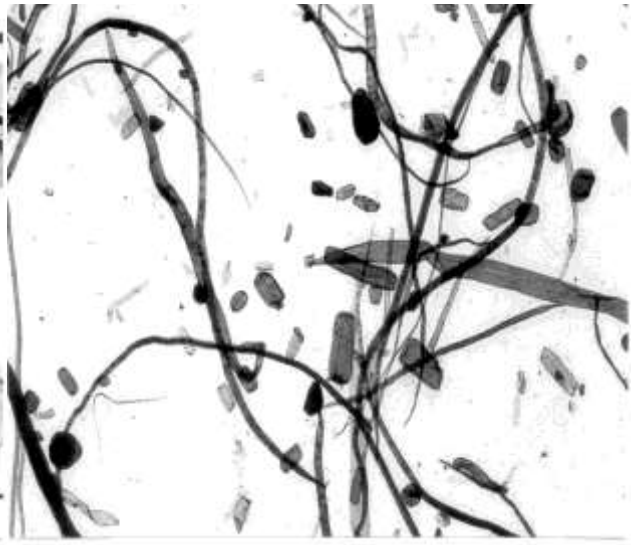

Fig. 16. Bamboo, 100x.

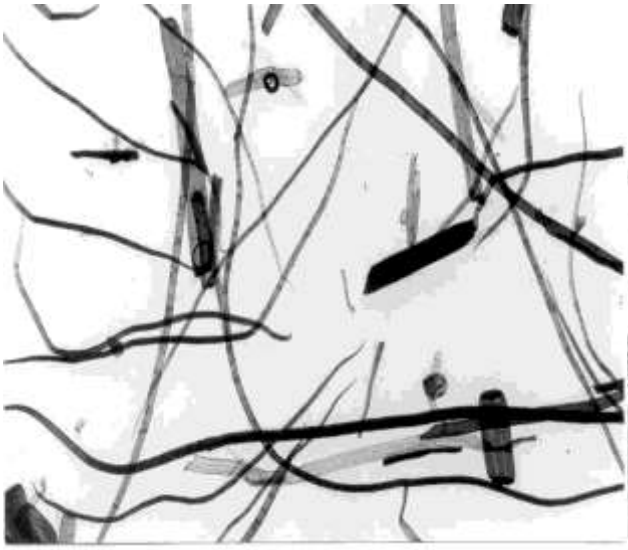

Fig. 17. Reed, 100x (*Arundo donax*).

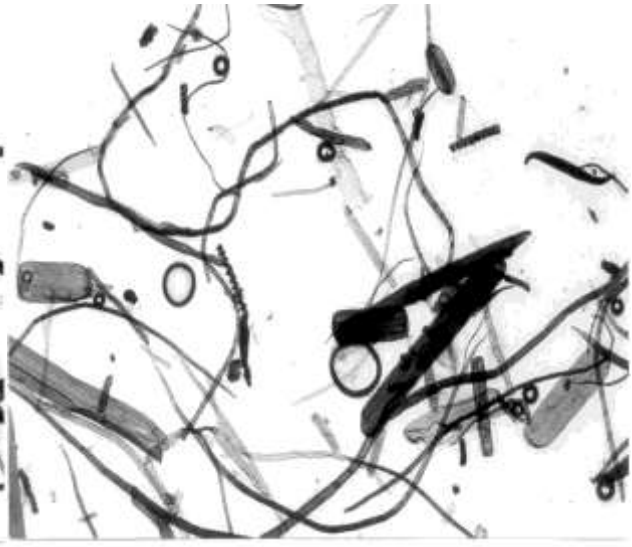

Fig. 18. Reed, 100x (*Phragmites communis*).

10.2 *Bast or bark fibers, dicotyledons*

10.2.1 *Ramie, Boehmeria nivea* (Fig. 22). Only one cell type, the pericycle fiber, is encountered in commercial ramie. Outstanding among the characteristics of these fibers is their comparatively large size which averages 120 mm in length and 50 μm in width. These dimensions of length and width are generally sufficient for the

purpose of identification. The diameter of a single fiber is quite variable throughout its length, ranging from sections that are flat and broad to others which are narrow and heavily walled. The ramie fiber tapers to a comparatively narrow, rounded tip. Prominent transverse fissures of irregular nature or faint longitudinal or spiral striations usually mark the cell walls.

10.2.2 *Hemp, Cannabis sativa* (Fig. 23). The pericyclic fibers of hemp have generally been isolated from their parent material before reaching the stage of pulp and papermaking; rope is one of the most common forms in which hemp is received from processing into paper. The long hemp fiber, averaging 20 mm, (Fig. 23) is also moderately wide, averaging 22 μm, this characteristic extending to the rounded extremities. In width the lumen is equal to or greater than the thickness of the cell wall, which is distinguished by longitudinal striations and transverse fractures. The latter are variable, appearing either as compressed areas or as cracks in the cell wall. Although similar to the linen fiber in size and markings, hemp may be distinguished on the basis of its wider cell cavities and the rounded ends of the fiber.

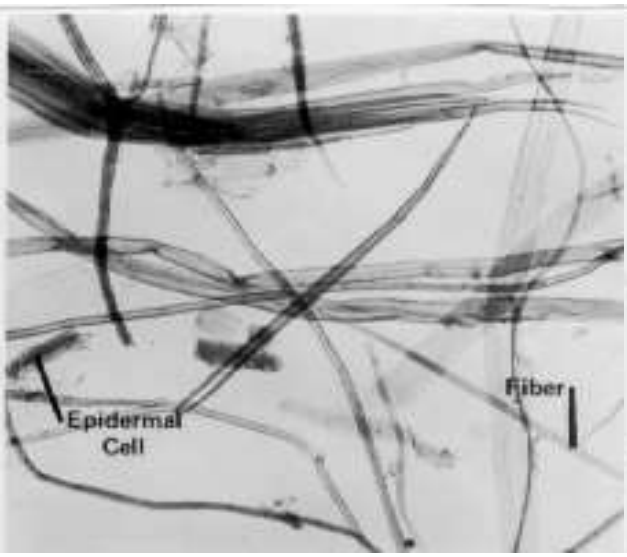

Fig. 19. Elephant grass, Napier grass, 100x (*Pennisetum purpureum*).

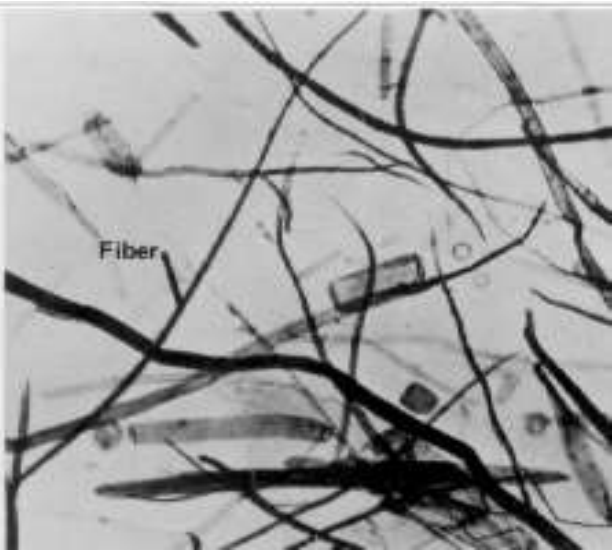

Fig. 20. Columbum grass, 100x (*Sorghum almum*).

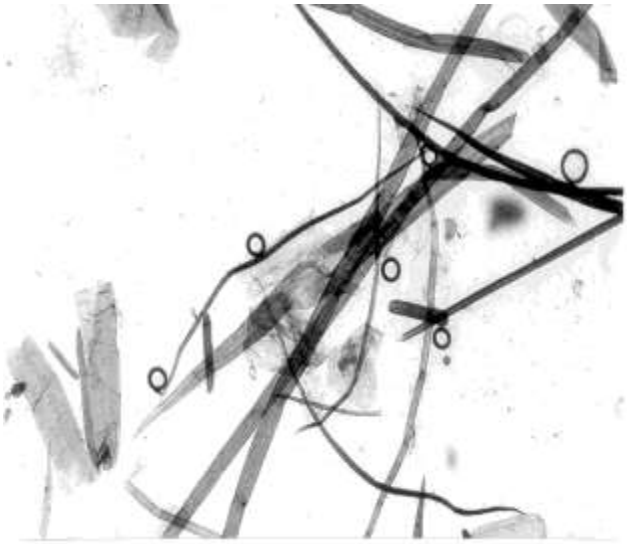

Fig. 21. Broomcorn, 100x (*Sorghum bicolor*).

10.2.3 *Flax, Linum usitatissimum* (Fig. 24). Linen fiber, which is derived from the pericycle of the flax plant, i**s** isolated from all other tissues of the plant in the decorticating process employed in its preparation. The ends of the nearly cylindrical, long fibers are pointed (Fig. 24). The cell walls are uniformly thick, enclosing a narrow lumen (Fig. 24) which at times is apparent only as a dark line. Transverse cracks or failures, and less frequently node-like swellings, characterize the cell walls of the species. Flax tow, which is more often used in the manufacture of paper, is distinguished from linen by the presence, in addition to the fibers already described, of fiber cells with broad cavities, together with epidermal cells and small vessels (Fig. 24).

Fig. 22. Ramie, 100x (*Boehmeria nivea*).

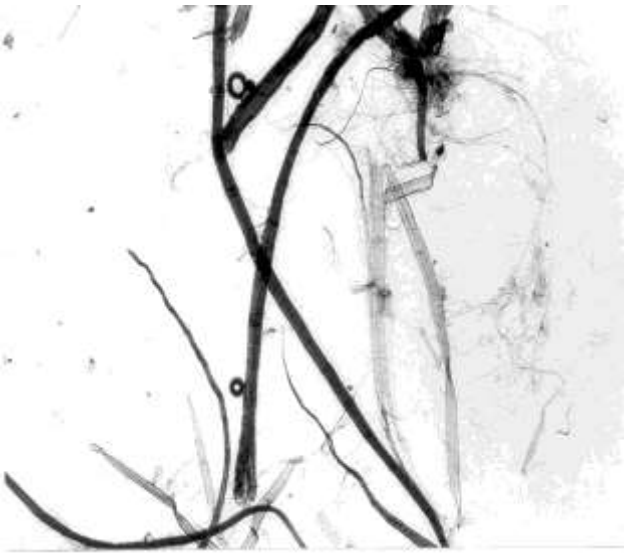

Fig. 23. Hemp, 100x (*Cannabis sativa*).

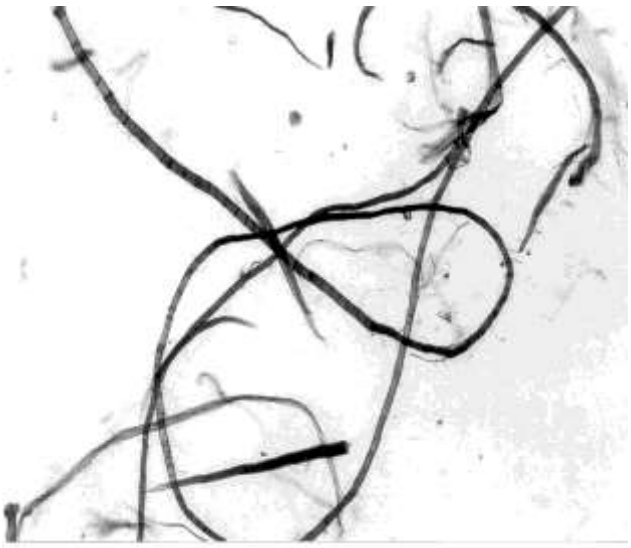

Fig. 24. Flax, 100x (*Linum usitatissimum*).

10.2.4 *Cotton stalk, Gossypium herbaceum* (Fig. 25). The bast fiber of the cotton stalk may be characterized by its extreme length; even the shortest of the entire bast fibers will average approximately 10 mm in length while the mean length may be closer to 25 mm. The seed hair of cotton (not depicted) differs from other fibers discussed, as the fiber is always torn at the basal end and rounded at the other extremity. In shape, the fiber is a long, flat, ribbon like cell, which is more or less twisted. At these points where the wall thickness is the greatest, the twisting of the fiber is less pronounced. Longitudinal and spiral striations in the cell wall are also common.

10.2.5 *Sunn hemp, Crotolaria juncea* (Fig. 26). Sunn hemp bast fibers may be observed to have lateral striations occurring at frequent intervals along the fiber. The spacing of the striations may be as often as every 20 to 40 μm. A slightly raised nodular area may also be seen in the region of the lateral striations. These lateral markings may be analogized to continuous stipule scars encircling a twig. The long narrow bast elements range in diameter form 10 to 20 μm.

10.2.6 *Kenaf, Hibiscus cannabinus* (Figs. 27-29). Kenaf bast fibers resemble those of Sunn hemp in that both contain the lateral striations (Fig. 28). The kenaf woody fibers (Figs. 27 and 29) retain the normal elongated ends and average 0.5 to 0.7 mm in length and 15 to 25 μm in width. Associated vessel elements and parenchyma cells may be observed in the unfractionated or woody core material.

10.2.7 *Okra, Hibicus esculentus* (Fig. 30) Bast fibers of okra may be narrow walled, having a lumen-to-cell ratio of perhaps 2:1. The highly perforated vessel elements may be observed to vary in length from 0.3 to 0.8 mm and in width from 50 to 170 μm. The bast fibers are generally smooth walled and free of any nodular projections or surface striations.

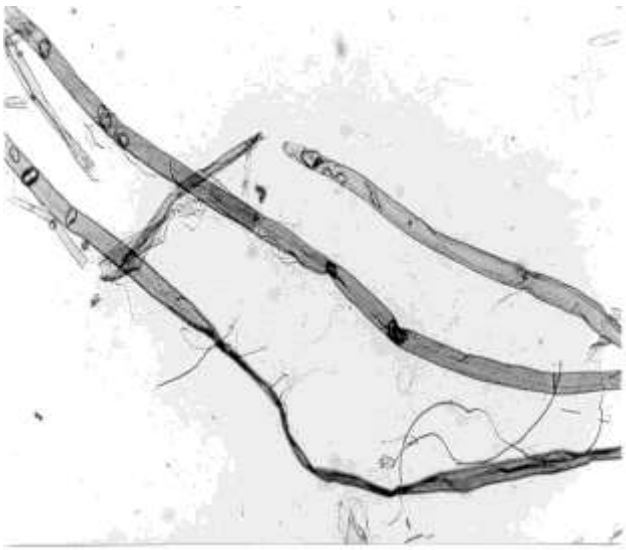

Fig. 25. Cotton stalk, 100x (*Gossypium herbaceum*).

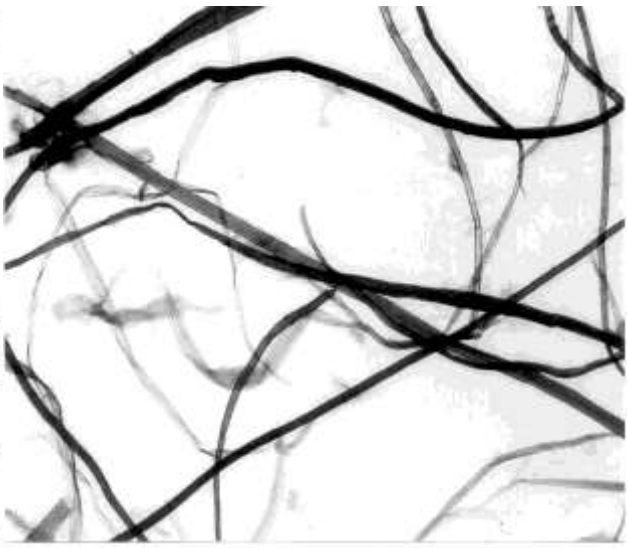

Fig. 26 Sunn hemp, 100x (*Crotalaria juncea*).

Fig. 27. Kenaf, unfractionated, 100x (*Hibiscus cannabinus*).

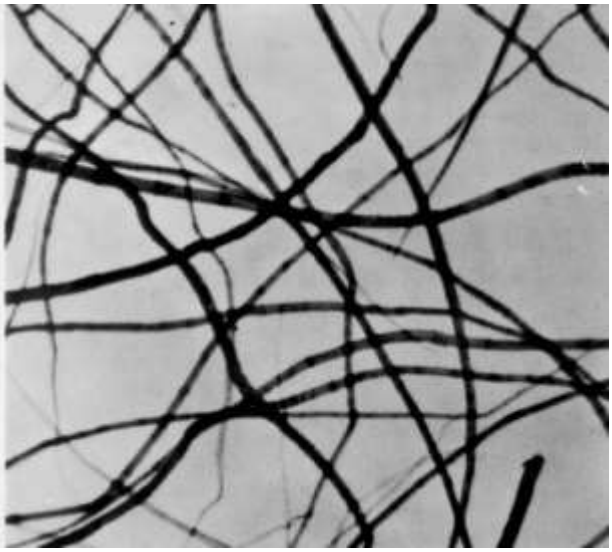

Fig. 28 Kenaf ~~Kanaf~~, bast fiber, 100x (*Hibuscus cannabinus*).

10.3 *Leaf fibers*

10.3.1 *Sisal, Agave sisalina* (Fig. 31). The terminal portion of the sisal leaf fiber is finely tapered and sharply pointed. The fiber is also comparatively slender, averaging 8 to 12 μm in width. The conspicuous absence of other cell types may be used as an aid in identifying sisal.

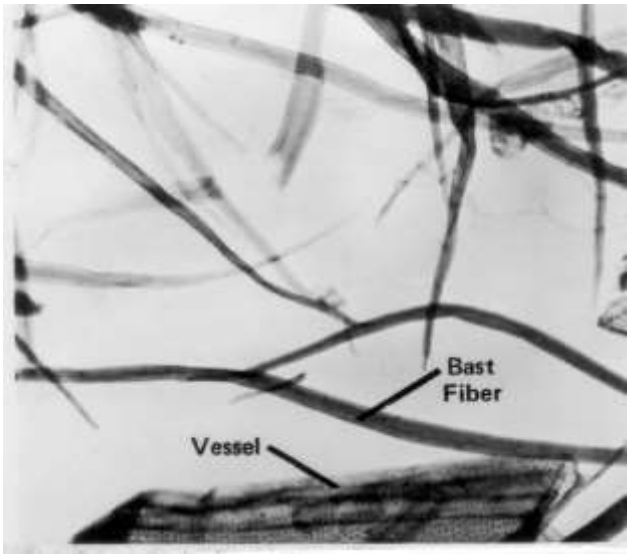

Fig. 29 Kenaf, wood core, 100x (*Hibiscus cannabinus*).

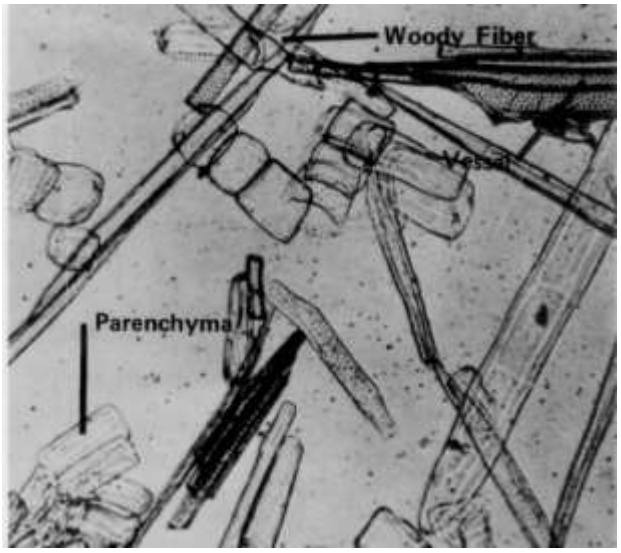

Fig. 30 Okra, 100x (*Hibiscus esculentus*).

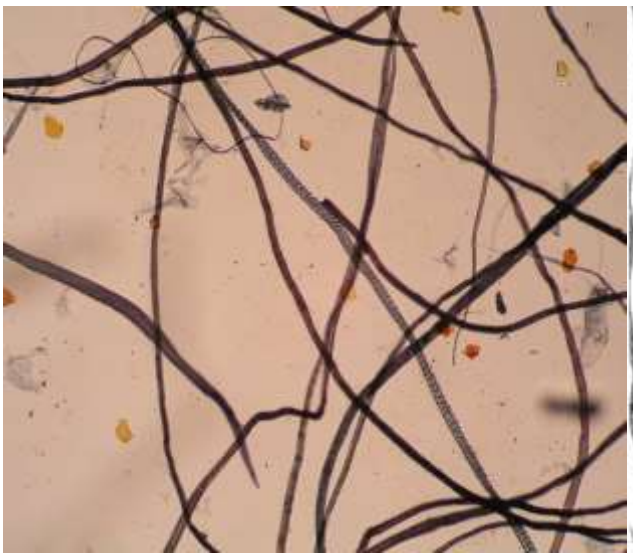

Fig. 31 Sisal, 100x (*Agave sisalina*).

Fig. 32 Manila hemp, 100x (*Musa texilis*).

10.3.2 *Manila hemp, Abaca, Musa textilis* (Fig. 32). Abaca leaf fiber is similar in appearance to sisal although it tends to be somewhat larger in diameter ranging from 10 to 20 μm. As with sisal, other cellular types are absent.

11. Report

List the type of fiber (seed hair, leaf stem, bast, or grass) and if possible the species.

12. Precision

12.1 Identification of nonwood fibers can be difficult and it is best to have reference samples for comparison.

12.2 Since the result of the test is qualitative, the accuracy and precision of this method is contingent on the knowledge and experience of the analyst.

13. Keywords

Reeds, Corn, Bamboo, Grasses, Hemp, Ramie, Flax, Cotton, Sunn hemp, Nonwood fibers, Nonwood plants, Sugar cane, Bagasse, Barley straw, Kenaf, Sisal, Oat straw, Rye straw, Manila hemp, Okra, Straw, Wheat straw, Rice straw, Identification, Species identification, Fiber, Plant fiber

14. Additional information

14.1 Effective date of issue: To be assigned.

14.2 Changes in the 2015 version included editorial changes and reclassifying from Standard Practice to Official Method.

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6. Graff, J. H., *A Color Atlas for Fiber Identification*, Institute of Paper Chemistry, Appleton, WI, 1940.

Your comments and suggestions on this procedure are earnestly requested and should be sent to the TAPPI Standards Department. ■