Studies on anatomical and chemical characteristics of some Non-wood fibrous plants for pulp and paper making

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ABSTRACT

Paper making fibres from woody sources can be successfully supplemented by fibres from non-wood species. At present, available supplies of such fibrous materials are limited upto cereal grain straws. sugercane bagasse and bamboo, which are inadequate to meet the increasing demand for more fibre screening and development research offer prospects of finding annually replenishable non-wood plant species that have potential use by the pulp & paper making industry In a continuing search for new fibre producing non-woody, plants. a scheme was devised to evaluate their suitability as a potential source of pulp & paper making fiber. The present studies are centred on Sesbania sesban, Sesbania aculeata and Cajanus cajan non-woody plants. Included in the evaluation of these plants are their anatomical characteristics. chemical composition. dimensional measurements and yield of fibrous constituents alongwith a qualitative physical and visual appraisal. The results of these investigations indicate that these non-wood fibrous species have a greatest promise as supplement sources of useful fibrous species and also have good opportunities for industrial acceptance in India.

Introduction :

Sociologic, technologic and economic progress of the world has been so closely associated with the production of paper that we must continually search for new sou ces of fibres with which to meet the increasing needs for that commodity. Historically, agricultural fibers were the first source of raw material for paper making. The paper industry is almost exclusively dependent on the vegetable kingdom for its raw material. Currently, most papermaking fiibres are derived from wood (1) and non-wood fibers accounts for only very–very little tonnage of the world paper production. Already, many areas of the world are deficient in the forest resources required to provide pulp wood for a rapidly expanding economy. Fortunately, cellulosic fibers represent a major structural component of most plants, consequently, non–wood species represent a huge reservoir of undeveloped raw materials. Limited availability or complete absence of indigenous pulp woods justifies resorting to these non–wood species as sources for pulp and paper–making. Many countries already rely on renewable sources of cellulosic fibres e.g , cereal straws, sugarcane bagasse, bamboos, esparto grass and others that might be produced within a given region. However even the quantity of a single species of a non–wood plant may not be adequate to meet all needs Such a situation exists in India. where stands of bamboo are insufficient to meet the increasing demands for pulp and paper products. We further need other potential sources of non–wood fibrous materials to bridge the gap between demand and supply to some–what extent. The disparity between pulp & paper production and population indicates that could be well corrected by the use of supplementary fibers, from non–wood plants.

Pulp and Paper can be made from many different plants, but whether or not a plant is well suited for this purpose depends largely on the shape of its cells. Cells are hollow structural units that compose plants, each cell consisting typically of a cell wall enclosing a cavity. In early stages of growth the cell cavities contain protoplasm, but soon after the cell wall is fully formed, this disappears from the cells that are of value for paper making, leaving only the hollow tubular or quill–shaped type of structure known as fibre. All plant fibre cells have a primary wall and secondary wall

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layers. The outer most secondary layer is S_1, which is followed ontogenetically by S_2 and S_3. Bamboo fibres tend to have five or more secondary wall layers. The primary (P) wall and S_1, S_2, S_3 layers mainly contain cellulose, Hemicellulose and lignin. The cellulose, hemicellulose and lignin may be distributed in different layer of wood fibre cells as :

Table—1

General cell wall chemical composition of coniferous fibres

Wall designation	Approximate chemical composition,%		
	Cellulose	Hemicellulose and pectins.	Lignin
P	10	20	70
S_1	35	25	40
S_2	55	30	15
S_3	55	40	5
Middle lamella (exist between the P walls of contiguous fibres)	0	10	90

Substances such as pectic materials, waxes, fats, starches, resin gums, organic crystals and other extractives, and proteins are usually not regular components of the space or unit volumes of fibres but exist in specific location. Except for the proteins and certain of the extractives, they are typically found only in the fibre lumens or on the fibre surface.

The bamboo fibres are uaiformly thick to thin walled, with gradually tapering pointed ends, smooth walls, narrow to wide lumen and very sparse slit like pits. They are often bent, curved or folded and invariably show compressed, somewhat buckled areas with transverse markings, which stand out rather prominently in thick walled fibres. The parenchyma cells are fairly abundant. They are squarish to rectangular in shape. Vessel elements with numerous pits are usually present. They may be short and discoid or barrel shaped or long and cylindrical with truncated or tailed ends and simple or scalariform perforation.

Bagasse fibres are thick to thin-walled, usually with straight, pointed ends and relatively more numerous slit like or lenticular pits than in bamboo. Transverse markings similar to those of bamboo are quite common. Parenchyma cells are very abundant usually appreciably larger than those of bamboo. Vessels are similar to bamboo·

Searching for possible new crops of nonwoody plant material involves the examination of a large number of plant samples. To check the suitability of a particular raw material in question for pulp and paper making, the initial tests involves consideration of anatomical characteristics, chemical composition, yield of fibrous constituents, and a qualitative, physical, visual, appraisal of the plants. Considerable amount of work have been done to study the effect of anatomical characteristics and chemical properties of wood fibres on the nature and quality of pulp. The combined effect of physical characteristics of the raw material thus determine the ultimate properties of the pulp and paper as follows :

Table—2

Strength table for morphological factors.

Sl. No.	Trend	Tensile and bursting strengths	Tearing strength	Folding strength	Sheet density
1.	Fibre length rising)	0 to +	+ +	0 to +	0 to —
2.	Cell wall chickness) rising Late (summer) wood fraction (Tube structure)	—	0 to +	—	—
3.	Cellwall thickness early) (spring) wood fraction) rising ribbon structure.)	+	0 to —	++	++
4.	Fibre length to width) rising (L/D) ratio)			+	
5.	Curling of fibres) rising	— —	+	+	—

0 no influence or no distinct influence.
+ marked positive influence
+ + decisive positive influence
— marked negative influence.
— — decisive negative influence.

Effect of chemical composition :

The chemical composition of non-wood plants varies somewhat but an average non-wood plant contains around 40% cellulose, 20-25% lignin, a few percent of so called extractives and the rest made up of a mixture of polymer, non-glucose carbohydrates, so called hemicellulose.

Water solubility provides a measure of tannins, gums sugars, colouring matter and starches in wood and pulp. The water solubles effect the pulp yield to some extent.

The one percent sodium hydroxide solubility of wood could indicate the degree of fungus decay or degradation by heat, and light, etc. As the wood decays or degrades the percentage of the alkali soluble material increases. It is often desirable to ascertain to what extent a low cellulose value is due to attack by fungi, because, in general, the greater such attack the lower the yield.

Alcohol- benzene solubility of wood is a measure of such substances as waxes, fats, resins, gums and phytosterols. The extractives influence both the pulping process and the quality of the resulting pulp. Extractives show up as deposits on critical machinery in the pulp mill and even more so in the paper mill. High content of extractives means a higher tendency for so called pitch troubles and also for inhomogeneities in the paper caused by resin particles. The resin, when they are present in relatively large quantities and distributed over the fibre surfaces, will make them hydrophobic. This means that paper made from such fibres show a slow water absorbance.

The percentage of lignin in the wood is reflected in the time required for chemical pulping, the higher the lignin content the longer the cooking time. The residual lignin present in the pulp influences paper properties and particularly so the stiffness, the more the lignin the higher the stiffness.

In chemical pulping, the cellulose is the main component to survive the cook and variations in the cellulose content of the wood is therefore directly reflected in variations in pulp yield. This is not only of the greatest importance for the economy in pulp production but the yield level is also reflected strongly in the properties, the higher the cellulose content of the pulp the higher the load bearing capacity of the individual fibres in the pulp.

Hemicelluloses are composed of hexosans (e. g. glucose) and pentosans (e. g. xylose) respectively. The hemicellulose has a much lower molecular weight than the cellulose and is also amorphous in nature. It will consequently to a large extent be dissolved during chemical pulpiug. However, the fairly low quantities of hemicellulose left in the pulp will have a great influence on quality, particularly on the swelling behaviour of the fibres. The higher the hemicellulose content the more rapid the swelling during, beating, which favourably influences the beatability of the pulp and also results in somewhat higher tensile breaking load in the paper. The ash content gives an estimation of the content of mineral salts and other inorganic, matters. It may be a useful guide to judge the quality of pulp while the presence of certain elements in the ash may be of special significance. Silica impairs the burning and sedimentations in the recovery process. When the wood contains large quantities of silica, it may show damaging effect on the processability of the wood or on the paper quality. The wood must be rejected on account of this or it must be sufficiently well cleaned before use.

It should be pointed out that it is extremely difficult, to separate the influence of one factor from that of another, because of the complexity of the pulping process. In all commercial pulping process, delignification, hemicellulose dissolution, cellulose depolymerisation and fiber attack, take place simultaneously. It is impossible to eliminate anyone of these effects completely, it is only possible to some extent to vary their respective intensity.

In the present investigations, the anatomical studies of (i) Sesbania sesban, (ii) Sesbania aculeata and (iii) Cajanus cajan have been done. The aim of the present study is to assess the suitability of these non-wood fibers plants for pulp and papermaking and to know the effect of fiber dimensions on the formation and structure of paper.

Experimental Procedures

Sampling and Proximate Chemical Analysis of Plant Materials :

The plant samples were collected from the nearby region of Saharanpur. On receipt at the laboratory, these samples were further air dried, and then stored in a dry location until removed for analysis. Samples for chemical analysis and measurement of cellular dimensions were obtained by random selection of about 1 kg. of whole plant stalk excluding seeds, leaves and roots. For chemical analysis, the stalks of S. sesban, S. aculeata and C. cajan were chipped. The chips were air dried and disintegrated in a Weverk laboratory disintegrator.

The-40+60 mesh wood meals were collected for chemical analysis. The proximate chemical analysis viz., cold and hot water solubility, 1% sodium hydroxide solubility, alcohol-benzene solubility (1:2V/V), lignin, pentosan, holocellulose, alpha, beta and gamma cellulose, Ash, Silica, Acetyl content and methoxyl content have been performed, to check the suitability of non-wood fibrous raw materials in question and the results of proximate chemical analysis are reported in table—3, alongwith the results of proximate chemical analysis of bamboo and bagasse reported in literature.

Maceration and cellular elements measurement :

Transverse sections (T.S.) and Longitudinal sections (L.S.) of 20 to 30 μ thickness of these non-wood fibrous plants were cut on Lietz base sladge microtome 1300. For morphological study the samples were subjected to a chemical physical maceration to separate the individual cellular elements from each other without damage. It involves the use of a hot aqueous acetic acid, sodium chlorite solution to remove most of the lignin and other binding materials without appreciable degradation of the cellulosic tissues. The microscope slides of cellular material were prepared according to IS standard method 5285-1969. Microscope slides were projected at a magnification of 40 × and the fibres length were measured, while the fiber width and cell wall thickness were obtained by measuring the projected images at a magnification of 160 X.

The photomicrographs numbers (1-9) represent the L. S. and T. S. sections of these non-wood fibrous plants. The frequency percentage curves of fibre length fibre diameter, lumen diameter and cell wall thickness are represented in figures 1 to 5 respectively. The values of density, fibre length, fibre diameter, cell wall thickness and different ratios of the above variables are reported in table—4.

Table—3

Proximate Chemical Analysis of S. sesban, S. aculeata, C. cajan, Bagasse and Bamboo.

Sl. No.	Particulars	S. sesban %	S. aculeata %	C. Cajan %	Bagasse[61] %	Bamboo[17] %
1.	Cold water solubility.	2.37	2.64	3.42	5.91	7.6
2.	Hot water solubility	6.30	3.32	5.10	7.85	8.5
3.	Alcohol-Benzene solubility (1:2 V/V)	4.45	3.28	4.14	6.30	3.4
4.	1% sodium hydroxide solubility.	24.70	22.40	19.66	33.6	26.8
5.	Lignin	17.65	20.79	19.72	20.3	24.3
6.	Pentosan	19.0	17.56	15.97	23.86	18 3
7.	Holocellulose	73.23	74.85	71.86	70.6	71.5
8.	Hemicellulose	27.80	26.40	25.24	28.45	27.6
9.	Alpha cellulose	45.24	48.0	46.31	42.0	43.5
10.	Beta cellulose	11.12	12.75	11.56	—	13.4
11.	Gama cellulose	16.42	13.40	13.50	—	14.0
12.	Ash	1.40	1.78	1.72	3.8	2.1
13.	Silica	0.38	0.50	0.56	2.1	1.4
14.	Acetyl content	2.61	2.40	2.18	—	2.50
15.	Methoxyl content	3.70	4.17	3.35	—	3.10

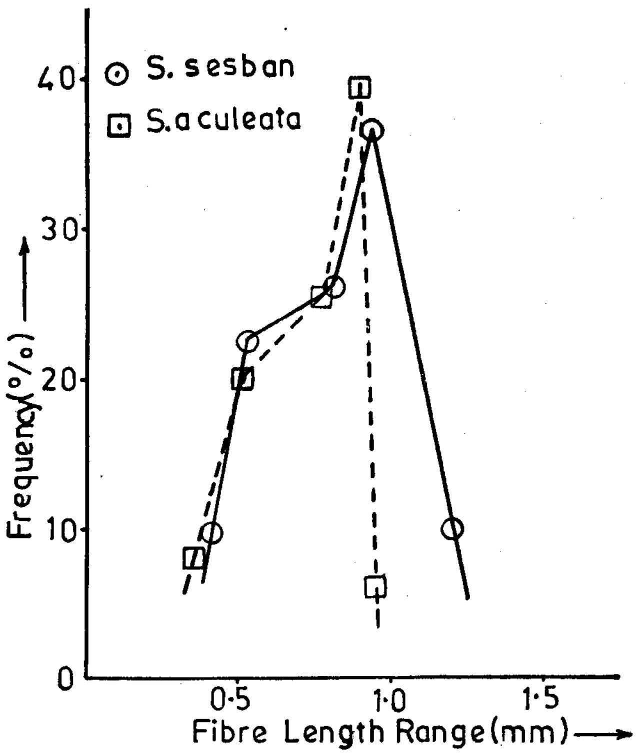


Fig-1: Plots Of Fibre Length Range(mm) VS Frequency(%) For S.sesban and S.aculeata.

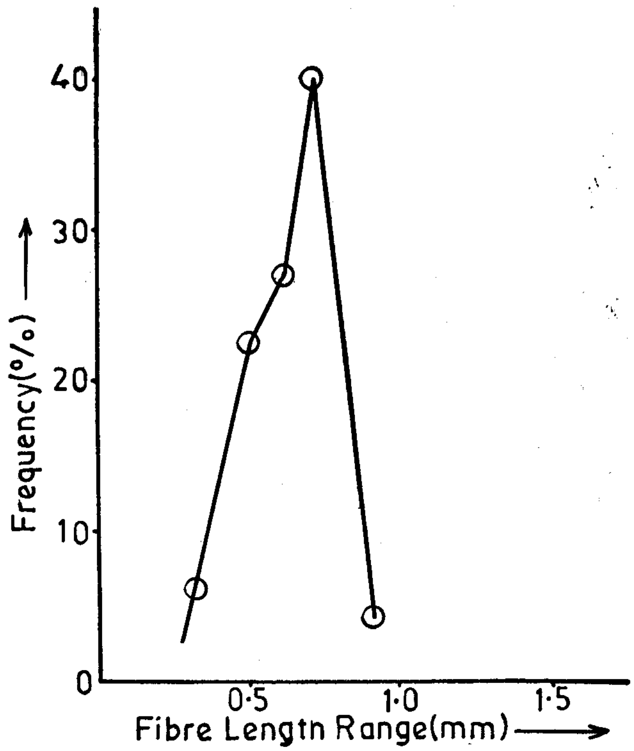


Fig. 2: Plots of Fibre Lengh Range(mm) VS Frequency for C cajan.

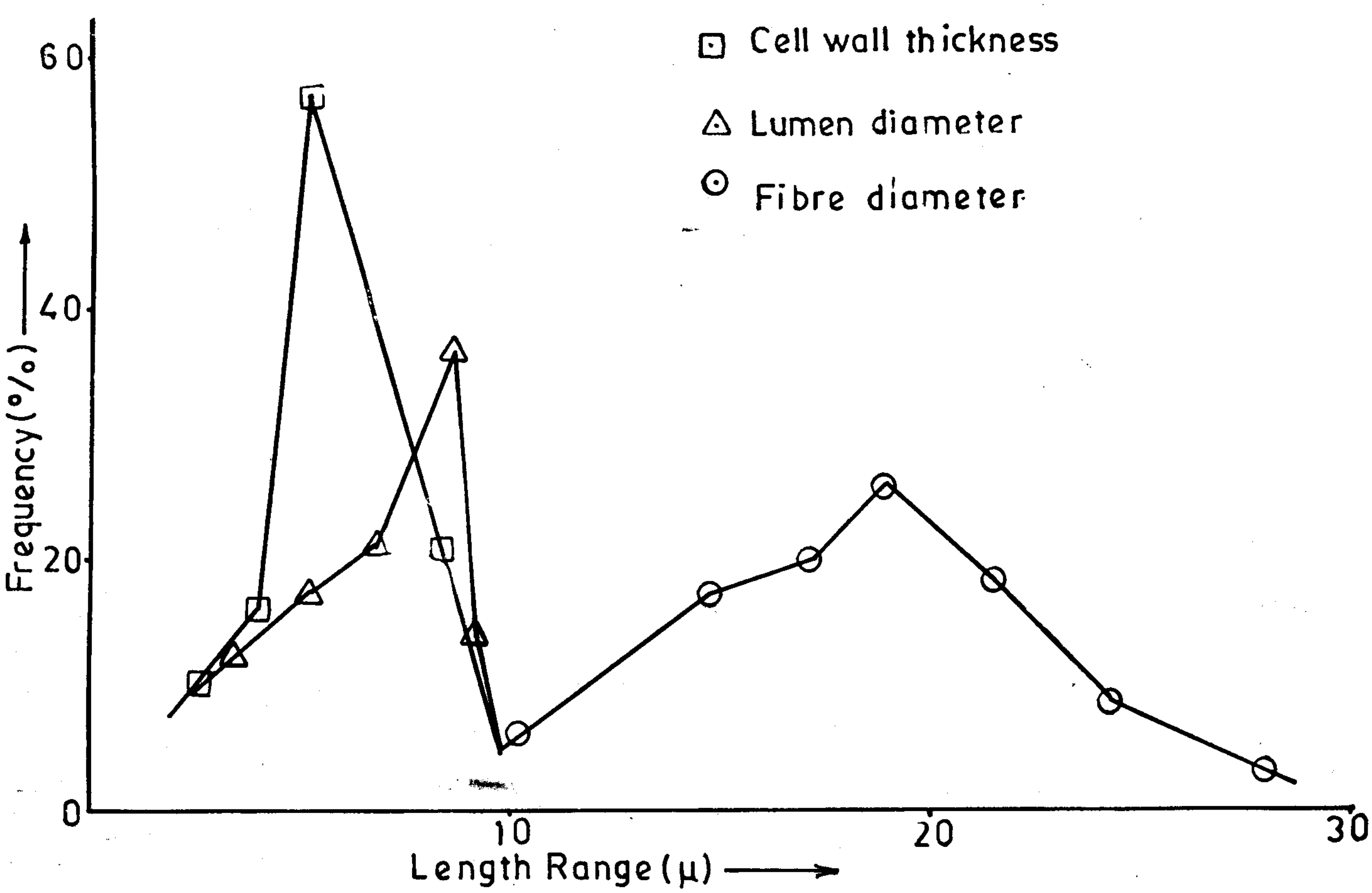


Fig-3: Plots Of Length Range(μ) Of Cell Wall Thickness, Lumendiameter and Fibre Diameter VS Frequency(%) For S.sesban.

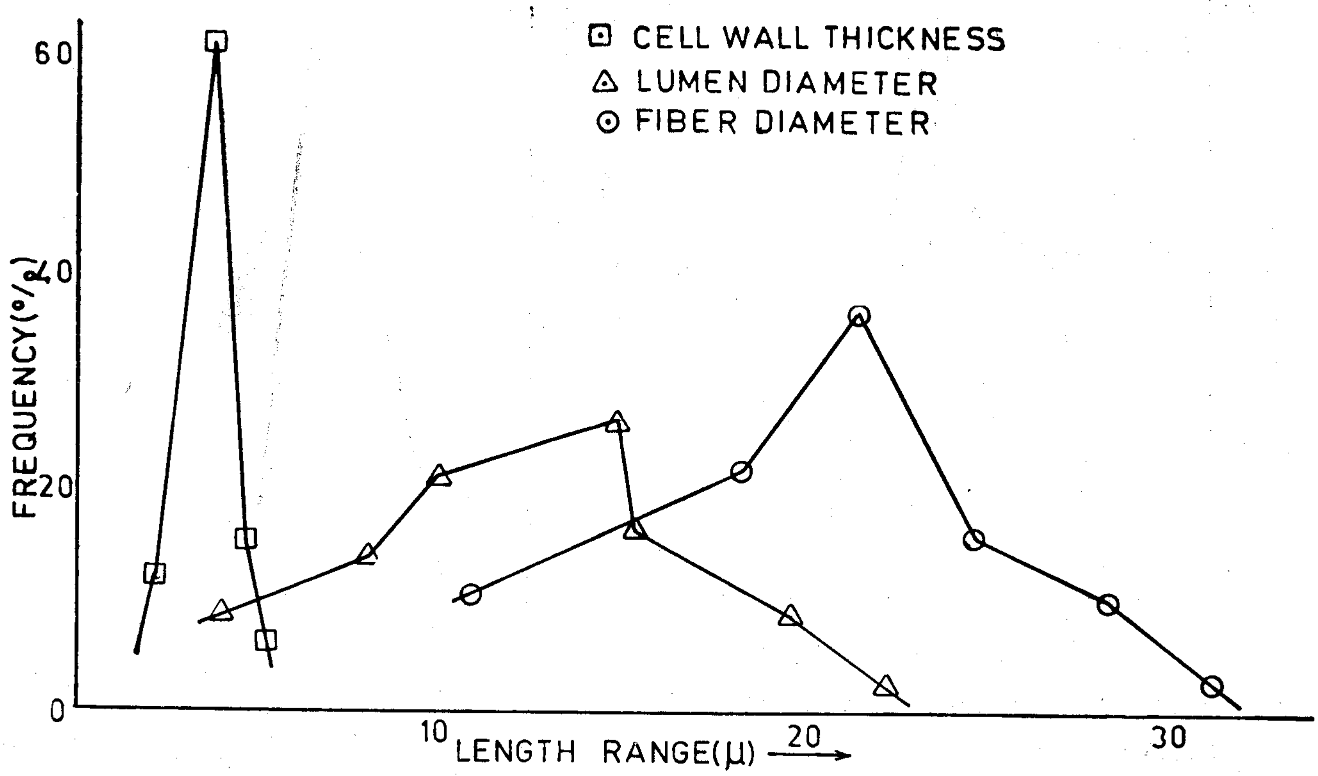


Fig-4: PLOTS OF LENGTH RANGE(μ) OF CELL WALL THICKNESS, LUMENDIAMETER, AND FIBRE DIAMETER VS FREQUENCY FOR S.aculeata

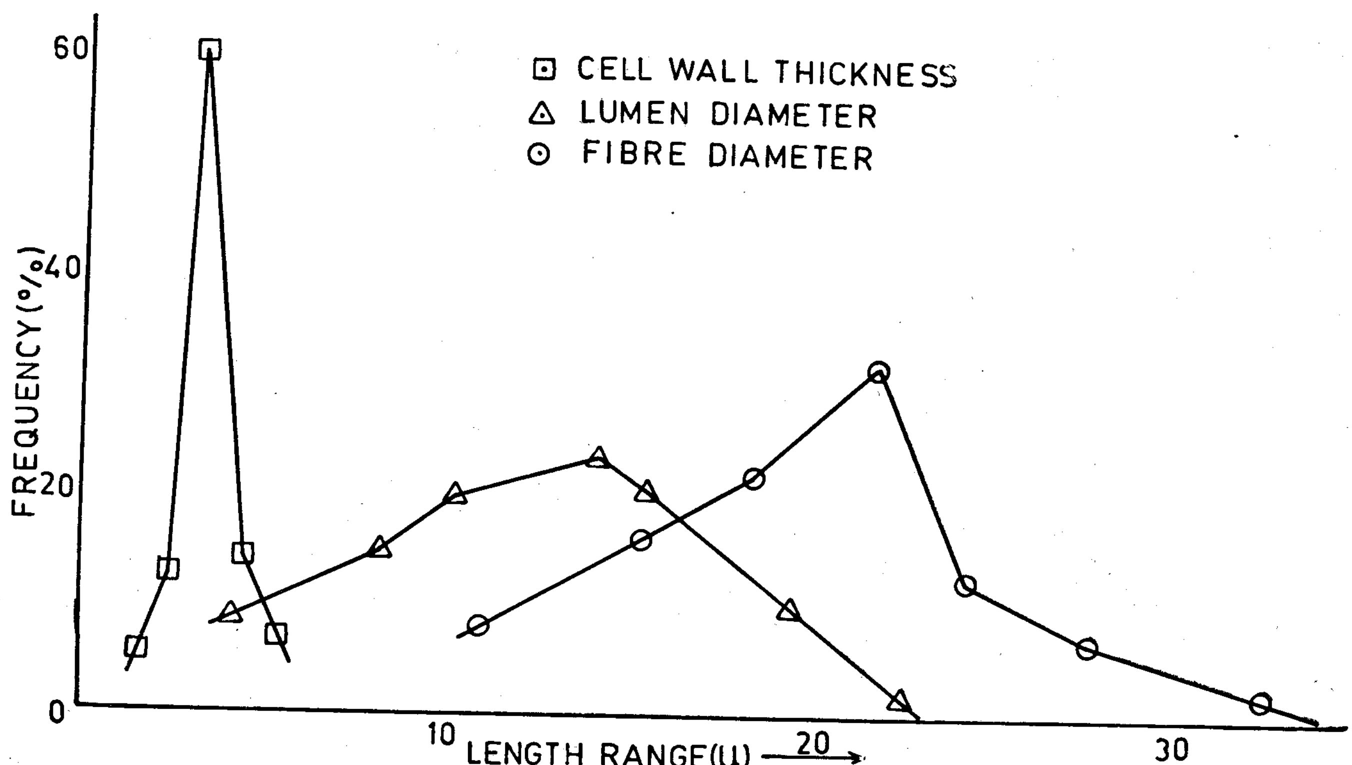
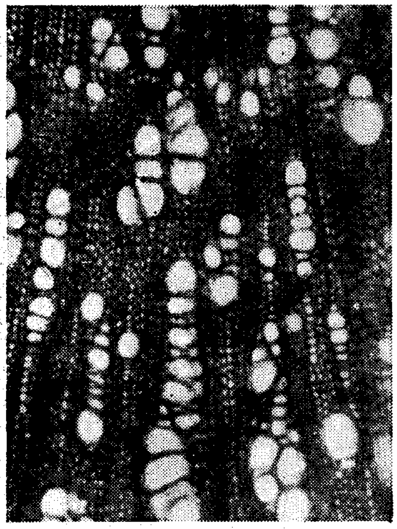
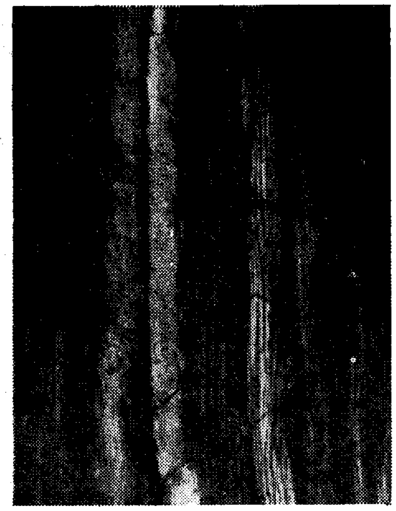


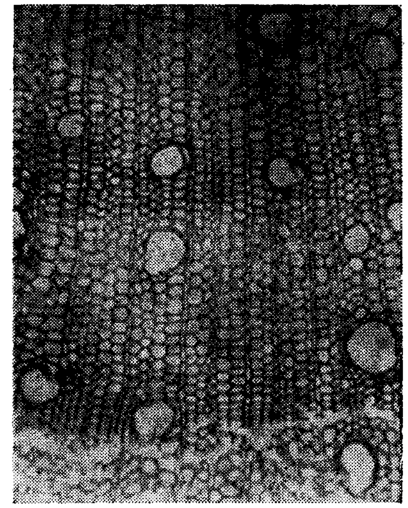
Fig-5: PLOT OF LENGTH RANGE(μ) OF CELL WALL THICKNESS, LUMEN DIAMETER AND FIBRE DIAMETER VS FREQENCY FOR C.cajan.



PHOTOMICROGRAPH 1
S. sesban, T.S. (100X)

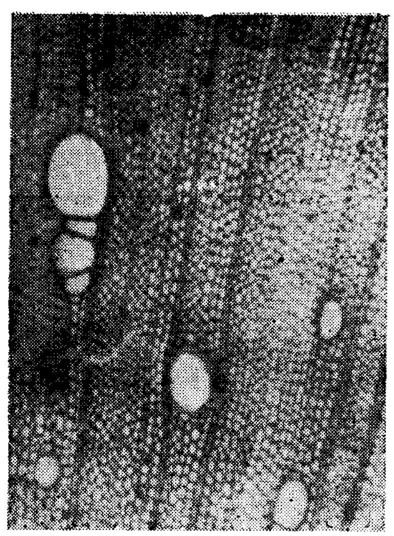


PHOTOMICROGRAPH 2
S. sesban, L.S. (100X)



PHOTOMICROGRAPH 3
S. aculeata, T.S. (100X)

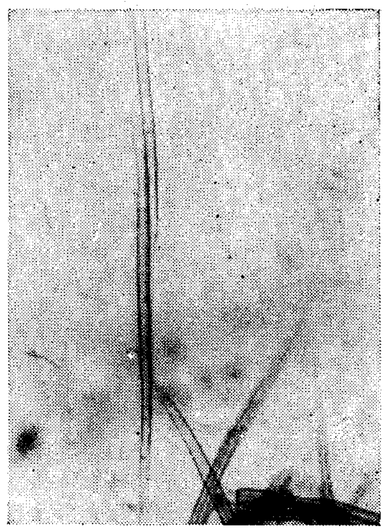
PHOTOMICROGRAPH 4
S. aculeata, (L.S. (100X)



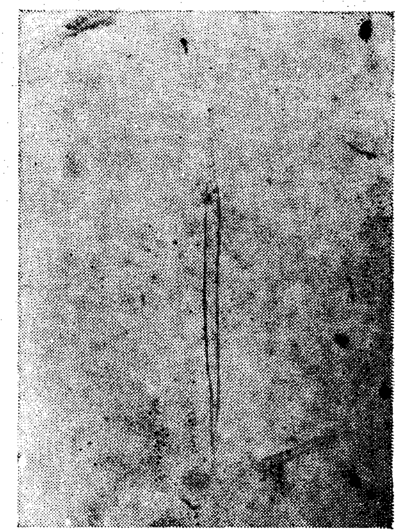
PHOTOMICROGRAPH 5
C. cajan, T.S. (100X)

PHOTOMICROGRAPH 6
C. cajan, L.S. (100X)

PHOTOMICROGRAPH 7
S. sesban fibers (100 X)



PHOTOMICROGRAPH 8
S. aculeata fibers (100X)



PHOTOMICROGRAPH 9
C. cajan fibers (100X)

Table—4
Morphological Characteristics of Sesbania sesban, Sesbania aculeata, Cajanus cajan and Bamboo.

Sl. No.	Particulars	S. sesban	S. aculeata	C. cajan	Bamboo[18]
1.	Colour	Light Brown	Light White	Light Brown	Light Green
2.	Density, gm/c.c.	0.498	0.36	0.485	0.521
3.	Fibre length (L) mm A/g.	0 914	0.843	0 765	1.7
	Variation.	0.410–1.12	0.356–0.956	0.312–0.910	1.5–4.4
4.	Fibre width, (D)/μ Average	19.174	21.576	22.122	23.60
	Variation.	10.355–28.120	10.836–31.240	10.870–32.760	
5.	Lumen width (d)/μ average	8.714	14.82	15.05	9.5
	Variation	3.450–9.784	4.02–22 120	4.10–22.642	
6.	Cell wall thickness, (W) μ average	5.235	3.38	3.54	7.0
	variation	2.60–9.756	1.657–5.120	1.620–5.442	
7.	Flexibility coefficient (d/D) x 100	45.44	68.68	68.03	40.5
8.	Ratio of twice cell wall thickness to fibre width (2W/D)	0.546	0.313	0 320	0.593
9.	Runkel ratio (2W/d)	1.20	0.456	0.470	1.47
10.	Ratio of cell wall area to total cross sectional area % (Muhlesteph) ratio	81.3	58.5	61.5	—
11.	Ratio of length to width (L/D)	47.66	39.07	34.67	72.0
12.	Ratio of cell wall thickness to Lumen width (W/d)	0.60	0.22	0.23	0.74

Results and discussion :

The results of proximate chemical analysis as given in table-3 indicated that the water solubles in this non-wood fibrous plants ranges from 3.32 to 6.30 % as compared to 8.5% and 7.85% in bamboo and bagasse respectively. The S. aculeata is having minimum water solubles (3.32%) while the water solubles in C. cajan is 5.10% and S. sesban 6.30%, which is maximum. The alcohol-benzene solubles in these non-wood fibrous plant ranges from 3.28 to 4.45% as compared to 3.40% and 6.30% in bamboo and bagasse respectively. The alcohol-benzene solubles comes under the catagory of extractive and these are totaly undesirable for pulp and paper making and they also directly affected the pulp yield. As indicated by the results of proximate chemical analysis that these plants are having moderate quantities of extractives so these will create lesser pitch troubles and also more homogenities in the paper sheets.

The 1 % sodium hydroxide soluble in these plants ranges from 19.66% to 24.70% as compared to 26 8% and 33.6% in bamboo and bagasse respectively. The C. cajan is having the minimum 1% sodium hydroxide solubles (19.66%) among these non-wood fibrous plants. The lignin in these plants ranges from 17.65 to 20.79% as compared to 20.30% and 24.3% in bagasse and bamboo respectively. The S. sesban is having minimum lignin content (17.65%) and S. aculeata is having maximum lignin content (20.79%) among these non-wood fibrous plants. As indicated these non-wood fibrous plants are having low lignin content so these will require comparatively less cooking chemicals and shorter cooking cycle with improved tensile, burst, tear fold and sheet density. These plants are having higher holocellulose ranges from 71.86 to 74.85% as compared to 71.5% in bamboo and 70.6% in bagasse. The alpha cellulose contents in these plants ranges from 45.24% to 48.0% as compared to 42.0% in bagasse and 43.5% in bamboo. As indicated these plants are having moderate quantities of alpha celluloses. The hemicellulose content in these plants ranges 25.24% to 27.8% compare to 27.6% in bamboo and 28.45% in bagasse. The pentosan content in these plants ranges from 15.97 to 19.0% as compared to 18.3% in bamboo and 23.86% in bagasse. As indicated these plants are having low pentosan content, therefore will give better pulp yield. The ash and silica contents in these plants ranges from 1.4 to 1.78% and 0.38 to 0.56% as compared to 3.8% and 2.1% in bagasse and 2.1% and 1.4% in bamboo. As indicated these plants are having quite low ash and silica content so these will show less damaging effect on the processability of the wood and will require less cleaning before use. The results of proximate chemical analysis of S. aculeata are quite comparable with the values reported by Sadawarte[2] etal.

All these non-wood fibrous plants consist of polygonal sclerenchyma cells, and the thickening of cells is due to the deposition of lignin. The microscopic study of T.S. and L.S. of S. sesban, S. aculeata and C. cajan revealed that the S. sesban have a large number of vessels arranged in a scattered manner, and they form diffuse porous wood. The vessels of S. aculeata have wide lumen but less in number than S. sesban, and they are arranged in a ring, and form ring porous wood. The vessels of C. cajan either present in group or in isolated form, but less in number. The vessels of S. sesban are small having oblique septa. The S. aculeata vessels are longer in size having oblique septa. The vessels of C. cajan are round with large lumen and transverse septa. The vessels of these plants are short, barrel shaped having numerous pits. The L.S. of S. sesban and L.S. of S. aculeata having unicerate medullary rays. The L S of C. cajan showed the presence of both bicerate and unicerate medullary rays. The fibres of S. sesban are thick walled, with gradually tapering pointed ends, smooth walls, narrow lumen and very sparsel it like pits The fibres of S. aculeata and C. cajan are thin walled elongated with pointed ends, smooth walls, with lumen. The fibre of S. aculeata have more sparse slit like pits. The combined effect of physical characteristics and chemical composition of the raw material thus determine the ultimate properties of the pulp and paper..

i) Tensile and Burst :

Both the tensile and bursting strength are dependent on the fiexibility of the fibres which may be recorded as density effect, cell wall thickness[3-4], cell wall area relative to total cross sectional area Munlsteph ratio) or as the ratio of lumen diameter to fibre diameter (the coefficient of flexibility) Petroff and Normand[5] found a correlation coefficient of 0.83 between the latter ratio and breaking length. The amount of fibre collapsed is also related to this ratio[6]. Fibre length is also important so far as there must be a certain minimum length.

ii) **Fold :**

Folding endurance has a direct proportional relationships with the flexibility of fibres[7] and fibre length i.e. folding endurance increases/decreases with an increase/decrease in fiber length and their flexibility, while the folding endurance has a indirect proportional relationship with the density of wood[4,7,8], cell wall thickness and Runkel ratio i.e. folding endurance increases/decreases with an decrease/increase in density, cell wall thickness and Runkel ratio.

iii) **Porosity :**

The porosity has a direct proportional relationship with the density of wood[9] and fibre diameter while the porosity has a indirect proportional relationship with fibre flexibility[10], cell wall thickness and fibre length.

iv) **Bulk :**

Bulk is the reciprocal of sheet density. It depends on the density of the wood, cell wall thickness[11,12] or the ratio of cell wall thickness to lumen diameter. An increase in the density of wood and cell wall thickness give rise to a sheet of higher density and lower bulk.

v) **Tear :**

The fibre length, extracted specific gravity[13] and cell wall thickness are the important factors controlling tear. The tearing strength has a direct proportional relationship with the fibre length, but beyond certain limits fibre length becomes insignificant.

vi) **Freeness :**

The freeness of pulp appears to be dependent on cell wall thickness, ratio of lumen diameter to cell diameter, fibre length and ratio of length to diameter. Among these the freeness of pulp has a direct proportional relationship with cell wall thickness[9] and fiber length while it has indirect proportional relationship with the ratio of lumen diameter to cell diameter and the ratio of length to diameter (l/d).

vii) **Yield ·**

The yield of the pulp can be correlated with the chemical composition of the wood and particularly the alpha cellulose content[14]. The density of the wood is also the determining factor of the yield[15]. This view is substantiated by Dinwoodie's work[15], who carried out the regression of the weight of pulp fibre obtained from mixed volume of chips on the ratio of 2w/d, which accounted for nearly 70% of the variation.

On the basis of above discussion, a correlation between anatomical characteristics and properties of pulp and paper for S. sesban, S. aculeata and C. cajan have been elucidated and may be as follows, in the descending order of merit.

Breaking Length and Burst Factor	
Density	Ss > Cc > Sa
Cell wall thickness	Ss > Cc > Sa
Muhlsteph ratio	Ss > Cc > Sa
Ratio of lumen to fibre diameter.	Sa > Cc > Ss
over-all	Sa > Cc > Ss
Fold :	
Density	Ss > Cc > Sa
Cell wall thickness	Ss > Cc > Sa
Flexibility	Sa > Cc > Ss
Fibre length	Ss > Sa > Cc
Runkel Ratio	Ss > Cc > Sa
Over-all	Sa > Cc > Ss
Porosity :	
Fibre flexibility	Sa > Cc > Ss
Density	Ss > Cc > Sa
Fibre diameter	Cc > Sa > Ss
Cell wall thickness	Ss > Cc > Sa
Fibre length	Ss > Sa > Cc
Over–all	Ss > Cc > Sa
Apparent Density :	
Density of wood	Ss > Cc > Sa
Cell wall thickness	Ss > Cc > Sa
Ratio of wall thickness to lumen diameter.	Ss > Cc > Sa
Over-all	Sa > Cc > Ss

Tear :

Fibre length	Ss > Sa > Cc
Cell wall thickness	Ss > Cc > Sa
Over-all	Ss > Sa > Cc

Freeness :

Cell wall thickness	Ss > Cc > Sa
Lumen to fibre diameter.	Sa > Cc > Ss

Ss—(Sesbania sesban), Sa—(Sesbania aculeata), Cc—(Cajanus cajan)

Fiber length	Ss > Sa > Ce
Ratio of fibre length to diameter.	Ss > Sa > Cc
Over-all	Ss > Sa > Cc

Yield :

Alpha Cellulose	Sa > Cc > Ss
Density	Ss > Cc > Sa
Over-all	Cc > Sa > Ss

Ss—(Sesbania sesban)
Sa—(Sesbania aculeata)
Cc—(Cajanus cajan).

CONCLUSION :

The results of proximate chemical analysis showed that these plants have a moderate quantities of solubles, so these will create lesser pitch troubles also more homogenities in the paper. These plants have low lignin and high alpha cellulose content, thereby require less cooking chemicals and gives compatively higher pulp yields.

The knowledge of the fibre structures is very useful for determining the various properties of pulp & paper. The fibre length of S. sesban is more in comparison to S. aculeata and C. cajan, hence S. sesban is likely to possess the maximum value for tear. The S. aculeata and C. cajan will give higher pulp yields with better values for tensile, burst and fold, than S. sesban, since all these properties are dependent on fibre width, wood density, cell wall thickness, cellulose and lignin content.

The S. sesban wood consists of a large number of vessels, fibres having thick walled with narrow lumen and the wood of S. aculeata consists of less number of vesseles. fibres having thin walled with wider lumen. While the wood of C. cajan also consists of less number of vessls, fibres having thin walled with wider lumen. The S. aculeata and C. cajan are somewhat better non-wood fibrous plants than S. sesban. On the basis of anatomical and chemical studies, it is concluded that S. aculeata, C. cajan and S. sesban are quite suitable non-wood fibrous raw material for pulp and paper making.

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