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Quality and Mechanical Properties of Plant Commercial Fibers

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Abstract: Twenty-four different plant species belonging to 19 families were analyzed in the current investigation. Plants were ranked according to the felting power, suitability of fibers and strength of the fibers. Among monocots, *Caryota urens* (garden palm) and *Eucalyptus camadulensis,* in dicotyledonous plant species had the strongest fibers. *Caryota urens* (garden palm) in monocots while *Terminalia arjuna* in dicots had high felting power. Cluster analysis had separated out the *Agave americana* in monocot which was significantly apart from *Saccharum spontaneum,* on the basis of derived characters like Slenderness ratio, Runkle ratio and Coefficient of suppleness. *Phoenix dactylifera* was dominant due to its great fiber length and lowest Runkle ratio. In this investigation, it was concluded that different plant species can be used for different purposes and evolution does not necessarily involve all the qualities of fibers at the same time.

Key words: Plant fibers, monocotyledons, dicotyledons, slenderness ratio, runkle ratio, coefficient of suppleness

Introduction

Wood is classified into two main groups i.e. the gymnosperms and the angiosperms. It is an assemblage of hollow fibers and other cells cemented together with lignin and hemicelluloses into a rigid, stiff, strong material. Technically, a plant fiber is a type of sclerenchyma cell characterized by very thick and tough secondary walls impregnated with lignin. Commercially, however, the term "fiber" more commonly refers to a mass of elongated plant material that is a collection of either fiber cells or entire vascular bundles.

Fiber plants have been utilized economically since ancient times. Flax is known to have been cultivated by man as early as 3,000 years B.C. in Europe and Egypt, and hemp at approximately the same time in China (Ash, 1948; Dewey, 1943). Commercial fibers are separated into Hard fibers and Soft fibers. Commercial fibers of Linum, Boehmaria and Corchorus are, in reality, a bundle of fibers and those from monocotyledonous leaves of Agave, *Musa textilis* and others are the vascular bundles with the surrounding sheaths of fibers. The principle fibers used in textile industry are the epidermal hairs of the cotton seeds. The earliest clothing was not made of the comfortable fabrics we have today, such as cotton, lycra, casmere and wool. Leather was a main fabric used. Clothing means fabric used to cover the body and cloth means a textile and/or fabric. Hemp fibers are used, mostly for industrial fabrics like, canvas, rope and twines. Although jeans today are made of 100% cotton, Levi Strauss, the inventor, originally made his clothes out of hemp! (Levetin and McMahon, 2003). Fibers are classified based on their usage (Schery, 1954): a) Textile fibers b) Cordage fibers, c) Brush fibers, d) Filling fibers used for stuffing upholstery, mattresses etc. Fibers are also used in paper industry and different types of papers can be made depending on their physical and chemical properties (Clark, 1965).

The shape of the fiber cell, its length and wall structure are important in the fiber industry. Special attention is paid to the length of the fiber, the extent to which neighboring fibers overlap and joined to one another. The orientation of cellulose units in the wall has an important effect on the physical properties of wood and commercial fibers. Elasticity and heat conductivity increase as the degree of orientation parallel to the length of the fiber increases. Commercially, the fibers are ranked according to the durability, tensile strength, length of the strands, fineness, uniformity and elasticity. The current study was undertaken to report the characteristics of fibers of the local flora keeping in mind their commercial importance. The fiber properties of commercial importance i.e. strength, suitability and durability were evaluated. Natural fibers are extremely important commercially, being used to make paper, ropes and other substances. Naturally the purchaser needs a method to verify the quality and identity of the pulp that has been received. Consequently, the fibers of many plants have been studied carefully to identify the characters that are of taxonomic as well as commercial importance.

Materials and Methods

Different plant species were collected to investigate the characteristics of fibers. All the species were collected from Botanical garden and Herbarium of B.Z. University,

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Multan. Maceration of the wood material was performed by Jeffrey's method (Johansen, 1940). The outer portion of stem toward the epidermis was peeled (Fahn, 1986) and cut into small pieces. The slices obtained from the stem were macerated (Ogbonnaya, 1992) and stained. Small wood pieces were placed in 10% aqueous Nitric acid and 10% aqueous chromic acid. The solution was heated for fifteen minutes. A thick glass rod with rounded ends was used to crush the material very gently and then washed with water thoroughly to remove the acid and thereafter stained with 1% safranin. The stained macerates were viewed under a calibrated light research microscope. Five slides were prepared for each specimen. Fifteen cells of each sample were measured and this was replicated three times. Following parameters were observed using calibrated research microscope. 1) Fiber length, 2) Fiber diameter, 3) Fiber lumen diameter 4) Wall thickness.
Data obtained was used to calculate the following parameters:

1) Slenderness ratio (SR) or felting power, which is a measure of the tear property of pulp in paper production (Rydholm, 1965) was calculated from L/D (L= Fiber length, D= Fiber diameter)
2) Runkle ratio (RR), which is a measure of the suitability of fiber for paper production was calculated from 2W/K (W= fiber wall thickness, K= Fiber lumen diameter)
3) Coefficient of Suppleness (CS) or flexibility coefficient, which is a measure of the strength properties of paper was calculated from K/D

Data for each parameter were analyzed by ANOVA using Minitab Computer Package. In this study, cluster analysis of the whole data set was made by using Multivariate Statistical Package. The plant groups were established by specifying the 3 levels of divisions in hierarchical diagram by Cluster analysis.

Results and Discussion

There was significant interspecific difference in fiber length of twenty-four plant species belonging to 19 plant families. *Saccharum spontaneum, Bombax malabaricum, Bauhinia variegata* had significantly shorter fiber length than *Mangifera indica, Terminalia arjuna* and *Nannorophs ritchieana*. *Phoenix dactylifera* in monocots had the longest fiber length (6.60^{f}) like *Mangifera indica* (6.49^{ef}) in dicots. Similarly in case of fiber width, *Morus alba, Saccharum munja, Bambusa bambos* had significantly less fiber width than *Pinus roxburghii, Phoenix dactylifera* and *Ficus elastica*. *Phoenix dactylifera and Ficus elastica* had greater fiber width i.e 3.50^{fg} and 3.49^{fg} in monocots and dicots respectively. On the other hand, S*accharum munja, Typha elephantina, Nannorophs ritchieana* had significantly less fiber lumen diameter than the species *Psidium guajava, Albizia lebbeck and Pinus roxburghii*. *Phoenix dactylifera* had greater fiber lumen diameter (3.29^{fg}) than S*accharum munja, Agave americana* and *Nannorophs ritchieana* in monocots. In case of dicots, *Psidium guajava* had great fiber lumen diameter (3.26^{efg}) than *Mangifera indica and Bauhinia variegata*. There were no significant differences in wall thickness between the species. Only *Bambusa bambose* among monocots had significantly greater wall thickness (2.09^{c}) than *saccharum spontaneum* and *Typha elephantina.*

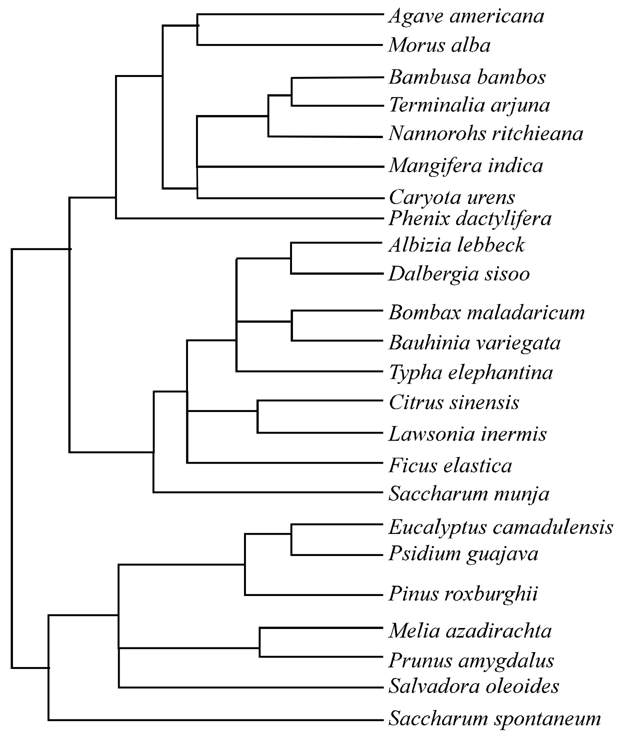

Fig. 1: Hierarchical classification on data set of 24 species (quantitative data

No differences were found in slenderness ratio of the plant species. *Caryota urens* in monocots had significantly high value of slenderness ratio (24.27^{d}) and *Terminalia arjuna* had highest slenderness ratio (24.31^{a}) in dicots. Differences were not observed in Runkle ratio between the species. *Nannorophs ritchieana* had significant Runkle ratio value (1.13^{b}) in monocots than *Saccharum munja, Bambusa bambos, Saccharum spontaneum.* Among dicots, *Morus alba* had significantly greater Runkle ratio than *Ficus elastica*, *Terminalia arjuna* and *Bauhinia variegata. Caryota urens* had

Table: 1: List of species in each group identified by Cluster Analysis at 3rd level of Hierarchy

Groups	No. of Species	List of Species
1	1	*Salvadora oleoides*
2	5	*Prunus amygdalus, Melia azadirachta, Pinus roxburghii, Psidium guajava, Eucalyptus camadulensis*
3	1	*Saccharum munja*
4	8	*Ficus elastica, Lawsonia innermis, Citrus sinensis, Typha elephantina, Bauhinia variegata, Bombax malabaricum, Dalbergia sisoo, Albizia lebbeck*
5	1	*Phoenix dactylifera*
6	7	*Caryota urens, Mangifera indica, Nannorophs ritchieana, Terminalia arjuna, Bambusa bambos, Morus alba, Agave americana*

Table 2: Ranking of the Commercial Fibers based on different Characters
Monocotyledons

Characters	Rank I	Rank II	Rank III	Rank IV
Fiber length (µm)	*Phoenix dactylifera* (6.60^{f})	*Caryota urens* (6.28^{ef})	Nannorophs ritchieana (6.19^{cde})	*Bambusa bambos* (6.18^{bcde})
Fiber width (µm)	*Phoenix dactylifera* (3.50^{fg})	*Caryota urens* (3.32^{cdefg})	*Saccharum spontaneum* (3.30^{bcdef})	*Bambusa bambos* (3.21^{abcdef})
Fiber lumen diameter (µm)	Phoenix dactylifera (3.29^{fg})	*Saccharum spontaneum* (2.93^{abcdef})	*Agave americana* (2.79^{abcd})	*Caryota urens* (2.77^{abcd})
Wall thickness (µm)	*Bambusa bambos* (2.09^{c})	*Saccharum spontaneum* (2.06^{c})	*Nannorophs ritchieana* (2.04^{bc})	*Caryota urens* (1.89^{abc})
Derived Characters				
Slenderness ratio (Tear property of pulp)	*Caryota urens* (24.31^{d})	*Saccharum munja* (24.27^{d})	*Phoenix dactylifera* (23.27^{cd})	*Bambusa bambos* (22.82^{cd})
Runkle ratio (Suitability of fibers)	*Nannorophs ritchieana* (1.13^{b})	*Bambusa bambos* (0.99^{ab})	*Saccharum munja* (0.96^{ab})	*Caryota urens* (0.93^{ab})
Coefficient of Suppleness (Strength properties)	*Caryota urens* (0.90^{b})	*Phoenix dactylifera* (0.79^{ab})	*Typha elephantina* (0.77^{ab})	*Agave americana* (0.75^{ab})

Table 3: Ranking of the Commercial Fibers based on different Characters
Dicotyledons

Characters	Rank I	Rank II	Rank III	Rank IV
Fiber length (µm)	Mangifera indica (6.49^{ef})	*Salvadora oleoides* (6.35^{ef})	*Albizia lebbeck* (6.27^{cdef})	*Meliaazadirachta*(6.24^{bcdef})Fiber
Fiber width (µm)	*Ficus elastica* (3.49^{fg})	*Mangifera indica* (3.47^{fg})	*Psidium guajava* (3.43^{efg})	*Bauhiniavariegata*(3.42^{efg})Fiber
Fiber lumen diameter (µm)	*Psidium guajava* (3.26^{efg})	*Ficus elastica* (3.20^{efg})	*Eucalyptus camadulensis* (3.18^{efg})	*Mangifera indica* (3.14^{defg})
Wall thickness (µm)	*Mangifera indica* (2.12^{c})	*Melia azadirachta* (2.10^{c})	*Salvadora oleoides* (2.07^{c})	*Terminalia arjuna* (2.05^{c})
Derived characters				
Slenderness ratio (Tear property of pulp)	*Terminalia arjuna* (22.94^{cd})	*Morus alba* (21.47^{bcd})	*Salvadora oleoides* (21.03^{abcd})	*Mangifera indica* (20.57^{abcd})
Runkle ratio (Suitability of fibers)	*Morus alba* (1.03^{ab})	*Mangifera indica* (1.00^{ab})	*Salvadora oleoides* (0.97^{ab})	*Bombax malabaricum* (0.94^{ab})
Coefficient of Suppleness (Strength properties)	*Eucalyptus camadulensis* (0.84^{ab})	*Lawsonia inermis* (0.80^{ab})	*Citrus sinensis* (0.79^{ab})	*Dalbergia sisoo* (0.78^{ab})

significantly highest Coefficient of Suppleness (0.79^{ab}) among monocots than *Agave americana, Saccharum munja, Bambusa bambos and Saccharum spontaneum.* While *Eucalyptus camadulensis* had significantly greater Coefficient of Suppleness (0.90^{b}) in dicots.

The first dichotomy splits off 7 species shown in hierarchical diagram (Fig. 1 and Table 1). This first group comprised of *Saccharum spontaneum, Salvadora oleoides, Prunus amygdalus, Melia azadirachta, Pinus roxburghii* etc. Of these 7 species, *Saccharum spontaneum* was different having lower value of Slenderness ratio (13.09^{a}). Remaining 6 species again split off in one and five species. Remaining 17 species were divided into two groups comprising of 9 and 8 species (Table 2). Of these nine species, *Saccharum munja* had small value of fiber width (2.99) and fiber lumen diameter (2.60^{a}) but it had highest Slenderness ratio. Remaining 8 species had somewhat, similar characters. *Phoenix dactylifera* was the main divisor specie separating the other species. *Phoenix dactylifera* had greatest fiber length but it had lowest Runkle ratio (RR). These two characters make it prominent from its related species.

The cluster analysis had separated out the monocotyledonous plant species from dicotyledonous one at different levels, suggesting the structural differences between two plant groups. This agreed with the findings of Metcalfe and Chalk (1950), Fahn (1990) and Esau (1965) etc. Cluster analysis had separated out the *Agave americana* in monocot *which* was significantly apart from *Saccharum spontaneum.* This separation was not based on fiber length, fiber width, fiber lumen diameter and the wall thickness, the characters usually used for phylogenetic studies. Instead the separation was based on the derived characters such as Slenderness ratio (SR), Runkle ratio (RR), Coefficient of Suppleness (CS). These results suggested the importance of derived characters when establishing the phylogenetic sequence of the species.

The hierarchical diagram had separated out the hard fibers from the soft fibers at each level of hierarchy. The fibers of monocotyledons are usually called leaf fibers and are classified as hard fibers. They are strongly lignified. Walls are usually hard and stiff. The fibers obtained from woody stem of dicotyledonous plants are the soft fibers. The Cannabis fiber was also used in making paper as well as the textile fiber. (Hui-Lin Li, 1975). This plant is also a great material for acquiring quality cellulose for paper and cardboard (Simpson and Ogorzally, 2001). It is an important source of fiber for rope as well.

In the current investigation, we had recorded the characters of anatomical, phylogenetic (Fiber length, Fiber width, fiber lumen diameter and wall thickness) and commercial importance (Felting power, Suitability of fiber, Strength property of fiber). Among the hard fibers, the fibers obtained from *Caryota urens* (garden palm) were the strongest fibers and had highest tearing properties. However with respect to the suitability of fibers for pulp making, *Nannorophs ritchieana* showed to be most suitable. However in terms of strength or durability, *Nannorophs ritchieana* was ranked behind the other monocotyledons. Therefore, it may be concluded that different monocotyledonous plant species can be used for different purposes. Among the wood fibers (soft) of dicotyledonous plant species, the fibers obtained from *Eucalyptus camadulensis* were the strongest and it was classified in rank-1 (Table 3). In terms of felting power, the fibers of *Terminalia arjuna* appeared to be important, while the fibers of *Morus alba* were most suitable for commercial purposes. The fiber characters of phylogenetic importance i.e. fiber length and wall thickness were also considered.

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