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Green Fibre-Agave Americana

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Abstract—*The growing environmental problems, problem of waste disposal and the depletion of non-renewable resources have stimulated the use of green materials compatible with the environment to reduce environmental impacts. Therefore, there is a need of designing products by using natural resources. Natural fibres seem to be a good alternative since they are abundantly available and there are good number of possibilities of using all the components of the fibre yielding crop, one such fibre yielding plant is Agave Americana. Leaves of this plant yield fibres and all the parts of this plant can be utilizes in many applications. The "zero-waste" utilization of the plant would enable its production and processing to be translated into a viable and sustainable industry. Agave Americana fibres are characterized by low density, high tenacity and high moisture absorbency in comparison with other leaf fibres. These fibres are significantly long and biodegradable. Therefore we can look this fibre as one of the sustainable resource for manufacturing technical applications. Detailed discussion is carried out on extraction, characterization and applications of Agave Americana fibre in this paper.*

1. INTRODUCTION

In view of recent global environmental issues, scientists worldwide have begun to show interest in exploiting the full potential of natural fibre and their diverse uses [1, 2]. There are plenty of renewable resources obtainable from the plant kingdom [3, 4] and has a vast resource for different natural fibres which are abundantly available in many parts of world. However, there are still number of other vegetable fibres which have not been used as textile fibres [2].

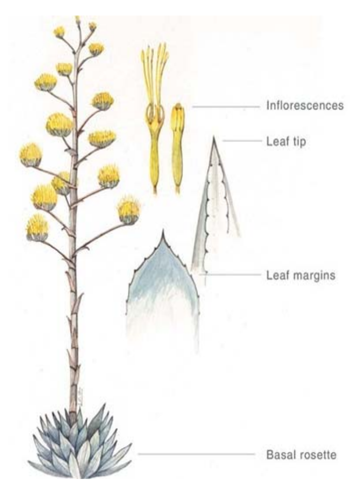


Fig. 1: Different parts of Agave Americana plant.

There are various plants in nature which are having various uses, but due to lack of knowledge we are unable to use that. From the plant kingdom, one of the abundant sources of strong natural fibre is "Agave Americana". Agave Americana fibres are also called as "Pita Fibres". The leaves of this plant contain fibres. Agave Americana is having the different uses; one of them is for getting the fibres. The plant based fibres are cellulosic in nature [3, 4].

(Illustration courtesy of Lara C. Gastinger, Stanardsville, Virginia)

Common names of Agave Americana are century plant, maguey or American aloe, which is a species of flowering plant in the family Agavaceae [3-7]. The plant is originally native to Mexico, Arizona and Texas but cultivated worldwide as an ornamental plant. It has become naturalized in many regions including the West Indies, parts of South America, the Mediterranean Basin, and parts of Africa, India, China, Korea, Thailand, New Zealand, Australia and an assortment of oceanic islands [2, 6, 8].

The genus Agave has about 275 species [9]. Agave blossoms only once during its life time and then dies, but produces suckers or adventitious shoots from the base, which continue its growth [5, 6, 9]. Agave plants are grown along railway line, road sides, and river banks and as a hedge plant in dry land areas throughout the country. Till date it is grown in patches and as border crop in a neglected condition [9]. It grew naturally, especially in the arid and semi-arid climates [2, 8]. The crop comes up on dry soils unsuitable for crop cultivation but grow vigorously on dry, well drained sandy loam soils [9].

The leaves are ready for harvesting from 3rd year onwards and the he older leaves of length not less than a meter is harvested. Each plant yields 40-50 leaves/year. The life cycle of the plant is up to 8-30 years [5- 7, 9, 10]. The content of fibre varies with variety from 2.5 - 4.5%. The fibre color varies from milky white to golden yellow, [3, 4, 9], and have a hard touch due to the existence of lignin on their surface. The yield per hector of this plant is 300 tons which give near about 6 tons fibre [3, 4].

Agave is a short stemmed plant bearing a rosette about 1.2m wide of gray-green leaves up to 1.8m long erect fleshy leaves, each with a spiny margin and a heavy spike at the tip. When it flowers, the spike has big yellow flowers and may reach 2.4m to 7.6m in height [2, 5, 6, 9-12].

2. EXTRACTION OF AGAVE AMERICAN FIBRES

Mature Agave Americana leaves are harvested from the field for fibre extraction. All lower leaves, standing at an angle of more than 45^0 to the vertical, are cut away from the plant by means of a sharp cutting tool like knife. After harvesting, the leaves are transported for fibre extraction. Before extraction, thorns on the leaf margins and the spine at the leaf tip are removed [1]. There are three major fibre extraction methods, viz. mechanical extraction, chemical extraction and retting process. After extraction of fibres by any of these methods all extracted fibres are washed away before drying. Proper drying is important as the fibre quality depends largely on moisture content. Artificial drying has been found to result in generally higher grade fibres than sun drying [13]. The fibres were dried under a shade to avoid bleaching by direct sunlight. Dry fibres are then combed and sorted into grades and packed into bales [3, 4].

2.1 Mechanical Method

In olden days hand decortication was done by rural folks whereby the leaves are pounded and the pulp is scraped away with a knife [3, 4, 14-16]. However hand decortication is time consuming and needs a lot of manpower. Now a day's decortication can be done efficiently through the use of a machine decorticator. In the process of decoration, leaves are crushed and beaten by a rotating wheel set with blunt knives, so that only fibres remain [3, 4]. Some decorticators are fed by hand and the pulp is first scraped from half of a leaf; the leaf is withdrawn; and then the opposite half is inserted for scraping. In some machines whole leaf is decorticated in single insert. [14].

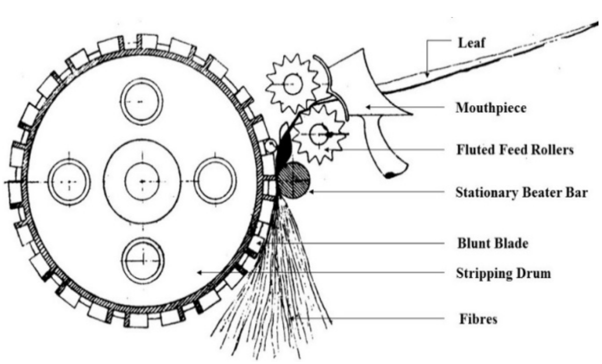


Fig. 2: Sketch of simple fibre decorticator.

Fig. 2 gives a sectional view of the most important organs of fibre decorticator. Agave Americana leaf is fed through the mouthpiece, then it passes through the fluted feed rollers, which hold the leaves as they are fed in against a top stationary bar (not shown in **Fig.** 2), while the stripping drum is beating out the vegetable matter as the leaf passes between it and the beater bar. The stripping drum diameter, width and speed varies according to different makes. The drum, scraping against the leaf, held in position by the beating bar and feed rollers beats off the bulk of the vegetable matter and leaves the fibres somewhat roughened and with a residue of vegetable matter remaining upon it [17].

The operations of fibre removal, washing and drying must be done promptly after the leaves are cut, otherwise the gums in the leaves harden, causing the pulp to adhere to the fibres and making it impossible to clean the fibres properly [15-17]. Mechanical extraction methods are not efficient in the removal of cementing compounds between fibres, mostly waxes, hemicelluloses, lignin and hydrocarbons [3, 4].

2.2 Chemical Method

Chemical fibre extraction involves the use of acids, alkali and enzymes. The use of acids in fibre extraction hydrolyses lignin and hemicellulose into shorter chain pentose molecules for cellulosic fibres like Agave Americana. Acid treatment results in the formation of reactive groups and causes fibres to fibrillate, revealing a higher degree of crystallinity of fibrils. Alkali use in fibre extraction dissolves the lingo-cellulosic material between fibres and lead to increased surface area, degree of polymerization, separate structural linkages between lignin and cellulose, and lower the breaking strength. Enzymatic processing degrades the lingo-cellulosic component in fibres and increase fibre swelling, lower the degree of polymerization and make fibres more pliable and softer [3, 4].

2.3 Retting Process

Retting is a well-researched method of extraction of fibres by a natural microbial process, degrading the non-fibrous matter which acts as glue between the fibres in woody plant parts and fibres without damaging the fibre cellulose. This process allows easy separation of individual fibre strands and the woody core. Since retting is a biological process, it requires both moisture and a warm temperature for microbial action to occur [18].

2.3.1 Natural Retting. It is a preferential rotting process to separate the fibre from lingo-cellulosic biomass without damaging the fibre cellulose. Retting is the microbial freeing of plant fibres from their surroundings [19]. The process takes up to three weeks. Retting microbes consume the non-fibrous cementing materials mainly pectin and hemicellulose. This gradually softens the leaves by the destruction of the less resisting intercellular adhesive substances. When fermentation has reached the appropriate stage, the fibres can be separated quite easily from the leaves. If retting process is allowed beyond this point, fibres themselves may become damaged. Under retting causes incomplete removal of gummy materials such as, pectin substances and extraction of fibre is difficult. Hence the progress of retting must be observed carefully at intervals to avoid fibre damage. Though the natural retting takes more time, the process is economical.

There are two traditional types of retting include water retting in which plant leaves are immersed in water (river, pond or tanks) and field or dew retting in which the crop is spread in the field where rain or dew provide moisture for retting. Water retting produces fibres of greater uniformity and higher quality than can be produced by field retting [14].

2.3.2 Enzymatic Retting. Enzymatic retting is the process in which the pectin materials surrounding the fibre bundles are degraded by industrially produced enzymes. Enzymatic retting is faster than natural fermentation retting and results into soft and desized textiles. This process offers greater process control, increased fibre yield and shorter processing time. Enzyme solution used in retting can be recycled several times making the process eco-friendly and cost effective [14, 20].

Pectinases and xylanases enzymes can be used for retting plant portions for fibre release. The enzyme can be used at higher concentrations to speed up the retting process [14, 22].

3. FIBRE MORPHOLOGY

By examining Agave Americana fibres under SEM, we can observe longitudinal streaks, which are characteristics of long vegetable fibres. Fibre is having composite structure. Ultimate fibres are held together by sticky and waxy substances such as lignin, pectin and hemicelluloses. Agave fibres occur as technical fibre, having oval and irregular sections with a large lumen and appears as a helical structure of square shape spires [12, 23].

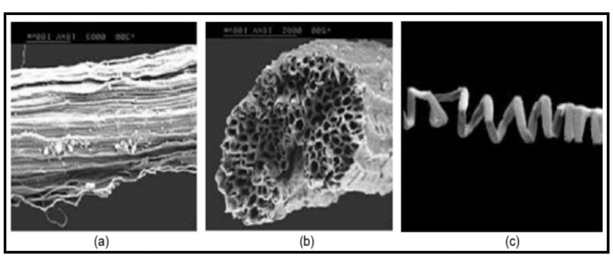


Fig. 3: (a) Longitudinal view of fibre (b) Cross-section view of fibre (c) Single elementary fibre.

Each Agave Americana fibre consists of a number of cells, generally referred to as ultimate fibres or ultimate cells. The overlapping ultimate fibres are held together with a waxy film to form the filament fibres. This implies that an individual fibre is made up of a complete vascular bundle or group of vascular bundles. The vascular bundle consists of transportation tissue vessels surrounded by a thick sheave of fibres cells. Each ultimate is polygonal in shape and has a lumen. Agave fibres in a leaf consist of both xylem and phloem and various ensheafing cells found scattered through a leaf pithy matrix. The cells are lignified to a greater or lesser degree and are hard in comparison with soft fibres. The entire fibro-vascular bundle serves as a unit fibre [24]. The of Agave fibres varies throughout the length and depends on how many ultimate fibres are there in the cross section [25].

Due to natural coting, Agave Americana fibres present a high resistance when they are exposed to weak chemical agents, as well as to UV light (108 hours). These fibres can be characterized by two parameters: the average length of a spiral side which is about 10.1μm and the average diameter which is equal to 3.1μm. The average diameter is very small compared to other natural fibres such as Flax, Sisal and Alfa. This particular structure plays important role in mechanical behavior of the technical fibres [12, 23].

4. EVALUATION OF FIBRES

Agave is noted for its strong, coarse fibre, superior and more flexible than Manila hemp [9]. These natural cellulosic fibres are characterized by a high moisture absorbency, a low-density & high tenacity in comparison with other textile fibres. The fibres obtained are flexible, smooth & lustrous and had similar burning characteristics like other known cellulosic fibres [2]. The fibres contain about 73-78% of lignified form of cellulose [9]. Fibre surface is covered with lignin, after removal of lignin from their surface fibres becomes flexible, smooth and lustrous. The fibres are significantly long with a mean length of 65.2cm and coarser with an average linear density equal to 24tex. The fibre has a tenacity of more than 35.96cN/tex when dry and 20.60cN/tex when wet. Agave Americana fibres are hydrophilic in nature. These fibres has moisture regain of 9.98% and moisture content of 9.19%. Agave fibres greatly vary in their properties with grade and within the same leaf. The fibre disintegrated when exposed to strong acid and alkalis, but was resistant to weak acids and alkalis [3, 4, 13].

4.1 Visual and Hand Evaluation

In visual and hand evaluation of Agave Americana fibres, the observation of fibre shape, color, surface texture are visually evaluated [14].

4.1.1 Physical Shape. The fibre is long, round and generally taper to a point, having one side thicker, especially from the lower side of the leaf.

4.1.2 Color. The color of the Agave Americana fibre ranges from off-white to yellowish depending upon the processing technique used for fibre extraction and the processing time. The retted fibre was darkened, which can be discolored with a naturally looking light brown color, which is due to bacterial action.

4.1.3 Luster. The fibres are semi dull in appearance. Which is due to the fact that they have the uneven surface and cross-sectional shape. A fibre with an irregular cross-section scatters light in all directions, resulting in a dull appearance with few high lights. Whereas properly extracted as well as single fibres appears lustrous.

4.1.4 Texture. The dry Agave Americana fibre is stiff, harsh, coarse and hard-surfaced, which is typical characteristic of all the leaf fibres. However when fibres are wet, they become flexible, smooth and slippery. The fibre feels strong and durable.

4.2 Burning Characteristics

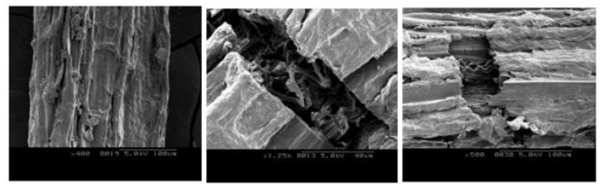
When the fibre sample was brought near the flame, it burn brightly. In the flame the fibre continued burning readily with a yellow-bright flame and continued burning even after removal of flame. The smell of burning Agave Americana fibre is like burning paper. Agave Americana fibre becomes very fragile when exposed to high temperature of up to 108^0C. The burning behavior of Agave Americana fibres similar to that of other natural cellulosic fibres [13].

4.3 Tensile Properties

4.3.1 Mechanical Behavior. Tenacity of Agave Americana fibre is in the range of 16-41cN/tex. The elongation of fibre at rupture is 2-4%. This implies that Agave Americana fibre can perform well where instantaneous forces act on the fibres during the use of end product. High degree of cellulose polymerization and crystallization processes due to many years of growth is one of the reason behind high strength. Higher values of tensile properties of these fibres indicated that it is strong enough to be a textile fibre. This implies that Agave Americana fibre can function well for furnishing fabrics, placemats, carpets, floor mats and rugs and upholstery fabrics as well as in fibre reinforced composites.

The tensile properties of Agave Americana fibre are not uniform. This can be explained by the fact that it is a natural fibre and natural fibres are subject to growth irregularities to the extent that fibres from the same plant are not uniform in size and properties. The outer leaf sheaths produce the strongest fibres while the inner sheaths produce the weakest fibres. The central fibres in a leaf have a high fracture strain while the peripheral fibres of leaf have lower tensile strength and higher extension. [14, 26]. Agave Americana fibre is rigid and has low elongation at break values. The wet strength of fibre is lower than that of in dry. However, elongation of break is higher when fibre is in wet condition [14, 16].

4.3.2 Rupture Behavior. Mechanical behavior of technical fibre of Agave Americana fibre is highly related to its fine structure. The fibre is more or less cracked depending on the elongation and this phenomena generates the deformation of the elementary fibres in a bundle. At small deformations, corresponding to elastic behavior, the lignin carries the applied load without passing it to the elementary fibres. Hence we can say that at small and medium deformations, physical and mechanical properties of technical fibre are related to physical and mechanical properties of wax and gum matters that link elementary fibres. At medium deformations, the elementary fibres begin to switch on without being really deformed. The spring form of the elementary fibres is responsible for extension behavior of fibre at this stage. At high deformation corresponding to plastic deformation, elementary fibres begin to be deformed until the rupture.



(a) Small Deformation (b) Medium Deformation (c) High Deformation

Fig. 4: Agave Americana fibres deformed at different levels.

Physical and mechanical properties are related to the properties of elementary fibres. In the rupture zone, the resistance of elementary fibres, their number, their dispersion and their adhesion to the natural matrix (lignin) explain the behavior of technical fibre [26].

4.4 Chemical Properties

4.4.1 Chemical Composition. Agave Americana fibres can be considered as naturally occurring composites consisting mainly of cellulose fibrils embedded in a lignin matrix. The main constituents of these fibres are cellulose, lignin and hemicellulose. However constituents like pectin, waxes, water-soluble substances, etc. are also present in small quantities. It is important to mention that the chemical composition of natural fibres like Agave Americana depends on various factors such as type of soil used, weather conditions, age of the plants, etc. The property of each constituent contributes to the overall properties of the fibre. Table 1 Exhibits the chemical composition of Agave Americana fibres [1].

Table 1: Chemical composition of Agave Americana fibres.

Sr. No.	Composition	Amount (%)
01.	Cellulose	68-80
02.	Hemicellulose	15
03.	Lignin	5-17
04.	Wax	0.26
05.	Moisture	8

4.4.2 Effect of different chemicals on Agave Americana fibres. Agave Americana fibres are stable in weak acids and weak alkalis, but has no effect on structure and tenacity of

Agave Americana fibre. Therefore fibres can be safely treated with bleaches, detergents and dyes which are weak basic or weak acidic in nature. Whereas in strong acids and strong bases, fibres were dissolved or distorted. The bonds connecting the subunits are unstable to acid and the result is a loss of tensile strength. Reaction with concentrated sodium hypochlorite results into bleaching of fibres, but after prolonged exposure, the fibre losses its strength and get disintegrated. This indicates that oxidizing solutions like sodium hypochlorite should only be used when cold and diluted and according to instructions given by the manufacturer. Therefore chlorine bleaches should be used for a short period of time and must be rinsed out thoroughly to avoid further damage to the fibre [13].

5. APPLICATIONS OF AGAVE AMERICANA FIBRES

Agave Americana fibres exhibit high tensile strength and have low density due to which in early days they are used in manufacturing twines and ropes for fishing and agricultural purposes. Further these fibres can be used for production of nets, carpets, rugs, doormats, bags, sacks, fish stringers, furniture webbing, drapes, upholstery padding, saddle pads, cushion stuffing, brush brittles, baskets, bracelets, headbands, sandals, decorative items, clothing and other woven objects. Papers also have been made from lower grade Agave Americana fibres. Agave Americana fibres are also used for embroidery of leather in a technique known as piteado [3-6, 9, 12, 13].

For potential uses, research findings showed that Agave Americana fibre can also be utilized for other industrial purposes. There can be a potential application of Agave Americana fibres in composites as well as in nonwovens. Bio plastics, geotextiles, carpets, fibre boards, dart boards molded furniture can also be manufactured using Agave Americana fibres. Agave Americana fibres can also be used in construction materials [12, 14, 27, 28].

6. ENVIRONMENTAL BENEFITS OF AGAVE AMERICANA PLANT AND FIBRES

Agave plants have four times more cellulose than the fastest growing eucalyptus tree, and it effectively captures CO_2 from the atmosphere. When properly maintained, it requires irrigation only three to four times per year. Agave Americana fibres have minimal environmental impact. The production does not need agricultural chemicals. During processing Agave Americana fibres produces only organic wastes which can often be reused. The by-products after the processing of the agave takes the form of bio-degradable organic matter which can be used as “compost” or as organic material to be returned to the land and as fuel for biogas production. In this way, they enhance soil fertility. Unlike synthetic fibres Agave Americana fibre is 100% biodegradable during its lifetime and Agave Americana ropes and other products can be recycled as paper. The plants can be also used as an effective hedge to protect crops and land from predators and the extensive root system helps to reduce soil erosion in arid areas. All the parts of Agave Americana plant can be used in many applications. This is truly a “no waste” plant.

7. CONCLUSION

Agave Americana fibres can be used in technical applications such as reinforced composite materials, paper making, non-woven fabrics, geotextiles, etc. The “zero-waste” utilization of the plant would enable its production and processing to be translated into a viable and sustainable industry.

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