The Role of Research & Development in the Global Competitiveness of Natural Fibre Products

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ABSTRACT

Natural fibres and their products were prevalent since the early civilization of our society. Since then, the utilisation and economic impact of natural fibre cultivation and down stream processing and products have been well established all over the world. This is attributed to the fact that every part of the fibre crop provides opportunities both in up and down streams processing for developing conventional as well as new products for wide ranging applications in textiles, packaging, building, automotive, aerospace, marine, electronic, leisure and household uses. This paper will provide and overview of the current production and consumption of natural fibres and the current status of research and development. It will also deal with future drivers for the growth and competitiveness of natural fibres. The competitive pressure from the new class of biodegradable synthetic fibres produced from naturally renewable raw materials will be also discussed.

INTRODUCTION

The economic impact of natural fibre cultivation and beneficiation is well established and recognised as a key driver for sustainable growth through agricultural and industrial revolutions, particularly for developing nations. Even developed countries, like the USA, Canada and the EU, have recently recognised the importance of natural fibres, such as flax, hemp and kenaf, which have been grown throughout the world for millennia, as a new source of products for both existing and new high-value added markets in textiles, such as composites, paper/pulp, and industrial/nutritional oils [1-3]. The possibilities of using all the components of the fibre crop provide wide ranging opportunities both, in up and down stream processing, for developing new applications in textiles, packaging, building, automotive, aerospace, marine, electronics, leisure and household.

The key drivers of growth and renewed interest in the field of natural fibres are attributed to new environmental awareness and regulations, such as the end-of-service life for automotive industries by the EU and carbon credit under the Kyoto protocol for minimising “green house” gas emission. While the discussion in this paper will be limited to only natural fibres from renewable agricultural crops for textile based applications, the demand for wood fibre is continuing unabated and showing no sign of slowing down, despite increased pressure to preserve forests and minimise carbon emission. The search for alternatives to this man-made deforestation will also stimulate interest in natural fibres from renewable agriculture [4].

CURRENT STATUS OF NATURAL FIBRES

(a) Production and Consumption

The combined global fibre production of manmade and natural fibres has increased from about 25 million tonnes in 1965 to 70.5 million tonnes in 2005 as shown in Figure 1. During this period, the share of natural fibres has decreased from 77% to 41%, whereas the per capita consumption of fibres has almost doubled, with a major increase in the developed nations [5]. The use of natural fibres for textile applications is currently dominated by cotton, wool and silk, which together account for almost 26.8 million tonnes out of 32.5 million tonnes of all natural fibres combined as shown in Table 1 [5]. Of these three natural fibres, cotton is dominant, accounting for 25.5 million tonnes of production in 2005 in comparison to 1.224 million tonnes of wool and 97 thousand tonnes of silk fibres [5]. This accounts for 92.1%, 4.4% and 3.5% contribution of cotton, wool and silk, respectively amongst them. The consumption of cotton has increased from about 10 million tonnes in 1960 to 25.5 million tonnes in 2005, the world average yield increasing from about 300 kg/ha in 1960 to 625 kg/ha in 2005 [5, 6]. In comparison to cotton, wool production has not shown much of a change, the average world production of wool was about 1.5 million tonnes in 1960, which then increased to 2.0 million tonnes in 1990, after which it steadily declined to the current average of about 1.2 million tonnes in 2005.

The total annual production of other natural fibres, such as kapok, ramie, flax, hemp, jute and jute-like, sisal, coir, etc., have remained largely constant — 5.9 million tonnes in 1965 to 5.7 million tonnes in 2005 as shown in Table 2 [5]. Amongst these, jute and jute like fibres occupy the dominant position, having an annual production of about 3.3 million tonnes in 2005, as shown in Table 2. During the period of 1965 to 2005, only kapok, ramie and coir fibres have shown an appreciable increase in production, all the other fibres having either remained constant, as in the case of flax or declined, as in the case of hemp and sisal, as shown in Table 2 [5].

The relative costs of flax, abaca, jute, sisal, coir, wood fibres and straws (mostly used in composites) in comparison to cotton are 70%, 50%, 22%, 20%, 16%, 7% and 4%, respectively. The relatively high prices of cotton and flax are a clear reflection of their demand and predominant use in high value added products, such as textiles and apparels [7, 8].

What is responsible for the differences in the consumption and production of these natural fibres besides differences in price? The answer lies in their physical and chemical properties, morphology, processing conditions, resultant products and applications and accumulated investment in research and development.

(b) Properties of Natural Fibres

The physical, chemical, mechanical and morphological properties of various bast and plant fibres have been compared by Franck [9]. Table 3 shows the physical and mechanical properties of some important natural fibres derived from plants. The dominant position of cotton can be appreciated in terms of its fineness, length, strength and elongation at break together with well established processing techniques and the considerable research efforts devoted to utilisation, from production to final product. Its suitability for apparel products is responsible for its high level of consumption and production. Other fibres, such as flax, jute and hemp have a higher tensile strength than cotton, but they are much coarser, due to problems in their extraction and relatively poor elongation at break which is also negatively influencing on their processing and applications. Most of these natural fibres are lighter due to their favourable density in comparison to other synthetic fibres and metallic materials, therefore applications in developing newer lighter composites are at the forefront of all development efforts. This attribute in combination with their excellent mechanical properties are advantageous where lighter and stronger materials are required, especially in transportation applications, where energy efficiency is influenced by the weight of the fast moving mass, for example automobiles and airplanes.

The physical and chemical morphology of natural fibres, their cell wall growth patterns and thickness, dimensions and shapes of the cells, cross-sectional shapes, distinctiveness of lumens, etc. besides their chemical compositions, affect the properties of the fibres. The readers are referred to excellent treatises by several authors [9-11] documenting the interacting effects of these parameters on the fibre quality.

CURRENT STATUS OF R&D

(a) Agricultural

Genetic modification of cotton plant genes has proved to be the single most important factor in increasing the production of cotton in recent years. This modern agricultural biotechnology aims at controlled manipulation of selected genes for achieving particular advantages, such as improved yield, disease resistance, insect and weed control, and stress tolerance [12, 13]. The genetic engineering of the cotton plant is still directed more to crop management, through insect and weed control, rather than to improving yield potential and fibre quality. This is attributed to economic and environmental considerations as insect and weed control using pesticides and herbicides are expensive and environmentally problematic. Economic, social and environmental benefits have accrued through reduced pesticide use, effective crop management, reduced production costs, improved yield and profitability, reduced farming risk and the opportunity to grow cotton in areas severely infested with pests [13]. Though limited research is reported so far, newer breeding strategies to improve yield and fibre quality with specific traits will certainly add more value to cotton fibre [14, 15]. Fibre quality data for transgenic cultivars suggest that fibre properties are acceptable. For example, a collateral approach to reduce short fibre content should be considered with simultaneous improvement in single fibre tensile strength. However, a further challenge is to integrate a strategy for fibre improvement with one that allows for simultaneous yield gains [14]. The success storey of genetics in cotton can be replicated in other plant fibres as well. Rather limited research efforts are underway in the case of jute, flax and hemp fibres, with most research efforts being directed to improving productivity, yield and the effect of early flowering on fibre quality [15, 16].

(b) Fibre Extraction

Considerable research efforts are directed to improve mechanical harvesting, picking and ginning practices in the case of cotton. The focus of modern ginning research is to maximise the ginning out-turn (cotton yield) and to minimise the trash content in the lint without damaging the fibre or adversely affecting subsequent processing. Such a balance approach has provided benefit to the down stream processing, due to a reduced intensity of the cleaning processes in spinning and thereby improving the resultant yarn quality. New automatic process controls in ginning have appeared recently, including the automatic monitoring and control of the fibre moisture content within the United States Department of Agriculture (USDA) recommended drying range of 5.5-7.5% moisture, automatic trash, short fibre, colour and neps monitoring and controls [17]. It is claimed that with Uster Intelligin the quality of cotton can be customised based on the incoming harvest quality to fit with the grower's price schedule and specifications from a mill at maximum throughput [17].

The question of improved retting processes for fibre degumming, which allows for the separation of the fibre from the woody part, and removal of non-cellulosic components, such as pectin, hemicellulose, lignin, waxes and fats for obtaining good quality fibres from the plants, such as flax, hemp, sisal, pineapple leaf, etc., is well researched [18-25]. Besides traditional dew and water retting processes, researchers have studied chemical and enzymatic retting, ultrasonic treatment, steam explosion and more recently osmotic pressure methods [26]. The steam explosion technique is also employed for extracting fibres from bast plants and it is claimed that individual and elemental fibres can be derived without the disintegration of the single cells [27, 28]. Enzymatic retting has not yet gained wide commercial acceptance, and although osmotic retting offers some promise, dew and water retting will remain as the practical method for de-gumming bast fibres in the foreseeable future, particularly in the developing countries where enzymes are expensive. New technologies are being developed for the effective decortication of un-retted bast fibres, which, if successful, will improve the competitiveness of such fibres vis-à-vis cotton [29].

(c) Processing

The processing of cotton into spun yarns is the most widely researched area, both by spinning machinery manufacturers and textile researchers. The quality of modern spinning equipment and processing techniques has improved to such an extent that the quality standards of spun yarns, as classified by the USTER Statistics, has improved considerably over the past few decades [30]. Readers are referred to the vast literature on the subject available in reputed textile journals, books and also on internet.

The traditional processing techniques for bast fibres, such as hemp, flax and jute, are outdated and economically unable to produce competitive products, except in a few isolated cases. New techniques for processing bast fibres on conventional staple spinning systems are being developed with a view to utilize existing spinning equipment without the need for the huge capital costs for specialised wet spinning machinery [31]. Attempts have been made to spin jute/viscose and jute/cotton blends on short-staple spinning equipment but spinnability is limited to the coarser yarn counts due to the inherent coarseness of jute and attendant processing problems [32, 33].

Through the applications of conventional or nanotechnology, newer finishing techniques and fibre modifications, such as ultraviolet protection, flame resistant and fire retardant treatments, antimicrobial finishing, easy care and wrinkle resistance, will continue to make rapid strides in the foreseeable future for adding multi-functionality and value to conventional textiles for apparel and industrial uses.

(d) Products

Fabrics and Apparel

Newer products from cotton are focused particularly on the apparel segment, creaseless/wrinkle-free cotton garments for smart casual wear, low shrinkage pure cotton fleeces, quality flatbed knits and the introduction of cotton-rich socks, are some examples of current trends. Furthermore, there is an opportunity for novel blends with cotton, e.g., 70:30 cotton/wool and cotton/flax to name a few, and altering cotton fibre surface properties to change the handle of cotton textiles and garments [32-34]. Due to its comfort and softness, cotton is still the first choice of sportsman and active consumers according to the survey of Cotton Incorporated [35]. This has led to the development of new moisture management finishing technologies in which the treatment actually reduces the absorption capacity of the fabric while taking the advantage of natural wicking properties of the cotton fibre. This new finishing treatment is termed ‘Wicking Window’ which creates a differential between the two surfaces of a cotton fabric which allows perspiration to move from the inner surface to the outer surface for easy spreading and rapid evaporation. This helps in keeping the wearer’s body dry and reducing clinging, therefore, enhancing the feeling of comfort [35].

Nonwoven

Beyond apparel markets there are opportunities in nonwoven materials and technical textiles. With the increasing awareness in environmental conservation, the use of natural fibres in disposable nonwovens is increasing. The disposable products for applications, such as wipes, baby diapers, adult incontinence, sanitary and feminine hygiene, medical etc. are being developed from the natural fibres due to their moisture and liquid absorbency properties, biodegradability and energy-saving natural renewal characteristics. Flax and viscose fibre based biodegradable wipes produced on spunlacing technology exhibited comparable physical, mechanical and absorption properties besides serviceability and biodegradability [36]. Environmental measures to regulate the disposal of industrial wipes and solvents applied to them are the drivers for the renewed research interest in natural fibre based products. Cotton-surfaced and cotton-core nonwovens made by employing special laminating techniques exhibits excellent soft handle, breathability, absorbency and tensile properties, making them ideal for many medical applications, such as isolation gowns, hospital drapes and gowns, shoe covers, head covers, underwear, pillowcases, acquisition, core and back layers of diapers, feminine hygiene pads, baby wipes, etc. [37]. Cotton based thermal bonded nonwovens, from cellulose acetate as a binder, provide innovative products to replace conventionally thermal bonded nonwovens from petroleum based polymers [38].

In medical applications, super-absorbent cellulosic fibres, such as cotton and viscose are gaining ground for wound care. These fibres can be carboxymethylated with chloroacetic acid under alkaline conditions. The treated fibres have much higher water and liquid absorbencies, which enable the wound to heal quickly by removing the exudates [39].

Natural fibres, such as flax, hemp, jute, coir, sisal, and kenaf, are being used in geotextiles and horticultural applications. Woven, knitted and nonwoven materials from natural fibres are used for reinforcement, drainage, erosion control and filtering applications in combination with other geosynthetics. Natural fibre based nonwoven geotextiles are suitable for applications where they have to perform temporary functions for a limited time and then degrade and dissolve in the ground [40].

Fibre Reinforced Composites

The challenge for the automotive industry is to produce lighter, inexpensive, environmentally sustainable vehicles that are safe, attractive, energy efficient and economical to operate. The social push and increasing environmental awareness of consumers have provided the ground for increasing the use of so called 'green' materials in the automotive sector. Advantages of using natural fibre reinforcement in automotive applications include:

- No net release of carbon dioxide in the environment.
- Up to 40 percent less weight compared with fibreglass based composites.
- Production consumes one-fifth the energy of typical fibreglass production.

The use of natural fibre composites in the European automotive market is higher than that in the U.S. Although natural fibre reinforced composites are not yet considered mature materials, most of them manufactured in Europe and are being currently supplied to the automotive industry. The properties of natural fibre composites do not currently match those of glass fibre reinforced composites. Nevertheless, with new research initiatives it is expected to reach the level of about 50 to 70 percent of the properties of equivalent glass fibre reinforced composites. The common technique of fabrication has been compression moulding. Compression moulding is simple and can take advantage of natural fibre nonwoven which can be impregnated with thermoplastic or thermoset polymers to produce the composite cost-effectively. Research is also being conducted on injection moulded natural fibre composites. Many automotive companies are looking at the possibility of injection moulding for producing lower cost interior and exterior panels [41-44]. Germany has become the leader in the use of natural fibre composites. The German auto manufacturers, Mercedes, BMW, Audi, and Volkswagen and others, have taken the initiative to introduce natural fibre composites for interior and exterior applications as shown in Table 4 [45]. The first commercial example is the inner door panel for the Mercedes-Benz, composed of 35% Baypreg F semi-rigid (PUR) elastomer from Bayer and 65% of a blend of flax, hemp and sisal. Flax, hemp, sisal, wool and other natural fibres are also used to make components in various models of Mercedes-Benz as shown in Figure 2. The moulding process, which was first introduced in 1997, is based on the use of natural fibre nonwovens made of flax and sisal pressed with PUR systems at an approximate ratio of 2:1. The successful manufacture of these lightweight, stiff and strong composite structures depends upon three interrelated variables, the type of reinforcement material, the chemistry of the matrix and the processing equipment that integrates them.

The European and North American market for bio-fibre reinforced thermoplastic composites reached 685 000 tonnes and a value of US$ 775 million in 2002. Wood-polymer composites accounted for 590 000 tonnes, with the balance being the other bio-fibre composites. Germany occupies a dominant market position in terms of product innovation, research and commercially available products. Two-thirds of all natural fibres used in the automotive industry within Europe are consumed in Germany. In Germany, car manufacturers are aiming to make every component of their vehicles either recyclable or biodegradable. Indeed, therefore, the use of bio-fibres has risen dramatically in recent years. The German automotive industry, for example, has increased its usage, from 4 000 tonnes in 1996 to 18 000 tonnes in 2003 [46, 47].

Besides ground transportation, natural fibre reinforced composites have also made significant strides in marine and recreational equipment, such as boats, canoes, surfing boards, etc. For example, a bio-boat developed from natural fibre reinforced composites having a thin polymer coating, is claimed to have a 10% lower weight but a higher impact resistance than conventional products [48]. Other applications of renewable biocomposites reported so far include the interior of railway compartments, industrial safety helmets and smaller marine vehicles [48].

The high stiffness and eco-friendly composition of natural fibre composites also make them an ideal choice for many moulded houseware, plant pots and cosmetics packaging, other interesting applications are decking and railing systems in the construction sector [49].

The mechanical properties of polypropylene composites reinforced with sisal, hemp, coir, kenaf and jute have been investigated in a recent study to ascertain if they can provide properties comparable to conventional glass fibre reinforced composites [50]. Among all the fibre composites tested, coir reinforced polypropylene composites exhibited the poorest mechanical properties whereas hemp composites showed the best. However, the coir composites displayed higher impact strength than the jute and kenaf composites [50]. There is a considerable amount of published material available in this area and the readers are referred to an excellent work by Mohanty et al [51] which provide wide ranging information on natural fibre composites.

FUTURE R&D DRIVERS FOR GROWTH

In agronomy and agricultural research, the modern biotechnology and agro-genomics hold considerable promise for future development. New research should be directed towards developing plant fibres with superior properties besides improvements in yield. Probably, researchers will move from biotechnology now to bionanotechnology in future for redesigning bio-molecules to achieving changes at sub-atomic level and thereby achieving properties superior to those achievable through conventional biotechnology. The lack of an adequate shelf life together with high variability in the physical and mechanical properties of natural fibres is the obstacle in many high-value technical applications where the tolerances are narrow. Cross-disciplinary research in this field should therefore focus on improving uniformity of the physical and mechanical properties and improved storage life of natural fibres and their products.

Fibre extraction and ginning technologies for cotton fibres have reached maturity now. Further refinement will be mostly directed to process control and optimization. Novel methods for deriving more elemental fibres from the bast plants will continue to improve the suitability of bast fibres in high value added processing. Researchers will attempt to develop simple and cost-effective processes for decortication and extraction to derive elemental fibres without having to resort to expensive enzymatic treatments and inconvenient chemical processes. The effluent treatment and associated environmental pollution laws will continue to offer challenges in finding economically viable alternative to chemical retting. To promote the use of flax, hemp and kenaf fibres in apparel applications, the fibre extraction research will have to be mindful of the requirements of existing equipment in the down stream processing, such as spinning. For effective commercialization on a large scale and producing economically viable and attractive products from bast fibres, which can compete well with other natural fibre based products, it is imperative that scientists focus on the realities of capital intensiveness of specialised processing machinery.

Use of natural fibres, other than cotton, wool and silk; in nonwoven products for automotive applications, will continue and major research efforts will be directed to optimize performance and minimize cost due to the competitive pressure witnessed by the automobile manufacturers. The current limitations of natural fibre reinforced composites lie in their lack of strength, impact resistance and poor resistance to cracking, which prevent their applications in load bearing structural and exterior components. Therefore, research will need to be directed to overcome the above limitations by developing new cost-effective additives and compatibilizers, improved processing conditions, understanding the fundamental mechanics of the fibre-matrix interface and stress transfer phenomena and reduction in moisture affinity. These research efforts should allow better use of raw materials, increased efficiency in processing, improved performance and new market opportunities. Emerging research trends will be concentrated in developing fully biodegradable composite materials by utilising new bioresins derived from natural materials. Such natural fibre based biocomposite material has to remain stable during their expected service life by preventing pre-mature biodegradation. In other words, control on biodegradability, through induced triggers, will be the focus of future research on natural fibre reinforced biocomposites.

Future research in the field of deriving nano-fibrils with adequate aspect ratio will certainly open-up new possibilities for natural fibres in the emerging field of nanotechnology. Such nano-fibrils will become an ideal reinforcement in a polymeric medium for the development of nanocomposites with special functional properties.

On the other hand, besides the development of regenerated cellulosic fibres, research on new biodegradable synthetic fibres from naturally renewable raw materials will continue. Obviously, it will be relatively easy to develop such fibres to meet with the exacting standards as required in the down stream processing. This will represent strong competition to agriculturally produced natural fibres and only well directed research efforts will secure the future of natural fibres in this ever increasing competitive scenario!

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Table 1: Production / Consumption of Cotton, Wool and Silk [5]

Year	Natural Fibers				
	Cotton	Wool	Silk	TOTAL	± in %
2005	25.459	1.224	97	26.780	7,0%
2004	23.710	1.221	98	25.029	10,3%
2003	21.357	1.229	97	22.683	-0,4%
2002	21.404	1.267	92	22.763	3,7%
2001	20.536	1.317	88	21.941	2,1%
2000	20.067	1.344	86	21.497	1,1%
1999	19.820	1.363	83	21.266	6,4%
1998	18.527	1.386	77	19.990	-1,0%
1997	18.690	1.424	75	20.189	-0,2%
1996	18.727	1.439	71	20.237	3,3%
1995	17.998	1.510	92	19.600	0,7%
1994	17.774	1.618	69	19.461	-0,9%
1993	17.885	1.678	68	19.631	-0,2%
1992	17.870	1.736	67	19.673	-0,3%
1991	17.745	1.928	67	19.740	-8,0%
1990	19.406	1.988	66	21.460	0,2%
1989	19.388	1.955	66	21.409	1,6%
1988	19.122	1.886	64	21.072	2,1%
1987	18.743	1.832	63	20.638	-0,5%
1986	18.891	1.789	63	20.743	17,0%
1985	15.929	1.744	59	17.732	9,2%
1984	14.440	1.744	56	16.240	3,4%
1983	13.993	1.657	55	15.705	1,5%
1982	13.782	1.632	55	15.469	1,8%
1981	13.516	1.616	57	15.189	-0,2%
1980	13.575	1.599	53	15.227	2,7%
1975	11.723	1.578	48	13.349	-0,2%
1970	11.784	1.659	41	13.484	0,1%
1965	11.884	1.484	33	13.401	2,9%
1960	10.113	1.463	31	11.607	4,2%
1950	6.647	1.057	19	7.723	n/a

Unit: '000 tonnes

Table 2: Production / Consumption of Other Natural Fibres [5]

Year	Other Natural Fibers							
	Kapok	Ramie	Flax	Hemp	Jute *	Sisal	Coir	TOTAL
2005	122	250	772	68	3.250	328	954	5.743
2004	123	249	789	67	3.247	314	948	5.736
2003	122	249	751	70	3.228	306	929	5.655
2002	126	243	767	75	3.275	285	907	5.677
2001	130	201	613	63	3.357	299	915	5.578
2000	130	165	482	54	3.050	407	945	5.234
1999	125	124	477	61	2.996	348	971	5.101
1998	123	127	401	74	3.076	284	931	5.016
1997	125	143	392	65	3.824	339	984	5.872
1996	124	149	563	67	3.626	290	1.043	5.862
1995	117	154	740	56	3.026	319	1.011	5.423
1994	108	124	592	52	3.329	322	728	5.255
1993	108	78	530	64	3.457	314	654	5.205
1992	106	72	592	76	3.573	390	628	5.437
1991	101	71	731	66	3.705	427	577	5.678
1990	104	106	688	84	3.668	380	589	5.619
1989	95	201	803	108	3.443	399	544	5.593
1988	95	346	919	152	3.323	379	485	5.699
1987	93	602	949	168	3.556	364	450	6.181
1986	100	255	738	156	4.489	461	462	6.661
1985	95	94	763	157	4.569	499	462	6.640
1984	91	61	834	153	3.621	446	425	5.631
1983	92	55	797	146	3.488	422	402	5.402
1982	85	70	636	134	3.263	512	435	5.136
1981	89	60	610	149	3.670	524	391	5.493
1980	74	56	620	186	3.609	548	385	5.479
1975	77	52	803	236	2.904	778	419	5.268
1970	74	73	703	280	3.264	782	421	5.597
1965	76	62	803	341	3.398	829	384	5.893

Unit: '000 tonnes

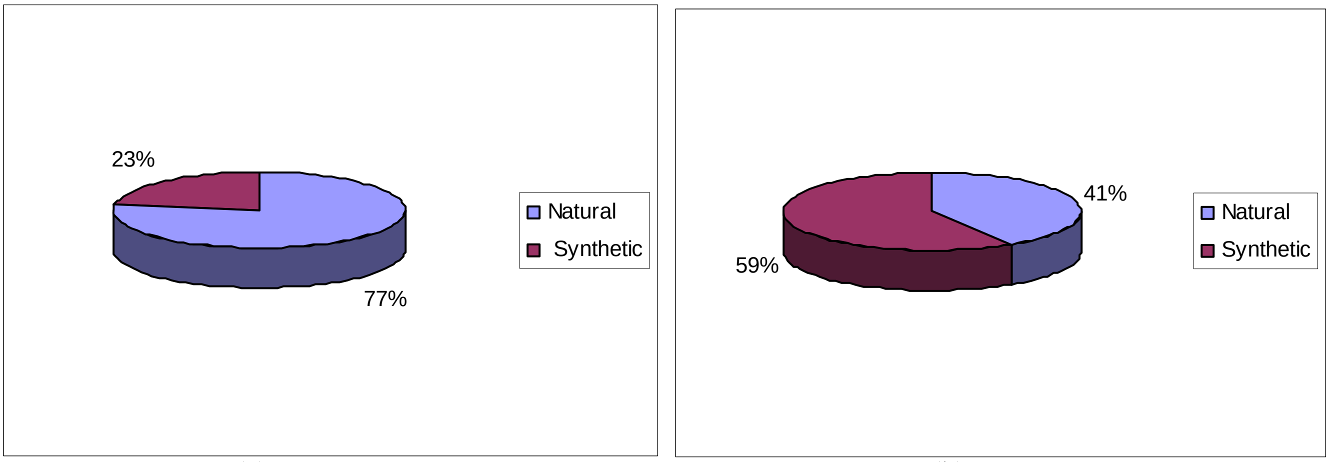
*** Jute and jute-like fibers**

Table 3: Properties of Some Natural Fibres from Plant Origins (Source: Ref. 9,51)

Fibre	Density (g/cm^3)	Fineness (µm)	Tensile Strength (MPa)	Elastic Modulus (GPa)	Elongation at Break (%)
Cotton	1.5-1.6	12-38	287-800	5.5-12.6	7-8
Flax	1.5	40-600	345-1500	27.6	2.7-3.2
Hemp	1.47	25-500	690	70	1.6
Jute	1.3-1.49	25-200	293-800	13-26.5	1.16-1.5
Kenaf	1.4	25-150	930	53	1.6
Ramie	1.55	20-125	400-938	61.4-128	1.2-3.8
Sisal	1.45	50-200	468-700	9.4-22	3-7
Pineapple Leaf	1.07 – 1.52	20-80	413-1627	34.5-82.5	1.6
Coir	1.15-1.46	100-460	131-220	4-6	15-30

Table 4 Current Use of Bio-Fibre Reinforced Composites in Different Models by Different Manufacturers

Manufacturer	Model
AUDI	A3, A4; A4 avant, A6, A8, Roadster, Coupe (seat back, side and back door panel, boot lining, spare tire lining)
BMW	3,5 and 7 Series and others (door panels, headliner panel, boot lining, seat back)
Daimer/Chrisler	A-Series, C-Series,, E-Series, S-Series, (door panels, windshields/dashboard, business table, pillar cover panel
FIAT	Punto, Brava, Marea, Alfa Romeo 146, 156
FORD	Mondeo CD 162, Focus (door panels, B-pillar, boot liner)
OPEL	Astra, Vectra, Zafira (headliner panel, door panels, pillar cover panel, instrument panel
PEUGEOT	New model 406
RENAULT	Clio
ROVER	Rover 2000 and others (insulation, rear storage shelf/panel)
SAAB	Door panels
SAAB	Door panels, seta back
SAAB	Golf A4, Passat Variant, Bora (door panel, seta back, boot lid finish panel, boot liner)
SAAB	C70, V70



(a) (b)

Figure 1: Consumption of Natural and Synthetic Fibres in 1960 (a) and 2005 (b), Source: Ref [5].

Figure 2: Different Components of Natural Fibre Reinforced Composites in Mercedes Sedan (Source: Ref. 44).