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Plant Fibres & Its Potential for Sustainable Development

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Abstract

Lignocellulosic fibres have served human beings as cords and coarse fabric for thousands of years and proved their sustainability. Hundreds of such fibres are available from bast (i.e. jute, flax, ramie, hemp), seed/fruit (i.e. coir, palm) and leaf (i.e. pineapple, sisal) of different plants. But presently, the manufacture of low-cost and attractive manmade fibres has attained the major share of the world's industry, resulting in a considerable decrease in the market share of natural fibres. To regain the lost glory of these fibres, more knowledge and education regarding natural fibres highlighting their positive qualities i.e., eco-friendliness, renewability, biodegradability, sustainability, hygroscopic nature, dye ability, low carbon footprint etc, for the consumers are essential. They have enormous potential to replace many manmade fibres in apparel, furnishing, and industrial uses. Bio-composites, particularly in the automobile sector, were found to be the most potential area. Composite is an effective way of applying natural fibres regarding environmental, economic, and technical feasibility. Selection of the most suitable natural fibre among the many alternatives for a particular application requires an integrated analysis comparing properties, availability, and price followed by a decision-making process. Some other potential industries may be furniture, medical, sports, construction, and household applications. Well-planned marketing strategy, new market-guided product development, value addition to other bio-wastes, the satisfaction of consumer need, proper branding of products, effective advertising and promotions are essential to increase the uses of lignocellulosic fibres along with need-based R & D effort and government initiative.

Key words: *Future potential; Lignocellulosic fibres; Market scenario, Products; Properties.*

Introduction

Since the early days of human existence, they depended upon animal skins and furs for warmth. However, as the years passed, their susceptibility and hide became more tender. Hence, man began to look for something that would keep him warm as well as elegant and comfortable. Consequently, he found the long, thin, and sufficiently strong fibres from plants and animals. Due to continuous endeavor, he was able to convert the fibres into flexible, warm, and comfortable material named cloth. In this way, textiles were developed over many hundreds of years with the importance of the second basic need of human beings after food.

The globe is blessed with plenty of renewable natural fibre resources from plants and animals. Hundreds of different natural fibres have been examined as raw materials for cloth. It was found that many of these fibres, along with their by-products, have immense potential for utilization as raw material for textile and non-textile applications.

The most suitable natural fibres have been selected as cotton, wool, jute, flax, and silk; and have become the basis of the textile industries of the world. Before the Industrial Revolution, people were engaged in the preparation of yarn and fabric as a household industry. It was considered a skilled occupation from one generation to the next. By the fourteenth century, the mechanisation had been started slowly. During the eighteenth century, the Industrial Revolution was initiated when steam rotated the wheel. In the nineteenth century, advancement in scientific knowledge continued the application of inventive and engineering skills to the textile processes. During the last fifty or sixty years, the increase in speed of production, quality consciousness, and, subsequently, automation has really begun to play a major role in the textile industry. As the chemistry and physics of textile fibres were learned, a range of completely new fibres was created, and this changed the entire outlook of the textile trade. Rayon, nylon, and other man-made fibres are being manufactured in enormous quantities with specific quality requirements, and nature's monopoly in textile fibre need has been broken. Since then, the research, exploration, and application of natural fibres have decreased drastically, and their technological development has been stopped. Due to continuous effort, cotton, silk, and wool recovered their glory to some extent in the present context.

These fibres, along with some other natural fibres have sustained and served the human beings for thousands of years. But presently, the manufacture of low-cost and attractive rayon and synthetic fibres has attained the major share of world industry, and output is increasing due to process friendliness and tailor-making opportunity. Natural fibres are facing great difficulty in competition with these issues. Therefore, to regain the lost glory of natural fibres, more knowledge and education regarding natural fibres highlighting their positive qualities i.e., eco-friendliness, renewability, biodegradability, sustainability, hygroscopic nature, dyeability, low carbon footprint, etc, for the consumers are essential. The advantages and disadvantages of natural fibres are shown in Table 1. Moreover, new applications of available, under-exploited, or unexploited natural fibres are important in exploring their property-application fusion with the help of research and development.

Table 1. Advantages and Disadvantages of Natural Fibres Product

Advantages of Natural Fibers	Disadvantages of Natural Fibers
1. **Environmental Aspects:** • renewable resources • low energy requirements during production • carbon dioxide neutrality • disposal by composting	• Lower strength, especially impact strength
2. **Biological Aspects:** • natural organic products • no dermal issue for their handling • do not pose a bio-hazard upon disposal	• Variable quality, influenced by weather
3. **Production Aspects:** • non-abrasive • great formability	• Poor moisture resistance which causes swelling of the fibres
4. **Component Weight Issues:** • lightweight (less than half the density of glass fibers)	• Restricted maximum processing temperature
5. **Financial Aspects:**	• Lower durability; Poor fire resistance
6. **General Aspects:** • safer crash behavior in tests (*i.e.*, no splintering) • good thermal insulation and acoustic properties due to their hollow tubular structures • high specific strength • good sound insulation • price fluctuation by harvest results or agricultural politic	• Poor fibre/matrix adhesion

[Namvar F., Jawaid M., Md Tahir P., Mohamad R., Azizi S., Khodavandi A., Rahman H. S. & Nayeri, M. D. (2014) **Potential use of plant fibres and their composites for biomedical applications,** *BioRes.,* 9(3), 5688-5706.]

Natural fibres can be divided into three main classes according to their source, (a) Vegetable fibres; (b) Animal fibres; (c) Mineral fibres. Vegetable fibres include the most important of all textile natural fibres. Cotton, flax, jute are widely used cellulose based vegetable fibres produced by plants. Animal fibres include mainly wool and silk, which are based on proteins from which much of the animal body is made. Mineral fibres are of limited importance in the textile trade. Asbestos is the most useful fibre of this class; it is made into industrial fabrics. Despite those, man has taken fibre-forming substances like cellulose or protein from nature and manipulated them into a fibrous form. Natural cellulose is the base material of artificial silk. Similarly, natural polymer made from the proteins of peanuts, milk, maize, and soybean make protein fibre.

The changes in natural and manmade fibres world production are given in Figure 1. Table 2 shows the world production in metric tons of the major lingo-cellulosic fibres.

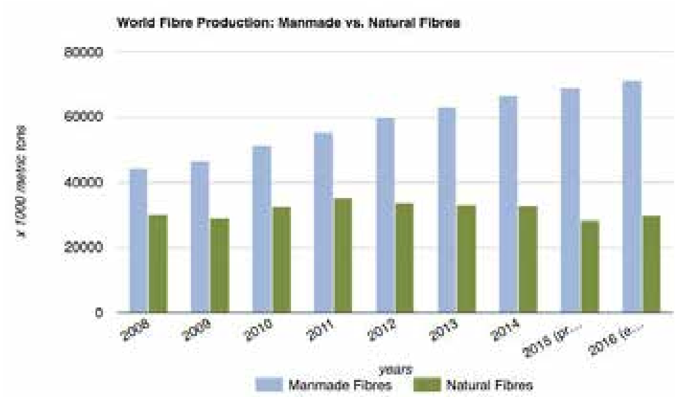

Fig. 1. Changes in natural and manmade fibres world production

[http://news.bio-based.eu/60-million-households-produce-natural-fibres-production-reached-30-million-tons-in-2016/]

Table 2. World Production in metric tons*

Fibre	Production, metric tons
Jute	3,400,000
Flax	314,556
Coir	1,099,233
Ramie	110,740
Sisal	279,963
Hemp	76,112
Banana	200,000
Nettle	Abundant
Pineapple	24,800,000
Sunhemp	130,000
Kenaf	770,000
Abaca	90,000

*2008-2015: FAO Statistics, 2014, 2015 & 2016, IWTO market information 2015, http://faostat3.fao.org/

A lot of research and promoting strategies have been adapted for cotton, wool, and silk in particular, and they have already been established in apparel and fashion textiles as sustainable fibre; they have been excluded from discussion in this chapter. The next important fibres are jute and flax, which are lingo-cellulosic. Jute is industrially successful in making packaging and carpet-backing. Flax utilisation is limited in very few areas and also slowly decreasing. The discussion in this chapter is restricted to lingo-cellulosic natural fibres because they have the enormous potential to replace petroleum-derived manmade fibres in apparel, furnishing, and industrial uses to reduce the pollution of nature. In this context, it is an important task to understand those fibres scientifically, along with the exploration of new fibres and apply the acquired knowledge in suitable applications. The chemical composition and properties of commercial lignocellulosic fibres are shown in Table 3 & 4.

Lesser known or under exploited fibres

This planet is the store and source of several plant fibres of various natures and properties. A small portion of it is used in the organised sector or semi-organised sector. These are known to us. The research and development of plant fibres, whatever was done, is concentrated in that small part only. Many of such fibres were used for various domestic purposes by the peoples of unorganised sectors, which are unknown or lesser known to us though they have enormous potential.

Economics and current market scenario

Table 5 shows the available products of common lignocellulosic fibres and their plant origin. The list of the countries and Indian states producing different lignocellulosic fibres is shown in Table 6. The average annual consumption of natural fibres doubled over 50 years. However, the consumption of synthetic fibres increased more than six-fold for the same period, decreasing natural fibre market share by 29%. The projected trend for natural fibres is even less optimistic. Several consumer-focused studies have been undertaken to understand these changes in textile fibre consumption. The results indicate that natural fibres enjoy a relatively favorable position regarding consumer awareness and preference. Consumers in most countries have indicated that it is essential to them that clothes should be made from natural fibres, and that they are willing to pay more for textiles made from natural fibres. Natural fibres continue to be identified by consumers as best suited for current fashions and comfort. Market shows that the seller can sell at a much higher price by informing the presence of natural fibre in the product. The price of natural fibres is highly variable. Even then, it can be said that ramie, hemp, and flax are more costly than banana, jute, and sisal followed by abaca, coir, kenaf, pineapple, and nettle.

Maintaining market share for natural fibres is also integral to ensuring the survival of related industries. As with any product, stagnating or declining end-user demand has an impact on every segment of the natural fibre supply chain. Retailers are constantly assessing the available products and market demand. A shift to alternative products has a critical impact on hundreds of millions of people employed by the natural fibre textile supply chain, most of whom are in the developing world.

To combat this situation the following actions may be taken

- Well planned marketing strategy, execution and constant market research with highly qualified people
- Stability in raw material prices
- Technological intervention to make better product in lower production cost
- To explore the uses of bye- products
- To develop market demanded diversified product.
- R & D intervention to develop better fibre
- Product with better aesthetic and functional property, R & D intervention needed.
- Remove the main drawbacks of natural fibre
- Convert the disadvantages into advantages selecting proper application.
- To understand the consumer buying behaviour zone wise.
- Branding of products.
- Logo highlighting positive points, e.g. eco-logo.
- Effective consumer advertising in different media
- Celebrity endorsement
- In-store promotions

SWOT Analysis of Lignocellulosic fibres in Indian aspect

Strength

- Biodegradable & Renewable
- Low cost & Light weight
- Easy to produce and abundantly available
- Physical & mechanical properties good
- No energy consumption during fibre production

- High cellulose content
- Increasing demand
- Adequate organised labour for production and conversion
- Reduction of environmental impact
- Rural employment & development
- Educated manpower and technological expertise

Weakness

- Some fibres are not spinnable
- Sensitive to water absorption
- Variations in quality and performance
- Poor strength than synthetic fibre
- Lack of awareness
- Lack of skilled human resources
- Difficult to commercialise

Opportunity

- Biodegradable packaging
- Engineered product
- Economic development
- Employment generation
- Growing demand of green material
- Established market
- Target to sustainability

Threat

- Higher cost of manufacturing
- Infancy of value chain
- Uncertainties in value chain
- Availability of land
- Uncertainty in production and productivity
- Dependency on climatic condition and water
- Insufficient availability of some fibres
- Price fluctuation

Future trends and conclusion

Sustainability

In recent years, the environment and sustainability have become critical issues in the textile industry. We have seen an increase in advertising using 'green' attributes to sell products. Moreover, Proper utilization of indigenously available agricultural products to their full extent will not only solve the problems of their disposal, improve the economy of cultivation, and give new employment potential. However, it will also open up reservoirs of natural resources for various requirements of the globe. Specially, the countries striving for progress cannot afford to waste any part of agricultural products since this means a waste of resources.

Create faith on consumers

Endeavoring to be at the forefront of technology is not enough if the consumers do not know, understand, or trust the facts about the product. It is imperative that there is a clear and credible communication link between the producer and the end customers.

Performance fabrics

Performance fabrics already play an essential role in today's needs. It will be even more critical for natural fibres to continue to focus on technical innovation and to communicate these innovations effectively to consumers.

New consumer markets

As the disposable income of developing countries increases and their economic status improves, people tend to prefer clean surroundings in their possessions, including textiles. If natural fibre manufacturers can change the perception of being static and lacking innovation, they stand a much better chance of improving market share.

Composites: a most potential area for lignocellulosic fibres

Composite is an effective way of applying natural fibres as reinforcement in terms of environmental, economic, and technical feasibility. They have beneficial properties such as low density, less expensive, suitable insulation properties, and low machine wear, along with eco-friendliness, non-toxicity, and biodegradability. The physical and mechanical properties of these composites can be enhanced through chemical treatment, improving compatibility and reducing moisture content of fibre by surface modification such as alkalization and addition of coupling agents. Ramie, hemp and flax are particularly suitable for composite reinforcement. However, jute and kenaf also have enough potential. These lingo-cellulosic fibres, particularly hemp, can be applied for structural elements that today are typically made of glass fibre. These fibres have significant variability in properties and price. Fibres such as flax, ramie and hemp are reported to have higher costs with no significant advantage in terms of properties. Therefore, selecting the most suitable natural fibre for a particular application requires an integrated analysis comparing properties, availability, and price followed by a decision-making process. Thus, material development fulfills functional and economic criteria, as well as meets ecological and social requirements of sustainability. This has led to a change in attitude in the sector of material sciences towards the selection of more environmentally friendly materials. The automotive industry is the most active and knowledge-intensive sector, which plays a vital role in the development of non and semi-structural parts. Approximately, 60 million automobiles and lorries are presently manufactured in the world per year, which indicates that a global potential market of natural fibre reinforcement in this sector is about 300,000 metric tons. Other potential industries are gradually developing, such as furniture, medical, sports, construction, and household applications.

Research

A shortage of quality raw materials, products, and processes is a notable hindrance limiting the industrial growth of those lingo-cellulosic fibres.

Areas need attention for sustainable growth of lignocellulosic fibres

- To develop textile items, fine and sufficiently strong fibres are required. Then, cultivation should be planned, focusing on the fibre. Sometimes, fibres are grown for some other purposes, but the by-product or waste is used as fibre. Like, in Belgium, flax is grown for fibre, but in India, the same plant is grown for an oil called linseed oil. If it is grown for oil, the plants will be over-matured, producing inferior fibre. Attempts have been made to develop a dual variety plant that can produce oil and spinable fibre. This is true for all the lignocellulosic fibres. It is a potential research area.
- Agro-climatic parameters of the field may affect the package of cultivation practices. So, it should be modified as per the knowledge of research.
- Quality of fibres is essential for quality product. The fibres are generated by extracting the fibrous material from the bast, leaf, seed/fruit. The retting or decortications, or degumming is one important process that determines the fibre quality. In cotton production, much fruitful initiative has been taken to get a good quality product. But in the case of lingo-cellulosic fibres, some discreet attempt has been made, but a holistic approach has yet to be adopted. Along with this, new scientific intervention is also required, like the use of eco-friendly chemicals. Microbes and enzymes can reduce the water requirement and time of retting by producing good quality fibre.
- The retting, decortications, or degumming processes have not been standardised for any of the fibres. These processes are performed by the almost illiterate and poor farmers. Maintaining the scientific systems is not possible for them for various reasons.
- The present era is the time of corporatization of all the items. Hence, cultivation and post-harvest processes up to fibre formation should come under big sector, maybe the user of the fibres, to follow standardised and uniform process, and then only the fibre quality will be assured by a strict maintenance of production process parameters. Though it has a tremendous socio-economic impact.
- Proper mechanisation in the cultivation and extraction of lingo-cellulosic fibres is required.
- Considering the variability, composition, and surface properties, each lingo-cellulosic fibre needs separate attention for optimum process and modification in machines.

- The main drawback of natural fibres is wide variability in length, diameter, strength etc. Advanced research on biotechnology can improve the quality. Genetic engineering can introduce some additional properties in favour of its processing.
- All the lingo-cellulosic fibre processing technology is age-old. Minimal attempt has been made for the processing technology, whereas technology for cotton processing has been given attention, and hence, development was speedy. Some technological advancement of the cotton system has been tried for lingo-cellulosic fibres after minor modification. But, it was not successful because the fibre properties are entirely different. Automation in required areas is needed to reduce human intervention, which will help to improve product quality.
- A holistic and integrated approach is essential. The parts, other than fibres of plants, should be utilised with value addition i.e. jute leaf and stem are used as fibre, food, fuel, and activated carbon. It will endorse the extra income and economic development of farmers. The entire process should be such that the total value chain of the fibre is benefitted.
- Grading and segregation are essential for each fibre. The method should be fibre specific. Different quality fibres can be utilised for different purposes. Some grading system are available in jute, kenaf, flax and ramie, but it needs further improvement. Other lingo-cellulosic fibres have no grading system at all.
- New technological intervention is needed for sustainable development i.e. nanotechnology, biotechnology, biochemistry, steam explosion, artificial intelligence etc.
- New and diversified areas for lingo-cellulosic fibres are to be identified for survival.
- Pre-treatment of fibre for better processibility /use is to be explored
- Lignin recovery from lignin-riched fibres and its utilization.
- Process control system using modern electronics need to be introduced in the processing
- Finishing and decoration of fibre/yarn/fabric using the mechanical or chemical or enzymatic systems is very important to make attractive to the consumer.

Any natural item or process is a gift to humanity. Nothing can be ignored or wasted. The primary duty of man is to have proper and optimised use of it. From the beginning of the human race, they are learning from the natural. Even today, we use bio-inspired computing for sustainable processes and product development. Improper conversion and utilisation of natural products or processes are harmful to society, though they can give an initial benefit. Proper eco-environmental auditing is essential before the release of any product or process. In this context, all the natural fibres have enormous potential if we can use them judiciously. The known natural fibres have also proved their sustainability from the ancient age without harm.

Table 3. Chemical composition of some important ligno-cellulosic fibres

Fibre	Cellulose	Hemi-cellulose	Pectin	Lignin	Fat/Wax
Jute	59-71	12-13	0.2-4.4	11.8-12.9	0.5
Flax	62-71	16-18	1.8-2.0	2.0-2.5	1.5
Coir	36-43	0.2-0.8	3-4	41-45	1.1
Ramie	68-76	13-14	1.9-2.1	0.6-1.1	0.3
Sisal	66-73	12-13	0.7-0.9	9.8-10.0	0.3
Hemp	67-75	16-18	0.8-1.2	2.9-3.3	0.7
Banana	48-59	12-16	2.7-4.1	16-20	-
Nettle	51-57	9-13	1.9-4.8	8-11	4.2
Pineapple	68-74	22-27	-	4-5	-
Sunhemp	67-70	15-17	0.3-0.5	3.3-3.6	0.4
Kenaf	44-57	16-20	1-2	10-16	-
Abaca	63-68	19-20	0.5 -0.8	5.1-5.5	0.2

Table 4. Properties of some important ligno-cellulosic fibres

Properties	Jute	Ramie	Sunnhemp	Flax	Pineapple	Sisal	Banana	Coir	Nettle	Kenaf	Hemp
Ultimate Cell											
Length, mm	0.8-6.0	20-25	5-20	26-65	3-9	0.5-6.0	1.0-4.5	1-1.5	4-6	1.5-11.0	35-40
Breadth, 10^{-3} mm	5-25	15-80	12-35	10-35	4-8	5-40	8-22	7-30	25-50	18-29	17-23
Wall thickness, 10^{-3} mm	3-9	9-16	3-11	8-17	-	3-9	3-10	-	-	-	-
Lumen, 10^{-3} mm	4.46	16.6	16.6	8.43	5.5	7.34	13.4	-	-	-	-
Fibre/Filament											
Length, mm	150-360	1200-1600	750-1000	300-900	250-600	600-1000	700-1100	44-183	19-80	900-1800	1000-3000
Linear Density, tex	1.2-5.0	0.4-0.8	5.5-17.0	4-10	2.5-6.0	16-35	4-6	25-63	0.5-0.8	1.9-2.2	0.38- 1.50
Tenacity, g/tex	30-50	40-65	30-40	45-55	25-45	40-45	30-45	11-17	49-58	22-26	40-70
Extension at break, %	1-2	3-4	2.5-3.5	3.5-4.0	2.5-4.0	2.5-4.5	1-2	13-24	1.1-1.3	2-2.5	2-3
Torsional rigidity, x 10^{-9} N-M^2	0.25-1.30	1-2	1-2	0.80-1.05	0.3-1.0	0.3-1.7	0.25-1.00	-	-	-	-
Flexural rigidity, x 10^{-9} N-M^2	3-6	0.8-1.2	125-175	1.8-2.5	2.5-4.0	125-175	12-30	1100-1280	-	-	-
Transverse swelling in water, %	20-22	12-15	18-20	30-36	18-20	18-20	16-20	14-17	13-16	18-20	18-26
Coefficient of friction, Parallel Perpendicular	0.54 0.47	0.61 0.50	0.50 0.40	0.44 0.39	0.62 0.57	-	-	0.31 0.26	-	-	
Bulk density, g/cc	1.45	1.56	1.53	1.55	1.50	1.45	1.35	1.40	1.4	1.45	1.48
Moisture regain, 65% RH	12.5	6.5	10.5	9.0	13	11	15	11.7	11	13	12
Micro-fibrillar angle, deg	8.1	-	-	-	14-18	10-22	11	30-49	-	-	6.2
Elastic modulus, GN/m^2	10-30	44	69	60-80	34-82	9-16	8-20	4-6	40	23	70
Electroical Specific resistance, Ω-kg/m^2	1.83	-	-	-	0.7-0.8	2.96	6.5-7	9-14	-	-	-

Table 5 Plant and products of lignocellulosic fibres

Type	Origin	Product
Jute, Mesta		 
Kenaf		 
Flax/ Linseed		 
Ramie		 
Hemp		 

Banana		 
Nettle		  
Sunnhemp		
Pineapple Leaf		  
Coconut -Seed		 
Sisal Leaf		

Table 6 Availability of Plant fibres

Fibre	Amount/year	Country	Indian states
Jute, Mesta	3,000,000 tonnes	India, Bangladesh, China, Myanmar, Nepal and Thailand. India and Bangladesh:	West Bengal, Bihar, and Assam. 10000 thousand bales
Kenaf	450 metric tonnes	India, Bangladesh and Thailand.	Madhya Pradesh, Andhra Pradesh and Tamil Nadu
Flax/ Linseed	2,925,282 tonnes	Canada, U.S.A. Argentina, Russia Belgium, Northern France and the Netherlands:	Madhya Pradesh, Karnataka, Chhattisgarh, Jharkhand, Bihar, Maharashtra, Odisha, Uttar Pradesh, West Bengal and Assam
Ramie	130,000 tonnes	China, South America, The Philippines, Korea, Japan and Indonesia:	Assam, Meghalaya.
Hemp	75,000 metric tonnes	Russia, Yugoslavia, Romania and Hungary:	Uttarakhand, northern Indian states
Banana/ Abaca	200 metric tonnes	India, Indonesia, Brazil, Mexico, Ecuador, China, Costa rica:	Tamilnadu, Maharastra, Gujrat, Andhra pradesh
Nettle	-	all countries of Europe, North America, North Africa, and parts of Asia	Uttarakhad and other Himalayan regions
Sunnhemp	70,000 tonnes	India, China, Korea (DPR), Pakistan, Bangladesh, Romania, Russia and CIS countries.	Bihar, Madhya Pradesh, Maharastra, Rajasthan, Orissa and Uttar Pradesh
Pineapple Leaf	24.8 million tonnes	Philippins, Thailand, Brazil, Costa Rica, China, India, Indonesia, Nigeria, Mexico, Vietnam, Colombo, Kenya	Assam, West Bengal, Karnataka, Meghalaya, Manipur, Arunachal Pradesh, Kerala and Bihar
Coconut -Seed	1,100,000 MT	India, Sri Lanka, Philippines, Indonesia, Malaysia, Fiji Islands, Vietnam, Hawai Islands, Papua, New Guinea, and Solomon Islands	Kerala, Tamil Nadu, Andhra Pradesh, and Karnataka
Sisal Leaf	260,000 tonnes	East Africa, Mexico, Haiti, Brazil and in other regions of South America	Orissa, Maharashtra and southern states

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