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Scope of Entrepreneurship Development in Non-edible Value Added Products of Coconut

Manikantan M R, Pandiselvam R, Shameena Beegum & Mathew A C

Introduction

Coconut is a versatile crop with several uses to mankind. Apart from the main product, the by-products obtained from the coconut crop have many alternative uses, thus, adding to the total value of the crop (Popenoe, 1969). A tremendous scope exists for use of coconut in a variety of non-food products. The development of cottage industries to produce such products is recommended to increase income of coconut growers. For historical reasons, cultivation of coconut and value addition of non-food products from coconut have taken deep roots in the state of Kerala. The rapid expansion of coconut cultivation in non-traditional areas increased the production of coconut and the industry has also developed gradually in the states of Tamil Nadu, Karnataka, Andhra Pradesh and Orissa. Among the non-food products of coconut, charcoal, activated carbon, and shell powder and coir or coconut fibre assume commercial importance. Other parts of the palm especially coconut wood and leaves are recently gaining attention.

Scope of entrepreneurship development in coconut by-product sector

Large number of people from the economically weaker sections of the society depends on coconut based non-food industry. Production of value added products is less with respect to the availability of raw material and market requirements. At the current level of production of activated carbon, charcoal and coir, the industry utilizes about 40% of the annual yield of coconut by-products in the country. There is possibility to increase the utilization to at least 60%. Therefore, there exists vast potential for stepping up of production of non-edible value added coconut products in India. The increased utilization of coconut husk, coconut shell and wood in the coconut growing states of India provides scope for development of fibre processing and charcoal/activated carbon processing sector and thereby augmenting rural employment. For example, the coir products like mats, rugs, carpets, cordages, ropes, fishing nets, etc are having both domestic and export demand (Gopal and Gupta, 2001). By proper utilization of coconut husk, the coconut farmers could augment the farm level income and employment. It has been shown that value addition of coir fibre, enhance income of fibre manufacturers by minimum of 20% and consequently increase the income of coir workers in fibre extraction units by minimum of 10% (Anonymous, 1960).

Value added products of coconut

Charcoal

In the developed world, charcoal is an almost indispensable industrial commodity, especially in metallurgy and as an adsorbent. With the development of the chemical industry and the increasing legislation concerned with control of the environment, the application of charcoal for purification of industrial waste has increased markedly. In the barbecue fuel market, charcoal has little competition and in almost all other applications charcoal could be substituted by coal, coke, petroleum coke or lignite. Charcoal produced from coconut products are listed below.

Coconut trunk charcoal

Coconut trunk and other saw mill residues are readily usable for charcoal making and for the production of energy (Romulo and Arancon, 2009). Coconut wood is similar to other woods in its characteristics as fuel, although the range of densities within the stem leads to variation in the energy potential (Anonymous, 1985). Charcoal and charcoal briquettes have higher heating value. They are easily handled and produce less smoke compared to wood.

For fuel purposes, coconut trunk charcoal (Fig.1) must be converted into briquettes to increase its strength and density as well as to improve its shipping properties. The briquettes have good crushing strength and burning properties. Sorghum grain is an effective binder for charcoal briquettes of coconut trunk.

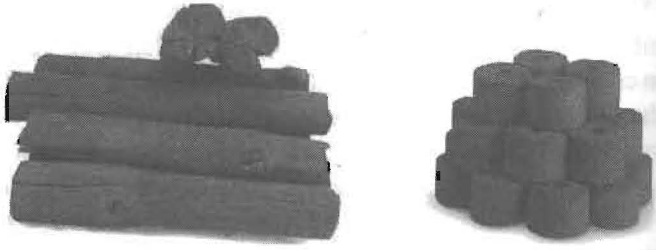


Fig.1: Coconut wood charcoal
(*Source:* http://www.thegreenhead.com/2013/04/afire-koko-all-natural-coconut-charcoal.php, Accessed on 22-03-2017)

Coconut shell charcoal

Most important produce derived from shell is charcoal. Coconut shell charcoal is recognized as one of the best fuels for cooking because of its pleasant smell. Yield of shell charcoal is about 30% of the weight of the shells used, and it is generally reckoned that about 17,000-24,000 whole shells makes one metric ton of charcoal (Anonymous, 1969). In general, shell charcoal is made by burning coconut shells in a limited supply of oxygen. Coconut shell used should be clean, fully dried and mature in order to get high quality charcoal. Among the different methods of producing coconut shell charcoal, the pit method and drum method are most widespread.

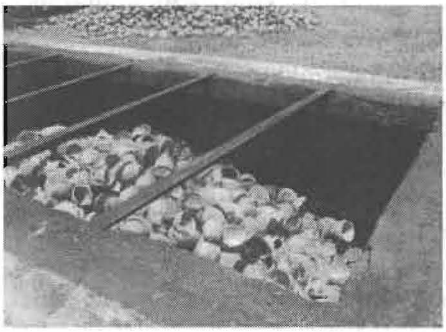
In pit method, the shells are often burnt in the pits (Fig.2a). Some dry shells, clean and free from adhering fibres of the husk, are placed at the bottom and set on fire. When the shells emit flame, they are slowly piled together, and more and more shells are added until the whole pit is filled. Pit is then covered with a zinc or iron plate, and the hole is made airtight by packing earth around the edges. It is preferable to use fire-resistant bricks for the lining, but, locally made bricks will stand up for a considerable time. Mud mortar is found to be more satisfactory than cement. Circular pits which are narrow at the top compared to the bottom or bottle-shaped pits are preferable as the firing is more easily controlled.

The drum kiln (Fig.2b) is one of the most widespread methods of coconut shell carbonization. It has 3 sets which consist of 6 holes, middle and upper layers and a lid. The drum also includes a chimney which is placed on the lid of the drum (Fig. 2c). Optimum carbonization of shell in a limited supply of oxygen provides good quality charcoal.

Raw shells must be put into the drum, leaving a 4 inch space in the centre of the drum, which plays an important role during carbonization allowing the flow of smoke. To start carbonization, a fire should be started in the middle of the circle using a piece of a coconut shell. Then, all the free space in the drum should be filled with raw materials. When the flame flares up, the chimney and the lid should be attached. The middle and the upper sets must be closed. When some of shells shrink to the bottom, more coconut shells should be added up to the brim of the drum. The process of carbonization begins at the bottom of the drum and goes up. When the carbonation is finished, a glow in the 6 holes of a set of the particular zone can be seen. When the holes of the bottom zone indicate this glow it means that the bottom set is closed, while the middle set is opened. When the carbonization in the middle zone is completed, its holes are closed and the bottom holes are opened. Closing of the top set of the holes after the full carbonization in the top region stops the airflow into the drum. The charcoal is collected and packed after about 8 hours when the drum is cooled. In general, 30 thousand coconut shells are needed to produce 1 ton of charcoal using drum method. Composition of coconut shell charcoal and coconut husk charcoal is given in Table 1 and economics of charcoal production is given in Table 2.

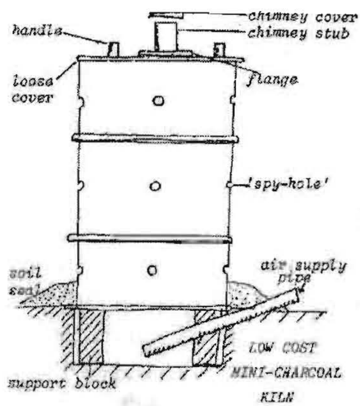
Table 1: Composition of coconut shell and coconut husk charcoal

Particular	Coconut shell charcoal	Coconut husk charcoal
Calorific value (MJ/kg)	27.0 – 31.8	26.0 to 27.0
Fixed carbon (%)	80.6 -88.5	76.6 – 80.0
Volatile matter (%)	11.6 -14.80	8.0 -10.0
Ash content (%)	3.0 – 4.7	7.0 -12.0
Moisture content (%)	2.0 – 3.5	3.0 – 5.5



(a) Pit method

(b) Drum method

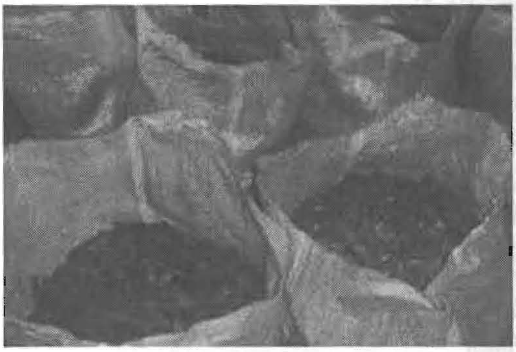


(c) Structure of drum

Fig. 2: Coconut shell charcoal production methods (*Source:* http://ukrfuel.com/news-how-to-make-coconut-shell-charcoal-39.html, Accessed on 22-03-2017).

(a) Carbonization

(b) Milling and sieving



(c) Packing in sacks

Fig. 3: Charcoal process flow chart

(*Source:* http://charcoalshell.blogspot.in, Accessed on 22-03-2017).

The processing of coconut shell charcoal briquettes includes the carbonization of the coconut shells and crushing which allows manufacturing different shape and sized charcoal briquettes (Fig.3). For this purpose, charcoal drum or stove and the charcoal powder making machine are used. Drum or the stove should maintain the temperature of 500 - 900°F.

Table 2: Economics of charcoal production one ton / day (30,000 coconut shells)

Items	Amount (Rs)
Land (cost variable)	35 cents
Building 1000 sq. ft.	2.5 lakhs
Plant machinery	10.5 lakhs
Preliminary & pre-operative expenses	2.0 lakhs
Contingencies	0.5 lakhs
Margin money for working capital	2.0 lakhs

(*Source:* http://coconutboard.nic.in/charcoal.htm, Accessed on 22-03-107)

Prior to the industrial revolution, charcoal was occasionally used as a cooking fuel. Historically, charcoal was used in great quantities for melting iron in bloomeries and later blast furnaces and finery forges. Charcoal can be used for the production of various syngas compositions. The syngas is typically used as fuel, including automotive propulsion or as a chemical feedstock. Charcoal may be used as a source of carbon in chemical reactions. It is mainly used for the production of carbon disulphide through the reaction of sulphur vapours with hot charcoal.

Charcoal may be activated to increase its effectiveness as a filter. Activated charcoal readily adsorbs a wide range of organic compounds dissolved or suspended in gases and liquids. In certain industrial processes, such as the purification of sucrose from cane sugar, impurities cause an undesirable colour, which can be removed with activated charcoal. It is also used to absorb odours and toxins in air. Charcoal filters are also used in some types of gas masks. Charcoal is also used in drawing and making rough sketches in painting.

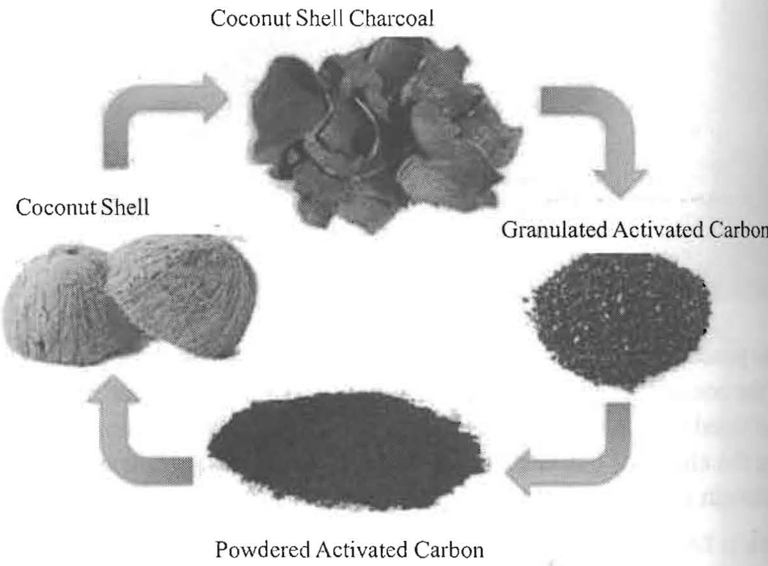


Fig. 4: Activated carbon from shell
(*Source:* http://sakthi-coir.com, Accessed on 24-03-2017)

Activated carbon

Activated carbon is a carbonaceous, highly porous adsorptive medium that has a complex structure composed primarily of carbon atoms. Coconut shells are mainly used to manufacture activated carbon (Fig.4). Activated carbon plays a very important role in solvent recovery processes, water and effluent treatment and in treatment of flue gas before discharge into the atmosphere. The intrinsic pore network in the lattice structure of activated carbon allows the removal of impurities from gaseous and liquid media through adsorption. This is the key to the performance of activated carbon.

Chemical activation or high temperature steam activation mechanisms are used in the production of activated carbon. In the activation process, shell charcoal is fed continuously into a retort. Normal activation process involves the use of steam at selected temperature for the selective oxidation of material, resulting in production of carbon with pores of molecular dimension. Shell carbon, having a cellulose base produces material with a finer pore structure than obtained from coals. Approximately, three tons of shell charcoal is needed to produce one ton of activated carbon. Retorts designed to produce activated carbon usually operate in one of the three ways-vertically, horizontally, or by means of a series of hearths. Vertical retort utilises steam and activation is controlled by the rate at which the material is withdrawn from the discharge hopper. Activation can be carried out with a variety of gases, including oxides of carbon, chlorine, and mixtures of steam and air. After withdrawal from the retorts, the material is cooled and passed through a series of granulators and screens, thereby attaining carbon of a known quality, available in variety of grade sizes to suit many applications.

For certain specific purpose, different process is used to prepare the activated carbon. This process consists of the treatment of crushed coconut shell with surface active chemicals followed by drying and subjecting the material to carbonization. The carbonized material is activated with steam followed by air to facilitate oxidation.

The activated material is subjected to steam quenching to reduce the bed temperature and is then discharged in a receptacle. The material is subsequently subjected to acid treatment to adjust the pH value. Acid treated activated material is then washed with water, dried and stored. Granular activated carbon produced from shell charcoal is an important industrial material, and the prospects for the intermediate charcoal appear to be good as long as quality is maintained. In general, activated carbon is used where the compound to be absorbed has a small molecular diameter or, if it is a gas, when a boiling point is below 100°C. The use of this type of carbon is also specially indicated where the concentration of the absorbate is very low. Shell based activated carbon (Fig.5) is considered superior to those obtained from other sources because it is generally dense, very hard, and highly retentive. They have a very fine pore structure, and their rate of absorption is generally faster than coal carbon. Economics of activated carbon production is given in Table 3. Process flow chart for production of activated carbon is given in Fig.6.

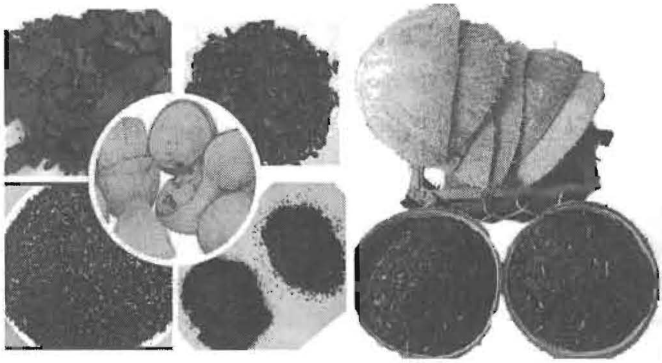


Fig.5: Coconut shell based activated carbon
(*Source:* http://sjzkzcable.en. Coconut-Shell-Activated-Carbon for-Water-Treatment.html, Accessed on 24-03-2017)

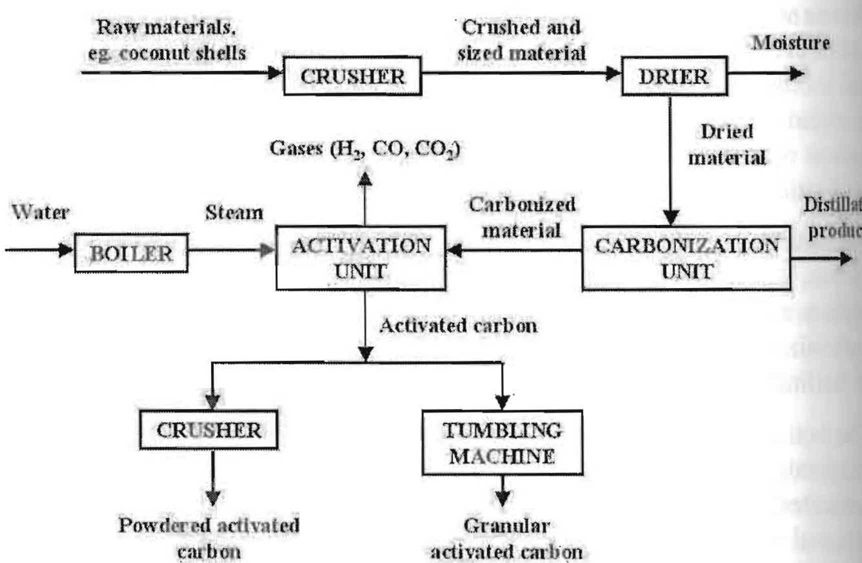


Fig. 6: Process flow chart for production of activated carbon from coconut shell
(*Source:* http://www.corecarbons.com/process.html, Accessed on 22-03-2017)

Table 3: Economics of activated carbon production

Items	Amount (Rs.)
Land	Two acres (cost variable)
Building -12000 sq.ft. @ Rs.600 per sq.ft.	72 lakhs
Plant & machinery	275 lakhs
Preliminary & pre-operative expenses	15 lakhs
Electrification	20 lakhs
Working capital (margin money)	50 lakhs

(*Source:* http://coconutboard.nic.in/activatd.htm, Accessed on 22-03-107)

Applications of activated carbon

- Activated carbon is playing an important role in the decolourization of sugar solution before it is crystallized to make granulated sugar in pure white colour.
- It is very useful in the manufacture of wine, alcohol, beer, rum, whisky, vodka etc. for purification of the ingredients as well as the final products. They are also used for decolourization, prevention of turbidity during ageing and for the removal of congeners that affect the taste or odour of the alcoholic beverages.
- The activated carbon is used in the fruit juice industry in the decolourization caused by complex compounds like polyphenols, melanoidins etc. They are also used to remove undesirable taste causing substances, colour changing chemicals that get added to the fruit juices during their manufacture.
- Activated carbon products are used to remove molasses compounds from citric acid, lactic acid and other forms of food substances made using bio-chemical processes. By using the activated carbon products it is possible to increase conversion of bio-chemical process rate during fermentation. Purification of gluconates and lactates is also achieved to the highest possible standards with the use of activated carbon products.
- Activated carbon is used in the manufacture of many of the starch based sweeteners like glucose, maltose, fructose, dextrose etc. They are mainly used for decolourization, polishing of syrups to comply with the highest standards and the requirements of the soft drink industry.
- Activated carbon is used for purification of natural glycerin. It is extensively used for the removal of organic impurities like odour causing substances and coloured matter to ensure the purity of glycerin that is necessary for other processes.
- Activated carbon products are finding their great use in the conversion of edible lactose into pharmaceutical grade lactose by effective removal of riboflavin from lactose.

Shell flour

The coconut shells are available from all coconut producing states in India. Kerala, Tamil Nadu, Karnataka and Andhra Pradesh contribute more than 90% of the production in the country (NIIR Board of Consultants and Engineers, 2012). A second important product derived from shell is shell flour. It is prepared by grinding clean coconut shells to a fine powder, the particle size depending on the end use. ISI specifications for coconut shell powder are given in Table 4.

Table 4: ISI specifications for coconut shell powder

Parameters	Specification
Appearance	Clear light brown free flowing powder
Moisture	Upto 10 per cent
Apparent density	0.6 to 0.7 g/cc
Ash content	Upto 1.5
Sieve analysis	Retained on 200 mesh sieves not to exceed 0.1%

Process

Coconut shells free from contamination are broken into small pieces (5 cm pieces) with the help of Jas Pounding Machine and fed into a pulverizer. The powder from the pulverizer is fed into a cyclone, where they are separated into coarse and fine particles and the ultra fine particles are collected in bag filters. From the cyclone, the coarser particles pass to the second hammer mill, and the ground products are subjected to the same air separation as the particles from the first grinding. The fine particles from the cyclone are fed into a vibrator-sieving unit and graded into the required mesh size for various end uses. The rejects from the sieving machine is recycled in the pulverizer for size reduction. Important requirements for consistent good quality coconut shell powder are proper selection of shell of proper stage of maturity and efficient machinery. Waste granules are used as fuel in solvent factory, sugar industries and boiler units. About 10 tons of coconut shell gives 7 – 8 tons of shell powder. The price is determined based on sieve size (grade) and it ranges from Rs. 4.50/kg for 80 mm grade to Rs. 8/kg for 300 mm grade shell powder. Process flow chart for the production of coconut shell powder is given in Fig.7. Details pertaining to the economics of production are furnished in Table 5.

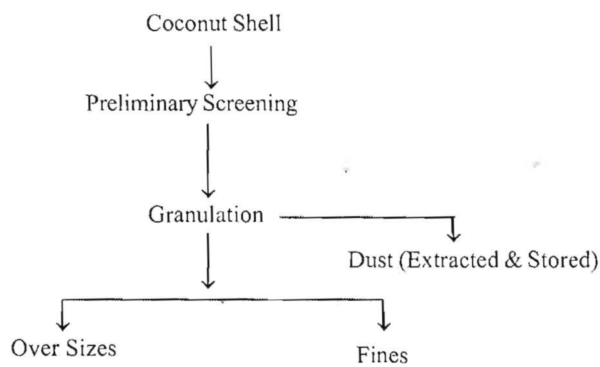


Fig. 7: Process flow chart for production of coconut shell powder
(*Source:* http://cpreec.org/77.htm, Accessed on 23-03-2017)

Table 5: Economics of coconut shell powder

One ton / day capacity (12000 shells yield one ton of shell powder)	
Land required (cost variable)	40 cents
Building (2000 sq. ft. building area)	Rs.10 lakhs
Plant and machinery	Rs.14.5 lakhs
Preliminary & pre-operative expenses	Rs.3.0 lakhs
Contingency	Rs.1.5 lakh
Working capital (margin money)	Rs.5.0 lakhs

(*Source:* http://coconutboard.nic.in/shelpwdr.htm, Accessed on 23-03-2017)

Uses of coconut shell powder

The shell powder is obtained as by-product from coconut oil industries and individual households (Fig.8). The powder has various uses as a filler in synthetic resin glues, filler and extender in phenolic moulding powders, mosquito repellent coils, mastic adhesives, resin casting, bituminous products etc., (Anonymous, 2015). Coconut shell powder finds its application in manufacturing mosquito coils as a burning medium (Fig. 9).

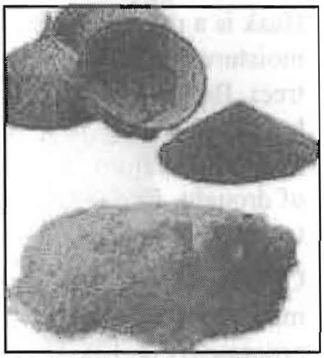


Fig. 8: Coconut shell powder

Coconut shell powder is used as thermo set moulding powder such as phenol formaldehyde moulding powder or bakelite and synthetic resin glues. Coconut shell powder of a particle size of 90-100 mesh is suitable as filler in the thermo set moulding powder and powder of 200-300 mesh size is used for synthetic resin glues. The demand in this sector is always on the increase (Resmi, 2015).

Fig. 9: Use of shell powder

It is used mainly as filler, replacing wood flour either partially or wholly in the manufacture of phenolic moulding powders by the thermoplastic sector. The inclusion of shell flour results in an improvement in the surface finish of the mouldings, and because of its higher resinous content and lower absorption properties, it can be used in higher concentrations than wood flour. Shell flour is also used as filler in phenolic glues for plywood and laminated sheet manufacture, filler for mosquito incense coils and filler in specialized surface finishes, resin castings, etc. As a mild abrasive, it is used as a soft blast to clean piston engines. It has been incorporated into hand cleaners and used as a diluent for potent insecticides (Grimwood, 1975).

Coconut husk

Coconut husk is one of the important by- products of coconut tree and coconut-based activities. Husk is the outer fibre (35%) of the nut, followed by the hard protective shell (12%). Dehusking of coconut is done at various stages in the marketing network. Except the husk obtained during dehusking at household level, the entire husk, including the unorganized marketing sector, reaches the coir industry, where it fetches a market value (Anonymous, 1970). In the coir industries, fibre is extracted from coconut husk. The thickness of the husk of an ordinary nut varies from 2.5-3.0 cm in the case of thin-husked nuts and 4.0-5.0 cm for thick husked ones.

Husk is a useful source of potash and valuable mulch for the conservation of moisture. These are often burnt to produce ash which is used to fertilize the trees. Burying the husk in the soil is more beneficial than burning. A layer of husk is placed in a ring, convex side upwards from about 0.3 m up to a distance of 1.8- 2.1 m from the base of the palm. This method is beneficial during period of drought. Husk can also be used in planting holes during coconut seedling transplantation.

Coir industry in India is one of the important rural industries. There are two methods of processing the coconut husk: namely, the manual and the mechanical processes (Fig. 10). The manual process is simple and no investment is needed for equipment.

Utilization of coconut husk

Coconut husk is generally removed from whole coconut at the farm site in close proximity to the trees from which they are harvested. After dehusking, the husks are piled and left to rot in the fields or normally burnt as waste. A greater portion is used as fuel in farm site copra making. To a certain extent, husks are also utilized in handicrafts, floor polishers and other minor applications.

Fig. 10: Extraction process of coir fibre
(*Source:* http://swapsushias.blogspot.in/2014/09/focus-coir-board-of-india.html#. WNN-oNR96t8, Accessed on 23-03-2017)

i. Coconut husk particle boards

Husk of matured coconut is the unique raw material to prepare particle boards (Fig.11). Usually, wood particle boards use 8-10% adhesives on weight basis, while coconut husk boards require only 0.25 % adhesives.

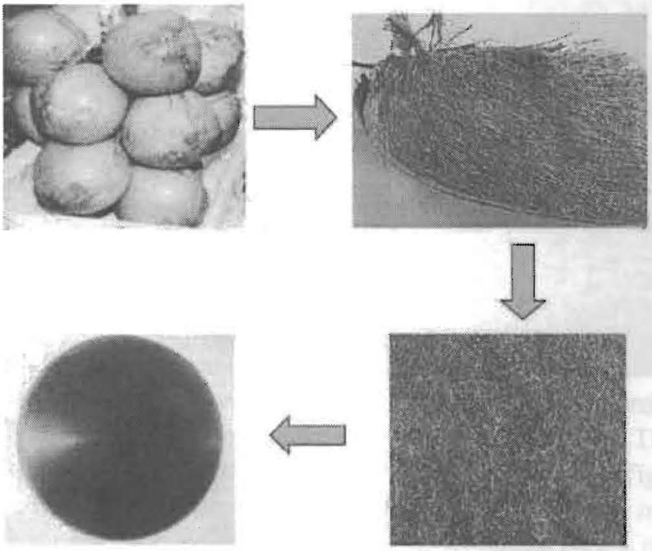
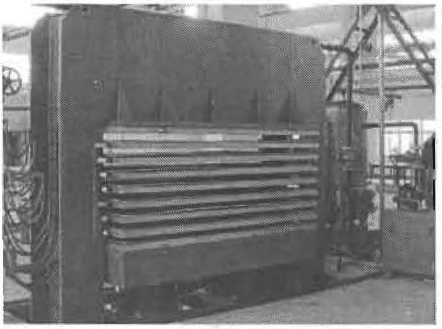


Fig. 11: Particle board from coconut husk
(Source: https://www.wur.nl/en/show/Ecocoboard-a-new-material-made-from-coconut-husk.htm, Accessed on 23-03-2017)

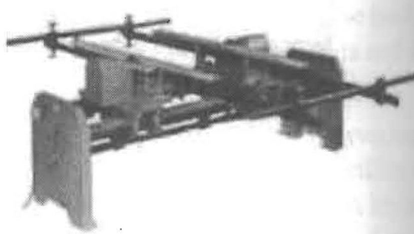
About 325 million coconut trees will yield 12 billion nuts from which about 4 million tons of particle board can be produced. Particle board is manufactured industrially by mixing coconut husk with resin and forming the mix into a sheet. Though, several types of resins are commonly used, formaldehyde based resin is the best in terms of cost and ease of use. Urea melamine resin or phenol formaldehyde resin is used to offer water resistance. Once, the resin has been mixed with the particles, the liquid mixture is made into a sheet. The sheets formed are hot-compressed under pressure in between 2 and 3 mega pascals and temperature between 140°C and 220°C. This process sets and hardens the glue. Boards are then cooled, trimmed and sanded. They can then be sold as raw board or by improving the surface through the addition of a wood veneer or laminate surface. Important machineries required to manufacture particle board are illustrated in Fig.12.

Machinery required

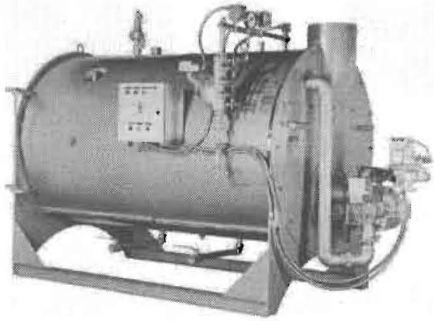
1. Hydraulic hot press
2. Power generator set
3. Boiler
4. Aluminium or steel plates
5. Blender (mixer)
6. Mat formation machine
7. DD Saw machine
8. Dryer
9. Screening machine



(a) Hydraulic hot press



(b) Saw machine



(c) Boiler

Fig. 12: Machineries required for manufacturing particle board

ii. Coconut fiber-cement board (CFB)

The coconut fiber-cement board (CFB) is relatively a new product (Fig 13 a) that makes use of coconut waste and can be combined with coconut wood (Anonymous, 2015). It is manufactured from fibrous materials like coconut coir, fronds, spathes, coconut top logs, or even shredded wood from small diameter fast-growing trees growing along the borders of coconut plantations. Manufacturing CFBs can be a good investment for the suppliers of construction materials, building contractors and private agencies involved in building low-cost houses (Fig 13b). The cement-fiber mixture is formed into mats and pressed to the desired thickness.

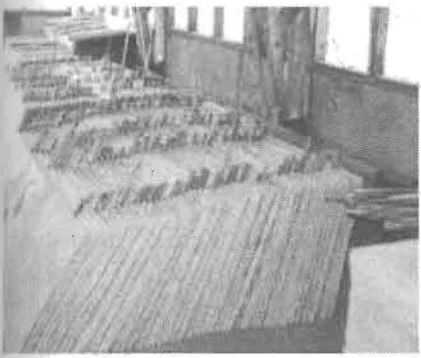


Fig.13a: Coconut fiber-cement board

Fig. 13b: House made of CFB and coconut **wood**

iii. Production of coir in industries

Coconut husk is the basic raw material of coir industry. At present, only 35% of total husk available is utilized by the industry while there is scope for utilizing at least 50% of the husk produced in the country. Husk of one coconut gives 90 g of coir fibre and 180 g of coir pith (Krishnamurthy *et al.,* 2009). There are two distinct varieties of coir namely white fibre and brown fibre (Fig.14). White fibre is extracted from retted coconut husk. Kerala produces mostly white fibre, which is used for making traditional coir products like mats, matting, rugs and carpets, which have an export market. Brown fibre is extracted from unretted husk. It is mainly used for the manufacture of curled coir. Curled coir is used in the rubberized coir mattresses, sofa cushion, bolsters, pillows, carpet underlay etc. The bristle fibre is a thick and long variety and is used for brush making. The mattress fibre which is a shorter staple fibre finds use in the upholstery, mattresses etc., for stuffing purpose. White fibre is extracted from green husks by mechanical defibring process.

Fig. 14: White and brown coir fibre

Process of producing coir fibre

Method of producing coir fibre from coconut husk is divided into three categories: traditional manual method, semi mechanical method and modern mechanical method. Traditional method with little mechanization is used to prepare yarn fibre, while bristle and mattress fibres are usually prepared by semi mechanical or mechanical methods.

Traditional and semi mechanical methods

i. Production of yarn fibre

Southern India is the chief source of coir yarn fibre, although small quantities are also prepared in southern parts of Asia. It is produced by traditional labour-intensive methods, including the natural bacteriological process of retting, where by the husks are soaked in water until the pith decomposes. Coconut is harvested every forty five days or so and then husked immediately in usual manner. A pit measuring 2.5 X 1.25 m will contain 1000 husks. Husks are then retted for eight to ten months in coastal lagoons or back water which are quite and undistributed but have ebb and flow ensuring a constant change of water. When the husks are sufficiently soft, they are washed and squeezed in water to remove the mud and bad smell. After removing the tough exocarp, remaining fibre is placed on hard wood and beaten traditionally with a strong round rod of tamarind heartwood until all the pith is removed. Dry fibres are then beaten and put through a winnowing machine, consisting of a number of knives with saw like teeth fixed to a shaft which is rotated by hand in a drum which will remove any small particles or pith.

The non-retting process involves direct decortication or mechanical extraction. Fresh husk before drying gives white fibre and the dried and retted husk gives brown fibre. Yield from retted husk is more than that from unretted husk. Average yield of white fibre from 1000 full husks in India is estimated as 81 kg with an average of about 50 kg of brittle fibre and 100 kg of mattress fibre.

Fibre is now spun into yarn either by hand or by using a wheel. Spinning on a wheel gives better quality yarn with a hard twist that is suitable for the manufacture of matting and other such materials. Two wheels are required for spinning, one is stationary and carries two spindles driven by the centre wheel and the other is mounted on three castors and has one spindle (Grimwood, 1975).

Grading of coir yarn

Two main classes of coir yarn are hard-twist or machine-twist and soft-twist (Fig. 15) or hand-twist; the grade names come from the locality where it is produced.

Soft- twist yarns are classified as beach and vycome both of which are subdivided into different numbers which vary in prices. Beach yarn is used for making mats and finer variety. Vycome yarn is used mainly for matting manufacture (Grimwood, 1975). Better quality fibres can be obtained if the nuts are harvested before they are fully ripe and the husk processed without delay. Retting can be carried out in almost any area where stagnant water is available. Some of the more modern mills have their own well-built concrete retting tanks but these are very expensive. The tanks are generally built in series by each unit and measures roughly 8×2.7×1.8 m. The water may be changed by pumping from one tank to another or by adding from a reserve supply. Retting time is reduced in some factories by soaking the husk for 30 to 40 h in hot water during which time they are weighted down with boards and stirred frequently. Periodically, the foul water is run off and replaced by clean water at the same temperature. Before soaking, the husk is crushed between fluted rollers to facilitate the penetration of water through the exocarp. At the large mill, the total capacity of the tank is said to be 2, 00,000 crushed husks or 1, 40,000 normal husk. If the husk is crushed previously, retting in tank is completed within three to seven days, otherwise they require seven to ten days. Retting in pits where the husks are not crushed and the water is not changed will take three to six weeks depending on the position of the husk of the pits. Those which are completely submerged require a shorter time than those on the surface.

After retting, next stage is extraction of fibre from the husk. Extraction of fibre requires the breaking down and removal of both the connective tissue and pith between the fibre and the outer exocarp. The process is called milling, and is carried out with specially constructed machine called drums. They are usually arranged in pairs and one is called the breaker drum and the other is the cleaner drum. Husk segments are first treated at the breaker drum which consists of a wooden wheel of about 0.9 m in diameter with 0.3 m wide and 1 m long into which iron nails have been bolted 3.8-5 cm apart. Main part of the wheel is enclosed in a wooden guard or casting with an opening of about 30 cm wide and is protected by a pair of iron bars. Nails are replaced every two months, because of wear and tear, since worn nails tend to split and damage the bristle fibre. Lower part of the casing of the wheel takes the form of a chute, through which the extracted fibre is delivered to the ground below. As the wheel

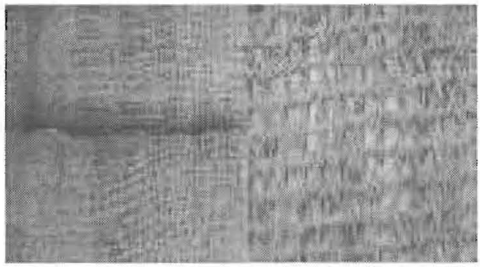


Fig. 15: Soft-twist yarn

revolves, first end of the husk and then the other are pressed between the bars. Nails tears away the short mattress fibre, which passes down the chute leaving the longer bristle fibre pith in the hands of the operator. It is generally accepted that one pair of drum can handle 2000 husks in a working day of eight hours and produce 100 kg of bristle and 200 kg of matress fibre. Therefore, a small mill with three or four pairs of drums should be able to produce 300-400 kg of bristle and 600-800 kg of mattress fibre per day.

Fibre grades

The fibres are used for spinning into yarn to manufacture mats and matting's, ropes, twines etc. Bristle fibre is long and stiff and is used for brushes and brooms. Coir is graded according to the colour and length of the fibre as also its refraction content. Four grades (Table 6) are recognized in India based on the specifications of Bureau of Indian Standards. First grade is mainly utilized for making superior quality fibre mats. Second grade constitutes fibre of white lustrous colour and the third slightly reddish or greyish coir containing pith. Fibre in fourth grade is mainly dark in colour and contains more pith and is used to make cheap yarn known as Beach yarn.

Table 6: Grading of coir

Sl No.	Grade	Maximum impurities	Length of fibre, proportion of medium and short fibres
1	I	2.0	70% by weight is long and remaining medium and short
2	II	3.0	50% by weight is long and remaining medium and short
3	III	5.0	30% by weight is long and remaining medium and short
4	IV	7.0	20% by weight is long and remaining medium and short

Coir yarn is woven into mats, matting's, carpets and rugs. Mats and matting's are woven on wooden handlooms; wheel spun yarn is used for warp and hand spun yarn for weft. Power-looms are seldom employed in India; on an account of coarseness of fibre, the yarn produced is coarse, and shuttles take only short length of yarn and need frequent replacements.

Coir products

Even though coconut palm is grown abundantly in all countries in the tropical belt, India and Sri Lanka stands first and second in the utilization of coconut husk for the manufacture and marketing of coir and coir products (Fig.16). India accounts for 71% of the world fibre production while Sri Lanka's share is 23%. Almost entire production of white fibre is from Kerala. Tamil Nadu, Karnataka, Andhra Pradesh and Orissa are the major brown fibre producing states. It is estimated that about 27% of the coconut husks produced in Kerala is utilized by the coir industry. The ability of coir yarn and ropes to withstand the prolonged action of sea water makes them especially suitable for use on boats

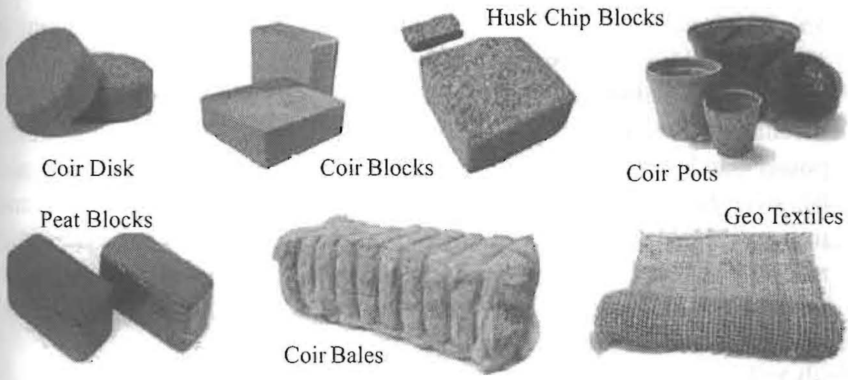


Fig. 16: Uses of coconut coir
(*Source:* http://www.usesofcoconut.com/benefits-and-uses-of-coconut-coir/, Accessed on 23-03-2017).

and ships. Coir fibre has also been used successfully in the manufacture of shockproof packing materials, hard board suitable for tabletops, doors, and pencil and battery containers. Hard boards obtained possess an attractive glaze, high tensile strength and high density and are suitable for railway coaches and cuttings.

i. *Artificial animal hair:* Bristle fibre and decorticated fibre are boiled for one hour in caustic soda solution. Then, the fibre is immersed in a dye bath composed of direct black dye, soda ash and salt for two hours and then cooled for 12h. Then, the fibre is dried, polished with emulsion of paraffin, washed with soap and soda ash and twisted. By these processes simulated animal hair (animal – hair like fibre) is produced. This is used as filling material for upholstery.

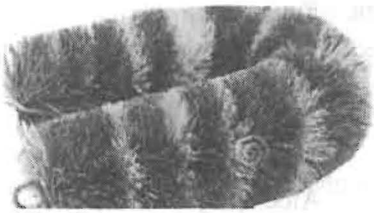


Fig. 17: Coir product- brush

ii. *Curling:* Mattress fibre, bristle fibre and decorticated fibre are twisted into ropes to produce curled fibre. Curling imparts special resilience to the fibre and the curl is permanent. Curled fibre is impregnated with rubber latex to produce rubberized coir, which is used for making car seats, filter pads, carpet underlay, cushion etc.

iii. *Flagging:* Ends of trimmed bristle fibre are immersed in a chemical solution and then split lengthwise by rotating pins or similar devices. This gives a soft feathery feel to the ends and improves sweeping efficiency of the brooms and brushes (Fig.17).

iv. *Spinning*: Mat variety of coir fibre is spun into yarn. In India, coir spinning is organized on a cottage industry basis and three methods of spinning are currently followed viz., (i) hand spinning, (ii) wheel spinning and (iii) mechanized spinning by using treadle operated machines. There are no power machines for spinning coir in India. Hand spun yarn is soft, and has even twist and thickness. Wheel spun yarn has higher strength and more uniformity in size and twist. Yarn produced by treadle-operated machine is less hairy, more regular in twist and has continuous length than wheel-spun yarn. Hand – twist yarn is used for matting and ropes. Soft-twist yarn is used for matting.

v. *Rope making*: Ropes and cordages are made out of coir yarn. Plain, hawser-laid and cable laid ropes are made in India.

vi. *Mats*: According to quality of yarn and method of weaving, mats are classified into three classes namely (i) coir mats (ii) fibre mats in which unspun coir is used for piles and (iii) speciality mats.

vii. *Mattings*: Patterns requiring up to 8 treadles are usually woven on ordinary looms. For designs requiring more than 8 treadles, Jacquard machines are employed.

viii. *Rugs*: These are mattings in rug sizes in attractive stenciled patterns.

ix. *Mourzouks*: Method of weaving mourzouks is different from that employed for matting. In this, special cross – weaving looms are used. Surface and patterns are formed by weft and not by warp. This method of weaving enables production of intricate geometrical and floral designs. Aloe and jute yarn may also be used as warp yarn.

x. *Carpets*: These are woven on matting looms. Warp strands are varied in thickness and number to produce thick and heavy fabric with a ribbed finish. Required design is secured by inserting coloured weft yarn.

xi. *Poly coir*: The Central Coir Research Institute of the Coir Board in collaboration with the Regional Research Laboratory, Thiruvananthapuram has developed "poly coir" which is made out of brown fibre. The coir felt, a non-woven material from coir fibre, is cut into appropriate width and coated with desired quantity of phenol formaldehyde resin by weight to form rolls of prepeg. The composite products from prepeg sheets are prepared by hot press moulding. The prepeg sheet is cut into the required size and stacked one over the other. The number of layers used is decided on the requirement of thickness of the component and the pressure applied for moulding which varies depending on the density and surface finish of the product. Trimming and polishing of the edges and wastage can be minimized by taking care of the size of prepeg sheet used for moulding. Major advantages of poly coir over plywood are (i) termite proof, (ii) water resistant, (iii) fire resistant, (iv) mouldable to desired shapes and (v) very good aesthetic appeal.

xii. *Coir matting decorative boards*: Coir matting, cut into required piece is treated with phenol formaldehyde resin and hot pressed to make the boards. The number of matting pieces can be suitably increased so as to make high-density boards.

Dyeing and printing of coir products

Colour and design are important for marketing coir products. For dyeing to bright tone, prior bleaching is necessary. Coir fibre may be bleached by SO_2 fumes by burning sulphur. Coir yarn may improve its colour and give it some amount of brightness. For dyeing of coir, different classes of dyes are used, viz, natural colouring matters like logwood, acid dyes, acid – mordant dyes, basic substantive dyes, sulphur dyes etc. Dyed yarn is exported from India to Australia for manufacture of matting.

Simple geometrical patterns and floral designs are printed on coir products by employing stencils and screens. Dye paste, resin thickness and chemicals to fix colours are applied through stencils. Dried prints are steamed for fixing. Fine designs of intricate configurations cannot be applied because of stiffness of coir fibre and roughness of coir products.

Geo-textiles

Coir geo-fabrics are woven coir nettings or mesh matting which is inexpensive, ready-to-use and effective items for a variety of applications including control of soil erosion and landslides, slope stabilization, seepage of water through canals and in other civil engineering applications like road embankments etc. In these applications, coir is used, because, it is natural, hard fibre with high tensile strength, durability and moisture resistance. Coir matting (mesh mat) are firmly laid on the slopes of canals, railway embankments, and road embankments and sown upon with grass seeds or slips are planted. With passage of time, the grass takes root and furnishes a permanent coverage, thereby stabilizing the soil. Coir matting also degrades and merges with the solid adding to nutrient content of the soil. Coir matting serves to hold the seed and soil intact, thereby preventing erosion during heavy rainstorms. It also serves to dampen the kinetic of flowing water and keep both soil and seeds in place.

Coir Pith

Coir pith constitutes as much as 70% of the husk and is now a waste product of coir industry. Accumulation of this waste in industrial yards causes environmental pollution and fire hazard. It is assessed that in India, 7.5 million tons of coir pith is produced annually. To obviate this problem, green technologies called coir pith composting units are promoted through formation of Self Help Groups. Every month, around 105 tons of coir pith is being converted to compost. (Resmi, 2015).

Uses of coir pith

i. In moisture conservation

The continuous application of coir dust will lead to a reduction in bulk density; improve the water holding capacity and organic carbon status of soil resulting in early flowering of palms. Coir pith has the ability to absorb and retain 10 times its weight of water (Tejano, 1984). Use of coir dust for a long period, will considerably improve the water holding capacity of the soil and the soil becomes more porous which allows better root penetration.

ii. Densification of composed coir pith

Tamil Nadu Agricultural University has developed a pelletizer for making pellets from coir pith compost. Compost is extruded into pellets of 6 to 8 mm diameter and 10 to 12 mm length. The unit is operated by a 5 hp electronic motor and had a capacity of 100 kg/h.

iii. As an energy source

a. Briquetting of coir pith

A continuous extruder type briquetting machine, consisting of screw shaft, barrel housing, extruder die pipe and gearbox has been developed at Tamil Nadu Agricultural University. The unit has a capacity of 125 kg per hour. Cow dung and molasses at various proportions to the coir pith were added (0, 10, 15, 20 and 25%) as binder. Briquettes produced had a calorific value in between 3000 to 3200 kcal/kg and cow dung mixed at 15% of coir pith resulted in better stability. This can be utilized as an alternative source of fuel.

b. Biogas

Pith can be added as a substitute in biogas generation, thus saving other energy producing materials.

c. Power gas

Coir pith can be used as a starting material for the production of gas by controlled combustion, which has been tried in industrial engines on a small scale

Miscellaneous products from coir pith

Many commercial products such as card boards, insulators, expansion joint filters etc. can be prepared using coir pith (Handreck, 1993). Polymers and composites can be prepared from pith by co-polymerising the lignin present in pith with either formaldehyde or phenols. Pith can also be used along with rubber to make composite flooring, ceiling floors and other similar products.

The pith in combination with cement has been found to be an excellent thermal insulating material. It is much lighter, easier to apply and gives much better thermal insulation for equal cost with lime concrete. Compared to modern methods, the cost is found to be only half to two-third. In the National Institute of Technology, Calicut, Kerala, coconut pith was successfully utilised in the production of a variety of light weight high strength bricks by the partial replacement of clay. In India, cashew nut shell liquid filled pith composite has been used as joint filler between concrete slabs in roofs, roads, and runway with a view to accommodate thermal movements. The pith joint fillers are resistant to alternate heating and wetting and also freezing and thawing. They are also resistant to termite and fungi and superior in qualities to those of bituminised fibre boards.

Coconut leaf

Coconut leaf is another product of importance for domestic use. Plaited and unplaited leaves are used for thatching houses, fencing and for making baskets. Leaves soaked in saline water before painting withstands climatic influences better than the unsoaked ones. Lifespan is only 1-2 years. Leaves being lignocellulosic in nature are susceptible to attack by sunlight, fungi, insects, rain and air. Thick walled sclerenchyma cells which impart mechanical strength to the tissues are relatively scarce in coconut leaf (Pillai *et al.,* 1981). Mathew (2004) could extract a useful fibre from the leaves. Here, the fresh leaves are boiled in water and separated into upper and lower halves. Each half is made into strips of convenient width and again boiled in 5 to 8 percent sodium carbonate solution for one to two hours. After thorough washing, they are immersed in a bleaching solution for one to three days with periodic stirring. Then, they are washed and dried in shade. These strips, which form smooth, semi transparent, water-proof threads are excellent for making hats, bonnets, mats, bags and slippers.

Midribs of the leaves are used for stiff brooms, bird cages and lobster and fish traps. The petioles, bunch stalks, spathes and stipules etc. are used as fuel. Roots have medicinal properties and hence the decoction of the roots is used as mouth wash. Roasted roots can be used as a dentifrice.

Coconut leaf weaving

Coconut leaf weaving is a traditional method to make some useful items for house hold things (Fig.18). Coconut leaf can be utilized for making hats, head band, fans, mats, bracelets and baskets as well as decorative items such as roses, grasshoppers, whips and fish (Rivera and Reuney, 2010).

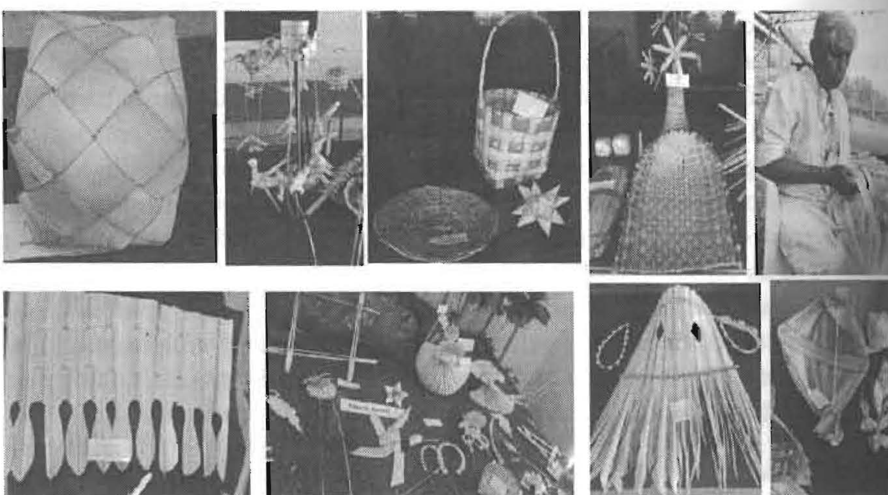


Fig. 18: Coconut leaf weaving

Conclusion

Coconut is one of the important fruit trees in the world, providing food for millions of people, especially in the tropical and subtropical regions. Apart from the main products, the by-products obtained from this crop have many alternative uses, thus adding to the total value of the crop. Products obtained add revenue to the farmers, processors and entrepreneurs who are involved in processing and marketing of the produce. Products obtained from the by-products are utilized in different sectors like food, feed and shelter, and to manufacture decorative materials. Thus, every part of the palm is beneficial to mankind and hence it is aptly described as "Kalpa Vriksha".

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