Chapter 13
Harvest and Postharvest Technology

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Abstract This chapter enlists salient harvest and postharvest technologies of coconut. Various harvesting and postharvest gadgets, tools, machineries and equipments developed by different institutions are described. Technologies related to storage of nuts, processing of fresh coconut kernel and coconut water into different edible products, processing of dry kernel/copra, extraction and refining of coconut oil and processing of coconut sap (neera/sweet toddy) are explained in detail. The industrial and nonedible applications of coconut husk, coconut shell, coconut wood and coconut leaf are also described. Various sections that include harvesting and processing, technologies on food products as well as non-food products to future strategy in relation to harvest and postharvest technologies of coconut are concisely illustrated. A complete value chain information from harvesting to consumption and industrial utilisation from farm to fork is narrated. The need for refining some of the important equipments and technologies is indicated to make them more cost-effective and eco-friendly.

13.1 Introduction

Postharvest processing ensures effective utilisation of harvested produce and the quality of the end product, which ultimately tells upon the consumption and acceptance of the produce. It has been estimated that there is considerable loss in many of the agricultural products after harvest. This is either because the postharvest technology has not been developed to the desired extent or because of the special problems in the marketing of the produce.

Edible copra (milling copra) for the extraction of coconut oil, desiccated coconut powder, fermented sap and jaggery from the sap is the important edible products

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of coconut palm. Coconut is an important source of vegetable oil used for both edible and industrial applications. India consumes 40% of coconuts for its culinary and religious purpose, 35% for copra, 6% for manufacture of value-added products (1% as virgin coconut oil, 1% as coconut milk/cream and 4% as desiccated coconut powder), 17% as tender nuts and 2% for seed purpose.

One of the main reasons for the fall in price of the coconut and its products is dependency of price of coconut oil which in turn depends on the cost of other vegetable oils and hence the importance of product diversification. The industry has been successful in evolving appropriate processing technologies for some of the value-added products of coconut. As a result, products like packed coconut milk, coconut creams, spray-dried coconut milk powder, virgin coconut oil, coconut chips, coconut water-based products like vinegar and *nata de coco*, coconut palm sap-based products like coconut jaggery, coconut sugar, etc., which have good commercial potential, have been developed. These products have become important as an agro-based raw material for many industries. As a result, it has become possible to encourage product diversification and development of value-added products in the industry.

13.2 Devices and Gadgets for Plant Protection and Anti-buckling

13.2.1 Telescopic Sprayer

The telescopic sprayer comprises of two coaxial pipes of ultra-lightweight (0.5 kg m^{-1}) which can be used to spray up to a height of 12.5 m. The pipe height can be locked at any desired level above 6 m. Marginal farmers could attach a rocker sprayer, whereas in large gardens, a power sprayer can be used. The telescopic pipe assembly developed by ICAR-Central Plantation Crops Research Institute (CPCRI) is very much useful if the garden is of uniform size and slope. They are lightweight and durable. This solves the constraint of height of palms in taking up plant protection measures.

13.2.2 Anti-buckling Device

Partial severing of the bunch stalk from the trunk is known as buckling, which is a serious problem often faced by coconut farmers. Heavy weight of bunches, long and less sturdy peduncle, wider angle between the leaf and the inflorescence and weak leaf petiole are some of the causes for buckling of bunches. ICAR-CPCRI has developed a mechanical gadget for bunch support (Baboo and Bhat 1980), which consists of a trunk-clamp, support-clamps and telescopic support-rods. The trunk-clamp is made in six different sizes to suit varying trunk girths. Support-clamps can be placed at any point on the trunk-clamp. Telescopic support-rods are made in two different sizes to suit bunches located at various heights and positions on the crown. The support can easily be fixed on the trunk of the palm. The fork end of the support-rod is inserted towards the tail end of the bunch (about one-fourth distance from the tip) to support the peduncle. The rod is slightly lifted up, and the other end of the rod is inserted in the support-clamp hole. One man can easily do the operation, and it is possible to support as many as six to eight bunches at a time. Harvesting of nuts can be done without removing the support-rod by severing the nuts first and the stalk last. After the nuts from the bunch are harvested, the support-rod can be used for another bunch that might require support. As the palm grows taller, the trunk-clamp has to be refixed at a higher level. Before removing the trunk-clamp, which is already fixed, another is fixed above the old clamp. The bunch already under support is then provided with another support-rod and the clamp, support fixed to the new trunk-clamp. The old ones can be removed and used for another palm. This operation may be necessary only once in two years.

13.3 Harvesting of Nuts

13.3.1 Stage of Maturity of Nuts at Harvest

Coconuts are harvested at different stages of maturity for specific uses. For tender nut purpose, harvesting is done when the nuts are 6–8 months old. For snowball tender nut and coconut chips purpose, 8–9 and 9–10 months old nuts are harvested, respectively. For the production of copra and other kernel-based products, only fully mature coconuts are harvested. The nuts reach full maturity in 11–12 months after the inflorescence is opened. At this stage, the output of copra and oil as well as brown fibre would be the maximum. In a study in India, it was found that compared to 12 month old nuts, the copra yield was less to the extent of 6% in 11 month old nuts, 16% in 10 month old nuts and 33% in 9 month old nuts. The corresponding reduction in the percentage of oil was found to be 5, 15 and 33%, respectively. In places where green husks are in demand for the production of white fibre, the usual practice is to harvest 11 month old nuts. The slightly low copra output at this stage would, however, be compensated by the additional income derived from the fibre and its products.

13.3.2 Harvesting

Though coconut palm produces an average of 12 inflorescences in a year, some of the inflorescences are likely to get aborted or fail to develop into fruit bunches due to environmental factors. Consequently, the number of bunches available for harvest is less than 12 in many areas. Similarly, the frequency of harvest also varies from country to country and also within the countries. In many areas, 6–12 harvests per year are the usual practice. In the properly managed gardens, harvest at monthly intervals is usually adopted. In the neglected gardens, bunches are not produced regularly, and, as such, not more than six harvests are possible in a year. In most of the coconut-growing countries, fully mature nuts of 12 months are harvested at bimonthly intervals.

13.3.3 Methods of Harvesting

Harvesting of coconuts is a skilled job and is generally performed by experienced climbers by climbing up to the top of the tree. Climbing is usually done with the help of a ladder, 3–4 m long. On reaching the top of the ladder, the climber invariably uses a rope ring at the feet or ankles for the next stage of climbing. The climber uses another rope ring for the hands also in some places. Climbing is also done by cutting notches on the trunk at convenient spaces, which is not a desirable practice because of the injury caused to the stem. Tied-on-husks are also used as steps for climbing. Another method involves the use of a rope loop which encircles the trunk and the climber. Various climbing devices have also been developed to reduce the drudgery involved in the climbing process for harvesting of coconuts (Thamban et al. 2011).

13.3.4 Harvesting Gadgets

13.3.4.1 Pole Harvesting

In Sri Lanka and also in some states in India, bunches are brought down by a knife attached to a long bamboo pole. But this will be very difficult to be used in very tall palms. In some countries such as Thailand and Malaysia, trained monkeys are also used to pluck the fruits.

13.3.4.2 Ultra-Lightweight Coconut Harvester

The harvester developed by CPCRI comprises of two coaxial pipes of ultra-lightweight (0.5 kg m^{-1}), which can be used to harvest up to a height of 12.5 m from the ground. The pipe height can be locked at any desired level above 6.25 m. On the top end of pipe, a specially designed knife is fitted using nuts and bolts. The harvesting knife could be fabricated by local craftsmen.

In Papua New Guinea, some of the African countries and other Pacific Islands, the fruits are allowed to ripe and fall down on their own, and the fallen nuts are collected at regular intervals.

In addition to harvesting, various other operations like cleaning the crown, pollination, tapping and insecticide application are being often neglected due to scarcity of climbers (Akyurt et al. 1839). Considering this scenario, many efforts have been made to ease the operation of palm climbing by developing gadgets and climbing devices. Davis (1961, 1963, 1964, 1977) developed three prototypes for palm climbing. Swamy and Patil (1975) developed a much simpler device which consists of movable supports for legs and hands and lifts alternately while the other one is gripped for climbing.

Various types of climbing devices like tractor-operated, self-propelled, manually operated and some robotic-type (electronic) devices have been developed and tested for harvesting coconut by both the government and private sector (Kolhe 2010; Kolhe and Jadhav 2011; Sial 1984; Shabana and Mohamad 1993). Among the manual types, one model was developed by an innovative farmer (Joseph model), another by TNAU (TNAU model) and the third by CPCRI (Singh et al. 2012) in India. Of all these manual devices, Joseph model is the only machine commercially available and used by professional climbers.

13.3.4.3 Paddle–Type Device

Chemberi Joseph Model Joseph model has got mainly two assemblies of similar construction. The steel rope wires of both top and bottom assembly need to be looped with the palm and locked. The user then climb on to the machine by placing one foot each on both the assemblies holding the handles provided. Standing on one assembly, the user lifts the other assembly to loosen the steel rope and raise it by hand. After attaining a comfortable height, he pushes back the assembly with foot so that it gets tightened to the palm. The user has to co-ordinate these two assemblies simultaneously by using hands and legs to climb on coconut palm. It does not require much skill and 2–3 days' training is enough to easily climb the palm.

ICAR-CPCRI has developed a safety attachment to this model of climbing machine. The safety device consists of a 6 mm steel rope of length slightly more than the circumference of the coconut trunk having an oval-shaped loop each at both ends. The only modification required in the climbing machine is providing two 6 mm metal (MS) rings at the bottom of the handle of the right leg unit of the climbing machine. The steel rope is taken through these loops around the palm, and one end of the steel rope is taken through the loop provided at the other end, making it a noose around the coconut palm. The free end is then connected to a commercially available body harness. The wire rope moves up and down along with the climbing machine during operation. In case of an eventuality of failure of the machine or accidental falling of the climber, the steel rope noose gets tightened to the coconut trunk and prevents the climber from further falling. The safety attachment is independent of the climbing machine and gives fool-proof safety to the climber from falling.

TNAU Model This is a sitting-type or push up-type model developed by Tamil Nadu Agricultural University (TNAU). The device has two MS frames – one upper and another lower one. They are connected by a belt while the equipment is on the coconut palm. The user has to sit on the seat which is provided on the upper frame and has to insert his foot between the rubber rollers available in the lower frame. The upper frame can be lifted by hands, and the lower frame has to be lifted by leg. In this type, the size can be adjusted as per the diameter of the palm. As both frames are positioned in an angle, it will get clung to the palm due to the friction by rubber bush, and the process has to be repeated for further climbing. Safety belt can be adjusted as per the body posture. Distance between the top and bottom frames can be adjusted by the belt as per convenience.

In Jamaica during 1976, Swiss equipment used in forestry for climbing, known as 'Baumvelo' (tree bicycle), was tried with some modifications for coconuts, but problems were faced when leaving the device near the crown of the tree. Sliding aluminium ladders are also being used as in Jamaica for coconut climbing. None of the above prototypes could reach the stage of full acceptability by the farmers and commercial production due to various reasons.

One farmer in Kerala has developed a successful model of tree climbing device, which is similar to the 'Baumvelo' tree bicycle. This device works on the principle of gripping the device through rings by self-weight with legs providing the motive power. The device has two stirrups and the rubber pad rings tightened or loosened on the trunk by wire rope connected to the sliding foot rest on the stirrups providing the gripping or loosening of the device. The alternate gripping action by hand and legs facilitates lifting and lowering of the gadget and thus enables the person to climb up or down. The unit is very cheap and handy and has become popular in India.

Attempts are also made by researchers at TNAU, ICAR – Central Institute of Agricultural Engineering (CIAE), Bhopal, and a local fabricator at Ratnagiri (India) to develop coconut harvesting machine based on self-propelled hydraulic mast. Efforts were made by local fabricators and innovative farmers also to make prototype of a 'robotic-type' coconut harvester. However, none of these machineries are yet fit for commercial use.

13.3.4.4 Tractor–Operated Multipurpose Hoist

TNAU has developed a tractor-operated multipurpose hoist that is amenable for fruit plucking, coconut harvesting, pruning, lopping and spraying tree crops. The equipment is attached to the back of a 45 hp agricultural tractor. Two persons can stand on the platform and do operations. Platform can reach a maximum height of 8.1 m.

13.3.4.5 Aerial Access Hoist for Coconut Harvesting

An aerial access hoist for coconut harvesting has also been developed by TNAU. The machine is the first of its kind in tractor-mounted form. A full-length chassis from front to rear of the tractor provides support. The entire weight of the hoist and moments is transmitted through the chassis to the stabilisers without transferring to the tractor chassis. Four palms can be accessed from a single position. The time required for positioning the unit and operating stabilisers is 1 min, and the time required for positioning against a palm of 10 m height is 2 min. The operator platform can be positioned by the operator himself. Lifting capacity of the machine is 120 kg.

13.3.4.6 Self–Propelled Hydraulic Multipurpose System

CIAE has developed a self-propelled hydraulic multipurpose system for orchard management operations which could be used for harvesting coconut also. The self-propelled hydraulic multipurpose system has a maximum vertical reach of 6 m, has a load carrying capacity of 200 kg and can be operated at maximum ground speed of 3 km h^{-1}. This machine was designed with dimensions of 2.2 m × 6.3 m × 1.89 m and can be used as a platform to reach fruits on trees for easy picking. It is hydraulically powered using 8.2 kW (11 hp) engine and has a low centre of gravity while still maintaining good ground clearance (290 mm) for good stability during operation. Lifting, lowering of the platform, forward and backward movement and steering of the machine are controlled by the operator from the platform itself. The hydraulic system of the machine has been designed to stop the movement of machine even if the engine needs to be shut off. The machine is easy to be operated and requires low maintenance.

13.4 Processing Machineries

The following devices were developed by ICAR-CPCRI (unless otherwise mentioned) to increase efficiency and reduce time required and drudgery involved.

13.4.1 Coconut Dehusking Machine

Coconut dehusking is the first postharvest operation in any coconut processing industry. Traditionally coconut is dehusked manually using a spike. Drudgery and risk of getting injured make the operation male dominated.

A power-operated semi-automatic coconut dehusking machine has been designed and fabricated. Dehusking is done by passing coconut over two spiked rollers rotating at different speeds in opposite directions. The coconut is pressed towards the rollers with the help of a pneumatic cylinder. Husk is removed by the rotating spikes. However, a small portion of the coir fibre would remain at the eye portion of the coconut. This would then fall on a pair of rollers rotating at the same speed but in opposite directions. The remaining coir also would be detached, and the fully dehusked coconut can be collected at the opposite side. The rollers are rotated by an electric motor. Feeding is done manually. Though the machine would not replace manual labour, the drudgery involved in dehusking is totally avoided. Anyone can use the machine even without any formal training. The machine has a capacity to dehusk 200 coconuts per hour. ‘Keramitra’, the coconut dehusking machine developed by Kerala Agricultural University (KAU), is a very popular device in households (Varghese and Jacob 2014). However, the extremely low output is a major constraint.

13.4.1.1 Coconut Dehusking Tool

An easy-to-operate simple coconut dehusking tool which is particularly useful for domestic purpose has been developed. It consists of mainly a stationary wedge, a movable wedge, a lever and a pedestal having a base. The new tool has the resemblance of a crowbar but has an additional mechanism for making the opening of the husk easier or effortless. The base of the tool is held firmly to the ground using the feet particularly with one foot on the side of the handle. The coconut is thrust on to the husking tool. On pulling the handle upwards with one of the hands, one sector of the husk is loosened from the shell. This is repeated three or four times for loosening the remaining sectors. It takes only about 8–20 s for husking a nut depending on the variety, maturity, etc. of the nut. It is light in weight, simple to use and handle and cheaper and can be used both indoors and outdoors.

13.4.1.2 Pedal–Operated Coconut Dehusker

This is a modified design based on the one developed by the Kerala Agricultural University (Indian Patent No.192670, 1995). About 100–120 nuts can be dehusked h^{-1}. The unit has been designed to withstand longer use. This unit has some advantages such as less requirement of energy for dehusking and reduced drudgery.

In India, three prototypes of mechanical dehuskers were developed in the 1980s. The first experimental prototype (Singh 1981) was provided with a set of three spring-loaded curved blades and a telescopic hand lever connected to the assembly. By pressing the hand lever manually, the blades pierce the husk, and on moving out in horizontal plane, the husk segments are removed. But the outturn was low and the breakage was to the extent of 5%. Moreover, it was not possible to dehusk the coconuts of all shapes and sizes in this prototype. This was modified by replacing the spring-loaded curved top blades with a set of straight blades fitted on a frame rotating freely in the shaft, to accommodate nuts of all shapes and sizes (Baboo and Bhat 1980). Here the breakage was reduced to 1%, but the outturn was further lowered to 500 coconuts in an 8-h operation as against 1500–2000 nuts in the traditional manual operation.

Another model with leg and hand operation was designed at ICAR-CPCRI in 1986. The device consists of a platform at waist level, with a frame. A shaft, which moves up and down on the platform, is operated by foot through linkages at the bottom end. The top end of the shaft is fixed with a circular plate on which a set of three fixed blades is provided. A rotating plate with guide slots is fitted in alignment and just below the bottom plate. The scooping blades move out radially when the rotating plate is rotated by a handle fixed on it. Another plate with three fixed blades is fixed at the top in such a way that the blades are faced in vertical alignment with guide slots by means of guide rods welded to them. The guide rods move freely in the radial guide slots in the bottom rotating plate. The plate can be rotated by pulling the handle. Coconut is kept inverted in between the top and bottom plates. The bottom plate assembly is lifted up by pressing the foot pedal; pressing it further, the bottom and top blades pierce into the husk. After piercing to the maximum, the handle is pulled out to rotate the free plate which in turn will actuate the scooping blades. Upon scooping, the husk gets detached from the nut into three portions. It involves less effort to dehusk the coconut. It can be fabricated locally and is simple in design and safe to operate. The outturn of this machine is 110 nuts h^{-1}, whereas the outturn by traditional way is about 160 nuts h^{-1}. But the main advantage of this machine is that an unskilled person can do this job without the risk of injury. It is 13–25% cheaper than the conventional method. Nijaguna (1988) has also developed another coconut dehusker, which works on similar principles.

A power-operated semi-automatic coconut husking machine has also been developed (CPCRI 1996). The machine consists of three main parts, viz. a rotating platform having a set of six coconut holders, a piercing system with shock absorber to avoid breakage of coconut due to excess load and a scooping blade set for splitting and loosening the husk. The required operating speed of various parts is achieved by using different types of gearboxes. The machine can dehusk 500–600 nuts h^{-1} much higher than the traditional spike method. Two unskilled labourers are required to operate this machine. It is economical and financially beneficial to farmers and copra manufacturers. The time required to dehusk one nut is 6 s.

Mechanical dehusking devices have been perfected and put to use in other countries as well. A portable spike has been developed at the IRHO for Côte d'Ivoire Region (Pomier 1984) which can dehusk 1200–1300 nuts per day. In Malaysia, a manually operated pneumatically powered dehusking device was developed (Alias and Hashim 1982) which gave an output of 75–80 nuts h^{-1}.

In Taiwan, a hydraulically operated coconut dehusking machine giving an output of 350–400 nuts per hour has been developed. The Tropical Development Research Institute (TDRI) has developed a power-driven coconut dehusker which has been commercially manufactured by M/s Jaffor Incorporated Ltd., UK. The capacity is reported to be 730 nuts h^{-1} (Coconis 1986).

The Caribbean Industrial Research Institute, Trinidad and Tobago (West Indies), has developed an electric motor-powered coconut dehusker (Rnam 1990). The capacity of the dehusker is 600–800 nuts h^{-1} and is powered by a 3 hp motor. The machine uses shearing force to strip the husk from the nut. The shearing action is produced by two spiked rollers which rotate in opposite directions and at different speeds.

In South Pacific Islands, dehusking of coconuts is not carried out; instead the whole nut is split into halves with an axe and the endosperm is gouged out in pieces, either while fresh or after preliminary drying. A machine for splitting coconuts in this way has also been developed, which splits the coconut into three parts.

13.4.2 Coconut Splitting Device

To solve the problem of splitting of coconuts by holding it in hand, a manually operated splitting device is developed. Knife of the machine is made of spring steel and is kept at a bevel angle of 25 degrees. As the cutting blade is made of spring steel, it does not require frequent sharpening. Nut is split manually by the impact force and the nut water is collected at the bottom.

13.4.3 Copra Dryers

The common practice of making copra is by sun drying the fresh coconut kernel on cement floor or on sand floor for 7–9 days. The endosperm of coconut is exposed while drying and so can be contaminated with dirt. Prolonged drying, especially during monsoon, also results in microbial infection. The energy-efficient dryers developed produce dust and microbial contamination-free copra in a short period (Vidhan Singh et al. 1999).

13.4.3.1 Small Holders' Copra Dryer

This is an indirect dryer that can dry up to 400 coconuts per batch, ideal for a farmer to make copra in his farm itself. Any agricultural waste could be used as fuel. It takes 36 h to get quality copra.

13.4.3.2 Shell-Fired Copra Dryer

This copra dryer works on indirect heating and natural convection principles using coconut shell as fuel. It requires less fuel, makes copra in short time and is less expensive too. Capacity of the dryer is 1000 nuts per batch. The copra obtained is light brown in colour which helps to fetch a better price in the market. The burner generates heat for 5 h without tending, and the residual heat is retained for one more hour. The average drying time is 24 h.

13.4.3.3 Forced Circulation Copra Dryer

Forced circulation dryers are more efficient and much faster than the dryers using natural convection to dry copra (Madhavan and Bosco 2002). Several types of such dryers are available in the market with varying capacities to suit the requirement of the copra industry.

13.4.3.4 Solar Tunnel Dryer

A solar tunnel dryer with a capacity of 1500 coconuts/batch is developed that produces good-quality copra in a shorter time (Madhavan and Bosco 2004). It consists of a semi-cylindrical shape tunnel structure having a transparent cover made from UV-stabilised polyethylene film of 200-micron thickness. The solar collector is the black polyethylene film of 250-micron thickness spread on the ground inside the dryer for better absorption of solar heat. The temperature inside the dryer is 20–25 °C higher than the ambient, and the RH value is 20–22% lower than the ambient. The copra, thus produced, is less infested by fungi and bacteria than the one produced by open sun drying. Drying time taken to dry copra is 32 sunshine hours. The dryer can also be used to dry arecanut, cocoa beans, cardamom, pepper and ginger.

13.4.3.5 Solar Cum Electrical Dryer with Agricultural Waste as Third Source of Energy

For cloudy and rainy days, a multisource dryer has been developed with solar energy as the main source of energy and electricity and biofuel as alternate sources of energy. The dryer consists of a semicircular parallel plate solar collector, electric heaters of 1000 W (six numbers), blower cum exhaust motor and the drying chamber. It is an auto-regulated dryer with temperature and humidity control. It is a batch-type dryer and the capacity of the dryer is 2000 coconuts batch^{-1}. The dryer can be used to dry other produce such as cardamom.

13.4.4 Coconut Deshelling Machine

A power-operated batch-type coconut deshelling machine has been developed to separate shell and copra after partial drying. Capacity of the machine is 400 half cups per batch. The optimum moisture content is 35% d.b for maximum deshelling efficiency of 92.16%. The optimum speed of the deshelling machine is 10 RPM, and the time taken for deshelling is 4 min batch^{-1} (Singh and Udhayakumar 2006).

13.4.5 Copra Moisture Meter

The quality of milling copra ultimately determines the quality of the oil and the residual cake. Good-quality copra will yield oil with free fatty acid (FFA) content of less than 1%. Moisture is the most important factor influencing the quality of copra. Copra with a moisture content of less than 6% is considered good quality as it is not easily damaged by insects, moulds or microorganisms. An electronic moisture meter was developed to determine the moisture content of copra, based on the electrical conductivity of the kernel. The instrument can read moisture content from 5% to 40%. It is very handy, and the accuracy is more than 94% in the lower levels of moisture content. It consists of an electronic unit, an output meter and a sensor. The sensor is made of a pair of steel rods of size 8 mm × 2 mm fixed 6 millimetres apart. The power supply is 9 V battery or equivalent. The instrument was calibrated against standard air-oven method. After switching on the instrument, adjust the Cal Port so that the meter needle rests on the 'Cal' position marked on the dial. Then, plug the sensor into the sensor socket. Probe the sensor into the inner side of copra. The reading now seen on the meter gives the percentage moisture content in the copra. The average moisture content from a minimum of three points is taken as the moisture content of copra. The instrument is handy and useful to copra processors and farmers. This unit is being marketed by M/s Kerala Agro Industries Corporation in view of its practical application (Madhavan 1987).

13.4.6 Tender Coconut Punch and Cutter

Tender nut punch and cutter are two simple devices to pierce and cut open the tender coconut. A clean hole sufficient enough to insert a straw is formed so that one can drink the fresh coconut water conveniently. The nut is placed on the wooden platform and cut open by pressing the lever attached to the blade. The efficiency is 20 tender coconuts h^{-1}.

13.4.7 Snowball Tender Nut Machine

Snowball tender coconut is a globular tender coconut containing tender coconut water inside. The ball is scooped out with the help of a specially devised tool after cutting the shell of tender coconut of 7–8 months maturity by using snowball tender coconut machine. The snowball tender coconut thereafter is made free of the adhering testa, packed hygienically to use either as fresh or after refrigerated storage. Output capacity is 250 coconuts in 8 h by one person.

13.4.8 Coconut Shell Removing Machine

Coconut shell removal is the second postharvest operation in a coconut processing industry using fresh coconut kernel as the raw material. Traditionally coconut shell is removed using a knife. Though women do this work, the labour-intensive process is not at all attractive to the processing industries. Coconut shell removing machine is intended to reduce both time and drudgery involved in the manual shell removal.

Two concentrically rotating multipointed circular blades and a stationary pointed blade on which coconut would be placed firmly are the major components of the shell removing machine. Coconut to be processed is pressed towards the rotating blades by firmly placing it on the stationary blade. Shell gets detached from the kernel due to the impact force of the rotating blade. The machine has a capacity to remove the shell of 150 coconuts h^{-1}.

13.4.9 Coconut Testa Removing Machine

Many high-value coconut products like coconut chips, virgin coconut oil, desiccated coconut powder, etc. require removal of testa. Manual removal of testa using potato peeler is a cumbersome and time-consuming process. Moreover, a sizable amount of coconut meat also would be lost along with the removed testa. The coconut testa removing machine developed reduces the drudgery and improves the efficiency and capacity of units that require removal of testa. The main component of the machine is a circular wheel covered with emery cloth or water paper attached to an electric motor. One person can remove testa of about 75 coconuts h^{-1}.

13.4.10 Coconut Slicing Machines

Slicing coconut kernel to produce chips of uniform thickness is the single most important unit operation in the coconut chips making process. Conventionally, this is done manually, and the process is very cumbersome and time-consuming. Moreover, quality of chips, especially uniformity of thickness, would depend on the skill of the operator. In order to make this operation simple and faster, two types of coconut slicing machines were developed.

13.4.11 Coconut Chips Making Machine: Electrical

The machine consists of two stainless steel slicing blades fixed on a circular blade supporting disc, a feeder to insert coconut endosperm for slicing, an exit guide to guide the sliced coconut chips towards the outlet and an electric motor as a prime mover. The electric motor rotates the blade supporting disc using a V-belt. When coconut endosperm comes into contact with the blades, it gets sliced. The sliced coconut chips are then guided towards the outlet by the exit guide and are collected in a container. Coconut chips of uniform and required thickness could be produced using this machine. Provision is made in the slicer to slice tuber crops, banana and vegetables. The capacity of the machine is 60 coconuts h^{-1}.

13.4.12 Manually Operated Coconut Slicing Machine

The machine is quite user-friendly especially for ladies who know operation of sewing machine. Approximately 25 coconuts can be sliced in 1 h using this machine.

13.4.13 Coconut Chips Dryers

The electrical dryer developed consists of a set of ten trays with wire-mesh screens for loading coconut slices. Temperature in the dryer is controlled automatically by a sensor and electronic control unit. Though the dryer is designed for 50 coconuts, the size could be enhanced to any desired capacity. Another prototype of chips dryers that uses agricultural waste as fuel has also been developed. Furnace of this indirect dryer is conveniently placed outdoor with the drying unit indoor. Temperature is controlled by a butterfly valve in the hot air inlet. Cost of drying is less than that of electrical dryer.

13.4.14 Coconut Grating Machines

Two coconut grating machines were developed to enhance the grating efficiency. First one is of single-user and the second one is of multiuser (four grating blades) type. These machines scrape off the coconut kernel into fine gratings with the help of stainless steel blade. The single-user machine has a capacity of 60 coconuts h^{-1}, and the multiuser has a capacity four times of the first one.

13.4.15 Coconut Pulveriser

The coconut pulveriser consists of a power-operated rotary blade. The coconut kernel pieces are fed into the chopper manually. Due to the impact of the rotary blade and the rubbing on the stationary blade, the coconut kernel turns into fine powder. The machine has a capacity of 250 coconuts h^{-1}.

13.4.16 Coconut Milk Extractors.

Four different coconut milk extractors have been developed to enhance the milk extraction efficiency. While two of them are manually operated, the other two are hydro pneumatic coconut milk extractors.

13.4.16.1 Manually Operated Milk Expellers.

Both the manually operated machines are similar to a hand-operated vertical screw press. The grated coconuts are kept in a perforated cylinder, and by rotating the handle provided at the top of the screw, the gratings are pressed. In one of the machines, the whole pressing process is done manually by rotating the handle. In the other one, an additional hydraulic jack is provided at the bottom. Gratings kept in the perforated cylinder are pressed initially by rotating the handle. Final pressing is done by operating lever of the hydraulic jack. The platform on which the perforated cylinder is kept moves up and exerts pressure on the coconut gratings thereby expelling coconut milk without much effort.

13.4.16.2 Screw-Type Coconut Milk Expellers

Two screw-type coconut milk expellers, single and double screw, with different capacities have been developed to extract coconut milk. The screw-type expellers have the maximum extraction efficiency among different types of coconut milk extractors. The single-screw expeller has a capacity of 300 coconuts h^{-1} and the double-screw has a capacity of 1000 coconuts h^{-1}.

13.4.17 Virgin Coconut Oil Cookers

The technique to produce virgin coconut oil (VCO) by hot processing method has been standardised and the protocol commercialised. Conventionally VCO is prepared by heating coconut milk in an open container at low flame with continuous stirring. It is done manually and the constant stirring is a laborious process. Many a times the milk gets charred when the stirring is not proper or when excess fuel is burnt. In order to overcome these limitations, two types of VCO cookers were developed to extract the VCO by hot processing (Mathew et al. 2014).

13.4.17.1 Virgin Coconut Oil Cooker: LPG/Biogas

This cooker consists of a double jacketed vessel filled with thermic fluid, which ensures efficient and uniform heat transfer to coconut milk in the cooker. Four Teflon-tipped stirrers are provided to stir coconut milk, which helps the cooker to distribute heat energy uniformly within the coconut milk. The stirrers are powered by an electric motor with a reduction gear. An outlet with a door attached to a lever is provided at the bottom of the cooker to take out the extracted oil. The cooker is supported by three legs with sufficient clearance from ground for easy collection of extracted oil. A thermometer is provided to measure the temperature of the thermic fluid so that it can be maintained at 100–120 °C. A safety valve is also provided for extra safety by releasing the pressure developed, if any, in the thermic fluid chamber. The cooker is heated by two burners provided at the bottom of the heating chamber. Biogas or LPG could be used as fuel. Virgin coconut oil cooker has a capacity of 125 litres which can be upscaled.

13.4.17.2 Agricultural Waste Fired Virgin Coconut Oil Cooker

In this cooker agricultural waste material is used as fuel. The design and construction features of the cooker are similar to the LPG/biogas model. A burning chamber is provided at the bottom of the double jacketed vessel. The cooker is heated by burning any agricultural waste, preferably coconut shell, in the burning chamber. An opening is provided at the front to feed the fuel. An exhaust to remove smoke is provided at the opposite side and is connected to a chimney kept outdoor for easy combustion of fuel. This can be fabricated as per the required capacity.

13.5 Storage of Coconuts

It is a common practice to store harvested nuts in heaps under shade for a few days, known as seasoning, before they are further processed. The advantages are:

1. Husking becomes easier.
2. Shelling is cleaner and easier, and the resulting shells are dry and hard and, when used as fuel, burn continuously and produce less smoke.
3. The moisture content of the meat decreases and the thickness of the meat layer increases. Consequently the yields of copra and oil increase.
4. The quality of copra produced is also superior to that of unstored nuts.

Studies have shown that storage of harvested nuts is beneficial only if the nuts are fully ripe and that good-quality copra can be obtained from nuts even immediately after harvest if the nuts are fully ripe. Though storage of comparatively immature nuts is helpful in obtaining a higher output of copra per nut, these are easily spoiled during storage. The results of a study conducted in India on storage of nuts are summarised in Table 13.1.

Table 13.1 Changes in copra content and nut spoilage during storage

	Changes in copra content (g) nut^{-1}				Nut spoilage (%)			
Maturity of nuts (months)	12	11	10	9	12	11	10	9
Storage								
Nil	161.1	150.0	128.2	96.8	–	–	–	–
30 days	162.5	150.4	135.2	117.6	2.24	3.16	22.02	58.33
60 days	162.2	156.8	138.9	127.0	7.62	13.10	31.55	78.57

Source: Rethinam and Bosco (2006)

The storage trials conducted at the Coconut Research Institute in Sri Lanka to study the quality of copra obtained from stored and unstored coconuts of different stages of ripeness showed that unripe green nuts when stored gave 25% more yield of copra with reduction of rubbery copra by 24% and the same without storage gave discoloured copra (Mathes and Marikkar 2010).

13.6 Food Products

Various products derived from the coconut palm are utilised as food either in their natural state or after processing into various products.

13.6.1 Products Derived from Wet Kernel

13.6.1.1 Wet Kernel

The kernel of 7–8 months old nut is consumed either as such or along with the sweet tender nut water. At this stage, the kernel will be very soft with maximum protein content and sugar which gradually decline as the nut matures. The kernel is considered ripe when the nut is 11–12 months old after fertilisation. The composition of unripe kernel is 90.50% moisture, 0.80% protein, 1.30% fat, 6.80% carbohydrates and 0.60% ash (Banzon et al. 1990).

As the nuts mature, the moisture, protein and ash content of the fresh endosperm slowly decreases, whereas the fat content increases. After the 10th month, the protein content undergoes practically no change, but the fat content continues to increase until it reaches its peak at 12th and 13th months. Subsequently, the fat content decreases until the 15th month (Hallexa and Seirra 1976). Table 13.2 shows the chemical composition of the kernel from three countries.

The ripe kernel derived from 11 to 12-months old nuts is used in different forms for edible uses both in the households and organised food industry. In the households, fresh kernel is used both in the grated form and in the form of milk or cream obtained by squeezing the gratings with or without the addition of water. Processed forms of kernel and milk find applications in the food industry.

Table 13.2 Composition of kernel from fresh coconuts in percentage

Source	Moisture	Protein	Fat	Crude fibre	Carbohydrates	Ash
U.K.[1*]	44.0	3.6	38.1	3.1	9.9	1.3
Sri Lanka[2]	44.0	4.6	38.2	2.3	9.7	1.2
India[3]	35.4	5.5	44.0	3.0	10.0	2.1

[a]Dendy and Timmins (1973); [2]Nathanael (1965); [3]Anonymous (1984)
bT.P.I. – Tropical Products Institute, UK

It is now possible to preserve kernel of 8–10-months old nuts. For this, the tender kernel is cut into strips of about 6 cm length and 2 cm width. These are put into cans, covered with hot syrup, exhausted at 80 °C, sealed and processed. The product has a shelf life of 4–6 months at ambient temperature and has been found to be microbiologically safe even after 1 year. In the Philippines, kernel from 8- to 9-months old nuts is first scooped out, the adhering testa is removed by using a sharp knife, and the pared meat after washing is cut into 0.5-cm-thick and 6-cm-long strips. The strips are put in cans to which 50 °C brix syrup with 0.01% sodium metabisulphite is added. The filled cans are then exhausted at 78 °C, sealed and processed at 110 °C for about 20 min. In the processing of jelly-like tender nuts of 6–7 months, the meat is scraped out, and an equal part of refined sugar is added. The mixture is cooked in low heat until the sugar is totally dissolved, hot packed in sterilised bottles and closed tightly.

Coconut kernel has been used as food since ancient times. Coconut kernel contains almost all essential vitamins and minerals, which are necessary for health. Coconut fat is made up of fatty acids of saturated, unsaturated and glycerol esters. The coefficient of digestibility of coconut oil is highest when compared with that of other fats. The coconut protein has a biological value of 71–77% and digestibility of 86–94%. Coconut contains the following carbohydrates: sucrose, raffinose, galactose, glucose, fructose, pentoses, cellulose, pentosans, starch, dextrin and galacton. The fresh kernel contains about 7% sugar though it is a poor source of minerals. It also contains 151 IU of thiamine, 1 mg of ascorbic acid (vitamin C), traces of vitamin A and 0.2 mg of tocopherol 100 g^{-1}. Coconut proteins are high in nutritive value and are fairly rich in lysine, methionine and tryptophane.

The fresh kernel of ripe coconut constitutes an essential ingredient in the recipes of diverse food preparations in the households as well as in food industries of different countries. In the household food preparation, fresh kernel is used extensively in the grated, paste or milk form. When the grating as such or in the form of ground paste is used, there is no loss of nutrients or wastage of kernel. Coconut is transported either as whole coconuts or after removal of a portion of husk to regions, where the palm is not cultivated.

By transporting the coconut kernel packages instead of whole or partially dehusked coconut, up to four times higher quantity (weight basis) could be transported. Predictive equations and regression models were developed to optimise the package parameters like respiration rate of kernel, permeability characters of polyfilm and partial gas pressures inside the package. Optimum gas composition of 5, 15 and 80% of O_2, CO_2 and N_2, respectively, was found to increase the shelf life of kernel under the storage temperatures of 15 °C and 25 °C.

Preservative mixture of butylated hydroxy anisole at 0.1% and propionic acid at 1000 ppm was found to increase the shelf life of kernel along with modified atmosphere package (MAP) system. At 15 °C storage temperature, low-density polyethylene film of thickness 0.041 mm and polypropylene film of 0.042 mm thickness and at 25 °C storage temperature low-density polyethylene film of 0.027 mm thickness were found to be the best for MAP. The shelf life of the kernel in MAP was increased to a minimum period of 90 and 25 days at 15 °C and 25 °C, respectively.

For vacuum package, 0.042-mm-thick polypropylene film was the best to store at both 15 °C and 25 °C. The shelf life of the kernel was increased to a minimum period of 60 and 20 days at 15 °C and 25 °C, respectively. The shelf life of the kernel stored in open condition at 15 and 25 °C was only 20 and 5 days, respectively (Bosco 1997).

The cost of production of one package of 0.15 kg at laboratory level was Rs. 0.49. A net benefit of 30 paise could be obtained by transporting and distributing the kernel at a distance of 1000 km. Further increase in the distance of transport increases the benefit. The loss of coconut due to crack development is reduced, indirectly increasing the benefit and profitability.

13.6.1.2 Sweet Coconut Chips

Dehydrated coconut chips can be prepared from coconut kernel with intermediate moisture (35–40% on wet basis). Moisture from mature coconut kernel is removed partially by osmotic dehydration by using osmotic mediums like sugar syrup. This osmotically dehydrated coconut slice is named as 'sweet coconut chips'.

Artificially dried coconut slices by use of conventional tray dryers or vacuum dryers are wholesome, nutritious and palatable, but it has not been, in general, found popular because it does not have the flavour, colour and texture of the original material even after rehydration. Freeze-drying of coconut slices results in good quality of dried material with long storage stability, but cost of processing is very high. Sweet coconut chips are crispy and can be packaged and marketed in laminated aluminium pouches, which will have a shelf life of 6 months. Since it is in a ready-to-eat form, it could be used at any time, as snacks or just like fresh kernel after rehydration of the chips in hot water.

13.6.1.3 Coconut Milk and Related Products

Coconut milk is an emulsion of coconut oil in water into which some of the soluble components of the meat have already been passed. It is prepared from fresh mature coconuts. In this process, the white coconut kernel is ground into slurry from which coconut milk is separated by pressing. In continuous process, coconut milk is extracted in the screw press. The milk is then centrifuged and further processed to get milk concentrate, coconut cream and milk powder. The stability of the emulsion is better in the pH regions where coconut proteins are more soluble (Monera and del Rosario 1982). Apart from household culinary uses, the coconut milk is utilised as a substitute for dairy cream in beverage-type milk as evaporated and sweet condensed milk (Banzon 1978) in the preparation of white soft cheese (Sanchez and Rasco 1983), yoghurt (Sanchez and Rasco 1984) and many other food items.

The milk is pleasant and sweet with an agreeable flavour. A comparison of the coconut milk with cow's milk has shown that white coconut milk is richer in fat but poorer in protein and sugar content. Diluted coconut milk is used as an adulterant

Table 13.3 Composition of coconut milk in percentage

Source	Moisture	Total solids	Ash	Fat	Protein (N × 6.25)	Total sugar as invert sugar
Philippines[a]	56.3	43. 7	1.2	33.4	4.1	5.0
Sri Lanka[b]	50.0	50.0	1.2	39.8	3.0	6.2
India[c]	51.0	37.0	1.8	26.0	4.5	5.5

[a]Jeganathan (1970); [b]Nathanael (1954); [c]Arumugham et al. (1993)

for cow milk in certain places. The proximate composition of coconut milk as reported by the Central Food Technological Research Institute (CFTRI) Mysore, India, is 41.0% moisture, 5.8% protein, 38–40% fat, 6.2% minerals and 9–11% carbohydrates. The composition of coconut milk is also subject to variation. The figures reported by other sources are given in Table 13.3.

Preserved Coconut Milk or Cream Preserved forms of coconut milk such as canned cream or milk and dehydrated whole milk are now becoming available in many countries. Commercial production of these products has been promoted in the Philippines, Thailand, Indonesia, Western Samoa, Sri Lanka and Malaysia.

The technology for the production and preservation of coconut milk has been perfected in India. In this process, pared kernels are first immersed in hot water for 10 min at 75 °C to 80 °C for microbial control. The kernels are then comminuted either using the hammer mill (3 mm) or the Krauss-Maffei disintegrator with 3 mm perforation. The optimum maturity of nut for achieving maximum yield of milk was found to be 11–12 months. The moisture content of the gratings is maintained at 40–45% for facilitating efficient extraction of milk. Pressure is applied on the comminuted kernel with or without the addition of water. The extraction of milk is done in a screw press. The extracted milk is passed through a vibratory sieve of 150 microns to ensure that the milk finally contain not more than 0.5% of the finely grated material. The milk is then pasteurised at 75 °C to 80 °C for 10 min using a plate heat exchanger. As an adjunct to heat treatment, sodium metabisulphite or the antibiotic nisin is used to enhance the shelf life of the finished product. After pasteurisation, stabilisers and emulsifiers are added to the milk for preventing the separation of the milk and for facilitating emulsion formation. Carboxy methyl cellulose (CMC) and guar gum were found to be good stabilisers. Among the emulsifiers tried, Tween 80 at 0.1–0.2% levels was found suitable in the presence of 0.5% CMC. The pasteurised milk is then passed through a colloidal mill and pressure homogeniser for the coagulum dispersal and the even distribution of emulsifiers and stabilisers. Pressure homogenisation at 4000 psi has been found to impart better stability to the finished product. For packing the product, hot filling and crown corking are presently followed. Other packing systems like flexible packing and canning are also found successful. The analytical data of the coconut milk produced in India are shown in Table 13.4 (Arumugham et al. 1993).

The technology developed in the Philippines has been patented under the Philippines Patent No. 5632. In this process, round mature nuts are selected and deshelled. After disintegration, the meat is mixed with one and a half to two times

Table 13.4 Composition of canned coconut milk products (in percentage)

Properties	Moisture	Protein	Fat	Carbohydrates
Canned cream	55.0	0.9	40.0	2.8
Canned whole milk	75.0	1.0	12.5	10.2

Source: NIIR Board of Consultants and Engineers (2012)

its weight of water and passed through a screw press or expeller to extract the milk. The extracted milk is centrifuged to separate the cream from the watery and solid portions of the extract. The cream is then mixed with water (half to two times its weight) and pasteurised for 15–30 min. The pasteurised cream is thoroughly mixed with sodium caseinate at 0.5% level to stabilise the cream and then homogenised. The homogenised mixture is then heated almost to boiling point and filled in cans or bottles and autoclaved at 115.5 °C for 40 min. The tin cans are cooled immediately by submerging in a cooling tank with running water before packing in carton boxes. In the process developed in the Philippines, the watery phase or skim milk is wasted as a result of centrifugation. In order to eliminate this wastage, a process to preserve the whole milk has been developed with the use of additional stabilisers. Both canned coconut cream and processed whole milk have been found to enjoy very high consumer acceptability. The composition of these products is given in Table 13.4.

The chemical composition and quality of coconut cream vary widely in different countries. The Tropical Products Institute, London, reported that the organoleptic qualities of a number of samples tested were inferior to those of freshly prepared cream, due to excessive heat treatment. As such, the TPI has standardised the processing technology with optimum heat treatments and judicious use of added emulsifiers and stabilisers. Here the coconut milk is first clarified at a temperature of about 45 °C in a centrifugal clarifier at 10,000 rpm. The clarified emulsion is fed to a centrifugal separator at a rate of 425 gph and a temperature of 38 °C by a centrifugal pump fitted with a 0.5 HP motor to separate the cream and the aqueous phases. The cream is then diluted with the aqueous phase to obtain three different concentrations (low, medium and high fat), and the creams are heated to 55 °C, and an emulsifier/stabiliser mixture of Triodan 55 (1% W/W) and bleached soya lecithin (0.1% W/W) is added with thorough mixing. The formulated creams are then subjected to a two-stage homogenisation, one at 3500 psi at 50 °C and the other 1 °C at 500 psi. The cream is then heated to 60 °C using a water bath arrangement, canned and sealed (Timmins and Kramer 1977).

In Thailand, coconut meat is soaked in sodium metabisulphite solution prepared by dissolving 1 gram of sodium metabisulphite in water for every coconut, for 1 or 2 h or overnight. After washing, the meat is grated and milk extracted using an expeller or screw press. The milk is evaporated at 60 °C to 70 °C in a steam-jacketed kettle equipped with a blade, rotating at 20 rpm with constant stirring for 4–6 h. About 600 ppm sodium metabisulphite and 240 g pectin for every 100 coconuts are then added to the milk concentrate. Finally the milk concentrate is pasteurised at

70 °C for 1 or 2 min. The concentrated cream is packed in sterilised lacquered tin cans or sterilised aluminium tubes at 70 °C, each containing 160–170 g net. The final product is greyish white in colour which turns white upon dilution with water. It has a proximate composition of 10–11% moisture, 76–80% fat and 6–7% protein. About 130 kg unhusked coconuts yield about 32 kg of processed cream.

In the process adopted in Malaysia, the pared kernels are sterilised in boiling water for 1–1.5 min prior to pulverisation and extraction of milk. The milk is concentrated in a steam-jacketed kettle at 80 °C for 12–14 h with continuous stirring. Sodium metabisulphite at 600 ppm is also added as a preservative. The product which is thick in consistency with 40–45% fat is packed both in cans and plastic pouches.

In Western Samoa, fresh nuts within 3 days of harvest are utilised for processing. The pared kernels are grated and the milk extracted in a screw press. The milk is diluted in the ratio of 2:1 and sterilised in a steam-jacketed kettle for about 30 min. The cream is subsequently homogenised while hot, canned and sealed. One hundred and eighty kg of unpared coconut kernel yields about 127 kg cream (Timmins and Kramer 1977).

In Singapore, the processed milk is packed in cans, tetra pack and combine packs. Besides coconut cream, various milk shakes like fruit juice, coconut water and to a small degree coconut cream are also produced in Singapore. In a study conducted in Indonesia, it was found that 160 g of cream was enough to satisfy the requirements of an average Indonesian family normally using four coconuts a day.

Coconut cream is mainly used as a fat source for the reconstitution of the skimmed dairy milk and as a component of infant milk powders. In the Philippines, the cream could be successfully included as a component for the production of recombined milk or filled milk into three types of milk products – beverage type, evaporated type and sweetened condensed type. Sanchez and Rasco (1983) found that about 60% of coconut milk can be used as cow's milk extender in processing white soft cheese. The product was comparable to that obtained from 100% cow's milk in flavour, aroma, texture and general acceptability. The shelf lives were 2 days and 1 week at ambient temperature (25 °C–30 °C) and refrigerated temperature (5 °C), respectively.

Coconut Cream Coconut cream is the concentrated coconut milk extracted from fresh coconut kernel. From 10,000 ripe coconuts, the yield is around 2500 kg of cream and a byproduct residue of 500 kg. This is an instant product, which can either be used directly or diluted with water to make preparations such as curries, sweets, desserts, puddings, etc. It can also be used in manufacture of bakery products and for flavouring foodstuffs. The technology for the preservation of coconut milk in the concentrated form has been standardised and its economic viability established through pilot testing. The product has also shown encouraging consumer acceptance in the domestic market (Ghosh 2015).

Bottled Coconut Milk The processing technology involves extraction of milk from finely grated unpared coconut with the addition of some water or coconut water, straining the milk in a cheese cloth into an aluminium kettle with 0.1% benzoic acid before placing the kettle in an autoclave at 117 °C for 3 min with steam injection. The temperature of the milk in the pot is then brought down to 80–85 °C, using running tap water. The milk is then homogenised for about 5 min and bottled at 70 °C to 80 °C in 230 ml sterilised soft drink glass bottles and sealed. The final product is as good as cow's milk and is highly nutritious (Seow and Gwee 1997). This is of high commercial utility to be used as a substitute for cow's milk and is being produced in many countries.

Dehydrated Coconut Milk This is produced on a commercial scale in the Philippines and Malaysia. In the Philippines, the fresh coconut milk is blended with small amounts of additives such as maltodextrin or casein and is spray dried. The final product is marketed in laminated foil bags. The powder is easily dissolved in water to form a milky white liquid obtaining the flavour and texture of coconut milk. It is suggested to mix or blend 100 g powder with 120 ml water to make coconut cream. About 1000 kg of kernel would yield 450 kg powder. The product contains 692 calories, 60.5% fat, 27.29% carbohydrates, 9.6% protein, 1.75% ash, 0.8–2.0% moisture and 0.02% crude fibre. In Malaysia, coconut milk powder is marketed in the domestic markets as 'Santan' and in overseas markets as coconut cream powder (Muralidharan and Jayashree 2011).

Coconut Jam from Coconut Milk Coconut jam is prepared using aqueous portion of the milk. In the process developed in the Philippines, coconut milk is extracted first after mixing coconut gratings with equal quantity of water. The milk is then mixed with brown sugar and glucose in the proportions of 10.25% and 5.5%, respectively, based on the weight of the milk. The mixture is cooked over a slow fire with constant stirring for about 20 min. The mixture is strained at this stage for removing suspended matter and again cooked over high heat. Before the mixture begins to thicken, citric acid at the rate of 0.25% of the original weight of the milk is added and cooking continued over low heat until the mixture thickens. The product is hot filled in sterilised containers and sealed hermetically. The jam so obtained has a rich creamy coconut flavour (Muralidharan and Jayashree 2011).

Coconut Syrup A commercial product known as coconut syrup is produced from coconut milk in the Philippines. For this, coconut milk is first extracted from the freshly grated pared coconut meat (Hagenmaier et al. 1975). After homogenisation, an equal quantity of sugar and 0.05% citric acid or 0.25% sodium phosphate are added and then steam-cooked to a total soluble solid content of 65–68%. The boiling hot syrup is poured into lacquered tin cans, sealed and cooled under running water. The coconut syrup contains 27.18% moisture, 3.11% protein and 63.47% total soluble solids. The syrup can be used for confectionery purposes. It gives a delicious instant drink, which is milk white in colour when mixed with water and is also an excellent bread spread (Sangamithra et al. 2013).

Coconut Honey This is another useful product prepared from coconut milk and is an excellent substitute for real honey. The milk is extracted from the gratings of unpared meat after adding an equal quantity of water. To this, 60% by weight of brown sugar and 30% by weight of glucose are added and then boiled in steam-heated containers until a thick consistency is reached. The product is then hot filled in lacquered tin containers or bottles and sealed. The final product is a golden-coloured thick paste with a nutty flavour. This can also be used as an excellent base for soft drink (Muralidharan and Jayashree 2011).

Coconut honey can be prepared from skim milk as well. One part of the skim milk is mixed with half part of refined sugar and half part of glucose and then blended with sodium alginate at 0.5% as a stabiliser. Coconut cream is sometimes added to improve the flavour of the product. The mixture is heated for 15 min, homogenised and cooked with constant stirring in steam-jacketed kettle to a total soluble solid content of about 75%. It is poured hot into sterilised containers and sealed hermetically (Banzon et al. 1990).

Coconut Cheese Fresh coconut meat is grated and pressed to extract milk. The milk is allowed to stand for 8 h, until the cream is collected at the top. The cream is slowly scooped out and the skimmed milk heated with vinegar to coagulate the proteins. This is mixed with cream and kneaded with salt. The process is simple and can be taken up as a household industry (Ghosh et al. 2000).

13.6.2 Coconut Skim Milk and its Products

Coconut skim milk is a solution of the soluble components of coconut after the cream is separated in a cream separator. This is one of the stages involved in the wet processing of coconut developed by the Texas A&M University. In this process, freshly prepared coconut milk from pared/unpared kernel is filtered through a 120 mesh vibrating screen, and the pH of the filtered milk is raised from 6.3 to 7.0 with the addition of sodium hydroxide. The milk is then pasteurised at about 60 °C for 1 h and subsequently centrifuged in a cream separator to yield the aqueous phase or the protein-rich skim milk besides the cream.

In the method suggested by Birosel et al. (1963), milk is extracted from the grated coconuts by hand without the addition of water. This is poured into clean wide-mouthed bottles up to half of the container's total volume and placed in the cold storage chamber at 17 °C. The bottles are taken out and then vigorously shaken until the coconut milk is separated into its different components. The fat forms one big white mass, whereas the skim milk remains in the liquid form. The fat and the coconut skim milk are stored in cold storage chamber.

The general composition of skim milk is 90.98% moisture, 1.956% oil, 2.641% protein, 0.324% reducing sugar with 0.013% acidity and 6.15 pH. Capulso et al.

(1981) investigated in detail the optimum conditions for maximum recovery of the proteins as well as their functional properties. Skim milk can be used for making a variety of products like spray-dried powder, coconut honey, coconut jam and sweetened condensed milk. In addition, it can also be used as a substitute for the preparation of fermented beverage concentrate and also as a source of vegetable casein. It is a good source of quality protein suitable for the preparation of many useful allied food products or as a supplementary protein source, especially in regions deficient in animal proteins.

13.6.2.1 Fermented Beverage Concentrate

The processing method has been developed by Sanchez and Rasco (1984). This is a type of cultured milk using skim milk as a substrate and *Lactobacillus bulgaricus* as a starter culture. For this process, the milk base should contain 10% total solids. On an average, coconut skim milk (CSM) is composed of 14.5% sugar and 85.5% water, whereas non-fat dry milk (NFDM) is composed of approximately 100% total solids. As such, different combinations of CSM and NFDM are formulated to maintain the 10% total solid content of milk base. This is then pasteurised at 90 °C for 30 min in a water bath, cooled to 40 °C and inoculated with 3% culture of *Lactobacillus bulgaricus.* The mixture is incubated at 37 °C–38 °C for 24 h. Curdled milk is homogenised for 5 min and heated to 60 °C. Sugar is then added in the ratio 1:1. The mixture is further heated to 80 °C and cooled down to 60 °C, and then 0.5% flavoured extract is added. The finished product is bottled and pasteurised in water bath at 70 °C for 30–60 s. Out of the different formulations of CSM and NFDM tried, a combination of 50% CSM and 50% NFDM was found to be optimal. The ready-to-drink fermented beverage (concentrate diluted at 1:3) contains 1.01% protein, 0.74% fat, 18.70% sugar and 79.25% water. The product is stable even after 2 months of storage, both at ambient and refrigerated temperatures. This is a highly nutritious drink suitable for kids and adults alike. Unlike carbonated drinks, the fermented beverage contains protein contributed by CSM and NFDM combination. It is non-fattening and easily digestible and is a perfect beverage for those suffering from digestive ailments. Similar products have been commercially prepared in other countries, for example, ‘Calpis’ in Japan and ‘Bulgaricus milk’ in Bulgaria.

13.6.2.2 Vegetable Casein

Skim milk is also a source of vegetable casein. In Brazil, the gastrointestinal disturbances were successfully treated in infants by feeding coconut milk, which shows that coconut skim milk having the same protein level (1.6%) as mother’s milk is well-absorbed by infants. Both produce a soft curd when acted on by the gastric juice.

13.6.2.3 Low-Fat Coconut Jam

Skim milk is also utilised for the production of low-fat coconut jam. The whole milk is subjected to centrifugation for the separation of skim milk. For every 20 kg skim milk, 3.75 kg of brown sugar and 1.25 kg of glucose are added, and the mixture is boiled for 20 min, blended, strained and boiled again. Citric acid is added just before cooking is complete, and boiling is continued to an end point of 75–76% total soluble solid content as measured with a hand refractometer. The hot jam is poured in sterilised containers and sealed hermetically (Banzon 1978).

13.6.2.4 Sweetened Condensed Milk

Skim milk is also utilised as a base for the production of sweetened condensed milk. Corn oil, coconut cream and sugar are added to the pasteurised milk, and the mixture is passed through a colloid mill. It is then heated in a steam-jacketed kettle with constant stirring to a total soluble solid content of 68%. The finished product is packed hot in sterilised tin cans and cooled immediately in cooling tanks. It contains protein (5.53%), fat (10.35%), carbohydrates (60.68%), calcium (112.62 mg per cent) as well as magnesium, iron, zinc and manganese.

The protein-rich skim milk is spray dried to yield a product similar to non-fat dry milk (NFDM) containing about 70% of the original protein present in coconut. The powder is white and deliquescent having a fresh coconut flavour, the average composition being 24% protein, 6% fat and 5% moisture. Maltodextrin is added as an additive to improve body and fluidity of the final product. This is an excellent coconut-flavoured beverage base. The detailed composition is given in Table 13.5 (Banzon 1978).

An attempt has been made to explore the possibilities of spray drying of coconut skim milk powder to produce coconut skim milk powder (CSMP) (Ganesan and Gothandapani 1999). The critical operations involved to produce CSMP are centrifuging, evaporation and spray drying. The coconut milk could be successfully centrifuged in a cream separator to produce coconut skim milk. The percentage of recovery is 71%. The skim milk has a low-fat content of 0.27% with total solids of 5%. The density is 1.084 g cc^{-1}. The per cent of cream and sludge recovered were 22% and 7%, respectively. The concentrated skim milk after evaporation contains 40% solid and 2.70% fat with a density of 1.25 g cc^{-1}.

The coconut skim milk could be successfully spray dried in a spray drier. The characteristic of the product was comparable with commercially available ones. The skim milk had a bulk density of 0.5 g cc^{-1} with moisture content of 3% with an ash content of 8%. The composition of the skim milk powder was protein 13% and fat 2.70% with sugar and carbohydrate at the level of 9 and 7%, respectively. The product could be successfully stored for more than 2 months under vacuum and at refrigeration at 15–20° C.

The microstructure of coconut skim milk powder was observed using scanning electron microscopy (SEM). Small surface folds and cracks were noticed in some

Table 13.5 Composition of dehydrated coconut milk (in percentage)

Constituent	1[a]	2[b]
Protein		
Crude (N × 6.25)	25	30
Low molecular weight N (as % N)	8	7
Fat		
Crude fat	5	7
Free fatty acids (as % of oil)	3.2	1.4
Nonsaponifiables (as % of oil)	3.2	–
Iodine value	6.3	–
Carbohydrates		
Reducing sugars	2.8	2.0
Reducing sugar after inversion	45	37
Sucrose	33	–
Crude fibre	0.03	0.03
Minerals		
Phosphorous	0.50	0.50
Calcium	0.17	0.06
Magnesium	0.26	0.36
Potassium	3.60	3.30
Sodium	0.90	1.40
Chlorine	1.60	1.60

[a]Coconut water used in processing; [b]Tap water used in processing

particles, whereas many samples contained small depressions, resembling the surface of moon. The surface of particle resembled honeycomb structure. Some of the particles were more wrinkled and curl (Ganesan and Gothandapani 1999).

13.6.2.5 Edible Coconut Flour

Partially defatted edible coconut grating is becoming acceptable to different categories of consumers for use in households, bakeries, confectionery units and hotels. Appropriate production technology has been perfected, and its commercial viability also has been established. Because of the low content of fat and higher percentages of protein, sugars and minerals, the product possesses better water holding and thickening properties.

During the processing of coconut cream and other related products, the fibrous residue obtained after expelling the milk is dried and powdered to obtain a product called coconut flour. The flour so obtained typically contains 7–8% protein, 3–5% moisture and 17% oil. It can be used as an ingredient in dietary foods because of its high fibre content. The protein contained in the flour is identical to the original meat. Better grade coconut flour is made by powdering the pressed cake obtained after extracting oil from quick dried gratings of coconut meat. Such partially defatted coconut gratings can find use in bakery and confectionery preparations as well

Table 13.6 Composition of coconut flour and desiccated coconut(in percentage)

Constituent	Coconut flour	Desiccated coconut
Moisture	3.83	1.70
Fat	41.43	70.05
Protein	17.32	8.30
Crude fibre	7.00	4.65
Ash	3.26	1.62
Total carbohydrates	27.16	13.69

Source: Satyavathy Krishnan Kutty (1987)

as in nutrition programmes in schools. The Central Food Technological Research Institute (CFTRI), Mysore, India, has developed a process for the manufacture of edible flour. Here the wet kernel is first separated from the shell by crushing the cups in a hand-operated gadget. After removing the shell pieces by hand, the kernel is pared, washed free of dirt and passed through a pin-type disintegrator, and gratings are sieved. The gratings are then dried in less than 30 min in a crossflow drier to less than 3% moisture. Oil is partially extracted from these gratings using a hydraulic press in 10 kg batches. This oil possesses better quality than commercial samples, and the residual product is white and powdery with good flavour. The composition of the flour is given in Table 13.6.

NIIST (CSIR), Trivandrum, India, also perfected the technology for the partial extraction of oil from desiccated coconut in order to produce, besides oil, good-quality coconut flour. Here the pared kernel pieces are first washed and soaked in hot water at 80 °C for 10–15 min to reduce the microbial load and also to inactivate enzymes. Here also, the kernel pieces are comminuted into fine gratings using a pin mill and dried at 60 °C–70 °C. The dried gratings are charged into a perforated stainless steel cage, and pressure is applied from the top using a downstroke hydraulic press till the desired level of oil has been expelled. The oil is stored for 10–12 h and filtered using a filter press in the presence of 0.1% super cell as filter aid. The partially defatted gratings are removed and powdered using a cake-breaker and further dried in an electric drier to a moisture content of 2–3%. The fat content of the final flour is adjusted to 40–45%. The shelf life of the product stored in sealed aluminium foil pouches is 4–6 months at ambient temperature and more than 1 year under refrigerated conditions. About 12–15% of the fresh meat constitutes a byproduct, with an oil content of 60% on dry weight basis. About 90% of this could be recovered as commercial-grade coconut oil.

The product has a low content of fat and higher percentages of protein, sugars and minerals and has been found to possess better water holding and thickening properties. The oil extracted from the dried gratings is of superior quality, which could command premium price. Flour derived after removing 60% oil has been found to have higher consumer acceptability. The proximate composition of flour from pared and unpared coconut as reported from different sources is given in Table 13.7. It is also seen that 5% coconut flour can replace proportionate amounts of wheat flour and non-fat dry milk powder used in school nutrition programmes without affecting baking qualities and food value.

Table 13.7 Proximate composition of coconut flour (in percentage)

Constituent	From pared coconut[a]	From unpared coconut[b]
Moisture	5.69	5.4
Fat	7.18	2.0
Crude fibre	9.21	9.8
Protein	20.39	24.9
Ash	5.41	5.3
Carbohydrates	–	62.4

[a]Balakrishnamurthi (1979); [b]Abdon (1967)

Table 13.8 Nutrient composition of coconut flour compared with various seed flours (in percentage)

Nutrient	Soybean	Ground nut	Sesame	Cotton seed	Coconut	
Moisture	5.00	11.00	5.60	9.20	11.20	5.40
Protein (N × 6.25)	60.00	52.00	33.30	51.10	20.90	24.90
Fat	7.00	8.90	12.20	5.50	13.30	2.00
Carbohydrate	30.00	21.80	38.10	25.80	39.20	52.60
Crude fibre	2.50	1.00	4.80	1.50	10.50	9.80
Ash	5.50	4.60	6.00	5.90	4.90	5.30
Calcium	0.33	0.67	2.38	0.36	0.16	0.07
Phosphorous	0.62	0.50	0.63	0.82	0.49	0.47
Iron	20.00	2.90	19.30	12.00	5.70	8.10
Thiamine	0.7	0.95	1.05	0.99	0.17	0.09
Niacin	5.70	19.50	5.30	5.20	4.10	2.30
Riboflavin	0.38	0.20	0.3	0.30	–	0.08

Source: Banzon et al. (1990)

Nutritionally coconut flour compares favourably with most of the common cereal flours as could be seen from Table 13.8.

These flours can also be utilised in different food formulations such as extrusion, baking and confectionery. They can also be used for enriching the nutritional values of wheat flour, rice flour, etc. The oil extracted from the dried gratings is of superior quality, which could command premium price. Coconut flour is naturally low in digestible carbohydrates and high in fibre content and good proteins and hence is a health-promoting food. This has four times more fibre than oat bran and two times more than wheat bran. Technologies are available now to prepare coconut milk residue and virgin coconut oil (VCO) cake flour-based compressed bar, porridge, *laddoo*, *halwa* and noodles. Processes for preparation of extrudates, pasta, muffin cakes and ready-to-eat food items such as coconut pickle and coconut chutney powder have been developed and standardised by ICAR-CPCRI. These products can be prepared from the byproducts obtained while preparing the coconut milk, coconut milk powder and virgin coconut oil. It may have some health benefits and may encourage the industry to produce value-added products or functional foods which can help in the proper control and management of chronic diseases. This offers scope for utilisation of coconut flour as a dietary component for diabetes. Low-fat, high-fibre coconut flour, a unique product from 'sapal', is a good source of dietary fibre. It is comparable with other cereal flours in terms of carbohydrate, fat and energy content and is a good ingredient in nutraceuticals.

13.7 Coconut Oil

Coconut oil is the most important consumable product from coconut. Coconut oil extracted by dry process from copra is called coconut oil or copra oil, and the one extracted from wet kernel is known as virgin coconut oil. Coconut oil is extracted from milling copra using appropriate milling devices.

13.7.1 Extraction Methods of Coconut Oil from Copra

In most of the coconut-producing countries, copra crushing is a traditional industry. In rural areas, copra is still crushed in *chekkus* for domestic consumption. Power-driven *chekkus* or rotary mills, expellers and hydraulic presses are used for crushing on a commercial scale. In the modern industrial units, solvent extraction planks are linked with the expellers or hydraulic presses for the maximum recovery of residual oil from the copra cake.

As a cottage industry, oil extraction is still done in the *chekkus* in the rural areas of India and Sri Lanka. The *chekku* is a fixed wooden or stone mortar inside which wooden pestle is made to revolve. The pestle is attached to a long pole which is moved round by a pair of bullocks or even by men. Copra is crushed as a result of the friction caused by the revolving pestle. The pressure on the pestle is regulated by levers and weights. Usually only 100 kg of copra can be crushed with *chekkus* in 8 h.

Power-driven *chekkus* or rotary mills are used in medium establishments for oil extraction from copra. In principle, they are similar to *chekkus*, but here, the mortar itself revolves against the pestle. Both the pestle and mortar are made of cast iron. The rotaries are worked in pairs and are driven either by steam, oil engine or electric motor. The crushing capacity of a rotary mill varies from 200 to 300 kg of copra day^{-1} shift. About 1 kg of *gum acacia* is added to every quintal of copra as a binding agent to facilitate the extraction of oil.

Expellers are used in large milling establishments, which vary in number from 1 to 24, but two expellers usually constitute a unit since double crushing gives the maximum extraction. The extraction takes place within a steel cage or barrel by means of a hardened steel worm or screw so arranged on a revolving shaft as to produce increasing pressure as the copra is pushed from one end of the cage to the other. The oil escapes through the openings built on the barrel and the cake through an adjustable pressure orifice at the end of the barrel. In large installations, the clean copra is first passed over an electric magnet, by chain conveyor for removing extraneous material. Then it is passed to a disintegrator for conversion into a coarse meal. The disintegrated copra meal is fed continuously by special conveyors to the expeller from which residual oil and cake are constantly forced out through separate streams.

While passing through the first expeller, the pulped copra yields about 50% oil. The resultant cake is again ground, heated and pressed in a second expeller to extract the remaining oil. Generally expellers can squeeze out about 95% of the oil present in the copra. The crude oil collected in underground tanks is pumped to a filter press, and clean filtered oil is finally pumped to big storage tanks. Smaller expeller units, like those in operation in many states in India, have a crushing capacity of 2–3 tonnes of copra per shift of 8 h. A few bigger units also are available with expellers of 20–40 tonnes capacity for pre-pressing and 7–20 tonnes capacity for pressing per shift of 8 h.

The residual oil present in the rotary and expeller crushed cakes can be extracted using solvent extraction plants. In this process, the cake is broken into bits and fed to flaking rolls. The resulting raw material is then treated with suitable solvents in a countercurrent extraction process. The solvent containing the dissolved oil is drawn off from the extracted residue and filtered. The oil is then separated from the solvent by distillation. The common hydrocarbon solvents used in the solvent extraction plants in India are benzene and hexane.

13.7.2 Yield of Oil from Copra

In *chekkus*, the yield of oil varies from 58% to 60%, in rotaries 62–63% and in expellers 63–65%. The residual oil in the cake ranges from 12% to 17% in *chekkus*. The rotary and expeller cakes normally contain 10–12% and 8–10% residual oil, respectively. High-pressure expeller cakes hold about 6% oil, while solvent-extracted cakes have very low oil content ranging from 0.5% to 1.0%.

13.7.3 Ensuring the Quality of Oil

For obtaining a better quality product, it is necessary to crush copra having a moisture content of less than 6%. The crushing process should be done in clean surroundings and the oil collected in clean equipments. The crude oil should be filter pressed without much time lag and the storage tanks frequently cleared of sediments and other settled impurities. The oil should be free from moisture, for instance, under the British Standard specification, the moisture content must be under 0.25%. In the case of refined oil, it is treated and subsequently washed, filtered and/or heated to 110–120 °C to remove traces of moisture. The latter treatment also effects sterilisation. The oil must be stored as far as possible away from light and air. The receptacles may be filled to the maximum possible extent in order to reduce the amount of surface exposed to light and air. Small quantities of oil can be successfully stored in soldered kerosene tins and large quantities in storage tanks.

13.7.3.1 Physical Properties of Coconut Oil

Coconut oil is colourless to pale brownish yellow, which is fluid in the tropics and is a solid fat in the temperate climate. In the solid state, its melting point ranges from 23 to 26 °C. Among the common vegetable oils, this has the lowest turbidity and has excellent properties for electrical insulation. The oil also possesses high inductivity. The heat of combustion of coconut oil is estimated at 9285 cal g^{-1} gross or 8697 cal g^{-1} net. The vapour pressure at 202 °C is 0.054 mm, at 227 °C is 0.16 mm, and at 50 °C is 0.37 mm. The principal physical characteristics of coconut oil are specific gravity (0.926 at 15 °C and 0.9188 at 25 °C), saponification value (251–263), iodine number (8.0–9.6.0), Polenske value (15–18), melting point (23–26 °C), titre of fatty acids (20.4–23.5) and melting point of completely hydrogenated fat (44.5 °C).

13.7.3.2 Chemical Properties of Coconut Oil

Coconut oil is rich in saturated fatty acids, mainly lauric and myristic acids with notable proportion of still lower fatty acids. In comparison with the leading edible vegetable oils, coconut oil is low in unsaturated and polyunsaturated acids, particularly, linoleic acid. It has got the highest saponification value and the lowest iodine value. On account of its low iodine value, it is classified as nondrying oil. Coconut oil contains the largest percentage of glycerol compared with other oils and fats as shown in Table 13.9.

The glycerides of coconut oil have not been quantitatively separated. But the presence of certain mixed glycerides along with their quantity and melting point has been established. It comprises of large glycerides, caprylo-lauromyristin (melting point 15 °C) and dilauromyristin (melting point 33 °C). Small glyceride laurodimyristin (melting point 38.1 °C) and very small glycerides dimyristopalmitin (melting point 45.1 °C) and dipalmitostearin (melting point 55 °C) are also components of coconut oil. Coconut oil contains the largest percentage of glycerol compared with other oils and fats as shown in Table 13.10.

The composition of fatty acids in coconut oil changes with increasing stage of maturity. In a study reported by Banzon et al. (1990), 8-month old nuts gave oil containing an average 30% oleic acid, 16% lauric acid and 20% linoleic acid. This decreased rapidly as the nuts matured. Thus, 10-, 11- and 12-month old nuts yielded oil containing a stabilised value of 5% oleic acid, 1% linoleic acid and 49% lauric acid.

Table 13.9 Percentage of fatty acid composition of coconut oil compared with other oils

	Coconut	Palm kernel	Babassu	Palm oil	Soya bean	Safflower
Saturated fatty acids						
Caprylic	8.24	1.40	3.50	–	–	–
Capric	7.19	2.90	4.50	–	–	–
Lauric	47.31	50.90	44.70	0.30	–	–
Myristic	17.00	18.40	17.50	1.10	0.10	0.10
Palmitic	8.85	8.70	9.70	45.20	10.50	6.50
Stearic	2.27	1.90	3.10	4.70	3.20	2.40
Arachidic	–	–	–	0.20	0.20	0.20
Unsaturated fatty acids						
Palmitoleic	1.00	–	–	–	–	–
Oleic	6.27	14.60	15.20	38.80	22.30	13.20
Linoleic	1.87	1.20	1.80	9.40	54.50	77.70
Linolenic	–	–	–	0.30	8.30	–
Arachidonic	–	–	–	–	0.90	–
Percentage unsaturated	9.14	15.80	17.0	48.50	86.0	90.80

Source: Rethinam and Bosco (2006)

Table 13.10 Glycerol in oils of different saponification value

Type of oil	Glycerol content (%)	Saponification value
Coconut oil	13.84	253
Palm kernel oil	13.57	248
Olive oil	10.45	191
Groundnut oil	10.45	191
Gingelly oil	10.45	191
Cotton seed oil	10.83	198
Palm oil, tallow, etc.	10.83	198
Sun flower oil, olive oil, etc.	10.45	191
Rape seed oil	9.57	175

Source: Rethinam and Bosco (2006)

13.7.4 Uses of Coconut Oil

The main use of coconut oil whether raw or refined is for edible purposes. Oil obtained by direct processing of wet kernel or by crushing good-quality copra in clean surroundings is used for cooking without any further refining. In India, raw coconut oil is preferred for edible purpose as cooking and frying oil.

13.7.4.1 Edible Uses

Because of its high content of saturated fatty acids, coconut oil is highly resistant to oxidative rancidity and retains a pleasing flavour. Hence, it is preferred as a fat source in the preparation of filled milk, as an instant milk powder and also as a confectionary fat in the preparation of ice cream, imitation cream or whipped cream. Hardened coconut oil creamed with sugar in the proportion 40:60 is extensively used in the developed countries as biscuit and water fillings. Because of the easy digestibility of coconut oil, it has been used as an essential ingredient in many ghee substitutes. But with the introduction of hydrogenated oils, coconut oil has now lost its eminence as a solid vegetable fat. It is still used to some extent in Europe as a constituent of margarine and shortenings and also to fill the skim milk byproduct of butter manufacture (Rethinam and Bosco 2006). For details on nutritional aspects and health benefits of coconut oil, please see Chap. 15.

13.7.4.2 Nonedible Uses

One of the major nonedible applications of coconut oil is in soap industry. Because of its high saponification value, it combines with concentrated solutions of caustic soda in the cold, saponification being completely effected within 6–24 h. Marine soaps that lather in hard water and which are soluble in brine are made from coconut oil. Unlike ordinary soaps, coconut oil soap will not precipitate in weak brine. Coconut oil contains the maximum content of glycerol (13.5%) among the vegetable oils. In soap making with coconut oil as the major ingredient, glycerol is an important byproduct. This is not often recovered in unorganised soap units. The recovery of glycerol is possible with improved facilities. The glycerol is used in various industries, especially in pharmaceuticals, in food industry and in the manufacture of nitroglycerine.

One important chemical derivative of coconut oil is methyl esters which are produced by treating coconut oil with alcohol. The most commonly used alcohol in the process is methyl alcohol which produces the methyl esters of coconut oil fatty acids. Since they are more stable and are easier to separate by fractional distillation than the fatty acids, they can be converted into a very wide range of chemical intermediates or into alcohols. Both the methyl esters and mixed fatty alcohols constitute the basic raw material for the manufacture of a wide variety of detergent intermediates particularly in the ethoxylated and sulphated form.

Coconut monoethanol amide (CMA) prepared with coconut oil as the starting material can be used as foam stabilisers and super flattening and thickening agents, for detergent shampoos and cosmetics. A suitable technique has been devised for its preparation, which will enable the oil to command a much higher market value (Arida et al. 1979). The chemistry of surfactants derived from coconut oil was studied. In fact, coconut oil is the basis of a number of surfactants since their hydrophobic chains contain 12–14 carbon atoms. Thus, coconut oil derivatives can be used as raw material for the synthesis of polyolesters and imidazolines.

13.7.5 Quality Standards for Coconut Oil

For coconut oil, there is no uniform international quality standard. In India, the two common grades are unclean and clean oils; the former is *chekku* and rotary oil and the latter is expeller oil which is usually filtered. The Asian and Pacific Coconut Community has recommended five different grades of coconut oil. Grade I refers to refined and deodorised oil, whereas grade II refers to refined oil. Grade III oil is white oil obtained by wet processing. Grades IV and V are referred to as Industrial Oil No. 1 and 2 obtained by the process of mechanical and solvent extraction, respectively.

Storage of oil in air-tight brown-coloured containers along with either sodium meta bisulphate, citric acid or common salt will increase the shelf life of the oil for more than 6 months. So also the quality is better in copra produced in the solar dryer, followed by electrical dryer and then by sun drying on cement floor.

13.7.6 Methods of Refining Coconut Oil

Crude coconut oil is refined using methods like neutralisation, physical refining, etc. and more recently using hydrogen peroxide and oxalic acid. The free fatty acid content comes down to less than 1% as a result of refining. Neutralisation is done with caustic soda solution. Oil is mixed with solutions directly, washed and dried. The dry oil at 90–95 °C is then leached by the addition of adsorptive earth (fuller's earth, activated earth, activated carbon). In addition to the removal of some pigments, traces of remaining soap, gums and other impurities are removed, and a completely clear product is obtained (Rethinam and Bosco 2006).

Physical refining is also possible which is carried out by steam distillation. The removal of off flavours also takes place, so that oil may be neutralised and deodorised at the same time. Since free fatty acids are more volatile than triglycerides, separation is effected.

Brown coconut oil extracted from inferior-quality copra can be bleached to light yellow colour by pretreatment with hydrogen peroxide or oxalic acid followed by bleaching with earth and carbon. The bleaching of solvent-extracted oil is done by pretreatment with aqueous solutions of oxalic, citric and tartaric acids. The advantage is that bleaching retains the characteristic sweet aroma of the original oil.

13.7.7 Rancidity in Coconut Oil

Unrefined coconut oil is susceptible to rancidity due to the presence of certain proportion of free fatty acids. This is accelerated by the presence of initial moisture and by the action of air, light and fat-splitting enzymes like lipase and peroxidase. The first stage of rancidity is hydrolysis to produce the free fatty acids, known as 'hydrolytic' rancidity, the rapidity of which varies with the initial acidity and the amount of moisture present. This is followed by the oxidation of the fatty acids involving double bonds to form hydroperoxides, which are responsible for the off flavours and further reactions. This is known as ‘oxidative’ rancidity. In fact, rancidity is considered to be the objectionable smell that results from the accumulation of decomposition products of the oxidation reaction.

Most of the free acids and the accompanying bad odour and taste originate in the copra itself before the oil has been extracted. Oil derived from damaged copra favours the growth and multiplication of microorganisms resulting in poor-quality oil. During storage, the melting point, smoke point, refractive index (RI), peroxide value (PV) and saponification value (SV) show an increase, while iodine value (IV) decreases (Tribold and Aurand 1963; Palaniswami et al. 1989). Ghani oil has a higher percentage of residual moisture and thus a faster rate of peroxide formation.

Microorganisms under favourable humidity and temperature also induce spoilage of oil besides producing toxic substances such as aflatoxins. Mukherji (1967) reported the presence of *Aspergillus niger* in homemade coconut oil. Hoover et al. (1973) isolated lipase from a strain of *Aspergillus flavus* causing deterioration of coconut oil. Oil contaminated with *R. nigricans* and *B. theobromae* turned rancid more quickly than those contaminated with *A. flavus*. Presence of aflatoxins in samples of coconut oil affected by *A. flavus* Link Ex Fries and aflatoxin production in coconut oil was also reported elsewhere (Schindler and Eisenberg 1968; Arseculeratne and De Silva 1971; Samarajewa 1972).

13.7.8 Coconut Cake

Traditionally coconut is dried to produce copra which is then milled or solvent extracted to get the oil. Fresh coconut kernel contains about 4–4.5% protein. Major portion of the original protein passes on to the coconut cake or poonac, which is the residual product after oil extraction. It forms about 32–40% of the copra after the extraction of oil. The output of cake and its final composition depend upon the extraction methods employed (Table 13.11). The cake however is not considered suitable as a protein supplement because in the process of oil extraction, the original

Table 13.11 Composition of coconut cake

	Expeller cake	Solvent-extracted meal
Moisture	7.0	8.9
Fat	6.7	2.4
Protein (N × 6.25)	21.2	21.4
Nitrogen-free extract	47.4	47.4
Fibre	11.2	13.3
Mineral matter	6.5	6.6

Source: Rethinam and Bosco (2006)

protein gets discoloured and denatured due to the generation of very high temperature. Hence it is mainly used in ruminant feeding.

Coconut cake is also useful for feeding poultry. The cake easily absorbs atmospheric moisture while in storage and consequently is prone to mould attack. The equilibrium moisture content of the cake at 40–70%, 80% and 90% relative humidity of the atmosphere is 10%, 20% and 30%, respectively.

In India, a study on the shelf life of coconut cake revealed that the moisture content of the cake at 79% RH was 15.2% and this was the critical moisture content at which it can be stored free from moulds. The study also showed that the cake could be stored without any spoilage up to about 6 months if alkathene bags or alkathene-lined containers are used. The rancidity of the cake could be effectively checked if its moisture content is kept below the critical level of 15.2%.

Coconut cake is sometimes used as manure for field crops. But the cake has a high carbon nitrogen ratio and is, therefore, not considered suitable for manuring seasonal crops. Coconut cake contains 3% nitrogen, 1.9% phosphorus pentoxide and 1.8% potassium oxide. As the nitrogen, phosphoric acid and potash contents of coconut cake are not high, it is not considered as valuable organic manure (Thampan 1987).

13.8 Virgin Coconut Oil

The fresh meat can also be processed to yield oil, which is known as virgin coconut oil (VCO). The processing method adopted for obtaining oil and other products directly from the fresh kernel is known as wet processing. Various processes developed in this direction could successfully extract good-quality oil directly from the wet kernel without passing through the copra stage.

For production of VCO, coconut milk is filtered and concentrated, and then cream is separated by centrifugation. The cream is stirred vigorously to get the virgin coconut oil by a process called phase inversion. The oil thus obtained is very clear and nutritious and has a longer shelf life. VCO can also be prepared by hot fermentation and fresh dry process. In hot process, coconut milk is heated until the evaporation of water and coagulation of protein to recover the oil. In fermentation process, the milk is allowed to stand for 16–24 h fermentation, and then oil is separated from the skim milk and fermented curd by decanting and filtering. The fresh dry process involves screw pressing or hydraulic pressing of dried pulverised coconut meat to produce VCO and food grade full protein and medium fat coconut flakes (Marina et al. 2009).

Though oil recovery from wet processing normally does not exceed 90% as against 95–97% oil in dry processing, it is gaining renewed interest mainly because of the possible economic advantages associated with the production of nutritionally rich products. Though the efficiency of oil recovery is less than that of dry processing, the other products derived from the process such as coconut protein, coconut flour, etc. make wet processing economically viable. The processing technologies already developed and tried in various centres are briefly described below.

13.8.1 Krauss–Maffei CFTRI Process

M/s Krauss Maffei of West Germany developed a process in which the husked nuts are first steamed in an autoclave for 10 min at a pressure of 3 kg cm^{-2}. The nuts are then cut, kernels scooped out and the kernel pieces passed into a cutter. These are further comminuted by passing through a roller mill. The kernel mass is then fed into a screw press and milk extracted and is separated by centrifugation into cream and water phases. The cream phase is heated to 92 °C, centrifuged and filtered to get good-quality oil. The water phase is heated to 98 °C in a flow heater to coagulate the protein, which is separated by centrifugation and dried. The leftover whey is then concentrated under vacuum to a syrup called 'coconut honey',and the fluffy residue after extraction of the milk is dried in a drier and powdered to get an edible-quality coconut meal. The recovery of oil is about 89%, as compared to about 95% in the conventional expeller process.

To improve the recovery, the CFTRI has made some modifications in the process utilising the M/s Krauss-Maffei plant. The meat was scooped out without subjecting the nuts to heat treatment and milled. The milled meat was first squeezed in a dewaterer under reduced pressure (2:1) and then fed into the K.M. Press (12:1). With this two-stage extraction method, roughly 93% of the oil was extracted into the milk, and the final recovery of the protein was also high (roughly 85%). The residue after the extraction of milk was dried and fed into an expeller to extract the residual oil.

In one of the trials, 220 kg of wet meat yielded 73.5 kg of clean oil, 5.7 kg of residual oil, 8 kg of protein and 1 kg of coconut honey. In this modified process, the direct oil recovery efficiency was 90%, which was definitely better than the conventional oil milling process. The composition of the various products obtained in the process is given in Table 13.12.

The water phase concentrate or the coconut honey was used for the preparation of two types of processed food: (1) infant food and protein food and (2) cereal flakes (NIIR Board of Consultants and Engineers 2012).

Table 13.12 Composition of products from K.M./CFTRI process (in percentage)

Material	Moisture	Protein (N × 6.25)	Fat	Minerals	Carbohydrates
Coconut honey (60° brix)	40.0	15.6	2.0	6.0	35.6
Acid-coagulated proteins (by centrifugation at pH 3.8–4.0)	6.0	74.3	6.1	6.1	10.5
Heat-coagulated protein (at 82 °C)	8.4	66.1	3.4	8.2	13.9
Residual meal	9.7	5.2	8.7	1.6 (ash)	25.1 (crude fibre)

Source: Rethinam and Bosco (2006)

Table 13.13 Composition of products from Texas A&M University process (in percentage)

Material	Oil	Crude fibre	Ash	Crude protein (N × 6.25)	$K_2 0$	CaO	$P_2 0_5$	$Fe_2 0$**3**	MgO	CI
Fibrous residue	22.0	23.0	0.6	3.4	–	–	–	--	–	--
Protein fraction of low solubility	19.0	3.0	7.3	57.0	0.62	0.39	1.9	0.07	1.0	–
Skim milk	5.0	–	9.0	31.0	3.3	0.07	0.5	0.004	–	1.6

Source: Rethinam and Bosco (2006)

13.8.2 Texas A&M University Process

This process known as the 'aqueous process' was developed by the Texas A&M University for the preparation of the coconut protein products (Samson et al. 1971). In this process, the scooped kernel is finely comminuted and mixed with heated coconut water. The mixture is then repeatedly pressed in a countercurrent system to remove the milk and other extractable components. The fibrous residue is dried. The milk is adjusted to pH 7.0 (from 6.3) with sodium hydroxide, pasteurised at 60 °C for 1 h and centrifuged while warm. Centrifugation yields three phases: (a) the cream or oil, (b) a protein fraction of low solubility and (c) protein-rich skim milk. The skim milk is spray dried to yield a tasty product, which resembles non-fat dry milk and can be a valuable commodity in food and beverage industry. The oil recovery has been reported to be 90%. The composition of the various products obtained in this process is given in Table 13.13.

The skim milk powder is rich in protein which contains good amount of important amino acids like lysine, leucine, phenyl alanine, threonine and valine.

13.8.3 The TPI Process

This process was developed by the Tropical Products Institute, London (Dendy and Timmins 1973). Here the fresh kernel is sliced, minced in a 5 mm plate of a wedge mill, mixed with half its weight of water and passed through a 1 mm plate assembly of a second wedge mill. The resulting slurry is then passed through the plate assembly of the second wedge mill. Then the emulsion is passed through a vibrating sieve to remove the coconut residue under a high-velocity overhead water spray. The residue is pressed again and the emulsions are pooled. The final residue is then dried and bagged to be used either as a ruminant feed or fed to an expeller mill to extract the residual oil.

The emulsion is adjusted to a pH 3.5–4.0 with acetic acid and allowed to stand for 6 h for the separation of cream and water phases. The lower water phase is removed either by gravity flow or by siphoning and discarded. The cream phase is centrifuged at 35 °C to separate the oil and protein. The protein component is vac-

Table 13.14 Composition of products from the TPI process (in percentage)

Produce	Fat	Crude protein	Moisture	Crude fibre	Ash	Carbohydrates
Protein isolate	7.2	82.0	4.9	0.6	4.95	0.35
Residue or meal	36.4	4.8	5.0	43.6	0.4	9.8

Source: Rethinam and Bosco (2006)

Table 13.15 Oil recovery from different wet processing methods

Processes	Products	Percentage of recovery
Krauss-Maffei	Oil, coconut protein, coconut honey and meal	89
Krauss-Maffei/ CFTRIprocess	Oil, residual oil, protein coagulate, coconut honey and meal	97
Texas A&M	Cream/oil, protein, skim milk and fibrous residues	90
TPI	Oil, protein isolate and meal	85

Source: Rethinam and Bosco (2006)

Table. 13.16 Composition of tender (TCW) and mature coconut water (MCW)

Constituents	TCW	MCW
Total sugar (per cent)	4.8	3.1
Total reducing sugar (per cent)	4.0	2.0
Total protein (mg/dl)	150	450
L-arginine (mg/dl)	30	150
Vitamin C (mg/dl)	25	15
Magnesium (mg/dl)	16	14
Potassium (mg/dl)	300	257
Calcium (mg/dl)	40	44

Source: Sandhya and Rajamohan (2008)

uum dried at 55–80 °C and the residual oil extracted with isopropanol. The final oil recovery is about 85% which is distinctly lower than that from the other two processes. In all these processes, the protein recovery was more or less the same, i.e. about 85%. The defatted protein is desolventised by vacuum drying for 1 h at 60 °C and milled to a powder. The product composition is shown in Table 13.14.

The products obtained and the percentage of oil recovery from the existing wet processing methods are compared in Tables 13.15 and 13.16.

The Industrial Technology Research Institute (erstwhile NIST), Philippines, initiated a programme for preparing edible oil for rural areas by wet processing of coconut. This was based on the 'substractive process' of Birosel et al. (1963). In the substractive process, the nuts are split and the meat dislodged from the shell and pared. The pared meat is conveyed to washing tanks and to the comminuter, which disintegrates and breaks the oil cells. The milk is extracted using a carver-hydraulic press, which is centrifuged to separate the coconut cream. This cream passes through the washing tanks six or more times to separate the cream from the other components except oil. On centrifugation of the cream, white oil free from odour and flavour is obtained.

Since this process requires specialised equipment, not ordinarily found in rural areas, a study was undertaken to simplify Birosel's procedure by using simple utensils that are readily available in the rural community. Here fresh-grated coconut meat from the local market was macerated and passed through a cheese cloth and pressed by hand to extract the milk. A second pressing was done on the pressed meal or 'sapal' after the addition of tap water, equal to the weight of the original coconut meat. The extracts were pooled and allowed to stand for gravity separation for 1 h in a plastic container with faucet. The milk is thus separated into skim milk and cream. The cream was filtered through a screen (140 mesh) to remove the last traces of residual meal and washed several times with tap water to remove any entrained salt. After 30 min, the cream was boiled at low heat, and the minimal dark fine solids were allowed to settle at the bottom. The oil was rapidly filtered in a dry cheese cloth or filter paper and stored in closed bottles. The oil yield was found to be 73.64%.

Considerable work has been carried out to recover the oil as well as high-grade protein from fresh coconut meat. Thus, Pratap Chakraborthy (1985) developed a process for the simultaneous extraction of oil as well as protein concentrate by ultrafiltration. Ultrafiltration yielded 15% more coconut protein than acid coagulation. The protein had superior functional properties and had higher chemical score due to better amino acid profile.

The technology for wet processing has reached to the extent that high-quality coconut-based food items are possible to be produced such as the natural oil, protein-rich skim milk powder or skim milk concentrate, coconut flour,coconut water concentrate,etc. Commercialisation of the same will lead to higher employment facilities and profit provided the products find consistent market demand.

A critical assessment of the various processes described above will bring into limelight some of the inherent limitations which discourage the commercial application of the technology. In all the processes, except the Krauss-Maffei/CFTRIprocess, the oil recovery is about 5–10% less compared to efficient milling process, which is a traditional industry in the major coconut-growing countries. In wet processing, the unit operations are more, and the processing cost may work out to four or five times that of normal processing. Moreover, the process is highly capital-oriented. Whether a ready market and favourable price relationship exists for the coconut protein and coconut flour and whether this will compensate for the high cost of production and justify the huge initial investment are still to be ascertained.

13.9 Desiccated Coconut

Desiccated coconut is the white kernel of coconut, comminuted and desiccated to a moisture content of less than 3%. The common grades have a particle size of less than 5 mm. It is a very important commercial product having demand all over the world in the confectionary and other food industries, as one of the main subsidiary ingredients of fillings for chocolate, candies and liquorice of all sorts. It is also used uncooked and as decoration for cakes, biscuits and ice cream and toasted for short eats.

Sri Lanka is the first country to manufacture desiccated coconut where the first mill was installed in the 1890s. The Philippines is another major producing country. Other countries producing small quantities of desiccated coconut are Malaysia, Indonesia, Fiji, Tonga, Côte d'Ivoire, Brazil and India. The major consumers of the product are the USA, West Germany, Australia, Canada, Japan, the Netherlands, Denmark, South Africa, Sweden, Belgium and the Middle East.

13.9.1 Processing of Desiccated Coconut

Deshelling and Paring Desiccated coconut is made out of fully mature nuts which have been stored for about a month to make the deshelling operation easier. The shell is removed by sharp taps on the shell by a small axe/chisel and the kernel separated from the shell. Shelling usually leaves the kernel including the testa intact with the water inside.

Next stage is paring the kernel to remove the brown testa using a special type of knife. The parings which amount to 12–15% of the kernel are usually sun dried, but sometimes over dried and pressed for oil, the yield being 60–62%. The resulting oil, known as paring oil, is of inferior quality and finds use in soap manufacture. The paring cake has approximately the same composition as the ordinary copra cake.

Washing The pared kernel is placed in tanks and sliced into two to release the coconut water. The sliced kernel pieces are then passed into other tanks through a two-stage washing. The coconut water is led into settling tanks, and the surface scums when formed are removed and boiled to get an oil of inferior quality. The resulting press cake has a high fertiliser value. This oil is not derived from the coconut water, but from the oil which has been washed away from the pared surface of the kernels.

Sterilising The kernel pieces after washing are sterilised by passing through large tanks containing boiling water. The pieces are carried in wire baskets continuously by mechanical device, and the movement of the baskets is adjusted in such a way that from one end of the tank to the other, a set period of 90 s is available for sterilisation. The oil layer that may form on the surface of the boiling water is removed at frequent intervals. In the Philippines, sterilisation is also effected by subjecting the disintegrated meat to live steam in stainless steel blanchers at about 80 °C for 5 min or 70 °C or 80 °C for 8–10 min. To stabilise the kernels, the sterilised pieces are immersed in a solution of sulphur dioxide.

Disintegrating and Desiccating The kernel pieces are transferred from the wire baskets straight to the disintegrator which shreds the kernel pieces to a fine wet meal. Disintegration is done by an attrition mill known as 'Devil Disintegrator' which shreds the kernels to pieces varying in size from 1 to 5 mm. When fancy grades are required, different cutting machines are used. The disintegrated product will have double the weight of the final product. This wet mass is subsequently desiccated or dried to a final moisture content of 2–2.5%. The dried product is allowed to cool on galvanised tables before being taken to the sifters for grading into coarse, medium and fine grades. For export, each grade is packed in plywood cases containing 50 kg. The product is available in other forms also such as extra fine shreds and threads and chips. In fully mechanised plants, as in the Philippines, the cooling system is integrated into the drying system. After drying, the product is sucked from the drier and blown along a pipe to a cyclone cooler mounted on a platform above the grading table and the packing section. At the time of packing, the temperature of the product will be about 40 °C, and the grading and packing are performed mechanically.

The following standard requirements and specifications for export-quality desiccated coconut have been recommended by the Asian and Pacific Coconut Community. Good desiccated coconut should be crisp and snow white in colour with a sweet pleasant fresh taste of the nut. The oil content range is from 68% to 72%, but the oil should not contain more than 0.1% free fatty acids. The moisture percent shall not exceed 3 for coarse, medium and fine grades and 3.5 for special grades such as thread and chips. The product shall also be free from all foreign matter including shell, coconut fibre, metal particles and textile fibre.

13.9.2 Yield of Desiccated Coconut (DC)

In India, 8000–9000 nuts yield 1 tonne of desiccated coconut. While the general figure in Sri Lanka is about 7000 nuts and in certain tracts, particularly in Chilaw District, 6000 nuts will give 1 tonne of DC. In the Philippines only 5500 selected nuts are needed to produce 1 tonne of desiccated coconut in most of the producing areas.

13.9.3 Composition

According to NIIR Board of Consultants and Engineers (2012), the main constituents of desiccated coconut are fat (67.5%), carbohydrates (5.9%), protein (9.30%) and pentosan (8.9%).

Good-quality desiccated coconut can be obtained by drying in the vacuum dryer at 100 °C in 200 mm of Hg vacuum. The drying time is reduced, in vacuum drying to 20 min instead of 40–50 min in conventional forced hot air drying. The colour and quality of the product are also very good. Due to vacuum, puffing of the desiccated coconut (about 40%) was also observed in vacuum drying.

13.10 Tender Coconut Water

Water from tender coconuts (7–8 months old) makes a refreshing and palatable drink particularly during summer. Tender nut water contains good amount of B group vitamins like nicotinic acid, pantothenic acid, ascorbic acid, riboflavin, biotin and minerals like Na, Ca, Mg, K, Fe, etc. The pH of the water varies from 4.8 to 5.3. The concentration of ascorbic acid ranges from 2.2 to 3.7 mg 100 ml^{-1}, which gradually diminishes as the kernel surrounding the water begins to harden. The percentage in respect of amino acids such as arginine, alanine, cystine and serine in the protein is higher than those in cow's milk. The tender nut water has a calorific value of 17.4 per 100g of water. When the nut is 7–8 months old, the nut water has the maximum concentration of sugar, and a large nut at this stage may contain over 28 g of sugar in solution. The tender nut water also contains various minerals of which potassium is the major constituent, and its concentration largely depends upon the nature of potash manuring.

13.10.1 Mature Coconut Water Vs Tender Nut Water

As the nut matures, the composition of the water especially the sugar content undergoes significant changes. During the early stages of development, the quantity of invert sugar present in the water increases and reaches a maximum at 220 days. After this stage, sucrose appears in the water and the concentration of total sugars falls and concentration of total solids also declines. Alanine, 2-aminobutyric acid and glutamic acid constitute about 75% of the free amino acids of the water from mature fresh nut. So, mature coconut water is not popular as a soft drink. The composition of tender nut water and mature nut water is given in Table 13.16.

Tender nuts are valued both for sweet water, which is a refreshing drink, and for its gelatinous kernel which is delicious. Moreover, the tender nut water has a number of medicinal properties, and it is an essential component in many of the Ayurvedic preparations. The use of tender coconut water is recommended in cases of gastro-enteritis and as a useful substitute to saline glucose in intravenous infusion. It is also prescribed in serious cases of diarrhoea and vomiting against dehydration of body tissues. It increases the blood circulation in the kidney and causes profuse dieresis. The values for the B group vitamins reported (Anon 1950) are nicotinic acid (0.64 g cc^{-1}), pantothenic acid (0.52 g cc^{-1}), biotin (0.02 g cc^{-1}), riboflavin (< 0.01), folic acid (0.003) and traces of thiamine and pyridoxine.

13.10.2 Products Derived from Tender Coconut

13.10.2.1 Snowball Tender Coconut

The soft tender kernel or solid endosperm of tender coconut is a delicious dessert. But the traditional method of its extraction is difficult, time-consuming and risky. In all the coconut-growing countries, a portion of the coconut is harvested at the tender stage (7–8 months) for using its water as a beverage. The kernel of the tender coconut is sometimes eaten or else thrown away, as it is difficult to remove it from the shell. The tender coconut kernel is good for convalescing patients. It contains good amount of nutrients. A technology for making snowball tender nut (SBTN) has been developed. SBTN is the tender coconut without husk, shell and testa which is in ball shape and white in colour. This white ball contains tender coconut water, which can be consumed by just inserting a straw through the top white tender coconut kernel. Coconut of 8-months maturity is more suitable for making SBTN. Making groove in the shell before scooping out the tender kernel with water is one of the important unit operations. For this, a suitable machine has been developed.

It is nutritive and is a drink and a snack at the same time. Since there is no refuse after the consumption, there is no littering of the premises. Since the snowball tender nut can be individually packaged and refrigerated under hygienic conditions, the shelf life of this product is prolonged, and therefore this ready-to-serve product is becoming popular.

Tender coconuts are usually transported and sold in their natural form, involving a lot of transportation cost due to the volume of the material. Further, the life of tender coconut water in the nut is short and therefore cannot be kept for a long period. A technology has been developed to extend the shelf life of the tender coconut water by packing in flexible pouches and aluminium beverage containers. Tender coconut water's characteristic flavour is contributed by heat-sensitive elements, and hence partial heat treatment combined with certain preservative is employed. To obtain a uniform taste, some of the sweetening agents are added. The product can be stored up to a period of 3 months under ambient condition and about 6 months under refrigerated condition. The flavour retention is better in the case of cans than flexible pouches.

The processing and packing of tender coconut water with a capacity of 10,000 tender nuts per day facilitates a direct employment potential of 30 personnel. The profitability after taking into account the prevailing prices of finished product is about 20% with a payback period of 3 years. Tender coconut water has a great potential as a health drink both in domestic and international market.

13.10.3 Products Derived from Mature Coconut Water (MCW)

Coconut water from mature nuts is mostly a waste product of the copra and desiccated coconut industries. Nevertheless, it has been recommended for the production of certain food products which could be developed on a cottage industry basis, for augmenting the income of coconut growers.

13.10.3.1 Bottled Coconut Water

Bottling of coconut water for use as a soft drink is gaining popularity. Coconut water can be marketed as a natural soft drink if preserved and packed. Although this product is already developed and marketed, limited shelf life is a constraint. Therefore, further investigation is required to extend the shelf life, to improve quality and to develop suitable packaging system for overcoming the problems of transportation and storage.

13.10.3.2 Coconut Water Concentrate

One of the problems for the use of coconut water as feedstock for the manufacture of beverage and other products is the cost of transportation and spoilage during transport of the material from the source to the beverage factory. A possible solution to this is to concentrate coconut water into a form that is easily rehydrated which will also help to reduce shipment weight, volume and cost, as well as improve product stability. Potential end users of the concentrate include not only the food and beverage industry but also the fermentation industry, hospitals, research laboratories and the beverage-consuming public.

Coconut water is adversely affected by extended processing at high temperature, so a nonthermal concentration process has to be used. One of the available techniques for producing coconut water concentrate is reverse osmosis. In the case of concentration of coconut water, the concentration is achieved by applying external pressure in order to overcome osmotic pressure and force the solvent (water) of all or most of the dissolved substances to evaporate in effect reversing the normal osmotic process. Concentration factor of five- to six folds can be obtained using 90 membranes at 4 MPa after 5 h of reverse osmosis with continuous retentate recirculation. Maximum concentrations of sugar and protein for the retentate, namely, 16.9 and 0.7%, respectively, are attained under these conditions.

13.10.3.3 Frozen Coconut Water

A brief description of the process is as follows. Fresh coconut water from newly opened coconuts is collected under hygienic condition. Suspended solids and oil in the samples are removed by means of three-way centrifuge. The removal of the solids and the oil is necessary in order to minimise fouling or clogging of the membranes. The salts present in coconut water may be removed if desired, prior to concentration, to produce a very sweet product. This is achievable by passing the centrifuged coconut water through a mixed-bed ion-exchange resin. However, additional costs are entailed, and problems dealing with re-generatability of the resin need to be overcome. The concentrate can be frozen or preserved in cans and after dilution to the desired strength can be used as a base for the production of carbonated and noncarbonated coconut beverages. The concentrated coconut water is also being used successfully in the brewery industry.

13.10.3.4 Coconut Vinegar

Coconut water can be converted into vinegar by using vinegar generators. The vinegar generator assembly comprises of a feed vat, an acetifier and a receiving vat for collection of vinegar. MCW consisting of about 3% sugar is concentrated to 10% level by fortifying with sugar, which is then fermented by inoculating the solution with yeast, *Saccharomyces cerevisiae.* After alcoholic fermentation for 4–5 days, the clear liquid is siphoned off and inoculated with mother vinegar containing *Acetobacter* bacteria. The alcoholic ferment obtained is then fed into a vinegar generator where the feed is uniformly sprayed over the surface of the porous packing medium (corn cobs). Here the alcoholic ferment is oxidised to acetic acid. The product is run out from the packing medium by gravity flow into the receiving vat from where it is recycled into the vinegar generator and the process of acidification is repeated until strength of 4% is attained. This acetified vinegar is then aged before bottling. The manufacture of coconut vinegar with a capacity of 500 litres day^{-1} involves a low capital investment with an employment potential of 10 persons. The profitability (taking into account the prevailing price) of the finished product is about 20%. Coconut vinegar enjoys a wide market as a preservative in pickling industry and as a flavouring agent for foodstuffs. A traditional popular drink, coconut lemonade, is prepared by boiling coconut water, sugar and lemon juice. A tangy coconut sauce can also be prepared from coconut water with red chilli, onion powder and little vinegar.

13.10.3.5 Coconut Honey from Coconut Water

Coconut honey is another product from coconut water containing many growth-promoting trace elements besides glucose, fructose and laevulose. Coconut water is filtered, evaporated and blended with a little golden syrup to produce coconut honey, a palatable, nutty-flavoured breakfast food, soft drinks additive and a sweetener.

13.10.3.6 Nata De Coco

Nata is a gelatinous substance formed by *Acetobacter* sp. on the surface of fermented coconut water. This product when preserved in sugar syrup is an excellent dessert and enhances the flavour and taste when mixed with other sweet preparations such as fruit salad. Nata de coco is prepared from MCW or coconut skim milk by mixing the medium with sugar, acetic acid and culture liquor. The recommended proportion of the ingredients is 1 kg of boiled, cooled and filtered coconut water, 65 g of sugar, 25 g of glacial acetic acid and 165 g of mother liquor. The mixture is allowed to stand undisturbed in wide-mouthed glass or plastic jars for 15–20 days. During this period, a white jelly-like thick surface growth is formed by the action of *Acetobacter xylinum.* The surface growth is harvested, sliced, acid washed, boiled in sugar syrup and preserved in either tin containers or bottles. The leftover liquid medium is used as the mother liquor for subsequent production. The gelatinous growth is composed mainly of polysaccharides, probably dextrose, and is cellulosic in nature. For the initial preparation of the starter liquor, three cups of pineapple residue left after the extraction of juice are mixed with six cups of water and one cup of sugar, and the mixture is left undisturbed in wide-mouthed glass jars covered with a thin cloth for approximately 2–3 weeks. The jelly-like growth which forms on the surface during this period is taken out, sliced into small cubes and used as the starter medium.

The product is served either mixed with other fruits or baked into a delicious cream pie or simply served with flavoured syrup. Since nata has no calorific value, it is a favoured delicacy. In the Philippines, where the nata is produced in large quantity, the demand is on the increase, both for domestic consumption and export.

13.10.3.7 Soft Drink

Coconut water has a potential use as a refreshing soft drink. In India, CSIR-National Institute for Interdisciplinary Science and Technology (NIIST), Thiruvananthapuram, has developed a technology for the formulation of noncarbonated beverage from coconut water of mature nuts. The process involves collection of water, upgradation, pasteurisation, filtration and bottling. The coconut water when collected from copra processing units is immediately filtered through a clean cheese cloth. Initial filtration at the collection centres reduces the bacterial load in the water. At the processing site, the pH of the coconut water is adjusted to 4.2 with citric acid and 0.1–0.15% sodium citrate. The addition of sodium citrate is to reduce the biting taste that may develop with the addition of citric acid. In some formulations, the use of 0.01–0.05% sodium chloride is found to improve the taste. The total soluble solid content is adjusted to 8–10% with refined sugar. Sodium benzoate is also added at the rate of 0.05% to increase shelf life. The formulation is immediately pasteurised at 94 °C for 25–30 min. The protein starts coagulating at 70 °C, and at this stage, super cell is added to aid sedimentation by co-precipitation. Excessive heat treatment is avoided as it imparts a cooked flavour to the finished product. Rigorous agitation is also avoided in order to prevent disintegration of the protein coagulation into fine particles. After pasteurisation, the formulation is passed through a pressure filtration system, and the filtered product is filled in sterilised returnable bottles and crown-corked under sterile conditions. The final temperature of the product in the bottle ranges between 72 °C and 75 °C. These can be stored for 3 months at ambient temperature without spoilage.

Processing technology has also been standardised for the preservation of tender coconut water obtained from 7- to 8-months old tender coconuts. During the processing, the precipitation after pasteurisation is much less, and it has been possible to obtain a clear product even without filtration. This also keeps well at ambient temperatures and is microbiologically safe for over 9 months.

13.10.3.8 Other Miscellaneous Uses

Even in the early 1890s, it was shown that coconut water is a medium for growing microorganisms like yeast for the production of which viable technology is available. The superiority of coconut water over molasses in yeast production is known. *Saccharomyces fragilis* can be grown on coconut water, yielding up to 0.54 g of dry yeast per g of total sugar at 40–45 °C. The resulting yeast which contains 45% protein is a rich source of amino acids and vitamins (Smith and Bull 1976).

For ensuring maximum yields, it is sufficient if 1 g of urea per litre of water is added as an additional nitrogen source. The yeast so produced after washing and drying will have a pale cream appearance, slight odour, a nutty taste and a good shelf life. In coconut complexes, where large number of coconut is processed, it would be feasible to grow the food yeast for the production of protein.

Quimio (1984) found that coconut water, both from mature nuts and tender nuts, can support the mycelial growth of edible mushroom. When incorporated with agar, coconut water performed almost equally well as the potato dextrose and malt extracts. Within 1-week incubation, 12 g dry weight of *Lentinus sajor-caju* mycelium can be harvested from 100 ml sterilised medium containing coconut water. Trials with other edible mushrooms such as *Volvariella volvacea*, *Auricularia polytrichia*, *Pleurotus sajor-caju*, *Tremella fuciformis* and *Agaricus bisporus* showed that the technique is successful.

Coconut water is also an excellent medium for culturing different organisms. Coconut water agar medium can be used as a routine laboratory agar medium for a number of plant pathogenic fungi such as *Fusarium*, *Colletotrichum*, *Pythium*, *Rhizopus*, *Botryodiplodia* and *Phytophthora.* Preliminary studies have shown that coconut water can also be a good sporulating medium for the non-sporulating fungi. It can even be dried into coconut water agar powder, ready to be rehydrated when needed, with the addition of peptone. The growth of *E. coronata* was faster when coconut water from either immature or mature nuts was included in the culture medium. Sugar-enriched coconut water can be used as a medium for the production of dextran by using *Leuconostoc mesenteroides*.

Coconut water also possesses growth-promoting activity. The water from tender nut shows better growth-promoting activity than that from mature ones. Gibberellin can be produced by cultivating *Gibberella fujikuroi* in coconut water. Apart from these, coconut water can be used for other miscellaneous purposes. It is mixed with lime to improve the adhesiveness of white wash. Fermented coconut water has been used successfully as a rubber coagulant to obtain good-quality rubber.

13.11 Toddy

Toddy is obtained by tapping the unopened spadix of the coconut palm. This is known as ‘tuba’ in the Philippines and ‘tuvak’ in Indonesia. The word tapping collectively connotes the extraction and the various manipulations for stimulating the palms to exude juice from a selected part. In the coconut palm, palmyra (*Borassus flabellifer* L.), and in the Indian sago palm (*Caryota urens* L.), it is the inflorescence that yields toddy on tapping, whereas in the date palm (*Phoenix dactylifera* Roxb), the juice exudes from the lateral portion of the young stem on being punctured.

13.11.1 Tapping Methods

In India and Sri Lanka, the spadix is considered ready for tapping when the female flowers within the unopened spathe cause a swelling at the base. In the process of tapping, the spathe is trained for a period of 3 weeks, which involves uniform beating all over the surface of the spathe daily with a tapping rod to rupture the cells and to induce the sap flow. During the process, the spathe gradually bends, and it is prevented from opening by tightly binding it with fibre. When the spadix is ready to yield the sap, about 4 or 5 cm is cut from the tip of the spathe, and an earthen receptacle is placed for sap collection. The interval between the beginning of tapping process and the commencement of sap flow is about 15 days extending to 21 days in summer months. The tapping is usually continued for a period of 6 months, and sometimes three spathes are continuously tapped. In Sri Lanka, the tapping continues for a period of 8 months, with a maximum toddy yield in the third month.

In Indonesia, the tapping begins when the spadix is about 1 month old. It is tightly wrapped in coconut leaves and the tip is cut about 1 cm long. The end is then lightly beaten with a round piece of wood, 30 cm long, till the flowers are bruised and the beaten part again wrapped with a piece of young leaf. This procedure is repeated several days until the flow of sap begins.

13.11.2 Yield of Toddy

The yield of toddy varies from palm to palm, season to season, day to day and even from spadix to spadix. There is also considerable variation between varieties. The yields of toddy obtained from different varieties of coconut in Sri Lanka are given in Table 13.17.

In India, an average of about 18 l of toddy spadix^{-1} has been recorded for a tapping period of 1 month. Palms which yield a large number of nuts have been found to yield up to 300 l of toddy during the 6 months of tapping with an average yield of about 50 l of toddy spadix^{-1}. On an average, the yield of toddy palm^{-1} day^{-1} is about 1.5 l.

In the Philippines, it was found that 40-years old palms under good management produce about 400 l of sap annually. In an experimental tapping of 100 palms, a daily yield of 1.38 l palm^{-1} was obtained. When calculated in a 12-h period, the flow during the day time was 0.64 l, and it was 0.74 l during the night (Gibbs 1911). The Laguna cultivars yield about 0.772 l day^{-1}, while the Coconino produces about 0.400 l day^{-1}. The annual yield reported for tall palm is about 370 l palm^{-1} (Fernandez 1978).

Table 13.17 Average toddy yields of tall, dwarf and hybrid coconut palms in Sri Lanka

Particulars	Average toddy yield (l)		
	Tall	Dwarf	Hybrid
Total yield for 365 days	577	110	792
Average yield per spadix (weighted average)	49.5	8.5	44.8
Range of yield per spadix	17–69	0.1–15	22–53
Number of spadices tapped	15	14	19

Source: NIIR Board of Consultants and Engineers (2012)

13.11.3 Kalparasa (Neera)

The trickled sap from the inflorescence is traditionally collected in earthen pots, and during this process it gets fermented. A coco-sap chiller technology has been developed by ICAR-CPCRI (Hebbar et al. 2015). A technology for production of hygienic and unfermented neera has been standardised by the Kerala Agricultural University also (Jayaprakash Naik et al. 2013). For details, please refer to Chap. 9.

13.11.4 Properties of Toddy

The fresh toddy obtained on tapping the coconut palm is mildly acidic and rich in sugar and vitamins. Apart from 10% to 15% sugar, it contains proteins, minerals and vitamins which makes it a nutritious drink and also an excellent fermenting medium. The fresh toddy, unless collected under sterile conditions, rapidly ferments, and the sugar is replaced by about 5–8% alcohol which on distillation yields strong liquor known as arrack. If the fermented toddy is kept further, it undergoes a process of acetic fermentation yielding the coconut vinegar containing about 4–7% acetic acid. The fresh toddy is also a source of baker's yeast. The composition of fresh as well as fermented toddy is given in Table 13.18.

Under natural conditions, toddy is fermented by the native microflora consisting of yeast and bacteria. *Saccharomyces* species of yeast has been identified to cause fermentation. Fully fermented toddy contains 6–7% (V/V) alcohol (Nathanael 1960). The fermented toddy may contain ethyl alcohol, aldehydes, higher alcohols or acetic acid. This is consumed as an alcoholic beverage in many coconut-growing countries. The composition of fermented toddy is given in Table 13.18.

Unson (1966) found that toddy can be preserved without fermenting by the addition of sulphanilamide or p-hydroxy-benzoic acid. Potty et al. (1978) attempted the preservation and bottling of coconut toddy. Here toddy was mixed with 5% activated carbon granules and pasteurised at 80 °C–82 °C. After centrifuging and autoclaving for 30 min with steam at atmospheric pressure, the product was bottled.

Table 13.18 Composition of fresh and fermented toddy

Fresh toddy		Fermented toddy	
Specific gravity	1.058–1.077	Specific gravity	0.998–1.033
Total solids	15.2–19.7 g 100 ml^{-1}	Acidity (as acetic)	0.32–0.67 (%)
		Water	98.2 (%)
Protein	0.23–0.32	Protein	0.2 (%)
Ash	0.11–0.41	Ether extract	0.1 (%)
Sucrose	12.3–17.4	Carbohydrates	1.3 (%)
		Mineral matter	0.01 (%)
Ascorbic acid	16.0–30.0	Calcium	<0.01 (%)
		Phosphorous	0.01 (%)
		B1	<51 μ 100 g^{-1}

Source: Browning and Symons (1916)

13.11.5 Effect of Tapping on Yield of Nuts

It has been found that tapping in medium- and poor-bearing palms improves the yield for about 4 years after discontinuation of tapping. In India, it was shown that tapping increases the yield of only poor bearers, while in the Philippines, the tapped palms fruited abundantly the year after the tapping but stopped for a few more years thereafter. However, a reduction in oil content of copra was seen ranging from 14.32 kg to 25.79 kg t^{-1} of copra. Similar results were reported from Malaysia also (Jack and Dennett 1925) indicating a reduction in the weight of meat (21 g), weight of copra (10.7 g), weight of oil (21.7 g) and oil content (3.3%) in the tapped palms.

13.11.6 Products Derived from Toddy

13.11.6.1 Jaggery

Unfermented toddy, when boiled to 118–120 °C and allowed to cool, solidifies. The solid mass is known as coconut jaggery or *gur*. During the production process, the scummy impurities along with froth are removed, and the saturated solution is poured out in moulds for hardening. Since the removal of scummy impurities involves considerable wastage of sugars, in certain places, frothing is avoided by adding a few drops of coconut oil or a little coconut grating. Before boiling, the juice is filtered through sand filters to remove the impurities, and a small quantity of alum is added to induce the precipitation of lime and magnesia. This will render the final jaggery much less deliquescent which gives a better colour and will enable to remain hard for a reasonable period. Twelve to fifteen percent jaggery is obtained from toddy. Jaggery contains 10.92% moisture, 68.35% sucrose, 6.58% reducing sugar, 2.17% ash, 1.64% protein and 8.72% of pectins and gums. The calorific value is 321.6100 g^{-1} (Anon 1984). The manufacture of coconut jaggery from coconut sap holds promise as a viable commercial venture.

13.11.6.2 Refined Sugar

The sugar content in sweet toddy tallies with that of cane sugar juice. On the basis of 175 palms to a hectare and 250 l of toddy palm^{-1} containing 15% crude sugar, the yield of raw sugar ha^{-1} would be about 6 tonnes. For recovering the raw sugar, toddy is treated with 2% lime to coagulate albuminous impurities. The limed toddy is then carbonated in two stages and filtered each time to remove excess lime. The clarified juice is evaporated to the extent of 75% sugar content, and the resultant syrup is concentrated in vacuum pans till crystallisation commences. The syrup is then discharged into crystallisers, and the crystalline sugar is separated by centrifugation. It is of nutritional value because of its low glycaemic index. But the process as a whole is not economically viable.

13.11.6.3 Vinegar from Coconut Toddy

Coconut toddy vinegar is formed when toddy is allowed to ferment for more than 24 h to yield acetic acid. Nathanael (1963) standardised the procedure for large-scale production of vinegar from coconut sap. Submerged fermentation using pure strain of *Acetobacter* and an isolated strain from jaggery were found to be suitable for vinegar production (Gupta et al. 1980). Besides this, a quicker method of vinegar production known as 'generator' process has been developed in Sri Lanka (Nathanael 1963). Its composition is density (30 °C, g cc^{-1}), acetic acid, total solids, potash and nitrogen (g 100 ml^{-1}) content of coconut vinegar range from 1.010 to 1.013, 4.7 to 5.4, 1.25 to 1.36, 0.16 to 0.22 and 0.025 to 0.033, respectively.

13.11.6.4 Treacle

This is the concentrated form of sweet toddy obtained by boiling the toddy. The final product is golden-coloured syrup. The recovery is about 16% of the toddy used. Treacle is considered a delicacy in many places, and its preparation is very common in Lakshadweep Islands.

13.11.6.5 Arrack

Arrack is the product obtained by the distillation of fermented toddy, the range of recovery being 17.5–25% of the original toddy. The reported ranges of analytical values of arrack are esters (164–258), total acids (116–158), fixed acids (6–13), volatile acids (105–152) and furfural (0.45–1.32). Double-distilled arrack is called coconut feni.

13.12 Other Food Products

13.12.1 Haustorium

When the nuts germinate, a spongy ball-like haustorium develops inside the nut. This is utilised for the preparation of various products like jam, marmalade, etc. It is sometimes sliced and preserved in sugar syrup for use as a constituent of fruit salad. Haustorium contains moisture (15.23%), ash (9.39%), protein (10.60%), fat (15.68%), carbohydrates (38.42%) and fibre (10.59%). The terminal bud or cabbage is also a delicacy. It is used raw or in salads and is sometimes pickled, canned or bottled as a preserve.

13.12.2 Dry Kernel or Copra

Copra and coconut oil are the principal products of coconut palm. The dried coconut endosperm is called copra. With an oil content of 65–70%, copra is the richest source of fat. Though there is variation in the oil content of copra derived from different regions, according to Indian Standards, 1 tonne of copra corresponds to about 680 kg of oil with an average extraction of about 645 kg of oil. There are two types of copra – edible copra and milling copra.

13.12.3 Edible Copra

Edible copra is available in two forms – ball copra and cup copra. Edible copra is used for sweet meat preparations in households and as an ingredient in the processed foods.

13.12.4 Ball Copra

Ball copra is made from fully mature (>12 months) whole unsplit nuts. The nuts are stored for about 8–12 months on a raised platform, usually made of bamboos, inside a shed. During this period, the coconut water slowly gets absorbed, and the kernel dries out and loosens itself from the shell. The nut at this stage is dehusked and the shell carefully removed to separate the whole dry kernel in the ball form. In some places, drying process is hastened by occasional heating of the nuts by a slow fire set under the platform.

Ball copra is soft, sweet, oily and cream coloured. Three grades of ball copra are available on weight basis, viz. ‘large’, ‘medium’ and ‘small’, depending on the number of copra required for a weight of 4 kg (< 20 for 'large', 20–40 for 'medium' and > 40 for 'small'). The moisture content shall in all cases be below 7%. This grading is being accepted generally in the marketing sector now.

13.12.4.1 Preparation of Ball Copra by Heat Treatment

In order to reduce the incubation period to the minimum, coconut is partially dehusked and heated in small holder's dryer at 55 °C–60 °C for 8 h daily for 3 days and stored in gunny bags for 10 days. This intermittent heating is repeated till all the nuts become ball copra. All the nuts under heat treatment become ball copra within 6 months, and the quality of the ball copra is also very good. In conventional method, it takes 11 months. In a similar way, puny nuts under heat treatment are transformed into ball copra within 3–4 months. Conversion of nuts into ball copra is faster during January to May compared to June to November period (Madhavan and Bosco 1991).

13.12.4.2 Cup Copra

Edible cup copra is prepared either from fully mature nuts or from stored nuts by cutting the dehusked nuts into halves and drying them in the sun. The cutting, drying and deshelling processes are done very carefully in order to get a good clean final product. In Sri Lanka and in some parts of India, hot air driers are used for the production of edible type of cup copra. In some copra markets in India, good-quality cups of uniform size are separated from bulk gatherings of commercial copra and marketed as edible copra at a premium price.

In Kerala, India, cup copra is classified into three grades. The major grade is 'Rajapur' copra. Here, the ball copra in which the kernel is completely dried out is cut into two and dried in the sun for 3 days. The second grade is called 'Malathi' where partially dried ball copra is cut and dried in the sun for 7 days. The third grade is known as 'Dil Pasand'. Nuts harvested and kept for 2–3 months are used for preparing this type of cup copra. Freshly harvested nuts also can be used. Nuts are split and dried in the sun for more than 7 days. Adequate care is taken in splitting the nuts and drying. Neat white copra cups separated from the bulk of milling copra are also sold as 'Dil Pasand' after trimming the edges.

13.12.5 Milling Copra

The conversion of fully mature coconuts into copra for milling purpose is the most common processing activity in the major coconut-producing countries. The unit operations involved in the process are dehusking, splitting the nuts into halves and drying the split halves. Drying is an important postharvest operation in the processing of coconut for the extraction of oil. For the efficient storage of copra and easy extraction of oil, fresh coconut meat, which contains 45–55% moisture, has to be dried to 5–6% moisture level to obtain the copra. The conventional system of copra drying is by spreading the split coconuts on an open surface for sun drying. This operation takes 6–8 days, and quality deterioration due to deposition of dirt and dust of wet kernel is unavoidable. Moreover, if the atmosphere is cloudy and the temperature goes down during the initial days of drying, the copra will get infested with mould. Copra obtained by this method is often of poor quality because of prolonged exposure to atmosphere resulting in microbial infection. During rainy season, with restricted sunshine, drying by artificial method is the only possible solution for making good-quality copra. The direct-type kiln dryers are not desirable as the copra becomes inferior in quality due to the smoking and improper drying. To obtain good-quality copra, particularly during rainy season, a suitable dryer using indirect heating for drying is essential. Drying must be carried out within 4 h of splitting since coconut kernel deteriorates very rapidly due to growth of mould and bacteria.

13.12.5.1 Dehusking

The first stage in the processing of coconut is the removal of the fibrous outer layer or the husk. In most of the coconut-growing countries, dehusking is done manually on a wooden spike provided with a sharp tip. The spike is fixed vertically into the ground with the sharp iron tip facing upwards, and the trained worker drives the husk against the sharp tip and, with three or four quick twists, tears it off. To make the dehusking operation more efficient and less tiresome, mechanical devices have been developed. Please see Sect. 13.4.1 for details.

13.12.5.2 Copra Drying

There is variation in the moisture and oil content from different parts of the endosperm. Studies conducted at the Coconut Research Institute, Ceylon (Sri Lanka), revealed that the moisture was more near the centre of the kernel and least in the outer region, 63.7 and 28.4%, respectively, while the oil content was the highest in the outer region (78.5%) and least in near the wet surface (49.2%). In a similar study conducted in the Regional Research Laboratory (CSIR) at Trivandrum, India, the variation in the moisture content was 61.9% in the inner region, 32.6% in the middle region, 18.1% in the outer region and 29.1% in the testa. The corresponding values for oil were 41.39%, 68.78%, 75.36% and 27.41%, respectively, on dry weight basis. Therefore the drying of copra has to be meticulously monitored for ensuring uniformity in drying.

Delay in drying of split nuts will cause deterioration of coconut kernel as it is a very good substrate for the growth of mould and bacteria. Microbial activity is related to the moisture content becoming much higher, say 20% or more (Nair 1984).

When drying is delayed, dipping the copra in dilute sodium carbonate and dilute sulphuric acid in conjunction with sun drying has been found to be successful to prevent deterioration of copra (Subramanyan 1966). Sreemulanathan et al. (1979) also confirmed that application of a coat of glacial acetic acid on the kernel surface prevented microbial growth during open sun drying. Treating the fresh meat with shell ash prior to drying (De Castro and Cora Nera 1978) and dipping the fresh kernel in 1000 ppm propionic acid for 60 min (Patil 1982) have also been found successful in preventing mould growth.

Drying Methods Different methods such as sun drying, solar drying, direct drying in kilns and indirect drying are used for copra drying. In many places, a combination of preliminary sun drying followed by kiln drying is followed.

Sun Drying This is the most popular and cheapest method of copra making, which is traditionally adopted in all the coconut-producing countries. In this method, the split nut halves (cups) are laid out in an open yard with the kernel portion facing the sun. After about 2 days of drying, the kernel gets detached from the shell. The partially dried kernel is then scooped out by means of a thin wooden lever. The detached kernel cups are again arranged in the yard for further drying. The drying process has to be continued for another 4–5 days to achieve the desired level of drying.

In Thailand, the preliminary drying of copra with shell is done only for 1 day after which deshelling and further drying are carried out. In Indonesia, the kernels are usually removed immediately after cracking and dewatering. In Sri Lanka, the drying time under the sun is about 9 days.

In India, sun drying takes 7–9 days (70–80 h) under the sun to obtain copra with 6% moisture content. Generally copra is dried on cement or concrete yards or on the bare soil surface. Patil and Nambiar (1982) found that black-painted palmyra mat surface reduced the drying time by 13%. Though good-quality copra could be produced by sun drying, the method is hindered during the monsoon. If proper care is not taken, the copra processed during the monsoon may have mould or get discoloured. Even though mould growth does not appear on the fresh meat until about 3 days, inadequate drying or intermittent drying develops sliminess on the surface of the meat resulting in subsequent discolouration. As such, copra drying has to be carried out without interruptions.

Solar Drying Solar energy can be more effectively utilised for copra drying by using solar heat collector-type drying systems. Patil (1984a) developed a polythene-covered drying gadget. Perforations are provided for air circulation on polythene sheet cover which is kept on a mild steel bar frame, and the gadget is kept on a black-painted palmyra mat surface. The cups are kept inside for drying. The temperature inside is above the ambient temperature, and 60 nuts per m^2 area can be placed and dried.

Solar cabinet dryer has been developed which is of chamber type having a direct heating and natural air convection arrangements (Patil 1984a). The dryer mainly consists of a drying cabinet provided with selectively coated solar aluminium absorbent sheet (sun sheet) as the drying surface, a trolley which supports the drying cabinet, sliding-type 4 mm transparent top cover, adjustable aluminium reflectors on hinges on three sides and transparent glass cover on all four sides. The drying surface capable of holding 100 nuts (200 cups) is kept at an inclination of 12.5° (equal to the latitude of the location). Thermocol insulation of about 25 mm thickness is provided between the sun sheet and plywood, for preventing heat loss. The aluminium reflectors with adjustable angle help in concentrating the solar radiation on the drying surface itself. The drying surface is so adjusted as to face the sun with the help of castor wheels, and an indicator rod is placed on top of the frame. For air inlet, a 10-cm-wide opening covered with expanded metal is provided at the bottom of the front side of the dryer. The exhaust provided at the rear top is also covered with expanded metal.

The split nuts are loaded on the drying surface with the cups facing up. The dryer is positioned to face the sun with the help of the indicator rod. The dryer is moved to track the sun twice during the day at 3-h intervals for the effective trapping of solar energy. Heat is generated inside the cabinet due to the absorption of solar radiation which promotes the rapid evaporation of moisture in the copra. The moisture-laden air escapes through the exhaust vent.

At the close of the day, the cups are covered with gunny cloth and the dryer is closed. On the second day, the kernel is detached from the shell and kept for further drying. The drying is continued every day from morning till evening to reduce the moisture content to less than 6%. The total drying time is 32 sunshine hours. Drying time is reduced by 50% compared to open sun drying. The quality of copra obtained is superior to that obtained by open sun drying. The dryer is versatile in design and can be adapted for drying other plantation crop produces also, such as cardamom, pepper, ginger, etc. It is easy to fabricate locally. It can be easily transported. It is very easy to operate and the maintenance cost is low. The cost of operation is negligible as there is no fuel requirement.

Direct Drying in Kilns The simplest direct heating system is the smoke drying. Here coconut husks and shells are fired in shallow pits over which a grill of wooden platform is erected on which the coconut cups are arranged in layers for drying. Firing is done either continuously or intermittently. Due to the uneven heat and heavy smoke, copra produced is of low quality and brownish with a smoky smell. The copra cake after extraction of oil is also not of good quality for use as animal feed.

In Kerala, India, kiln drying is combined with sun drying as it makes it less susceptible to mould infection. In the more common kilns, brick or mud walls are provided with tiled or thatched roof. In the Philippines, smoke dryers are called *tapahans* with a capacity of 400–4000 nuts batch^{-1}. Some of them are very large requiring larger area.

Improvements have been introduced in kiln drying in many countries in order to minimise the emission of smoke while drying. In the improved kilns, coconut shell is the commonly used fuel. With controlled burning of the fuel and adequate ventilation systems, excessive emission of smoke is avoided, and better quality of the final product is ensured. These kilns consist of a cabinet containing a rectangular grill 2–2.5 m above ground level. The bottom space is enclosed, where the firepit is made in serrated brick hearths. The kiln is roofed mostly of corrugated iron sheet and the roof is extended over a verandah. The four sides of the kiln are covered with brick walls.

The split coconuts to be dried are kept on the grill, with the kernel portion of the bottom layer facing upwards. The upper layers are arranged downwards up to a thickness of 30 cm. Coconut shells of even size are interlocked and laid loosely in single or double rows in the firepit. In order to avoid excessive emission of smoke, some shells are ignited outside the kiln and brought in while they are burning. The fire moves slowly burning the arranged shells without smoke. Six to eight firings are required with a drying time of 3–4 days. The drying temperature should not exceed 70 °C in the initial hours, and subsequent drying should be completed at 60 °C (Thampan 1987). Mostly the deshelling is done after two to four firings.

Various types of smokeless kilns are in current use. Cooke-type kilns are used in Malaysia and Sri Lanka. Here the hot air stream is more uniformly spread out from the firing tunnel outlet so that a traveling cone of heat is created below the drying platform. Varghese and Thomas (1952) modified and adopted the Malaysian kilns to suit Indian conditions. The drying chamber is made of red earth with bamboo grills which are loaded with coconut halves. These are placed one over the other on the drying platform. A perforated iron sheet hung 0.5 m below the grill platform serves as heat spreader. The drying time is 34 h at a temperature of 53–60 °C. The IST-NA Coco dryer developed by the NIST Philippines has a capacity of 1500–2000 nuts. In these large capacity dryers, fuel used is mostly charcoal or diesel oil.

Drying by Indirect Heat Here, the products of combustion do not come into contact with the coconut kernel, and as such high-quality smoke-free white copra can be produced. The hot combusted gases and the flame produced heat the clean air coming inside the dryer, through a heat exchanger, usually a metallic drum, without mixing with the clean air.

Indirect heating dryers are of two types based on the method of hot air circulation: (i) natural draft type and (ii) forced circulation type.

Natural Draft Dryer In these dryers, any type of fuel can be used, including the dry agricultural waste materials like coconut husk, shells, fronds, dry firewood, etc., available in the plantations. Copra is smoke-free with minimum deterioration during storage. But the higher consumption of fuel and higher cost of installation are the limitations.

These dryers essentially consist of a kiln and a heating unit. The kiln may be of a single compartment or several compartments, either vertical or laterally placed adjacent to a closed combustion system designed to obtain the maximum heat. The combustion unit consists of a furnace or firebox usually made of fire bricks from which flue pipes of suitable dimensions pass beneath the kiln along its full length and are connected with a damper chimney at the end opposite to the furnace. The flue pipes are inclined vertically up to 5° for easy flow of flue gases. In certain dryers, thermal efficiency is improved by providing additional furnace with damper controls. Sufficient inlets for the entry of cold air are provided on the walls below the level of flue pipes. The gases of burning fuel in the furnace pass through the flue pipes and heat the air around them. The hot air so produced moves into the kiln where the split nuts or copra are arranged. As the hot air passes through the layers of split nuts or copra, it removes the moisture, and the moisture-laden air is exhausted out by damper ventilators at the top of the kiln. For efficient drying, the drying bed thickness is not allowed to exceed 30–40 cm. Here the copra does not come into contact with smoke but only with the uncontaminated hot air because the flue pipes are connected to a chimney for the smoke to escape outside.

Simple smoke-free collapsible copra dryer has been developed to suit medium-sized plantation crop holdings and processing units (Vidhan Singh et al. 1999). The dryer is designed to hold 1000–1500 coconuts depending on the size of the nuts. The total drying time is 24 h. The dryer consists of a drying chamber, a unique burner, a heat exchanger and ventilation holes. This dryer was fabricated using locally available materials such as asbestos cement sheet, galvanised iron (GI) sheet, mild steel (MS) angle and fire-resistant plywood. Asbestos cement sheet has been provided only where the copra does not come into direct contact. The contact area (sides) with copra is provided with heat-resistant plywood. The shape of the heat exchanger is designed to avoid the flame coming into contact with the copra. The burner has thick fireclay lining. Broken shell pieces are used as fuel.

The use of indirect dryers has been promoted recently in India for making quality copra. Different models of low-cost indirect dryers have been designed and developed to suit small- and medium-sized coconut holdings (1 ha). These dryers have indirect heating and natural air convection arrangements.

The dryer uses low-cost agricultural waste as fuel. The dryer is comprised of (a) drying chamber, (b) plenum chamber, (c) burning cum heat exchanging unit and (d) chimney with regulators. The drying chamber is the upper portion of the dryer. It is made of asbestos cement sheets on sides and wire-mesh tray at the base supported on MS angle frame. The chamber just below the drying area is the plenum chamber. It is made of asbestos cement sheets supported on MS angle frame. An adjustable opening is provided at the bottom to facilitate entry of fresh air into the chamber. The burning cum heat exchanging unit is a 30-cm-diameter cylinder made of 22-gauge corrugated GI sheet. It is located in the centre of the plenum chamber at an inclination of 3° angle towards the exhaust side where it is connected to a chimney. The other end of the cylinder is covered by a damper with holes for entry of air for combustion. The fuel is burnt in a wire-mesh tray inside this cylinder. The outer surface of the cylinder at the points of contact on the plenum chamber sides is sealed with plaster of Paris. The chimney has a diameter of 10 cm and is made of GI sheet. Two butterfly valves are provided to the chimney, which regulate the escape of flue gases as well as the entry of air into the burning unit for combustion. By adjusting the valves, the drying air temperature is also controlled. The chimney is partially covered by asbestos rope cemented with plaster of Paris.

The small holder's dryer has a capacity to dry 400 coconuts (Patil 1984b). The fuel requirement is about 28 kg of coconut husk and shell. The fuel is fed as and when required to keep the fire burning. The drying air temperature is maintained at 60°–70 °C by adjusting the valves in the chimney. After 10–15 h of drying, the partially dried copra could be scooped out from the shell. The copra cups are to be raked every 2 h for uniform drying. The total drying period is over 4 days with overnight breaks till the moisture content of copra is reduced to 6%. The actual drying time is about 36 h.

The medium holder's dryer for holdings of above 1 hectare introduced by the CPCRI has more or less the same design as that of the small holder's dryer (Annamalai et al. 1989). It is designed to dry 1000–1200 coconuts batch^{-1}. The overall dimensions of the dryer are 2.5 m (L) × 1.2 m (B) × 1.75 m (H), and it requires a housing shed of 7 m^2 area. The drying chamber has an area of 3 m^2 and volume of 1.2 m^3. Three doors on hinges are provided on one side of the chamber to facilitate easier loading and unloading of the produce. The volume of the plenum chamber which is just below the drying chamber is 2.25 m^3. At the bottom of the plenum chamber, a 15-cm-wide opening is provided on either side along the length with baffles on hinges for fresh air flow into the dryer. The burning cum heat exchanging unit is a 45-cm-diameter cylinder made of 22-gauge galvanised iron sheet. It is housed at the centre of the plenum chamber longitudinally at a vertical inclination of 4° angle towards the exhaust side where it is connected to a 15-cm-diameter chimney. The volume of the cylinder is 0.40 m^3 and the surface area is 3.5 m^2. GI sheet fins are provided on the upper half of the cylinder for better heat transfer. The lower end of the cylinder is fixed on plenum chamber wall with a damper having holes for entry of air for facilitating combustion of fuel. The fuel is burnt inside the cylinder in a MS flat tray of size 100 cm × 43 cm × 15 cm. Two butterfly valves are provided in the chimney to regulate the escape of gases and entry of air for combustion which in turn controls the rate of combustion of fuel and the drying air temperature. The ratio of dryer width and burning cylinder width is 3:1. The fuel requirement is 110 kg of coconut husk and shell. At a drying air temperature of 60–70 °C, the dispelling could be done after 10–16 h. After about 12 h of continuous drying overnight, tempering is given to facilitate diffusion of moisture from the inner side. The copra cups are to be raked every 2 h for uniform drying. The total drying period is over 3 days with overnight breaks till the moisture content of copra is reduced to 5–6%. The actual drying time is 33–37 h.

A low-cost dryer for larger holdings has also been introduced during 1987. The capacity of the dryer is 3000–4500 nuts batch^{-1} and the drying time is 34–36 h. The fuel requirement is 800–1000 coconut shells and husks. By controlled fuel feeding, the drying air temperature could be maintained at about 55 °C to 70 °C. The overall dimension of the dryer is 4.6 m × 3 m × 2.6 m (Madhavan and Bosco 1991).

Indirect Heating with Forced Hot Air Systems These dryers are more efficient with reduced drying time. But the installation cost is high compared to the natural draft dryers. Here the hot air is forced into the drying system by means of a blower driven by diesel engine or electric motor. Husks, shells, firewood, electric power or oil can be used as fuel. This dryer usually consists of a furnace and an array of flue pipes with chimney, a drying chamber and a blower. The fresh air is heated by the flue gases passing through the flue pipes serving as heat exchanger. This hot air is forced into the drying chamber by the blower.

Different types of forced hot air driers are developed which use either solid fuel or automated diesel. They are Chula hot air dryers (BDO and BDI model and oil fired), Lister reversible airflow dryer, Pearson's patent dryer, Comessa dryer of Comoro Islands, ASP dryer in New Guinea, electrical dryer of CPCRI and agricultural waste-fuelled dryer of TNAU, India. Of these, Pearson's patent dryer is installed in many estates in Sri Lanka.

Electrical Drying The electrical dryer developed at the ICAR-CPCRI has a capacity of 1000 nuts per batch with drying time of 2 days at 60 °C. The dryer has been improved by modifying the drying systems. It is a tray dryer with mixed flow and forced hot air circulation. The main components of the dryer are drying chamber, plenum chamber, heating unit and blower unit. Drying chamber is made of jack wood planks lined with GI sheet inside. The air distribution chamber located vertically at the centre is made of GI sheet with perforations on both sides. The drying chamber can accommodate 10 trays of 92 cm × 45 cm size and is made of welded wire mesh. The trays are kept on aluminium angle runners on both sides of the air distribution unit. The top of the drying chamber is open with an adjustable lid to serve as exhaust. The heating unit consists of heaters of 6 KW capacity each and a blower equipped with 0.5 hp., 1440 rpm electric motor (Madhavan et al. 1998).

The temperature of inlet air is kept at 60 °C for copra. The dryer is operated continuously for 12 h initially and is switched off. The trays are taken out and the shells are separated from the kernel. Then the trays with the kernel cups are reloaded into the dryer with cups facing up, and the dryer is switched on again. The drying is continued till the desired moisture level of 6% is attained. Total drying time is 32 h. This dryer could be a feasible proposition for cooperatives, medium growers and copra processors. The dryer can be used in rainy season also when sun drying is not possible. The quality of copra is good, white and mould-free. Dryer design is simple and can be fabricated locally. A semi-skilled person can operate it. Mixed-type airflow provides uniform drying of the produce and hence no need for mixing.

Solar cum electrical dryer with agricultural waste as third source of energy has been designed for the capacity of 3000–3500 coconut batch^{-1}. It consists of a double-pass solar collector, fan, electric heaters and trolleys with trays to carry the drying materials. Electric heaters are provided before the fan so that hot air from the heater can also be drawn by it. The double-pass solar collector is of semicircular shape of 1.5 metre radius, and the drying chamber is the space below the collector where coconuts are kept in trays. The transparent cover of the collector is made of LDPE film of 200 micron size, and the absorber is black LDPE film of 250 micron size. The casing is provided with black-painted GI sheet of 26-gauge thickness. Hot air from the collector is sucked by the blower which is also fixed inside the drying chamber. Electronic control circuits are designed to switch on the heaters only when the temperature of the drying chamber is less than 50 °C. When the temperature of the drying chamber is higher than 70 °C, the electric heaters and the blower will be switched off. These temperature limits can be varied as per requirement.

13.12.5.3 Quality of Copra

The quality of milling copra ultimately determines the quality of the oil and the residual cake. The quality of copra is influenced by (i) moisture content, (ii) colour and cleanliness, (iii) microbial load, (iv) rubberiness, (v) case hardening and (vi) charring.

Moisture is the most important factor influencing the quality of copra. Copra with a moisture content of less than 6% is considered as good quality since it is not easily damaged by insects, moulds or microorganisms. An electronic moisture metre to determine the moisture content of copra was developed (Madhavan 1987), based on the electrical conductivity of the kernel. The instrument can read moisture content from 5% to 40%. It is very handy, and the accuracy is more than 94% in the lower levels of moisture content readings. Please see Sect. 13.4.5 for details.

Nuts from dwarf variety palms, unripe nuts as well as those from sulphur-deficient palms yield rubbery copra. This copra undergoes rapid deterioration, and good copra also becomes susceptible to microbial infestation when mixed with rubbery copra (Southern 1957).

Case hardening of copra is seen when nuts are dried in kilns and hot air dryers with no temperature control. If the initial drying temperature is too high, case hardening can occur, preventing the moisture from the interior of the meat from diffusing rapidly to the outside layers. Case-hardened copra develops a hard smooth surface covering a wet core. While drying copra, the temperature should not exceed 70 °C in the early stages and 60 °C subsequently, which will otherwise result in charring. The oil from charred copra will be turbid with a burnt odour.

Bio Deterioration of Copra Defective methods of processing and high moisture content of copra are the major factors responsible for copra deterioration. Coconut kernel is a favourable substrate for the growth of microorganisms. If drying is done under open conditions, copra spoilage due to fungal infection is very common. Usually bacterial action starts during the initial stages of drying, and later mould infection occurs. A gap of more than 4 h between splitting and drying facilitates the activities of bacteria. With relative humidity of 80% at temperatures above 30 °C, bacteria multiply rapidly, and within 4 h, a surface slime begins to develop on the wet kernel. The slime continues to develop, and it becomes more pronounced during the first and second days of drying. The bacteria are active at moisture levels above 20%. As a result of the bacterial growth, the copra loses white colour, turns red and becomes slimy. *Serratia marcescens*, *Staphylococcus aureus* and *Bacillus* sp. are the common bacteria, which cause discolouration, sliminess and softening of the copra (Rethinam and Bosco 2006).

The penetrating moulds make their appearance after the bacterial growth. *Rhizopus* sp. or the white mould thrives on wet meat and destroys a very high percentage of oil, and the oil from the infected kernel has a high percentage of free fatty acid. *Aspergillus niger* group or black mould has a lower moisture requirement. This mould causes considerable loss of oil up to 40%. The *Aspergillus flavus* group or brown mould is the most serious of all moulds. It flourishes at 8–12% of moisture, and the oil loss in this case also may be more than 40%. It causes maximum colour change and rancidity in the oil. The *Penicillium glaucum* group or the green mould is commonly found on copra and grows well on the copra with moisture content of 6%. This fungus does not penetrate deeper and causes only minimum reduction in oil content. In addition to these, only two other fungi, *Mucor hiemalis* and *Aspergillus tamarii* (yellow mould), are often found on copra causing considerable loss. Pure coconut oil is not a suitable medium for the growth of microorganisms. Moulds produce free fatty acid in the copra, and bacteria cause decomposition of albumin in the moist copra. Oil prepared from such spoiled copra becomes rancid quickly with bad taste and odour.

Fungi also cause deterioration of copra followed by bacteria *P. frequentans*,which is found to cause spoilage even at a moisture content of 4% (Nair and Sreemulanathan 1970). Rao et al. (1971) observed the presence of *Botryodiplodia theobromae* during the blackening of coconut kernel. Paul (1969) and Susamma and Menon (1981) isolated a number of fungi and bacteria from deteriorated copra. The fungi isolated were *R. stolonifer*, *R. oryzae*, *Mucor hiemalis*, *P. citrinum*, *Curvularia senegalensis*, *Cochliobolus lunatus*, *Paecilomyces lilanicus*, *Aspergillus oryzae* and *Aspergillus fumigatus*. Bacteria causing spoilage were identified as *R. subtilis*, *E. aerogenes*, *Pseudomonas fluorescens* and *Sarcina lutea*. The chemical change in the amino acid content due to fungal infection was also investigated (Sierra 1971; Susamma et al. 1981). Pests can also cause serious damage to stored copra. For details please see Chap. 12.

Storage of Copra The general observation is that the copra on storage is affected by excessive mould growth when the relative humidity is greater than 85% at room temperature or greater than 95% at 40 °C. In many of the establishments, it is a usual practice to dry copra under the sun for one or two days before bagging and storing. Painting of upper surface of the roof of the storage structure with white reflective paint has been reported to reduce temperature fluctuations within 10 °C thus preventing serious condensation effect. The walls also should be shaded from direct sunlight and should be provided with sufficient number of adjustable ventilators.

Sulphuring the copra is effective for storing for longer periods during rainy season. Fumigation of copra with methyl bromide at the rate of 3 kg 100 m^{-3} for 48 h with a gas-proof sheet is recommended when copra is stored in godowns. Fumigation with sulphur dioxide or lindane smoke or pyrethrum and piperonyl butoxide as a fog is also resorted to. Fumigation with a mixture of carbon dioxide and ethylene oxide (99:1) is effective against insect pests of copra. A chemical treatment of dipping fresh kernel in 1000 ppm propionic acid for 60 min to preserve it up to 49 days without further drying had been developed (Patil 1982).

Table 13.19 Standard specifications for copra

SI. No.	Characteristics	Grade 1	Grade 2	Grade 3
1.	Moisture content (per cent by weight, maximum)	6	6	6
2.	Oil content (on moisture-free basis) (per cent by weight, minimum)	70	68	66
3.	Free fatty acid (per cent as lauric, per cent by weight, maximum)	1	3	6
4.	Aflatoxin content (in parts per million, maximum)	20	20	20
5.	Impurities (per cent weight)	0.5	1	2
6.	Immature kernels (wrinkled) (per cent maximum)	Nil	5	10
7.	Mouldy cups (per cent by count, maximum)	Nil	4	8

Source: NIIR Board of Consultants and Engineers (2012)

Use of proper packing materials is also an important factor. Polythene/alkathene-lined gunny bags or netted polythene bags can be used for safe storage of copra even during the rainy season (Nalinakumari 1989). Multiwalled paper bags could keep copra free from insects up to 3 months, and those treated with pyrethrin could be kept up to 9 months. Studies at ICAR-CPCRI, during 1989, have indicated that copra stored in tin containers and polythene bags and fumigated with biogas, neem leaf gas, carbon dioxide and sulphur dioxide are effective in controlling microbial infestation during storage. Copra could be stored for more than 6 months by exposing it either to biogas for 1–3 days or to neem leaf gas for 15 days immediately after splitting prior to storage in any air-tight container.

Grades of Copra In all the coconut-growing countries, there are recognised grades of copra which form the basis of the trade transactions. Though each producing country has standards for grading, there is no common and uniform international standard for copra. Standard contract terms for milling copra are in force in India since 1949. In Sri Lanka, three grades of copra are defined based on moisture content, oil content and FFA level of pressed oil. In the Philippines, four classes and seven grades of copra are available based on type of moisture content and drying system used. In Western Samoa, grading is done based on the method of drying adopted.

Grade specifications for milling copra as suggested by the Asian and Pacific Coconut Community for adoption by member countries are shown in Table 13.19.

13.13 Non-food Products

Among the non-food products of coconut, coconut fibre, coconut pith and coconut shell assume commercial importance. Other parts of the palm especially coconut wood and leaves are also gaining attention.

13.13.1 Coconut Husk

The husk usually forms 35–45% of the weight of the whole nut when ripe. About 30% of the husk is fibre and 70% is coir dust. At present, only 35% of the total husk available is utilised by the industry, while there is scope for economically utilising at least 50% of the husk produced. When the nuts mature, the quantity of the fibre in the husk does not decrease, but it is the moisture in the fibrous mass of the husk which disappears. Thickness of the husk of an ordinary nut varies from 2.5 to 3.0 cm in the case of thin husked nuts and 4.0–5.0 cm for thick husked ones. The products of importance derived from coconut husk are coir fibre and coir pith.

13.13.1.1 Coir Fibre

There are two distinct varieties of coir, namely, white fibre and brown fibre. The white fibre is extracted from retted coconut husk and is used for making traditional coir products like mats, mattings, rugs and carpets. Brown fibre is extracted from unretted husk. It is mainly used for the manufacture of curled coir, which is used in the rubberised coir mattresses, sofa cushion, bolsters, pillows, carpet underlay, etc. In India, white fibre production has dominance, whereas in other countries, the production is confined to brown fibre. India and Sri Lanka contribute about 65% and 32%, respectively, of world coir fibre production.

Structure and Properties of Coir Fibre The chemical constituents of pure coir are cellulose (32–43%), lignin (40–45%), hemicellulose (0.15–0.25%) and pectin which makes it more extensible compared to other natural fibres. The fibre is weather-resistant and also resistant to fungal and bacterial decomposition which are attributed to the high lignin content. Lignin is the main constituent responsible for the stiffness of the coir and also partly responsible for the natural colour of the fibre. Generally, mature nuts have higher lignin and cellulose than tender nuts.

Fibre is polygonal to round in section. It is a multicellular fibre with a central pore called lacuna. The larger fibres have a length of up to 35 cm and can be 0.3–1.0 mm in diameter, being thickest in the middle. X-ray studies have indicated a spiral orientation of 45° to the fibrils (Bhowmick and Debnath 1984). There are three types of fibres, namely, mat fibre, bristle fibre and mattress fibre. Mat fibres are generally used for making yarn out of which ropes and floor coverings are made. Brushes, brooms, bags, net and twines are made from bristle fibre. Mattress fibre is mainly used for stuffing mattresses, pillows and cushions.

The white fibre or mat fibre is extracted from unripe husks by bacteriological process of retting, while the brown fibre is extracted from ripe dry husks by the mechanical defibering process. Husks from 10- to 11-months old nuts have been found to give superior-quality white fibre. Among the different states in India, white fibre production is concentrated in Kerala, whereas in other states such as Tamil Nadu, Karnataka and Odisha, the production is confined to brown fibre.

Extraction of fibre – Natural Retting Retting involves soaking the husk in water, preferably saline water, until the fibre becomes loose and soft. Water flows in and out of the soaking sites with the rise and fall of the tide. The efficiency of retting depends on many parameters like temperature, water quality, rate of removal of the foul water and stresses that husks are subjected to during the retting process.

Retting process essentially consists of a microbiological degradation of the pectic substances which hold the fibres together prior to soaking. The husk becomes soft, and a number of substances like carbohydrates, glucosides, tannins and nitrogen compounds are acted upon by a great variety of microorganisms which produce various organic acids and gas. When the fermentation progresses, the temperature of the husk increases, and water becomes turbid due to gas formation and frothing. At this stage, pectin in the middle lamella of the husk slowly dissolves. Subsequently the rate of fermentation slows down, and water becomes clear when the husk is ready for removal. The process is quicker during summer since heat is necessary for fermentation. The average retting period is 8–9 months in saline water and 4–5 months in freshwater. Saline water is preferred since the salts prevent over-fermentation and discolouration of the fibre. But investigations of Jayasankar (1966) and Bhat and Nampoothiri (1973) have indicated that under controlled conditions, salinity has no influence on the microflora and its activity.

It has been found that soaking of crushed husk reduces the retting period (Nagarajan et al. 1987). Crushing can be done by simple crushing rollers, similar to sugarcane crushers. Similarly, if the husks soaked for 1 month are removed, crushed and put back again, the retting period can be reduced to 3 months.

Mechanical and Chemical Methods of Retting Mechanical methods of retting are employed in areas where facilities for natural retting do not exist. Either dry or green husks are soaked in cement tanks or in specially dug pits for a period varying from a few hours to 6 weeks, and the fibre is extracted manually or mechanically. In medium to major coir units, cement tanks each measuring 8 m × 2.7 m × 1.8 m are built-in series with facilities for frequent change of water. In some units, the husk is first crushed in crushers and put in retting tanks where they undergo fermentation for a minimum period of 72 h. These processes however do not yield fibre of spinnable quality, but yield only bristle and mattress fibres.

Various chemical methods also have been developed for retting of husk. The advantages claimed are a higher yield of uniform-quality fibre and a considerable saving of time. But the economics of chemical retting compared to the natural process has not been fully investigated for commercial exploitation. In the Nanji process, the green or dry husks are partially crushed and treated under steam pressure of 5.6–7.0 kg cm^{-2} with sodium sulphate or sodium carbonate containing a trace of aluminium sulphate for 1–2 h. During this process, the pith is loosened from the fibre and removed by washing. The fibre obtained is of good quality, but slightly darker than that of natural retting. In the Elod and Thomas process, crushed husk is immersed in hot water twice. Slaked lime is added during the second immersion to avoid discolouration. Subsequently, the fibre is extracted mechanically. In the

Rowell process, crushed husk is subjected to a high steam pressure, and the fibres come out loose from the steaming chambers. In the Vander Jagt process, husks are first split into pieces. The pieces are boiled with a week solution of caustic soda and squeezed. The compressed fibres are reopened, softened and cleaned. Good-quality fibre is obtained within 2 h by this process. In the Hayes Gratze process, the husk is first split into sections by special cutting machines. The split pieces are then immersed in water, pressed or rolled and boiled in a solution of water and ionised oil of pH 17 maintained at 93 °C. Coconut oil is sometimes used for the preparation of ionised oil. Carren (1966) developed another method where the husk is fermented for 4 days at 37 °C with the aid of *Aspergillus* sp. previously isolated from partially retted husk. This process is reported to have given 37% fibre output.

Experiments carried out to improve the retting process reveal that inoculation of ret. microflora mass multiplied in the laboratory, collected from areas known for poor retting, leads to bettering the colour of the fibre, besides reducing the period of retting (Nagarajan et al. 1987). Coir fibre can also be extracted by decortication of dry husks. However, there is a need for developing a process requiring lesser retting period and yielding fibre of uniform quality irrespective of the seasonal and environmental variations.

Extraction of White Fibre After natural retting, the husk is taken out of water, washed and the outer skin is peeled off. The husk is then placed on wooden blocks and beaten with a wooden mallet to separate the fibre from the pith. It is then cleaned and spread in shade for drying. Occasionally, the fibre spread is beaten and tossed up for further cleaning and also for thorough mixing of long and short fibres. For making superior type of fibre especially for spinning, the fibre is combed in a specially designed combing or willowing machine, which consists of a number of knives with saw like teeth mounted on a wooden shaft set spirally and which is rotated by hand within a drum. The fibre from the retted husk is also extracted mechanically. The beaten husk is torn on rolling cylinders with nails on the cylinder casting. The raw coir fibre thus obtained is further cleaned by means of blowing fans. The machine helps to soften and remove the last traces of pith on the fibre, and the processed fibre is clean and more or less parallel. The fibres are then rolled into slivers which are used for spinning.

Extraction of Brown Fibre The extraction of fibre from the partially wet husk is carried out in specially constructed machines called drums. The drums are operated in pairs, and each pair consists of a breaker drum and a cleaner drum. The drum consists of an iron flywheel to the rim of which a number of wooden planks in two layers are fixed. A number of nails of about 6 cm long are fixed on the outer layer of the planks at intervals of about two with more than half the length of the nails projecting from the surface. For fibre extraction, the husk is held firmly between two rods fitted on the front side of the breaker drum so that one half of the husk is combed on the revolving drum. Then the second half is also combed similarly. In the breaker drum which is driven at a higher speed than the cleaner drum, the outer skins and some of the short fibres and pith are removed and get collected at the base of the drum. This is fed on to a sifter for separation of the fibre from the pith and dust. The fibres obtained are short and thin and are known as mattress fibre.

During the combing process, the longer fibres or bristle remain in the hands of the operator. The partially combed-out husk segments containing the bristle fibre are combed a second time by another operator in the cleaner drum for removing the remaining pith and smaller fibre. The long stiff fibres which remain with the cleaner or dresser drum operator are subsequently washed, dried and combed again for the final removal of the short fibres. The long fibres obtained after the final combing are called bristle fibres. In another method, mattress fibre is obtained from unrett husks using a husk bursting machine. The fibre so obtained is considered more suitable for the manufacture of rubberised coir.

The yield of fibre is subject to considerable variation depending upon the season, method of extraction and the quality of fibre produced. Yield from rett husk is more than that from unrett husk. The yield is less during monsoon as compared to summer season. Taking all these into consideration, it is estimated that the average yield of fibre from an average-sized fully mature nut weighing 1.1 kg is 80 gm of white fibre (George and Joshi 1961). In Sri Lanka, 1000 full husks yield an average of about 50 kg of bristle fibre and 100 kg of mattress fibre.

Varieties of Fibre and Grades The fibres are used for spinning into yarn for manufacturing mats and mattings, ropes, twines, etc. The bristle fibre which is long and stiff is preferred for brushes and brooms. The bulk of the fibre produced in India is mat fibre which is used for spinning into yarn and for manufacturing mats and mattings, ropes, twines, etc. The mattress fibre which is short and thin is generally used in mattresses, upholstery, cushions, etc. The bristle fibre which is long and stiff 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 are recognised in India on the basis of the specifications drawn up by the Indian Standards Institution for coir fibre (Table 13.20).

Spinning of Coir Yarn The spinning of coir yarn is a traditional cottage industry in India, which is concentrated in backwater areas where natural retting is in vogue. Hand spinning, wheel spinning and machine spinning are the common methods adopted for this purpose.

In hand spinning, the fibre is rolled between the palms with a clockwise twist into strands of short length. When sufficient quantity is made, the strands are taken in pairs and twisted together in the opposite direction to form a two-ply yarn. The yarn is then held in position by the toes, and individual pieces of yarn are joined together one after another by continuing the counter twist using both the palms till the required length for a knot (6–18 m) is reached. The yarn is then reeled in the form of a hank and a knot made at the end. One worker is estimated to make about 2–2.5 kg of yarn day^{-1}.

In wheel spinning, two wheels are used. One wheel with two spindles is fitted to a stationary stand, and the other one with one spindle is mounted on wheels which

Table 13.20 Characteristics of coir fibre of various grades

Grade	Maximum impurities (%)	Length of fibre, proportion of long, medium and short fibres	Colour and utility
1	2.0	At least 70% by weight 'long' and the remaining 'medium' and/or 'short'	Making superior-quality double warp fancy fibre mats
2	3.0	At least 50% by weight 'long' and the remaining 'medium' and/or 'short'	Constitutes fibre of white lustrous colour
3	5.0	At least 80% by weight 'medium' and the remaining 'long' and/or 'short'	Slightly reddish or greyish coir containing little pith
4	7.0	At least 20% by weight 'medium' and/or 'long' and the remaining 'short'	Dark in colour containing more pith, used for making cheaper yarn known as beach yarn

Source: NIIR Board of Consultants and Engineers (2012)

can be moved forwards and backwards. In the actual working, one can rotate the wheel on the stationery stand by moving a handle fixed to its axis. Two persons make the strands by hooking short length of fibre strands onto the spindles of the stationary wheel and walking back deliver the fibre continuously to form strands of uniform thickness. The stationary wheel is made to rotate continuously to give the necessary twist to the strand. When they complete a length of about 15–18 m of strand each, the rotation of the stationary wheel is stopped. The two ends of the single strands are then joined together and hooked to the spindle of the movable wheel. One of the workers now takes charge of this movable wheel and rotates it to give the two-strand yarn a twist in a direction opposite to that of the single strands. The other worker now moves forwards towards the stationary wheel with a yarn guide in hand, which is a triangular block of wood, grooved on the sides. It regulates the counter twist, prevents knots and kinks and binds the strands very close. The spun yarn in lengths of 12–15 m is reeled into hanks. About 100 strands of 15 m length each and weighing about 15 kg can be produced day^{-1}.

Hand spun yarn is soft and has uniformity of twist and thickness. But the method is nowadays becoming more or less obsolete. Wheel spinning is the popular method of yarn spinning, but with some inherent defects. It requires long open yard and process is interrupted during monsoon. Mechanical spinning has been introduced to obviate these defects, but the output is very limited.

Coir yarn is graded according to colour, Scorage, moisture content and presence of sand, salt, etc. Bright golden-coloured yarns are considered to be the best, while the lower grades are comparatively dull and dark in colour. Scorage is another important factor in the classification of yarns. It represents one-20th the number of strands of yarns which could be held close to each other without overlapping in a span of 0.9 m.

Utilisation of Coir fibre and Yarn Coconut fibre is used in the preparation of hard-boards, fibre boards and building boards. The hardboards prepared from coconut fibre by the Asplund process have outstanding flexibility. Fibre boards can be made from the husk of immature coconut by pressing them at 160 °C for 20 min. They are suitable for roofing, panelling and replacing plywood in tea chests. George and Joshi (1961) made hardboards and insulating boards from dry husk of mature coconuts after softening them with dilute sodium hydroxide solution and also from coir shearing waste softened with slaked lime solution. Building board was also developed by mixing the husk material with water and subjecting to elevated temperature and pressure (Totheringhan 1982). Semana et al. (1988) prepared standard-type hardboard by blending of coconut coir pulp and petiole pulp (50:50).

The coir yarn finds various domestic uses. For commercial purposes, the yarn is used for making ropes, mats, mattings, nets, bags, etc. Coir fibre of inferior quality and the mattress fibre are used for stuffing mattresses, cushions, upholstery, etc. The bristle fibre goes in the manufacture of brushes and brooms. The mattress fibre, decorticated fibre and bristle fibre and their mixtures are twisted into ropes to produce curled fibre which is used in the manufacture of rubberised coir. Coir and coir products have also been found useful in soil erosion control, road construction and as reinforcement in cement matrix.

Coir Fabrics for Groundwater Recharge Compared to other natural fibres,coir fibres degrade very slowly, and hence coir woven fabrics with loop construction retain moisture in the soil which can be used in water harvesting. Besides this, when the degradation of lignin starts, the acidic phenolic leaches may decompose even hard laterites and make the soil porous and help in downward seepage of water. It has been the experience of the farmers to condition the hard soil by stacking coconut husk in pits in the palm basins. This improves groundwater level in hard lateritic terrain. Infiltration trenches at suitable locations with bore holes at the bottom to a significant depth (i.e. rocky bed or water table) can be made. These bore holes can be lined with reinforced and treated coir felt, and metal chips can be loosely filled inside the trenches and bore holes. The top of the trenches can be covered with coir net with loop structure and fixed to a bamboo frame. This arrangement will ensure the collection of surface rainwater and encourage percolation enriching the collector wells, besides raising the groundwater level.

Coir Geotextiles Coir netting is an ideal material for prevention of soil erosion. Coir geo-fabrics are woven coir nettings or mesh mattings. They are inexpensive, ready-to-use and effective items for a variety of applications including control of soil erosion, control of landslides, slope stabilisation, seepage of water through canals and in other civil engineering applications like road embankments, etc. In these applications, coir is used because it is a natural hard fibre with high tensile strength, durability and moisture resistance.

Coir-Cement Composite Panel Reinforced composite panels are made using coir fibre of 50–350 mm long and 0.10–0.40 mm diameter. The fibres soaked in water initially for 1–2 h are thoroughly mixed with predetermined quantity of Portland cement and chemical admixture. The coated fibres are uniformly spread on a mould and pressed for 6–8 h to the required thickness. The pressed panel is moist cured for 10 days and dried under natural conditions for 4–6 days and trimmed to required size.

Husk Particle Boards Husk of mature coconut is a unique raw material to prepare particle boards, in view of the fact that wooden particle boards use 8–10% adhesives on weight basis, while coconut husk boards require only 0.25% adhesives. However, care has to be taken to see that the ingredients in pith are allowed to separate out from the fibre, while the chips should be of free-flowing nature. It should not interlock into bundles during handling and storage.

13.13.1.2 Coir Pith and its Uses

Coir pith constitutes as much as 70% of the husk and is now a waste product of the coir industry. Accumulation of this waste in industrial yards causes environmental pollution and fire hazard. Pith generally mixed with short fibres contains lignin, cellulose and hemicellulose as major constituents. Coir pith is open cell foam. The cells are of almost uniform size and cylindrical in shape. The walls are very thin and empty cavities (lumen) are comparatively large. Average lumen size of the pith is 50 mm. The maximum water holding capacity is 624%. The composition of coir pith is given in Table 13.21.

The main uses of coir pith are briefed below.

Manure Various studies have shown the advantages of application of coir dust to improve soil property and increase yield (Loganathan and Lakshminarasimhan 1979; Ramaswamy and Kothandaraman 1985; Clarson 1986). The continuous

Table 13.21 Composition of coir pith in percentage

	Fine coir dust	Coarse coir dust	Husk
Moisture	15.77	20.39	–
Organic matter	86.87	96.43	96.5
Ash	13.13	3.57	3.5
Organic matter			
Nitrogen	1.00	0.39	0.29
Potash	0.39	0.33	0.31
Lignin	37.71	43.65	45.45
Pentosan	11.95	13.10	19.15
Ratio of pentosan to lignin	0.32	0.30	0.42
Ash			
Sand	9.29	0.87	0.36
P_2O_5	0.07	0.06	0.08
Lime	0.79	0.87	0.94

Source: NIIR Board of Consultants and Engineers (2012) application of coir dust influences reduction in bulk density and improves the water holding capacity and organic carbon status of soil. Coir pith absorbs over eight times its weight of water and parts with it slowly. It has been found that by incorporation of 2% by weight of coir dust with sandy soil, the water holding capacity of the latter is increased by 40%. It is an excellent organic mulch in all kinds of soils. Nagarajan et al. (1987) found that coir pith after inoculation with *Pleurotus sajor-caju* and treatment with urea showed a definite reduction in the cellulose and lignin contents on incubation for 26 days at room temperature. The total nitrogen and other nutrients increased, while the C:N ratio was narrowed from 112:1–24:1. The values of N, P_2O_5 and K (percentage) in cattle manure are 9.86, 4.82 and 1.81, respectively, whereas they are 4.42, 0.71 and 1.02 in coir dust.

The lignocellulosic components of coir pith can be acted upon by lignocellulolytic fungi (Uyenco and Ochoa 1984), converting it into a biomass product which can be used as an animal feed or fertiliser.

Composting of coir pith has the advantages of detoxifying phenolic compounds, which are deleterious to microbial growth, reducing the bulk of the material and converting plant nutrients to a form more readily available to plants. A technology has been developed by Tamil Nadu Agricultural University, India, to detoxify phenolics of coir pith and produce bio-polymerising enzymes using basidiomycetous fungus, *Pleurotus sajor-caju*. To compost 1 tonne of coir pith, five spawn bottles (one spawn bottle contains 350 g of *Pleurotus* fungus culture raised on sorghum or pearl millet grain) and 5 kg of urea are required. After 30 days of decomposition, coir pith turns into a black mass of compost with reduced lignin, cellulose, organic carbon and C:N ratio. The volume of the material is also reduced by 50% (Rethinam and Bosco 2006).

As a Source of Furfural, Oxalic Acid and Gypsum Coir dust contains pentosans which are the only source in the world for furfural production, involving a two-stage process (Thiagarajan 1987). About 90–95% of the weight can be eliminated at the original site of accumulation. The residue after the extraction of furfural can be used for the manufacture of oxalic acid by heating with caustic alkalis to a temperature of about 240 °C. Crude sodium oxalate is formed which can be converted to calcium oxalate by lime, regenerating the caustic alkalis for reuse. The calcium oxalate can be decomposed with waste sulphuric acid to produce oxalic acid and gypsum. Gypsum can be used as a fertiliser.

Aslam Ali and Bhaskar (1980) reported that when pith is treated with concentrated nitric acid containing vanadium pentoxide (0.05% by weight of the pith) and heated for 6 h at 80 °C, it gives oxalic acid crystals after filtration and evaporation. The recovery on weight basis is 31–33%. The nitrogen fumes can be recovered and the nitric acid can be reapplied. The oxalic acid finds varied uses as mordant in dyeing and cloth printing, as a bleaching agent, anodizer, in detergents and in metal polishes.

Biogas Production A mechanical mixer has been developed for proper mixing of coir pith and cow dung. The output is connected to biogas plant through a 2 inch pipe for direct delivery of mixture to the plant. Cow dung and coir pith are put in the required ratio on volume basis, and water is added in the ratio of 1:1 (cow dung + coir pith/water). For optimum biogas production, the C:N ratio should be in the range of 25–30, and in the case of 80% cow dung and 20% coir pith, the C:N ratio was 26.18, and the production of gas was high and was on par with 100% cow dung.

When temperature is more than 33 °C, the production of gas is constant, whereas gas production is low when the temperature falls below 30 °C. When a modified dual fuel engine was run with biogas, it was observed that in 8 h of operation, approximately 10 m^3 biogas is consumed, thereby saving 5 litres of diesel. But due to continuous operation of the engine with dual fuel, the rings and piston head were damaged indicating the presence of sulphur in the gas. So the maintenance cost is higher as compared to running the engine on diesel.

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. It is estimated that an energy equivalent to two million tonnes of coconut waste is available in the Philippines.

As Fluidised Fuel Dried coconut pith could be blown with air to burn in suspension using a blower. A fluid furnace using pith has been developed. The furnace was evaluated using multiple injection points. As the outlet pipe provided was of lesser diameter, burning of coconut pith was difficult, and also smoke formation was more. The modified furnace was provided with holes of larger diameter at different points to study the effect of injection of pith with air using a blower. It was observed that injecting at about 0.80 m from the ground level was suitable to burn 75% of the pith in suspension and the balance is burnt at the bottom where a heap of shell is in burning condition. The air keeps the pith rotating in circular motion, and the large particles are thrown outwards by the centrifugal force and burnt near the walls, while the smaller particles are burnt in suspension in the air. The exhaust temperature was about 380 ° C. The temperature around the furnace is about 85 °C, which is used to the dry pith.

A 400-nut copra dryer has been developed which can be connected to the fluid furnace. The highest furnace efficiency obtained was 80% at the pith feed rate of 10 kg h^{-1} and air flow rate of 87.6 cum h^{-1}. The temperature of the flue gas varied from 80 °C to 350 °C at various pith feed rates. The pith and air were introduced at various angles, and it was observed that the best results are obtained when the pith was introduced tangentially. About 400 nuts can be dried from the initial moisture content of 48% to less than 5% in 36 h.

Particle Board Using Coir Pith A process for the production of particle board from coir pith has been optimised. The process includes the preparation of the coir pith, mixing with resin (phenol-formaldehyde and urea-formaldehyde), mat formation and hot pressing.

Densification Varadaraju and Gothandapani (1998) developed a pelletiser for making pellets from decomposed coir pith. The unit is operated by a 5 hp. electric motor and has a capacity of 100 kg h^{-1} for extruding the pellets of 6–8 mm diameter and 10–12 mm length at 25% moisture content. The coir pith pellet with optimum durability, compaction and expansion ratios of 0.82, 3.14 and 1.33, respectively, is obtained.

Briquetting A continuous extruder-type briquetting machine, consisting of screw shaft, barrel housing, extruder die pipe and gear box, has been developed by Devadas (1996) with a capacity of 125 kg h^{-1}. Briquettes produced from coir pith using cow dung or molasses as binder having a calorific value of 3000–3200 kcal h^{-1} were used as an alternative source of fuel. Tender coconut husk with tender shell can be crushed into powder form. It can be converted into fuel briquette after bringing the moisture content to about 15%.

Building Materials A technology for the production of coir-cement corrugated roofing sheet has been developed (Viswanathan 1998). It is observed that the temperature is lowered by 1–4 ° C in coir-cement corrugated roofing than that in asbestos. Lightweight bricks using coconut pith in the proportion of up to 80:20 (clay and pith) by weight are found successful (Dan 1992). Medium-density (0.9 g cc^{-1}) particle boards of size 25 cm × 25 cm, using coir pith with phenol-formaldehyde and urea-formaldehyde as binder, have also been produced. The strength characteristics of the boards are on par with other commercial boards (Viswanathan and Gothandapani 1998). However, the water absorption and swelling characteristics are high which are not desirable for use in exteriors.

Miscellaneous Products from Coir Pith Many commercial products such as hardboards, insulators, expansion joint filters, etc. can be prepared using coir pith. A process developed in the Philippines during 1962 could convert coconut pith into charcoal briquettes by a continuous process. The gas can be used as domestic fuel and tar and liquor condensates as wood preservatives, and charcoal can be in the production of many chemicals like calcium chloride, carbon disulphide, silicon carbide, etc.

Medium-density particle board using coir pith has been produced, and the strength characteristics have been determined (Viswanathan and Gothandapani 1998). This board, made of phenol-formaldehyde resin, meets the strength requirements of the Bureau of Indian Standards. Particle boards of size 250 mm × 250 mm x 12 mm thickness with density 0.9 g cc^{-1} were produced from the coir pith of uniform particle sizes 2.1, 1.2, 0.80 and 0.40 mm. Particle boards were produced from mixed size of coir pith either with or without fibre. Phenol-formaldehyde and urea-formaldehyde resins of liquid type with hardeners are used for the purpose. Polymers and composites can be prepared from pith by copolymerising 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 and easier to apply and gives much better thermal insulation at a cost equal to that of lime concrete. Coconut pith was successfully utilised in the production of a variety of lightweight high-strength bricks by the partial replacement of clay with pith. 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 accommodating thermal movements. The pith joint fillers have been found resistant to alternate heating and wetting as well as to freezing and thawing. They have also been found resistant to termite and fungi and superior in qualities to those of bituminised fibre boards (Rethinam and Bosco 2006).

Mushroom cultivation is an economically feasible and eco-friendly process for bioconversion of coir pith into high-quality protein food. Oyster mushrooms are the ideal ones for the coconut sector due to their ability to utilise lignin-rich pith and due to the climatic conditions prevailing in plantations which are ideal for its growth.

The steps in oyster mushroom cultivation include development of spawn, substrate preparation, spawning, incubation for spawn running and opening and maintenance of beds for cropping. Polyethylene bag method is commonly followed for spawning. The bags are punched to facilitate cross ventilation. Spawning is done by multilayered technique using 3% spawn. Coconut bunch waste such as leaf stalk, mixtures of leaf stalk + coir pith (1:1) and coir pith + bunch waste (1:1) are suitable substrates.

Vermiculture technology involves the use of earthworms as versatile bioreactors for effective recycling of non-toxic organic wastes to produce high-quality manure. The byproducts from coconut plantations are converted to vermicompost with a nutrient content of 1.8% nitrogen, 0.2% phosphorus and 0.2% potassium using a locally isolated earthworm species *Eudrilus eugeniae.*

13.14 Coconut Shell

Coconut shell, the endocarp of coconut, is another important commercial product. Its main use is as a fuel. To a lesser extent, it is used as a raw material for the manufacture of hookah shells, various domestic utensils, curios, fancy items, etc. The commercial utilisation of coconut shell for the production of shell charcoal, activated carbon, shell flour, etc. is gaining importance in the producing countries with an expanding market demand. The coconut shell contains moisture (6.76%), ash (1.32%), pentosan (10.01%), lignin (32.22%) and cellulose (50.99%) (Narayanamurthy and Singh 1954).

13.14.1 Major Shell Products

Shell charcoal, activated carbon and shell flour are the main commercial products obtained from the shell. Major portion of the shell is used as fuel, for the production of copra and for domestic purpose. Much of the coconut shell is scattered in small quantities in individual farms. Setting up a viable industry based on coconut shell is likely to succeed only where large quantities of shell are available at one point as in large plantations, desiccated coconut factory, centralised copra processing plant, etc. The shell charcoal is already in high demand in the world market.

13.14.1.1 Coconut Shell Charcoal

Shell charcoal is manufactured by burning shell obtained from fully mature nuts in a limited supply of air, sufficient only for carbonisation, but not for complete destruction. Charcoal output is just under 30% of the weight of the original shell, which depends much on the efficiency of processing. In Sri Lanka and the Philippines, 17,000–24,000 whole shells for 1 tonne of charcoal is the usual requirement. In Malaysia, four times the number of nuts giving 100 kg of copra is required to make 100 kg of charcoal. This works out to 18,000–20,000 whole shells for 1 tonne of charcoal. In India, the average output has been found to be 35 kg of charcoal from 1000 whole shells equivalent to 30,000 whole shells for 1 tonne of charcoal. The popular methods adopted for the production of shell charcoal in different countries are discussed briefly below:

Covered Pit Method In this method, the carbonisation takes place in a pit of 1.25 m diameter and 2 m depth. The pit is excavated in such a way that the bottom tapers down to a point. The fire is started at the bottom, and the shells are heaped as the fire spreads. Towards the end, a thin mild steel plate is placed on the heap, and as the shells settle down, the lid comes to rest on the edges of the pit. The edges of the lid are covered with earth and left for 4–5 days to complete the carbonisation and further cooling. Then the lid is removed and charcoal collected. The charcoal produced is of uniform quality and is free from soil contamination. The yield ranges from 28% to 32% of the original weight of the shells used.

Modified Pit Method The pit is lined with fire bricks or GI sheets. The shells are then put in a thin layer at the bottom and ignited with kerosene. More shells are heaped during ignition to completely cover the pit. The pit is then covered with a corrugated iron sheet, leaving a gap of about 2 inches. The nature of the smoke that emits out is an indication of the progress of carbonisation. Towards the end of carbonisation, the colour of the smoke will change to pale blue from the initial dense white and steamy smoke. Now, the gap is closed and sides are sealed with mud. The pit is then left to cool for 4–5 days.

The Drum Method An ordinary 55 gallon gasoline drum is used for the carbonisation. The bottom of the drum is removed by cutting around the inside rim. The top is provided with two or three holes of 5 cm × 8 cm size equidistant from the two plug holes which are also kept open. The drum is placed on two 2.5 cm iron pipes with the open end up. The shells are then tightly stocked inside and fire lit between the base of the drum and the ground. As the charge burns, the contents of the drums are frequently shaken and fresh shells added in between. A restricted air circulation is allowed in the drum which is ensured by covering a portion of the space between the drum and the ground with soil. When the drum is filled with charcoal, the removed lid is replaced on the top tightly and the drum with the contents turned upside down on a bag. It is left standing until the smoke clears up. The holes are then covered with soil, and bottom is also piled up with sand around. The drum if properly sealed is ready to be discharged the next morning.

Properties of Coconut Shell Charcoal Good coconut shell charcoal is uniformly dark, snaps with a clean shining fracture and produces a metallic sound when dropped on hard ground. Underburnt shells do not give a metallic sound and a clean fracture, while overburnt ones are friable, and the surface of the fracture sounds dull when dropped and easily crumbles. Coconut shell charcoal contains the highest percentage of fixed carbon of all the ligneous charcoals. The average composition of good charcoal is moisture, 6.24%; volatiles, 5.46%; ash, 0.54%; and fixed carbon, 87.76%. The particle size should be such that less than 5% shall pass through 0.63 cm mesh sieve (Rethinam and Bosco 2006).

The charcoal has a high adsorption capacity for gases and colouring matter and can, therefore, be used as a refining agent both as a deodoriser and as a decolouriser. The shell charcoal also finds way to laundries, smitheries, etc. Well-powdered shell charcoal finds limited use as a dentifrice. The charcoal is used by gold smiths in melting gold and silver and for other metal works. The commercial value of shell charcoal lies in its use as the primary raw material for the production of activated carbon.

13.14.1.2 Activated Carbon

Activated carbon plays a very important part in solvent recovery processes, water and effluent treatment and the treatment of flue gas before its discharge into the atmosphere. Activated carbon is extensively used as agents for purifying, refining and bleaching of volatile oils and chemical solutions. They are also in demand as an adsorbent of gases. The common raw materials used for the manufacture of activated carbons are carbonaceous substances such as coal, lignite, wood and charcoal. Superfine coconut charcoal is one of the useful materials for activation. In the activation process, shell charcoal is fed continuously into a retort. The normal activation process involves the use of steam at selected temperatures for the selective oxidation of the material, resulting in the production of carbon with pores of molecular dimensions. Approximately 3 tonnes of shell charcoal is needed to produce a ton of activated carbon. 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 obtaining a carbon of known quality, in a variety of grade sizes to suit most of the applications.

A large number of plants based entirely on coconut shell charcoal have come up in the major coconut-growing countries. In India, the use of coconut shell for the manufacture of activated carbon is covered by the Indian Patent No. 109082. Here, coconut shells are crushed and treated with surface-active chemical followed by drying and carbonisation. It is then steam activated at 900 °C followed by air to facilitate oxidation and steam quenched to reduce the bed temperature. The material is then discharged in a receptacle and subjected to acid treatment to adjust the pH value. Finally the activated material is washed with water, dried and stored. Coconut shell-based activated carbon constitutes 10% of the total production of activated carbon in the world.

13.14.1.3 Coconut Shell Flour

It is prepared by grinding clean coconut shell to a fine powder. The shell is first pre-crushed in a beater-type disintegrator into 5 cm pieces, which are then conveyed to the first hammer mill. Suction in the conveying system draws the particles of flour into a cyclone, where they are separated into coarse and fine particles. Ultrafine particles are drawn away and collected separately. 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 onto a vibrator-sieving unit and graded into the required mesh size. The shell flour should be a free-flowing powder and clear light brown in colour. The moisture and ash content shall not exceed 10 and 1.5%, respectively. The apparent density ranges from 0.6 to 0.7 g cc^{-1}. The particle size of shell flour which passes through 200 mesh sieve of British Standard should be between 6 and 10 microns (Rethinam and Bosco 2006).

Shell flour is used mainly as a filler, replacing wood flour either partially or wholly in the manufacture of phenolic moulding powders by the thermoplastic sector. It is used successfully with specialised surface finishes, liquid products, mastic adhesives, resin casting, mild abrasive products, hand cleaners and bituminous products. The shell flour gives a smooth and lustrous finish to moulded articles and improves their resistance to moisture and heat. Because of its higher resinous content and lower absorption properties, it can be used in higher concentrations than wood flour. Shell flour is used in the production of glues which is used in plywood industry. It is also used as a fuel and as a substitute for bunker oil in boiler operations. Shell flour has a variety of other uses. It is used as a filler for mosquito incense coils, filler in specialised 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.

Destructive Distillation of Shells In the ordinary method of charcoal making, about 70% of the shell weight is lost in the smoke. If the burning is done in retorts, heated from outside, and the vapour given off is condensed, apart from the recovery of good-quality charcoal, various chemical products of immense industrial value can also be obtained. This process is popularly known as destructive distillation of shells. The products include shell charcoal, which remains in the carbonising apparatus, pyroligneous acid, settled tar and uncondensable gases.

Experiments were conducted in Malaysia long back in 1929 on destructive distillation of coconut shell and the recovery of the byproducts besides charcoal. An experimental plant consisting of a retort 90 cm long and 60 cm in diameter holding 110 to135 kg of shell with a water-cooled vertical cooler was used. The distillate was treated for the byproducts. After the mechanical separation of the tar, the pyroligneous acid was redistilled from a still in order to eliminate dissolved tar and tarry condensation products, the residue in the still being completely freed from acetic acid by the injection of steam. The redistilled liquid which contained all the acetic acid and methyl alcohol was neutralised with lime and partially redistilled to recover the methyl alcohol leaving the acetate of lime in solution. This on evaporation dried up and gave the commercial product known as grey acetate of lime. The acetate of lime was treated in a special still with sulphuric acid and the crude acetic acid which distilled over was further purified by rectification. Out of 100 kg of shell, 40 kg of charcoal and 4.68 kg of acetic acid were obtained, besides smaller quantities of other byproducts such as tar, methyl alcohol and crude creosote oil from the tar.

In India, experiments were started in 1920, and product recovery could be established in subsequent years. It was reported that the average recovery of the products are charcoal (35–37%), pyroligneous acid (6–9%), settled tar (25–37%) and uncondensable gases (17–20%). The tar contained 70% phenols of which 32.6% was mono phenols, 21.3% diphenols and 46.1% triphenols.

In Sri Lanka, Nathanael (1964), on the basis of his pilot plant studies, reported that destructive distillation of the shell yields monomers like phenol, furfural, catechol, butadiene, etc. which could be used for the production of polymers. The shell tar contains about 30% phenols and furfural and croton aldehyde in lesser amounts, which are the potential raw materials for polymer development. Destructive distillation of 1 tonne of coconut shell was found to yield 300 kg each of uncondensable gases and charcoal, 350 kg pyroligneous acid (acetic acid 36%, wood spirit 13.5%) and 50 kg tar (5 kg phenol, 10 kg creosote, 10 kg pitch and natural oils in variable quantity).

The process of destructive distillation on an industrial scale could be divided into five different phases. (1) As a result of external heating to about 170 °C, the moisture in the shells evaporates, and no gas is formed. (2) When the temperature rises from 170° to 280 °C due to external heating, pyroligneous acid vapour, a little tarry vapour and gas consisting almost entirely of carbon monoxide and dioxide are evolved. (3) With no external heating, at about 290 °C, concentration of carbon in the charcoal takes place, and large quantities of hydrocarbon, acetic acid, wood naphtha and tar are produced when the temperature rises to 380–400 °C. (4) The charcoal is fully carbonised and the volatiles are completely driven off at about 600 °C–700 °C. Sometimes, a maximum temperature of 900 °C may be reached in retorts, and (5) the charcoal cools down in an atmosphere of hydrocarbons in the carbonising apparatus itself.

The shell charcoal obtained through this process is of the best quality attracting a high demand. The pyroligneous liquor, which is impure acetic acid, is a good

Table 13.22 Energy from coconut products

Components	Kg	KCal kg^{-1}	Energy KCal	% Total energy
Coconut oil	0.12	9000	1080	27.7
Carbohydrates and proteins	0.06	4000	225	5.7
Shell	0.18	5500	990	25.4
Husk	0.40	4000	1600	41.1
Total	0.76	22,500	3895	99.9

Source: Rethinam and Bosco (2006)

substitute for the coagulation of rubber latex, and the quality of smoked sheets was found to be on par with standard smoked sheets. The crude liquor may be further processed for the production of grey acetate of lime, which is also a marketable commodity. The carbolic acid and creosote present in the distilled tar may find useful applications. Destructive distillation will however be commercially viable only if sufficient quantity of shell could be centralised with minimum expense from the integrated processing areas.

13.14.1.4 Shell as an Energy Source

Coconut plantation has the advantage of producing energy besides food. The shell, husk and leaves have alluring prospects as energy source which needs to be exploited. Even if only 1% of the shell and husk is made use of, the energy produced is still in the order of 38.5 million litres of gasoline equivalent per day. 0.05 kg shell charcoal of 362 kcal and 0.086 kg of husk charcoal of 548 kcal can be obtained from 0.40 kg husk and 0.18 kg shell of one coconut, respectively. The energy obtained from the components of an average coconut is given in Table 13.22.

13.14.1.5 Other Uses of Coconut Shell

It is found feasible to use coconut shell in building construction in India (Balagopal and Menon 1987). In the constructions of load-bearing walls, the use of coconut shell cellular blocks made up of concrete masonry units (in which coconut shells were incorporated) was found to contribute to as much as 30% saving in material without loss in strength. The shells contribute substantially to the strength of the blocks by virtue of their inherent shell compressive strength. It was also found that the shell is capable of carrying a load of 100–400 kg at its top portion. The coconut shell cellular blocks could be produced by arranging the shells in the mould of a block making device prior to pouring the cement matrix (Cement sand-gravel of 1:3:6 by volume). After curing and drying for about 4 weeks, the blocks could be used in the construction of load-bearing walls. Adopting similar process, non-load-bearing partition walls having a thickness of 12 cm could also be produced. A single row of shells is accommodated in the 12-cm-wide block, whereas two interlocking rows of shells are accommodated in the 20 cm block.

13.15 Miscellaneous Products of Coconut

13.15.1 Coconut Wood

Coconut wood is currently a substitute to conventional wood. It is sold in lumber yards especially in coconut-producing areas. The timber can be used as materials for furniture items, novelties, wares and carvings. Since it is a highly dense material, it can be used in building components such as posts, trusses, doors, window frames, girders, etc. The top portion of the trunk is suitable for firewood, while the slabs and offcuts from saw milling can be converted into charcoal of good quality.

13.15.1.1 Preservation of Coconut Timber

Coconut wood is now available in plenty and will continue to be so for many years to come. Coconut wood belongs to the non-durable group of timber. When used in situations favourable to attack by decay fungi and wood-boring insects, the hard dermal portion of the trunk will last only for a period of 1–2 years. The soft inner portion will deteriorate in a few months when left exposed to the weather. Coconut wood should be properly treated to protect it against attack of wood-destroying organisms especially when used with ground contact and exposed to the weather. Attempts have been made to find the most suitable preservation technique and to select the best preservatives with respect to the various end uses of the treated wood. The methods tested for applying the preservatives are brushing or spraying, dipping, soaking/steeping, dip diffusion, double diffusion and hot and cold bath method. The wood preservatives used were copper chrome boron, copper chrome arsenate, zinc chloride + potassium dichromate, boric acid + borax, copper sulphate, potassium dichromate + arsenic pentoxide, cashew nut shell oil and creosote with bunker oil. The treated wood was tested for its shelf life by putting the wood for the following end uses: interior with ground contact, interior without ground contact, exposed with ground contact and exposed without ground contact. The following are the results obtained from the study. 1. Among the preserving methods dipping performed better than brushing. 2. For the end use exposed with ground contact, treatment with chemical creosote was found to be very effective. 3. All the treated as well as control samples were found to be intact for the end use interior without ground contact. Coconut wood is also found useful in the manufacture of particle boards. In a trial in the Tropical Products Institute, the timber was converted into flakes, dried to a moisture content of 5–8% and sprayed with a synthetic resin binder and a urea-formaldehyde/hardener mixture, at the rate of 0.8% by weight of the finished board. The sprayed articles were compressed at an elevated temperature and pressure for about 15 min in a hydraulic press to produce boards of 240 cm by 120 cm with 15, 22.5 or 30 cm thickness. The finished boards were found to be comparable to other quality products. Manufacture of pulp and paper from coconut stem is also a possibility.

13.16 Coconut Leaf

Coconut leaf is another product of importance for domestic use. The plaited and unplaited leaves are used for thatching houses, fencing and making baskets. The lifespan of coconut leaf is only 1–2 years. The leaves soaked in saline water before plaiting withstand climatic influences better than the unsoaked ones. The leaves being lignocellulosic in nature are affected by sunlight, rain and air and are susceptible to attack by fungi, insects, etc. The thick-walled sclerenchyma cells which impart mechanical strength to the tissues are relatively scarce in coconut leaf. Treatment with Bordeaux mixture (Pillai et al. 1983) is undertaken for increased longevity. Fibres can be extracted from fresh 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 5–8% sodium carbonate solution for 1–2 h. After thorough washing, they are immersed in a bleaching solution for 1–3 days with periodic stirring. Then they are washed and dried in shade. These strips, which form smooth, semi-transparent, waterproof threads, are excellent for making hats, bonnets, mats, bags and slippers.

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

13.17 Future Strategy

Coconut processing sector has to be strengthened by focusing attention on nontraditional products from coconut. Research undertaken in the past has generated viable technologies for the manufacture of diversified products from coconut. A few of them are still in their infancy requiring refinement in packaging and quality upgradation. There is an urgent need to undertake pilot-scale trials for commercialising some of the products such as coconut milk powder and coconut water-based beverages.

Various market promotional activities and consumer awareness campaigns are the need of the hour to strengthen the coconut-based economy. Strategic planning and implementation for free flow of proven technologies which have not reached the farmers/entrepreneurs; strong public-private-farmer partnership approach with needed technical support; strong market promotion through marketing networks; bilateral, regional and international collaborations with strong political will and commitment from government side; and determination of farmers for increased farm-level processing are essential to make the coconut industry competitive. Priority should be given for integrated processing of coconut, which is flexible enough to adjust to the market response.

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