# CHEMICAL AND TECHNOLOGICAL INVESTIGATIONS ON COCONUT PRODUCTS

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## Introduction

The products of the coconut palm (*Cocos nucifera*, Linn.) are legion, and their uses according to an old saying are as numerous as the days of the year. The palm, which has been described as the most important of all ' trees ' and its strange medley of products are most valuable, because they are vitally linked up with the domestic economy of most tropical coconut growing countries of the world, where the palm has been established for centuries. Every part of the palm is utilized for the benefit of the human race in some way or another, and the fruit in particular provides important articles of food which are indispensable in every household.

As the importance of the coconut palm as a factor both in the internal and external economy of these countries has been increasingly realised, there has been much work directed in producing countries to the improvement of coconut products. In the Philippines, India and Ceylon Corporations and Research Institutes have been set up in fairly recent times for undertaking, assisting or encouraging agricultural industrial, technological and economic research on the coconut palm and its products. As far back as 1929 the Department of Agriculture, Straits Settlements and Federated Malay States, appointed a full-time officer for research on coconut products.

It is a universal conviction that technical research is fundamental to our future welfare. The politician, the academic scientist, the industrialist and the journalist are all concerned about the application of science to industry and are anxiously watching present trends in industrial science and its future possibilities.

If research on coconut products is to give a fillip to our own particular industry, then coconut production should cease to be regarded as a mere agricultural process, but instead be viewed as a highly ramified INDUSTRY designed to embrace and explore the industrial possibilities, by the development of new uses for the multifarious coconut products which were known. In other words, the harvest of coconuts would not be the end of our labours, but a starting point and source of raw material for a series of manufacturing processes, which call for more research, enterprise, planning, organization and capitalization.

The present article reviews recent research on coconut products, especially that carried out in Ceylon, and its scope has been confined principally to investigations on the non-agricultural aspects of the principal coconut products.

## PRODUCTS OF THE HUSK

In the strict botanical sense the coconut is a fibrous drupe and not a nut and is usually three-sided with rounded angles, more or less ovoid in outline, but varying considerably in shape according to variety.

Structurally, it consists of a pericarp and endosperm (kernel) within which is a fluid known locally as 'coconut water' and elsewhere as 'milk', which varies in volume depending on the maturity of the fruit. In transverse and longitudinal sections the pericarp itself can be differentiated into three distinct layers. A thin, smooth, leathery outer skin or epicarp (which can be peeled off), a middle fibrous mesocarp and the inner hard shell or endocarp. (Plate 1). The familiar husk of the coconut, actually representing the exocarp (i.e. the epi and mesocarps combined), is firmly attached to the shell, which again is firmly united with the kernel over the entire surface of the latter.

The exocarp or husk is thick, coarse, bulky and fibrous and can be removed from the 'stone' or familiar coconut of commerce, by the use of suitable dehusking implements. It consists of strands of fibro-vascular bundles or 'coir' embedded in a non-fibrous parenchymatous "corky" connective tissue sometimes referred to as 'pith' which ultimately becomes coir dust. The strands are composed of a highly lignified form of cellulose - hence their harshness and brittleness. Besides playing a protective role in preventing serious damage to the fruit proper when it falls from the palm, the husk also aids in dispersal by providing buoyancy for flotation on water. In this connection too the exocarp has a special function in affording a more or less tough waterproof covering to the 'nut' whereby its living properties or potentialities for germination are preserved.

The most important product which can be extracted from the husk is the fibre or coir. The husk after processing by the appropriate methods can actually give rise to a variety of coir products including Bristle Fibre, Mattress fibre, Coir Yarn, Cordage, Matting, Brushes and other coir manufactures. Apart from these a considerable amount of residue or coir dust is also produced during the milling operations involved in extracting the fibre. In places where the value of the husk is not remunerative they are used agriculturally on estates with dual functions as mulch and manure.

Coconuts are grown in Ceylon primarily for the manufacture of copra, oil and desiccated coconut, the manufacture of fibre being only of secondary importance. It is therefore not surprising that much research has not been projected to study the retting processes, extraction, composition, attributes, qualities and uses of coconut fibre on a scale commensurate with the importance of the product.

**Properties of Coir Fibre**

It is extraordinary how little is known and how little has been done to investigate the fibre as a chemical or physical material and to study its possibilities of exploitation in new directions, thus rendering it suitable for utilization in new spheres of industry.

*Kirk*[1] states that Claviez working in Saxony gives the fibre as being tubular in section. *Copeland*[2] giving data for the size of ultimate cells of the various textile fibres of commerce shows that the ultimate individual coir cells are the shortest of all commercial fibres extracted from plants having an approximate length of 0.7 cm., and an average diameter of 20 microns. [1 micron = 0.001 mm.]. The long strands which are more commonly referred to as the coconut fibres, have a length of 30 cms., or so, depending on the nut from which they are extracted whilst the diameter is somewhere about 0.3 cm. The same author further states that the cross section of the fibre is roundish and somewhat heart shaped, "the concavity or groove along one side being the place where the vessels are located. The fibre is strongly lignified and to this is due its colour and harshness and its relative brittleness as compared with pure cellulose fibres".

According to *Heerman* and *Herzog*[3], of the total area of cross section 76.8 per cent is cell wall and 23.2 per cent is lumen which is round and somewhat narrow. The end of the fibre according to them is blunt and stumpy, and microscopically the pores in the fibre are small and oval. In the ash the chief constituent is composed of siliceous particles of yeast-like appearance grouped together, The ductility of coir or its ability to stretch beyond its elastic limit without rupture, as well as its power to take up a permanent stretch when so loaded is of the greatest commercial consequence. This property is possibly linked up with the physical structure of the cell wall itself. With regard to elasticity, *Choudary*[1] states that coir fibre will extend by fully 25 per cent of its original length before rupture, whilst Copeland confirms this figure. He remarks that ropes made of coir will stretch more than ropes made of any other commercial fibres of a similar nature. This property makes coir ropes singularly efficacious where intermittent or jerky strains are concerned. Coir also has another great advantage in that it is more durable than most other fibres, particularly where water exposure is concerned, and has unique powers of resistance to microbiological attack. In other words its breaking or tensile strength is not appreciably reduced owing to its resistance to decay.

Very little is known as to the chemical nature of the coir fibre and analysis shows considerable variation according to the retting, the type of nut and origin. *Sampson*[5] quotes comparative figures regarding the analyses of the fresh and the retted husk suggesting that there is not an excessive loss of fertilizer ingredients in the process of retting, except in the case of potash. *Mitchell*[6] quotes some figures for the content of soluble chlorine in coir fibre ranging between 0.013 to 0.070 per cent. The salt content apparently is influenced by the nature of the retting liquor. *Salgado*[7] in certain comprehensive studies on the utilization of the husk for manurial purposes gives detailed analyses (along with previously recorded data) for the mineral constituents of husk ash. It is interesting to note that some of the maximum figures recorded for the water soluble potash (as $K_2O$) range between the high values 31.36 and 35.60 per cent. This is in conformity with the observation of most workers that the coconut uses both in its products and in its body a conspicuously large amount of potash. Perhaps another factor relevant to the composition of the husk, is the tannin present in the fibre. *Choudary* (*loc. cit.*) shows that the ratio of tannins to non-tannins in the husk is very low, being 0.2 to 0.4, and the percentage of extractable tannin on the weight of the husk is about 1.3 per cent. He has concluded that "the substance s of no use for the tanning of leather".

Regarding the organic matter in the husk *Joachim*[8] gives a figure of 96.5 per cent (dry basis), of which 45.45 per cent is lignin and 19.15 per cent is pentosan. From the point of view of decomposability (as measured by the pentosan/lignin ratio of 0.42), it could be said that the husk would be only very slowly decomposed in the soil unless accelerated by other means. A pentosan/lignin ratio above unity is usally reckoned to favour rapid decomposition. Though there has not been much scientific investigation, coir workers in India maintain that coconut husk from nuts about ten months old yield the best fibre in colour as well as in strength. If the methoxyl content could be regarded as an index of the extent of lignification, then the figures of *Menon*[9] would confirm this belief. In his study, samples of fibre from coconut husks of different ages were analysed for methoxyl and "Cross and Bevan" cellulose (i.e. cellulose isolated from the fibre by successive chlorination and alkali treatment). The maximum for the methoxyl value and a minimum for the cellulose for the fibre from nuts 10 months old appear to confirm the belief that the best fibre is recoverable at this stage. The tannin matter in the husk has been reported to increase in quantity as the nut matures and it may be a disintegration product of lignin. If this is so the apparent increase in cellulose which Menon records after the tenth month may be due to the elimination of this lignin component.

Pectin has been found by workers to be more plentiful in the tender coconut fibre than in the commercial fibre and could not be identified in the dry senescent fibre, which however has been found to contain hemicellulose. The analyses of tender coconut husk appear to suggest that so far as coir fibre is concerned, pectins or pentosans are not the precursors of lignin — these are more likely to be more soluble aromatic compounds of a phenolic or tannin nature which are present in the husk in abundance, In general the figures for coir fibre may be said to belie its physical properties, because its high lignin value especially (which is over 40.0) does not correspond with its remarkable extensibility and spinning qualities.

**Retting of Coconut Husks**

From the point of view of the manufacture of coir goods, observations have been made that the nature of the water used in the retting operations is not so important as the age of the husks when the nuts are harvested. As already pointed out, it is certain that the immature green husk about ten months old gives the best fibre of a pleasing yellow colour. Coir fibre from Travancore has been noted for its superiority over the Ceylon product, and the fact that immature nuts are employed in that part of India could doubtless be adduced as the principal reason for this difference in quality. In Ceylon however, where emphasis is on copra, oil and dessiccated coconut production, this cannot be done, as *ripe* nuts are required for the manufacture of these products. From what has been stated earlier it should be obvious that in the mature nut the fibre is exceedingly lignified and is therefore dark, harsh, stiff and brittle in consistency which properties would make the fibre suitable only for the making of products like matting and brushes. Smooth and elastic fibres from the green husk (as made in Travancore) however would give it value for finer work and as a stuffing material.

The period of retting is an important factor in the production of coir. It has been observed that soaking (whether in salt or fresh-water) should be allowed to go on as short a time as possible as will make it economically possible to clean the fibre. The retting process appears to be due solely to the action of bacteria which dissolve the middle layer of cells of the connective or ground tissue of the husk, leaving the fibres loose. The best method of shortening the retting period is by crushing the husks before soaking. When this is done, the period of retting may be reduced to about one fourth the normal time. However when pre-crushing is used, expelled tannin matter should preferably be washed off and not be allowed to dry on the husks or be exposed to the air before soaking.

Chemical methods of bleaching, and at least five patented processes for the chemical disintegration of the fibres from the pith are available[10], and it is claimed that by means of these it is possible to hasten the period of retting without damaging the fibre and in fact bring about an improvement of quality and appearance. According to one of these processes — the Van der Jagt Process it is further claimed that the texture of coir fibre could be so improved that it could be woven to form a coarse fabric utilizable in the manufacture of bags for the transport of fertilizers, cattle food, sugar and similar commodities. It is felt that as long as the manufacture of coir is based on its low-cost production (as a cottage industry) these processes must remain of purely academic interest unless it can be proved that coir fibre of considerably improved value can be obtained economically by these methods. This is clearly a subject for investigation.

The production of dry-milled fibre from unretted husks by mechanical means is in quite another category. It is the application of continuous rapid processing by purely physical means — a process consisting of mechanical crushing, beating and winnowing in continuous production lines. At present, highly efficient 3-stage decorticating and screening machines have been installed in certain fibre mills in Ceylon. The decorticating process consists essentially of a husk bursting operation followed by a sifting operation. Segments of the husk are fed into the *Husk Bursting Mill* where they are exploded by impact and instantly discharged through a top opening into a connecting *Duct* along which they pass on the air blast into a *Sifter* where they are further opened and screened. Fibre is discharged at the end of the sifter and dust through the screen forming the undershield of the machine. It should however be pointed out that when husks are dry-milled only mattress fibre is produced, and to a certain extent the finer fibres valuable for making yarn may also get broken up in the process.

*Coir Dust.*—A discussion on the products of the coconut husk will not be complete without reference to " coir " dust. This product is still reckoned as an industrial waste from the coir fibre mills, in spite of diverse attempts to explore avenues of potential utilization.

Coir fibre dust has been found to have limited agricultural and industrial uses which are worth enumeration. The dust has some use as a soil mulch and has been particularly used for this purpose in citrus culture. It absorbs as much as eight times its weight of water with which it parts fairly slowly. Two per cent mixed with sandy soil has been found to increase the water holding capacity of the latter by 40 per cent. It is commonly so used in gardening. The manurial value of the material by itself is very small except the dust derived from the " dry milled " fibre, which contains about 0.5 to 0.6 per cent of potash (as $K_2O$).

Various trials for industrial utilization have been made with coir dust. As a paper making material it has been found unsatisfactory by *Hooper* in India, and by *Menon* in Ceylon. *Gonsalves* (English Patent 4968/1905) used coir dust, as an absorbent for nitroglycerine in making explosives. Recent trials have mostly aimed at using the dust as a cheap filling material for various types of boards. In 1936, experiments were conducted in England to make insulating boards for refrigerators, but the chief difficulty encountered was the water retaining capacity of the dust making the boards liable to warping and deterioration.

The most successful results appear to have been obtained locally, based on joint experiments carried out by the Coconut and Rubber Research Institutes. Using small scale machinery, investigations were carried out on the possibility of using coir fibre dust in combination with rubber to form composition flooring, ceiling board and similar materials. Though the work was not exhaustive, yet encouraging results have been obtained and published[11]. Samples of flooring prepared by combining coir dust with rubber and other compounding materials both in the form of sheets (containing 50 per cent fine coir dust) and tiles (37.5 per cent coir dust), have been found to keep without deterioration for a period exceeding five years.

In some mills the dust is compressed into cakes or ' briquettes ' to squeeze out as much water as possible and used as fuel for boilers. It has not been found very satisfactory and cannot usually be used alone but has to be mixed with shells, bitumen and/or firewood.

During recent years, experimental trials were carried out by the Department of Industries (Ceylon) to explore the possibilities of the utilization of coir dust for the manufacture of a suitable substitute for imported thermal insulating material. It was thought that a substitute for cork could be prepared by pressing rubber impregnated coir dust into suitable slabs. Unfortunately the mechanical strength of the resulting slabs was found to be unsatisfactory even over a wide range of rubber contents of 20–40 per cent and the resulting blocks were found to be too fragile for use. It was concluded that the rubber which was the major contributory factor on the cost of the block was manifesting no real bonding property at all. Experiments with bitumen (and solid pitch) too as a binding agent did not appear attractive. Cork which is provided by nature in the form of fairly regular geometrical solids of definite size normally requires relatively little bonding agent unlike coir dust which is a fine powder.

Recently, promising results have been obtained and reported by the Plastics Division of the Imperial Chemical Industries (Export) Ltd., who carried out trials on the preparation of coir dust boards bonded with phenolformaldehyde resins. Suitable samples of coir dust (from the dry milled fibre) were supplied for these trials by the Coconut Research Institute. The economic possibilities of the process however need further investigation.

According to recent press reports, interest seems to have been evinced by certain firms in the European continent in coir dust as a possible source of furfural. The latter is a valuable basic agent, in the plastics industry, having dual uses, being employed directly as a solvent and indirectly in the form of various synthetic resins and moulding compounds in conjunction with amines, phenol and formaldehyde.

Available analytical data show that the organic matter in coir dust contains over 10 per cent of pentosans (dry weight). On this basis a recovery of over 5 per cent of furfuraldehyde from the dust could not be regarded as an outrageous estimate, knowing that the organic matter itself averages over 85 per cent of the dust (dry basis). The process of recovering the furfural from the dust would probably consist of treating the product with high pressure steam in the presence of hydrochloric or sulphuric acids and certain (metallic) catalysts. The process, its economic possibilities, and other complementary lines of work clearly warrant full investigation.

**Miscellaneous Investigations**

During World War II, coir netting was used by the military authorities to camouflage gun sites, but it was found inflammable. A successful method of fire-proofing coir using silicate of soda and lime was evolved at the Coconut Research Institute. It was found to be cheap and effective and was adopted by the Army.

In concluding the discussion on the products of the husk, reference should be made to the unpublished observations of *S. R. K. Menon* in Ceylon, on the economic possibilities of :—

(*a*) The use of green husks from tender nuts, and green immature coconuts naturally falling from the palm, as a raw material for the manufacture in Ceylon, of artificial leather or "Coconite".

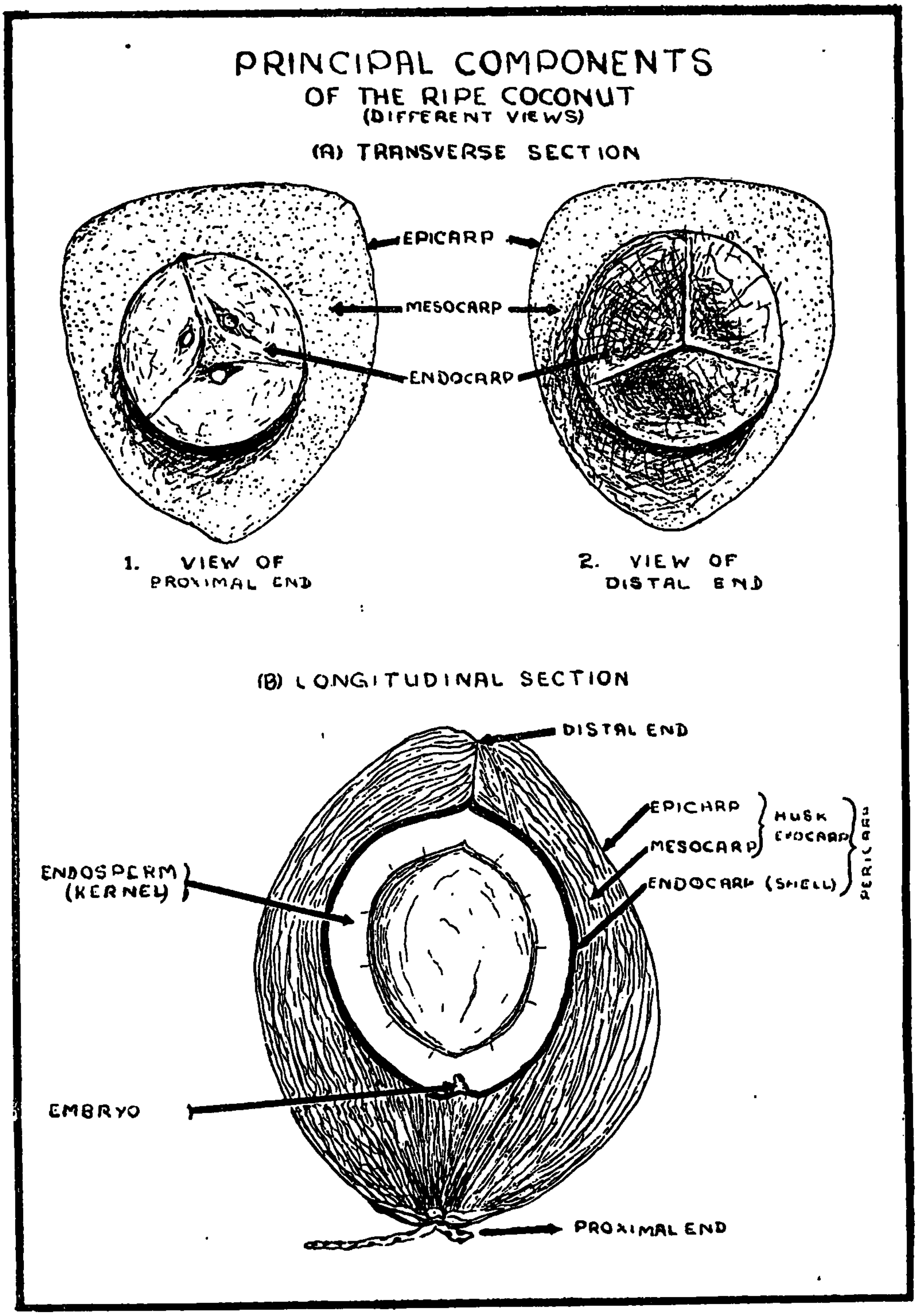
It is claimed that the voluminous pithy matter of the mature nuts is absent in the tender ones, which contain instead a dark red colloidal cellulosic cement, which when pressed hydraulically between heated plate ends yields a tough leathery product with a shiny and smooth surface. Samples of this product reveal that the fibres from the immature nuts cling fast to the binding matter and yield easily to compression. During the period of war emergency a small scale plant was installed for turning out this product which was used as a substitute for asbestos ceiling, and panelling boards. Its manufacture has not so far been undertaken on a proper commercial scale.

(*b*) The utilization of dry mature husks for the manufacture of paper board.

The possible manufacture of paper board from the dry mature husks has been claimed which is quite distinct from "Coconite" for which immature nuts alone are used.

In the manufacture of paper board the fibres are separated mechanically from the husks in a swing hammer machine and lixiviated with hot water in order to be purified from adhering tannin like compounds, and are then digested under pressure in rotary digestors in milk of lime. The digestion leaves the fibres softened and chemically altered. The inventor claims that the product could be marketed either as wet-pulp or be converted into paper boards.

The experimental laboratory work involved in the foregoing investigations were carried out at the Coconut Research Institute (Ceylon), and the processes have already been patented by the inventor.




PRINCIPAL COMPONENTS OF THE RIPE COCONUT (DIFFERENT VIEWS)

## PRODUCTS OF THE SHELL

The hard endocarp (or shell) of the coconut encloses the seed or kernel and has three ridges on the outside corresponding to the three fused carpels of the ovary from which the fruit actually developed. Corresponding to the carpels there are three germinal pores or " eyes " present in the endocarp, at the proximal end of the nut where it is attached to the fruit stalk. Usually the one associated with the embryo (the " soft " eye) remains permeable, whereas the other two are smaller and hard. Immediately under the " soft " or germinating eye the rudimentary germ or embryo is situated from where it forces its way out during sprouting. In cross section the fruit is somewhat triangular and the ridges on the endocarp actually alternate with the angles of the exocarp. (Plate I, B).

Before considering the products and uses of coconut shells, which can be as diverse as the ingenuity of man can possibly make them, it will be useful to consider their nature and composition. Though the lignin content is higher and the cellulose content lower, coconut shells are similar in chemical composition to hard woods. There has been a general impression that since the shells burn in such a characteristic way, they are likely to contain oily or resinous substances. Actually they contain little or no oily and resinous matter. The ash from burned shells contains a fair amount of potash though less than in the ash of the husk.

*Child* and *Ramanathan*[12] based on work done at the Coconut Research Institute (Ceylon), have recorded the results of standard chemical analytical determinations on coconut shells which with the exception of cellulose are in general agreement with those previously reported by *Fleck* and his co-workers[13]. The figures obtained by the former average 36.51 per cent (lignin), 53.06 per cent (cellulose), 29.27 per cent (total pentosans) and 0.61 per cent (ash), all calculated on the dry weight. The corresponding figure obtained for cellulose by the other workers (employing a different method of estimation) has been given as 44.98 per cent. The analytical data indicate that cognate laboratory studies are likely to give further results of theoretical interest, especially in lignin chemistry as applied to the cell wall substances of coconut shells.

Judging from the fact that the dry distillation products of coconut shells show considerable quantitative differences from those of woods, it is also likely that there are features in the composition of the shells which are not reflected by the existing analytical methods.

*Utilization of Shells*.—The uses to which coconut shells have been, and can be put to, could be described as being partly ornamental, partly domestic and partly industrial. As the shell is hard, and takes on a polish, it can be carved, decorated with lacquer, inlaid with silver or other metals and generally used with ornamental effect. Articles of very attractive appearance and characteristic of the various countries of origin are being produced by expert craftsmen. Of decorative work, illustrations have been published of very ornate Indian work including lamps, goblets, flower vases and a strange medley of other things by *J. Shortt*[14], and of more modern Ceylon ware by *Pieris*[15]. Three good illustrations in the latter publication show bangles, buttons, cuff links, ash trays, trinket dishes and paper weights, and a complete tea set, including pot, six cups and sugar bowl.

Regarding the innumerable domestic uses, coconut shells have always been used in the domestic economy of producing countries in a variety of peculiar and important ways. Half shells continue to be used as drinking bowls in toddy taverns, as receptacles for collecting rubber latex, as scoops and ladles when suitably fitted with handles, as begging bowls, and vessels for divine oblation in temples.

It should be pointed out that of the enormous quantities of shells produced annually in coconut-growing countries the uses discussed above account for only a negligible fraction. Undoubtedly in most countries the bulk of the shells produced are commonly used as domestic fuel ; laundries, bakeries and the like using up fair quantities. Though a large number is probably so used domestically, yet, especially in countries where a well developed plantation industry exists, the shells are principally used for firing copra-kilns. In Ceylon, as much as two-thirds of the shells produced on a plantation, may be burned for drying copra. Shells are not favoured as a boiler fuel owing to the rapid corrosive effect of the vapours on fire-bars, etc., due partly to the nature of the combustion products and partly the high temperature reached.

Apart from their direct use as fuel, the manufacture of charcoal represents at present the only important direction in which coconut shells are economically utilised. At present however, the charcoal is made in Ceylon entirely by the time-honoured process of burning in pits with exclusion of air, and all the exports are in this crude form, there being no development of the manufacture of " activated carbon." The possibility of the manufacture of active carbon has been considered in the Philippines, India and in Ceylon and some preliminary investigations have been carried out in these countries.

In the Philippines *Clemente* and his colleagues[16] found that among 41 different kinds of wood charcoal, the coconut shell product had the highest adsorption for potassium hydroxide and the lowest for hydrochloric and acetic acids. Decolorizing charcoals were prepared by *Clemente* and *Pascual*[17] from coconut shells, husk and cake by impregnating with zinc chloride and carbonizing. They were found to be as active as Norit by *Samaniego* and *de Leon*[18] who prepared charcoals activated in various ways from rice bran, rice hulls, coconut shells and corn cobs. The best decolorizing action, (as estimated by its adsorption of iodine) was obtained with coconut shell charcoal prepared by impregnating with phosphoric acid. It also proved a satisfactory gas adsorbent when impregnated with caustic soda. Rao in India[19] studied various raw materials, including coconut shells, as sources of active charcoal suitable for sugar refining. Satisfactory gas adsorbent charcoal was prepared by *Neubauer* and *Rands*[20] in New Zealand by steam activation of crude coconut charcoal from Samoa. Similar laboratory investigations are believed to have been carried out by the Department of Industries in Ceylon but nothing has been published. In general, it may be concluded that though a fair amount of work (with promising results) has been carried out in some of the coconut producing countries on the activation of coconut shell charcoal, yet no steps have been taken towards production on commercial lines.

In the present method of manufacture of charcoal, the shells are usually burned in pits which may be anything from a simple hole in the ground to large brick-lined pits with steel lids. Accounts of the procedure adopted are given by *Cooke*[21] and by *Child*[22]. In New Guinea *Hutchinson*[23] has described a method of burning shells in 40 gallon oil drums. Up to the present, steel and brickwork kilns such as the Hornsby Patent seem nowhere to have come into use. The production of retort charcoal by carbonization, with recovery of by-products has been successfully carried out in the Ceylon Government Acetic Acid Factory which was established under war conditions, and later closed down owing to post-war competition.

Thirteen commercial samples prepared in Ceylon examined at the Coconut Research Institute have shown that besides over or under burning, the common faults of pit charcoal are (*a*) excessive moisture, due to too much water being used to damp down when opening the pit (*b*) high salt content due to brackish water being used to damp down and (*c*) contamination with gritty matter, sand or earth. In general, the analytical results showed that Importers' specifications for commercial shell charcoal were reasonable, with the exception that the standards imposed for moisture and volatile matter were somewhat stringent. Regarding the calorific value of coconut shell charcoal, it is maintained that expressed in B.Th.U. per lb., it should not be less than 13,000.

Coconut shell charcoal has developed from a minor local product used as fuel, to a general commercial product owing to its value as a raw material for the manufacture of activated charcoal. Regarding its possibilities of use as a fuel for gas producers for motor vehicles it is believed that the high percentage of tar products in pit charcoal would make it unsuitable, owing to possible fouling of pistons and valves and clogging of the gas filters. The possible utilization of the higher grade retort charcoal, should however be of economic interest to coconut producing countries and is well worth investigation.

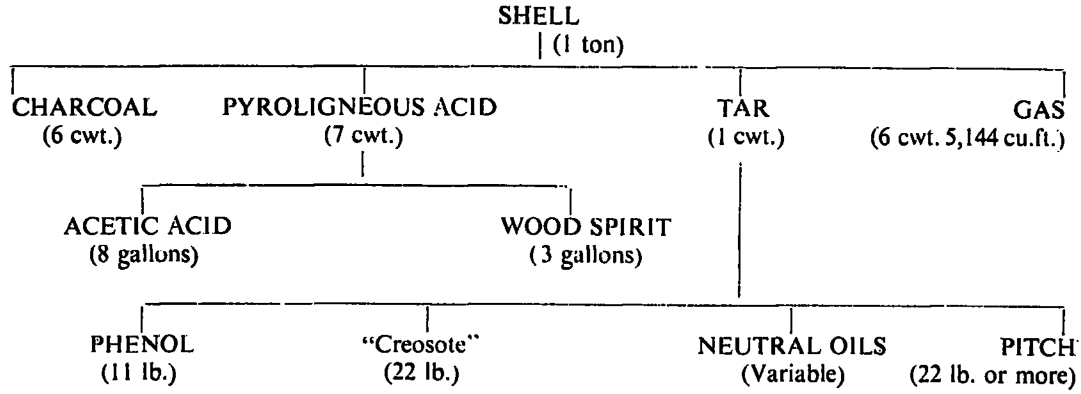
*Distillation Products.*—Fundamental analytical work done at the Coconut Research Institute, on the composition and distillation products of Shells, has provided the basis for subsequent work on the commercial utilization of coconut shell products.

The primary products of the destructive distillation of coconut shells *are charcoal* which remains in the retort, *pyroligneous liquor* and *settled tar* which distil over, and *uncondensable gases*. *Child*[24] based on laboratory studies and semi-commercial trials states that (excluding extreme figures) 100 lb. of shells would yield 34 lb. charcoal, 40 lb. pyroligneous acid (of up to 12.5 per cent acetic acid content), 6 lb. of tar and 20 lb. of gas.

The pyroligneous liquor (or acid) may be regarded as an impure dilute acetic acid contaminated with other compounds. It is a dark, reddish-coloured liquid with a strong empyreumatic odour. During re-distillation of this liquor, a low boiling fraction (of some importance) " wood naphtha " could be recovered. This is actually a mixture of methyl alcohol and acetone. The percentage has been reported as 2.5 to 3.0 per cent in the liquor or 1–12 per cent on the original shells. If the distilled pyroligneous acid is neutralized with lime and evaporated to dryness, acetate of lime known commercially as " grey acetate " can be recovered. From this acetic acid may be obtained by treatment with sulphuric acid using specialized technique. Without going through the intermediate stage of acetate of lime, a solvent extraction process using the tar oils was employed with success at the Government Acetic Acid factory for concentrating the acetic acid in the pyroligneous liquor.

According to *Child* (*loc. cit.*) the settled tar is a very complex mixture, and also more variable in composition than the pyroligneous acid. By simple fractional distillation of the tar, phenol, creosote and pitch could be recovered and the creosote fraction in particular (which distils over between 190° and 230°C) should be interesting for further study.

The following table shows the approximate quantities of the principal products obtainable on dry distilling a ton of shells :—



Apart from the various uses for coconut shells enumerated above, the finely ground product called "coconut shell flour" has now become a commercial product being used as a filler in plastics It gives a smooth and lustrous finish to moulded articles and is reckoned to improve resistance to moisture and heat. Another interesting use of the finely ground shells, as an adulterant for spices, has been reported in 1900 from America.

The information available on the chemical and industrial aspects of the products of coconut shells is indeed voluminous and cannot be covered fully in a general article like the present one. An excellent detailed review of all aspects of coconut shells has been made by *Child*[25] in a series of publications which would amply reward perusal. The survey exhaustively covers the present state of knowledge on the composition, uses, world production statistics, and status of coconut shells as a potentially valuable raw material for industrial exploitation.

## PRODUCTS OF THE KERNEL

The hollow seed of the coconut which is encased in the hard shell is composed of a thin brown skin (seed coat or testa) enclosing the *solid* endosperm (stored food for the embryo) or oleaginous white 'meat' (about ½" thick) around the very small embryo. As the testa is firmly and almost inseparably united with the white meat, the connotation of the term kernel may be taken to include this joint structure.

The kernel of the mature coconut is firm and rich in oil and is in fact the most valuable part of the fruit, as it provides important articles of food. Samples of the fresh kernel examined by the writer have been found to consist on an average of 48.0 per cent moisture, 35.5 per cent oil and 16.5 per cent oil free residue.

Besides the direct use of the raw kernel, grated meat and milk for culinary purposes, the principal products of the kernel may be said to include copra, oil, desiccated coconut, and copra cake or poonac.

**Copra** — Practically the whole of the coconut crop that is used to make oil and poonac is first converted to copra which is actually the dried kernel. As the meat from the freshly opened nut contains moisture amounting to close on 50 per cent along with a high percentage of oil it is really a perfect medium for the growth of bacteria fungi and moulds. It is therefore immediately liable to deterioration and very susceptible to attack by these organisms, with the development of free fatty acids and rancidity. In order to enhance its keeping qualities and inhibit the growth of moulds therefore the method employed is to reduce its moisture content to under seven or preferably six per cent to produce the commodity known as *copra*. The origin of this term is traceable to South India and should therefore be used to designate and distinguish the dried kernel as opposed to the fresh kernel of the coconut.

Where rainfall is meagre, sunny periods of long duration and winds fairly strong and persistent, copra of superlative quality can be made by availing of direct solar heat coupled with natural air currents. As weather can be a capricious factor, the popular method employed in Ceylon and other countries for the manufacture of copra combine sun-drying with some form of artificial kiln drying.

Recorded oil percentages of copra from various producing countries are very variable, and standard text-books quote a range of 57-75 per cent. The sources of these figures vary in reliability and in many cases are not representative. *Cooke*[26] has pointed out that copra badly deteriorated through mould attack may give an abnormally high yield of (inferior) oil. Similarly *Child* and *Nathanael*[27] showed that the copra made from the kernel still remaining in seven-month old seedlings had an oil content as high as 77 per cent (dry weight). These high percentages are ascribed to the fact that in germination or mould damage, the inside layers, which have the lowest oil content, are removed.

A thorough examination involving large numbers of analyses have been carried out on copra at the Coconut Research Institute (Ceylon). Low percentages of oil have often been found with copra from immature nuts. Variations however do occur with normal copra from good ripe nuts. In the present state of knowledge, it is not possible to draw definite conclusions regarding the influence of such factors as climate, soil conditions and genetic differences on the oil content of copra.

*Child* and *Nathanael*[28] found no seasonal fluctuations or differences between estate copra from various provinces in Ceylon. Analyses on 52 representative samples of Ceylon Estate No. 1 copra showed an average moisture content of 6.8 per cent and oil (dry basis) 68.3 per cent. In comparison, figures quoted for Malayan Estate copra averaged moisture 6.9 per cent and oil (dry basis) 65.6 per cent. The difference in oil percentage may be associated with the slower process of drying adopted in Ceylon and perhaps partly to an unexplained fundamental difference between the nuts of the two countries. Regarding No. 2 and No. 3 grades of Ceylon estate copra, 24 samples of each were examined by the same authors and the results indicated that the samples contained on an average slightly higher oil percentages than No. 1 Estate Copra. Their physical nature was found to be the only objection for their use for milling and their greater tendency to deterioration by moulds an objection for their overseas shipment.

*Child* and *Salgado*[29] have found that during the second year after application, different fertilizer treatments did not affect the oil or nitrogen content of the copra. The unpublished work of the writer, further shows that even after 12 years' differential treatments (involving nitrogen, phosphoric acid and potash), no significant effects were evident.

Some interesting observations on the copra from fallen nuts have shown that though the copra yield is higher and the out-turn (number of nuts required to produce 560 lb. or a candy of copra) better, yet the quality otherwise is not so attractive.

Studies made on the oil contents of copra from the Maldives, Cocos Islands, Papua, Malabar, Malayan dwarf palms and Philippine giant varieties have shown that varietal differences are not very pronounced, but the oil content of copra is mostly affected by the maturity of the nut.

Commercial copra has only one use, namely in the manufacture of oil and its single by-product, coconut cake or poonac. Superfine edible grades of copra however are to a certain extent, domestically consumed as such in Ceylon and India.

**Coconut Oil** — Unlike some other fruits, it can be said that almost all the oil of the coconut is present in the kernel. In commercial practice, the oil is recovered only after the meat is dried into copra.

In India and Ceylon, copra is crushed for oil in *chekkus*, rotary ghanis (power driven chekkus), expellers and hydraulic presses depending on the scale of production. Solvent extraction plants have been in use in the Philippines for the extraction of coconut oil and have been recently introduced to Ceylon.

Many processes have been patented for obtaining the oil from the fresh coconut meat without the intermediate production of copra — for example, the Beckmann bacterial process[30] and the V.G. Lava process of pressing the fresh meat and breaking the water-oil emulsion obtained by biochemical means[31]. None of these has yet been applied on a commercial scale to coconut oil production.

Upon expelling, Ceylon Estate Copra, dried to 4 per cent moisture content may be expected to give a practical oil yield of 62-63 per cent, and 37-38 per cent, of poonac containing about 11 per cent moisture and 6-9.5 per cent of residual oil, depending upon the efficiency of the expeller. With other types of milling equipment however the oil recoveries would be determined by their respective efficiencies.

As prepared in the tropics coconut oil is a colourless to pale brownish yellow oil. In temperate climates it appears as an unctuous, somewhat crystalline, solid fat with a melting range of 20°-26°C. It has a distinct odour of coconut unless refined, and is reckoned to be the least variable of the commercial fats. A number of fatty acid analyses are on record and they reflect the consistency in composition of the oil from different sources. The saturated acids average about 91 per cent of which lauric acid is the most predominant constituent having been reported to range between 44.7 and 51.0 per cent. The unsaturated fatty acids amounting to about 9 per cent include oleic and linoleic acids. The glyceride structure is necessarily complicated and fully saturated glycerides have been reported by *Hilditch* to amount to 84 per cent. It should be interesting to note that although the mixed acids of coconut oil contain about 50 per cent of lauric acid, trilaurin is not present.

Commercial unrefined coconut oil always contains a certain proportion of free fatty acid. This is to some extent, an indication of rancidity and is higher in oils pressed from stale deteriorated copra. Commercial mill oils from Ceylon have been rarely found to contain over 2.0 per cent (as lauric). In the case of the coconut there occurs very little lipolysis in clean copra, and highly acid oils may be regarded as having been derived from mouldy copra, or resulting from storage of the oils when wet and containing foots, (cake residue, etc.). Besides conforming to the general standards for coconut oil, edible grades are required to possess an acidity below 0.10 per cent (as lauric) ; they should be sweet and neutral in taste and odour and conform to stringent standards for colour. Refined coconut oil has been sold in Europe under a wide variety of trade or proprietary names, among the best known being, Cocolardo, Cocoline, Lactine, Laureol, Nucoline, Nutrex, Palmine and Vegetaline. With the introduction of hydrogenated oils, it may be said that coconut oil has lost its pre-eminence as a solid vegetable fat. The oil however still finds use in specialised products, such as 'coconut stearin' employed as a substitute for cacao-butter in chocolate manufacture. This is actually obtained by the process known as 'winterising', which consists of separating various melting point fractions by hydraulic pressing of the partly solidified oil at various temperatures. Coconut oil can of course be hardened by hydrogenation, and its melting point raised to about 44.5°C. Though small hydrogenation plants have been installed in Ceylon, the local demand would not justify a big scale edible oil industry, unless possibilities for export business can be established.

Commercially, coconut oil is mainly used in the manufacture of soap and margarine, while appreciable and increasing quantities are also being used in biscuits and confectionery. A large volume of pure coconut oil is also employed in tropical countries as a cooking fat, besides its use for other domestic purposes.

**Coconut Cake (Poonac)** — Coconut poonac should really be regarded as a by-product of the oil milling industry, and when it is ground it gives rise to coconut meal or copra meal. Poonac is also referred to in the trade as expeller cake, copra cake or coconut press cake.

As indicated earlier, coconut cake can vary in composition according to the efficiency of pressing. Depending principally on the milling equipment or method of extraction used, coconut cake is marketed in various grades which include hydraulic (or roll) poonac, expeller poonac, chekku poonac and parings poonac. Products like ' Xtralac ' and ' Morlac ' are also coconut cakes but are blended residues of low oil content derived from the solvent extraction process. Hydraulic press poonac comes on the market in flat round cakes, but the other grades in dark coloured broken lumps of various sizes. The product sold as ' sediment ' poonac however is quite distinct from the above, and is actually a residue (rich in protein) recovered from the filter pads of presses employed for straining mill oil. Chemical investigations by the writer have shown that the protein content of sediment poonac (on the oil-free basis) could be as high as 38.2 per cent (dry weight). The corresponding protein contents of the other grades of poonac ranging between 16.2 per cent and 26.3 per cent. According to *Johns* and *Jones*[32], coconut globulin (containing 17.5 per cent of nitrogen) is the chief protein in coconut cake and based on the amino acid composition of the globulin, and as the sole source of protein they regard it as adequate in an otherwise complete diet. By a patented process, it has been found possible to extract the protein in a pure form which may have application in animal and human nutrition. On the basis of certain results obtained by the writer, it could be stated that the soluble sugars in coconut meat consist almost entirely of sucrose, and would amount to about 16 per cent in average quality mill poonac. It is however known that a certain amount of caramelization takes place during pressing, especially in expellers. The higher carbohydrates have been little investigated.

Between the most efficient hydraulic press (poonac 5 per cent oil) and the least efficient *chekku* (poonac 22 per cent oil), the poonac yield from copra may be said to range from 33 to 42 per cent.

Coconut cake and meal which are valuable protein concentrates are used as supplementary foods for cattle, pigs and poultry and on this subject there is a considerable but scattered literature. High oil content *chekku* poonac is usually not given to milch cattle but is useful for fattening pigs. During times of local surpluses coconut cake has been employed as an organic fertilizer and an outline of its method of utilization for this purpose is embodied in a publication by *Salgado*[33]. The use of poonac as a boiler fuel for locomotives has been suggested, but it is hardly within the realm of normal economics. Coconut poonac from good quality copra is somewhat sweet and palatable with an agreeable smell and is relished by livestock. The cake from inferior, mouldy and rancid copra however is unpleasant and unsuitable as a stock feed.

**Desiccated Coconut.**—This product of the kernel is manufactured from the white part of the kernel only, after removal of the 'parings' or brown testa. The fresh white meat is first shredded or disintegrated and then desiccated in hot air driers at 140°-180°F to below 2 per cent moisture content. Good desiccated coconut is of pure white colour, crisp and with a fresh taste of the nut. Its oil content ranges between 68-72 per cent, with a free fatty acidity not exceeding 0.1 per cent. Desiccated coconut is widely used in confectionery and biscuit manufacture, and domestic cake-making. Its manufacture is confined mostly to Ceylon and the Philippines, though a fair amount is also prepared in New Guinea and Papua.

Though machines (such as the ' IZOD ' patent coconut paring machine) have been devised for paring the rind, in Ceylon the operation is done by hand using special knives. Anything up to 15 per cent of the kernel by weight may be removed in the form of parings. After removal of the skin, the peeled meat is then lightly broken up with mallets or ramrods. The broken pieces after rinsing in running water are then fed into the hopper of a disintegrator where it is immediately reduced to fine meal and discharged into a collecting box below. For the usual product the meat comes out in grated form, but if so desired ' fancy cuts ' such as chips, threads and macaroons can also be produced. The disintegrated meat is next passed through the drying chamber of a tray-type Drier, through which hot air under pressure from a fan circulates. The time taken for drying the disintegrated wet meat to the requisite moisture content usually ranges from 20 to 25 minutes. After cooling on galvanized tables the product is next passed through a sifter for separation into grades, and chutes are so arranged that each grade (coarse, medium, fine and extra fine) could be collected separately. The graded product is finally packed in ply-wood chests (of 130 lbs. capacity) lined with grease-proof paper.

The manufacture of desiccated coconut is only partly mechanised in Ceylon whereas in big factories in the Philippines, with the exception of the shelling and paring operations the entire process is done by machinery.

The keeping qualities of desiccated coconut like those of copra, depend almost entirely upon its moisture content. In the presence of more than a minimal amount of moisture it readily becomes a prey to the attack of moulds. It is therefore very essential that the moisture content be reduced certainly below 3 per cent and packed in such a way as to prevent absorption of moisture from the air. It has been found that if properly dried and packed, desiccated coconut should not require the addition of any preservatives, and in fact such additions would generally be undesirable. Shipments received in a spoiled condition at overseas destinations have usually been found to be more often the result of packing imperfectly dried material than of moisture absorption in transit.

Desiccated coconut contains over 70 per cent of oil (dry basis), and oven tests done at the Coconut Research Institute have shown that at moderately high temperatures, (above 90°F), it 'spits' oil causing 'case staining.' The results have shown that at 55°C (131°F) as much as 6.2 per cent of the oil can be lost. For hot climates, it may be a good plan to deliberately reduce the oil content by light pressing to provide a " tropical DCN " of lower oil content than the usual 68–72 per cent. Like most edible products of high fat content, desiccated coconut readily picks up taints from odours given off in its vicinity. It has been found that aluminium foil is the best impervious wrapping to keep out undesirable odour. The use of this opaque foil also helps in checking rancidity, which is known to be accelerated in fatty substances by the action of light. Except for cost considerations from all other points of view including prevention of moisture absorption, exclusion of light and air, and prevention of tainting, the use of sealed tins is really the best method of packing desiccated coconut.

According to a recent report issued by the Ceylon Institute of Scientific and Industrial Research[34] experiments have been carried out on the preparation of desiccated coconut employing pneumatic tube drying methods which are said to offer the advantage of continuous production. The report says that " Tests with small scale pneumatic tube driers show that coconut can be dried down to 2.4 per cent moisture in about 30 seconds under modest heat ; and probably in much less time in larger single-pass units. In the present equipment some particles show discolouration which must be eliminated by further study. If this last problem can be solved the method offers great promise, and moreover involves drying equipment which can easily be manufactured in Ceylon". It is also reported that by centrifugal treatment a good proportion of the initial water could be removed from the disintegrated coconut meat thereby eliminating about two-thirds of the artificial drying time. A certain percentage of oil too is removed in the process which makes the product suitable for certain markets such as confectionery, though not for the general trade. These investigations have been carried out with a view to effecting improvements in heat economy and hygiene in drying methods currently used in Ceylon.

It may be useful at this stage to consider briefly certain by-products of the desiccated coconut industry. The parings which amount from 12–15 per cent of the kernels are always dried and pressed for oil, yielding about 55 per cent in a good expeller. *Parings oil* has a somewhat different composition from that of ordinary coconut oil and has acid values higher than usual for commercial coconut oil. Parings oil is mostly used in local soap-making. Though *parings poonac* has approximately the same formal analytical composition as ordinary poonac, it is generally believed to be better than the latter as a stock feed as its vitamin content is reckoned to be higher.

In most desiccated coconut mills the mixture of wash-water and nut water is run into baffle settling tanks. The scum which rises is collected and when boiled down and pressed yields a low grade red coloured oil usually referred to as " drain oil " and a *press-cake* with high fertilizer value. The writer has been successful in evolving a method for bleaching drain oil to a water white colour by combined treatments with a Fulmont activated earth and charcoal. It is felt that the process could be applied economically for the refining of drain oil, if the free fatty acids in the original oil are partly neutralised by alkali treatment prior to bleaching operations.

When desiccated coconut is pressed, there is obtained about 65 per cent of pure white oil. The residue which corresponds to poonac from copra can be ground to a suitable degree of fineness to form *coconut flour* which is sometimes marketed. Using a mixture with 50 per cent wheat flour it has been found that very satisfactory cakes could be prepared. Coconut flour is richer than wheat flour in protein and coconut protein is considered to be biologically superior to that of cereal flours. The unsatisfactory keeping qualities of coconut flour however is a great defect and its manufacture on a commercial scale would depend on complete removal of the oil by solvent extraction. The presence of any residual oil would make it difficult to grind to powder besides impairing its keeping qualities.

The kernel of the coconut contains all three of the major food constituents protein, fat and carbohydrates required in human and other animal nutrition, though it is not an equally good source of all of them. On the whole the coconut is not regarded as a good source of vitamins. Fat soluble vitamins A and E, but not D have been reported in the kernel and oil but none of these is present in sufficient quantities. It is also believed that certain water soluble vitamins are present in coconut cake.

In discussing the subject of coconut kernel reference should be made to the substance known as *coconut milk* which is the white, creamy emulsion obtained by pressing the fresh grated kernel. It is used commonly in the preparation of oriental foods and for culinary purposes in Ceylon households. It contains a good deal of the constituents of the kernel without so much of the indigestible fibre. Available analytical data on a typical sample show that coconut milk may be expected, to contain about 52 per cent moisture, 27 per cent oil, 16 per cent carbohydrate, 4 per cent protein and 1 per cent mineral substances. It cannot satisfactorily be used as a substitute for cow milk owing to its deficiency in vitamins and certain mineral substances.

## COCONUT WATER

Coconut water which is frequently and less accurately referred to as 'milk' in the literature is the fluid inside the hollow of the coconut and is really the *liquid* endosperm of the fruit which has become 'water' the fats having been largely absorbed. It plays an important role in the ripening of the fruit and in germination, and its composition changes during these processes. In the unripe fruit the cavity within the endosperm is entirely filled with coconut water, which diminishes progressively in volume as the fruit ripens, and on long storage or during the advanced stages of germination the liquid is completely absorbed by the nut. The water from the tender coconut has a pleasant sweet taste and is a refreshing drink.

The concentration of total solids in coconut water at the earliest stage of its appearance is about 2 per cent which increases gradually as the nut ripens, reaching a maximum at about the seventh month (just before the deposition of solid endosperm) and again declines. Before the water finally disappears during germination it has been found to contain about 2 per cent of total solids as at the beginning. Sugars are the most important organic constituents in the water, and the literature contains conflicting statements on the nature of the sugars in coconut water.

Comprehensive studies on the sugars, and the fermentation products of coconut water have been made by *Child* and *Nathanael*[35] and [36]. It has been established that in the 'Kurumba', i.e. at the 5-6 month stage at which the nut water is commonly drunk as a beverage the concentration of sugars is near or at its maximum consisting almost entirely of easily assimilable invert sugar. Nut water samples from Malayan dwarf palms and fancy King Coconut varieties have also been examined and found to show during development a similar cycle of changes to the tall palms, but the sugar concentrations at the maximum were somewhat higher. It could be said that at the drinking stage the total sugars would amount to over an ounce per fruit and there is little reason to doubt that they consist of glucose, fructose and sucrose (cane sugar), Large volumes of coconut water from ripe nuts are run off as a waste product of copra and desiccated coconut manufacture. As against 5 per cent of total sugars in the kurumba, the water from ripe nuts contains only about 2 per cent. In agreement with previous workers, it has been concluded that it cannot be regarded as an economic source of sugar or alcohol. The possibility of using these effluents for the propogation of yeast and bacteria which are employed in the manufacture of antibiotics is an interesting speculation and appears to warrant investigation.

The principal inorganic constituent of nut water is potash. The work of *Salgado*[37] has shown that the potash content of coconut water is markedly influenced by potash manuring. On an average the water from 1,000 mature nuts could be expected to contain about 0.5 lb. of potash. It would thus be useful for sprinkling compost heaps which would thereby become enriched with potash, a constituent in which composts intended for manuring coconut palms are sometimes deficient. The water could also be applied directly as a fertilizer to coconut palms preferably after neutralizing with slaked lime.

A number of figures for *ascorbic acid* (vitamin C) in coconut water have been reported and they range from 0.7 to 3.7 mg/100 ml. *J. M. Venderbelt*[38] has also published figures for the vitamin B complex. In general, it can be said that though small quantities are present, coconut water is really a meagre source of vitamins. As a beverage, the water of the unripe coconut has the advantage of being sterile. It contains a modicum of easily available sugars, but it is not otherwise of any particular nutritive value.

## PRODUCTS OF THE SAP

'Tapping' is the term applied to the operations connected with the artificial extraction of the juice of palms. In the coconut palm it is the tender unopened inflorescence which is tapped. The exudate of sweet juice drawn this way can be used as a fresh beverage or converted into various products such as alcoholic drinks, sugar, treacle, jaggery and vinegar.

Though there can be very wide divergence in the yield of sap, it is usually reckoned for purposes of commercial tapping in Ceylon that a coconut palm would yield about one-fifth of a gallon (909 ml.) of toddy per day. The writer, based on careful yield records[39] has found that much higher yields (averaging 1,700 ml. per day) could be obtained from selected palms during an eight month tapping period. In spite of certain advantages, the dwarf variety of the coconut palm has been found to be uneconomical in Ceylon as a source of toddy for industrial utilization.

In considering the composition of the sap from the coconut palm, it is important to distinguish between the fresh unfermented juice usually referred to as 'sweet toddy' and the sap in various stages of fermentation called 'toddy'. Variations in the quality of the sweet-toddy (especially with regard to sugar content) have been observed by many workers and the weather perhaps is the principal factor affecting its composition, because it is known that during the rainy season the sap is usually more dilute. The juice of the palm really compares, very favourably with the sugarcane, not only regarding its sugar content but also in purity. According to *Norris*, *Viswanath* and *Nair*[40] the fresh sap is supposed to contain 15 per cent of cane sugar and one per cent of glucose. Other observers, including the writer have found in the perfectly fresh sap only very small quantities of reducing sugars, and cane sugar concentrations ranging between 12 and 18 per cent. As a representative working average, 15 per cent of sucrose could be adopted as a reliable figure. Apart from the sugars the sap also contains about 25 per cent of non-fermentable matter containing 0.5 per cent of ash and 2 per cent of organic solids including proteins, fat, gummy substances and minor constituents.

Of the mineral constituents, it will be interesting to note that 0.2 per cent is potash which remains unaltered throughout both processes of alcoholic and acetic fermentations of the sap. One other very important minor constituent which should receive mention in this connection is vitamin C or ascorbic acid. This occurs in sweet toddy to as great an extent as 3 parts per thousand and does not appear to be affected by alcoholic fermentation. *H. N. Banerjee*[41] has reported 16 to 30 mg. of ascorbic acid per 10 ml. of fresh toddy and states that the content did not change after spontaneous fermentation for 24 hours. He further mentions that of all the plant saps examined the juice from the coconut palm was found to be the richest source of ascorbic acid. Besides this, fermented toddy is also stated to provide supplies of the complex of vitamins now grouped under the letter B, particularly $B_2$. Their presence has not been demonstrated in the unfermented sap, but probably they are derived from the growing yeasts which cause the fermentation. Investigation of toddy yeasts as a source of these B vitamins and calciferol is very desirable.

**Coconut Treacle and Jaggery (Gur)** — Knowing that sweet toddy is essentially a water solution of sugar, the preparation of treacle or jaggery (crude sugar) is merely a process of concentrating the sugar by evaporation of water. By suitable means the process could also be carried a step further to obtain pure crystalline cane sugar. Though technically the project is possible, economically the manufacture of sugar from coconut toddy would prove fantastically too expensive unless tapping costs could be considerably reduced.

Sweet toddy is used in Ceylon for the manufacture, mostly as a cottage industry of treacle and jaggery. Coconut treacle in particular by reason of a certain flavour of its own commands a fair price but one not at all related to the value of its sugar content. During World War II enhanced sugar prices proved an opportunity for fostering treacle and jaggery making as palatable products in their own right, though not as industrial raw material.

Laboratory investigations have shown that to obtain coconut treacle of the proper consistency, the sweet toddy should be concentrated so that there is about 75-80 per cent of cane sugar in the finished product. On the basis that the sucrose content of the raw material is 15 per cent it would be evident that the sweet toddy would need to be concentrated 5 to 5½ times. In other words about 5 to 6 bottles of sweet toddy would yield a bottle of treacle. It has been found that a clear product resembling 'golden syrup' could be obtained if proper care is exercised during the boiling down process. Clarification with hyflo-supercel would yield a clean product but satisfactory results can be obtained by first straining the toddy, boiling down partly, allowing the sediment formed to settle out and then pouring off the clear thin syrup. This may have to be repeated once or twice during the boiling down. Owing to difficulty of controlling the heat from an open fire a sand bath has been found very satisfactory. Heating by means of steam towards the end of the operation has been found to give the best results, but in the cottage it is difficult without the necessary equipment. The use of slightly fermented toddy causes some inversion, and has been found to prevent the deposition of cane sugar crystals.

The principal flaw in village prepared coconut treacle is its dark colour resulting from caramelization of sugar due to overheating. The above method of preparation prevents this decomposition and gives a clear product with a pleasing golden colour. However, coconut treacle refined in this way appears to be less palatable to local tastes than the unrefined product. It is thought that the process of refining removes to a certain extent the particular flavour characteristic of the syrup.

The principal difference between treacle and jaggery making is that in the latter procedure the strained sweet toddy is boiled down to crystallizing point when the partly caramelized sugar sets to a solid. Allowing for losses; the yield of jaggery would be somewhat lower than the percentage of sugar in the fresh sap and could be expected to range between 12 and 15 per cent. From fairly good sap at least one-twelfth its weight of jaggery should be recoverable without difficulty, and its quality would of course depend altogether upon the care with which it is made.

Well prepared coconut jaggery can be far superior to palmyrah jaggery. As made locally however, it is dark in colour, containing a good deal of foreign matter and is indeed not a clean product. In addition, it has little keeping power and quickly runs into molasses when stored.

The writer has observed that though 'Hal' bark (Vateria acuminata) can be satisfactorily employed as an anti-ferment in treacle-making it is not satisfactory when the sweet toddy is to be used for jaggery manufacture. The bark merely retards fermentation but does not arrest it completely. The presence of enzymes produced during, even a small degree of fermentation impairs the setting qualities of the resulting jaggery very much. In the case of treacle however, it has already been pointed out that a little inversion is an advantage. Coating the inside of the collecting pots with freshly slaked lime has been found the most efficient method in jaggery manufacture, provided the quantity used is carefully adjusted and any excess removed by alum treatment prior to boiling down.

The use of stocking filters for straining any suspended impurities and cleaning out the collecting vessel with a little copper sulphate solution have been found to greatly improve the quality of the finished jaggery.

The possibility of manufacturing refined sugar from sweet toddy has been much discussed. The whole prospect breaks down on the question of collection and tapping costs. The problem of collecting the sap in quantity and in an unfermented form to a central refinery is a major one which would also involve considerable changes in excise policy. The possibility of jaggery made on a cottage scale being collected and refined at a central factory would again be faced with the insuperable problem of costs, far in excess of harvesting and crushing an equivalent amount of sugar cane.

**Fermented Toddy** — The sap of the palm as usually collected for sale in taverns, or the manufacture of arrack and vinegar is in a state of active fermentation owing to the action of micro-organisms collected from the surroundings and is referred to as toddy. Though the composition of toddy would actually depend on the precise state of fermentation of the juice, *Browning* and *Symons*[12] on the basis of the examination of 50 samples as sold over the counter at taverns in Ceylon, found on an average 5.4 per cent alcohol (V/V), 0.51 per cent acidity (as acetic) and 1.012 specific gravity. The figures (especially the low alcohol) indicate that the samples examined were incompletely fermented. The writer has found in fully fermented samples (as collected for arrack and vinegar manufacture) alcohol contents ranging between 6.0-7.5 per cent (V/V). Laboratory studies however have shown that if modified methods of collection and fermentation are employed very much higher alcohol recoveries could be obtained from the sap and in fact one sample has been found to yield as much as 10.3 per cent (V/V) of alcohol. These studies have conclusively shown that wasteful losses of valuable alcohol take place in the current method of tapping and handling employed by the existing fermentation industries in Ceylon.

**Arrack** — The alcoholic liquor produced by the distillation of fermented toddy is called arrack and is prepared in many coconut growing countries, notably the Philippines and Ceylon. As the process of distillation is one of concentrating alcohol by separating it as vapour from the watery base and condensing the vapour, arrack contains none of the minor constituents of toddy except small quantities of volatile compounds which give it its flavour. Ordinary arrack is now bottled and sold at $40^{\circ}$u.p. (34.2 per cent V/V), after maturation for a period of five years.

Before 1924 arrack distillation in Ceylon was carried on in about 250 small pot stills of a primitive type giving a very inferior spirit. It is now carried on in ten large distilleries, eight of which are privately owned, one run on a co-operative basis and the other worked directly by Government.

Some improvements in the quality of Ceylon arrack resulted since certain modifications in the procedural details prior to distillation were introduced with the new excise policy of 1924. Insistence on the distillation of toddy without undue delay before acetification has started; a system of graduated straining of the toddy, and greater cleanliness in operation have been mainly responsible for these improvements. These refinements also relate to certain features which are capable of being checked by chemical analysis, such as acidity and the presence of traces of deleterious metals such as copper. It will be obvious that if toddy distilled is stale, some of its alcohol will have been acetified, and not only will the yield of arrack be reduced, but the product will tend to be acid since acetic acid is volatile and distils over with the alcohol.

Between 1939 and 1942 an extensive and successful series of experiments were carried out jointly by the Coconut Research Institute, the Excise Department and the Government Analyst, on the production of an improved grade of arrack by double distillation. On the basis of these experiments which were carried out at a distillery, a satisfactory operational schedule has been evolved for the manufacture of double distilled arrack, which is now being produced and sold at a strength of $27^{\circ}$ u.p. (41.6 per cent V/V). The collateral laboratory investigations, have also been very useful and have added considerably to our knowledge of the chemistry of arrack. It will be interesting to mention that some of the minor constituents which give its flavour have been isolated and identified. As with treacle it has been found that over-refining gives an insipid neutral or 'silent' spirit owing to the removal of the flavoury substances along with the undesirable ones. Whisky, brandy, gin and rum have their own characters and a good arrack should take its place among them on its own merits.

The economic arguments against toddy as a base for sugar manufacture apply with even more force to the production of power alcohol. It has been found that about 20 gallons of toddy (at Rs. 2/- per gallon) would be required to produce a gallon of rectified spirits (90 per cent alcohol). For internal combustion engines rectified spirits will not serve; power alcohol must be 99 per cent pure, and costs much more than rectified spirits to produce. Even though technically there are no difficulties about making power alcohol from toddy; as long as tapping costs are high, it must certainly remain an expensive base and manifestly unsuitable for this purpose.

**Vinegar** — Nearly every writer who has dealt with the subject of the useful products of the coconut alludes to the vinegar prepared from the juice. Coconut toddy vinegar when well made is reported to be of good strength and colour of the highest keeping qualities and very superior flavour.

It can be stated that the coconut vinegar industry in Ceylon has not progressed much since 1924, when it was first brought under proper excise control. A survey of the quality of vinegar produced by the existing industry, has revealed that much improvement is necessary both in methods of production and the quality of the manufactured product. In the writer's opinion, the chief difficulty experienced by vinegar makers appears to be their inability to get proper acetification of their toddy, due partly to lack of control during processing and partly to the fact that the present method of manufacture is not ideally suited for commercial production.

It has also come to light that in a number of factories wasteful loss of alcohol and acid takes place owing to injudicious handling of the raw material during the various stages of manufacture. Where producers are unable to get their product to contain over 4 per cent acid of biological origin by genuine brewing, then they resort to malpractices and wilful sophistication for the purpose of compliance with legal definitions of standard.

Fourteen different brands of locally manufactured genuine coconut toddy vinegar were examined by the writer, and the volatile acidity (as acetic) was found to average 3.89 per cent ranging between 3.07 per cent and 5.13 per cent. Only six out of the fourteen samples passed the minimum acid requirement of 4.0 per cent. It was also found that the residual unoxidised alcohol in the samples averaged 0.97 per cent (V/V) ranging between 0.04 per cent and 3.11 per cent (V/V). In general the analytical results obtained in these studies coupled with visual observations revealed that the common defects in the local product were low acidity, low total soluble solids, incomplete acetification and sedimentation. The majority of the samples examined in these studies were also characterised by off-tastes and objectionable flavours in spite of their storage for protracted periods in wooden maturation casks.

Successful laboratory experiments followed by pilot plant trials have proved the possibility of using the continuous " Generator " process for the manufacture of high grade coconut toddy vinegar. Fifty charges of fermented toddy put through the laboratory experimental generator gave vinegar in 144 hours (6 days) with an overall acid strength of 7.26 per cent. This process shows great promise of removing the principal disabilities of the existing industry by combining speed of action and economy of labour with simplicity and ease of operation. As the process is continuous and takes place in a closed acetifier it is more hygienic than the ' VAT ' process employed at present, which attracts dust, flies, wasps and undesirable putrefactive organisms from the air. The saving of factory floor space could be estimated by the fact that a generator with a collection chamber capacity of 150 gallons will produce the same volume of vinegar per year as nine 1,000 gallon acetification vats. As the conversion of vats into generators does not present much difficulty, producers already in the industry employing the ' VAT ' process would not be involved in any heavy expenditure in adopting the 'Generator' process. Two vinegar makers in the island have already partly adopted the new process with satisfactory results and are taking steps for a complete change over in the near future.

The sap of the coconut palm and its products are a useful adjunct to the coconut industry and contribute several million rupees in excise duties to the Island's revenue. There is ample scope for concerted effort on the part of all concerned for the general improvement of the industries associated with these products.

## MISCELLANEOUS COCONUT PRODUCTS

Apart from the principal coconut products already considered, there are also numerous other minor products, some of which require brief mention.

The trunk or stem of the coconut palm is close grained, hard and heavy and is commonly used for rafters and ridge poles. It is hardly a commercial timber, though it has been used for ornamental purposes under the name 'porcupine' wood.

The fronds or leaves of the coconut palm have been put to many uses, the most important of which is in the making of thatching for houses. The stalks or butt-ends make good fuel and the midribs of the leaflets are tied into bundles and used as besoms or stiff garden brooms.

*Georgi* and *Teik*[43] give the average weight of a whole frond as 17 lbs. and on the basis of 14 fronds shed in a year from each of 50 palms on an acre, the removal of nutrients per acre by fronds annually is reported to be 32.5 lbs. nitrogen, 13.0 lbs. phosphoric acid, 35.5 lbs. potash 14.0 lbs. lime and 21.5 lbs. of magnesia. The results of *Salgado*[44] however indicate that there is a considerable amount of translocation of mineral nutrients from the fronds as they dry off, before they are shed, presumably to the growing parts of the palm.

*Sampson* (loc. cit.) gives analytical figures for the mineral constituents of coconut roots. Decoctions of the roots are reported to be astringent and to have been used medicinally in dysentery and in mouth washes and gargles.

According to *Mathews*[45] besides the fibre from the husk of the coconut, the leaf of the palm also yields a fibre that has considerable use in the manufacture of mats and slippers.

## CONCLUSION

The scientific investigation of coconut products is really a correlated study. In industrial practice the processing of the products of the fruit could very well form a continuous series of manufacturing operations interdependent on each other. Similarly with the products of the sap, unity of treatment and continuity of processing could very well lead to great economic saving.

From the agricultural point of view, the cultivation of the coconut palm has received considerable attention in the various countries where it is grown. It cannot be said however that the development of the subsequent industrial processes for the economic utilization of its products has received equal encouragement. The industry has a great wealth of raw materials which provide a unique opportunity for exploitation in directions hitherto untried and therefore ripe for the application of scientific method and research. Modern industry must have a scientific foundation, and the fundamental characteristics of coconut products must be further explored by scientific research, if knowledge is to be gathered for their development in new directions.

Though there is at present, vast empirical knowledge born of experience, yet the acceleration of the economic production of manufactured coconut products could only be achieved by more careful treatment of the raw materials. Some of the existing haphazard industrial methods in particular could be rendered more remunerative and made to cater for the dictates of modern requirements only by the introduction and application of modified and refined techniques of processing and manufacture. It is axiomatic that the *via media* is clearly scientific research and exploitation, and the successful application of the findings therefrom under practical conditions.

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