

## Seventy five years of research in processing and product development in plantation crops - coconut, arecanut and cocoa

**K.B. Hebbar<sup>1,\*</sup>, Pandiselvam R<sup>1</sup>, Shameena Beegum P.P.<sup>1</sup>, Ramesh S.V.<sup>1</sup>, Manikantan M. R.<sup>1</sup> and Mathew A.C.<sup>1</sup>**

ICAR-Central, Plantation Crops Research Institute, Kasaragod, Kerala, India

Corresponding author: hebbar.kb@icar.gov.in

### ABSTRACT

Coconut and arecanut are the major plantation crops and their cultivation has deep root in the culture and history of India. Cocoa is an understory crop of coconut and arecanut and is of recent origin to India. In order to enhance the production of coconut and arecanut in India number of committees and organizations were set up both during pre-independence and post-independence periods. These institutional mechanisms suggested research needs to enhance the productivity, better management of pest and diseases and marketing. However, it was rarely felt that there is a need for research on advanced processing and product diversification in India. During 1990s there was sufficient area expansion and steady increase in productivity that resulted in market glut leading to price crash thereby emphasized the need for value addition and product diversification so as to stabilize the price for the produce. Though value addition of plantation crop products is at its nascent stage in India, the recent innovations and the value chains systems developed can transform the farmers into entrepreneurs and can easily increase their income. There are well established organizations for research (ICAR-Central Plantation Crops Research Institute and State Agricultural universities), various developmental agencies [Coconut Development Board (CDB), Directorate of Arecanut and Spices Development (DASD)], funding sources (like central and state government schemes, NABARD etc.) and to implement these value chains, farmer producer organizations are being established in each producing states. In this review we present the research developments during the last 75 years on value added products and product diversification of coconut, arecanut and cocoa which can be effortlessly taken up as a cottage or small scale industries.

**Keywords:** value addition; plantation crops; food processing; machineries; industrial uses

### INTRODUCTION

Palms are among the best known and most extensively cultivated plant species native to tropical and subtropical regions of the world. Some of the palm trees native to India are coconut (*Cocos nucifera* L.), palmyra (*Borassus flabellifer* L.), date (*Phoenix dactylifera* L.), fish tail (kithul) (*Caryota urens* L.), pejibaye (*Bactris gasipaes* L.), arecanut (*Areca catechu* L.), sago (*Cycas revolute* Thunb.), royal (*Roystonea regia* (Kunth) O.F.Cook), oil palm (*Elaeis guineensis* Jacq.), fox tail (*Wodyetia bifurcata* A.K.Irvine), doum (*Hyphaene thebaica* (L.) Mart.) and aren palm (*Arenga pinnata* (Wurmb) Merr.). Most of these palms have been extensively used by humans for various purposes since time immemorial. The palms with the greatest importance in Indian commerce are the coconut and areca nut, both are primarily cultivated in south Indian coastal and hilly interiors. Coconut is the main source of vegetable

oil and fat, while arecanut is a stimulant but both possess a huge repertoire of biochemicals such as polyphenols, antioxidants, minerals and vitamins. In coconut the husk of the fruit is the source of coir, used for ropes and mats; the hard inner fruit layer (endocarp) is used as fuel and to make charcoal, cups, bottles, and trinkets; coconut "juice" or "water" (liquid endosperm) is a tasty beverage; the flesh (solid endosperm) is eaten raw or dried to form copra, a source of oil (widely used for food preparation and industrial purposes) and oil cake (cattle feed); the flesh may also be grated, mixed with water, and pressed to obtain coconut milk, used in food preparation and as a substitute for cow's milk. The sap obtained from tapping the inflorescence, or flower stalk, is drunken unfermented (*Kalparasa*<sup>®</sup> *neera*) or fermented (toddy) and is a source of sugar, vitamins, antioxidants and minerals. Trunks are used in

construction and furniture making, and leaves are used in a variety of ways in domestic economies. The nut of arecanut tree is used chiefly for chewing, which gives kind of pleasure for the chewers. Areca tree provides fodder for cattle, edible fruits, building materials, fuels and fibres. Cocoa is used to make chocolate milk, cakes, chocolate bars, chips and other confectionary items.

The evolution of research in plantation crops such as coconut, arecanut and cocoa has immense roots in the culture and history of the region where these crops are grown. Furthermore, the research and developmental facets of these plantation crops cannot be witnessed as a standalone aspect considering the intricate relationships these crops weave in the social fabric of the regions where it is cultivated. In 1950s the area under coconut and arecanut was only 6 lakh ha and 1 lakh ha, respectively with a corresponding production of 3281 million nuts and 80000 tonnes. Hence, the research priority during the period was to increase the productivity to meet the domestic demand for consumption. With the coordinated efforts of the research, the productivity of both coconut and arecanut started showing steady increase since 1990s which in combination with area expansion resulted in an initial steady and later glut in production (Fig.1). At present 22,000 million nuts of coconut is produced from 2.1 m ha area with an average productivity of above 10500 nuts /ha. The enhanced productivity during 1990s and the accompanying price crash had necessitated the need for value addition and by product utilization to increase the income from per unit area.

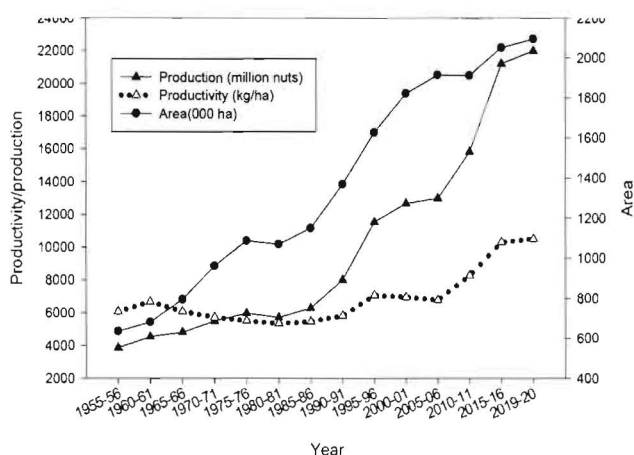


Fig.1: Area production and productivity of coconut (Source: <https://coconutboard.nic.in/statistics.aspx>)

A glimpse of traditional products of coconut at the global scale in the year 1993 reveals that coconut kernel-based

products, oleochemicals, raw materials for soap industry etc. were dominant. However, in the year 2018 it was observed that more than 100 diverse products are made available for the consumers (ICC Secretariat Presentation, Coconut for a better future, Vanuatu coconut summit-2019, Santo, Vanuatu). In order to promote research on plantation crops Central Plantation Crops Research Institute (CPCRI) was established in 1970 and the Central Coconut Research Station (CCRS) Kayamkulam and Central Arecanut Research Station (CARS) at Vittal, Karnataka were designated as Regional Stations. To further strengthen developmental activities Coconut Development Board (CDB) under the Ministry of Agriculture was established in 1981. A centrally sponsored scheme "Technology Mission on Coconut (TMOC)" was initiated in 2002 to encourage the production of value added products and their export. CDB had taken initiatives in the formation of Coconut Producer Societies (CPS), Coconut Producers Federation (CPF) and Coconut Producers Company by mobilization of small and marginal coconut farmers in contiguous areas.

Areca nut/betel nut (*Areca catechu* L.) is an important commercial crop cultivated through tropical India, East Africa, Far East Asia, and South Pacific. India is the major producer and consumer of arecanut in the world. The present global production of areca nut is about 1.214 million tonnes from an area of 0.958 million ha. India ranks first in both area and production. In India, areca nut is cultivated in an area of 473 thousand ha with an annual production of 703 thousand tones (Fig.2). Karnataka is the major producer as the state shares 59.32 % of crop followed by other major producers such as Kerala, Assam and West Bengal (Fig. 2). Although, the production of areca nut is localized in a few states, the commercial products are widely distributed across the country and are being consumed by all classes of people. Areca nut industry forms the economic backbone of nearly six million people in India and for many of them it is the sole means of livelihood. Compared to coconut the research progress on value addition and product development of arecanut is meager as a result even today more than 95% of the arecanut produced goes for chewing.

Since 1970 research in arecanut is conducted by the ICAR-Central Plantation Crops Research Institute at its Regional Station at Vittal and Research Centres at Kidu (both in the Dakshina Kannada district of Karnataka), Mohitnagar (West Bengal) and Kahikuchi (Assam) while the developmental portfolio rests with the Directorate of Arecanut and Spices Development (DASD), Kozhikode in Kerala. In fact, comprehensive R&D efforts in arecanut started as early as 1947 with the establishment of an ad-hoc arecanut committee by the ICAR to study the problems of arecanut industry and subsequently, the Central Arecanut Research

Station (CARS) was established at Vittal in 1956. Consequent to the establishment of the CPCRI in 1970, the CARS became the Regional Station of the Institute. Government of Karnataka and Kerala set up Central Arecanut Marketing and Processing Cooperative Limited (CAMPCO) in July 1973, for procurement of the bulk of the produce, for proper storage and timely release of produce coinciding with the demand. An expert committee constituted in 2001 to look into the market glut and the consequent unprecedented fall in prices and a great farmer distress recommended technical and financial assistance for the entrepreneurs to encourage / promote alternate uses of arecanut by-products such as arecanut stem, leaf sheath etc. for making disposable plates and cups, caps, umbrellas, curios and other products derived from arecanut. National Horticulture Board (NHB) was advised to fund for such projects.

Processing Co-operative (CAMPCO), during 1990's started procuring, processing and marketing cocoa products. From the year 2006 onwards, the domestic cocoa prices have become attractive with steady increase, and by the end of 2009, the prices have reached record high in comparison to the previous 31 years. In recent times, cocoa is fast spreading in states of Andhra Pradesh and Tamil Nadu. In the global production scenario, India is a very small player with the production share of a meagre 0.3%. It is mainly cultivated in four major southern states of Kerala, Karnataka, Tamil Nadu and Andhra Pradesh.

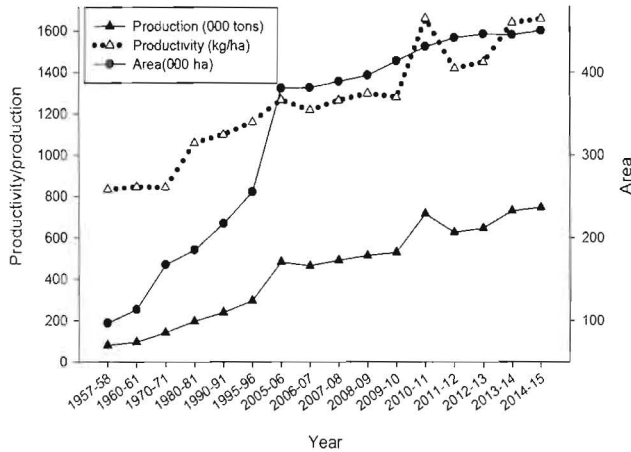


Fig. 2: Area, production and productivity of arecanut in India

Cocoa entered in India way back in 1798 and tropical diversified congenial climate in India especially in the southern part provided immense scope for its cultivation (Malhotra *et al.*, 2016). However, the cultivation on a commercial scale began only in 1970 and hence, cocoa cultivation in India is of recent origin. Since 1964, CPCRI has been continuously engaged in research on various facets of cocoa cultivation. The real commercialization phase of India's cocoa economy commenced post Independence in 1965, when the Cadbury India Private Limited started the direct involvement in promotion of the crop. At first, *Criollo* beans were cultivated and later when *Forastero* cocoa plants were brought in from West Africa, these *Criollo* trees were removed to avoid cross pollination. In the early 1970s, global cocoa prices soared and many plantations in Kerala began cultivating the trees. But, when the prices suddenly dropped within a decade or two, most of the cocoa planters moved to rubber and other crops. Central Arecanut Marketing and

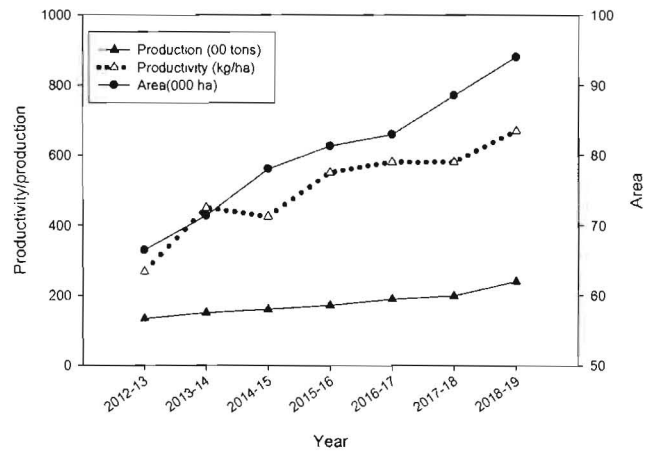


Fig. 3: Area production and productivity of cocoa (Source: www.dccd.gov.in)

The cocoa industry in the country has expanded to a considerable extent in recent years, with a production of 27,072 MT tonnes of cocoa from an area of 1,03,376 ha with an average productivity of 669 Kg/ha and contributing more than Rs.2,000 million annually to the national GDP (DCCD, 2021). Although the per capita cocoa consumption in India (0.04 kg/head) is meagre in comparison with major cocoa consumers, the consumption has been steadily increasing over the last 10-15 years, reflecting the increasing purchasing power of the expanding middle class segment in India. Taking into consideration, the present day consumption patterns and growth of confectionery industry in India at around 15-20 %, the demand for cocoa is likely to increase in coming years. The demand for cocoa by 2050 is projected at 212 thousand tonnes against the estimated supply of 121 thousand tonnes.

This review compiles the major value added and diversified products and processing machineries developed during the last 75 years for coconut, arecanut and cocoa in India.

### ADVANCES IN COCONUT PROCESSING

Even though India is a leading producer of coconut in the world scenario, the country has not attained a desired

product diversification. Coconut processing is confined to handful of sectors such as copra production, coconut oil extraction and desiccated coconut powder preparation in food industry. Besides, coir and coir-based products form another important component of coconut processing. Among the food processing sector, approximately 40% of coconut is utilized for culinary and religious purposes whereas 35 % is used for oil extraction via copra production and very miniscule proportion (6%) is being utilized in the manufacture of value added products (1% virgin coconut oil, 1% as coconut milk or cream, and 4% as desiccated coconut), 17% is consumed as tender nuts and 2% for coconuts are utilized in seedling production.

Unlike India, other Asian countries like Philippines, Indonesia and Vietnam etc., have ushered in an era of coconut product diversification utilizing state-of-the-art technologies available in food processing sector. The changes in food habits and introduction of cheaper edible oil alternatives including oil palm and soybean have led to the decline in use of coconut oil in food and edible oil sectors. Thus, a prime reason for sharp decline in the price of coconut and its products could be attributed to the greater dependence of this sector on the price of coconut oil which in turn is influenced by the international supply of other vegetable oils. In this context, diversification of coconut food products and processing technologies has an immense potential to achieve remuneration and to enhance the export of coconut based products.

Coconut serves as the basic raw material for a series of agro-processing activities and sustains the lively hood of over 10 million people in the country. Copra, Coconut Oil, Desiccated Coconut, Coconut Cream, Coconut Milk Powder, Virgin coconut oil, Coconut chips etc. are few among the products using coconut kernel as the raw material. Many of the unit operations involved in coconut processing was done manually till recently. These unit operations involved in the production process were all quite cumbersome and involves a lot of drudgery, especially for the women folk. The unfavourable benefit-cost ratio due to the high labour involvement was the major reason that prevented entrepreneurs from taking up the coconut processing technology. Research and development by private entrepreneurs and institutions in public sector led to the development of a series of machineries that could reduce the drudgery and made the coconut processing industry more competitive.

### Tree Climber

Climbing the coconut palm is an essential operation for various activities such as harvesting, cleaning, pollinating, sap collection and other research and plant protection-related

activities. Due to the its cylindrical structure and unbranched, single stem manually climbing on coconut is very difficult. Kushwaha and Singh (2015) reported that amongst the various models tested *Chemperi* model (pedal type) climbing device was found most suitable, for which CPCRI introduced a safety attachment device (Fig. 4). This safety attachment had eliminated the risk of falling down. Further, robotic type climber has also been developed and tested but were not successful up till now.



Fig. 4: Safety attachment device for coconut tree climbers

### Invention on sap collection and its value addition

Coconut sap, normally called as *neera* is the phloem sap from the unopened coconut spadix. It is a very good health drink, rich in sugars, protein, amino acids, minerals, antioxidants, and vitamins. ICAR-CPCRI developed '**Coco sap chiller**' collects fresh, hygienic and unfermented sap (Fig.5) (Hebbar *et al* 2015b) and is called as Kalparasa®. Coco-sap chiller is a light weight HDPE insulated portable device which is directly connected to the coconut and the ice cubes placed inside the box keeps the inner temperature low and thus collects the sap in its original form (Hebbar *et al* 2015a; 2015b) (Fig.5).



Fig. 5: Coco-sap chiller developed by ICAR-CPCRI for the collection of unfermented coconut inflorescence sap.

Kalparasa collected by coco-sap chiller under low temperature can be sold as fresh juice in local market with the adherence to quality standards prescribed by CPCRI. pH of the fresh sap is  $7 \pm 0.5$ . pH > 7 is ideal for promotion to health drink. Other quality parameters easily judged are degrees Brix around 14; color golden brown; and taste sweet and delicious (Fig. 6.). The collected sap can be stored for any length of time under sub-zero temperature. The sap gets frozen and just before use it is thawed to get the original liquid form. Dispensers are used to keep it cool in kiosks or *neera* hub for selling fresh sap (Hebbar *et al*

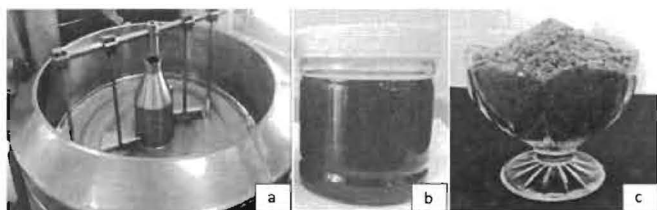


2018).

Fig. 6: Comparison of collection of coconut inflorescence sap by traditional method and coco-sap chiller method (a) Earthen pot connected to the unopened inflorescence to collect the sap; (b) Coconut sap collected by traditional method. (c) Coco-sap chiller; (d) Coco-sap chiller connected to the unopened inflorescence and (e) Coconut sap collected by coco-sap chiller method

### Kalparasa-product diversification and value addition

The hygienic, zero-alcoholic sap collected by CPCRI method is easy to process in a natural way without the use of chemicals into various value added products which fetches premium prices both in domestic and international markets. Very good quality coconut sugar, jaggery, nectar or syrup



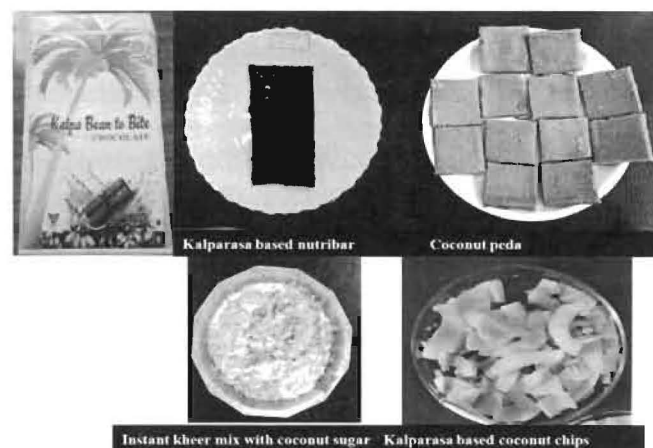
can be produced in double jacketed cookers with temperature regulation and stirring facility (Fig. 7.).

Fig. 7: Coconut sap concentrate and sugar are prepared by evaporating the moisture from the fresh sap. (a) Specially designed double jacketed cooker; (b) coconut sap concentrate and (c) coconut sugar

Coconut sugar is the best natural sweetener which possesses several health benefits - contains all essential amino acids required for protein synthesis; considerable amount of minerals like calcium, magnesium, zinc, iron and copper; rich in electrolytes like sodium and potassium; abundant in dietary fibers which normalizes bowel movements and digestion; rich source of phenolics which are potent and important contributors in reducing oxidative stress due to their antioxidant activity (Hebbar *et al* 2020). Moreover its

glycemic index is low and is in the range of 35 to 54 Gi/ serving and eating a low glycemic index diet reduces the risk of chronic diseases such as Type 2 diabetes.

From the coconut sugar, products like Kalpa Bar a coconut sugar based chocolate purely from plant based ingredients without milk is prepared. (Fig. 8.). Kalpa Drinking Chocolate is an instantised blend of low GI coconut sugar, crafted from fine cocoa powder formulated to produce the



delicious drinking chocolate. The product is soluble instantly in hot or cold milk releasing the chocolate aroma. Fresh Kalparasa based milk sweets are prepared in West Bengal (Hebbar *et al* 2017) (Fig. 8).

Fig. 8: Second line of products from Kalparasa and coconut sugar

CPCRI, Kasaragod has developed the complete production to consumption value chain from Kalparasa collection to either it to be sold as health drink or to be processed into value added products *viz.*, coconut sugar, jaggery, concentrate, syrup etc (Hebbar *et al* 2018). Also developed on campus training module for a minimum period of two to three days for those entrepreneurs who wish to collect Kalparasa and market it as juice or process into value added products. The technology has been commercialized to more than 55 entrepreneurs/ Coconut producer

Companies in almost all the coconut growing states and two patents and a trade mark have been granted (Hebbar 2021; Hebbar and Augustine 2021). The characterization of sap and its value added products for complete nutrient profile (Hebbar *et al.*, 2020) along with the documentation of technology know-how enabled the technology buyer to form FPOs and facilitated to obtain FSSAI certification for their products. Few of the start ups in Pollachi, TN and few firms in Karnataka had produced coconut sugar and selling in malls and online markets like Amazon, FlipKarts, India mart etc. Institute could also establish linkage with Industries for the manufacture of cocosap chiller and for

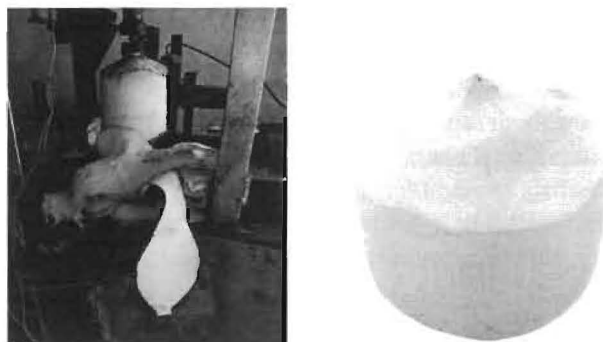
the production of dark chocolate and drinking chocolate using coconut sugar.

### Tender Coconut Processing

Tender nuts are predominantly utilized as such as nutritious beverages. The nutritional and therapeutic value of tender coconut water has resulted in increased consumption and demand globally. Although technologies are available for the processing of tender coconut water into packaged soft drinks, consumer preference is for the natural taste of tender coconut. ICAR-CPCRI developed tender coconut punch and Cutter in 2012 (Patent: 233744) which is safe to pierce the tender coconut and to cut open it after drinking the water inside (Manikantan *et al.*, 2018) over the traditional way of cutting using lengthy knife (Pandiselvam *et al.*, 2020a). ICAR-CPCRI in 2021 has developed an automatic cutting machine that is working based on the concept of conversion of rotary motion to linear motion which has further simplified this process. Further, tender coconuts are used in the production of different value added products such as snowball, chips, and frozen coconut delicacy. These tender coconut based products warrants harvest of the nuts at specific maturity stage. However, no tools/gadgets are commercially available to identify the maturity of the tender coconut.

Snow Ball Tender Coconut (SBTC) is a product developed from tender coconut having 8-9 months maturity. It is nothing but the soft white ball obtained after neatly removing the outer shell. The main unit operation in the snow ball tender nut making is to take a groove around the shell on its middle (Manikantan *et al.*, 2018). Then, the white kernel is scooped out from the tender nut without shell with the water inside intact.

The bulky nature of tender coconut can be reduced by trimming out the husk to leave it as two-third of the original weight (Pandiselvam *et al.*, 2020a) without damaging the shell (Pandiselvam *et al.*, 2020b). A minimum of 20–35% of the coconut weight can be reduced by performing trimming operation (Pandiselvam *et al.*, 2019; Pandiselvam *et al.*, 2021a). This not only ensures considerable reduction in the ratio of weight/volume of the nut but also results in an attractive look (diamond/pentagonal shape). ICAR-CPCRI has developed a linear actuator-based trimming machine for tender coconuts (Fig. 9). Nevertheless, browning and mold development in the nuts following the trimming process requires to be controlled with careful use of chemical solution without contaminating the kernel and the water (Pandiselvam *et al.*, 2020a). An image processing-based automatic tender coconut trimming



machine is required to be developed for large scale production of trimmed tender coconuts.

**Fig. 9:** Trimming Machine for the production of minimally processed tender nuts

The bottled tender coconut water has a great demand in worldwide. The CDB and Defence Food Research Laboratory (DFRL), Mysore has developed a technology for processing and packing of tender coconut water either in pouches and aluminum containers with a shelf life of 6 months (extendible upto 12 months under refrigerated conditions). The thermal treatments applied for the preservation of tender coconut water has a negative impact on the quality and flavor profile (Pandiselvam *et al.*, 2021b). In this context, different non-thermal food processing technologies such as ozone, cold plasma, ultraviolet, high-pressure processing, pulsed light, and ultrasound are being attempted to extend the shelf life of tender coconut water (Prithviraj *et al.*, 2021). However, the limitations of non-thermal technologies such as the high initial investment and non-availability of commercial scale equipments restrict their practical utility in industries.

### Processing of Matured Coconut

**De-husking** is the first post harvest operation in any coconut processing industry. Traditionally coconut is dehusked manually using a spike. 'Keramitra', the coconut dehusking machine developed by KAU is a very popular device in the households. However, it's extremely low output is a major constraint. A power-operated semi automatic coconut de-husking machine has been designed and fabricated at ICAR-CPCRI (Deo *et al.*, 2020a). The machine has a capacity to de-husk 200 coconuts per hour.

**Shell remover** has two concentrically rotating multi pointed circular blades and a stationary pointed blade on which coconut would be placed firmly are the major components of the shell removing machine (Deo *et al.*, 2020b). The machine has a capacity to remove the shell of 150 coconuts per hour. **Testa remover** can remove testa of about 75 coconuts per hour. Two **gratings machines** were

developed by ICAR-CPCRI to enhance the grating efficiency. First one is of single user and the second one is of multi user (four grating blades) type. The motorized coconut grating machines developed scrapes off the deshelled coconut flesh into fine gratings with the help of stainless steel blade. The single user machine has a capacity of 60 nuts/h and the multi user has a capacity 240 nuts/h.

**Pulveriser** is very important for the production of desiccated coconut powder and coconut milk. The coconut kernel pieces are fed into the hopper manually. The machine has a capacity of 250 nuts/h. Four different **milk extractors** are developed at ICAR-CPCRI to enhance the milk extraction efficiency. Two are manually operated and two are hydro-pneumatic. 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 the first machine the whole pressing process is done manually by rotating the handle. In the second machine an additional hydraulic jack is provided at the bottom (Manikantan *et al.*, 2018). Two hydro pneumatic coconut milk extractors of different capacities were also developed to enhance the extraction efficiency of coconut milk. The operation of both the machines is completely automated using a programmable logical controller. They are useful for large scale extraction of coconut milk in coconut milk processing industries and virgin coconut oil production centres. The smaller machine could handle 250 nuts/h where as the bigger machine can handle 500 nuts/h. 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 per hour and the double screw has capacity of 1000 coconuts per hour (Manikantan *et al.*, 2015). Various post-harvest machineries for the processing of coconut have been developed (Fig. 11)

### Value Added Products from Coconut kernel

Wet coconut kernel is generally utilized in households either in the grated form and as a milk or cream obtained by squeezing the gratings with or without the addition of water. To increase the shelf life of matured kernels to 4-6 months, small pieces of the kernels are preserved in hot syrup exhausted at 80 °C, sealed and processed. Alternatively the kernels are preserved in a 50 °C Brix syrup with 0.01% sodium metabisulphite as a preservative. Tender nuts are preserved in jelly-like consistency using refined sugar, packed and sealed in cans. Earlier, the preservation methodology utilized a mixture of butylated hydroxy anisole (0.1%) and propionic acid (1000 ppm) coupled with

modified atmosphere package system, or vacuum packaging. Even freeze-drying of coconut slices preserves the inherent flavor but cost of production escalates.

Matured coconut is mainly used for oil extraction and virgin coconut oil (VCO)-produced from freshly grated coconut endosperm milk- is a premium value added product with immense nutritional potential. A number of VCO production processes being followed in India and elsewhere cause variations in the physicochemical properties, which in turn potentially affect the nutritional and medicinal properties of VCO. ICAR-CPCRI has standardized the protocol and commercialized the technique to producing virgin coconut oil by hot and fermentation processing methods (Fig.10). Two types of VCO cookers (differing in their fuel sources-LPG/biogas or agricultural waste) were developed at CPCRI to extract the VCO by hot processing (Mathew *et al.*, 2014). VCO cooker developed by the ICAR-CPCRI consists of a double jacketed vessel filled with thermic fluid of capacity of 125 litre. However, a VCO cooker of any capacity can be fabricated by scaling up the design (Mathew *et al.*, 2014). Alternatively microbial fermentation process is also followed to recover oil from the skim milk and fermented curd. Screw pressing or hydraulic pressing of pulverized meat is also followed to extract VCO (Marina *et al.* 2009). The technologies developed for wet processing to recover oil are a) Krauss Maffei process developed in Germany utilizes centrifugation process to separate cream and water phases followed by processing of cream into oil with a recovery of about 89%. Further improvement in this process by CFTRI had led to enhancement in the oil recovery to 93%. Also the water phase or coconut honey is utilized for the preparation of processed foods such as infant protein food and cereal flakes (NIIR Board of Consultants and Engineers 2012). The physical and biochemical properties of VCO from the hot process (VCO-



Hot), fermentation (VCO-Fer), expelled from dried gratings (VCO-EDG), centrifugation (VCO-Cen), and conventionally

prepared copra coconut oil (CCO) and the required quality standards were documented (Ramesh *et al.* 2020).

Fig. 10: Virgin coconut oil (VCO) developed by ICAR-CPCRI

### Edible coconut flour

Coconut meat gratings, when partially defatted, forms an excellent source of nutritious ingredient for use in household, bakery or confectionary preparations. Relatively low fat content along with high proportion of protein, minerals and sugars, and as a rich source of dietary fibre, the product has appreciable acceptance among the consumers. CFTRI, Mysore, and National Institute for Interdisciplinary Science and Technology (NIIST-CSIR), Trivandrum, India has developed a process for the manufacture of edible flour. Coconut flour has relatively low digestible carbohydrate and high fibre contents (Banzon *et al.* 1990) and hence at least 5% of wheat flour and non-fat dry milk powder in school nutrition programmes without compromising the baking qualities and food value (Balakrishnamurthi 1979). Other value added products developed are nutribars, porridge, traditional sweets (*laddoo*, *halwa*), noodles, extrudates, pasta, muffin cakes and ready-to-eat food items such as coconut pickle and coconut chutney powder at ICAR-CPCRI and other national research organizations.

### Desiccated coconut powder (DCP)

It is white kernel of coconut of particle size less than 5 mm, processed to retain moisture content (<3%) following comminution and desiccation. DCP has demand all over the world as an important ingredient for fillings in various confectionary products such as chocolates, candies etc and in related food industries. Besides Sri Lanka, East Asian countries such as The Philippines, Malaysia, Indonesia, and others such as Fiji, Tonga, Côte d'Ivoire, Brazil and India are producers of DCP. The major consumers are North America, Western Europe and Middle East.

**Coconut chips** (also a patented technology of the CPCRI) are a ready-to-eat, snowy white crisp and healthy non fried snack prepared from 8 to 9 month old fresh kernel through osmotic dehydration in a forced hot air electrical dryer at 70-80°C for 5-6 h to less than 3% moisture content. The kernels undergo paring, blanching, slicing and osmotic dehydration to prepare ready to eat chips. Kernels are sliced using a slicing machine.

**Extrudate-based products:** Co-products of coconut processing industries such as coconut milk residue (CMR), virgin coconut oil cake, deoiled copra are obtained from VCO, coconut milk powder, coconut milk yogurt and flavored coconut milk based processing industries. Besides, rich source of dietary fiber and polyphenols, they are

presently either underutilized as animal feed or thrown as waste (Manikantan *et al.*, 2015). It was observed that 25% corn flour, 15% CMR flour, 220 rpm screw speed and 140 °C temperature gave an optimized product of 0.956 desirability (Pandiselvam *et al.*, 2018). Coconut haustorium-based extrudates i.e., incorporation of 20% coconut haustorium in rice (50%) and maize (30%) based extrudates resulted in healthy and nutritious products (Arivalagan *et al.*, 2018).

### Coconut-milk based products

Coconut milk from the kernel is processed to obtain milk concentrate, coconut cream and milk powder. In addition to its use in household culinary preparations, coconut milk is an excellent and nutritious substitute for dairy cream, preparation of white cheese, and yoghurts. Further, coconut milk is preserved either as a dehydrated whole milk, canned milk or cream in many countries including Philippines, Thailand, Indonesia, Western Samoa, Sri Lanka and Malaysia. The processing technology for preservation of coconut milk in India involves Pasteurisation at 75 °C to 80 °C for 10 min, addition of preservatives such as nisin, sodium metabisulfite along with the stabilizers such as carboxy methyl cellulose (CMC) and guar gum (Arumugham *et al.* 1993). The coconut cream serves as a fat source of skimmed dairy milk and infant milk powders.

Bottled coconut milk after treatment with 0.1% benzoic acid, and thermal treatment (117 °C for 3 min.) followed by cooling is a substitute for cow's milk widely used in many countries. Coconut milk is also marketed in the form of dry powder following dehydration utilizing spray dry process along with the addition of maltodextrin or casein (Muralidharan and Jayashree 2011). Alternatively, coconut syrup is produced using the homogenized coconut milk with the addition of sugar and citric acid (0.05%) or sodium phosphate (0.25%) in a steam cooking process to attain TSS of ~65%. This syrup is used in confectionary preparations or consumed as an instant drink when mixed with water or as bread spread (Sangamithra *et al.* 2013). Coconut honey could be produced by steam boiling the coconut milk mixed with 90% of sugars (60% of brown sugar and 30% of glucose) to achieve a thick consistency, golden brown colour product with nutty flavor that serves as an excellent base for soft drink preparation (Muralidharan and Jayashree, 2011). Coconut cheese is a nutritious product, which can be produced at house hold level units, by heating the skimmed milk with vinegar to coagulate the proteins followed by mixing with cream and kneading with salt (Ghosh 2015).

Coconut skim milk is a protein-rich soluble component of coconut milk obtained by separating the cream using a

separator devised by Texas A&M University, US. It serves as an important ingredient of various products namely spray-dried powder, coconut honey, coconut jam, fermented beverage concentrate, sweetened condensed milk and as a source of casein.

**Frozen coconut delicacy:** In view of increased demand for non-dairy products from ever increasing strict vegetarian and lactose intolerant population, ICAR-CPCRI has come out with a coconut based “Frozen Coconut Delicacy”, which is composed of coconut milk, coconut sugar/refined sugar, tender coconut water and pulp (Beegum *et al.*, 2021). It is a premium product which is completely natural and healthy. It is enriched with vitamins, minerals and healthy fatty acids. Due to lauric acid rich coconut milk and potassium rich tender coconut water, this will be a functional and nutraceutical food.

**Products from mature coconut water**

Coconut water from mature nuts is considered a waste produce in copra or desiccated coconut powder industries. **Coconut water concentrate (CWC)** is concentrated by adopting reverse osmosis technique and utilized by the end user industries such as food and beverage, hospitals, fermentation industries and research laboratories receive the product. Fresh coconut water, after the removal of solids and oil, could also be frozen or concentrated and canned as **frozen coconut water** for further use in the production of carbonated or non-carbonated beverages. Another product is **coconut vinegar** which enjoys preference as a preservative in pickling industry and as a flavouring agent for foodstuffs. **Coconut honey** is produced by evaporating the water followed by addition of golden syrup to form a nutty-flavoured sweetener that could

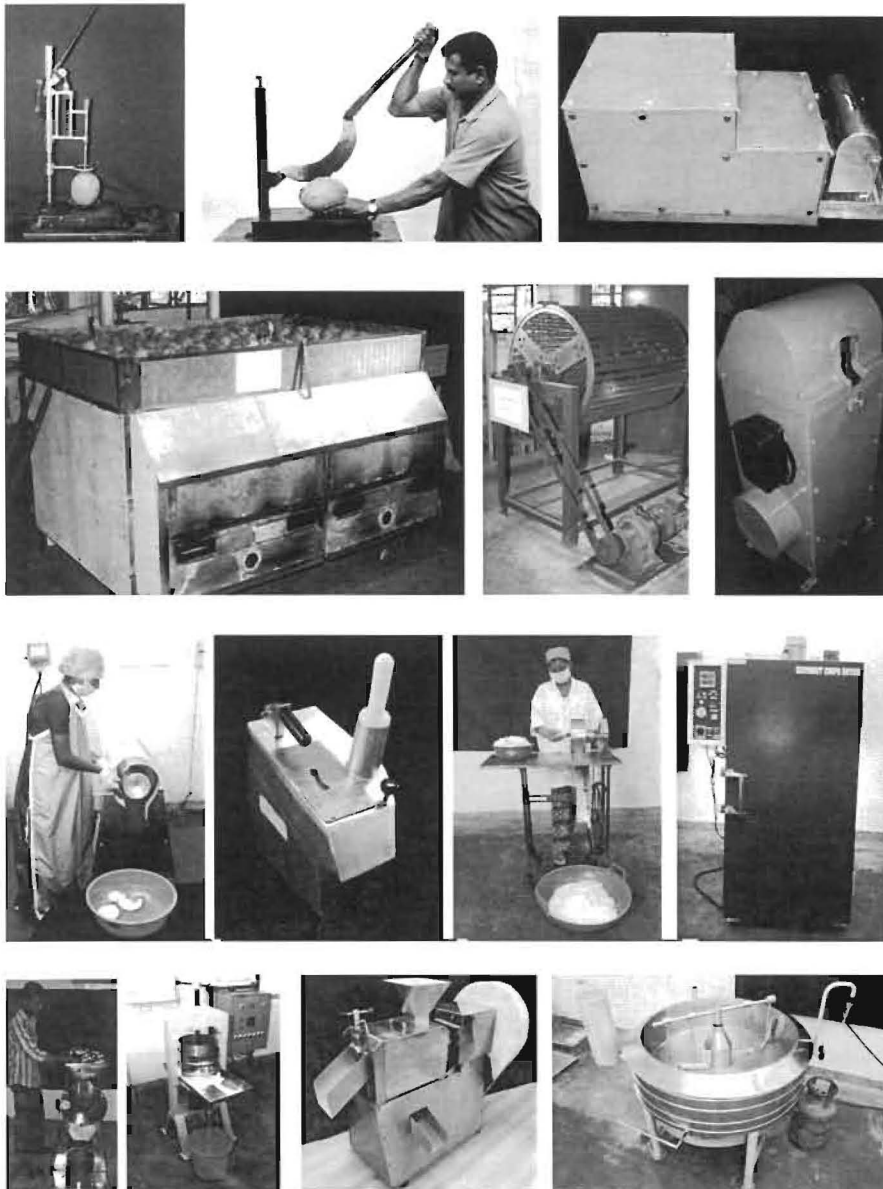


Fig. 11: Post-harvest machineries for processing of coconut and production of value added products

be an additive to breakfast food, and a soft drinks additive. **Nata de coco** is another flavoured delicacy in food industry and Philippines is one of the largest producers of nata de coco.

## ARECANUT PROCESSING, VALUE ADDITION AND PRODUCT DIVERSIFICATION

In India, arecanut is marketed as unhusked, whole fruit, dehusked and dried nut, boiled and dried whole kernel or their cuts. Nearly 20% of total areca production in the country is consumed as ripe fruit and the rest in the form of whole nut and processed forms (Chowdappa *et al.*, 2020). Market of semi ripe, fully ripe or fermented arecanut has enjoyed considerable value in Assam, Kerala and West Bengal. In Kerala, about 25% of the produce is marketed after harvest either at semi-ripe or fully ripe or fermented arecanut. About 70% of the production is converted into processed arecanut. In Assam 90% of the crop is consumed locally in the form of semi ripe, fully ripe or fermented arecanut (Mula *et al.*, 2015). The remaining 10% of the production are converted into processed arecanut. Bulk of the production in Maharashtra is in the form of ripe nut. In Goa, it is harvested only when they are ripened. About 92% of the production is converted into *Chali* and the remaining consumed as fresh nut or preserved in water for use in the off-season (Bhat *et al.*, 2017).

Arecanut dehusking is a labour intensive process as the nuts are to be cut into longitudinal sections or *choor* and transverse sections called *kottai* depending upon their maturity stages. However, rotary drum type mechanical dehuskers are available which has a capacity of 30kg/h (Kiran *et al.*, 2014). A semi-mechanical dehusker developed by Gandhi Krishi Vigyan Kendra (GKVK), Bangalore has the capacity of 160 kg per day reducing the drudgery to great extent. Similarly some of the local inventions of semi mechanized peeling machines have greatly assisted in reducing the drudgery involved in manual processing of arecanuts.

The boiled arecanuts are currently dried in open sun drying process for 8-10 days. Though metallic fabricated trays are used for drying the nuts, artificial dryers are also utilized when adequate sun light is not available. To expedite the process of drying, a solar-cum-biomass dryer was designed by Tamil Nadu Agricultural University which could reduce the moisture content of the nuts from 40% to 11% in 15 hours besides maintaining the quality parameters of the arecanut when compared to open sun drying process. Similarly, ICAR-CPCRI has developed solar and agricultural waste fired dryers capable of processing 50 Kg/batch and 150 kg/batch arecanuts, respectively.

The entire processing of raw arecanut deshuking, cutting, boiling and drying could be performed in a reliable and safe manner by adopting a recently developed Automatic Arecanut Processing Unit developed by Kumar *et al.*, (2019).

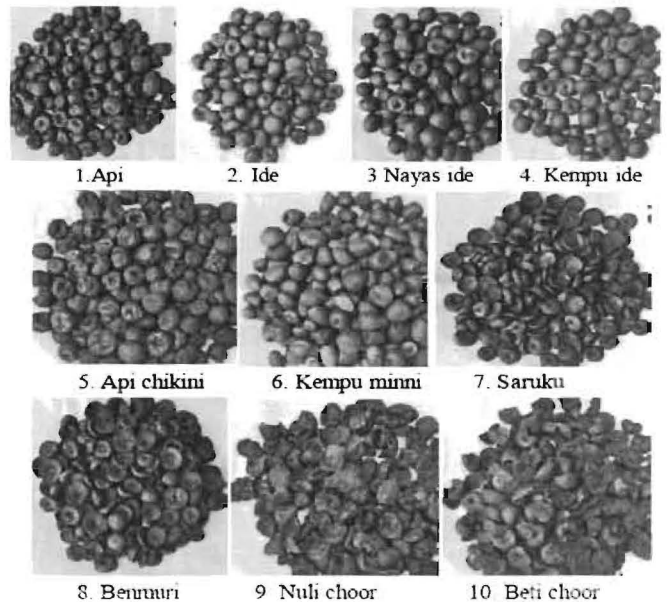
### Grading

Processed arecanut is sorted into different quality grades at the farm level before marketing. For example, farmers bringing nuts to Shimoga regulated market, grade the processed nuts in to three types, namely '*Hasa*', '*Bette*' and '*Gorabalu*'. The farmers producing *Chali* also undertake the grading at the farm level. For example, the farmers in the coastal districts classify *Chali* into '*Old Supari*', '*New Supari*' and so on. These grade specifications and designations are based on several quality attributes to meet the market demand to prepare value added end products in important centers spread across India (Fig. 12 and Fig. 13).



1.Mora 2. Moti 3. Sevardhan 4. Jam 5. Jeeni 6. Lindi

Fig. 12. Commercial grades of areca nut *chali*



1.Api 2. Ide 3. Nayas ide 4. Kempu ide

5. Api chikini 6. Kempu minni 7. Saruku

8. Benruuri 9. Nuli choor 10. Beti choor

Fig. 13: Some of the grades of processed arecanut

### Moisture content and water activity ( $a_w$ ) for safe storage

Appropriate moisture content for safe storage of arecanut is imperative hence a study conducted in ICAR-CPCRI sourced arecanut samples from different places during dry and rainy seasons, processed (red) and *chali* and their sub-

types. It revealed that the arecanut samples showed mean water activity  $a_w$  of  $<0.71$  (corresponding moisture content of  $<11.3\%$ ) which is safe and unlikely to cause nut deterioration during storage, that includes discoloration, musty odors, dry matter loss, tissue disintegration, nutritional and processing quality losses, and mycotoxin accumulation, due to fungal contamination. Hence, the arecanut growers, processing industries, quality standard organization like FSSAI must ensure  $a_w$  of  $<0.71$  for dried arecanut samples for its safe storage as well as safe for mastication (Hebbar *et al.*, 2021).

### As masticatory

The practice of chewing betel leaves after meals was mentioned in the Charaka and Sushruta Samhitas and Kashyapa Bhojanakalpa (75 AD to 300 CE) (Prakash, 1961). During c.730 to 1200 CE, chewing betel leaves with some spices after meals was a common custom. In 1654 CE, Niccolao Manucci referred to the habit of betel chewing and the use of *paan* by royals. Basavaraja, the King of Keladi, enumerated various locations for the best betel leaves and areca nuts in his treatise, *Shivatathvaratnakara* in c. 1700 CE (Desai, 1980).

Arecanut is either consumed alone or as a betel quid wherein betel leaf, slaked lime and others such as tobacco, catechu, spices and sweetness are included (Mathew *et al.*, 2014). In general a betel quid contains betel leaf, arecanut and slaked lime and may contain others like cardamom, saffron, clove, aniseed, turmeric, mustard or sweeteners. The different modes of consumption of arecanut are: (a) arecanut alone, (b) arecanut with betel leaf and any other ingredients except tobacco, and (c) arecanut with betel leaf and any other ingredients including tobacco. A variety of processed and packaged arecanut products are available such as (a) *pakku* or *supari* – processed, flavoured and packaged arecanut, (b) *pan masala* – a preparation of arecanut, catechu, cardamom, lime and variety of perfuming and flavouring materials, (c) *gutka* – it is a variant of *pan masala*, which in addition to these ingredients contain flavoured chewing tobacco. *Pan masala* and *gutka* are often sweetened (Anonymous, 2004). The rise of commercial pan masala and gutka about three decades ago caused an exponential growth in the sales of smokeless tobacco along with arecanut products besides developing export-oriented markets (Sushma and Sharang, 2005). It could be attributed to the portable, convenient and cheap packaging which further increased the shelf life of these products (Mathew *et al.*, 2014).

### Medicinal and pharmaceutical uses

Arecanut has greater importance in the ancient system of medicines such as Ayurveda, Unani and Homeopathy. The

seeds of arecanut have been widely used in clinical practices in China and other south and Southeast Asian countries. Since time immemorial, arecanut is being used for chewing as it is believed to have lots of medicinal properties. The potential and proven pharmacological uses of arecanut, applications in traditional medicine, are reviewed by Peng *et al.*, (2015). WHO has enumerated multiple beneficial effects of consumption of arecanut. Chewing arecanut sweetens the breath, removes bad taste from the mouth, strengthens the gums and checks perspiration. It has potent antioxidant, anti-inflammatory and analgesic, antiulcer, hypolipidemic, antidiabetic and neuroprotective properties. It is also traditionally used in a number of ailments for its laxative, digestive, carminative, antiulser, antidiarrhoeal, anthelmintic, antimalarial, antihypertension, diuretic, prohealing, antibacterial, hypoglycaemic, antiheartburn properties (Arivalagan *et al.*, 2020; Amudhan *et al.* 2012).

### Biochemical composition

Arecanut is characterized with diverse biochemicals namely nitrogenous compounds, vitamins, minerals, phenolics [including simple phenolics, condensed tannins, hydrolyzable tannins, no tannin flavans (e.g., catechin, epicatechin)], flavonoids, triterpenes, fatty acids (Peng *et al.*, 2015) and alkaloids such as arecoline, arecaidine, guvacoline, and guvacine, arecatemine A to C of pharmacological importance (Tang *et al.*, 2017). Alkaloids are characteristic components of *A. catechu*, and arecoline, with a content of 0.3–0.6%, is the main alkaloid. The predominant alkaloids are of the pyridine type and include arecoline, arecaidine, guavacoline, guavacine, arecolidine, ethyl N-methyl-1,2,5,6-tetrahydro-pyridine-3-carboxylate, methylnicotinate, ethylnicotinate, methyl N-methylpiperidine-3-carboxylate, ethyl N-methylpiperidine-3-carboxylate, nicotine isoguvacine), and homoarecoline. Tannins are another characteristic component of *A. catechu*, and the main types are condensed tannins (also called proanthocyanidins). Tannins are one of the main constituents that contribute to the perception of the taste of food (astringency and bitterness perception). Further many triterpenes and steroids have been reported.

The biochemical composition of marketed arecanut depends on the maturity of the nut since processed arecanut are made from both green and ripe nuts. Tender arecanut comprise around 30-37% of tannins, hence the tannins obtained as a byproduct (Shivasankar and Govindarajan, 1963). It has multiple utilities such as in drying leather, clothes, and rope, in the preparation of black writing ink, as an adhesive used in manufacture of plywood, and as food colourant (Swain *et al.*, 2016). The arecanut lipid obtained from the nut (~10-12%) could be blend with cocoa, following the refining process, to develop confectionary

products. Also, it can form a reasonable substitute for hydrogenated fat of plant origin used in the preparation of sweets. The furfural and xylose obtained from the arecanut husk fibre is relatively a good source for multiple industrial applications. The mineral matter contains calcium (0.05%) phosphorus (0.13%) and iron (1.5 mg/100 g). Arecoline has been a proven muscarinic cholinergic receptor agonist and hence it improves the conditions of Alzheimer presenile dementia. The development of arecoline-loaded transdermal patch with potential pharmacological effect suggests the untapped potential of arecanut (Wu *et al.*, 2014)

### Effect on human health

There are numerous reports to show that arecanut chewing might cause cancer. However, in a recent Interactive Workshop entitled 'Arecanut and Human Health' conducted at ICAR-CPCRI involving large number of medical practitioners were of the opinion that reports on the effects of arecanut consumption on human health are only observational and not based on any systematic scientific studies (Chowdappa *et al.*, 2018). The adverse effects reported in association with arecanut chewing might be due to several other factors such as small sample size, the role of other ingredients used in the preparation of betel quid, the quality of arecanuts (including contaminations and adulterations) used for making different preparations of chewing products, etc. Further, a survey conducted by ICAR-CPCRI during 2020 in traditional arecanut chewing belts of Karnataka and Kerala, further revealed that there was no significant difference in health of chewers and non-chewers (Jose *et al.*, 2020).

In addition, studies have showed that at lower concentration (1.5 to 5 g/kg body weight) arecanut found to arrest the growth and multiplication of several human cancer cells such as MCP-7 breast cancer cells, SGC-7901 gastric cancer cells and SMMC-7721 liver cancer cells (Anajwala *et al.*, 2010; Xing *et al.*, 2010). Certain studies carried out on both normal as well as immune suppressed laboratory mice for two years confirmed that the extracts of arecanut and betel quid without tobacco were not carcinogenic (Garg *et al.*, 2014). It was also reported that the betel quid ingredients from several Asian countries also did not induce any carcinogenic activity (Dunham and Herrold, 1962). In another study, consuming arecoline, the main alkaloid principle of arecanut, at a dose of 100mg/kg body weight per day was reported to be safe to Wistar albino rat (Wei *et al.*, 2015).

The antioxidant activity of arecanut might play active role in repairing DNA damage in cancer cells. The methanol extract of eight month old arecanut husk showed a dose dependent inhibition of comet formation (Phaechamud *et*

*al.*, 2009). In a recent study at the Winship Cancer Institute of Emory University, Atlanta, USA, the arecoline hydrobromide found to arrest the growth of cancer cells. It was reported that the arecoline hydrobromide inhibited the activity of the enzyme ACAT1 (acetyl-CoA acetyltransferase) which lead to attenuation of cancer cell proliferation and tumor growth in mice (Fan *et al.*, 2016).

All these reports confirm that arecanut in its pure form and at right dose is not dangerous but has got a plethora of medicinal properties including curing ulcers, wounds and even cancer. Most of its folklore medicinal properties are now validated by scientific evidences but still others need to be validated. Detailed studies on the nature of active principle(s) responsible for all these properties and clinical trials on them are warranted to utilize such plant products effectively and profitably as these palms are available in plenty in most of the South and Southeast Asian Countries.

### Agri-business opportunities

Several value-added technologies are available for arecanut by-product utilization such as making eco-friendly disposable plates and bowls from areca leaf sheath, leaf sheath fodder, oyster mushroom production from leaf and bunch wastes (Fig. 14) and vermicomposting. But only very few commercial (small-scale) ventures are operating at present. About 3.5 billion arecanut leaves and leaf sheaths are produced every year and have the potential to facilitate production of 0.3 billion kg of mushroom and Rs.7 billion worth areca leaf sheath plates and bowls (Patil *et al.*, 2019). Analysis of carboxy methylcellulose coated arecanut leaf sheath could be utilized as a suitable transparent packaging material (Disanayake *et al.*, 2021). Vermicomposting of arecanut leaf wastes per hectare can generate a net income of Rs. 20,000 and this can be taken up as a microenterprise, instead of the prevailing unscientific dumping of wastes in the plantations.



Fig.14: Utilization of leaf sheath for production of disposable plates and mushroom

Bio-softened arecanut husk fibres can be exploited commercially for the production of furnishing fabrics, textiles etc. by blending with cotton, viscose and polyester (Rajan *et al.*, 2005). It is also utilized in the preparation of reinforcing material having potential applications in construction, automobile and aerospace industries (Muralidhar *et al.*, 2019). But, efforts of developing commercially-viable technologies for products like tooth

brush, paper boards, plyboards, hardboards and plastics from arecanut husk mixed with conventional raw materials has to be taken up in collaboration with industrial R&D institutions. From a long term perspective, the fact remains that, in spite of early leads, not much progress has so far been made in taking them forward in to developing commercially-viable products/processes/business enterprises, which can change the destiny of this crop. Unfortunately, the only small consolation is the development of few small-scale industrial units making plates and cups from arecanut leaf.

## COCOA PROCESSING

Cocoa or cacao is popularly known as 'food of god'. The cocoa beans, the economic part of cocoa are derived from the mature cocoa pods and processed to get the end products such as chocolate, cocoa butter and cocoa powder. Cocoa butter is also used in moisturizing creams and soaps while cocoa powder is often used as chocolate flavouring. Cocoa is considered as a functional food because of its richness in terms of flavonoids, polyphenols and antioxidant properties.

### Post harvest quality of beans

The pre-harvest factors including genotypes, growing conditions or agro techniques, seasons, pollination, fertilization, pre and post harvest handling etc. influence the bean quality such as bean size, flavor etc. Bean size with respect to bean indices, moisture content, shelling percentage, nib or kernel recovery and fat contents add value to the marketable bean. Elite clones and hybrids are developed with rich bean qualities. Clones rich in polyphenols, procyanidins, fat, antioxidant properties etc. have been identified. Fatty acid profiles obtained from clones and hybrids are high in stearic acid. In the recent years, flavour improvement has been given importance in order to develop specialty chocolates with a blend of Criollo and Forastero beans. Bean size is highly varying with genotypes, changes in climate and processing which are to be taken care of in order to maintain the quality of the cocoa beans.

### Harvesting

Traditionally, farmers harvest cocoa using wooden mallet or poles and sickles. During 1980s, CPCRI, regional station Vittal has developed a cocoa harvesting tool to harvest the pods even from more than 2 m height (Fig.15). It eliminated the use of a ladder for climbing the tree and also performs the function of a sickle or knife used for harvesting pods which are at the lower branches and main stem (CPCRI, 1980).



Fig. 15. Cocoa harvesting using a) cocoa harvester b) sickle (Source: Apshara and Hubballi, 2013)

## Primary processing: Fermentation and drying

### Fermentation

Fermentation and drying of beans are the primary processing operations which require utmost care. Fermentation, drying and roasting are critical steps influencing the characteristic chocolate flavour. Despite the large scale cocoa plantations in the country, the process of fermentation suffers from many drawbacks. Even today, majority of the cocoa farmers sell the wet beans to the collection centers established by manufacturing firms. From 1980s onwards, CAMPCO has been procuring fruits/ pods instead of wet beans.

### Mechanization in fermentation

The primary and secondary processing facilities were created at KAU during 1995 under the KAU- Cooperative Cocoa Research Project (CCRP) (Peter, 2002). Attempts were made in India to develop small scale methods of fermentation such as mini box, mini basket, tray and heap methods using bean lots substantially smaller than those required for the standard methods. Later, small scale fermentation methods were standardized by KAU. The efficacy of some of the methods was also studied based on the pH of the beans and cut test (Kumaran *et al.*, 1981; Premalatha, 1983). For large scale fermentation, farmers follow heap, tray and box methods. Similar kind of small scale fermentation is practiced in ICAR-CPCRI, Vittal. The effect of fermentation methods on the quality of different accessions were also studied at Vittal (Amudhan and Apshara, 2015). The studies on the biochemical changes occurring during fermentation was well explored in international publications and in India. Of late in 2020, KCAET, Tavannur under KAU has developed a cocoa bean fermentor (Srikanth *et al.*, 2019) which needs to be popularized among the farming community (Fig.16). Generally fermentation completes within 5-7 days depending on season.

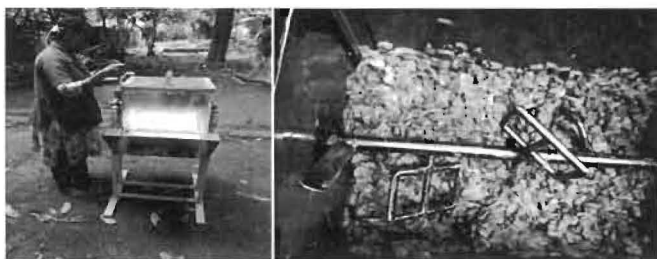


Fig. 16: Cocoa bean fermentor developed at KAU

**Drying**

The beans after fermentation are generally dried under sun which is the simplest and most popular method followed in most of the cocoa producing countries. In India, beans are dried on raised ground or on concrete floor and exposed to sun for about 4-12 days depending on the climatic condition. CPCRI has developed a small scale electrical drier of 40 kg bean capacity mainly to dry the bean during monsoon season which is the main harvest season for cocoa (CPCRI, 1980). Of late, cross flow electrical dryer is commercially available for drying of cocoa beans. Temperature in the drier is maintained at 70°C as quick drying results in increased acidity in beans. The moisture content of well dried beans is around 6-7%. Interrupted drying with short period of drying followed by longer resting period showed better migration of moisture to the surface during the rest period which resulted in good quality as mentioned by Asopa and Narayan, (1990).

Following drying, the beans are sorted manually or mechanically to remove flat, slate, shriveled, broken and clumped beans and other extraneous materials and packaged in polythene lined (150 – 200 gauge) gunny bags or jute bags. The International Standard recommends that the samples should amount to not less than 300 beans for every tonne of cocoa. For bagged cocoa, samples should be taken from not less than 30% of the bags, and for bulk cocoa there should be not less than 5 samplings per tonne. Bean counts are another measure of quality that producing countries often use, though there is no internationally accepted bean size classification (Fig.17).



2 to 3 days      3 to 4 days      4 to 5 days      > 6 days

Fig. 17: Appearance of bean during fermentation process

**Secondary processing**

Secondary processing involves the conversion of dried beans to chocolates and other products. The steps involved

in secondary processing are cleaning, roasting, kibbling/bean breaking, winnowing and grinding. Secondary processing is mainly done in big factories of Cadbury or CAMPCO. A small scale cocoa butter extractor was designed in India by way back in 1982 (Ganesan, 1982). Cocoa butter recovery is ranges from 50-58% (Peter, 2003) and fat content in the left over cake is ranges from 11-25%.

**Bean to bar chocolate:** Cocoa is an understory crop of coconut. A small farmer who grows both coconut and cocoa can prepare the chocolate using the well fermented, dried cocoa beans and coconut sugar with or without cocoa butter as a cottage industry and referred to as ‘Bean to bar’ chocolate and thus directly benefits the farming community (Fig.19). Lately, chocolate production with palm sugar has emerged as a healthy alternative and accords multiple health benefits due to low glycemic index (GI) of natural sugars. Dark chocolate with coconut sugar production protocol was optimized at ICAR-CPCRI. Due to higher proportion of cocoa and presence of natural sugar, bean to bar chocolates have high polyphenols, flavonoids, antioxidants and minerals.



Fig. 19: Bean to bite dark chocolate

Home level chocolate processing studies undertaken by the Kerala Agricultural University opened up way to utilize cocoa in the homesteads, ensuring women empowerment, improve income from unit area of land and make available farm fresh and natural chocolates at comparatively affordable prices (Suma and Minimol, 2018).

**By-products utilization**

Cocoa pod husk constitutes 70-80% of the pod weight which is generally discarded after collection of beans. Pod husk is utilized for pulp and paper production (Daud *et al.*, 2013). Mucilage is utilized for making fruit wine. Cocoa sweating is also used for making alcohol and vinegar. Cocoa shell is another by-product of cocoa (12-25% recovery from beans). Both cocoa shell and cocoa husk contain

phytochemical compounds which are potential to inhibit the growth of pathogenic bacteria in food products (Kayaputri *et al.*, 2020). Cocoa butter extracted from discarded cocoa beans, with little or no commercial value, can be used in the production of toilet soap and body pomade.

## CONCLUSION

Though mechanization could reduce drudgery involved in all unit operations in coconut processing involvement of human labour could not be avoided. This human intervention in each processing operations make the production line rather slow and costly. Automation of these unit operations from de husking to the final product would be the future strategy for coconut industry and research institutions. In arecanut the effects of arecanut on human health are found to depend on the dose of arecanut and mode of administration. At a normal or lower dose either areca nut extract or the arecoline is found to be safe. The off-target effects of areca nut and other chewing products containing areca nut might be due to their high doses or application in unusual manner like injection, direct exposure to cultured cells or due to several other factors such as contaminations and adulteration, the effect of other ingredients of betel quid or pan masala and the food habits of individuals etc. Hence, the future research objectives shall explore the metabolic profile of arecanut in order to identify novel biomolecules offering immense health benefits. A non-thermal based commercially viable technologies need to be optimized for the shelf life extension of coconut beverages. In cocoa domestic supply chain of cocoa in India is still in rudimentary stages. CAMPCO and Cadbury India Ltd (now Mondelez India) are the major procuring agencies in India, who are directly procuring the cocoa beans from farmers. The value share of the producer / farmer is a meager 32% because most of the farmers sell the produce as wet beans, even without doing minimal processing. Drying yards, primary processing facilities, and storage facilities are lacking in the case of most of the cocoa farmers. Since the stringent food safety standards and trace back systems are evolving in international arena, it is a real challenge to establish robust procuring system in the upstream end of the cocoa value chain in the country. Focus is needed to establish village level primary processing units and capacity building for fermentation and drying of cocoa beans with the formation of strong farmer aggregates, women SHG's and rural youths.

## Acknowledgements

The authors gratefully acknowledge the funding for this study from Indian Council of Agricultural Research (ICAR) (ICAR-CPCRI Project No: 1000766014).

## REFERENCES

- Amudhan, M.S., Begum, V.H and Hebbar, K.B. 2012. A Review on phytochemical and pharmacological potential of *Areca catechu* L. seed. International Journal of Pharmaceutical Sciences and Research, **3**: 4151-4157.
- Amudhan, M.S., and Apshara, S.E. 2015. A comparative study on antioxidant activity and biochemical profile of exotic cocoa (*Theobroma cacao* L.) clones. Journal of Plantation Crops, **43**: 231-235
- Anajwala, C.C., Patel, R.M., Dakhara, S.L. and Jariwala, J.K. 2010. In vitro cytotoxicity study of *Agave americana*, *Strychnos nuxvomica* and *Areca catechu* extracts using MCF-7 cell line. Journal of Advanced Pharmaceutical Technology and Research, **1**: 245-252
- Anonymous, 2004. IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. Betel-quid and areca-nut chewing and some areca-nut derived nitrosamines. IARC Monogr Eval Carcinog Risks Hum **85**, 1–334. PubMed
- Apshara, S.E. and Hubballi. V.N. (2013). Cocoa to chocolate (Training manual). CPCRI Regional Station, Vittal, Karnataka. 12p
- Arivalagan, M., Manikantan, M. R., Yasmeen, A. M., Sreejith, S., Balasubramanian, D., Hebbar, K. B., and Kanade, S. R. 2018. Physiochemical and nutritional characterization of coconut (*Cocos nucifera* L.) haustorium based extrudates. LWT, **89**: 171-178.
- Asopa, V.N. and Narayanan. S. (1990). Cocoa Production and Marketing in India. Oxford & IBH Publishing Co. Pvt. Ltd. 50-78pp
- Balakrishnamurthi, T.S. (1979). Correspondence with D.E. Peters cited in Tech. Data Handbook on the coconut. Philippine Coconut Authority, Philippines
- Banzon, J.A., Gonzalez, O.N., de Leon, S.Y., Sanchez, P.C. (1990). Coconut as food. Philippines Coconut Research Development Foundation, Philippines
- Beegum, P. P., Nair, J. P., Manikantan, M. R., Pandiselvam, R., Shill, S., Neenu, S., & Hebbar, K. B. 2021. Effect of coconut milk, tender coconut and coconut sugar on the physico-chemical and sensory attributes in ice cream. Journal of Food Science and Technology, **10**: 1-12.
- Bhat, S.K., Pandiselvam, R. and Jaganathan, D. 2017. Processing and Value Addition of Arecanut. In: Product Diversification in Plantation Crops (Eds: M. R. Manikantan and P. Chowdappa), Today and Tomorrow Printers and Publishers, New Delhi, pp 119-134.
- Chowdappa, P, 2020. Arecanut. Today & Tomorrow's Printers and Publishers, New Delhi. pp.304. ISBN-9788170196648, 8170196647
- Chowdappa, P., Hebbar, K.B. and Ramesh, S.V. 2018. Arecanut and human health. Current Science, **115**:1025-26
- CPCRI. (1980). A knife for harvesting cacao and a small drier for cacao beans. Pamphlet. No. 15. Central Plantation Crops Research Institute, Kasaragod. Kerala. 10p.
- Daud, Z., Kassim, A. S. M., Aripin, A. M., Awang, H., and Hatta, M. Z. M. 2013. Chemical composition and morphological of cocoa pod husks and cassava peels for pulp and paper production. *Australian Journal of Basic and Applied Sciences*, **7**: 406-411.
- DCCD, 2021. Production scenario of cocoa. <https://www.dccd.gov.in/Content.aspx?mid=20&tid=1> Retrieved on 26.12.2021.
- Deo, M. M., Mathew, A. C., Manikantan, M. R., and Hebbar, K. B. 2020a. Performance evaluation of semi-automatic coconut dehusking machine for West Coast Tall variety of coconut. International Journal of Current Microbiology & Applied Science, **9**: 3187-94.
- Deo, M. M., Mathew, A. C., Manikantan, M. R., & Hebbar, K. B. 2020b. Performance evaluation of power operated coconut de-shelling machine for different varieties of coconut: Evaluation of Coconut De-shelling machine. Journal of Agricultural Search **7**: 154-157.
- Dissanayake, D.G.K., Weerasinghe, D., Perera, T.D.R., Bandara, M.M.A.L., Thathsara, S.K.T. and Perera, S. 2021. Waste Biomass Valor, **12**: 5725–5742. <https://doi.org/10.1007/s12649-021-01382-5>

- Dunham, L. J and Herrold, K. M. 1962. Failure to produce tumors in the hamster cheek pouch by exposure to ingredients of betel quid: histopathologic changes in the pouch and other organs by exposure to known carcinogens. *Journal of the National Cancer Institute* **29**: 1047-1067.
- Fan, J., Lin, R., Xia, S., Chen, D., Elf, S.E, Liu, S, *et al.* 2016. Tetrameric acetyl-CoA acetyltransferase 1 is important for tumor growth. *Molecular Cell*, **64**:859-874
- FSSAI. 2021. Revised standards of Chocolate and FSSAI Registration for chocolate Manufacturers. <https://fssaiindia.in/fssai-food-safety-license-registration-for/chocolate-manufacturers/> Retrieved on 27.12.2021
- Ganeshan, V. 1982. Development of small scale equipment for extraction of cocoa butter and production of cocoa butter and production of cocoa powder. M.Tech. Ag.Engg. Thesis, Kerala
- Garg, A., Chaturvedi, P. and Gupta, P.C. 2014. A review of the systemic adverse effects of areca nut or betel nut. *Indian Journal of Medical and Paediatric Oncology*, **35**:3-9 <https://dx.doi.org/10.4103%2F0971-5851.133702>
- Ghosh, D.K., 2015. Postharvest, product diversification and value addition in Coconut. In: Sharangi A., Datta S., (eds) *Value Addition of Horticultural Crops: Recent Trends and Future Directions*, 125-165. Springer, New Delhi.
- Hebbar, K.B., Manikantan, M.R. and Chowdappa, P. 2017. Kalparasa to boost rural economy. *Indian Horticulture*, **62**: 71-74.
- Hebbar, K. B. and Augustine (2021). 'Cocosap chiller' Patent No 373309
- Hebbar, K. B., Arivalagan, M., Manikantan, M. R., Mathew, A. C., and Chowdappa, P. (2015a). Kalparasa collection and value addition. In Technical Bulletin no. 92, ICAR-CPCRI, Kasaragod, Kerala
- Hebbar, K.B., M. Arivalagan, M.R. Manikantan, A.C. Mathew, C. Thamban, G.V. Thomas, and P. Chowdappa. 2015b. Coconut inflorescence sap and its value addition as sugar—Collection techniques, yield, properties and market perspective. *Current Science*, 109: 1–7.
- Hebbar, K.B., M. Arivalagan, K.C. Pavithra, T.K. Roy, M. Gopal, K.S. Shivashankara and P. Chowdappa. 2020. Nutritional profiling of coconut (*Cocos nucifera* L.) inflorescence sap collected using novel coco-sap chiller method and its value added products. *Journal of Food Measurement and Characterization*, **14**:2703-2712.
- Hebbar, K.B., Padmanabhan, S., Ramesh, S.V., Bhat, S.K., Shameena Beegum, P.P., Pandiselvam, R., Manikantan, M.R. and Mathew, A.C. 2021. Moisture content and water activity of arecanut samples: A need to revisit storage guidelines. *Journal of Plantation Crops*, **49**:136-141
- Hebbar, K.B., Pandiselvam, R., Manikantan, M.R., Arivalagan, M., Beegum and P. S. and Chowdappa. P. 2018. Palm Sap—quality profiles, fermentation chemistry, and preservation methods. *Sugar Tech*, **20**: 621–634.
- ICC Secretariat. 2019. Coconut for a better future, Vanuatu coconut summit-2019, Santo, Vanuatu) (<https://unctad.org/meetings/en/SessionalDocuments/Opening%20-%20ICC%20Presentation%20-%20Santo%2030%20Oct%202019.pdf>)
- Kayaputri, L., Djali, M., Sukri, N and Fazaryasti, R. H. (2020). The antimicrobial effectiveness of cacao shell and cacao husk combination on inhibition of pathogenic bacteria in food products. *IOP Conf. Series: Earth and Environmental Science*, 443- 451. doi:10.1088/1755-1315/443/1/012077
- Kiran, K., Govind, A.K., Bandi, M. and Shivasharanayya. 2014. Design, development and testing of an areca nut dehusking agri-machine. *International Journal of Engineering Research and Applications*, **7**: 109-115
- Kumar Y., Louis, R.S., D'Souza, D., Floyd, S., Varghese, E.B. and Gopalakrishna, B.K. (2019). AIP Conference Proceedings 2080, 040010. Published Online: 08 March 2019 <https://doi.org/10.1063/1.5092928>
- Kumaran, K., Prasannakumari, S., and Nair, P.C.S. (1981). Experiments on small scale fermentation of cocoa beans. II. Effect of different factors for aeration on the extent of fermentation and quality of cured beans. *Proc. PLACROSYM III*. 125-137pp
- Kushwaha, H. L. and Singh, D. 2015. Development of Safety Attachment for Coconut Climbing Device. *Agricultural Engineering Today*, **39**: 9-15.
- Malhotra, S K., Hubballi, V.N. and Chowdappa, P. 2016. Augmenting Cocoa Production in India. *The cashew and Cocoa Journal*, **6**: 7-14.
- Manikantan, M. R., Arivalagan, M., Mathew, A. C. and Hebbar, K. B. 2015. Effect of process parameters on recovery of hot process virgin coconut oil and co-products utilization. *Journal of Plantation Crops*, **43**:139-144.
- Manikantan, M. R., Pandiselvam, R., Beegum, S. and Mathew A.C. 2018. Harvest and postharvest technology. In *The coconut palm (Cocos nucifera L.)—Research and Development perspectives* (eds. K.U.K. Nampoothiri et al.), Springer, Singapore. pp. 635-722.
- Marina, A.M., Che Mana, Y.B., Amin, I. 2009. Virgin coconut oil: emerging functional food oil. *Trends in Food Science and Technology*, **20**:481–487
- Mathew, A.C., Madhavan, K.A and Arumuganathan, T. 2014. Development and performance evaluation of virgin coconut oil cooker. *Agric Mech Asia Africa Latin America*, **45**: 56-59.
- Mathew, A. G. and Govindarajan, V.S. 1963. Polyphenolic substances of arecanut II. Changes during maturation and ripening. *Phytochemistry*, **3**: 657-65
- Mathew, P., Austin, R.D., Varghese, S.S. and Manojkumar, A.D. 2014. Role of arecanut and its commercial products in oral submucous fibrosis – a review. *Journal of Advanced Medical and Dental Sciences Research*, **2**: 192–200.
- Mula, G., Sarker, S.C. and Sarkar, A. 2015. Agri-business potentiality in arecanut processing: a study in the North Bengal districts of West Bengal. *Economic Affairs*, DOI: 10.5958/0976-4666.2015.00086.8
- Muralidhar, N., Kaliveeran, V., Arumugam, V. and Reddy, I.S. 2019. A study on areca nut husk fibre extraction, composite panel preparation and mechanical characteristics of the composites. *Journal of The Institution of Engineers (India): Series D*, **100**:135-145.
- Muralidharan, K., Jayashree, A. 2011. Value addition, product diversification and by-product utilization in coconut. *Indian Coconut Journal*, **7**: 4–10
- Pandiselvam, R., Khanashyam, A.C., Manikantan, M.R., Balasubramanian, D., Beegum, P.S., Ramesh, S.V., Kothakota, A., Nirai, V. and Shil, S. 2021. Textural Properties of Coconut Meat: Implication on the Design of Fiber Extraction and Coconut Processing Equipment. *Journal of Natural Fibers*. <https://doi.org/10.1080/15440478.2021.2009401>
- Pandiselvam, R., Manikantan, M. R., Balasubramanian, D., Beegum, P. S., Mathew, A. C., Ramesh, S. V., ... & Nirai, V. 2020b. Mechanical properties of tender coconut (*Cocos nucifera* L.): Implications for the design of processing machineries. *Journal of Food Process Engineering*, **43**: e13349. <https://doi.org/10.1111/jfpe.13349>
- Pandiselvam, R., Manikantan, M. R., Beegum, S., Mathew, A. C., Ramesh, S. V., Gopal, M., & Hebbar, K. B. 2020a. Preservation Protocol for Trimmed Tender Coconut. *Indian Coconut Journal*. p25.
- Pandiselvam, R., Manikantan, M. R., Subhashree, N., Mathew, A. C., Balasubramanian, D., Shameena Beegum, P. P., ... & Hebbar, K. B. 2019. Correlation and principal component analysis of physical properties of tender coconut (*Cocos nucifera* L.) in relation to the development of trimming machine. *Journal of Food Process Engineering*, **42**: e13217. <https://doi.org/10.1111/jfpe.13217>
- Pandiselvam, R., Manikantan, M. R., Sunoj, S., Sreejith, S., and Beegum, S. 2019. Modeling of coconut milk residue incorporated rice corn extrudates properties using multiple linear regression and artificial neural network. *Journal of Food Process Engineering*, **42**: e12981.
- Pandiselvam, R., Prithviraj, V., Manikantan, M. R., Beegum, P. S., Ramesh, S. V., Padmanabhan, S., ... & Khaneghah, A. M. 2021b. Central composite design, pareto analysis, and artificial neural network for modeling of microwave processing parameters for tender coconut water. *Measurement: Food*, 100015. <https://doi.org/10.1016/j.meaf.2021.100015>
- Patil, K.K.R., Chinnappa, B., Manjunatha, G.R. and Sowmya, H.S. 2019. Eco-friendly Arecanut Leaf Sheath Products: An Economic Analysis. *Indian Journal of Ecology*, **46**:431-436

- Peng, W., Liu, Y.J., Wu, N., Sun, T., He, X.Y., Gao, Y.X. and Wu, C.J. 2015. *Areca catechu* L. (*Areceaceae*): a review of its traditional uses, botany, phytochemistry, pharmacology and toxicology. *Journal of Ethnopharmacology*, **164**:340-356.
- Peter, K.V. 2002. *Plantation Crops*. National book Trust, New Delhi. 94-123pp
- Phaechamud, T., Toprasri, P. and Chinpaisal, C., 2009. Antioxidant activity of *Areca catechu* extracts in human hepatocarcinoma HepG2 cell lines. *Pharmaceutical Biology*, **47**:242-247.
- Premlatha T. 1983. Studies on the fermentation and curing of cocoa beans. MSc. (Ag.) thesis. Kerala Agricultural University, Thrissur, Kerala.
- Prithviraj, V., Pandiselvam, R., Babu, A. C., Kothakota, A., Manikantan, M. R., Ramesh, S. V., ... & Hebbar, K. B. 2021. Emerging non-thermal processing techniques for preservation of tender coconut water. *LWT*, **149**: 111850. <https://doi.org/10.1016/j.lwt.2021.111850>
- Rajan, A., Kurup, J.G. and Abraham, T.E. 2005. Biosoftening of arecanut fiber for value added products. *Biochemical Engineering Journal*, **25**: 237-242.
- Ramesh, S. V., Pandiselvam, R., Thushara, R., Manikantan, M. R., Hebbar, K. B., Beegum, S., & Shil, S. 2020. Engineering intervention for production of virgin coconut oil by hot process and multivariate analysis of quality attributes of virgin coconut oil extracted by various methods. *Journal of Food Process Engineering*, **43**: e13395. Doi: 10.1111/jfpe.13395
- Sangamithra, A., Swamy, G.J., Sorna, P.R., Chandrasekar, V., Sasikala, S., Hasker, E. 2013. Coconut: an extensive review on value added products. *Indian Food Ind Mag*, **32**:29-36
- Shivasankar, S., and Govindarajan, V.S. 1963. Equilibrium relative humidity relationship of processed arecanut and whole dried arecanut. *Food Science*, **12**: 317-321.
- Srikanth, V., Rajesh, G.K., Kothakota A. 2019. Physico-chemical and microbial changes in cocoa beans during different methods of fermentation. *Indian Journal of Ecology*, **46**: 154-159
- Suma, B. and Minimol, J.S. 2018. Scope of Entrepreneurial Development in Cocoa processing. In: *Entrepreneurship and Skill Development in Horticultural Processing* (Ed: Sudheer. K.P and Indira V). New India Publishing Agency, New Delhi. 189-213pp
- Sushma, C. and Sharang, C., 2005. Pan masala advertisements are surrogate for tobacco products. *Indian journal of cancer*, **42**: p.94.
- Swain, S., Din, M., Ram, C. and Gangaiah, B., 2016. Post harvest processing and value addition in coconut, arecanut and spices in Islands. In: *Integrated Farming Systems for Tropical Islands of India* (eds. B. Gangaiah and S. Dam Roy) pp.152-157.
- Tang, S.-N., Zhang, J., Liu, D., Liu, Z.-W., Zhang, X.-Q., & Ye, W.-C. 2017. Three new areca alkaloids from the nuts of *Areca catechu*. *Journal of Asian Natural Products Research*, **19**: 1155-1159.
- Wei, X., Zhang, J., Niu, J., Zhou, X., Li, J. and Li, B. 2015. Evaluation of arecoline hydrobromide toxicity after a 14- day repeated oral administration in Wistar rats. *PLoS ONE*, **10**: e0120165
- Wu P.-C., Tsai P.-J., Lin S.-C., and Huang, Y.-B. 2014. Formulation Optimization of Arecoline Patches. *The Scientific World Journal*, 945168, <http://dx.doi.org/10.1155/2014/945168>
- Xing, Z., Jiao, W., Zhuang, H., Wen-li, M. and Hao-fu, D. 2010. Antioxidant and cytotoxic phenolic compounds of areca nut (*Areca catechu*). *Chemical Research in Chinese Universities*, **26**: 161-164.