The Potential of Coconut By-Products to Foster Food Security and Sustainability in Sri Lanka

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Abstract Coconut (*Cocos nucifera* L.) is an important crop, mainly in the tropical and subtropical regions of the globe. It is one of the top ten useful trees in the world, providing food and non-food benefits to millions of people worldwide. As coconut is the second largest crop in extent next to staple crop 'Rice' in Sri Lanka, it plays a vital role in the household food security. The annual production of coconuts in the country is reported to be about 2.8 billion nuts, out of which 1.8 billion is used for household consumption, and the balance of 1 billion is being available for manufacture of coconut products. In recent times, factors like climate change, fragmentation of coconut lands, and prevalence of pest and diseases pose major risk for future coconut yield in the country. Maximizing the utilization of the coconut sector's by-products is proposed as a proactive approach to address coconut-based food insecurity in Sri Lanka. Coconut shell, coconut testa, coconut sap of the inflorescence, and mature coconut water released from factories are some of the by-products of coconut industry, showing great potential. Utilizing them for food purposes might entail various direct and indirect economic benefits and positive environmental impacts, while reducing disposal costs and increasing the value of the coconut tree.

Keywords Climate change impact · Coconut by-products · Food security · Sri Lanka · Sustainability

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1 Introduction

Coconut palm (*Cocos nucifera L.*), an important member of the family palmaceae, is grown in more than 90 countries worldwide, with a total production of 54 billion nuts per annum. Indonesia, being the world's largest producer of coconuts in recent times, contributed about 16,235 million nuts in the year 2018. India produced about 14,700 million nuts in the same year and became the second largest producer of coconut (FAOSTAT 2019). The steady growth of Indian coconut sector in recent times is mainly due to expansion of the cultivation into new areas as well as the increased productivity of coconut farming. The Philippines is the third largest producer of coconuts in recent times, but the world's biggest exporter of a range of coconut products (FAOSTAT 2019). Fresh coconut, desiccated coconut, copra meal, coconut milk powder, coconut water, liquid coconut milk, Nata de Coco, virgin coconut oil, etc., are some of the edible products, which bring large amount of foreign exchange to Sri Lanka.

Being a commodity, coconut plays a significant role as a means of livelihood and a source of national income to Sri Lanka. It is the second largest crop in extent in the country next to staple crop 'Rice.' The annual production of coconuts in Sri Lanka is reported to be about 2.8 billion nuts, out of which 1.8 billion is required for household consumption of fresh nuts, and the balance of only 1 billion is being available for manufacture of coconut products by industries (Dissanayeke 2005). In fact, the amount of coconuts remaining for industries to process various products is hardly sufficient in the present scenario. According to some estimates, at least 800 million more nuts are required to run the industries smoothly without shortage of raw material. A multitude of factors has remained as hurdle for the stagnation of nut production in Sri Lanka. The possibility of expansion of coconut cultivation beyond the traditional coconut triangle is limited due to various reasons. Climate change, fragmentation of coconut lands for other uses, and threats from pests and diseases are said to be some of the other significant factors which have contributed immensely to this situation.

1.1 Impacts of Climate Change

Climate change accompanied by extreme weather patterns is really a significant challenge to the entire agricultural system, both in Sri Lanka and elsewhere in the world. Since coconut is a rain-fed crop, climate change and extreme weather patterns would definitely affect the availability and utility of coconut in various spheres. Being a tropical country with seasonal rainfall, Sri Lanka has already witnessed the impact of drought on the annual nut yield. Particularly, the coconut cultivation in the dry and intermediate zones of Sri Lanka has been highly affected due to recurrent dry weather. According to data collected over several years, the inter-annual nut yield variation is well correlated with the rainfall pattern existing in the major coconut growing areas of Sri Lanka. As climate change impacts are expected to be prominent by 2050, there is likely a higher risk of drought-related water stress for coconut farming in Sri Lanka (Pathiraja et al. 2015). Past studies on climate change have showed the effect of daytime dry weather on the reduction of coconut yields. Based on coconut data from 1971 to 2001, about 60% variation in coconut production has been noticed due to climate-related factors. During the period from 1960 to 1990, an annual temperature increase of 0.016 °C has been observed across the whole country (Peiris et al. 2008). Not only the number of warm days and warm nights have increased, but also the average annual rainfall has dropped significantly during this period (Pathiraja et al. 2015). With the increase in temperature, the coconut yield has been severely affected. In order to ameliorate the severity of dry weather on coconut yield, the Coconut Research Institute of Sri Lanka recommended various counter-measures, such as mulching, rain water harvesting, and drip irrigation. The success of these measures depends heavily on the level of adoption by the stakeholders in the estate sector.

1.2 Impact of Land Fragmentation

Statistics of the past have shown that coconut occupies about 21% of the arable lands in Sri Lanka, which is almost 400,000 ha (Weerawardana et al. 2015; Pathiraja et al. 2015). Most of these lands are mainly concentrated in the districts of Puttalam, Kurunegala, and Gampaha due to various agro-climatic factors (Dissanayeke 2005). Coconut cultivation is tended to decline, especially in these three districts owing to a multitude of factors related to land fragmentation and lands being devoted for alternative uses. With the population growth, the demand for land to be used for housing construction and urban infrastructure development has steadily increased in the major coconut growing areas. Consequently, coconut estates are fragmented into small plots of land to create new residential areas and shopping complexes. While accomplishing this exercise, felling of coconut trees is done indiscriminately without giving due consideration for replanting in alternative areas. This trend has greatly contributed to the shortage of fresh nut availability for the local demand. Owing to a lack of coconuts, the coconut oil production was on the decline as producers of coconut oil were unable to run their factories in full operation. Although an expansion of the coconut cultivation had been reported in the dry-zone districts of Anuradhapura, Moneragala, and Polonnaruwa within the period 1982–2002, its contribution was still far below when compared to the increasing annual demand for coconuts (Dissanayeke 2005).

1.3 Impact of Pest and Diseases

Pests and diseases of coconut palms negatively impact the annual coconut production and food security in Sri Lanka. According to available studies, coconut palm is often attacked by a number of insect pests all around the year. Nearly 55 insect pests and mite species associated with the coconut palm have been identified in Sri Lanka (Fernando 2014). The tall nature of coconut palm poses a great challenge in conducting pest management practices effectively in the estate sector. The major pests of coconut such as coconut mite (*Aceria guerreronis* Keifer), coconut caterpillar (*Opisina arenosella* Walker1), red weevil (*Rhynchophorus ferrugineus* Olivier), Plesispa beetle (*Plesispa reichei* Chapuis), and black beetle (*Oryctes rhinoceros* Linnaeus) are prevalent in both the dry and wet zones (Fernando 2014). Among various pests, red weevil is widely considered as the most devastating insect pest, which affects coconut palms in most parts of the South and Southeast Asia (Kumara et al. 2015). Particularly, it can cause fatal damages to young coconut palms aging between 3 and 10 years. The coconut mite (*Aceria guerreronis* Keifer) is the next most important pest, which damages immature nuts of coconut palms causing serious yield losses. As coconut mite colonizes and feeds on the meristematic tissue beneath the bracts of the developing fruits, it would lead to immature nut fall and malformation of developing nuts. Previous studies showed that an economic loss of 10–13% would occur due to this pest attack (Wickramananda et al. 2007).

The leaf eating caterpillar known as *O. arenosella* is yet another serious pest of coconut which is prevalent in many coconut growing areas of the country. Extensive leaf damages by this pest lead to yield losses as this pest causes severe damage leading to the reduction of the rate of flower spikes and increases in the premature nut fall (Kumara et al. 2015). The black beetle, which is commonly known as rhinoceros's beetle, is prevalent in all parts of Sri Lanka all around the year. When compared to mature palm, young palms below five years of age are more prone to severe damages by this pest. The damages by the adult beetles feeding in the bud region of seedlings and young palms would cause severe setback in the growth of young coconut palms (Fernando 2014). Past surveys have already shown that 72% of coconut growers experience black beetle damage in their plantations (Peiris et al. 2006). Apart from pests, coconut palms are also vulnerable to plant diseases, such as leaf scorch, leaf wilt, and stem bleeding in recent years. A leaf wilt disease spread over the southern part of Sri Lanka during 2002–2006, affected roughly about 336,000 coconut palms (Wijesekara and Fernando 2013). As a short-term measure, most of these palms were uprooted to prevent the spread of this disease to other parts of the country.

2 Utilization of Coconut By-Products

2.1 Coconut Shell

Nutshell is one of the important components of the whole coconut. According to some estimates, per nutshell weight is about 12–14% of the total husked nut weight (Perera et al. 2014). As a solid by-product, coconut shell is reported to cause environmental unfriendliness to people living in major producing countries. It is a common knowledge that the coconut shell thrown in open yards is an ideal breeding ground for dengue mosquitoes. It is because of the fact that there is a high possibility for rain water being get collected in it. This may provide a conducive environment for the growth of mosquito larvae. When coconut shells are disposed by open burning, it will cause emission of greenhouse gases, known to contribute immensely to global warming.

Nevertheless, the negative environmental effects of nut shell can be minimized effectively by practicing more sustainable strategies. The use of agricultural waste receives more attention now due to the tendency to produce natural products from them (Raihana et al. 2015). The extraction of valuable bioactive natural products from agro-wastes has already been discussed extensively elsewhere in the literature (Kumar et al. 2017). In an early report, Thebo et al. (2016) demonstrated that the extracts of nutshell can be effective against human pathogenic fungi, including *Aspergillus niger, Aspergillus flavus, Trichophyton rubrum, Microsporum canis, Microsporum gypseum, Aspergillus fumigates, Trichophyton mentagrophyte,* and *Trichophyton vercossum.* The phyto-chemical constituents of the nutshell have been attributed to the above-mentioned bioactivities. Multiple reports have previously indicated that the major constituents of nutshell are cellulose, hemicelluloses, and lignin (Liyanage and Pieris 2015). The variability observed in chemical composition as well as the shell particle distribution was responsible for the mechanical and physical properties of coconut shell. The coconut shell particles as shown in Fig. 1, find applications in polymer and ceramic matrix composites, in activated carbon and charcoal powder production, and as filler in concrete reinforcement (Ikumapayi et al. 2020).

The nutshell has been the subject of several investigations leading to biofuel generation as well as production of activated carbons (Fig. 1). In many parts of Asia and Africa, the nutshells are used as a source of energy for industrial boilers while its usage as gravel for plantation road maintenance was remarkable. The nutshells are shown to be useful for the production of activated carbon, mosquito repellent coil, and as fillers in plastic. The ash of coconut shell consists mainly of chemical constituents, such as silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), and iron (III) oxides, which are known to react with the product coming from the cement hydration process, providing additional strength to cementation (Sareena et al. 2012). A comparison of strength characteristics between coconut shell and palm kernel showed that the concrete of coconut shell has greater compressive strength than that made with palm kernel shell when mixing in the same proportions.

Fig. 1 Coconut (**a**), nutshell (**b**), shell powder (**c**), and charcoal powder (**d**). *Source* Photo by the authors

The partial combustion of coconut shell will yield charcoal, which is an industrially important raw material for several high-value end products. As an alternative path for open burning, partial burning of nutshell can be possible in a properly designed heat recovery vessel. This would not only reduce air pollution, but also help reuse the heat dissipating from the partial burning. The released carbon monoxide from this process could generate ample amount of heat, if subjected to further burning. The steam activation of charcoal would produce activated carbon, which has multiple industrial applications. Activated carbon produced from charcoal is used in a broad range of applications from industrial to residential uses that include drinking water purification, ground and municipal water treatment, power plant, and landfill gas emissions. Among different agro-waste materials utilized globally, coconut shell is reported to have produced the highest amount of activated carbon (Ikumapayi et al. 2020). Charcoal is commonly used as a fuel by fast-food industries, since it is a promising replacement for normal coal due to high heat capacity and nice fragrance produced during burning. Coconut charcoal has also been confirmed for its efficacy as a natural tooth whitener, promising purifier as well as a moisturizer.

2.2 *Coconut Testa*

Coconut testa (CT), which occurs as an outer brown layer of the fresh coconut kernel, is a rich source of oil. According to some previous studies, it is the part of the coconut kernel where oil is more concentrated (Marasinghe et al. 2019; Adekola et al. 2017).

Fig. 2 A dehydrated sample of coconut testa. *Source* Photo by the authors

As the removal of testa from the kernel is a requirement for the processing of products such as desiccated coconut, coconut cream, and milk powder, a substantial quantity of testa is generated on a daily basis by coconut factories (Fig. 2). Based on the fruit component study by Perera et al. (2014), it is claimed that about 6500 kg of wet CT can be generated out of 100,000 nuts of Sri Lankan tall variety. Hence, it is worthwhile to pay attention to maximize the use of this bio-waste in productive applications.

The flow chart in Fig. 3 depicts some of the important steps involved in the recovery of oil from CT. Since testa is the part of the fresh kernel used for oil extraction, the oil extracted traditionally is known as coconut testa oil (CTO) (Marikkar and Nasyrah 2012). The dehydration of CT is usually done either by sun drying or kiln drying. Large-scale producers, however, use mechanized dryers for the same purpose. During the oil extraction, the dried testa is disintegrated into smaller pieces prior to feeding into oil expellers. The crude oil extracted is subsequently subjected to sedimentation and filtration (Fig. 3).

The CTO is in fact a unique oil which might be mistaken as an ordinary coconut oil produced from dried copra. Despite the differences in the quality indices, the CTO has been synonymously used with ordinary coconut oil by local traders. Owing to this reason, researchers in the past attempted the application of principle component analysis to fatty acid data to distinguish CTO from ordinary coconut oil (Marikkar and Nasyrah 2012). The general quality characteristics of CTO would be slightly different from those of copra-derived oil as shown in Table 1. Generally, the FFA content of CTO supplied by oil milling industry might exceed the limit shown in Table 1.

According to Table 1, the fatty acid composition of CTO is also slightly different from that of the ordinary coconut oil, especially with regard to some unsaturated fatty acids. The CTO is usually found to have higher iodine value mainly due to the

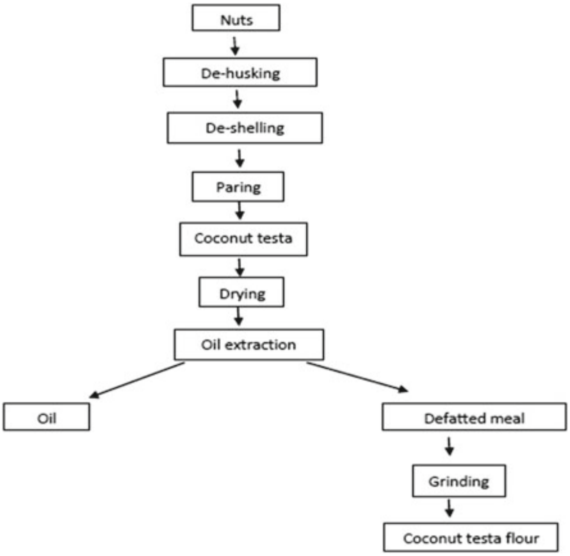

Fig. 3 Process flow chart of producing coconut testa oil and defatted testa flour

Table 1 Comparative chemical characteristics of ordinary coconut oil and coconut testa oil[1]

Parameter	Ordinary coconut oil	Coconut testa oil
Iodine value (Wijs)	7.6–10.0	15.5–16.9
Saponification value (mg KOH/Kg)	>250	>250
Unsaponifiable matter (%)	0.80	0.8
Free fatty acid (%)	<0.8	<0.8
Fatty acid composition		
C6:0	0.52	0.12
C8:0	4.50	3.14
C10:0	4.20	3.15
C12:0	48.60	38.60
C14:0	21.20	21.67
C16:0	9.10	12.67
C18:0	2.80	4.12
C18:1	5.80	14.22
C18:2	2.60	2.15
C18:3	Tr	Tr
MCFA (%)	57.82	45.01
LCSFA (%)	33.10	38.46

[1]Abbreviations: Tr., trace level, MCFA, medium chain fatty acid, LCSFA, long chain saturated fatty acid, *Source* Marikkar et al. (2007)

increased amounts of oleic ($C_{18:1}$) and linoleic ($C_{18:2}$) acids (Table 1). As a result, the oxidative stability of CTO is expected to be slightly lower than that of ordinary coconut oil. This feature should be given consideration when using CTO as a frying medium in preparation of foods meant to be kept on shelves for months. Food regulatory authorities operating in several countries have given guidelines regarding the tolerable limits of acid value and peroxide value in frying oils. During deep frying, the oxidation process becomes more vigorous and leads to the development of rancid smell in the fried products (Marikkar et al. 2007). In these situations, the addition of little amounts of anti-oxidants such as rosemary and sage extracts would be desirable.

The extraction of CTO, as depicted in Fig. 3, would lead to the generation of an edible grade defatted residue as a by-product. The defatted residue from CT could be crushed into powder form (CTF), which showed good functional properties (Marasinghe et al. 2021). A comparative analysis of the physicochemical and functional properties of wheat flour (WF) and CT flours [CTF] displayed differences in almost all properties including swelling capacity, water absorption capacity, oil absorption capacity, emulsion activity, bulk density, etc. (Table 2). As a noteworthy feature, the swelling capacity of CTF (30) was higher than WF (20). According to Suresh and Samsher (2013), swelling capacity of flour may be influenced by varietal differences, particle size differences, and processing methods. According to Table 2, the bulk density of CTF (0.66) was slightly higher than that of WF (0.49). The bulk density (g/cm^3) of flour is defined as the density measured without the influence of any compression (Chandra et al. 2015). Lam et al. (2008), previously stated that the bulk density of flour samples depends on particle size, density of individual particle, moisture, and surface characteristics, which are generally influenced by the preparation method. Undoubtedly, the preparation methods of CTF and WF were not similar as WF was cereal-based while CTF was non-cereal-based. According to Suresh and Samsher (2013), the high bulk density of flour suggests its suitability for multiple uses in food preparations.

The water absorption capacity of WF and CTF were 65% and 75%, respectively (Table 2). Berton et al. (2002) stated that the water absorption capacity is associated with protein and starch contents of flour. In fact, the protein and crude fiber contents of CTF were relatively higher than those of WF (Table 2). As the ability of protein to enhance the formation and stabilization of emulsions is important for many applications, information on emulsion activity of flour is beneficial (Cauvain and Young 2006). As shown in Table 2, the emulsion activity of CTF was lower (25) than WF (50). Some of the previous researchers found that the emulsion activity of flour would increase with higher amounts of soluble proteins (Garba and Kaur 2014) and reduce with fiber content. The increased crude fiber content, as noticed before in CTF, could be a probable reason for the lower emulsion activity displayed by CTF.

Foods with high dietary fiber content are highly regarded as diets for patients suffering from diabetes mellitus (Trinidad et al. 2001). According to some previous studies, the coconut flour from residue left after coconut milk extraction was reported to have 60.9% total dietary fiber, 56.8% insoluble dietary fiber, and 3.8% soluble dietary fiber per 100 g of flour (Gunathilake et al. 2009; Trinidad et al. 2001). Rushdah et al. (2022) found that CTF had 68.74–72.87% total dietary fiber, 53.18–55.85%

Table 2 Functional and nutritional properties of CTF and WF

Functional/Nutritional properties	Flour-type	
	CTF	WF
Swelling capacity (ml)	30	20
Water absorption capacity (%)	75	65
Oil absorption capacity (%)	52.7	58.50
Emulsion activity (%)	25	50
Least gelation concentration (%, w/v)	18	8
Bulk density (g/cc)	0.66	0.49
Moisture (%)	2.27	14.0
Ash (%)	4.50	1.82
Protein (%)	23.82	11.68
Fat (%)	10.17	1.91
Total carbohydrate (by difference)	59.24	70.59

Source Marasinghe et al. (2019) and Marikkar et al. (2020)

insoluble dietary fiber, and 13.65–18.05% soluble dietary fiber per 100 g of flour. This suggested its suitability in formulating low-calorie snacks and breakfast cereals for diabetes patients.

Cookies are hardly regarded as a healthy snack because of their high levels of rapidly digestible carbohydrate, high fat content, low levels of fiber, and only modest amounts of protein (Klunklin and Savage 2018). As the distribution of soluble and non-soluble dietary fiber of CTF is encouraging, Marikkar et al. (2020) investigated the substitution of WF with CTF in preparation of cookies. Wheat flour substitution up to 30% by CTF was possible without affecting the overall acceptability of cookies (Marikkar et al. 2020). With increasing level of substitution, the fiber and protein contents were increased while the amylose content and hardness of the cookies were decreased. In another study, formulations of string hoppers incorporated with CTF were done by mixing white rice flour (RF) with CTF in four different ratios: F_1 (RF: CTF = 70:30); F_2 (RF: CTF = 75:25); F_3 (RF: CTF = 80:20); and F_4 (RF: CTF = 85:15) (Rushdah et al. 2022). Likewise, the formulation of flat-bread rotti was done by mixing wheat flour (WF) with CTF in four different ratios: P_1 (WF: CTF = 60:40); P_2 (WF: CTF = 70:30); P_3 (WF: CTF = 80:20); and P_4 (WF: CTF = 90:10). According to sensory evaluation, the highest score of overall acceptability and other sensory attributes were observed for composite flour mixtures incorporated with 25% of CTF in rice flour for string hoppers (idiyappa), and 20% of CTF in wheat flour for flat-bread (rotti) (Rushdah et al. 2022).

2.3 Utilization of Mature Nut Water

Coconut water from young coconut is well known as a delectable drink to quench thirst. In contrast, the taste of mature nut water might differ considerably from that of the tender nut water due to changes in composition and other chemical parameters. With increasing maturity of nuts, pH of nut water might change and the concentration of total sugars may decline leading to the changes in sweetness (Ranasinghe et al. 2003). Even many more changes might be possible in the taste of the mature nut water collected from coconuts, which have undergone more than three weeks of seasoning. It is understood that the changes in pH and titrable acidity during prolong storage in open yards could be the probable reason. According to past experience, nut water released from copra, desiccated coconut, and milk-producing industries look turbid in appearance as the pH is found to be in the range of 6–7. As they are unpalatable, coconut processing industries are often compelled to discard them without any productive use. In most cases, nut water gets mixed with the process wash water of mills and discarded into nearby streams or ponds, leading to environmental pollution.

As mature coconut water contains about 2.5–3.0% sugar, it can be utilized as a fermentation substrate for producing vinegar. Since the amount of fermentable sugars present in the starting material is fairly low, it is needed to be supplemented with added sugar derived from low-cost sources. The vinegar production usually involves a dual-stage fermentation process, in which sugars are converted initially to ethanol by the action of yeast (*Saccharomyces cerevisiae*) in anaerobic fermentation. In the second stage of fermentation, the Acetobacter oxidizes ethanol into acetic acid (Gunathilake and Fernando 2007). Although the alcoholic fermentation step of the vinegar process is faster (4–5 days), the acetic fermentation step might take about 2–3 months for completion. To accelerate the vinegar formation, a generator process has been devised to maximize the surface exposure of fermented nut water into oxygen. This would enhance the air supply for acetobacter to oxidize ethanol into acetic acid efficiently. With the recycling of the stock solution, the total fermentation time can be reduced to 1–2 weeks. When the vinegar reaches its maximum strength, the acidity would be around 4%. The acetified vinegar is usually allowed to aging before bottling (Gunathilake and Fernando 2007).

2.4 Coconut Sap Liquid

A sugar-rich fluid called coconut sap drips out, when cutting the edge of an unopened inflorescence of coconut trees. This out-flowing sap can be collected either into a clay pot or a polythene bag (Fig. 4). The unfermented sap may contain sucrose, proteins, vitamins, and minerals. As the sap has about 13–15% of sugar, it may be converted into brown sugar, which is useful as an alternative for cane sugar used in Sri Lanka.

Fig. 4 Coconut sap collection from the inflorescence of coconut palm. *Source* Photo by the authors

Of the total sugars present in the fresh sap, sucrose is always the most dominant constituent, followed by fructose and glucose (Purnomo and Mufida 2004).

Naturally, the sap that drips out of the inflorescence might undergo hydrolysis by the invertase activity, which would negatively impact brown sugar formation. If the solid brown sugar product is desired from coconut sap, it may be necessary to take some precautionary measures to retard the invertase activity as well as fermentation. In the rural Sri Lanka, smoke curing and adding little slaked lime into the collection pot are practiced to prevent fermentation. This might have helped minimize the microbial activity by maintaining the pH of the sap within the basic range. Alternatively, sodium meta-bisulfide in place of slaked lime can be used for the preservation of coconut sap (Samarajeewa et al. 1985). Food additives, such as para-hydroxy benzoate, benzoic acid, and potassium sorbate are said to display some effectiveness in controlling the fermentation of coconut sap. However, the use of some of these substances in food applications is restricted on the grounds of food safety concerns. Hence, several plant materials are being used by village folk to preserve coconut sap during the time of collection. For instance, finely cut dried stem-bark of 'Hal' tree (*Vateria Copallifera*) is popularly used in Sri Lanka to preserve coconut sap. According to some studies, the dried exocarp of mangosteen (*Garcinia mangostana*) fruit could also be added into sap collection pot for the same purpose (Purnomo and Mufida 2004). The anti-ferment activity of these plant materials is believed to be related to some bioactive constituents present in them (Joze et al. 2008; Gunawardane et al. 1986).

Besides the preventive measures to arrest fermentation, it may also be necessary to cross-check the suitability of coconut sap before processing. Some studies showed that an instant acidity test using litmus paper would be useful in this regard. The coconut sap displaying a pH value above 5.5 would be ideal for producing solid brown sugar while those displaying below this value would be suitable for coconut treacle or brown syrup. For the production of sugary products, the preserved sap is boiled in open pans at 105 °C. When the boiling is continued uninterruptedly, the solution would normally become more viscous. Depending on the ratio between sucrose and reducing sugars, the sap may be turned either into brown sugar or sap syrup. On average, 150 g of brown sugar can be recovered from a liter of coconut sap. Brown sugar from coconut sap has been widely used as an ingredient in several Indonesian culinary preparations, mainly due to the specific taste and flavors imparted onto end products. For instance, it is an important ingredient for sweet soy sauce (kecap manis) and intermediate moist meat (dendeng) in Indonesia (Purnomo 2007). The sap samples displaying pH below 4 would have undergone considerable fermentation, and become suitable as a raw material for fermented products such as arrack and vinegar (Jayasekara 1997).

If coconut sap is left over a period of time, it may become fermented, leading to an alcohol drink locally known as '*toddy*.' This fermentation process proceeds through three steps: an initial lactic acid fermentation; a middle alcoholic fermentation; and finally acetic fermentation. Analysis showed that only sucrose, fructose, and glucose were detected during the early stage of natural fermentation lasting about 7 h (Xia et al. 2011). However, almost no sucrose was detected after 58 h of natural fermentation. The ethanol content increased significantly from day 1 to day 5 of fermentation and achieved its maximum of 90 g/kg at day 7, but it was found to be decreasing in the later stage (Xia et al. 2011). The total acidity increased constantly from day 1 to day 3; the acids present in the fermenting sap include lactic, acetic, tartaric, malic, and citric acids, but the volatile acid mainly consists of acetic acid (Xia et al. 2011). If the fermentation is allowed to proceed to the third stage, a condiment called vinegar is produced. This is commonly used as an important preservative in food processing.

3 Concluding Remarks

Coconut is a multi-purpose tree crop with several benefits to human kind. Characterization of various components of coconut tree and its fruits established coconut's uniqueness to foster food security. One of the important approaches to face food shortage is to maximize the use of industrial by-products to produce edible and non-edible goods. The kernel of the coconut fruit is found to contain all macro- and micronutrients required for human diet. Thus, it can help overcome nutritional insecurity. Coconut testa left after food processing is one of the by-products and can be used to produce coconut testa oil, which can supplement partly for the annual requirement of coconut oil in the country. Coconut testa flour produced from the residue left after the extraction of oil can be supplemented with wheat flour to make low-glycemic food products. It was demonstrated that string hoppers (idiyappa) and flat-bread (rotti) of acceptable quality could be prepared using composite flour mixtures of 25% of coconut testa flour in rice flour and 20% of coconut testa flour in wheat flour, respectively. Coconut sap dripping out of the inflorescence when cut open can be used to produce coconut wine, brown sugar, syrup, and honey. These sweeteners can be used to supplement annual requirement of cane sugar in the country. The mature coconut water released from food processing industries is a potential raw material to produce coconut vinegar, a valuable food preservative. A host of other by-products available from coconut tree and its fruit could help address challenges induced by climate change. Nutshell, for example, is one of the important components of the whole coconut. When subjected to control combustion, it can help produce heat as well as charcoal. Coconut charcoal can be converted to activated carbon, which is used in a broad range of applications from industrial to residential uses.

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