Chapter

Coconut: Nutritional and Industrial Significance

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Abstract

The purpose of this chapter is to collate the current knowledge on the usefulness and nutritional value of coconut food products. The coconut palm grows in the tropical regions of the world. The coconut kernel is a major source of lipids, proteins and functional dietary components. Coconut occupies the ninth position supplying 2.6 metric tons of oil to the vegetable oil market. The coconut kernel is consumed fresh or in other edible forms. The desiccated coconut, virgin coconut oil and coconut water with nutraceutical value are gaining new markets as functional foods. Virgin coconut oil is recognized for its nutritional significance. Nut water is a nutritious natural beverage. Coconut milk, virgin coconut oil and coconut flour possess antioxidant properties. Coconut sugar products are of low glycemic index. Fermentation of the sap yields coconut wines, coconut vinegar and distilled spirits. Modern society prefers natural coconut-based foods over processed food formulations containing additives. As an industrial crop, coconut generates income to the countries engaged in cultivating, processing and exporting the products. The usefulness of coconut arising from its nutritional and industrial significance is only partly understood in the modern world.

Keywords: coconut oil, desiccated coconut, coconut milk, coconut sap, coconut flour, coconut sugar, nutrition

1. Introduction

Coconut palm, *Cocos nucifera* L. in the family *Arecaceae*, is a perennial plant cultivated in tropical and subtropical countries for its food value and for its parts as non-food components. The global production of coconuts was 63.7 million metric tons in 2021. **Table 1** gives the coconut production in the top 10 coconut cultivating countries in the world in 2021, accounting for 91% of global production, out of more than 90 countries cultivating coconut [1].

Coconut occupies the ninth position accounting for 1% of the vegetable oils in the global market. **Table 2** gives the top 10 vegetable oils consumed in the world in 2020 [2].

Coconut continues to be a major source of lipids (described as an oil) and proteins in the tropical countries, consumed as domestic preparations from the kernel and the coconut oil (CO) [3].

A coconut palm produces 13 bunches of nuts annually, with each bunch containing 5–20 nuts depending on the soil nutrient status. A nut may weigh between 500 and 1100 g depending on the variety. On average, 53% of a mature nut consists of

Country	Million metric tons
Indonesia	17.2
Philippines	14.7
India	14.3
Sri Lanka	2.5
Brazil	2.5
Vietnam	1.9
Papua New Guinea	1.8
Myanmar	1.2
Mexico	1.1
Thailand	0.8

Table 1.
Coconut production in the top 10 coconut cultivating countries in the world in 2021.

Vegetable oil	Million tons
Palm	75.9
Soybean	58.6
Rapeseed	25.2
Sunflower	20.6
Groundnut	4.6
Cottonseed	4.3
Olive	3.4
Maize	2.8
coconut	2.6
Sesame	1.0

Table 2.
The top 10 vegetable oils consumed in the world in 2020.

the kernel (solid endosperm) by wet weight and 19% the coconut water (liquid endosperm). The rest is the hard, shockproof, shell (endocarp) [4]. The kernels and coconut water are industrially processed or used in culinary preparations in coconut cultivating countries. The coconut shell and husk are non-food industrial products, while the trunk is hard timber. The coconut inflorescence, delivering the nutrients to the developing coconut kernel, is tapped by preventing the opening of the spathe to collect the phloem sap. Tapping enhances the physiological activities of the inflorescence. Slicing off the callus tissues formed in the tip of the inflorescence, twice a day, allows continuous oozing of sap through tapping. The sap is converted to coconut sugar, coconut treacle (syrup), coconut wine, coconut spirits and coconut vinegar, domestically and industrially.

Coconut kernel is smoke dried conventionally in direct hot air kilns to produce copra or in modern indirect hot air driers to produce desiccated coconut industrially. Coconut oil (CO) expelled from the copra is purified physically or chemically

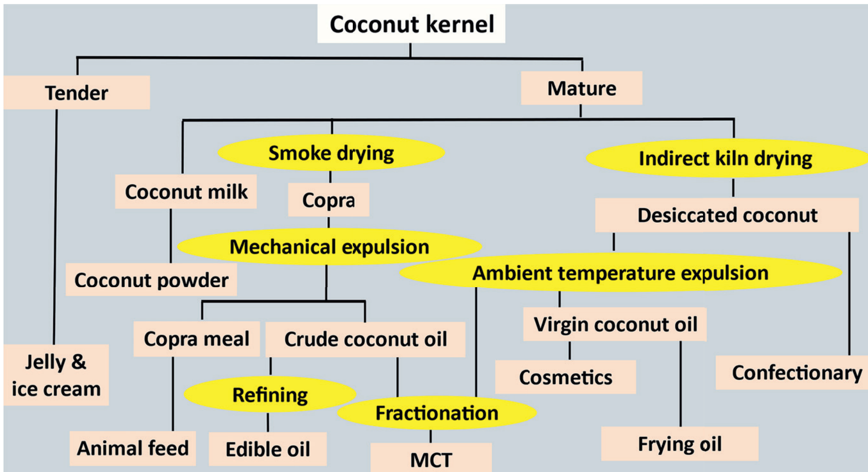

Figure 1.
Edible products derived from the coconut kernel.

to make the oil safe for consumption. Virgin coconut oil (VCO) is extracted under temperature-controlled conditions from the dried or wet kernel. CO is marketed in the following three forms.

a. Unrefined coconut oil (UCO) extracted from copra.

b. Refined, bleached and deodorized coconut oil (RBDCO) having the glycerides totally in pure form.

c. Virgin coconut oil (VCO), expelled from grated dried coconut kernels under controlled temperature, or separated from aqueous extracts of grated coconut enzymatically by fermentation, or by centrifugation.

The residue (copra meal or copra cake) left after extraction of UCO from copra is an animal feed. It is rich in antioxidants. The dried residue (coconut flour) left after extraction of VCO is a confectionary item. **Figure 1** shows the edible products derived from the coconut kernel. A discussion on the nutritional and industrial properties of the products follows the figure.

2. Coconut kernel

The kernel is the main coconut food component. The kernel is formed by converting phloem sap consisting of 15–18% sucrose, accumulating inside the shell into mannans and galactomannans as main carbohydrates. Kernel formation begins around the 7th month after fertilization of the flower, reaching maximum by 12 months of growth [5]. Mature kernels contain galactomannans consisting of 61% polysaccharides, 26% mannans and 13% cellulose [6]. Galactomannans are reserved polysaccharides in the kernel. A host of enzymes, including α-D-galactosidase, β-mannase and β-mannosidase, are active in forming the kernel. Later, similar enzymatic interactions convert the reserve polysaccharides in the kernel to produce the cotyledon for germination [7]. The enzymatic activities finally govern the kernel characteristics derived from insoluble mannans and soluble galactomannans.

High activity of α-D-galactosidase results in the formation of the mature hard kernel, while deficiency of α-D-galactosidase results in the formation of water-soluble galactomannans in a special type of nut called 'makapuno', produced occasionally along with the normal nuts. The 'makapuno' nuts contain a kernel of gelatinous texture, filling the shell completely due to increased water-soluble galactomannan content [8]. A recessive gene governs the 'makapuno' trait [9]. Differential gene expressions are known to bring about variations in the physical nature of the kernels and constituents in it.

The balance between galactose and mannose ratios decides the cellular structure and the endosperm content in the kernel [10]. The cellular structure in the kernel is rich in insoluble mannans and cellulose. Complete acid hydrolysis of the coconut kernel yields monosaccharides, such as glucose, galactose, xylose, rhamnose, arabinose and mannose [11]. The proteins are bound to different extents with dietary fiber in the kernels at cellular level, physically and chemically. An interphase of phospholipids and glycolipids links six proteins, including predominant gluten surrounding oil globules. The cells of the coconut kernel embed oil globules carrying triacyl glycerides. The triacyl glycerides appear in higher concentrations toward the outside of the kernels [12]. A gradation of glycerides occurs in the kernel with medium chain triglycerides (MCTs) occupying the inner layers and long chain triglycerides containing unsaturated fatty acids toward outer layers [13].

The kernel is a useful source of dietary fiber, contributing to consumer health. Galactomannans in the kernel function as effective dietary fibers reducing blood sugar levels, triglycerides and LDL-cholesterol in persons with type 2 diabetes [14]. These functional properties make coconut kernel a nutritionally rich food. The dietary fiber from coconut kernel controls the formation of free radicals and prevents lipid peroxidase activity in the gut of rats, providing nutritional benefits [15]. The coconut kernel polysaccharides carry the potential to stimulate the growth of gut bacteria, improving the gut health and easing bowel movement. The benefit is associated with prebiotic soluble polysaccharides [16]. The dietary fiber remains in the coconut flour residue after extracting VCO or coconut milk [17]. Modern food formulations prefer coconut flour due to its nutritional significance, arising from the dietary fiber and extremely low gluten content. The wheat flour blends with coconut flour are of low glycemic index. The nutritionally rich constituents in coconut kernel need further exploration for their health benefits.

2.1 Foods from the kernel

The two major natural foods in fresh coconuts are the kernel (solid endosperm) and the water (liquid endosperm). Several functional foods and confectionaries are produced from the kernel. **Table 3** gives the average percent composition of the major constituents in coconut foods, summarized from the US Department of Agriculture (USDA) food data files [18]. The values may vary by about 4% with reports from other sources, due to variations in the maturity of the coconuts analyzed and the differences in the analytical methods.

A comparison of the composition of the fresh coconut kernels with the products shows removal of moisture by drying (desiccated coconut) or addition of water (milk, cream) as primary processes. The products retain the food value of the three

Product	Moisture	Oil	Protein	Carbohydrates	Fiber
Fresh kernel	47	33.5	3.3	15.2	9
Coconut oil RBDCO	0.01–0.09	98.6–99.4	0	0.8	0
Desiccated coconut	< 4	62–67	6.7–8.2	18.7	6.7
Coconut milk	67.6	23.2	2.3	5.5	2.2
Coconut flour	2.4–6.9	11–19	13–18	59	34
Coconut water	95	0	0.2	4.2	0

Table 3.
Average percent composition of the major constituents in coconut foods.

major nutrients such as carbohydrates, lipids (oils) and proteins during primary processing. The three nutrients carry unique characteristics in composition, making coconut food products nutritionally different from other nut products.

The oil in the coconut kernel consists of 90–98% triglycerides, 1–8% diglycerides and 0.4–2% monoglycerides. The content of monoglycerides tends to increase toward outer parts of the kernel, close to the testa. Testa is the brown hard cellular layer in the kernel in contact with the hard shell. The oil from testa is rich in tocopherols, tocotrienols and phenolics of a high nutraceutical value [19]. The triglycerides carry lauric acid concentrations up to 48% at maturity of nuts, suggesting CO as a lauric oil.

Phenolics, such as salicylic acid, p-hydroxy benzoic acid, syringic acid, m-coumaric acid, gallic acid, caffeic acid and catechin, are present in the coconut kernel [20]. The same acids are present in coconut water in lower concentrations. A variety of pharmacologically active substances, including the kernel and its products [21], are present in coconut-based foods. Predominant antioxidant activity in kernel and coconut water, antidiabetic activity of the kernel protein, cardioprotective and hepatoprotective effects of coconut water, and antihypertensive activity of kernels, are identified based on animal experiments, indicating potential benefits to human health [21]. The coconut kernel has 389 μg/100 g of phenolic acids and 100 mg/100 g of tocopherols bringing health benefits to the consumers. Higher concentrations of antioxidants, tocopherols, tocotrienols and phenolics are present in the testa, suggesting higher functional properties. In manufacturing desiccated coconut, the outer brown testa is sliced off as parings. Oil extracted from parings is of industrially low value due to brown color, though rich in functional ingredients [19]. Parings oil carries high potential for use in processed food formulations. Nutritional benefits associated with direct consumption of coconut kernels are immense, in contrast to consumption of CO.

2.2 Coconut oil

Of the three forms of CO marketed, RBDCO is widely consumed and subjected to research on its nutritional and industrial significance. Refining removes the micronutrients, antinutrient contaminants and free fatty acids in CO. The refined oil is neutral and does not carry the color and aroma of coconut, preferred by consumers in coconut cultivating countries. CO is fractionated to separate MCT of desired composition, for use in food formulations claiming health benefits. The benefits include providing energy to brain and supporting weight loss in humans.

2.2.1 Unrefined coconut oil

Coconut oil (CO) is expelled from sundried or smoke-dried, ground, steamed coconut (copra) commercially. It is filtered and marketed in the unrefined form retaining the nutrients. Bulk of the CO consumed domestically in the coconut-producing countries is in the unrefined form, preferred for its nutty smell and characteristic coconut flavor. UCO is inexpensive. Though rich with nutrients, UCO carries antinutrients, aflatoxins and free fatty acids produced due to poor copra storage practices [22, 23], and polycyclic aromatic hydrocarbons generated during mechanical expulsion of oil on reaching temperatures of 110–120° C. The heat generates polycyclic aromatic hydrocarbons in the oil [24]. There are recent methods combining solar drying with thermal drying, in more efficient rotary driers generating copra of better quality that could yield oils free of carcinogenic contaminants [25].

2.2.2 Refined coconut oil

Physical refining of CO removes some of the minor constituents in CO by adsorption into clays and/or charcoal, while chemical refining yields neutral glycerides of fatty acids. Chemical refining includes alkali treatment, bleaching and deodorization to produce RBDCO, eliminating the characteristic aroma and flavor associated with UCO.

The composition of fatty acids hydrolyzed from the glycerides in UCO, RBDCO and VCO is substantially equivalent. The only significant chemical difference is in the diglyceride content of 1% (w/w) in VCO against 4.1% in RBDCO [26]. The difference shows partial thermal hydrolysis of triglycerides during expulsion or natural enzymatic hydrolysis at the copra stage of processing. **Table 4** gives the per capita annual consumption of RBDCO in 2019. CO consumption in major coconut-producing countries is 10-fold higher than the global consumption, or consumption in the USA.

Fresh coconut kernels in semi-mature and mature stages are consumed directly, or used in preparing dishes of grated coconuts, or as coconut milk in culinary preparations, or as ingredients in desserts, in coconut cultivating countries. The actual exposure to CO through direct consumption of kernels in the coconut cultivating countries could be higher than the values given in **Table 4**.

Coconut oil (CO) differs in its composition from other edible oils. The differences in the composition of fatty acids of glycerides in edible oils result in its nutritional and industrial significance. The composition of fatty acids in CO has led to discussions on its nutritional significance as a dietary source. The fatty acids from the glycerides in

Region or country	kg per capita / year
Global	0.26
USA	0.20
Asia	0.38
Philippines	3.7
Indonesia	2.2
India	0.17
Sri Lanka	1.4

Table 4.
Per capita annual consumption of RBDCO in 2019 [27].

Fatty acid	Property	Coconut	Palm	Olive	Peanut
Caproic	C6:0	0.52	nd	nd	nd
Caprylic	C8:0	7.6	nd	nd	nd
Capric	C10:0	5.5	nd	nd	nd
Lauric	C12:0	47.7	0.2	nd	nd
Myristic	C14:0	19.9	1.1	nd	0.04
Palmitic	C16:0	8	44	16.5	7.5
Stearic	C18:0	2.7	4.5	2.3	2.1
Arachidic	C20:0	nd	0.1	0.43	1.01
Behenic	C22:0	nd	nd	0.15	nd
Palmitoleic	C16:1 (n-7)	nd	nd	1.8	0.07
Oleic	C18:1 cis (n-9)	nd	39.2	66.4	71.1
Oleic	C18:1trans (n-9)	nd	nd	nd	nd
Gadoleic	C20:1(n-9)	nd	nd	0.30	nd
Linoleic	C18:2 cis (n-6)	1.6	10.1	16.4	18.2
Linolenic	C18:3 (n-3)	nd	0.4	1.6	nd
Medium chain	C6 to C12 acids	61		0	0
Long chain	C13 to C21 acids	31		106	100
Saturated fatty acids		91.9	49	19	1.6
Unsaturated fatty acids		1.8	49	86	89.4
Monounsaturated fatty acids		0	40	68.5	71.2
Polyunsaturated fatty acids		1.6	9	18	18.2

nd = not detectable.

Table 5.
Percent composition of major fatty acids in glycerides of coconut, palm, olive and peanut oils [28, 29].

vegetable oils are converted to methyl esters to quantify them, for scientific discussion of their properties. **Table 5** gives percent composition of major fatty acids in glycerides of coconut, palm, olive and peanut oils.

Fatty acid compositions of the glycerides of the vegetable oils reported in different studies may vary by about 3% from the values given in **Table 5**, due to natural variations associated with maturity of the raw materials and the differences in quantification methods. The comparisons are therefore based on major differences in types and proportions of fatty acids.

Vegetable oils and animal fats contribute to the human diet, providing energy and constituents with bearings on human health. The lipids (oils or fats) of different origin are compared for their nutritional benefits or possible detrimental effects on human nutrition. CO with a high concentration of saturated C6 to C12 fatty acids grouped as medium chain fatty acids, arising from MCT, differ from other oils functionally. The short chain and MCT fractions account together for 61% of the total fatty acids in CO. A scientific view exists in identifying the high MCT percentage in CO as nutritionally positive, arising from differences in metabolic pathways taken by fatty acids in the human body.

Current guidelines of the World Health Organization (WHO) recommend limiting energy from total lipids to less than 30%, and energy from saturated fatty acids to less than 10% of the total energy derived from the diet [30]. There is low consensus in interpreting the WHO guideline for CO among the scientists. While some scientists apply the guideline equally to all edible lipids, others consider CO-derived lipids to be different, being largely of MCT origin, against glycerides of long chain fatty acids in most vegetable oils. Lauric acid, a saturated medium chain acid, is the predominant fatty acid in CO. Medium chain fatty acids are commercially defined as having 6 to 10 carbons (C6–C10), while the physiological and metabolic definitions identify medium chain fatty acids as those with C6–C12 [31]. The commercial definition does not consider lauric acid as a medium chain fatty acid. Lauric acid appears to behave both as a medium chain and as a long chain fatty acid in human metabolism. The lauric acid in CO appears to take two metabolic pathways, with 67% of it following the portal passage, not contributing to the formation of chylomicrons and HDL- or LDL-cholesterol, in contrast to the pathway taken by saturated long chain saturated fatty acids [32]. On a theoretical basis, two-thirds of the lauric acid and the C6 to C10 acids consisting of 13.6% making a total of 45% in CO may be following portal pathway through the liver without reaching chylomicrons. The two views on metabolic mechanisms have led to low consensus on the nutritional significance of CO. Clinical trials from different angles attempt to understand the actual effects of CO on human health. **Table 6** summarizes the conclusions suggested in Meta-studies, after assessing clinical research publications on the effect of CO on human health by scientists.

YEAR: Conclusions [Ref]
2023: "The current evidence from shorter term randomized controlled trials suggests that replacement of coconut oil with cis-unsaturated oils lowers total and LDL-cholesterol, whereas for the association between coconut oil intake and cardiovascular disease, less evidence is available" [33]
2022: "Coconut oil intake revealed no clinically relevant improvement in lipid profile and body composition compared to other oils/fats. Strategies to advise the public on the consumption of other oils, not coconut oil, due to proven cardiometabolic benefits should be implemented" [34]
2020: "In summary, consistent, and strong evidence shows that coconut oil has an adverse effect on lipid parameters associated with cardio-metabolic health, with limited studies to conclude the effects of atopic dermatitis and oil pulling" [35]
2020: "While the evidence related to the connection between saturated fat intake and heart disease may be inconclusive and thus not be in full support of reversing suggestion to avoid saturated fats, certainly a revision is justified. A more in-depth investigation of the connection between different types of saturated fat and disease is warranted" [36]
2020: "Compared with animal oils, coconut oil demonstrated a better lipid profile. In comparison with plant oils, coconut oil significantly increased HDL-C and LDL-C. Better lipid profiles were reported with VCO" [37]
2020: "Coconut oil consumption results in significantly higher LDL-cholesterol than nontropical vegetable oils. This should inform choices about coconut oil consumption" [38]
2016: "Observational evidence suggests that consumption of coconut flesh or squeezed coconut in the context of traditional dietary patterns does not lead to adverse cardiovascular outcomes. However, due to large differences in dietary and lifestyle patterns, these findings cannot be applied to a typical Western diet. Overall, the weight of the evidence from intervention studies to date suggests that replacing coconut oil with cis unsaturated fats would alter blood lipid profiles in a manner consistent with a reduction in risk factors for cardiovascular disease" [39]

Table 6.
Conclusions suggested in Meta-studies, after assessing clinical research publications on the effect of CO on human health by scientists.

The range of information summarized in **Table 6** indicates the difficulty in concluding CO as a nutritionally unhealthy or healthy vegetable oil based on the high lauric acid content in the coconut glycerides. Evidence clearly shows CO to be nutritionally better than edible animal fats. Though studies have attempted to recognize the relationship between saturated fatty acids in diet and heart disease, a direct and clear correlation has not been evident as fatty acids are only one factor leading to heart diseases [28]. Lifestyles, relationships between individual fatty acids, the functions of each fatty acid and the biochemical pathways taken by acids in human body appear to lead to health effects, rather than straight relationship between structures of fatty acids and human health, as established through multifactorial effects applying Spearman's correlation. Excessive energy consumption together with inadequate exercise is one of the causes of heart diseases. All fats and oils contribute to heart disease by supplying high energy when consumed in excess [28]. At least half the calories from CO arise from the saturated MCT. Metabolism of CO occurs through mechanisms different from metabolism of other vegetable oils, at least partly. As a strategy to substitute saturated fatty acids in CO by polyunsaturated fatty acids partly, and work out a formula that may be healthier, blending CO with other oils appears to be a practical choice. The aim would be to shift toward the globally accepted guideline of 10% saturated fats in the diet. **Table 7** gives percent fatty acid composition of a proposed coconut (C'nut) and palm oil blend (1:1), compared with three vegetable oils as an improved health option. The proposed blend may reduce the burden on the liver to manage excessive amounts of saturated fatty acids, meeting modern expectations on contributions from edible oils.

The proposed blend is industrially possible, less costly and offers an improved nutrient balance toward the recommended energy intake limit from saturated vegetable oils, and beneficial suggestions described for unsaturated fatty acids. The usefulness of coconut oil would increase as a blend to keep up with the needs of the modern world.

2.2.3 Virgin coconut oil

Virgin coconut oil exhibits health benefits and better nutritious properties than CO. Non-thermal methods extract VCO in the natural form, from the kernels. The fresh mature kernel is grated or cut into small pieces in the same way as for processing desiccated coconut and dried using indirect heat, under mild conditions, to extract VCO. The oil is expelled at a temperature below 50° C, to prevent the formation of polycyclic aromatic hydrocarbons. Alternately, grated fresh kernel is blended with water to extract

Fatty acid type	Peanut	Olive	Palm kernel	Palm	C'nut	1:1
Saturated (SFA)	10.7	19.4	82.1	49.9	92.1	71
Monounsaturated (MUSF)	71.1	68.2	15.4	39.2	6.2	23
Polyunsaturated (PUSF)	18.2	18.0	2.4	10.5	1.6	6
Medium chain	0	0	54.8	0.2	61.3	27
Long chain	100	100	30	99.4	39.7	65

Table 7.
Percent fatty acid composition of a proposed coconut (C'nut) and palm oil blend (1:1), compared with three vegetable oils as an improved health option.

the milk or the cream. The filtered extract is allowed to ferment naturally or treated with enzymes to destabilize the oil-in-water emulsion, releasing the oil. Centrifugation separates oil from the water. Freezing and thawing are practiced in separating water from VCO in the emulsion in certain processes. The dry extraction of VCO from desiccated coconuts carries the advantage of providing less water globules in oil, which may serve as enclosures for spoilage bacteria to grow, reducing product quality. The nutraceuticals from the kernel retained in VCO make it a healthy food component. VCO is rich in antioxidants, vitamins and phytosterols originating from the fresh kernel [40].

There are no significant differences in the composition of triacyl glyceryl esters of fatty acids among VCO and RBDCO other than due to the degree of maturity of coconuts or natural variations in coconut varieties. The quality parameters tested to recognize VCO from CO, namely iodine value, saponification value, peroxide value, anisidine value and free fatty acid, show comparable figures indicating their similarity in the main fatty acid components [40].

The VCO and UCO possess better inherent nutritional characteristics due to phenolic and other minor constituents than RBDCO. The total phenolic content expressed as mg gallic acid equivalents (GAE)/ 100 g was 2- to 4-fold higher in VCO and UCO than in RBDCO. The total antioxidant activity is 1.5-fold higher in VCO and UCO than in RBDCO [41]. The high heat of processing and refining of RBDCO destroys phenolics partly, while the phenolics remain stable in the preparation of VCO. Rangana et al. [42] reported up to 8.3 mg GAE/100 ml of VCO. The VCO is gaining recognition as a modern version of CO in the markets due to its antioxidant activity and phenolic content, recognized as healthy characteristics. The VCO also carries modest concentrations of tocopherol and tocotrienol [43]. The main phenolic acids in the VCO consist of caffeic acid, syringic acid, p-coumaric acid, vanillic acid and ferulic acid [44, 45]. The total phenolics extracted into VCO from the kernels vary with the extraction methods. The distribution of phenols in the kernel is not homogeneous; high concentrations of phenols are in the outer areas of the kernel, close to the testa. However, testa is removed from rest of the kernel by paring, reducing the appearance of phenolics in desiccated coconut, and VCO. The VCO carries potential as a raw material to extract bioactive compounds carrying anti-inflammatory effects [46–48]. VCO having phenolics and added sweeteners possess market value as ingredients in chocolates with health claims.

In an exposure study of middle-aged humans to VCO and olive oil, no differences were observed in the synthesis of HDL-cholesterol between the two groups; VCO did not increase the LDL-cholesterol significantly compared to olive oil. The nutritional effects of VCO are proven to be different from those of RBDCO in several studies. The relevance of examining total dietary contributions from the VCO, rather than properties of individual components in oil, is a better approach against the current background of consuming heavily processed foods, formulated from highly purified constituents [49]. VCO is in demand for the cosmetic industry as a base for skin care and hair care products.

Though with limited research, there is evidence showing the benefits of the VCO on Alzheimer's disease. The benefits arise from the ketone bodies released in the liver due to rapid metabolism of MCT in VCO, providing an alternate energy source for the brain, and helping in neuronal viability. The antioxidants in VCO contribute beneficially, relieving oxidative stress on the brains providing protection [50]. The results of the study need to be complemented with more research, though positive effects are reported with consumption of VCO in persons with Alzheimer's disease. Modern World is recognizing the usefulness of VCO with emerging new knowledge.

2.3 Desiccated coconut

Shredded coconut kernels are thermally dehydrated under relatively mild heat to manufacture desiccated coconut, following certified food safety management practices. Desiccated coconut carries the total complement of constituents in the fresh kernels including MCT in higher concentrations, due to the removal of water (**Table 3**). Desiccated coconut is rich in carbohydrates including dietary fiber, proteins, vitamins, minerals and antioxidants. The desiccated coconut provides a healthy balance of constituents as a food ingredient than RBDCO. The dietary fiber from coconut kernel protects the colon in rats, preventing the formation of unwanted free radicals, which may otherwise act on the mucosa of the lining in the lower gastrointestinal tract. The observation suggests health benefits on the consumption of desiccated coconuts [15]. Dietary fiber regulates fat absorption and food intake, lowers digestion, absorption and metabolism, reducing the energy intake. Consumption of coconut in the form of desiccated coconut may ameliorate the unhealthy effects described for the consumption of RBDCO. Desiccated coconut forms a minor component in desserts and culinary preparations for consumers. Modern commercial food formulations incorporate desiccated coconut to provide functional properties. The desiccated coconut is used in baking, adding sweetness, giving nutty flavor to cakes, cookies and muffins, in smoothies, in energy bars and in ice cream toppings.

2.4 Coconut milk and cream

Liquid from the comminuted coconut kernels is squeezed, after blending with or without water, to obtain coconut milk. The milk is separated from the solid by filtration. The milk may contain 15–35% lipids, 4–6% carbohydrates and 2–3.5% protein as an emulsion, varying with the method of extraction. Codex standard for coconut milk stipulates 10% lipids, 2.7% non-fat solids and 12.7–25.3% total solids as minimum requirements. The standard recognizes coconut cream by stipulating double the amounts of lipids, non-fat solids and higher total solids compared to coconut milk, in line with extraction with minimal water or no water [51]. Coconut milk is the most widely used form of coconut in the coconut cultivating countries for culinary preparations. In the Philippines, 60% of the coconut harvest end up in culinary preparations. The corresponding figure in Sri Lanka is 75%. The global figure is 25%. Coconut milk is canned as milk or in concentrated form as cream, with stabilizers to prevent separation of water from oil. Canning protects milk from microbial spoilage. Coconut milk carries a mean antioxidant activity of 575 mg EGA/100 g, which is higher than that of cow milk. Coconut milk contains albumins, globulins, prolamins and gluten as the main protein components [52]. The proteins in the extracted coconut milk serve as natural emulsifiers for several hours, preventing immediate separation of the oil from the water.

Coconut milk is spray dried to a powder for preservation. A study on consumption of a porridge prepared using coconut milk powder was shown to increase the HDL-cholesterol and decrease LDL-cholesterol in 60 volunteers, suggesting that coconut milk behaves differently to CO in human metabolism [53]. Most arguments associated with detrimental effects of the RBDCO toward health do not appear to be valid, with the coconut milk consumed daily in the coconut cultivating countries. The nutritional benefit of coconut is associated with its way of consumption, natural or refined. The questionable health properties identified with coconut consumption are associated with highly refined CO, while the beneficial properties are associated with natural forms of coconut products. Natural coconut products consist of a mix of carbohydrates, lipids, proteins and nutraceuticals. The constituents bound together as a mixed source of nutrients and energy appear to behave nutritionally differently from the purified RBDCO. The observation on the mixed source of nutrients in coconut milk supports the 'Polynesian paradox' on food patterns, with the existence of populations physically isolated from the rest of the world consuming coconuts as the chief source of calories, mostly with fish in the diet. The reported total lipid consumption in them is less than 35% and the isolated populations are free of atherosclerosis [54].

The consumption of coconut in the form of milk, cream or kernels by populations in Pacific Islands does not appear to cause cardiovascular problems against CO consumption in other countries. CO is researched intensely for its detrimental effects in the populations already on lipid- and carbohydrate-rich diets, which is different from the consumption of coconut in unprocessed forms having dietary fiber, proteins and antioxidants in Pacific Islands. The nutritional difference in the two types of exposures, refined and unrefined forms, is yet to be fully supported by rigorous research with controls for wide scientific acceptance leaving out biases [33].

2.5 Coconut flour

Coconut flour (coconut meal) is the residue left on extraction of the coconut milk or the VCO. The residue is dried and ground to a fine powder. The carbohydrates associated with the soluble dietary fiber in the coconut flour contain predominantly mannose and galactose, retained in the kernel during extraction of the VCO. The coconut cell wall polysaccharides are rich sources of total fiber, carrying high water holding, oil holding and swelling capacities, contributing excellent nutritional characteristics to foods [17]. The nutraceutical property in the soluble dietary fiber is associated with its antioxidant activity, low glycemic index *in vitro*, and high oil holding and water holding capacities, qualifying the coconut flour for its potential as a functional food [55]. The coconut flour exhibits biofunctions such as absorption of bile salts and toxic ions in the digestive system. It is a low-cost product with high nutritional significance. Coconut flour is a potential ingredient in biscuit manufacture [56]. New food formulations harnessing the nutritional benefits arising from the dietary fiber in the coconut flour are appearing in markets of developed countries [57]. With rapid recognition of the VCO as a healthy oil leading to increased industrial production, coconut flour would find new markets as a nutritionally rich byproduct to be used in new food formulations, and in recipes for soups, pancakes, etc., substituting up to 20% wheat flour.

2.6 Coconut water

Coconut water forms the medium for transfer of phloem sap into the coconut kernel. The reverse transfer of nutrients from the kernel into haustoria (cotyledon) during germination of coconut seed too occurs through the coconut water. The coconut water of cytoplasmic origin is in equilibrium with the soluble constituents in the kernel and provides the venue for biochemical reactions. Coconut water from nuts at the age of 5–7 months is a refreshing beverage containing 2.4–5.6% sucrose, 0.6–1.5% reducing sugars and up to 0.5% protein, depending on the variety of the coconut palm. Coconut water is a rich source of minerals containing 150–350 mg potassium per 100 ml, 18–46 mg calcium per 100 ml, 4–45 mg sodium per 100 ml and 7–15 mg magnesium per 100 ml along with several minerals in trace quantities. The water is rich with B and

C vitamins, though in lesser amounts than in most fruits. It contains a variety of sugar alcohols, amino acids, enzymes and phytohormones [58]. The combined properties of low acidity compared to those of fruit juices, isotonic mineral composition, low-calorie content, the traces of amino acids and phytohormones provide valuable nutritional and rehydration properties to coconut water as a natural beverage. It is an excellent sports nutrition drink. Its aroma is due to the combination of about 30 known volatiles and trace constituents. Coconut water shows notable polyphenol oxidase activity and peroxidase activity making it a nutraceutical drink [59]. Chang and Wu [60] reported (+) catechin and (−) epicatechin concentrations of 0.344 and 0.242 μg/ml, respectively, in coconut water adding to its nutraceutical value.

Coconut water is a fresh natural beverage consumed directly or preserved in tetra-packs. It has also found application for intravenous rehydration, substituting saline solutions due to its isotonic electrolyte composition [61]. The tender coconut water shows notable antioxidant activity and free radical scavenging capacity due to the ability of the metalloenzymes or minerals to release electrons, quenching the free radicals in the human body [58, 62]. Coconut water is gaining consumer acceptance as a base for smoothies, blend for fruit juices, lemonades and a cooking ingredient.

2.7 Coconut cotyledon

During germination of the coconut into seeds, the nutrient reserves in the kernels move into cotyledons (haustoria) to produce the sprouts, which end up as coconut seedlings. The cotyledons, possessing a sweet soft texture, are a delicacy. The cotyledons contain 10–13 mg/g carbohydrates, 1–2 mg/g proteins and 13–15 mg/g lipids. The cotyledons carry total phenols, tannins and alkaloids in amounts equivalent to the concentrations in the kernel. The cotyledons are rich in cardiac glycosides indicating strong health benefits [63]. The cotyledon is yet to be explored for its health benefits and marketing as a canned product industrially.

2.8 Copra meal

Copra meal (copra cake) is the residue of mechanical extraction of CO from copra. Copra meal is caramelized due to high heat of expulsion. It is an inexpensive nutritious feed, preferred for farm animals due to the residual oil, proteins and cellulose that could be digested by the ruminants. The proteins in copra meal contain glutelin predominantly [64]. There is the possibility of improving the digestibility of copra meal as a chicken feed, by enzymatic degradation of the cellulose [65]. Use of thermostable phenolic extracts of antioxidants from the copra meal, as alternatives to synthetic antioxidants in preventing lipid peroxidation in food systems, is suggested, based on *in vivo* experiments [66, 67]. Copra meal is a useful component in animal feeds and with potential to be used in extracting ingredients for human foods.

3. Inflorescence sap products

Phloem sap flowing through the inflorescence to produce the nuts is tapped to obtain the sweet sap. The inflorescence is sliced daily and tapped to artificially simulate the flow of sap. Slicing is done 2 to 4 times a day. The inflorescence tied to prevent opening is 'tapped' mildly using a wooden mallet to enhance the oozing of the sap through the 'wound', created by slicing off the callus tissues regularly [68, 69].

The clear oozing sap contains 15–18% sucrose at pH of 7. The sap collects into plastic bottles or earthenware pots hung on to the inflorescence and tied down in a semi-horizontal position. The sweetness of the sap attracts bees. The microorganisms naturally adhering to the body surfaces of bees contaminate the collecting sap, starting natural fermentation. A plant yields about 0.6 to 3 liters of sap per day, averaging 1.5 liters.

The natural fermentation of sap is arrested by applying slaked lime on inner wall of the collecting vessel to provide an alkaline pH [70], or by adding predetermined amounts of sodium metabisulfite solutions [71] or placing the powdered bark of *Vateria acuminata* plant in the sap collecting pots [72]. There are reports of using different preservatives for the same purpose [73]. The anti-ferments serve as microbial stats, suppressing natural fermentation during accumulation of the sap in the collecting equipment. Collection of sap into chilled boxes minimizes fermentation of the sap [74]. **Figure 2** summarizes the foods and beverages developed from coconut phloem sap.

The unfermented sap is a sweet beverage consumed fresh. It is marketed in tetra-packs as a natural drink. The sap is nutritious [75]. Coconut syrup (treacle), coconut jaggery (a hard brown sweet mass) or crystalline coconut sugar is produced by concentrating the sap as cottage industries in coconut cultivating countries. Concentrating the sap by boiling down to one-sixth of its volume produces treacle, which is similar in properties to golden syrup. Concentration of the sap in open pans over direct flame causes high caramelization. The treacle is self-preserving due to sugar content of more than 67%. The partial hydrolysis of sucrose in the sap during boiling results in a mixture of sugars in the treacle, consisting of sucrose, glucose and fructose in varying concentrations. On further concentration of treacle and cooling, it crystallizes the coconut sugar. Continued concentration of treacle results in a hard sugary mass called jaggery [72]. The glycemic index of coconut sugar is 55 or low, identifying it as healthy, compared to cane sugar of glycemic index 60. The low glycemic index is due to presence of the prebiotic fiber, inulin, in the coconut sap. Although coconut sugar contains potassium, calcium, iron and zinc, their nutritional contribution is insignificant. The coconut sugar carries the same number of calories and amount of carbohydrates as the table sugar. There is increasing

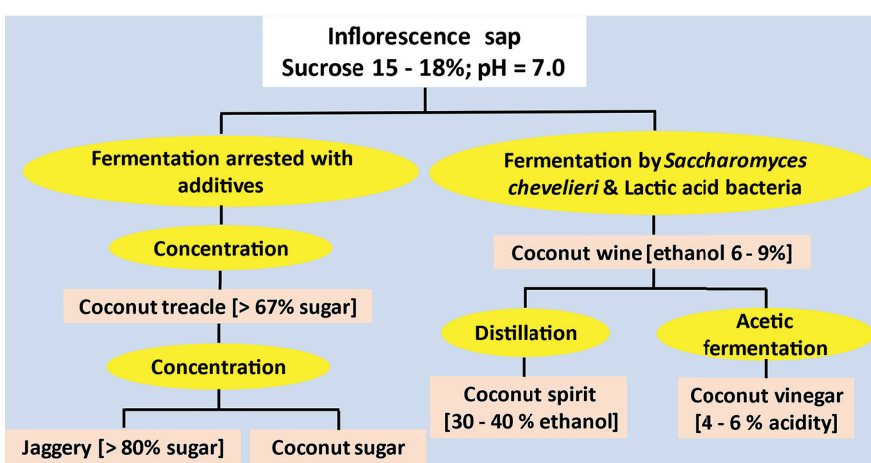

Figure 2.
Foods and beverages developed from coconut phloem sap.

recognition on the usefulness of coconut sugar as a natural sweetener in unrefined form, with potential health benefits [76].

The coconut sap ferments naturally to alcoholic beverage toddy (coconut wine). Toddy is distilled to arrack (spirit) industrially. A variety of yeasts and bacteria ferment the phloem sap during collection. The initial fermentation is caused by lactic acid bacteria, lowering the pH from 7 to 4.5, thereby providing a conducive environment for alcoholic fermentation by the yeasts. Seventeen species of yeasts belonging to eight genera and bacteria belonging to seven genera have been recognized among 200 cultures isolated from fermenting coconut sap. Of the yeasts, the predominant genus *Saccharomyces chevalieri* (35%) is the main ethanol producer [77]. Varying fermentation capacities of yeasts and ability to use them in industrial fermentations in continuous cultures have been explored for the 200 isolates of toddy yeasts [78]. The coconut wine containing 6–7% ethanol is consumed fresh or preserved by pasteurization. Among the microorganisms fermenting coconut sap naturally, there are hydrogen sulfide producers, giving obnoxious flavor at times to the coconut wine.

Distillate from the coconut wine is blended in the same way as other alcoholic spirits, to 30–40% ethanol for sale as a hard liquor. The coconut spirit contains a variety of characteristic congeners including higher alcohols, esters and traces of methanol. The lactic acid produced during initial fermentation generates high concentrations of ethyl lactate in the coconut spirits in the same way as in heavy whiskeys [79].

When coconut wine is left stored for months, it gets converted by the acetic acid bacteria, *Acetobacter suboxydans* and *Acetobacter overoxydans*, to vinegar containing 4–6% acetic acid. The conversion is enhanced industrially by setting up the bacterial cultures on surfaces of wood shavings or corn cobs and circulating the fermenting alcoholic sap on bacterial surfaces to allow aerated reactions, in wooden vats [80]. Coconut vinegar, being a natural product rich in potassium and sodium, is preferred in the modern world over synthetic vinegar for use in food preparations.

Coconut-producing countries have developed appropriate technologies to operate medium and large-scale industries to generate products from the coconut inflorescence sap. Sugars and alcoholic beverages from coconut palm have appeared in markets in developed countries. Coconut sugar is becoming a natural product of demand due to its low glycemic index compared to cane sugar.

4. Conclusions

Coconut plays a significant role in the diet of the populations in the coconut cultivating countries as a source of calories from oil. The proteins and nutraceuticals in the kernels benefit human health. Refined coconut oil produced industrially by conventional processes has raised research interest due to high concentration of medium chain fatty acids and high volume of saturated fatty acid glycerides in it, in contrast to the composition of other vegetable oils. Discussions on health benefits and detrimental effects associated with RBDCO continue. There is new evidence on the nutritional benefits of desiccated coconut, VCO, coconut milk, coconut flour, coconut water and coconut sugar as natural foods that have not undergone chemical refining. The antioxidant activities of the coconut foods and the dietary fiber in them, other than in RBDCO, have gained nutritional attention. With increased consumer demand for natural foods, coconut in unrefined forms may gain higher global recognition as useful and healthy nutritious modern foods.

Conflict of interest

The author declares no conflict of interest.

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