GRASAS Y ACEITES 73 (3)
July-September 2022, e466
ISSN-L: 0017-3495
https://doi.org/10.3989/gya.0674211

Phenolic antioxidants in coconut oil: Factors affecting the quantity and quality. A review

N. Jayathilaka and K.N. Seneviratne✉

Department of Chemistry, Faculty of Science, University of Kelaniya, Kelaniya, Sri Lanka.

✉Corresponding author: kapilas@kln.ac.lk

Submitted: 03 June 2021; Accepted: 12 July 2021; Published online: 08 September 2022

SUMMARY: The total phenol content (TPC) in coconut oil varies with extraction method, variety, nature of coconut kernel components and geographical origin. Commonly reported TPCs of coconut oils extracted by dry methods and wet methods are in the range of 70-300 mg/kg and 250-650 mg/kg, respectively. Based on the commonly reported data, the TPC of coconut oil varies by up to 527 mg/kg oil, 180 mg/kg oil, and 172 mg/kg oil due to the influence of the extraction method, coconut variety and the nature of kernel components, respectively. The identity of the phenolic compounds also varies with the extraction method. Caffeic acid, catechin, *p*-coumaric acid, ferulic acid, and syringic acid are present in different quantities in coconut oil when extracted by all methods. However, chlorogenic acid, cinnamic acid, epigallocatechin, gallic acid, vanillic and epicatechin are present only in some coconut oils. Many free phenolic compounds present in olive oil are also present in coconut oil.

KEYWORDS: *Copra oil; Olive oil; Phenolic antioxidants; Virgin coconut oil.*

RESUMEN: ***Antioxidantes fenólicos en el aceite de coco: factores que afectan la cantidad y la calidad. Revisión.*** El contenido total de fenoles (CTF) del aceite de coco varía según el método de extracción, la variedad, la naturaleza de los componentes del grano de coco y el origen geográfico. Los CTF comúnmente reportados de aceites de coco extraídos por métodos secos y métodos húmedos están en el rango de 70-300 mg/kg y 250-650 mg/kg respectivamente. En base a estos datos comúnmente reportados, el CTF de los aceites de coco varía hasta 527 mg/kg de aceite, 180 mg/kg de aceite y 172 mg/kg de aceite debido a la influencia del método de extracción, la variedad del coco y la naturaleza de los componentes del grano, respectivamente. La identidad de los compuestos fenólicos también varía con el método de extracción. El ácido caféico, la catequina, el ácido *p*-cumárico, el ácido ferúlico y el ácido siríngico están presentes en diferentes cantidades en los aceites de coco extraídos por todos los métodos. Sin embargo, el ácido clorogénico, el ácido cinámico, la epigalocatequina, el ácido gálico, la vainillina y la epicatequina están presentes solo en algunos aceites de coco. Muchos compuestos fenólicos libres que están presentes en el aceite de oliva también están presentes en el aceite de coco.

PALABRAS CLAVE: *Aceite de copra; Aceite de oliva; Aceite virgen de coco; Antioxidantes fenólicos.*

Citation/Cómo citar este artículo: Jayathilaka N, Seneviratne. KN. 2022. Phenolic antioxidants in coconut oil: Factors affecting the quantity and quality. A review. *Grasas y Aceites* **73** (3), e466. https://doi.org/10.3989/gya.0674211

1. INTRODUCTION

Natural phenolic substances are ubiquitously-distributed secondary metabolites in berries, fruits, vegetables, coffee, herbs and edible oils. Main phenolic substances include phenolic acids, phenolic alcohols and flavonoids. Plant phenolic compounds have drawn the attention of researchers due to their antioxidant properties. The antioxidant mechanisms of the phenolic compounds in plants have been well established (Michalak, 2006; Zeb, 2020). The antioxidant properties of the phenolic compounds in plants are connected to beneficial health effects such as conferring protection against the development of cancer, diabetes, cardiovascular diseases and neurodegenerative diseases (Pandey and Rizvi, 2009). The phenolic compounds in plants can also act as food preservatives that can inhibit the lipid oxidation in edible oils and fish oils owing to their high polyunsaturated fat contents (Maqsood *et al.,* 2014). The color and flavor properties of natural foods as well as processed foods and beverages are also controlled by plants' phenolic compounds (Cheynier, 2012).

During the extraction of edible oils, the phenolic compounds of kernel materials are incorporated into the oils. Edible oils have saponifiable and unsaponifiable compounds. The saponifiable fraction may account for 90–98% of the total mass of oil while the unsaponifiable content varies from 2–10% (Narasinga Rao, 2001). The saponifiable fraction includes triglycerides, diglycerides, monoglycerides, fatty acids and other saponifiable lipids. The minor unsaponifiable fraction includes phenolic compounds, flavonoids, vitamin E, sterols, hydrocarbons, etc. (Moura Fe *et al.,* 1975). In coconut oil, the saponifiable fraction may amount to up to 99.5% of the weight of the oil (Gutfinger and Letan, 1974). In edible oils with no sedimentations or insoluble materials, the saponifiable fraction can be observed as a clear solution and unsaponifiable compounds are dissolved in the saponifiable fraction.

Phenolic compounds in several edible oils have been reported and most of these studies are limited to assessing phenolic compounds in a particular oil (Mannino *et al.,* 1999; Tripoli *et al.,* 2005; Siger *et al.,* 2008; Janu *et al.,* 2013). Among them, a vast majority of research has been focused on the phenolic fraction of olive oil (Kiritsakis, 1998; Ryan and Robards, 1998; Boskou *et al.,* 2005; Galvano *et al.,* 2007; Servili *et al.,* 2009). In addition to the studies on the phenolic compounds in specific edible oils, a recent report has comprehensively reviewed the different classes of phenolic compounds in several edible oils (Zeb, 2021). As phenolic compounds are polar molecules, their solubility in the oils is low. However, these minor components improve the quality of edible oils by enhancing health benefits and sensory properties (Visioli and Galli, 1998). The interest in the phenolic substances in coconut oil is also due to their antioxidant activity and related health benefits (Seneviratne *et al.,* 2011; Lima *et al.,* 2015; Narayanankutty *et al.,* 2018; Rohman *et al.,* 2021; Senanayake *et al.,* 2021). In addition, the phenolic compounds present in coconut oil and coconut oil meal improve the shelf-life of coconut oil as well as other edible oils and baked food (Senanayake *et al.,* 2019). Even though there is a wealth of literature regarding research conducted on the phenolic substances of olive oil and other common edible oils, the first report on the phenolic substances in coconut oil was published in 2008 (Seneviratne and Dissanayake, 2008). Since then, there has been a growing number of studies on the phenolic fraction of coconut oil. Emulsions of virgin coconut oil (VCO) containing ferulic acid and *p*-coumaric acid have been prepared with various sweeteners to improve the palatability of VCO (Wiyani *et al.,* 2020). The addition of VCO to dark chocolate formulations has shown that the nutritional properties of dark chocolate are improved by the phenolic compounds in VCO (Rashid *et al.,* 2017). New studies indicate that coconut oil improves the absorption of phenolic compounds in rats and humans, suggesting that the naturally-present phenolic compounds in coconut oil are more bioavailable than the phenolic compounds in aqueous foods (Prasadani *et al.,* 2017; Weerakoon *et al.,* 2021). Despite several health and nutritional advantages and applications as food preservatives, the quality and quantity of the phenolic compounds in coconut oil have not been reviewed. Therefore, the present review aimed to comprehensively review the up-to-date knowledge on the effect of extraction conditions, variety, country of origin and nature of kernel material on the phenolic composition of coconut oil.

2. EXTRACTION METHODS AND PHENOLIC CONTENTS

The most important factor affecting the phenolic content in coconut oil is the method of extraction (Seneviratne and Jayathilaka, 2015; Seneviratne and Jayathilaka, 2016). The coconut kernel is different from all other seed kernels due to its bulkiness and high percentage (59%) of coconut oil in the dried kernel (Gutfinger and Letan, 1974). Therefore, the extraction of coconut oil is less cumbersome compared to the extraction of other edible oils. Different methods of coconut oil extraction are summarized in Figure 1. Coconut oil prepared by the wet extraction methods under cold conditions is called VCO. In addition, VCO is also produced by dry extraction by pressing high quality dried coconut kernels under cold conditions.

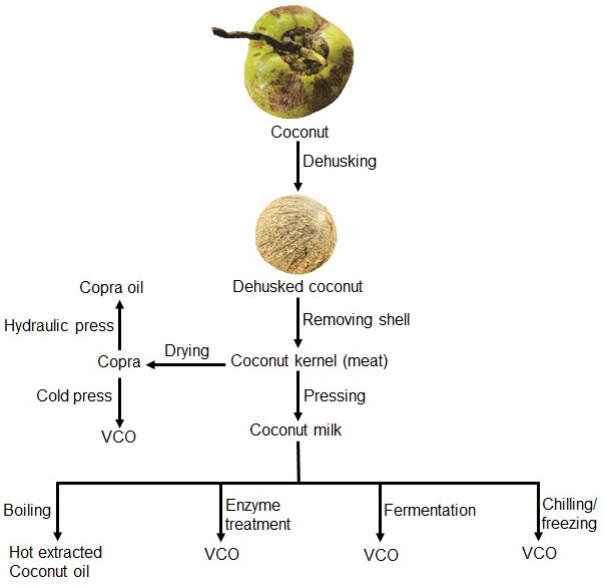

FIGURE 1. Different extraction methods of coconut oil

2.1. Dry methods of coconut oil extraction

Dry methods involve a drying step of coconut kernels before the extraction of coconut oil. Fresh coconut kernels can be dried by sun drying or by any suitable mechanical drying method. Fresh coconut kernel contains carbohydrates (13.0 g/100 g), water (36.3 mL/100 g), proteins (4.5 g/100 g), lipids (41.6 g/100 g), fiber (3.6 g/100 g) and minerals (1 g/100 g) (Lal *et al.,* 2003). Different quantities of water and lipids up to 50 and 34%, respectively, have been reported in coconut kernels, (Withana-Gamage *et al.,* 2005). In the dry methods, coconut oil is extracted by pressing dried coconut kernels to squeeze out coconut oil. For this purpose, the moisture content of the coconut kernel should not exceed 6% (Seneviratne and Jayathilaka, 2016). Coconut oil extracted in this way is also called copra oil. VCO is also produced by this dry method by pressing dried coconut kernels under cold conditions without letting the temperature rise above 60–70 ºC during the pressing process. While pressing dried coconut kernels, a part of the phenolic substances in the coconut kernel is incorporated into the coconut oil. The TPC of the coconut oil extracted by dry methods is found to be relatively lower compared to that of coconut oil extracted by wet methods (Seneviratne *et al.,* 2009; Srivastava *et al.,* 2016).

2.2. Wet methods of coconut oil extraction

In addition to the dry method, coconut oil is extracted by wet extraction methods where an aqueous emulsion of coconut kernel (coconut milk) is processed for the extraction of coconut oil. Coconut milk contains fat, sugars, proteins and phenolic compounds (Alyaqoubi *et al.,* 2015; Nadeeshani *et al.,* 2015). Gallic acid, chlorogenic acid, *p*-hydroxybenzoic acid, caffeic acid, vanillic acid, syringic acid and ferulic acid are the major phenolic compounds in coconut milk (Karunasiri *et al.,* 2020a).

2.2.1. Boiling method (Hot extraction)

Coconut milk is boiled to evaporate water. In this process, proteins denature and carbohydrates and proteins are deposited at the bottom of the container. When the aqueous layer evaporates, the oil layer can easily be separated by decanting. During this boiling process, the temperature of the mixture may reach up to 125 ºC. Due to high temperatures, the solubility of the phenolic substances in coconut oil increases. While the oil layer is in contact with the solid kernel material at the bottom of the container, phenolic substances are easily dissolved in the oil layer. Therefore, coconut oil prepared by boiling coconut milk has a high TPC and contains a larger number of phenolic substances compared to coconut oil prepared by dry extraction methods (Seneviratne *et al.,* 2009).

2.2.2. Chilling, freezing, centrifugation methods

After chilling or freezing coconut milk, the water can be removed by decanting followed by centrifugation of the resultant mixture in the liquid form to further remove water. Direct centrifugation of coconut milk emulsion without chilling or freezing to separate coconut oil can also be done. Heating to about 60 ºC prior to centrifugation is effective in isolating oil. However, this direct centrifugation needs stronger and laborious centrifugation steps (Gopala Krishna *et al.,* 2010; Ngampeerapong *et al.,* 2018). Chilling to about 10 ºC or freezing to about –4 ºC for 6 hours, followed by centrifugation is more effective in producing VCO.

2.2.3. Fermentation

Pure cultures of *Lactobacillus* strains have been used in some cases for the fermentation of coconut milk to separate coconut oil (Che Man *et al.,* 1997; Satheesh and Prasad, 2014). However, fermentation also occurs without any addition of microorganisms if coconut milk is exposed to air for over 8–12 hours or longer (Marina *et al.,* 2009a). Due to enzyme and microbial action, coconut oil separates from the coconut milk emulsion (Seneviratne and Jayathilaka, 2015). The coconut oil layer can then be siphoned out after the separation of layers.

Copra oil is refined to remove any free fatty acids and peroxides and then bleached and deodorized. Refined, bleached and deodorized coconut oil is called RBD coconut oil. The TPCs reported as gallic acid equivalents (GAE) in coconut oils prepared by different extraction methods are given in Table 1.

3. PHENOLIC CONTENT AND COCONUT VARIETY

Most studies on the phenolic composition of coconut varieties are limited to those done on a particular variety and there are limited studies that compare the differences in composition among the different varieties. The TPC of the VCO extracted by freezing coconut milk from West African Tall variety is 160.2 mg/kg. Methanol (60%) was used to extract phenolic compounds in this study (Ahmad *et al.,* 2015). Coconut kernels of Dwarf x Tall variety from India indicate the presence of coumaric acid, caffeic acid and chlorogenic acid. (Dhanyakrishnan *et al.,* 2018). The TPC of coconut water from the Malayan green coconut variety is 95.15 mg/L; while that of the Malayan yellow coconut variety is 46.85 mg/L. (Adubofuor *et al.,* 2016). Even though there is a limited number of reports on the phenolic composition of coconut oil from different coconut cultivars, most of such data cannot be compared because of the different conditions used for the extraction of coconut oil or different extraction conditions used for the extraction of the phenolic substances from the coconut oil. A systematic comparison of the TPC in coconut oil extracted from three coconut varieties and three hybrids of these varieties grown in Thailand has been reported (Arlee *et al.,* 2013). According to this study, the TPC of VCO extracted by natural fermentation may vary significantly among cultivars and hybrids. However, the range of TPC in coconut oil extracted by the fermentation method for three cultivars and three hybrids is 481–554 mg/kg. The TPC in VCO prepared by cold pressed dry method may also vary significantly ($p \leq 0.05$) among varieties and cultivars. Nevertheless, the range of TPC is 486–579 mg/kg. The TPC in VCO from two cultivars grown in Mexico also shows that there is a significant difference in TPC with cultivar. The TPC in this study varies in the range 600–780 mg/kg (Elodio-Policarpo *et al.,* 2019).

4. EFFECT OF GEOGRAPHICAL ORIGIN ON PHENOLIC CONTENT

VCO has become popular as a functional oil due to its health benefits. The major contributor to the numerous health benefits is phenolic compounds (Srivastava *et al.,* 2018). Thailand, Indonesia, India, Malaysia, Sri Lanka and Vietnam are the main producers of VCO in the world. Even though phenolic compounds play a major role in providing health benefits to consumers, phenolic quality and quantity are not included in coconut oil standards. Detailed studies on the influence of geographical origin on the TPC in coconut oil have not been carried out. However, VCO samples obtained from the markets of Malaysia and Indonesia have been compared (Marina *et al.,* 2009b). The results indicated that the TPCs in the Malaysian VCO samples were 118–292 mg/kg; while those of the Indonesian VCO samples were 78–251 mg/kg.

5. NATURE OF COCONUT KERNEL COMPONENTS

There are two components in the coconut kernel: white coconut meat and coconut testa. The interior part of the coconut kernel is the thick, fleshy, white

TABLE 1. TPCs in coconut oils prepared by different extraction methods expressed as gallic acid equivalents (GAE)

	TPC (Reported Units)	TPC (mg/kg oil)	Reference
Dry methods			
Dry method (copra oil)	72.1 ± 5.6 mg/kg	72 ± 6	Seneviratne and Dissanayake, 2005
	91 ± 11 mg/kg	91 ± 11	Seneviratne and Dissanayake, 2008
	64.4 mg/100g	644	Arunima and Rajamohan, 2013; Nevin and Rajamohan, 2004
	292.06 ± 10.04 mg/kg	292 ± 10	Azevedo *et al.,* 2020
	1.56-8.57 mg/g	1560-8570	Ghani *et al.,* 2018
	182.82 ± 15.24 µg/g	183 ± 15	Srivastava *et al.,* 2016
	18.1 ± 2.01 mg/100g	181 ± 20	Narayanankutty *et al.,* 2016
Dry method (VCO)	1.18 mg/g	1180	Perera *et al.,* 2019
	49.82 mg/kg	49.82	Khalil *et al.,* 2020
Wet methods			
Wet method (Boiling)	506 ± 20 mg/kg	506 ± 20	Seneviratne and Dissanayake, 2005
	618 ± 46 mg/kg	618 ± 46	Seneviratne and Dissanayake, 2008
	650.35 ± 25.11 µg/g	650 ± 25	Srivastava *et al.,* 2016
Wet method (Fermentation) VCO	59.30 ± 0.39 mg/g	59,300 ± 390	Prapun *et al.,* 2016
	59.44 ± 13.40 mg/100g	594 ± 134	Ngampeerapong *et al.,* 2018
	57.11 ± 0.05 mg/100g	571 ± 1	Famurewa *et al.,* 2018
	12.54 ± 0.96 mg/g	12,540 ± 960	Ghani *et al.,* 2018
	~25 mg/100g	~250	Marina *et al.,* 2009a
	401.23±20.11µg/g	401 ± 20	Srivastava *et al.,* 2016
Chilling/freezing and Centrifugation	~18 mg/100g	~180	Marina *et al.,* 2009a
	1.16 ± 0.05 mg/g	1160 ± 50	Ghani *et al.,* 2018
	16.02 ± 0.44 mg/100g	160 ± 4	Ahmad *et al.,* 2015
	84 mg/100g	840	Arunima and Rajamohan, 2013; Nevin and Rajamohan, 2004
	32.24 ± 1.2 mg/100 g	322 ± 12	Narayanankutty *et al.,* 2016
Centrifugation	Not detected		Ngampeerapong *et al.,* 2018
Enzyme-assisted	35.02 ± 0.10 mg/g	35,020 ± 100	Prapun *et al.,* 2016
RBD coconut oil	~12 mg/100g	~120	Marina *et al.,* 2009a
	6.14 mg/100g	61	Marina *et al.,* 2009b
	2.1 ± 0.19 mg/100g	21 ± 2	Prasanth Kumar *et al.,* 2015

coconut kernel, which is known as white coconut meat. The thin brown outer skin of the white coconut kernel between the white coconut meat and the coconut shell is known as coconut testa. When water evaporates from the coconut meat during the drying of coconut halves, white coconut meat and testa separates from the shell (Figure 2). Both testa and coconut meat are taken for dry or wet extraction of coconut oil unless coconut testa is purposely removed. The TPCs in coconut meat from three coconut types from Indonesia, Vietnam and Thailand have been compared (Ngampeerapong and Chavasit, 2019). Shredded coconut meat was extracted with 80% methanol. This study reported that the TPCs of coconut meat were 72,122 mg/kg (Thailand variety), 63,910 mg/kg (Indonesian variety) and 103,421 mg/kg (Vietnam variety). However, the same paper indicated that the

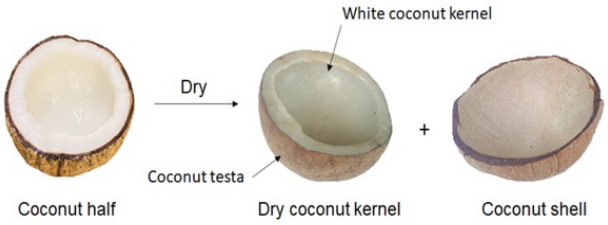

FIGURE 2. Coconut kernel components and coconut shell

percentages of moisture + protein + fat + carbohydrates of coconut meat added up to 99.09% (Thailand variety), 99.01% (Indonesian variety) and 99.06% (Vietnam variety). Therefore, the phenolic contents of ~7% (Thailand variety), ~6% (Indonesian variety) and 10% (Vietnam variety) may not be realistic. The moisture content in the coconut meat was about

50% according to the analysis of this research. Coconut kernels contain free amino acids (Baptist, 1963). These amino acids interfere with the determination of TPC by the Folin-Ciocalteu method (Everette *et al.,* 2010; Bastola *et al.,* 2017). Sugars also interfere with the Folin-Ciocalteu method (Sanchez-Rangel *et al.,* 2013; Muñoz-Bernal *et al.,* 2017). Proteins in coconut meat can be precipitated prior to the determination of TPC in coconut milk to avoid interference (Kwon *et al.,* 1996; Nadeeshani *et al.,* 2015). Interference by amino acids, proteins and sugars in the coconut meat may contribute to the high readings of TPCs in some studies. However, the reported phenolic contents of 98–100 mg/kg for coconut meat may be more reasonable (Mahayothee *et al.,* 2016).

6. COCONUT TESTA

Coconut testa is a very minor component of coconut meat. It is difficult to give an exact estimate of the phenolic contents in pure coconut testa since part of white coconut meat also combines with coconut testa during the paring of coconut meat to separate testa. Coconut testa is the richer source of phenolic compounds compared to white coconut meat (Seneviratne *et al.,* 2009; Seneviratne *et al.,* 2016). A study indicates that the TPC in the coconut oil extracted from the whole copra with both white kernel and brown testa is 1.4 ± 0.19 mg/100 g (14 ± 2 mg/kg); while coconut oils extracted from white coconut kernel alone and coconut testa alone contain 1.1 ± 0.11 mg/100 g (11 ± 1 mg/kg) and 1.9 ± 0.12 mg/100 g (19 ± 1 mg/kg) of phenolic substances, respectively (Appaiah *et al.,* 2014). Reports indicate that the extraction efficiency of phenolic compounds from coconut testa significantly ($P \leq 0.05$) varies with the solvent system, while the acidification of the solvent increases the extraction efficiency. For example, the extraction of phenolic compounds from dry and defatted testa by 80% ethanol gives TPC of 72.7 ± 1.9 mg/g (72,700 ± 1900 mg/kg); while the extraction of dry and defatted testa with acidified 80% ethanol gives TPC of 93.9 ± 5.3 mg/g (93,900 ± 5,300 mg/kg) (Arivalagan *et al.,* 2018). Phenolic compounds were extracted from powdered coconut testa with methanol using Soxhlet extraction. The reported phenolic quantities were unusually high with over 80% (822 mg/g) of the weight of the plant extract being phenolic compounds (Ojha *et al.,* 2019). If these phenolic quantities were expressed for coconut testa powder instead of plant extract, a better comparison could have been made with other reported values. The phenolic composition of coconut testa also varied with the coconut cultivar. The TPCs in coconut testa powder produced from four different coconut cultivars grown in Sri Lanka, namely San Raman, Gon Thembili, Ranthembili and Tall x Tall varied in the range of 27,530–62,580 mg/kg due to cultivar (Marasinghe *et al.,* 2019).

In both the wet and dry processing of coconut kernels for oil extraction, both coconut meat and testa can be used. Even though coconut testa is the main source of phenolic substances in coconut kernels, due to its brown color, coconut testa adds a light-yellow color to the coconut oil. Colorless coconut oil is commercially preferred. Therefore, coconut testa is removed during the preparation of desiccated coconut as well as in the large-scale preparation of VCO by both wet and dry methods.

The TPCs in coconut oil extracted from only white coconut kernels and white coconut kernels with coconut testa under wet hot extraction conditions were 78 ± 2 and 250 ± 4 mg/kg, respectively (Seneviratne *et al.,* 2009). Higher phenolic contents in the coconut oil extracted by using white kernels with coconut testa was due to the richer phenolic contents in testa compared to white coconut kernels.

The phenolic contents in coconut kernel components (white coconut meat and testa) are not fully incorporated into coconut oil during wet or dry extraction methods. Therefore, the residue after the expulsion of coconut oil from coconut kernel components is also rich in phenolic antioxidants (Illam *et al.,* 2017; Karunasiri *et al.,* 2020b).

7. VARIATION OF REPORTED TPC VALUES

Table 1 shows that the TPC clearly depends on the method of extraction of coconut oil. According to Table 1, there is a wide range of TPC reported by different authors for copra oil. The range of TPC in copra oil is 91–644 mg/kg, based on the reported studies (Nevin and Rajamohan, 2004; Seneviratne and Dissanayake, 2005; Seneviratne and Dissanayake, 2008; Arunima and Rajamohan, 2013; de Azevedo *et al.,* 2020). However, the TPC values reported by Ghani *et al.* (2018) for dry extracted coconut oil, the TPC values reported by Prapun *et al.* (2016) and by Ghani *et al.* (2018) for VCO extracted by fermentation methods and the TPC value reported for VCO prepared by the enzymatic extraction by Prapun *et al.* (2016) seem

unusually higher than the values reported by other researchers. Even though the phenolic contents depend on many factors other than the extraction method, these extremely high phenolic contents compared to the other reported values may not be reasonably explained. The TPC in coconut oil prepared by oven-dried grated coconut meat and sun-dried grated coconut meat were reported in one study as 1.56 ± 0.24 mg/g (1560 ± 240 mg/kg) and 8.57 ± 0.36 mg/g (8570 ± 360 mg/kg), respectively (Ghani *et al.,* 2018). The values are higher than any other reported values for coconut oil prepared by dry methods (Table 1). The difference in phenolic contents between coconut oils prepared by oven-dried and sun-dried coconut meat was attributed to the possibility of destroying phenolic substances during the drying process. However, the temperature used in the drying process was 40 ºC in this study. Even higher temperatures up to 60–70 ºC were used in the production of VCO and thermally unstable compounds were not affected by 60–70 ºC temperatures. The TPC in coconut oil varied in the order: fermentation > chilling > RBD, suggesting that the steps involved in the RBD process removed some phenolic substances (Marina *et al.,* 2009a).

If unusually high values for TPC were omitted and if extraction method was considered the only variable, the maximum additional phenolic content that could be incorporated into coconut oil by changing the extraction method compared to the extraction method that gave the lowest phenolic content is about 527 mg/kg (Seneviratne and Dissanayake, 2008). Therefore, up to 527 mg/kg phenolic compounds can be incorporated into coconut oil by changing the extraction method. Not many studies have been conducted to evaluate how phenolic compounds in coconut oil vary with the variety of coconut. The limited data available for the variation of TPC with variety is up to 180 mg/kg. The influence of geographical origin on the TPC cannot be computed due to a lack of sufficient relevant data. TPC may change by up to 172 mg/kg due to the influence of the nature of coconut kernel components based on the reported values (Seneviratne *et al.,* 2009).

8. COMPOSITION OF PHENOLIC COMPOUNDS IN COCONUT OIL ACCORDING TO EXTRACTION METHOD

The individual phenolic antioxidants in coconut oil have been identified and quantified. Caffeic acid, *p*-coumaric acid, ferulic acid, catechin, dihydrokaempferol, rosmarinic acid and quercetin were identified by mass spectroscopy coupled with liquid chromatography (LC-MS) (Seneviratne and Dissanayake, 2008; Illam *et al.,* 2017). The structures of commonly reported phenolic compounds present in coconut oil are given in Figure 3. The quantities of the individual phenolic compounds were higher in coconut oil prepared by boiling coconut milk (hot extracted coconut oil) compared to copra oil prepared by pressing coconut copra (Seneviratne *et al.,* 2009; Srivastava *et al.,* 2016). The TPC was also higher in hot extracted coconut oil compared to VCO prepared by fermentation (Table 1) (Seneviratne *et al.,* 2009; Srivastava *et al.,* 2016). In the hot extraction method, coconut milk emulsion is heated for a long time till water in the emulsion evaporates. During this evaporation, water and oil layers separate and with the evaporation of water, hydrophilic phenolic compounds are concentrated in the aqueous phase. This allows higher partitioning of phenolic antioxidants in the oil layer. The high temperature used in the hot extraction method favored the dissolving of phenolic compounds in the oil layer (Seneviratne *et al.,* 2009). Consistent with the higher

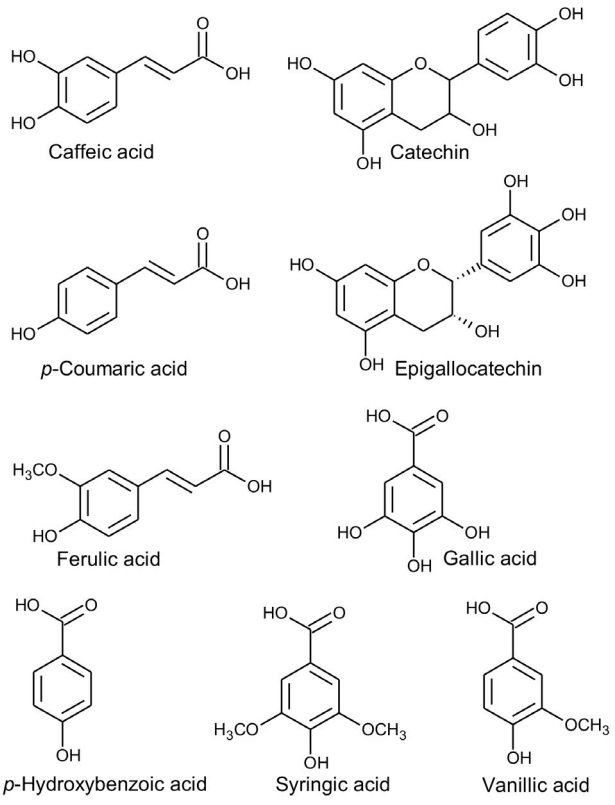

FIGURE 3. Commonly found phenolic compounds in coconut oil

TABLE 2. Phenolic compounds in coconut oil extracted by different methods

	Phenolic content mg/kg*			
Phenolic compound	Copra oil	Boiling	Fermentation	Chilling/centrifugation
Caffeic acid	0.0052 ± 0.0004 (Arunima and Rajamohan, 2013)	4.6 ± 1.5 (Seneviratne *et al.,* 2009) 1.59 ± 0.12 (Srivastava *et al.,* 2016)	0.12 ± 0.1 (Marina *et al.,* 2009a)	0.0083 ± 0.0007 (Arunima and Rajamohan, 2013)
Catechin	0.0062 ± 0.0006 (Arunima and Rajamohan, 2013) 0.21 ± 0.02 (Srivastava *et al.,* 2016)	81.7 ± 22.7 (Seneviratne *et al.,* 2009) 18.15 ± 0.93 (Srivastava *et al.,* 2016)	12.35 ± 1.03 (Srivastava *et al.,* 2016)	0.0098 ± 0.0007 (Arunima and Rajamohan, 2013)
Chlorogenic acid		1.55 ± 0.11 (Srivastava *et al.,* 2016)		
Cinnamic acid	0.024 ± 0.009 (Appaiah *et al.,* 2014)	-		
p-Coumaric acid	0.100 ± 0.007 (Appaiah *et al.,* 2014) 0.049 ± 005 (Arunima and Rajamohan, 2013)	0.53 ± 0.06 (Srivastava *et al.,* 2016)	0.75 ± 0.1 (Marina *et al.,* 2009a)	0.55±0.3 (Marina *et al.,* 2009a) 0.054 ± 0.005 (Arunima and Rajamohan, 2013)
Epigallocatechin		26.7 ± 1.7 (Seneviratne *et al*., 2009)		
Epicatechin		1.4 ± 0.6 (Seneviratne *et al.,* 2009) 2.62 ± 0.24 (Srivastava *et al.,* 2016)		
Ferulic acid	0.017 ± 0.005 (Appaiah *et al.,* 2014) 0.020 ± 0.002 (Arunima and Rajamohan, 2013)	22.1 ± 8.9 (Seneviratne *et al.,* 2009) 12.83 ± 0.94 (Srivastava *et al.,* 2016)	5.09 ± 2.3 (Marina *et al.,* 2009a) 2.36 ± 0.32 (Srivastava *et al.,* 2016)	5.04±3.0 (Marina *et al.,* 2009a) 0.099 ± 0.009 (Arunima and Rajamohan, 2013)
Gallic acid	0.247 ± 0.012 (Appaiah *et al.,* 2014) 1.06 ± 0.05 (Srivastava *et al.,* 2016)	20.2 ± 10.1 (Seneviratne *et al.,* 2009) 25.29 ± 1.11 (Srivastava *et al.,* 2016)	18.01 ± 1.16 (Srivastava *et al.,* 2016)	
p-Hydroxybenzoic acid	0.076 ± 0.001 (Appaiah *et al.,* 2014)	4.8 ± 1.0 (Seneviratne *et al.,* 2009)		
Syringic acid	0.179 ± 0.004 (Appaiah *et al.,* 2014) 2.45 ± 0.2 (Arunima and Rajamohan, 2013)	4.1 ± 0.9 (Seneviratne *et al.,* 2009)	0.45±0.3 (Marina *et al.,* 2009a)	0.90±0.1 (Marina *et al.,* 2009a) 25.1 ± 2.3 (Arunima and Rajamohan, 2013)
Vanillic acid	0.638 ± 0.003 (Appaiah *et al.,* 2014)	-	2.08 ±1.4 (Marina *et al.,* 2009a) 1.03 ± 0.06 (Srivastava *et al.,* 2016)	

*Units were converted where appropriate

TPC of hot extracted coconut oil, the number and the quantity of the phenolic compounds were also higher in hot extracted coconut oil (Table 2) (Seneviratne *et al.,* 2009; Srivastava *et al.,* 2016). In addition to the results in Table 2, another author also reported 4.04 $x10^{-2}$ ppm gallic acid in the phenolic extracts of VCO with no information on the extraction method (Librado and Von Luigi, 2013). Other reports have also indicated that the quantities of individual phenolic acids in coconut oil vary with extraction method (Marina *et al.,* 2009a). For example, Table 2 shows that the quantities (mg/kg) of phenolic compounds in coconut oils prepared by fermentation method and by chilling/centrifugation method contain different

amounts of individual phenolic compounds. Vanillic acid and caffeic acid were not detected in VCO prepared by chilling and centrifugation; while those two phenolic compounds were detected in coconut oil prepared by fermentation. Catechin and epigallocatechin are the common flavonoids present in coconut oil (Table 2). In addition, quercetin (1.62 ± 0.09 mg/kg) has been reported in hot extracted coconut oil (Srivastava *et al.,* 2016). Myricetin-3-*o*-glucoside has also been reported to be present in VCO with no clear origin (Illam *et al.,* 2017).

9. REFINING AND PHENOLIC CONTENT

RBD coconut oil is prepared by procedures involving chemical and physical steps. In physical refining, degumming is done in the first step by treating the oil with phosphoric acid to remove phospholipids. Then the oil is heated to 80–90 °C and bleached by passing through a mixture of bleaching earth and activated carbon. Finally, the deodorizing and removal of free fatty acids are done by exposing the oil to a vacuum at 220–240 °C. The main difference in chemical refining is that free fatty acids are removed by treating the oil with a pre-determined amount of NaOH to neutralize fatty acids instead of removing free fatty acids under vacuum distillation. The resultant sodium salts in fatty acids (soap) are washed away with water. Refining, bleaching and deodorization remove most of the phenolic substances, tocopherols and sterols from coconut oil (Liu *et al.,* 2019a; Deen *et al.,* 2021). One study indicated that the TPC in crude copra oil was 618 mg/kg. However, the remaining TPC of this oil after the RBD process was 20 mg/kg (Pavan Kumar *et al.,* 2018). The TPCs in commercial RBD coconut oil purchased from the Indian market were 21 ± 2 mg/kg; while those in crude oil samples were in the range of 27–191 mg/kg. The maximum total phenol content reported for RBD oil is 120 mg/kg, according to Table 1. Some studies also reported almost zero (0.1 ± 0.0 mg/kg) TPC for RBD coconut oil (Liu *et al.,* 2019b). Individual phenolic compounds are also different in RBD coconut oil compared to other coconut oils. For example, the vanillic and syringic acids present in coconut oil extracted by fermentation are absent in RBD coconut oil. The ferulic acid content present in coconut oil extracted by the fermentation method is 5.09 ± 2.3 mg/kg; while RBD coconut oil contained only 1.39 ± 0.2 mg/kg (Marina *et al.,* 2009a). Therefore, the nutritional properties expected from the phenolic antioxidants present in crude or virgin oils may not be fully expected from RBD oils. Due to the removal of phenolic compounds, RBD coconut oil is less stable against oxidation compared to VCO (Koh and Long, 2012). RBD also has different sensory properties compared to crude coconut oil or VCO due to the removal of phenolic compounds and different volatile organic matter (Chang *et al.,* 2020).

10. COMPARISON WITH OLIVE OIL PHENOLICS

The TPCs in olive oil have been reported in numerous publications. Commonly reported ranges include 45-532 mg/kg (Mannino *et al.,* 1999; Bayram *et al.,* 2012). The TPC in the olive oil of three Italian varieties show significant ($p \leq 0.05$) differences and changes in the range of 367–530 mg/kg (Sicari, 2017); while the TPC of some traditionally prepared Turkish olive oils from different olive varieties ranges from 22.5 to 97.1 mg/kg (Tanilgana *et al*., 2007). The TPCs in the olive oils from six Italian olive varieties prepared by a novel cooling treatment of olive paste varied in the range of 410–1005 mg/kg (Veneziani *et al.,* 2017; Veneziani *et al.,* 2018). Olive oil from two Croatian olive varieties, Bianchera and Busa, contained 312 and 248 mg/kg, respectively (Skevin *et al.,* 2003). Mean TPC and maximum TPC in olive oil from olive varieties in Greece were 483 mg/kg and 4003 mg/kg, respectively (Diamantakos *et al.,* 2021). Due to the differences in phenolic profiles, the fingerprinting of phenolic composition with suitable chemometric methods can be used to differentiate the varietal origin of olive oil (Bajoub *et al.,* 2017).

Geographical conditions also play an important role in the TPC of olive oil. The TPC in the same olive variety drastically changed from 513–1084 with the geographical area (Mansour *et al.,* 2017). European olive varieties grown in Tunisia produced different phenolic profiles compared to the traditional growing areas and the most important factor affecting the phenolic composition was suggested to be altitude (Dabbou *et al.,* 2009). In addition to the olive variety and geographical origin, the ripening stage of the olives and the crushing method also affect the phenolic composition according to studies done in Italy and Spain (Giovacchino *et al.,* 2002; Navajas-Porras *et al.,* 2020).

Several phenolic compounds present in coconut oil such as caffeic acid, ferulic acid, gallic acid, *p*-hydroxybenzoic acid, syringic acid, vanillic acid, *p*-coumaric and cinnamic acid have been reported to be present in olive oil as well (Ryan and Robards, 1998; Boskou *et al*., 2005). In addition to free phenolics and flavonoids, several bound phenolic compounds are also present in olive oil (Servili and Montedoro, 2002; Jimenez-Lopez *et al.,* 2020). However, only three bound phenolic compounds have been reported so far for coconut oil (Seneviratne *et al.,* 2009; Illam *et al*., 2017). The phenolic compounds in both olive oil and coconut oil are responsible for beneficial health effects (Covas *et al.,* 2006; Seneviratne and Jayathilaka, 2015; Narayanankutty *et al.,* 2018; Deen *et al.,* 2021). The aroma and flavor of olive oil correlate with the phenol content (Kiritsakis, 1998; Genovese *et al.,* 2018; Pedan *et al.,* 2019). Even though the sensory properties of virgin coconut oil have been studied (Villarino, Dy and Lizada, 2007, Lukic *et al.,* 2017; Fiorini *et al.,* 2018), the correlation between phenolic compounds and sensory properties in coconut oil needs further research.

11. CONCLUSIONS

The common range of TPC for coconut oil extracted with any variable such as extraction method, variety, coconut kernel material, etc. is 72–650 mg/kg according to reported values. However, unusually high values for TPC have also been reported for coconut oil and coconut meat. Even though the extraction method, variety, hybrids, refining, etc. affect the TPC in coconut oil, these factors may not account for some unusually high TPC values reported. Interference by other compounds such as amino acids and sugars during the determination of phenolic content using the Folin-Ciocalteu assay and possible calculation errors during converting colorimetric readings to given quantities in (mg/g, mg/100 g or mg/kg) units may be possible causes for the large deviation of TPC values in some reports. The RBD process removes phenolic compounds from coconut oil. Depending on the efficiency of the RBD process, the TPC in RBD coconut oil varies between 0–120 mg/kg. The antioxidant activity and health benefits of the phenolic compounds in coconut oil have been sufficiently reported. Even though there has been substantial work done on the extraction method and phenolic composition, sufficient studies have not been conducted to assess the effect of the wide range of coconut varieties available in different geographical origins on the phenolic composition. Therefore, information on the variation in phenolic composition with coconut variety and geographical origin presented in the present review was based on the limited literature available. Careful review of the literature also indicates that there are very limited studies on the identification of phenolic compounds in coconut oil by HPLC methods. Most of the reported phenolic compounds in coconut oils are free phenolic acids and flavonoids. Several of these free phenolic compounds present in coconut oil are also present in olive oil. However, the presence of glycosides, aglycones, secoiridoid derivates or any other bound forms of phenolic compounds in coconut oil have not been reported. Therefore, further studies are necessary to elucidate the complete phenolic profile of coconut oil. In addition, further studies are necessary to investigate how the phenolic compounds in coconut oil are related to the sensory properties of coconut oil.

ACKNOWLEDGMENTS

This work was supported by the grants provided by University of Kelaniya, Sri Lanka (Grant RP/03/02/06/01/2017 and Grant RP/03/02/06/03/2018 and Ministry of Higher Education and University Grants Commission, Sri Lanka (AHEAD RIC).

DATA AVAILABILITY

All the data presented in the paper are included in the manuscript and references.

CONFLICT OF INTERESTS

The authors declare that they have no conflict of interest.

REFERENCES

Adubofuor J, Amoah I, Osei-Bonsu I. 2016. Sensory and physicochemical properties of pasteurized coconut water from two varieties of coconut. *Food Sci. Qual. Manag*. **54**, ISSN 2225–0557.

Ahmad Z, Hasham R, Aman Nor NF, Sarmidi MR. 2015. Physico-chemical and antioxidant analysis of virgin coconut oil using West African Tall

variety. *J. Adv. Res. Mater. Sci*. **13**, 1–10. ISSN (online): 2289–7992.

Alyaqoubi S, Abdullah A, Samudi M, Abdullah N, Addai ZR, Musa KH. 2015. Study of antioxidant activity and physicochemical properties of coconut milk (*Pati santan*) in Malaysia. *J. Chem. Pharm. Res.* **7**, 967–973.

Appaiah P, Sunil L, Prasanth Kumar PK, Gopala Krishna AG. 2014. Composition of coconut testa, coconut kernel and its oil. *J. Am. Oil Chem. Soc.* **91**, 917–924. http://doi.org/10.1007/s11746-014-2447-9.

Arivalagan M, Roy TK, Yasmeen AM, Pavithra KC, Jwala PN, Shivasankara KS, Manikantan MR, Hebbar KB, Kanade SR. 2018. Extraction of phenolic compounds with antioxidant potential from coconut (*Cocos nucifera* L.) testa and identification of phenolic acids and flavonoids using UPLC coupled with TQD-MS/MS. *LWT* **92**, 116–126. http://doi.org/10.1016/j.lwt.2018.02.024.

Arlee R, Suanphairoch S, Pakdeechanuan P. 2013. Differences in chemical components and antioxidant-related substances in virgin coconut oil from coconut hybrids and their parents. *Int. Food Res. J.* **20**, 2103–2109.

Arunima S, Rajamohan T. 2013. Effect of virgin coconut oil enriched diet on the antioxidant status and paraoxonase 1 activity in ameliorating the oxidative stress in rats - a comparative study. *Food Funct.* **4**, 1402–1409. http://doi.org/10.1039/c3fo60085h.

Bajoub A, Medina-Rodríguez S, Gómez-Romero M, Ajal EA, Bagur-González MG, Fernández-Gutiérrez A, Carrasco-Pancorbo A. 2017. Assessing the varietal origin of extra-virgin olive oil using liquid chromatography fingerprints of phenolic compound, data fusion and chemometrics. *Food Chem*. **215**, 245–255. http://dx.doi.org/10.1016/j.foodchem.2016.07.140.

Baptist NG. 1963. Free amino-acids in the endosperm of the developing coconut (*Cocos nucifera*). *J. Exp. Bot.* **14**, 29–41. http://doi.org/10.1093/jxb/14.1.29.

Bastola KP, Guragain YN, Bhadriraju Vadlani PV. 2017. Evaluation of standards and interfering compounds in the determination of phenolics by Folin-Ciocalteu assay method for effective bioprocessing of biomass. *Am. J. Analyt. Chem*. **8**, 416–431. http://doi.org/10.4236/ajac.2017.86032.

Bayram B, Esatbeyoglu T, Schulze N, Özçelik B, Frank J, Rimbach G. 2012. Comprehensive analysis of polyphenols in 55 extra virgin olive oils by HPLC-ECD and their correlation with antioxidant activities. *Plant Food Hum. Nutr*. **67**, 326–336. http://doi.org/10.1007/s11130-012-0315-z.

Boskou D, Blekas G, Tsimidou M. 2005. Phenolic compounds in olive oil and olives. *Curr. Top. Nutraceutical Res*. **3**, 125–136.

Chang M, Zhao P, Zhang T, Wang Y, Guo X, Liu R, Jin Q, Wang X. 2020. Characteristic volatiles fingerprints and profiles determination in different grades of coconut oil by HS-GC-IMS and HS-SPME-GC-MS. *Int. J. Food. Sci. Tech*. **55**, 3670–3679. https://doi.org/10.1111/ijfs.14664.

Che Man YB, Abdul Karim MIB, Ten CT. 1997. Extraction of coconut oil with *Lactobacillus plantarum* 1041 IAM. *J. Am. Oil Chem. Soc.* **74**, 1115–1119. http://doi.org/10.1007/s11746-997-0033-0.

Cheynier V. 2012. Phenolic compounds: from plants to foods. *Phytochem. Rev.* **11,** 153–177. http://doi.org/10.1007/s11101-012-9242-8.

Covas MI, Ruiz-Gutierrez V, de la Torre R, Kafatos A, Lamuela-Raventos RM, Osada J, Owen RW, Visioli F. 2006. Minor components of olive oil: Evidence to date of health benefits in humans. *Nutr. Rev.* **64**, S20–S30. http://doi.org/10.1111/j.1753-4887.2006.tb00260.x.

Dhanyakrishnan R, Sunithaa MC, Prakash Kumara BP, Sandyab S, Nevin KG. 2018. Morphological and molecular effects of phenolic extract from coconut kernel on human prostate cancer cell growth in vitro *Mediterr. J. Nutr. Metab*. **11**, 21–36. http://doi.org/10.3233/MNM-17174.

de Azevedo WM, de Oliveira LFR, Alcantara MA, Cordeiro AMTDM, Damasceno KSFDSC, Araujo NKD, de Assis CF, de Sousa Jr FC. 2020. Physicochemical characterization, fatty acid profile, antioxidant activity and antibacterial potential of cacay oil, coconut oil and cacay butter. *PLoS ONE* **15**. e0232224. http://doi.org/10.1371/journal.pone.0232224.

Deen A, Visvanathan R, Wickramarachchi D, Marikkar N, Nammi S. Jayawardana BC, Liyanage R. 2021. Chemical composition and health benefits of coconut oil: an overview. *J. Sci. Food Agric*. **101**, 2182–2193. http://doi.org/10.1002/jsfa.10870.

Diamantakos P, Ioannidis K, Papanikolaou C, Tsolakou A, Rigakou A, Melliou E, Magiatis P. 2021. A new definition of the term "High-Phenolic Olive Oil" based on large scale statistical data of Greek olive oils analyzed by qNMR. *Molecules* **26**, 1115. https://doi.org/10.3390/molecules26041115.

Dabbou S, Issaoui M, Esposto S, Sifi S, Taticchi A, Servili M, Montedoro, GF, Hammami M. 2009. Cultivar and growing area effects on minor compounds of olive oil from autochthonous and European introduced cultivars in Tunisia. *J. Sci. Food Agric.* **89** 1314–1325. http://doi.org/10.1002/jsfa.3588.

Elodio-Policarpo F, Peñaloza-Herrera B, Maldonado-Astudillo YI, Jimenez-Hernandez J, Flores-Casamayor V, Arámbula-Villa G, Salazar R. 2019. Thermal stability of virgin coconut oil obtained from two cultivars grown in Guerrero, Mexico. *Rev. Fitotec. Mex*. **42**, 101–109.

Everette JD, Bryant QM, Green AM, Abbey YA, Wangila GW, Walker RB. 2010. Thorough study of reactivity of various compound classes towards the Folin-Ciocalteu Reagent. *J. Agric. Food Chem*. **58**, 8139–8144. http://doi.org/10.1021/jf1005935.

Famurewaa AC, Ejezieb AJ, Ugwu-Ejeziec CS, Ikekpeazud EJ, Ejezie FE. 2018. Antioxidant and anti-inflammatory mechanisms of polyphenols isolated from virgin coconut oil attenuate cadmium-induced oxidative stress-mediated nephrotoxicity and inflammation in rats. *J. Appl. Biomed.* **16**, 281–288. http://doi.org/10.1016/j.jab.2018.02.003.

Fiorini D, Boarelli MC, Conti P, Alfei B, Caprioli G, Ricciutelli M, Sagratini, G, Fedeli, D, Gabbianelli R, Pacetti D. 2018. Chemical and sensory differences between high price and low price extra virgin olive oils. *Food Res. Int*. **105**, 65–75. https://doi.org/10.1016/j.foodres.2017.11.005.

Galvano F, Fauci LL, Graziani G, Ferracane R, Masella R, Di Giacomo C, Scacco A, D'Archivio M, Vanella L, Galvano G. 2007. Phenolic compounds and antioxidant activity of Italian extra virgin olive oil Monti Iblei. *J. Med. Food* **10**, 650–656. http://doi.org/10.1089/jmf.2007.409.

Genovese A, Yang N, Linforth R, Sacchi· R, Ian Fisk I. 2018. The role of phenolic compounds on olive oil aroma release. *Food Res. Int*. **112**, 319–327. http://doi.org/10.1016/j.foodres.2018.06.054.

Ghani NAA, Channip A-A, Hwa PCH, Ja'afar F, Yasin HM, Usman A. 2018. Physicochemical properties, antioxidant capacities, and metal contents of virgin coconut oil produced by wet and dry processes. *Food Sci. Nutr.* **6**, 1298–1306. http://doi.org/10.1002/fsn3.671.

Giovacchino LD, Sestili S, Vincenzo DD. 2002. Influence of olive processing on virgin olive oil quality. *Eur. J. Lipid Sci. Technol.* **104**, 587–601. https://doi.org/10.1002/1438-9312(200210)104:9/10<587::AID-EJLT587>3.0.CO;2-M.

Gopala Krishna AG, Raj G, Bhatnagar AS, Prasanth Kumar PK, Chandrashekar P. 2010. Coconut oil: Chemistry, production and Its applications—A Review. *Indian Coconut J*. **73**, 15–27.

Gutfinger T, Letan A. 1974. Studies of unsaponifiables in several vegetable oils. *Lipids* **9**, 658-663. http://doi.org/10.1007/BF02532171.

Illam SP, Narayanankutty A, Raghavamenon AC. 2017. Polyphenols of virgin coconut oil prevent pro-oxidant mediated cell death. *Toxicol. Mech. Methods* **27**, 442–450. http://doi.org/10.1080/15376516.2017.1320458.

Janu C, Soban Kumar DR, Reshma MV, Jayamurthy P, Sundaresan A, Nisha P. 2013. Comparative study on the total phenolic content and radical scavenging activity of common edible vegetable oils. *J. Food Biochem.* **38**, 38–49. http://doi.org/10.1111/jfbc.12023.

Jimenez-Lopez C, Carpena M, Lourenço-Lopes C, Gallardo-Gomez M, Lorenzo JM, Barba FJ, Prieto MA, Simal-Gandara J. 2020. Bioactive compounds and quality of extra virgin olive oil. *Foods* **9**, 1014. http://doi.org/10.3390/foods9081014.

Karunasiri AN, Gunawardane M, Senanayake CM, Jayathilaka N, Seneviratne KN. 2020a. Antioxidant and nutritional properties of domestic and commercial coconut milk preparations, *Int. J. Food Sci.* Article ID 3489605. http://doi.org/10.1155/2020/3489605.

Karunasiri AN, Senanayake CM, Hapugaswatta H, Jayathilaka N, Seneviratne KN. 2020b. Protective effect of coconut oil meal phenolic antioxidants against macromolecular damage. *In Vitro* and *In Vivo* study. *J. Chem.* http://doi.org/10.1155/2020/3503165.

Khalil HMA, Salama HH, Al-Mokaddem AK, Aljuaydi SH, Edris AE. 2020. Edible dairy formula fortified with coconut oil for neuroprotection

against aluminium chloride-induced Alzheimer's disease in rats, *J. Funct. Foods* **75**, 104296. http://doi.org/10.1016/j.jff.2020.104296.

Kiritsakis AK. 1998. Flavor components of olive oil—A Review. *J. Am. Oil Chem. Soc.* **75**, 673–681. http://doi.org/10.1007/s11746-998-0205-6.

Koh SP, Long K. 2012. Oxidative stability study of virgin coconut oil during deep frying. *J. Trop. Agric. and Food Sc.* **40**, 35–44.

Kwon K, Park KH, Rhee KC. 1996. Fractionation and characterization of proteins from Coconut (*Cocos nucifera* L.). *J. Agric. Food Chem.* **44**, 1741–1745. http://doi.org/10.1021/jf9504273.

Lal JJ, Sreeranjit Kumar CV, Indira M. 2003. Coconut palm, in *Encyclopedia of Food Sciences and Nutrition,* 2nd ed, Academic Press, pp 1464–1475.

Librado AS, Von Luigi MV. 2013. Phenolic-dependent anti-lipid peroxidative, antimodulatory and antioxidant activity of virgin coconut oil *in vitro*. *Int. Food Res.* **20**, 1683–1689.

Lima EBC, Sousa CNS, Meneses LN, Ximenes NC, Santos Júnior MA, Vasconcelos GS, Lima NBC, Patrocínio MCA, Macedo D, Vasconcelos SMM. 2015. *Cocos nucifera* (L.) (Arecaceae): A phytochemical and pharmacological review. *Braz. J. Med. Biol. Res*. **48**, 953–964. http://doi.org/10.1590/1414-431X20154773.

Liu R, Lu M, Zhang T, Zhang Z, Jin Q, Chang M, Wang X. 2019a. Evaluation of the antioxidant properties of micronutrients in different vegetable oils. *Eur. J. Lipid Sci. Technol.* 1900079. http://doi.org/10.1002/ejlt.201900079.

Liu R, Guo X, Cheng, M, Zheng L, Gong M, Chang, M, Jin Q, Wang X. 2019b. Effects of chemical refinement on the quality of coconut oil. *J. Food Sci. Technol.* **56**, 3109–3116. https://doi.org/10.1007/s13197-019-03810-w.

Lukic I, Zanetic M, Spika MJ, Lukic M, Koprivnjak O, Bubola KB. 2017. Complex interactive effects of ripening degree, malaxation duration and temperature on Oblica cv. virgin olive oil phenols, volatiles and sensory quality. *Food Chem.* **232***,* 610-620. http://dx.doi.org/10.1016/j.foodchem.2017.04.047.

Mahayothee B, Koomyart I, Khuwijitjaru, P, Siriwongwilaichat P, Nagle M, Müller J. 2016. Phenolic compounds, antioxidant activity, and medium chain fatty acids profiles of coconut water and meat at different maturity stages, *Int. J. Food Prop*. **19**, 2041-2051. http://doi.org/10.1080/10942912.2015.1099042.

Mannino S, Buratti S, Cosio MS, Pellegrini N. 1999. Evaluation of the 'antioxidant power' of olive oils based on a FIA system with amperometric detection. *Analyst* **124**, 1115-1118. http://doi.org/10.1039/a902007a.

Mansour AB, Chtourou F, Khbou W, Flamini G, Bouaziz M. 2017. Phenolic and volatile compounds of Neb Jmel olive oil cultivar according to their geographical origin using chemometrics. *Eur. Food Res. Technol.* **243,** 403-418. https://doi.org/10.1007/s00217-016-2754-5.

Marasinghe S, Marikkar N, Wimalasiri S, Jayasinghe L, Liyanage, R. 2019. Comparison of antioxidant properties of coconut testa flour of selected local coconut cultivars of Sri Lanka. *Proceedings,* **36**, 124. http://doi.org/10.3390/proceedings2019036124.

Marina AM, Che Man YB, Nazimah SAH, Amin I. 2009a. Antioxidant capacity and phenolic acids of virgin coconut oil. *Int. J. Food Sci. Nutr*. **60**, 114123. http://doi.org/10.1080/09637480802549127.

Marina AM, Che Man YB, Nazimah SAH, Amin I. 2009b. Chemical properties of virgin coconut oil. *J. Am. Oil Chem. Soc.* **86**, 301-307. http://doi.org/10.1007/s11746-009-1351-1.

Maqsood S, Benjakul S, Abushelaibi A, Alam A. 2014. Phenolic compounds and plant phenolic extracts as natural antioxidants in prevention of lipid oxidation in seafood: A detailed review. *Compr. Rev. Food Sci. F.* **13**, 1125-1140. http://doi.org/10.1111/1541-4337.12106.

Michalak A. 2006. Phenolic compounds and their antioxidant activity in plants growing under heavy metal stress. *Pol. J. Environ. Stud*. **15**, 523-530.

Moura Fe JA, Brown WH, Whiting FM, Stull JW. 1975. Unsaponifiable matter of crude and processed coconut oil. *J. Sci. Food. Agric.* **26**, 523-531. http://doi.org/10.1002/jsfa.2740260417.

Muñoz-Bernal OA, Torres-Aguirre GA, Núñez-Gastélum JA, de la Rosa LA, Rodrigo-García J, Fernando Ayala-Zavala J, Álvarez-Parrilla E. 2017. New approach to the interaction between Folin-Ciocalteu reactive and sugars during the quantification of total phenols. *TIP Revista Especializada en Ciencias Químico-Biológicas* **20**, 23-28. http://doi.org/10.1016/j.recqb.2017.04.003.

Nadeeshani R, Wijayaratna UN, Prasadani WC, Ekanayake S, Seneviratne KN, Jayathilaka N. 2015. Comparison of the basic nutritional characteristics of the first extract and second extract of coconut milk. *Int. J. Innov. Res. Sci. Eng. Technol.* **4.** http://doi.org/10.15680/IJIRSET.2015.0410003.

Narasinga Rao BS. 2001. Nonglyceride components of edible oils and fats. 1. Chemistry and distribution. *Food Nutr. Bull.* **22**, 81-86. http://doi.org/10.1177/156482650102200113.

Narayanankutty A, Mukesh RK, Ayoob SK, Ramavarma SK, Suseela IM, Manalil JK, Kuzhivelil BT, Raghavamenon AC. 2016. Virgin coconut oil maintains redox status and improves glycemic conditions in high fructose fed rats. *J. Food. Sci. Technol.* **53**, 895-901. http://doi.org/10.1007/s13197-015-2040-8.

Narayanankutty A, Illam SP, Raghavamenon AC. 2018. Health impacts of different edible oils prepared from coconut (*Cocos nucifera*): A comprehensive review. *Trends Food Sci. Technol.* **80**, 1-7. http://doi.org/10.1016/j.tifs.2018.07.025.

Navajas-Porras B, Pérez-Burilloa S, Morales-Péreza J, Rufán-Henaresa J.A, Pastoriza S. 2020. Relationship of quality parameters, antioxidant capacity and total phenolic content of EVOO with ripening state and olive variety. *Food Chem*. **325**, 126926. https://doi.org/10.1016/j.foodchem.2020.126926.

Nevin KG, Rajamohan T. 2004. Beneficial effects of virgin coconut oil on lipid parameters and in vitro LDL oxidation. *Clin. Biochem.* **37**, 830-835. http://doi.org/10.1016/j.clinbiochem.2004.04.010.

Ngampeerapong C, Chavasit V, Durst RW. 2018. Bioactive and nutritional compounds in virgin coconut oils. *Malays. J. Nutr.* **24**, 257-267.

Ngampeerapong C, Chavasit V. 2019. Nutritional and bioactive compounds in coconut meat of different sources: Thailand, Indonesia and Vietnam. *CMU J. Nat. Sci.* **18**, 562-573.

Ojha SB, Roy S, Das S, Dhangadamajhi G. 2019. Phytochemicals screening, phenolic estimation and evaluation for anti-oxidant, anti-inflammatory and anti-microbial activities of sequentially Soxhlet extracted coconut testa. *Food Nutr. Sci.* **10**, 900-922. http://doi.org/10.4236/fns.2019.108065.

Pandey KB, Rizvi SI. 2009. Plant polyphenols as dietary antioxidants in human health and disease. *Oxid. Med. Cell. Longev*. **2**, 270-278. http://doi.org/10.4161/oxim.2.5.9498.

Pavan Kumar GV, Lakshmi NVVSS, Deena C, Bhavani B, Rajendra Kumar P. 2018. Copra oil: chemistry, production. An extensive review on Indian specifications and functional aspects. *Ukr. J. Food Sci.* **6**, 32-45. http://doi.org/10.24263/2310-1008- 2018-6-1-6.

Pedan V, Popp M, Rohn S, Nyfelern M, Bongartz A. 2019. Characterization of phenolic compounds and their contribution to sensory properties of olive oil. *Molecules* **24,** 2041. http://doi.org/10.3390/molecules24112041.

Perera DN, Ranaweera KKDS, Marapana RAUJ, Hewavitharana GG. 2019. Development of spicy flavored virgin coconut oil by incorporating a mixture of spices oleoresins. *Oilseeds & fats Crops and Lipids* **27**, 55. http://doi.org/10.1051/ocl/2020050.

Prapun R, Cheetangdee N, Udomrati S. 2016. Characterization of virgin coconut oil (VCO) recovered by different techniques and fruit maturities. *Int. Food Res.* **23**, 2117-2124.

Prasadani WC, Senanayake CM, Jayathilaka N, Ekanayake S, Seneviratne KN. 2017. Effect of three edible oils on the intestinal absorption of caffeic acid: An in vivo and in vitro study. *PLoS ONE* **12,** e0179292. https://doi.org/ 10.1371/journal.pone.0179292.

Prasanth Kumar PK, Gopala Krishna AG. 2015. Physicochemical characteristics of commercial coconut oils produced in India. *Grasas Aceites* **66**, e062. http://doi.org/10.3989/gya.0228141.

Rashid ANAD, Misson M, Yaakob H, Latiff NA, Sarmidi MR. 2017. Addition of virgin coconut oil: Influence on the nutritional value and consumer acceptance of dark chocolate. *Transactions on Science and Technology* **4**, No. 426-431.

Rohman A, Irnawati, Erwanto Y, Lukitaningsih E, Rafi M, Fadzilah NA, Windarsih A, Sulaiman A, Zakaria Z. 2019. Virgin coconut oil: Extraction, physicochemical properties, biological activities and its authentication analysis. *Food Rev. Int.* **37**, 46-66. http://doi.org/10.1080/87559129.2019.1687515.

Ryan D, Robards K. 1998. Phenolic compounds in olives. *Analyst* **123,** 31R–44R.

Sanchez-Rangel JC, Benavides J, Heredia JB, Cisnero-Zevallos L, Jacobo-Velazquez D. A. 2013. The

Folin–Ciocalteu assay revisited: improvement of its specificity for total phenolic content determination. *Anal. Methods* **5**, 5990-5999. http://doi.org/10.1039/c3ay41125g.

Satheesh N, Prasad NBL. 2014. Production of virgin coconut oil by induced fermentation with *Lactobacillus plantarum* NDRI strain 184. *Croatian Journal of Food Technology, Biotechnology and Nutrition* **9**, 37-42.

Senanayake CM, Algama CH, Wimalasekara RL, Weerakoon WNMTDN, Jayathilaka N, Seneviratne KN. 2019. Improvement of oxidative stability and microbial shelf life of vanilla cake by coconut oil meal and sesame oil meal phenolic extracts. *J. Food Qual*. 1263629. https://doi.org/10.1155/2019/1263629.

Senanayake CM, Hapugaswatta H, Samarawickrama GR, Jayathilaka N, Seneviratne KN. 2021. Effect of chain length and saturation of the fatty acids in dietary triglycerides on lipid metabolism in Wistar rats. *J. Food Biochem.* 00:e13664. https://doi.org/10.1111/jfbc.13664.

Seneviratne KN, Dissanayake DMS. 2005. Effect of method of extraction on the quality of coconut oil. *Journal of Science of the University of Kelaniya Sri Lanka*. **2**, 63-72.

Seneviratne KN, Dissanayake DMS. 2008. Variation of phenolic content in coconut oil extracted by two conventional methods. *Int. J. Food Sci. Technol.* **43**, 597-602. http://doi.org/10.1111/j.1365-2621.2006.01493.x.

Seneviratne KN, Hapuarachchi CD, Ekanayake S. 2009. Comparison of the phenolic-dependent antioxidant properties of coconut oil extracted under cold and hot conditions. *Food Chem.***114**, 1444-1449. http://doi.org/10.1016/j.foodchem.2008.11.038.

Seneviratne KN, Kotuwegedara RT, Ekanayake S. 2011. Serum cholesterol and triglyceride levels of rats fed with consumer selected coconut oil blends. *Int. Food Res. J.* **18**, 1303-1308.

Seneviratne KN, Jayathilaka N. 2015. Production method and coconut oil quality, in Apetrei C. (Ed.) *Corn and Coconut Oil: Antioxidant Properties, Uses and Health Benefits*; Nova Publishers: New York, pp 103-130.

Seneviratne K, Jayathilaka N. 2016. *Coconut oil: chemistry and nutrition*. Lakva Publishers: Battaramulla, Sri Lanka.

Seneviratne KN, Prasadani WC, Jayawardena B. 2016. Phenolic extracts of coconut oil cake: a potential alternative for synthetic antioxidants. *Food Sci. Technol. (Campinas)* **36**, 591-597. http://doi.org/10.1590/1678-457X.07316.

Servili M, Montedoro GF. 2002. Contribution of phenolic compounds to virgin olive oil quality. *Eur. J. Lipid Sci. Technol.* **104**, 602-613. http://doi.org/10.1002/1438-9312(200210)104:9/10<602::AID-EJLT602>3.0.CO;2-X

Servili M, Esposto S, Fabiani R, Urbani S, Taticchi A, Mariucci FR, Selvaggini R, Montedoro GF. 2009. Phenolic compounds in olive oil: antioxidant, health and organoleptic activities according to their chemical structure. *Inflammopharmacology* **17**, 76-84. http://doi.org/10.1007/s10787-008-8014-y.

Sicari V. 2017. Antioxidant potential of extra virgin olive oils extracted from three different varieties cultivated in the Italian province of Reggio Calabria. *J. Appl. Bot. Food Qual.* **90**, 76-82. http://doi.org/10.5073/JABFQ.2017.090.011.

Siger A, Nogala-kalucka M. Lampart-szczapa E. 2008. The content and antioxidant activity of phenolic compounds in cold-pressed plant oil. *J. Food Lipids* **15***,* 137-149. http://doi.org/10.1111/j.1745-4522.2007.00107.x.

Skevin D, Rade D, Strucelj D, Mokrovcak Z, Nederal S, Bencic D. 2003. The influence of variety and harvest time on the bitterness and phenolic compounds of olive oil. *Eur. J. Lipid Sci. Technol*. **105**, 536-541. http://doi.org/10.1002/ejlt.200300782.

Srivastava Y, Semwal AD, Majumdar A. 2016. Quantitative and qualitative analysis of bioactive components present in virgin coconut oil. *Cogent Food & Agric.* **2**, 1164929. http://doi.org/10.1080/23311932.2016.1164929.

Srivastava Y, Semwal AD, Sharma GK. 2018. Virgin Coconut Oil as Functional Oil, in Grumezescu AM, Holban AM. (Ed.) Therapeutic, Probiotic and Unconventional Foods; Academic Press. pp 291-301. https://doi.org/10.1016/B978-0-12-814625-5.00015-7.

Tanilgana K, Özcanb MM, Ünver A. 2007. Physical and chemical characteristics of five Turkish olive *(Olea europea L.)* varieties and their oils. *Grasas Aceites* **58**, 142-147. https://doi.org/10.3989/gya.2007.v58.i2.78.

Tripoli E, Giammanco M, Tabacchi G, Majo DD, Giammanco S, Guardia ML. 2005. The phenolic compounds of olive oil: structure, biological activity and beneficial effects on human health. *Nutr. Res. Rev.* **18**, 98-112. http://doi.org/10.1079/NRR200495.

Veneziani G, Esposto S, Taticchi A, Urbani S, Selvaggini R, Di Maio I, Sordini, Servili M. 2017. Cooling treatment of olive paste during the oil processing: impact on the yield and extra virgin olive oil quality. *Food Chem*. **221**, 107-113. https://doi.org/10.1016/j.foodchem.2016.10.067.

Veneziani G, Esposto S, Taticchi A, Urbani S, Selvaggini R, Sordini B, Servili M. 2018. Characterization of phenolic and volatile composition of extra virgin olive oil extracted from six Italian cultivars using a cooling treatment of olive paste. *LWT* **87**, 523-528. https://doi.org/10.1016/j.lwt.2017.09.034.

Villarino BJ, Dy LM, Lizada MCC. 2007. Descriptive sensory evaluation of virgin coconut oil and refined, bleached and deodorized coconut oil. *LWT* **40**, 193-199. http://doi.org/10.1016/j.lwt.2005.11.007.

Visioli F, Galli C. 1998. Olive oil phenols and their potential effects on human health. *J. Agric. Food Chem.* **46**, 4292-4296. http://doi.org/10.1021/jf980049c.

Weerakoon WNMTDN, Anjali NVP, Jayathilaka N, Seneviratne KN. 2021. Soybean oil and coconut oil enhance the absorption of chlorogenic acid in humans. *J. Food Biochem.* e13823. http://doi.org/10.1111/jfbc.13823.

Withana-Gamage TS, Perera SP, Wanasundara UN. 2005. Edible oil and fat products: Edible oils, in *Bailey's Industrial Oil and Fat Products*, *7th ed.* http://doi.org/10.1002/047167849X.bio054.pub2.

Wiyani L, Rahmawati, Aminah, Aladin A, Mustafiah, Juniar, ME. 2020. Antioxidant activity of virgin coconut oil and virgin coconut oil emulsion. *Sys. Rev. Pharm*, **11**, 973-979. http://doi.org/10.31838/srp.2020.5.139.

Zeb A. 2020. Concept, mechanism, and applications of phenolic antioxidants in foods. *J. Food Biochem*. **44**, e13394. https://doi.org/10.1111/jfbc.13394.

Zeb A. 2021. A comprehensive review on different classes of polyphenolic compounds present in edible oils. *Food Res. Inter. 143*, 110312. https://doi.org/10.1016/j.foodres.2021.110312.