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Chapter 6

HEALTH BENEFITS OF VIRGIN COCONUT OIL

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ABSTRACT

Virgin coconut oil (VCO) is a product that can be produced from fresh coconut meat, milk, or residue. Over the years, it has become known as a popular functional food oil. It is considered to be the newest, high-value coconut product, very much sought for its human, nutraceutical benefits, as well as a functional food. Its increasing popularity can be attributed to numerous studies showing its beneficial effects. Several studies have investigated the pharmacological properties of VCO including anti-inflammatory, analgesic, antipyretic, anti-oxidant, anti-stress, and antimicrobial properties. Furthermore, other studies have also investigated the bone loss prevention as well as cardioprotective

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effects of VCO. For example, administration of VCO in animal studies (i.e., Sprague-Dawley rats) showed significant antithrombotic effect compared to copra oil. The effects were comparable with sunflower oil fed animals. This chapter will discuss the chemical properties, sources, synthesis, preparation, uses, and worldwide production of VCO. A particular focus will be on the health benefits of VCO including its most recent findings.

ABBREVIATIONS

AA	Arachidonic acid
APCC	Asian Pacific Coconut Community
APP	Acute-phase protein
BAFPS	Bureau of Agriculture and Fisheries Product Standards
BM	Bawalan-Masa
COX-2	Cyclooxygenase-2
CMV	Cytomegalovirus
DCN	Desiccated Coconut
DME	Direct Micro Expelling
EBV	Epstein-Barr Virus
FA	Fatty Acid
FFA	Free fatty acid
GAE	Gallic acid equivalents
GPX	Glutathione peroxidase
GSH	Glutathione
HDL	High-density lipoprotein
ICS	International Certification Services
IL-6	Interleukin-6
iNOS	Inducible nitric oxide synthase
LDL	Low-density lipoprotein
MCFA	Medium chain fatty acid
MCT	Medium chain triglyceride
MDA	Malondialdehyde
MIC	Minimum inhibitory concentration
NO	Nitric oxide
NSAID	Non-steroidal inflammatory drug
PG	Prostaglandin
PNS	Philippine National Standard
P. acnes	*Propionibacterium acnes*
RA	Rheumatoid arthritis
RBD	Refined, bleached, deodorized
SFA	Saturated fatty acid
SOD	Superoxide dismutase
TNF-α	tumor necrosis factors-α
VCO	Virgin coconut oil

1.0. INTRODUCTION

Coconut oil is one of the most important food oils in the world as a source of dietary fat. It is extensively used as cooking oil, and also in food industries such as confectionary and baking products [1]. There are two types of coconut oil based on how they are obtained from the coconut meat: refined, bleached and deodorized coconut oil (RBD) and virgin coconut oil (VCO). RBD oil is made from copra, which is the dried coconut kernel or meat, produced through smoke drying, sun drying or a combination of both. Then the clean, ground and steamed copra is pressed to obtain the coconut oil. Although coconut is one of the healthiest foods known to mankind, the drying process and unhygienic storage and handling makes the extracted oil unsafe for human consumption. Therefore the refining, bleaching, and deodorizing process is necessary after the extraction. This process requires heating the oil at high temperatures, between 204°C and 245°C, which destroys the essential amino acids, tocopherols (i.e., Vitamin E) and other valuable compounds present in coconut oil [2-6].

Coconut oil can also be extracted from fresh coconut kernels, the process of which does not involve high temperature treatments. The Philippine national standard defines VCO as the oil obtained from the fresh, mature kernel (meat) of the coconut by mechanical or natural means, with or without the use of heat, without undergoing chemical refining, bleaching or deodorizing processes, which does not lead to the alteration of the nature of the oil [5]. This is the purest form of coconut oil, which has the fresh coconut aroma and contains natural Vitamin E and other valuable compounds present in the coconut meat. VCO has a clear water appearance. RDB oil, in contrast, can appear yellow, pink or red-orange due to the contaminants (microbial or other), or high temperature processing. VCO has low free fatty acid content and peroxide value since it does not undergo the copra-making process, which eliminates atmospheric and hydrolytic oxidation compared to the RBD process [5].

There is a growing demand for VCO in United Sates and other developed countries, which can be attributed to the increasing number of books, journal articles and other scientific literature published on the health benefits of VCO. The amount of VCO manufactured in tropical countries has grown rapidly in the last two decades. For example, the number of VCO producers increased from 20 in 2003 to 200-300 producers in 2005 in the Philippines [7]. The exported VCO from the Philippines has increased from 19 metric tons to 177 metric tons from 2002 to 2004 as reported [8]. It was reported in another document published by the Philippine Coconut Authority that the export of VCO increased from 2737 metric tons to 6002 metric tons from 2010 to 2012 showing that the demand and the production of VCO is rapidly increasing [9]. Worldwide production of VCO shall further be discussed in the succeeding sections.

2.0. CHEMICAL PROPERTIES OF VCO

VCO, which is extracted directly from coconut milk by a wet process under controlled temperature conditions, retains more of its beneficial components than copra oil. Particularly, this extraction process avoids the loss of minor components such as pro-vitamin A, vitamin E and polyphenols due to UV irradiation from sunlight during the drying of copra [4, 3, 10]. VCO has a rich content of medium chain fatty acids (MCFAs), predominantly lauric acid;

others include caproic acid, caprylic acid and capric acid [10]. A study conducted by Mansor et al., [10] on VCO extracted by different processing methods reported that the lauric acid contents ranged from 46.36%-48.42% and the total MCFA in the oil (caproic acid, caprylic acid, capric acid and lauric acid) ranged from 59.02% to 62.27% of the total fatty acids. According to his findings, the highest lauric acid content was reported from the samples extracted using the fermentation process, followed by fresh-dry, chilling, and enzyme methods.

Apart from the high concentration of MCFAs, VCO also contains saturated fatty acids (SFAs) such as myristic acid, palmitic acid, and stearic acid, as well as unsaturated fatty acids, both mono-and di-unsaturated fatty acids. As reported by Mansor et al., [10] the concentrations of SFA and total unsaturated fatty acids ranged from 28% to 31% and 6.73% to 8.13%, respectively. Table 1 presents the fatty acid compositions of VCO produced from different methods and the Asian Pacific Coconut Community (APCC) standard compositions for VCO [10]. Variations in fatty acid composition could result from different methods of processing among VCO samples (Table 1) [3, 10, 11].

Iodine value, saponification value, and peroxide content are some of the most important chemical properties that are vital in characterizing the quality of VCO. Other important physicochemical properties in VCO include free fatty acid composition, moisture content, and viscosity (Table 2).

Iodine value of VCO gives an indication of its saturation level. The low content of iodine value as described by Mansor et al. (Table 2) [10] and Marina et al. [3] verified that VCO has high degree of saturation. Consequently, VCO has high resistance to oxidative rancidity. Free fatty acids (FFAs) are responsible for the undesirable flavor and aromas present in VCO and are formed by the hydrolytic rancidity, due to ester hydrolysis either by lipases or moisture. Measured FFA contents were varied from 0.29-0.46 (mg KOH/g oil) in a study conducted by Mansor et al. [10]

Table 1. Fatty acid (FA) composition of VCO produced from different methods and APCC standard compositions for VCO (% area)

FA	Extraction Method				APCC Standard
	Chilling	Enzyme	Fermentation	Fresh-dry	
C6 (caproic acid)	0.57 ± 0.00	0.52 ± 0.00	0.57 ± 0.01	0.55 ± 0.00	0.40-0.60
C8 (caprylic acid)	7.39 ± 0.03	6.63 ± 0.01	7.21±0.13	7.23 ± 0.00	5.00-10.00
C10 (capric acid)	6.15 ± 0.01	5.49±0.00	6.07±0.10	5.94 ± 0.01	4.50-8.00
C12 (lauric acid)	48.05 ± 0.11	46.36±0.00	48.42 ± 0.90	48.07 ± 0.02	43.00-53.00
C14 (myristic acid)	18.45 ± 0.03	19.54±0.01	18.75 ± 0.34	19.23 ± 0.00	16.00-21.00
C16 (palmitic)	8.94 ± 0.05	9.94 ± 0.01	9.06 ± 0.16	8.91 ± 0.01	7.50-10.00
C18 (stearic acid)	2.96 ± 0.03	3.37 ± 0.00	3.15 ± 0.00	3.17 ± 0.09	2.00-4.00
C18: 1 (oleic acid)	6.18 ± 0.03	6.50 ± 0.01	6.35 ± 0.01	5.79 ± 0.01	5.00-10.00
C18: 2 (linoleic acid)	1.31 ± 0.01	1.63 ± 0.00	1.36 ± 0.00	1.12 ± 0.00	1.00-2.50

Table 2. Physicochemical analysis of VCO extracted using the different methods [10]

Analysis	Extraction Method				APCC Standard, 2007
	Chilling	Fermentation	Fresh-dry	Enzyme	
Iodine value (g I_2/100 g fats)	4.13 ± 0.02	4.30 ± 0.07	4.18 ± 0.04	4.26 ± 0.05	4.10
Free fatty acid (mg KOH/g oil)	0.31 ± 0.01	0.29 ± 0.02	0.46 ± 0.01	0.35 ± 0.01	0.5 max
Saponification value (mg KOH/g oil)	258.23 ± 3.09	256.73 ± 0.85	258.42 ± 1.41	262.72 ± 0.32	250-260 min
Moisture content (% wt)	0.11 ± 0.01	0.06 ± 0.00	0.04 ± 0.00	0.11 ± 0.01	0.1-0.5
Viscosity (Pa.s)	48.93 ± 0.31	48.73 ± 0.46	50.93 ± 0.31	48.93 ± 0.31	NA

The saponification value, another important chemical characteristic, measuresthe average molecular weight of all the fatty acids present in VCO. One study found out that VCO has very high saponification values compared to other vegetable oils (3). The higher the saponification value, the shorter the fatty acids on the glycerol backbone, indicating that VCO contains a higher amount of short-chain fatty acids. Mansor et al. reported the saponification values from four different extraction methods (Table 2) [10].

VCO can also be characterized by the presence of antioxidants. Tocopherols, which are natural lipophilic antioxidants, are known to be found in vegetable oils including VCO. Mansor et al. [10] detected three types of tocopherols present in VCO including beta, gamma and delta forms. Beta-tocopherol ranged from 0.04 – 0.05 mg/kg, gamma-tocopherol ranged from 0.01–0.05 mg/kg, and delta-tocopherol was detected at a very low concentration levels (1.30 x 10-5 to 1.10 x 10-3 mg/kg) in VCO.

VCO is also good source of phenolic compounds, which are potential natural antioxidants found in foods. Total phenolic contents present in VCO will vary based on coconut varieties and oil extraction processes [4, 3, 10]. VCO has been shown to have a high total phenolic content (11.82–29.18 mg gallic acid equivalents [GAE]/100g oil), which is responsible for its high antioxidant properties (antioxidant activity ranging from 52.54% to 79.87%) [12]. Another study conducted by Arlee et al. has reported total phenolic contents of VCO ranged from 48.17–57.89 mg GAE/100 g oil [13].

Moisture content is another important quality characteristics for oils and fats. Low moisture levels will increase the shelf life by preventing oxidation and rancidity processes, whereas high moisture content will assist in hydrolysis. Mansor et al. reported the moisture content (% wt) and viscosities for VCO extracted using four extraction methods (Table 2) [10]. The highest recorded viscosity was from fresh-dry method while the lowest was from fermentation method.

Besides the abovementioned properties, formation of peroxides and hydroperoxide in the initial stage of lipid oxidation is also an important property of VCO that should be noted, because it reflects the tendency of the oil to become rancid. As observed by Marina et al. [3] peroxide values ranged from 0.21 to 0.63 mequiv oxygen/kg oil, which were far below the maximum limits according to Codex standard [14].

3.0. SOURCES, SYNTHESIS, PREPARATION, AND USES OF VCO

3.1. Sources

Coconut oil extracted from the fruit of the coconut palm (*Cocos nucifera L.*) is of two different types: (i) coconut or copra oil obtained from dry coconut flesh and (ii) VCO acquired from fresh coconut flesh. VCO can either be obtained directly from the fresh comminuted (grated, chopped, granulated) coconut meat or from coconut milk or from coconut milk residue [5]. However, the choice of the technology to be implemented for VCO processing depends on various parameters such as scale of operations, the degree of mechanization desired, the amount of investment available and the demands of the prospective buyer [5].

3.2. Processing of VCO

The Philippine National Standard (PNS) for VCO (PNS/The Bureau of Agriculture and Fisheries Product Standards (BAFPS) 22:2004/International Certification Services (ICS) 67.2000.10) defines it as: "oil obtained from the fresh, mature kernel (meat) of the coconut by mechanical or natural means, with or without the use of heat, without undergoing chemical refining, bleaching or deodorizing, and which does not lead to the alteration of the nature of the oil. VCO is essentially water-clear or colorless. It contains natural vitamin E and has not undergone any hydrolytic and atmospheric oxidation as demonstrated by its very low free-fatty acid content (even without refining) and low peroxide value [15]." VCO has a fresh coconut aroma and its intensity depends on the extraction process. Hence, unlike refined coconut oil, the production process of VCO does not go through the RBD procedures, which are carried out at high temperature between 204°C and 245°C as mentioned earlier [16]. VCO can be produced even at home without the need for any specialized equipment. As a means to ensure the production of high quality oil, the VCO processor used at home or plant should strictly comply with the good manufacturing practices and quality control procedures [17].

The production of VCO is divided into three stages, (i) pre-processing, (ii) processing and (iii) post processing.

3.2.1. Pre-processing Stage

The pre-processing stage involves all the steps performed before the opening of the fresh coconut such as on-farm activities (harvesting, collection and husking of nuts), transport from the farm to the VCO processing site (factory or home), storage, and selection for daily processing [18].

3.2.2. Processing Stage

The processing stage begins with the opening of the fresh kernel and is complete until the final recovery of VCO. The VCO production process can be carried out in eight different ways based on the desired final quality of oil [5, 4, 19-20]. The common method of classification is based on whether a dry or wet process is employed. However, methods can also be classified based on the precursor form of coconut used (Figure 1).

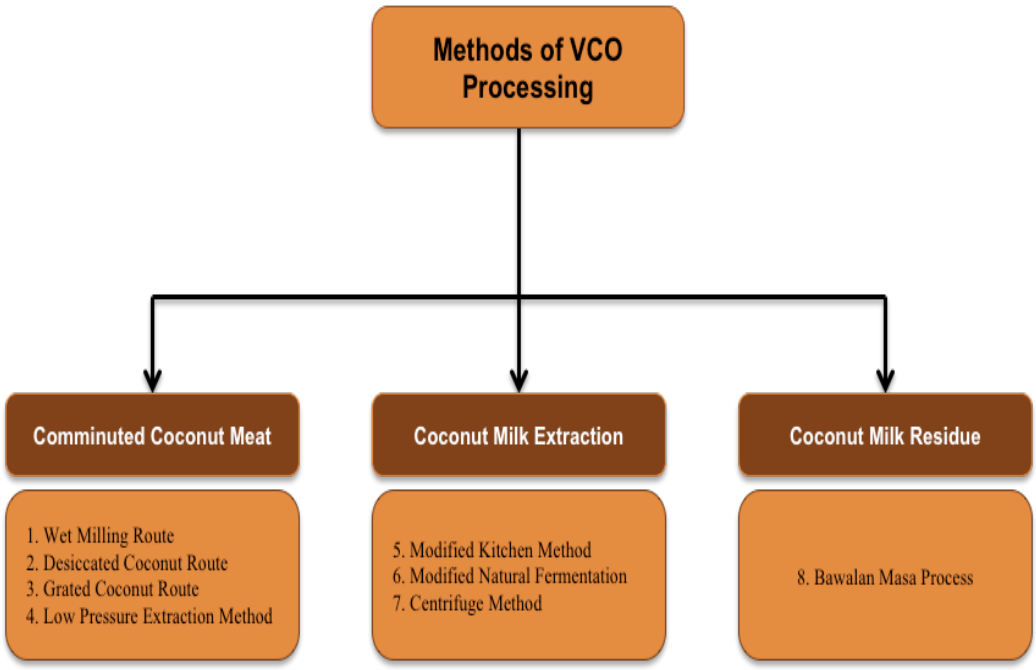

Figure 1. Methods of VCO processing.

A. **Fresh Coconut Meat**

(i) High Pressure Expelling Process

The high pressure expelling process is considered to be the most appropriate method to process a capacity of 3000 or more coconuts a day [5]. The method demands the use of mechanical dryers and high-pressure expellers that are equipped with water-cooled shafts. VCO obtained from the high-pressure expeller process is highly viscous as it contains all of the natural gums present in the parent fresh kernel. There are three different types of high-pressure expeller method of VCO production based on the mode of preparation of kernels prior to drying, the Wet Milling Route, the Desiccated Coconut Route, and the Grated Coconut Route [5, 17].

- **Wet Milling Route**. In the wet milling route, the de-shelled meat is first washed with copious amount of water and then milled. The particulated coconut meat is then dried to 75°C and the oil is extracted using a screw-type press to produce VCO and coconut flakes [8].
- **Desiccated Coconut (DCN) Route**. The DCN route involves washing, grinding, blanching and drying of the coconut meat. The ground meat is dried to a moisture content level of 2.5-3% using a conveyor type hot air dryer with three diminishing temperature levels (100°C, 85°C, and 65°C) (17)°. Desiccated coconut products, which do not pass the accepted quality standards in terms of color and microbial content, can still be processed into high value VCO [8, 17].

- **Grated Coconut Route.** The grated coconut route is similar to the DCN route except that it requires fewer processing steps and equipment [8].

(ii) Fresh-Dry Low-Pressure Extraction Technique

This method is also known as the intermediate moisture content technique [17]. Utilizing a low pressure of approximately 460 psi, oil can be extracted from most seeds and nuts provided the moisture content is maintained between 10-13%. Likewise, oil can be extracted from finely grated and dried coconut meat if moisture content levels are within the optimum range. The grated kernels dried either by indirect hot air drying or solar drying is placed in bags made of cheesecloth [17]. The oil extraction process is carried out in a bridge press, which facilitates easy removal of the residue, and as the cheesecloth acts as a filter, the resultant oil contains only a less amount of fine kernel particles. While the extraction process performed with low moisture content meat results in reduced oil quantity, high moisture content meat yields relatively turbid oil owing to a mixture of oil and coconut milk. The acceptable level of moisture content in VCO should be 0.1% or less [17].

B. Milk Extraction

(i) Modified Kitchen Method

For many decades, people in coconut producing areas like the Philippines and India produced coconut oil for hair and massage applications by boiling the extracted coconut milk from freshly grated or comminuted coconut meat [17]. Nevertheless, the dark yellow oil, thus produced possesses a very short shelf life and becomes sour within three to five days. A slightly modified procedure known as the Modified Kitchen Method utilizes the same principle with the exception that the heating systems are properly controlled so as to prevent the recovered oil from turning yellow. Moreover, the recovered oil is further dried to maintain moisture content less than 0.2%, in order to extend the shelf life. Although, the method produces VCO with an intense coconut aroma, the final recovery of oil is relatively low when compared to other methods due to the fact that a major portion of the oil gets trapped in the protein residue [17].

The modified kitchen method includes two distinct parts, (i) Extraction of coconut milk, and (ii) processing of VCO from the coconut milk. Extraction process can be done manually or through the use of a hydraulic press. The grated kernel is mashed and placed in a cheese bag (manual method) or a white net bag (hydraulic jack method), and tightly squeezed to produce the coconut milk. Often times a second extraction is also performed to enhance the oil quantity. The squeezed milk is then allowed to settle preferably for two hours so as to distinguish the separation of coconut cream (oily phase) and skim milk (aqueous phase) layers [21]. After scooping the coconut cream from the top, the cream is heated maintaining an initial temperature of 90^{o}C for the first hour and later reduced to 80^{o}C to allow the coagulation of protein. And as the oil separates, the temperature is further reduced, and continuous stirring is done to facilitate uniform heat through the mixture. The oil produced is scooped out from the wok carefully and filtered through a cotton-plugged funnel (small scale) or a pressure filter can also be used for large scale processing [17].

(ii) Modified Natural Fermentation Method

The Modified Natural Fermentation Method requires much less investment, with moderate labor and energy inputs compared to all the currently available VCO processing technologies. Dayrit, et al. [22] suggested that the natural fermentation method is a familiar process for the production of VCO which can be conveniently performed both at the household level and at the industrial scale.

This method of VCO production is similar to that of the Modified Kitchen Method except that the extracted coconut milk is diluted and allowed to stand for hours to undergo natural fermentation. Fermentation can also be induced by the addition of foreign substances such as *Lactobacillus plantarum* [23]. The maximum permissible level of FFA content in VCO is 0.1%. However, the FFA content of VCO produced by traditional natural fermentation method ranges from 0.33–0.38%. The reason for such high FFA content in VCO obtained through traditional method could be attributed to the long hours of settling time (36-48 hours). Hence, as a means to obtain water clear VCO with acceptable FFA levels, the fermentation time is regulated to a maximum of 16 hours. The finely grated fresh kernel is subject to a hydraulic press for the extraction of coconut milk. The extracted coconut milk is mixed with one portion of water and left to settle at ~40°C for a maximum of 16 hours for fermentation to occur [24]. The fermenting container displays five distinct layers comprising of different components in ascending order: (i) gummy sediment at the bottom, (ii) fermented skim milk, (iii) fermented curd layer, (iv) VCO layer and (v) a top layer of fermented curd. The top layer of fermented curd is scooped out and the VCO layer is separated and filtered through a filtering funnel plugged with cotton. The fermented skim milk obtained in this process is unfit for human consumption and should be discarded. In certain cases, the coconut milk emulsion can also be separated by adjusting the pH of the emulsion between 3 and 5.6 and inoculated with bacteria cultures [25].

(iii) Centrifuge Method

The best quality VCO can generally be achieved through the centrifuge process [26-27]. There are two different types of centrifuge processing of VCO: (i) the two-phase (liquid-liquid) centrifuge process and (ii) the three phase (liquid-liquid-solid) centrifuge process. Based on how the VCO is recovered from the coconut cream, the two-phase (liquid-liquid) centrifuge process can have slight modifications. Three different routes have been reported. (i) The cream is subjected to vacuum evaporation to remove water and coagulate the protein. (ii) The cream is frozen and heated in a double boiler and is filtered to remove the coagulated protein. (iii) The cream is heated in a controlled temperature to coagulate the protein and remove water. In all the three cases the resultant oil is filtered through a filter press followed by vacuum drying to remove traces of water [28-29].

Compared to the two-phase centrifuge process, the three-phase centrifuge process is simpler: the filtered coconut milk is passed through a three-phase centrifuge system where the individual components are separated by an applied centrifugal force [28]. The coconut milk after its extraction is mixed with one portion of hot water and is fed into the centrifuge. The cloudy oil that comes out of the centrifuge is again mixed with the second portion of hot water and fed again into the centrifuge for a second pass. The final oil is filtered to remove any solid particles and vacuum dried to afford water clear VCO. The scales of operation of VCO are relatively large owing to the high investment cost [17].

C. Coconut Milk Residue

The Bawalan-Masa Process

The Bawalan-Masa Process (BM) is a hybrid of fresh-dry and the fresh-wet processes [17]. The precursor for the VCO extraction in BM process is the coconut milk residue, which represents approximately 25-50% of the weight of the freshly grated coconut meat. The residue is blanched and dried in a mechanical dryer to reach specific moisture content. The defatting of the dried residue under controlled conditions in a specially designed equipment produce VCO and low fat, high fiber coconut flakes. The oil containing fine particles is filtered through a mechanical filter to give a clear VCO. Coconut flakes obtained as a by-product during the process can be re-dried and ground to produce coconut residue flour. The VCO, thus, produced is very light in texture and is easily absorbed and has a very mild coconut scent [17].

3.2.3. Post Processing Stage

The post processing stage includes all processes that are conducted to improve the quality of the produced VCO. It includes oil drying (removal of moisture content), ageing (removal of the sour smell), and fine filtration (removal of fine residue). Table 3 gives the comparison data of the overall quantity and moisture content of the recovered oil of all the methods discussed so far [5].

3.3. Uses of VCO

VCO has a wide array of uses and applications, which can be classified as either edible or inedible categories. A comprehensive review of its health benefits is discussed in the succeeding sections.

Edible Applications

- VCO serves as an important source of energy in diet [5].
- VCO is used as cooking and frying oil due to its exceptional resistance to rancidity development, and it enhances the flavor of food [5].
- Due to its nature of unchanging palatability, VCO is used as a substitute for buttermilk in filled milk, filled cheese and ice cream [5].

Inedible Applications

- It is used as a skin and hair conditioner [17].
- Aromatherapy and massage oils [30].
- Oil base for a variety of cosmetic and skin care products [31].

Synopsis of Health Benefits

- VCO is the only naturally available low-calorie fat [32].

- VCO boosts the immune system and protects humans from atherosclerosis and cardiovascular disease [32].
- Digestion of VCO takes place easily without the need for bile.
- VCO stimulates metabolism and prevents obesity [33-34].
- It also inhibits cancer causing agents [35].
- It increases the absorption of vitamins, minerals and amino acids [32].
- VCO has the potential to prevent exercise and chronic cold restraint stress-induced damage and restores the antioxidant balance [36].
- The presence of polyphenols and medium-chain fatty acids in VCO imparts anti-stress activity [36].
- Wound-healing rate was increased in skin of rats treated with VCO [19].
- VCO was also used as an 'ethnomedicine' to treat gastrointestinal problems and minor cuts, injuries and swelling [37].
- Effective and safe as mineral oil when used as a moisturizer for mild to moderate xerosis [38].
- Dried-and fermented-processed VCO has hepatoprotective property [39].
- Has anti-oxidant activities and does not adversely affect serum lipid levels [40].
- Has anti-diabetic effects [41].
- VCO displayed inhibition of *Candida sp.* responsible for fungal infection [42].
- The fatty acid present in VCO acts as a potential immunostimulant, which increases immunity through the increase of lymphocyte and Th-CD4 in chickens vaccinated against *Avian influenza* virus [43].

Table 3. Comparative data of VCO obtained by different processes [5, 17]

Type of Process			Quality of Oil	Recovery
Fresh-Dry Processes	High-Pressure Expelling	Wet Milling Route	FFA–0.05-0.08% MC – 0.07-0.1%	60 kg per 100 kg of dried milled kernel
		Desiccated Coconut Route	FFA– 0.05-0.08% MC – 0.0-0.1%	58 kg per 100 kg of desiccated coconut
		Grated Coconut Route	FFA– 0.05-0.08% MC – 0.07-0.1%	30 kg per 100 kg of fresh grated kernel
	Low-Pressure	Low pressure Extraction	FFA– 0.1-0.2% MC – 0.17% & below	25 kg per 100 kg of fresh grated coconut kernel
Fresh-Wet Processes	Coconut Milk Extraction	Modified Kitchen Method	FFA– 0.1% MC – 0.14% & below	16.5 kg per 100 kg of fresh grated coconut kernel
		Modified Natural Fermentation Method	FFA– 0.1% MC – 0.12% & below	34 L per 100 L of coconut milk
		Centrifuge Method (2-phase)	FFA– 0.04-0.08% MC – 0.1% & below	28 L oil per 100 L of coconut milk
	Coconut Milk Residue	Bawalan-Masa Process	FFA– 0.05-0.08% MC – 0.07-0.12%	17 kg per 100 kg of wet residue

4.0. WORLDWIDE PRODUCTION OF VCO

4.1. How Production of VCO Changed through Time

While it may be the common assumption that the production process of VCO has changed through time, this may not actually be the case. The actual production processes and the methodology behind them have not consistently changed. Fermentation and the unheated and "cold pressed" procedures are the most typical methods used in the mass production of VCO and have not been seen to drastically change over time. These methods are not to be confused with RBD coconut oil (chemically refined, bleached, deodorized) methods [44-45]. However, what has been observed throughout time is an ongoing debate as to which method is actually the best, which is the focus of multiple research groups around the world. For example, a study conducted in 2005 at the University of the Philippines suggested that VCO in general contained more antioxidants than that of RBDs [44]. Nonetheless, the real concern was focused on the question as to which method, fermentation or unheated and "cold pressed", produced more antioxidants. The study concluded that the VCO prepared with heat through the fermentation process contained on the average a significant amount more antioxidants than other methods [44]. A few of these antioxidants included superoxide dismutase, malondialdehyde, Vitamin E, phytosterols, and phenolic compounds, in which were found to have a variety of different functions and benefits [46]. Further studies conducted, which include a study done in 2005 in Malaysia and another in 2011 in Sri Lanka, proved that all methods that involve heating the VCO produces more antioxidants [46-47].

4.2. Largest Producers of VCO

As previously mentioned, the studies conducted were located in a variety of different countries including the Philippines, Malaysia, Sri Lanka, India, etc. The significance of mentioning the location of these studies lies in the fact that these countries are all the major producers of VCO. The leading coconut-producing country is the Philippines, followed by Indonesia, India, Sri Lanka, Thailand, and Malaysia; most of which had universities that conducted significant studies relating to debate between the methods behind producing VCO. There are multiple factors to consider as to why these countries are the ideal location for the production of VCO. Primarily, these countries are located in areas very favorable for coconut palm growth, in which reasons include average rainfall per year, sunlight, sandy soil, and humidity [48-49]. The Philippine coconut industry in and of itself accounts for 1.5% of gross national product (GNP) and is the highest net foreign exchange earner in agricultural exports. The Philippines coconut industry employs nearly 20 million people, which accounts for around one-third of the country's entire population. The industry earns approximately $510 million in U.S. currency on an annual basis. Across the globe, Indonesia and the Philippines were the world's two largest producers of coconuts with an estimated production of 16.3 mn tonnes and 14.4 mn tonnes from 3.3 mn ha and 2.7 mn ha, respectively. India is the third largest with an estimated world coconut production of 10 mn tonnes from 1.9 mn ha. The major exporters were Philippines and Indonesia while India consumed most of its coconut product. Across the Western Hemisphere, Central America, Jamaica, Brazil, and Mexico were

the major producers of coconut. The major coconut oil importing countries in the world included EU-15 (15%), the USA (33%), Malaysia (5%), South Korea (4%), East Europe (4%), and Singapore (4%) [50].

Coconut oil accounts for approximately 20% of all vegetable oils used worldwide [51]. Examination of the world coconut oil supply and distribution for over a decade (2002/03 to 2015/16) shows a steady decline in the total supply of the oil starting from 2013/14 (Figure 2). This total supply of the world coconut oil is the sum of the beginning stocks, production, and imports. The decline can be attributed primarily to the decrease in the beginning stocks available for the coconut oil supply. Worldwide exportation of the coconut oil has not tremendously varied over the past five years. Industrial domestic consumption and food use domestic consumption of the coconut oil have also started to increase slightly since 2014/15. Overall, the worldwide ending stocks available for the coconut oil have steadily declined since 2011/12 [52].

4.3. Economic Benefits and Analysis of VCO

VCO was flagged as an unhealthy food product and a possible contributor to heart disease around 40 years ago. However, over the years this idea has been adjusted [53]. Saturated fatty acids in coconut oil gave the oil a bad reputation and resulted in its sparse consumption [53]. However, an increasingly new wave of consumers have flocked to the oil as new studies have proposed health effects including weight loss and analgesic, antipyretic, cardio-protective and anti-carcinogenic effects. The economic boom, which has followed in the wake of these new studies, has generated a very lucrative market in coconut producing countries on a wide scale [54]. In general, VCO production has benefited the local economies, but in other cases the opposite seems to be true.

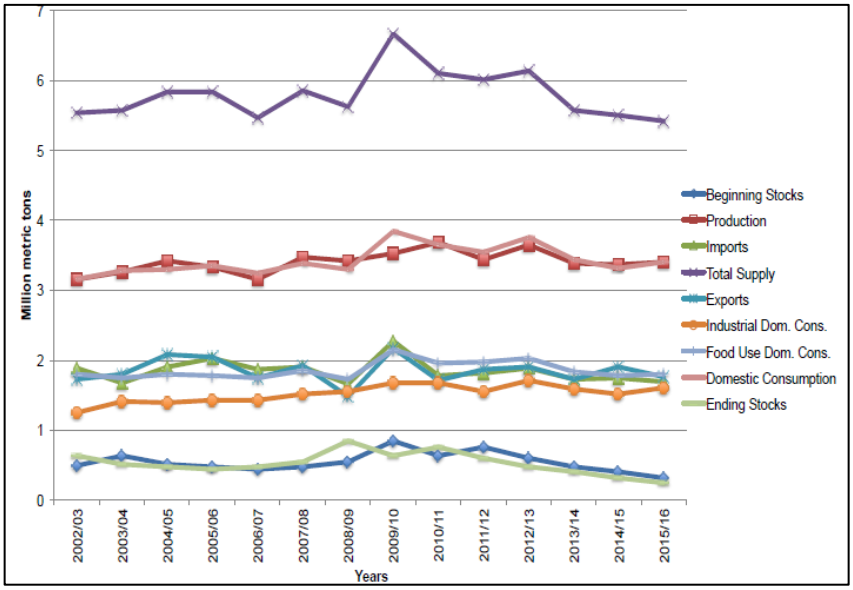

Figure 2. World coconut oil supply and distribution [52].

One of the chief examples of the positive effects is the development of a VCO industry in the Solomon Islands, which before the turn of the century primarily produced copra [55]. After the dried coconut kernel was harvested, it was then shipped off and processed away from the site where it was harvested. The coconut oil demand has brought new prosperity to the islands, which before were plagued with poverty. Dr. Etherington, a Stanford educated economist developed a system called Direct Micro Expelling (DME), which presses the oil on a small scale and obtains it in little under an hour. This allowed the people of the Solomon Islands to expand their use of the coconuts, effectively utilizing more of the coconut at the village level of the coconut oil production [55]. Dr. Etherington's company, Kokonut Pacific, has installed more than 40 DME systems in the Solomon Islands, and sees potential to put in more than 300 in the coming years.

The world's leading producer of coconut oil, the Philippines has shown how lucrative this industry can be. About one third of the population in the Philippines is directly or indirectly employed by the coconut industry in the Philippines [54]. The boom of the coconut oil has generated a massive industry in the Philippines, but some argue that the influx of business has not stimulated the economy at every level. Numerous farmers still live in poverty even though their crop has grown in value. Evidence of this, is based in the facts that coconut farmers are still some of the poorest farmers in the world. It is estimated that sixty percent of the farmers living in the Philippines live in poverty [56].

5.0. BENEFICIAL EFFECTS OF VCO

5.1. Anti-Inflammatory Properties of VCO

Inflammation is a protective response of the immune system against pathogens, but can also result to damaging consequences if not regulated [57]. The complex immune processes and mediators involved in the inflammatory response can induce and aggravate many diseases. Recent studies have found that inflammation plays a key role in various human diseases that are not primarily disorders of the immune system, which includes cancer, atherosclerosis, ischemic heart disease, and neurodegenerative diseases such as Alzheimer's disease [57]. However, current medications have adverse effects and there is a need for more effective and safer anti-inflammatory therapeutics. Thus, VCO offers the potential for further research and development of anti-inflammatory therapies. Different groups have shown great interest in exploring the anti-inflammatory effects of VCO because of its high phenolic contents. Some of the phenolic acids identified in VCO include caffeic acid, p-coumaric acid and feulic acid [58]. Polyphenols control and reduce inflammation through a series of pathways, therefore, preventing cancer and other diseases with an inflammatory pathogenesis. Therefore, it is of interest of this section to summarize the anti-inflammatory action of VCO that has been investigated [59].

5.1.1. Anti-Inflammatory and Anti-Oxidant Properties of VCO Inanimal Models of Rheumatoid Arthritis

Arthritis is caused by joint inflammation that can ultimately lead to disability. Rheumatoid Arthritis (RA) in particular is a chronic inflammation that affects synovial joints

and progressively results to destruction of articular cartilage. Current medications used to treat RA have side effects; the need for effective therapeutics that also permit greater compliance is what drive the investigation into products such as VCO. Vysakh et al. explored the anti-inflammatory effect of the polyphenolic fraction extracted from VCO on experimental arthritis [60]. Their results demonstrated the potential health benefit of VCO on adjuvant induced arthritis in rats, and determined that mechanism behind this action is due to its antioxidant and anti-inflammatory effects. Their findings on how VCO inhibits arthritis can be summarized as follows:

- **Downregulated (inducible nitric oxide (NO) synthase) iNOS expression.** Nitrite production in VCO treated animals was reduced significantly compared to adjuvant treated rat. This suggests that reduction of chronic inflammation in arthritic animals might be due to the downregulation of iNOS expression followed by decreased cellular production of NO. Therefore, the anti-inflammatory activity of VCO may be due to their ability to counteract NO induced oxidative damage, which eventually helps in the remodeling of cells.
- **Decreased cyclooxygenase-2 (COX-2) expressions.** During inflammation, COX-2 enhances the synthesis of prostaglandins (PGs) that are associated with inflammation. The activity of total COX and COX-2 expressions was decreased in VCO treated rats. Reduction of paw swelling and decreased expression of COX-2 indicate the immunological protection provided by VCO.
- **Inhibited tumor necrosis factors-α (TNF-α) activity.** TNF-α may play a role in the pathology of RA. Blocking of TNF-α followed by inactivation of T cells, macrophages, and fibroblasts interrupts the inflammatory process. This anti-TNF-α activity supports further pharmacological research on VCO, in hopes of improving anti-inflammatory medications.
- **Downregulated Interleukin-6 (IL-6) expression.** IL-6 plays a devastating role in cartilage and bone degradation during arthritis. VCO supplementation significantly downregulated the expression of IL-6 in paw tissue of arthritic rats. VCO supplementation also restored the levels of acute-phase proteins (APPs) to near normal values in arthritic rats. Thus, decreased IL-6 production correlated with decreased APP production, thereby reducing disease severity.
- **Enhanced Glutathione (GSH) and superoxide dismutase (SOD) activity**. Polyphenols from VCO enhanced the activity of GSH and SOD, which help preserve the integrity of cellular membranes. VCO administration produced a significant increase in free radical scavenging activity of antioxidant enzymes like glutathione peroxidase (GPX) and catalase.
- **Decreased lipid peroxidation.** The elevated levels of lipid peroxidation were significantly decreased after VCO treatment. VCO reduces free radicals formation as well as inflammation. These results imply that adjuvant induced arthritis may be associated with lipid peroxidation and demonstrates the anti-arthritic effect of VCO. VCO reduced lipid peroxidation causing a modulation in cellular antioxidant defense system.

Intahphuak et al. also explored the inhibitory activity of VCO against acute and chronic inflammation. They found that VCO exhibited moderate anti-inflammation on carageenin- and arachidonic acid (AA)-induced hind paw edema in rats as well as on ethyl phenylpropiolate-induced ear edema, which are all models of acute inflammation [59]. Consistent with the findings by Vysakh et al., they also demonstrated that the consumption of VCO aided in inhibiting the expected immune factor responses to endotoxin, and diminished the production of pro-inflammatory cytokines *in vivo*. They also found that the mode of action of VCO to inhibit inflammation may also involve the lipoxygenase pathway because it is effective in AA-induced rat paw edema model. AA-induced edema animal model has been reported to be resistant to selective COX inhibitors but sensitive for detecting the *in vivo* anti-inflammatory activity of lipoxygenase inhibitors [61].

The group also investigated the effects of VCO on cotton pellet-induced granuloma formation in rats and compared it to the effects of the known anti-inflammatory drugs indomethacin, and prednisolone. Granulomatous inflammation is a distinctive pattern of chronic inflammatory reaction. Indomethacin and prednisolone inhibited granuloma formation by interfering with the proliferative phase of inflammation. However, both drugs also caused weight gain. They have shown that VCO also inhibited granuloma formation but did not result in weight gain. VCO exhibited an inhibitory effect on chronic inflammation by reducing the transudative weight, granuloma formation, and serumalkaline phosphatase activity. The results obtained suggest that VCO probably inhibits the proliferative phase of chronic inflammation but avoids the steroidal-like effect, as it had no effect on body weight gain and dry thymus weight. The activity of VCO on the alkaline phosphatase level in serum may be due to its inhibitory effect on inflammatory cell activity and/or stabilization of the lysosomal membrane.

Similar to the paper of Intahphuak et al. [59], Zakaria et al. [85] investigated the anti-inflammatory effects of VCO using *in vivo* models. The group utilized two types of VCO, produced by standard drying (VCOA) and fermentation (VCOB) on animal models (mice/rats) of both acute and chronic inflammation. The VCOs exhibited anti-inflammatory activity in an acute model (carrageenan-induced paw edema test), consistent with the findings of Intahphuak et al. with the same animal model. Comparing the two, VCOB showed a greater anti-inflammatory effect than VCOA. However, in contrast to the findings of Intahpuak et al. [59], the VCOs did not show ant-inflammatory effects on chronic (cotton-pellet-induced granuloma test) model of inflammation.

5.1.2. Anti-Inflammatory Effect of VCO against E.Coli Endotoxin

Dietary fat influences many aspects of immune function. *Escherichia coli* endotoxin is a potent stimulator of interleukin 1 production from macrophages. The present study examines how feeding rats high-fat diets either rich (corn oil) or poor (coconut oil) in linoleate at high and low concentrations affect responses to endotoxin. Spleen phosphatidylcholine linoleate contents were higher in the corn oil than in the coconut oil group and arachidonate concentrations were highest in the group fed a high concentration of corn oil. Coconut oil completely abolished the responses to endotoxin. The inhibitory effects of coconut oil against the endotoxin largely be due to reduced prostaglandin and leukotriene synthesis [62].

Similar to the aforementioned study, Sadeghi et al. (1999) carried out an investigation on the effect of dietary oils such as coconut oil, corn oil, olive oil, safflower oil and fish oil on *in*

vivo cytokine response to bacterial lipopolysaccharide [63]. These dietary oils were fed to mice for 5 weeks and the mice were then injected with a non-lethal dose of *Escherichia coli.* The mice were sacrificed after 90 or 180 minutes post *E. Coli* injection to measure plasma cytikine concntrations. The results showed lower peak plasma concentrations of TNF-alpha, IL-1beta and IL-6 in mice fed with coconut oil and fish oil compared to other dietary oils. Moreover, peak plasma IL-10 concentrations were higher in mice fed with coconut oil than in mice fed with other oils. These results suggest that coconut oil diminishes production of pro-inflammatory cytokines *in vivo* and diminishes enhanced production of IL-10. This appears to be an additional anti-inflammatory effect of this oil, which could give added benefit in various clinical conditions.

5.1.3. Therapeutic Effect of VCO on Inflammatory Acne Vulgaris

VCO contains a large amount of lauric acid, which has been shown to have antibacterial property on *Propionibacterium acnes* (*P. acnes*). This served as the motivation to investigate the anti-inflammatory property of lauric acid on acnes vulgaris. The anti-inflammatory activity of VCO has also been explored on Acne vulgaris. Acne vulgaris or simply acne, is the most common human skin infection and its prevalence is about 80% in the majority of the countries worldwide [64]. Inflammatory lesions of acne may lead to acne scarring and may have an impact on psychosocial health [65]. Acne is caused by *P. acnes*, a Gram-positive anaerobic bacterium that dwells in the pilosebaceous follicles of the skin. Although *P. acnes* is part of the normal skin bacterial flora, it plays a key role in the development of inflammatory acne when it proliferates and colonizes the pilosebaceous unit. Previous studies have found that *P. acnes* triggers the production of proinflammatory cytokines that are mediated by Toll-like receptors [66]. In another study, Nakatsuji et al. demonstrated the potential of lauric acid as an alternative option for antibacterial therapy in acne treatment. Lauric acid showed stronger antimicrobial activity as compared with benzoyl peroxide against skin bacteria, including *P. acnes*, *in vitro*. It also showed therapeutic potential against *P. acnes*-induced inflammation *in vivo*. This study evaluated the antimicrobial property of lauric acid against *P. acnes* both *in vitro* and *in vivo*. Both intradermal injection and epicutaneous application of lauric acid effectively decreased the number of *P. acnes* colonized with mouse ears, thereby relieving *P. acnes*-induced ear swelling and granulomatous inflammation. This promising result showed the potential of using lauric acid as an alternative treatment for antibiotic therapy of *acne vulgaris* [67].

5.2. Analgesic and Antipyretic Potential of VCO

Intahphuak et al. found that VCO demonstrated a moderate analgesic effect on acetic acid-induced writhing response in mice [59]. VCO at high doses (1000-4000 mg/kg) decreased the number of writhes induced by acetic acid significantly (~30-60%). This effect is modest compared to the known non-steroidal anti-inflammatory drug (NSAID) drug, Indomethacin, which only requires 10 mg/kg dose to markedly decrease the writhing response by ~80%. The mechanism of acetic acid-induced algesia involves the release of endogenous substances such as H^+, K^+, serotonin, histamine, bradykinin, PGs, and substance that excite pain-nerve endings. The analgesic effect of VCO could be due to its ability to block both the synthesis and release of these endogenous substances responsible for pain.

The analgesic effect of VCO was also assessed by Zakaria et al. [85] using several tests. The group utilized acetic-acid induced abdominal constrictions, hot plate test and formalin-induced paw licking test on mice or rats. The VCOs (VCOA and VCOB) exhibited analgesic effect in both the abdominal constriction test and hot plate test indicating their activity in blocking both peripherally and centrally mediated pain induced by chemical and thermal stimuli. The peripheral and central effects of VCOs were further confirmed by their effectiveness in reducing pain in the formalin test. Compared to the analgesics, acetyl acetic acid and morphine, VCOs were less effective even at higher concentration.

5.2.1. Antipyretic Effect Effects of VCO on Yeast-Induced Hyperthermia in Rats

Intahphuak et al. also studied the antipyretic potential of VCO. Fever is a clinical sign of inflammation; elevation in body temperature occurs when the concentration of PGE2 in certain parts of the brain increase. The group demonstrated that VCO exhibited antipyretic activity on yeast-induced hyperthermia. The antipyretic activity of VCO most probably is due to the inhibition of cyclooxygenase, therefore blocking the synthesis or release of PGs in the thermoregulatory center. This mode of action is similar to that of Ibuprofen, a non-steroidal anti-inflammatory agent that possesses antipyretic activity [59].

5.3. Antioxidant, Anti-Stress, and Anticancer Benefits

Mainstream popularity of VCO has led to misinformation regarding potential benefits and how it is beneficial. For example, many companies touted the Vitamin E content of VCO and interchange the benefits of the two. Vitamin E comes in several forms and refers to a group of compounds that include tocopherols and tocotrienols. Coconuts have been shown to have modest tocopherol and tocotrienol concentrations of 0.07, 0.79, 0.18, and 1.04 mg/100 g edible weight of γ-T, α-T3, γ-T3, and total, respectively [68]. Regarding potential anticancer properties, Jordan, et al developed tocopherol-rich nanoemulsions which were shown to possess anticancer activity [69]. This finding shows that VCO may possess some anticancer activity due to the presence of tocopherols and tocotrienols. Also, in a separate study, VCO enriched with zinc was shown to increase the number of helper T_{cd4} and cytotoxic T_c cells [70]. T_c cells release cytokines, which are capable of activating macrophages, thereby eliminating virus-infected cells and destroying cancer cells. Thus, VCO appears to have some anticancer value. However there are a couple of things to bear in mind. One is that VCO only has a small amount of vitamin E and many other fruits and vegetables have more of these tocopherols and tocotrienols. Another thing to note is that to the author's knowledge there appears limited evidence as of yet to support VCO having significant anticancer properties. The greater body of working comparison, instead supports VCO having antioxidant, anti-inflammatory, and immunomodulatory effects [71].

In the body, lipoproteins carry cholesterol through the body, to or away from cells. Low-density lipoprotein (LDL) carries cholesterol through the body and into cells. High-density lipoprotein (HDL) carries cholesterol away from cells. When LDL is carrying cholesterol into the cells of arteries, it can become trapped within artery walls. If there are free radicals within the body or other oxidizing substances, plaque can form and restrict blood vessels [72].

The lipid peroxides are typically unstable, decomposing to form a complex series of compounds [69, 71, 73-74]. These newly formed compounds often include reactive carbonyl

compounds comprised of reactive carbon-oxygen double bonds. Malondialdehyde (MDA) is a product formed from the decomposition of polyunsaturated fatty acid peroxides. Measurement of the MDA is an indicator of lipid peroxidation. The assays often used include chromogenic reagent, which reacts with MDA to form a stable chromophore whose absorbance maximum can then be measured by UV-VIS spectrophotometry. Antioxidant activity is assessed by measuring lipid peroxidation/oxidative stress and antioxidant capacity through the evaluation of the MDA concentration and other antioxidant enzyme levels, which often increase in response [69, 71, 73-74]. These enzymes may include catalase, glutathione peroxidase (GPX), glutathione reductase, and superoxide dismutase (SOD). The presence of polyphenols and the medium chain fatty acids are said to contribute to the antioxidant activity/antioxidant capacity of VCO.

Lipid peroxidation from free radicals and oxidants is a well-established injury mechanism in both plants and animals and is used to indicate oxidative stress in cells as well as tissues [69, 71, 73-74]. Oxidative stress can occur due to this free radical generation in the body leading to bone stress as well as organ damage, including the heart. Antioxidants generally do not reduce cholesterol levels, but rather they prevent plaque from building up by binding to and removing free radical scavengers and other oxidants, thus preventing LDL oxidation. The polyphenol groups present in VCO were found to be capable of preventing *in vitro* LDL oxidation, thus, VCO does provide antioxidant benefits and numerous studies have shown these benefits when VCO has been added to the rat diet [69, 73-77]. In one of these studies, VCO had a greater inhibitory effect on microsomal lipid peroxidation compared to copra and groundnut oil and so is a better antioxidant [73]. The VCO increased the level of antioxidant enzymes and, thus, was able to prevent lipid peroxidation. Findings in this study showed that VCO also reduced LDL and increased HDL cholesterol and total cholesterol levels [73].

The antioxidant properties of coconut oil obtained through the various methods have often been examined. The antioxidant properties of coconut oil obtained from different extraction methods are different in scale. For example, Seneviratne, et al. concluded that a hot method of extraction of coconut oil can produce an oil that contains more phenolic compounds than a coconut oil extracted under cold conditions [78]. As a result of this, coconut oil extracted under hot conditions showed higher antioxidant potential than coconut oil extracted under cold conditions since the phenolic compounds are the free radical scavengers. Therefore, consumption of VCO that have undergone different methods of processing may result in VCO with different antioxidant content and, thus, slightly different potential health benefits. Other extraction methods for coconut oil have been examined as well with a goal of using only as little processing as can be to keep the properties of the virgin material. An extraction using supercritical carbon dioxide resulted in 99% extraction efficiency [79]. Use of this method would result in minimal alteration of virgin material and maximum recovery of oil, however it would have a high extraction cost.

The properties of coconut oil may vary in look, taste and composition depending on methods used to obtain the oil from the nut, regardless of whether the method involves processing (non-VCO) or not (VCO) (3-4, 46). For example, in one study, VCO was obtained through two separate methods: through chilling and also through fermentation, and both were compared to each other as well as coconut oil obtained through the RBD process [80]. The VCO obtained through fermentation showed a stronger scavenging effect and higher antioxidant activity than the VCO obtained from the chilling method. The VCO from use of the chilling method showed a higher reducing power than fermentation obtained VCO and the

RBD oil. The VCO obtained via either method showed a greater antioxidant capacity and higher phenolic acid content than the RBD processed oil.

The loss/change in hormone such as estrogen through naturally growing older or other means leads to a progressive accumulation of oxidative damage in tissue and bone [81]. In 2012, Abujazia, et al., showed that addition of 8% VCO (8 g VCO to 100 g chow) to the rat diet caused a significant decrease in stress-induced MDA levels in bone [81]. In these studies, female rats were subjected to ovariectomy or sham manipulation in order to simulate postmenopausal osteoporosis. The removal or manipulation of the ovaries and subsequent change in hormones leads to progressive loss of bone matrix in the rat, and, thus, a useful model for the occurrence in postmenopausal women. Osteoporosis is bone inflammation associated with oxidative stress and in this study the stress due to lipid peroxidation was estimated by an MDA assay kit using tibia bone sample. Rats subjected to ovariectomy also had higher GPX and SOD concentrations compared to control groups which seems to indicate that VCO prevents the lipid peroxidation and increases the concentrations of antioxidant enzymes in the rat model used. Although the SOD concentration was increased, the increase was not statistically significant unlike the MDA and GPX concentrations, which were statistically significant and the results of these studies indicate alignment with other studies showing the effectiveness of VCO in maintaining bone structure. VCO prevented loss of bone density by preserving bone mass in the rat model.

A similar study from the same group and also using the postmenopausal osteoporosis rat model was performed by Hayatullina, et al. using an 8% (8 g VCO to 100 g chow) VCO supplemented diet [82]. A diet supplemented with VCO led to rats with significantly greater bone volume in rats that had ovariectomy or sham manipulation than those without VCO in the diet. These findings support the evidence for reduction of bone loss density through lipid peroxidation in the estrogen deficient ovariectomized rat by inclusion of a VCO enhanced diet.

VCO then, clearly is effective as an antioxidant when included in the diet. How might VCO compare as an antioxidant to several other oils deemed healthy enough to be included as part of a balanced diet? Findings by Arunima, et al. revealed that a diet supplemented with VCO was more effective at reducing oxidative stress in rats than olive, sunflower and copra oil [36, 83]. In these studies, VCO functioned to help increase several enzyme activities including those of catalase, glutathione peroxidase, and glutathione reductase and superoxide dismutase. Enzymatic activity in the rat model used in this work supports findings indicating the antioxidant ability of VCO as part of a balanced diet. VCO also decreased tissue lipid levels in this study as it did in those previously mentioned.

Studies in similar animal models regarding the antioxidant capacity of VCO have continued to reinforce findings from previous rat studies. Yeap examined *in vivo* antioxidant and anti-stress properties of VCO in mice [36]. The studies showed that stress induced lipid peroxidation from mice administered the forced swim test and cold restraint stress test at 4°C was reduced in mice serum through the use of VCO at doses of 10 ml/kg animal weight. VCO also caused an increase in the liver superoxide dismutase enzyme level and administration led to restoration of balance in brain monoamine neurotransmitter levels, particularly serotonin. Since administration of VCO blocked the increase of serotonin seen in untreated, stressed animals, the depletion of this neurotransmitter was not observed in the VCO-treated animals. This study demonstrated the potential for VCO in blocking stress-induced inflammation and lipid peroxidation.

Thus, VCO consumption as part of a balanced diet is beneficial due to the known antioxidant/antistress properties. It turns out that antioxidant properties are also seen in the topical application of VCO in addition to dietary intake of VCO. Nevin, et al., 2010, showed that rats treated topically with VCO to excision wounds healed faster. 0.5 ml and 1.0 ml of VCO was applied to wounded Sprague-Dawley rats [19]. Lipid peroxide levels were lower in the VCO treated wounds versus control. Antioxidant activity was also proven based on the alteration of enzyme levels of glutathione and MDA. Thus topical application of VCO is beneficial in addition to dietary intake.

Clearly, we have seen how VCO can reduce lipid peroxidation and alter enzyme levels associated with oxidative stress. VCO can eliminate or reduce the loss in bone density due to accumulation of oxidative damage. VCO can also reduce or eliminate oxidative damage in body organs as well. For example, oxidative stress can lead to hepatic toxicity [84]. Treatment with VCO was shown to help protect liver function, reduce liver damage associated with lipid peroxidation and lead to an improvement in hepatic antioxidant enzymes, enzyme activity and liver fatty acid level [39, 85-86]. Treatment with VCO was shown to help protect liver function, reduce liver damage associated with lipid peroxidation and lead to an improvement in hepatic antioxidant enzymes, enzyme activity and liver fatty acid level

5.4. Cardioprotective Effects

VCO has a rich content of MCFAs consisting of caproic acid, caprylic acid, capric acid, and lauric acid [10]. It contains high amount (65%) of medium chain triglycerides (MCTs). These MCTs are directly absorbed from the intestinal tract and sent directly to the liver and doesn't participate in the biosynthesis and transport of cholesterol [87] and, thereby provides a quick source of energy. As a result, VCO was found to be effective against cholesterol levels. VCO was found to reduce the total cholesterol, triglyceride, phospholipid, and LDL, and increase the HDL in the serum and tissues [73]. In addition, the polyphenolic component found in VCO was capable of reducing lipid levels and LDL significantly [74].

VCO was also reported to prevent hypertension and improves endothelial functions in rats fed with repeatedly heated palm oil [88]. In another similar study, it was reported that VCO supplementation demonstrated a cardioprotective effect by preventing an elevated blood pressure when rats were fed with repeatedly heated palm oil [89]. VCO at a dose of 1.43 ml/kg reported protective effects on the vascular and cardiac tissue remodeling when rats were fed with repeatedly heated palm oil [90].

The higher reaction polyphenols in VCO are responsible for its anti-inflammatory and anti-oxidant effects and therefore helps in the prevention of cardiovascular disease and atherosclerosis [60]. Animals fed with VCO were found to have better coagulation studies with lower fibrin levels and better prothrombin time when compared with copra oil and sunflower oil [12]. VCO administration to rats increased anti-oxidant activity and lowered lipids and thrombotic factors compared to normal coconut oil [76].

In a prospective open label trial in humans, it was found that a 4-week supplementation of VCO significantly reduced waist circumference and improved lipid profile and it is safe for use in humans [91]. In another study, it was found that coconut oil consumption did not

elevate serum total cholesterol or serum triglycerides in a cohort of 1,839 Filipino women [92].

As described in this section, the existing literature reports the cardiovascular health benefits of VCO. However, evidence pertaining to VCO use is limited and more research in this area is needed to definitively recommend dietary VCO to improve cardiovascular disease risk.

5.5. Bone Loss Prevention

Oxidative stress and free radicals are implicated in the pathogenesis of osteoporosis. Therefore, antioxidants are likely to prevent the disease. In one study, it was shown that VCO effectively improved bone structure and prevented bone loss in osteoporosis rats and this effect can be attributed to the polyphenols present in VCO [82]. Further, VCO supplementation showed a significant improvement in the bone antioxidant status by preventing lipid peroxidation and increasing levels of glutathione peroxidase and superoxide dismutase enzymes in the osteoporotic rat model [81].

5.6. Antimicrobial Effects

VCO has a long history of use as an antibacterial agent. A history of safe topical use and no known or reported cases of adverse effects opens up more possibilities of the use of VCO against infections. VCO contains high quantities of MCFA like lauric acid, caproic acid, and caprylic acid; studies have shown that these MCFA are responsible for its antibacterial, antifungal, antiviral, and properties [93].

- ***Antibacterial activity***. MCFAs and their derivatives are effective in destroying lipid-coated bacteria by disintegrating their lipid membrane. The antimicrobial activity of VCO might be due to an active compound monolaurin, which is a product of lauric acid metabolization [94]. Lauric acid is the predominant fatty acid in the coconut oil [95]. It is also present in breast milk and was found to helpsupport healthy growth in breastfed infants and was shown to possess antimicrobial properties [96].
  VCO and monolaurin have shown antibacterial effects on *Staphylococcus aureus*, and can be useful in the proactive treatment of atopic dermatitis colonization [97]. Similarly, in pediatric patients with mild to moderate atopic dermatitis, a topical application of VCO for 8 weeks was superior to that of mineral oil based on clinical and instrumental assessments [98]. In contrast, VCO did not inhibit the growth of *Staphylococcus aureus* and the morphology of *Staphylococcus aureus* cells exposed to the oil was not different from that of the untreated cells. This effect might be attributed to the low concentration of lauric acid (0.47 mg/ml) in VCO, which is below the minimum inhibitory concentration (MIC) of lauric acid (1.6 mg/ml) [99]. Another study demonstrated the inhibition of growth of antibiotic resistant *Clostridium difficile* mediated by MCFAs, which are derived from VCO [100]. Hydrolyzed VCO was more effective against *Pseudomonas aeruginosa*, while unhydrolyzed VCO did not inhibit the bacterial growth [101]. In another study,

enzymatic hydrolysis of VCO inhibited growth of Salmonella species in *in vitro* and *in vivo* studies [102].

- ***Antifungal activity***. Since VCO is a rich source of MCFA, which possesses antifungal activity, a study in Nigeria reported its effectiveness as an antifungal agent, and compared its action to fluconazole, a first line of treatment against drug resistant *Candidaalbicans*. The study concluded the oil to be very potent against *Candida species* at 100% concentration when compared to fluconazole and therefore, can be used in the treatment of fungal infections caused by *Candidaspecies* [42]. Capric acid was more effective against *Candidaalbicans*, while lauric acid was the most active at lower concentrations.
- ***Antiviral activity***. VCO was found to be effective against lipid-coated viruses, such as Epstein-Barr Virus (EBV), influenza virus, leukemia virus, hepatitis C virus, and Cytomegalovirus (CMV); it acts by disrupting viral membranes, assembly, and maturation. Lauric acid has greater antiviral activity than caprylic acid, capric acid, or myristic acid [103]. Monolaurin acts by solubilizing the lipids and phospholipids in the envelope of the virus and, thereby causes disintegration of the envelope [53].

6.0. CONCLUSION

VCO is becoming popular as a functional food oil due to increasing public awareness about its health benefits. VCO is obtained from the fresh, mature kernel (meat) of the coconut by mechanical or natural means, with or without the use of heat, without undergoing chemical refining, bleaching or de-odorizing process, which does not lead to the alteration of the nature of the oil and preserves the essential amino acids, tocopherols (vitamin E) and other valuable compounds present in coconut oil. Recently published literature about the health benefits of VCO has been a boost for the growing demand of VCO.

VCO has a rich content of MCFAs, predominantly lauric acid and some SFAs with a higher amount of myristic acid compared to other SFAs. The properties such as higher levels of saponification, phenolic compounds and tocopherols and low iodine numbers and peroxide values make VCO a potential healthy addition to the normal diet.

As discussed before, there are several methods by which one can produce VCO. Accordingly, the quality and quantity of the final oil produced vary with the different processing techniques employed for extraction. Also, the produced VCO possess varied organoleptic characteristics. The high-pressure expelling method and Bawalan-Masa method generally produce VCO with a longer shelf life of one year or more. The modified kitchen method incurs a very low investment cost and is prone to rancidity development after five days if moisture is not properly removed after extraction. A two-stage centrifuge process can produce best quality VCO with coconut aroma. However, the best oil recovery is achieved with a high pressure expelling method. Hence, in order to ensure that only high quality VCO is produced, it is highly recommended adhering to the principles of good manufacturing practices.

Different groups in animal models have evaluated the anti-inflammatory, analgesic and antipyretic properties of VCO. VCO inhibits both acute and chronic inflammation in RA induced animal models when used in high dose. In other studies, VCO also exhibited

moderate analgesic and antipyretic effect on acetic acid-induced pain and yeast-induced hyperthermia, respectively. There are very few studies on the analgesic and antipyretic activity of VCO and, thus, needs further investigation. These preliminary studies give encouraging results to further exploit the therapeutic potential of VCO.

On the other hand, other studies proved that there are indeed beneficial antioxidant properties in VCO. A diet enhanced with VCO may have potential health benefits as long as the fatty acid content in the diet is moderated. Unadulterated VCO may also be richer in antioxidants providing greater health benefits than RBD or other means of obtaining the coconut oil. Of course, maintaining a proper balance of saturated fatty acids in the diet is important and this should be kept in mind when VCO is included in dietary intake.

VCO with limited pharmacotherapeutic properties is gaining popularity in the modern society. From the existing literature, there are many health benefits including cardioprotective effects, bone loss prevention, antibacterial, antifungal, and antiviral effects. However, more research is needed to provide conclusive evidence against clinical applications.

7.0. FUTURE DIRECTIONS

VCO is currently enjoying a great deal of positive press thanks to increased publicity about its potential health benefits. Although it is being touted as the latest "superfood," with ascribed qualities that run the gamut from causing weight loss to fighting cancer, it is likely that future research on VCO will focus on its anti-inflammatory properties. This is because inflammation is now attracting attention from scientists as a potential unifying factor among multiple diseases. Recent studies have shown that tissue degeneration due to chronic inflammation plays a role in the pathogenesis of such different diseases as type 2 diabetes, Alzheimer's, and age-related macular degeneration [105]. While inflammatory mediators are usually produced in response to cellular injury, they are also released from fat cells, which explains the increased risk that overweight people face for a variety of conditions.

A 2016 study published in the neurology journal *Brain* showed that brain inflammation is likely a driving factor behind Alzheimer's disease, rather than simply an immune reaction after brain pathology has already set in [106] Treatment of inflammation in Alzheimer's mice stalled their loss of neuronal connections, and improved their memory loss and behavioral problems. However, treatment did not stop the progression of amyloid plaque buildup in the mice's brains. Interestingly, the results of this study dovetail with those of a 2015 study published by the University of Valencia, which found that administration of 40 mL/day of VCO to Alzheimer's patients produced a statistically significant improvement in cognitive status [107]. It is important to note, however, that this study ascribed the beneficial affects of VCO to the cellular energy source, namely ketones, provided by its medium-chain triglycerides. Other studies with similar results also prefer the ketogenic hypothesis to the anti-inflammatory hypothesis [108]. Nevertheless, considering the novelty of the association between Alzheimer's disease and inflammation, it is likely that more light will be shed on how much of a role VCO's anti-inflammatory properties play in its therapeutic effects on Alzheimer's patients.

The ketogenic and oxidizing properties of VCO have also attracted attention in recent years, particularly in the context of weight loss. The most recent example is the craze for so-

called “bulletproof coffee,” which was claimed to heighten alertness, suppress appetite, and increase fat burning via ketosis, due to the addition of butter and medium-chain triglycerides (often in the form of VCO). The current scientific standpoint towards bulletproof coffee is one of skepticism, considering the variability of results and lack of formal research. However, the potential association between weight loss/ketogenesis and VCO alone is a current hot topic in research. A study due out in 2016 correlates a high-VCO diet with improvement in hyperglycemia and dyslipidemia in high fructose-fed rats [109]. A 2014 study reported that VCO significantly increased hepatic lipid metabolism and fatty acid oxidation compared to copra oil [110]. Research in this area is ongoing.

In summary, the future directions of VCO research seem to focus most on its anti-inflammatory and ketogenic/lipid oxidizing properties. Furthermore, both these areas of research appear most popular in the context of treating Alzheimer’s disease and promoting weight loss. While results for these topics of investigation remain preliminary, they are the focus of nearly all the most recent papers published on the health effects of VCO. We may, thus, anticipate that research into the correlation of VCO administration with inflammation, lipid levels, weight loss, and Alzheimer’s is ongoing, and that more complete information is forthcoming.

8.0. REFERENCES

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