Virgin Coconut Oil and Its Antimicrobial Properties against Pathogenic Microorganisms: A Review

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Abstract—Virgin coconut oil (VCO) is the purest form of coconut oil, essentially water-clear or colourless that consists mainly of medium chain saturated fatty acids. For over many decades, the biological properties of VCO have been widely explored and investigated due to their antimicrobial potentials. The large concentration of medium chain fatty acids (MCFAs) including lauric acid (LA) and its monoglyceride form, monolaurin makes VCO effective in their mode of actions against pathogenic microorganisms. Thus, VCO could be used as a daily supplement or an alternative remedy against microbial infections. We review and discuss the current state of knowledge of VCO studies and focus on its antibacterial, antifungal, and antiviral activities aiming to unravel the underlying mechanisms of VCO inhibition of these pathogenic microorganisms.

Keywords—virgin coconut oil, medium chain fatty acids, antimicrobial, antibacterial, antifungal, antiviral

I. INTRODUCTION

Cocos nucifera, a vital member of the family Arecaceae (palm family) popularly known as coconut, coco, coco-da-bahia, or coconut-of-the-beach [1], is being produced and exported by India, Sri Lanka, Malaysia, and Indonesia [2]. Often referred to as the “tree of life”, every part of the coconut tree can be either consumed by humans or animals or converted into other products such as brushes from the coir, spoon and ladle from the shell, food wrapper from the weaved leaves, and house furniture from the trunk. Not only known for providing meat alternative, juice, and milk, coconut is also a good source of oil [3].

Derived from copra, coconut oil is colourless to the pale brownish yellow dried kernel or ‘meat’ of coconut. The Malays in the Peninsular Malaysia refer to coconut oil as true oil and in India, it has been recognised as the healthiest oil in Ayurvedic medicine, a teaching based on the Veda (circa 1,500 BC) [4]. Also, coconut was valued as a medicinal plant for centuries in the Thai traditional medicine [5]. Records also show that in the United States, coconut oil has been one of the major sources of dietary fats, prior to the introduction of American edible oil (soybean and corn) in the mid-1940s [6].

Unlike palm oil, coconut oil can be routinely homemade, easily available oil that is natural and free from chemical treatment. Coconut oil has a low oxidation point where oxidation process only takes place after two years of storage, making it very stable due to high presence of saturated fat [7]. Usage of coconut oil as frying and cooking oil has been well known, but its uses as a cheaper alternative to relatively expensive butterfat in filled milk, filled cheese, and ice cream makings may need more public awareness and promotion. The non-food application of coconut oil is acknowledged in the production of soaps, rubbers, elastomers, and also derivatives such as alkanolamides [8]. Generally, coconut oil is available in three major forms, which are refined coconut oil (RCO), copra oil (CO), and virgin coconut oil (VCO) [9,10].
mixture of saturated fatty acids which commonly consists of 6–12 carbons chain [19,23]. The MCFAs of VCO consists of caproic acid (C6), caprylic acid (C8), capric acid (C10), and lauric acid (C12). The LCFA s of VCO consist of myristic acid (C14), palmitic acid (C16), palmitoleic acid (C16:1), stearic acid (C18), oleic acid (C18:1), linoleic acid (C18:2), and linolenic acid (C18:3) [24].

In 2007, Department of Standards Malaysia has affirmed that the composition of VCO’s fatty acids falls within the range as specified in Table I. VCO naturally contains a 3:1 ratio mixture of MCFAs and LCFA s [25] where the saturated MCFAs comprises two-thirds of coconut oil’s fatty acids, the saturated LCFA s are less than one-third, and the unsaturated fatty acids are less than a tenth of its fatty acids [26]. Coconut oil is about 90% saturated fatty acids and is highly saturated oil [27]. Remarkably, coconut oil has the major amount of caprylic acid, capric acid and LA among the palm oils and can be considered as the most saturated oil compared to palm, soybean, and corn oils and animal fats [8]. Coconut oil is hence a unique vegetable oil because it is the only oil where approximately 50% of the fatty acid composition is LA [22,28].

### TABLE I. FATTY ACIDS COMPOSITION OF VCO

<table>
<thead>
<tr>
<th>Common name</th>
<th>Carbon number</th>
<th>Composition (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Caproic acid</td>
<td>C6:0</td>
<td>0.80–0.95</td>
</tr>
<tr>
<td>Caprylic acid</td>
<td>C8:0</td>
<td>8.00–9.00</td>
</tr>
<tr>
<td>Capric acid</td>
<td>C10:0</td>
<td>5.00–7.00</td>
</tr>
<tr>
<td>Lauric acid</td>
<td>C12:0</td>
<td>47.00–50.00</td>
</tr>
<tr>
<td>Myristic acid</td>
<td>C14:0</td>
<td>17.00–18.50</td>
</tr>
<tr>
<td>Palmitic acid</td>
<td>C16:0</td>
<td>7.50–9.50</td>
</tr>
<tr>
<td>Palmitoleic acid</td>
<td>C16:1</td>
<td>ND</td>
</tr>
<tr>
<td>Stearic acid</td>
<td>C18:0</td>
<td>2.50–3.50</td>
</tr>
<tr>
<td>Oleic acid</td>
<td>C18:1</td>
<td>4.50–6.00</td>
</tr>
<tr>
<td>Linoleic acid</td>
<td>C18:2</td>
<td>0.70–1.50</td>
</tr>
<tr>
<td>Linolenic acid</td>
<td>C18:3</td>
<td>ND</td>
</tr>
</tbody>
</table>

*ND = Non-detectable

Dayrit [22] attributed many of the advantages of coconut oil to the existence of LA. Similarly, DebMandal & Mandal [29] and Marina et al. [30] declared that the most abundant and powerful MCFAs in VCO is LA which comprises nearly 50% of coconut’s fat content. Previously, Santoso et al. [31] also reported that the fatty acid composition of lipid from kopyor (mature coconut) meat was dominated by LA. Interestingly, studies had shown that human breast milk and VCO share similar fat content. Kabara [4] and Hayatullina et al. [32] highlighted that 60% of VCO MCFAs is similar in composition to human breast milk. LA and linoleic acids amount to 5% and 15%, respectively, of total fatty acids in human milk that function as determinants of anti-infective activity [33]. Also, Koletzko et al. [34] reported that major part of the lipids of the mother’s milk is composed of the saturated fatty acids (C12–C18).

Our body converts LA into monolaurin, a monoglyceride composed of a glycerol unit and it is present in many animals and plants [35]. Monolaurin has been identified by many researchers to be the protective substance that keeps infants against viral and...
bacterial infections [36]. Even though there is no patent data pertaining to how much monolaurin is actually formed from LA in the human body, nevertheless, there is evidence that some are formed. MCFAs have a number of unique properties which give them advantages over the most common LCFAs. At the level of the mitochondrion, MCFAs can increase oxidative metabolism in muscle.

While most LCFAs are stored in the adipocytes [37], MCFAs are far less likely to be stored in adipocytes and because of this; MCFAs have been reported to suppress fat deposition [27] through improved thermogenesis and fat oxidation in animal and human subject [19]. The fact that MCFAs are less efficiently stored than other fatty acids and are highly prone to oxidative metabolism once ingested, implies that they have a short half-life and are unlikely to promote obesity via direct storage in adipocytes [38]. Moreover, in contrast to LCFAs, MCFAs can prevent the induction of oxidative stress that usually arises due to excess lipid intake [39].

It was not a very long time ago that many epidemiological and nutritional studies suggested that the consumption of high amounts of saturated fat and cholesterol [40] led to high blood cholesterol which ultimately left VCO at a disadvantage and received a bad reputation. However, the tides have turned for VCO as recent clinical studies have shown multiple positive outcomes offering counter arguments recognising them as highly valuable and healthy oils [30]. Studies have shown that the use of VCO in diet can regulate blood fats and increase the HDL cholesterol level while decreasing the LDL significantly [15] thus disproving the myth that coconut oil increases cholesterol while decreasing the LDL significantly [30]. Studies have shown that the use of VCO in diet can regulate blood fats and increase the HDL cholesterol level while decreasing the LDL significantly [15] thus disproving the myth that coconut oil increases cholesterol while decreasing the LDL significantly [30].

C. Antimicrobial activities of virgin coconut oil

The high potentials of coconut oil as medicine were ascertained by Kabara in the 1970s, who found coconut oil’s antibacterial, antiviral, and antifungal activities were exerted by its MCFAs [41]. The recognition of coconut oil antimicrobial activities was also reported by Hierholzer and Kabara [42] which focused on virucidal effects of monolaurin RNA and DNA viruses. Recently, experimental outcomes from many studies discovered that monolaurin had not only antimicrobial activity against various gram-positive and gram-negative bacterial cells [1,3,43] but also antifungal and antiviral properties [44,45,46,47,48]. Manohar et al. [49] showed that coconut oils, when used as food flavouring agents, exhibited a wide range of antimicrobial activities. Among MCFAs, LA and its derivatives were found to be the most effective antimicrobial agents for foods and cosmetics [46,50]. The antimicrobial effects of fatty acids are additive and their total concentration is vital for bacterial growth inhibition [35].

D. Antibacterial action of coconut oil

MCFAs with 6 to 12 carbons, possessed significant yet skewed activity against gram-positive bacteria, but not against gram-negative bacteria. McKellar et al. [51] reported that MCFAs and LCFAs could not actually inhibit the growth of gram-negative bacteria. However, in a current study, ample inhibition was observed for the gram-negative bacteria, Escherichia coli and Salmonella enteritidis [7]. Via diffusion agar method, Sihombing et al. [52] found that VCO was more effective against Bacillus cereus, a gram-positive bacterium compared to E. coli due to the presence of MCFAs and its monoglyceride form especially monolaurin. Widyarti et al. [53] showed that the antibacterial activity of LA was very potent and was effective against Staphylococcus aureus.

Similarly, the effect of LA on the growth of bacteria was investigated and it was evident from the study that LA was the most effective inhibitor against S. aureus [54] and Pseudomonas aeruginosa, a common opportunistic bacterium that causes infection in immunocompromised individuals [55]. Further, Verallo-Rowell et al. [56] found that VCO was useful in the treatment of atopic dermatitis caused by S. aureus. Wang and Johnson [57] examine the effectiveness of monolaurin on the growth of Listeria monocytogenes, a human foodborne pathogen. A transmission electron scanning (TEM) analysis was done to observe the morphological changes in the bacteria cells. Results of their study showed that cytoplasmic content of treated bacteria cell appeared to separate from cell envelope. Breakage of the cell envelope also was observed.

Moreover, studies on medium-chain saturated and long-chain unsaturated monoglycerides added to supplement infant formula established that both can effectively inactivate a gram-negative bacterium, Haemophilus influenzae [58] while Thaweboon et al. [43] reported that coconut oil exhibited antimicrobial activity against Streptococcus mutans by evaluating its effect on biofilm models formed on salivary-coated microtitre plates. It has been also reported that fatty acids extracts obtained after the hydrolysis of coconut fat showed high antimicrobial potential against gram-positive bacteria, B. cereus and L. monocytogenes and gram-negative bacteria, E. coli and S. enteritidis [7]. Only recently, Odel et al. [59] further proved that LA could hinder the maturity of S. aureus, B. cereus, E. coli, and Salmonella thypimurium, but the inhibition was still lower than the Ciprofloxacin, an antibiotic used to treat a number of bacterial infections. Khor et al. [25] concluded that the acidic pH nature of VCO between 2.52 and 4.38 may be an important attribute to its microbial inhibitory action. The antibacterial activity of MCFAs has been summarized in Table II.

E. Antifungal action of coconut oil

Presently, VCO and its MCFAs have been used broadly against fungi and most of the researches were focusing on Candida albicans, the most common and frequently isolated fungus from the human body. An in vitro study by Arnfinnsson et al. [60] showed that capric acid and LA had the strong ability to inhibit the growth of C. albicans. The result reported that even at
demonstrated the utmost resistance to coconut oil. The C. krusei species tested showed the highest susceptibility to coconut oil while C. albicans showed the highest resistance. Among all the Candida species, only 16% of Candida species were affected by coconut oil. At 100% concentration of coconut oil, all the Candida species were sensitive to coconut oil and the results revealed that at 100% concentration of coconut oil, all the Candida species were sensitive to coconut oil while at the lowest concentration (0.79%), only 35% of Candida species were affected by coconut oil. Among all the species tested, C. albicans showed the highest susceptibility to coconut oil while C. krusei demonstrated the utmost resistance to coconut oil.

Antifungal activity of coconut oil has also been studied by Winarski and Purwanto [63] where a vaginal candidiasis patient was successfully treated with zinc-enriched VCO that might have acted as an immunostimulants. Haematological test by Micros-OT was done on a part of the blood and using ELISA, the level of Interleukin-2 (IL-2) and Immunoglobulin-G (IgG) were tested with the use of plasma. Results showed that enriched VCO retained neutrophil and natural killer cells numbers in the body, but improved number of T-cytotoxic and T-helper cells. The enriched VCO also increased the level of IL-2 while the level of IgG changed from equivocal to negative. Latest, in comparison with ketoconazole, antifungal activity of C. albicans isolated from children with early childhood caries was tested using coconut oil [64] and it was validated that coconut oil had comparable antifungal activity with ketoconazole. The antifungal activity of coconut oil against C. albicans was also found to be higher than probiotic, a live microorganism that grants a health benefit on the host when administered in adequate amounts. Fungal activity of coconut oil and its MCFAs have been summarized in Table II.

F. Antiviral action of coconut oil

The antiviral activity of monolaurin was tested against many enveloped human RNA and DNA viruses and the results concluded that all viruses were reduced in infectivity at 1% concentration of the monolaurin additive [42]. In the presence of LA, Hornung et al. [45] indicated that the replication of vesicular stomatitis virus (VSV) was inhibited by several orders of magnitude where the inhibitory effect was reversible. They reported that the quantity of matrix protein, one of the five functional proteins encoded by the virus placed in the plasma membrane, was found to be noticeably decreasing after the treatment with LA. Similarly, in the same year, a study on inactivation of visna virus (VV), VSV, and herpes simplex virus (HSV) by free fatty acids and monoglycerides was done. With the uses of a series of antiviral activity assays and electron microscopy, Thormar et al. [65] reported that MCFAs could inactivate VV and other enveloped viruses causing more than a 3,000- to 10,000-fold reduction in virus titer.

Correspondingly, by having coconut oil in the daily diet, Dayrit [66] stated that the viral load of HIV patients could be reduced, showing that it has an antiviral effect. According to Enig [67], the AIDS organisation, Keep Hope Alive, has documented several HIV/AIDS patients whose viral load reduced to undetectable levels when they added coconut oil to their daily diet or their anti-HIV medication. The positive antiviral action was seen not only with the monoglyceride of LA but with coconut oil itself indicating that coconut oil was metabolised to monoglyceride forms of caprylic acid, capric acid, and LA to which it must owe its antipathogenic activity. A year later, Enig [68] claimed that monolaurin could inactivate viruses including HIV, measles virus, HSV, VSV, and cytomegalovirus (CV) to some extent.

In addition, Arora et al. [69] stated that coconut oil was very effective against various viruses with lipid capsules, such as VV, CV, and also Epstein-Barr virus. Yuniwati et al. [70] investigated the effect of VCO on lymphocyte and CD4 (cluster of differentiating), a surface protein on T lymphocyte, in chicken which had been vaccinated against the avian influenza virus. The study which applied the completely randomised factorial design method concluded that fatty acids of VCO were able to boost the amount of lymphocyte and CD4 on vaccinated or unvaccinated broiler chicken showing that VCO was potentially acting as an immunomodulator which therefore could increase chicken immunity and in combating a viral infection. The antiviral activity of VCO and its MCFAs has been summarised in Table II.

G. Action mechanism of coconut oil against pathogenic microorganisms

The exact mechanism by which VCO exerts its antimicrobial effects is still largely unknown. Of the coconut derived metabolites, LA may have the most antimicrobial activity [71]. According to DebMandal and Mandal [29], LA and its monoglyceride found in coconut oil are effective in obliterating a wide variety of lipid-coated bacteria by disintegrating their lipid membranes. The MCFAs in coconut oil principally destroy microbial organisms by disturbing their membranes, thus interfering with virus assembly and maturation [69]. Besides, monolaurin is known to produce highly ordered membranes, which is thought to disrupt membrane function by affecting signal transduction due to blockage of promoters, uncoupling of energy systems, altered respiration state, and altered amino acid uptake [72].
TABLE II. EFFECT OF VCO ON THE PATHOGENIC MICROORGANISMS

<table>
<thead>
<tr>
<th>Antimicrobial properties</th>
<th>Compound</th>
<th>Inhibited Microorganisms</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antibacterial</td>
<td>Monolaurin, Lauric acid and linoleic acid</td>
<td>Listeria monocytogenes</td>
<td>Wang &amp; Johnson, 1992</td>
</tr>
<tr>
<td></td>
<td>Monolaurin and monocaprin</td>
<td>Helicobacter pylori</td>
<td>Bergsson et al., 2002</td>
</tr>
<tr>
<td></td>
<td>Coconut oil</td>
<td>Streptococcus mutans</td>
<td>Thaweboon et al., 2011</td>
</tr>
<tr>
<td></td>
<td>Lauric acid and monolaurin</td>
<td>Bacillus cereus</td>
<td>Stihobming et al., 2014</td>
</tr>
<tr>
<td></td>
<td>Monolaurin</td>
<td>Staphylococcus aureus</td>
<td>Widiyarti et al., 2009</td>
</tr>
<tr>
<td>Antifungal</td>
<td>Lauric acid</td>
<td>Staphylococcus aureus</td>
<td>Kitahara et al., 2004</td>
</tr>
<tr>
<td></td>
<td>Virgin coconut oil</td>
<td>Pseudomonas aeruginosa</td>
<td>Silalahi et al., 2014</td>
</tr>
<tr>
<td></td>
<td>MCFAs</td>
<td>Staphylococcus aureus</td>
<td>Verallo-Rowell et al., 2008</td>
</tr>
<tr>
<td></td>
<td>MCFAs</td>
<td>Escherichia coli and Salmonella enteritidis</td>
<td>Parfene et al., 2013</td>
</tr>
<tr>
<td></td>
<td>Lauric acid and capric acid</td>
<td>Candida albicans</td>
<td>Antfinnsson et al., 2001</td>
</tr>
<tr>
<td></td>
<td>Virgin coconut oil</td>
<td>Candida sp.</td>
<td>Winars &amp; Purwanto, 2008</td>
</tr>
<tr>
<td></td>
<td>Coconut oil</td>
<td>Candida albicans</td>
<td>Thaweboon et al., 2011</td>
</tr>
<tr>
<td></td>
<td>Virgin coconut oil</td>
<td>Candida albicans</td>
<td>Lima et al., 2015</td>
</tr>
<tr>
<td>Antiviral</td>
<td>Monolaurin</td>
<td>human RNA and DNA viruses</td>
<td>Hierholzer &amp; Kabara, 1982</td>
</tr>
<tr>
<td></td>
<td>Lauric acid</td>
<td>Vesicular stomatitis virus</td>
<td>Hornung et al., 1994</td>
</tr>
<tr>
<td></td>
<td>Lauric acid and monolaurin</td>
<td>HIV virus</td>
<td>Eng, 1997</td>
</tr>
<tr>
<td></td>
<td>Virgin coconut oil</td>
<td>Avian Influenza virus</td>
<td>Yuniwarti et al., 2012</td>
</tr>
</tbody>
</table>

Monolaurin had been reported to cause a constant increase in leakage of cell membranes of S. aureus [35, 73]. Several researchers suggested that VCO was needed to be metabolised by enzymes prior to releasing its antimicrobial components of MCFAs, caprylic acid, capric acid, and LA. A particularly intriguing and unresolved mystery of the VCO actions concerns the actual mechanism by which fatty acids are bactericidal to pathogens. Although largely unknown, some disruption of the lipid membranes of the susceptible organisms by VCO or its metabolites cannot be entirely overruled [58]. Hierholzer and Kabara [42] suggested that a key factor in the virucidal activity of monolaurin was associated with a generalised disintegration of the cell envelope signifying that solubilisation of the lipids and phospholipids in the cell envelope had occurred. The viral envelope was found to be affected by fatty acids, causing leakage and at even higher concentrations, a complete disintegration of the envelope and the viral particles occurred [65].

Recent electron microscopic evidence of several microbes after being exposed to fatty acids suggested that the cell membranes of Clostridium perfringens, Chlamydia trachomatis, Streptococcus agalactiae, C. albicans, and S. aureus were disrupted with subsequent lysis of the bacteria [71]. Similarly, Warth [74] and Voegas and Correia [75] also supported that micromolar concentrations of fatty acids have a direct effect on the cellular membranes enzymatic activities. Finally, polyunsaturated fatty acids have been documented to inhibit microorganisms through autoxidation and formation of peroxides and radicals [76] and potentially involving bacterial iron [77].

IV. DISCUSSION

The current findings on the advantageous of VCO especially on its antimicrobial activity have gathered many attentions from researchers around the world to investigate further as control of infections is crucial on the health agenda of many developing countries, and the use of VCO could serve as a cheaper alternative means of controlling infections. Considerably more studies need to be embarked on especially on the action mechanisms of VCO. Molecular studies and tests on VCO’s mechanism should be done in order to evaluate its action in detailed particularly on microbe’s membrane lipid. It is suggested also that future studies look into the mechanism involving other parts of the microbes that might yield novel knowledge and understanding. New methodologies on how to isolate the single fatty acids and obtaining its bioactive compound also need to be explored as it can be used in the investigation of antimicrobial activity, thus demonstrating the underlying mechanisms.

Despite many research, some limitations of the studies on VCO must be acknowledged. We believe that many researchers are having a great difficulty when dealing with the process to isolate specific compounds from VCO. There is no exact method on how to isolate the compound. Different parameters like temperature, pressure, and time need to be adjusted according to the sample types and target compounds involved. Besides, when running the antimicrobial test, researchers were having a problem in dissolving or diluting the VCO. Methanol, ethanol, and dimethyl sulfoxide (DMSO) are the organic solvents that are being used frequently to dilute VCO. Nevertheless, these solvents have antibacterial property as well, making the test results inaccurate. Until recently, most of the antimicrobial tests were done directly only between the tested microorganisms and the extracts itself. Somehow, in reality, when we are dealing with the microbial infections in the body, there are actually many systems involved, cooperating with each other in combating infections. Hence, a more complex method should be
considered so that we can create a better environment for testing the antimicrobial activity.

The information discussed in this review explains that VCO possesses various types of fatty acids which have been associated with its biological and medicinal properties. Based on the summary compiled herein on the antimicrobial activities of VCO, it is noted that VCO contains various potent bioactive compounds, most of which might have bactericidal, virucidal, and fungicidal benefits with less or no adverse effects. Above and beyond, the emergence of the microbial resistance, together with the low availability of antimicrobial agents which are often opted as the last resorts have created a threat to the medical community and practitioners alike, demands for a continuous need to explore nature in search of new antimicrobial compounds with novel targets and modes of action. In this regard, researchers are neither wrong nor weak to turn their attention towards antimicrobials of the plant origin. Even though there is much research on coconut oil, extensive research and investigation on the antimicrobial potency of VCO are necessary to validate the use of VCO as a valuable antimicrobial agent and exploit the oil’s potential therapeutic benefits to combat various diseases.

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