Antimicrobial Properties of Lauric Acid and Monolaurin in Virgin Coconut Oil: A Review

Febri Odel Nitbani[1],*, Putra Jiwamurwa Pama Tjitda[2], Fidelis Nitti[1], J. Jumina[3], Annytha Ina Rohi Detha[4]

Abstract

Virgin coconut oil is obtained by wet processing of coconut milk using fermentation, centrifugation, enzymatic extraction, and the microwave heating method. Presently, VCO has several positive effects and benefits to human health, hence, it is regularly consumed and widely known as a unique functional food. VCO contains lauric acid (45 to 52 %). By lipase in the digestive system, VCO can undergo a breakdown into lauric acid, 1-monolaurin, and 2-monolaurin. These components have both hydrophilic and lipophilic groups and are also recognized as excellent antimicrobial lipids. Furthermore, lauric acid and monolaurin can be used as antibacterial, antifungal, and antiviral with broad-spectrum inhibition. Lauric acid and monolaurin have a strong ability to destroy gram-positive bacteria, especially *S. aureus*, fungi such as *C. Albicans*, and viruses including vesicular stomatitis virus (VSV), herpes simplex virus (HSV), and visna virus (VV). Lauric acid and monolaurin interact with certain functional groups located in the cell membrane and can cause damage to the cell. In general, the potential of VCO as healthy food is contributed by lauric acid and monolaurin which are antimicrobial agents.

Keywords: Antimicrobial, Lauric acid, Monolaurin, Virgin coconut oil

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1 Introduction

Coconut palm (*Cocos nucifera* L) often referred to as the tree of life is a typical tropical plant that grows easily in areas with abundant sunlight and regular rainfall. In Indonesia, coconut palms are cultivated exclusively by smallholders and are scattered evenly in most of the islands which accounts for a total of 3 377 376 ha in 2020. With a total production of 15 billion nuts per year, Indonesia is among the top three world's largest producers of coconut along with Malaysia and India. This places coconut on the top list of Indonesia's non-oil commodities from the plantation sector.

The coconut plant is sometimes referred to as the tree of life because not only the nuts can be consumed by humans, but other parts are also convertible into useful products. Coconut oil is among the edible products obtained from the plant aside from its juice, milk, and meat, it is the oil extracted from coconut flesh. The color ranges from pale brownish-yellow to colorless, depending on the production methods. Compared to other types of palm oil, the production of coconut oil can be carried out on a small scale through either dry or wet processes [1]. While the former process uses coconut milk extracted from raw flesh, the latter requires that the oil is extracted from the copra, namely dried meat of the coconut, through a mechanical pressure or solvent extraction.

Virgin coconut oil (VCO) is generated by mechanical or natural means from the fresh matured kernel of coconut and is among the three major forms of coconut oil along with refined coconut oil (RCO) and copra oil (CO). The production of VCO can be carried out with or without the use of heat, and

[1] Dr. Febri Odel Nitbani, Dr. Fidelis Nitti
Department of Chemistry, Faculty of Science and Engineering, University of Nusa Cendana, Jl. Adisucipto, Penfui, Kupang, Nusa Tenggara Timur, 85001, Indonesia.
E-Mail: febri_nitbani@yahoo.com

[2] Putra Jiwamurwa Pama Tjitda, S.Si., M.Sc
Department of Pharmacy, Health Polytechnic of Kupang, Jl. Adisucipto, Penfui, Kupang, Nusa Tenggara Timur, 85111, Indonesia.

[3] Prof. Jumina
Department of Chemistry, Faculty of Mathematics and Natural Sciences, Universitas Gadjah Mada, Sekip Utara, Yogyakarta, 5528, Indonesia.

[4] Dr. Annytha Ina Rohi Detha
Department of Animal Diseases and Veterinary Public Health, Faculty of Veterinary Medicine, University of Nusa Cendana, Jl. Adisucipto, Penfui, Kupang, Nusa Tenggara Timur, 85001, Indonesia.

chemical refining is not required. Given that the extraction process does not involve high heat or additional chemicals as well as UV treatments, no alteration or transformation of its chemical components occurs. Therefore, the original and beneficial oil active components such as antioxidants, vitamins, and polyphenols can be retained. Furthermore, VCO is widely known to serve as a functional food and also offers health benefits to humans in a wide range of applications such as food, beverage, pharmaceutical, medicinal, and cosmetics [2].

In contrast to other plant oils which are composed of only long-chain fatty acids, coconut oil including VCO consists of mixtures between short and medium-chain fatty acids, with high lauric acid (LA) content ranging from 45–53 % [3, 4]. Therefore, the unique and beneficial properties of VCO have been attributed to the existence of LA, which is a saturated medium-chain fatty acid. In the human body, LA is digested by lipase enzyme into monolaurin, a monoester composed of glycerol and lauric acid. Among all the beneficial properties, monolaurin and LA have been reported as the main components responsible for the miracle antimicrobial properties of coconut oils by several studies [5, 6]. The present study discusses the fatty acid and monoglyceride in coconut oils from a chemical perspective including their antimicrobial activity. The antimicrobial activities of lauric acid and monolaurin examined include antibacterial, anti-fungal, and antiviral properties, including their mechanism of action.

2 Coconut Oil (*Cocos nucifera* L.)

Categorized as vegetable oils, coconut oils are abundantly and easily produced from the flesh. For centuries, coconut oils and their derivatives have been widely known and used in a variety of applications such as culinary, cosmetics, and medicinal ingredients [2]. For example, in several religious rituals, people of certain ethnicities in Indonesia and other countries use coconut oils as a ritual complement. According to a report by F. M Dayrit et al. [7] in January 2020, coconut oils and their derivatives are considered effective and safe antiviral agents for the Novel Coronavirus (nCoV-19). To date, reports show that both traditional and modern people still use coconut oils because they are inexpensive and can be afforded by people with lower-level income. In addition, as coconut oils are extracted from plants, they are considered safe and effective as a medicinal ingredient.

According to Krishna [1], coconut oils can be categorized into several types, namely virgin coconut oil (VCO) and coconut oil. VCO can be extracted from the wet substrate which is generated from dry coconut also called copra. Meanwhile, coconut oil can be produced through solvent extraction of the mashed flesh. Coconut oil from copra is produced through a dry process by continuous pressing using expellers and hydraulic presses. Meantime, coconut oil is generated from coconut milk using the wet extraction process. Traditionally, several ethnicities in Indonesia produce coconut oil by heating the milk at a temperature higher than 100 °C for 4–6 h to remove the water content. This is then followed by the filtration process to obtain golden yellow coconut oil with a fresh odor. The filtration step is necessary to obtain pure coconut oil by separating the pulp that is formed during the heating process. Generally, the dark yellow color formed indicates that the oil contains several non-saponified compounds such as phytosterols. Despite the simplicity of the procedure, the coconut oil generated through this process usually does not last long and becomes rancid quickly.

3 Virgin Coconut Oil

The wet process is used to produce virgin coconut oil (VCO) without involving the heating process [8]. One of the well-known techniques in the production of VCO is fermentation using a microorganism starter [8–12]. Several wet processes developed to produce VCO are fermentation, centrifugation, enzymatically extraction, and microwave heating.

3.1 Fermentation

One of the well-known techniques in the production of VCO is the fermentation using a microorganism starter [8–12]. Coconut milk offers natural and induced fermentation using microorganisms. Natural fermentation takes a long time, but the inherent flavor and necessary nutrition of VCO are preserved. Meanwhile, the induced fermentation generally takes place for 2–3 days after the addition of microbes to the coconut milk. Consequently, the fermented virgin coconut oil (FVCO) obtained in the organic phase can be separated from the aqueous phase. Although a high yield of VCO is obtained from induced fermentation, it produces low-quality oil with an unpleasant odor.

3.2 Centrifugation

Efforts to improve the quality of oil produced by the fermentation method have been proposed by using the centrifugation technique [13]. The centrifugation of coconut milk produces a cream that requires heating at a temperature of 80 °C to remove the water residue. The final centrifugation process of the heated cream forms a high-quality colorless oil with a yield of 87.5 % [1]. The advantages of the centrifugation technique include short consumption time and high quality [13]. Conversely, this method gives the lowest rendement of the VCO. A high rendement of 13.80 % was achieved at centrifugation speed of 1200 rpm for 120 min and at 40 °C.

3.3 Enzymatically Extraction

The production of VCO through extraction using enzymes is an environmentally friendly process [14]. The principle of enzymatic extraction involves the degradation of protein in coconut milk using protease enzyme which degrades the emulsion of coconut milk to form VCO. Furthermore, VCO extraction using enzyme is carried out in a mild condition and is non-toxic. Several studies reported that the mixture of enzymes converts coconut milk to VCO with higher rendement > 80 %.

For example, hemicellulose, pectinase, cellulase, and gamanase mixtures can increase the rendement of VCO by 84 % at 50 °C for 5 h in acidic conditions [15].

3.4 Microwave Technique

Another option to improve the quality of the oil produced by the fermentation process is by using the microwave technique [16]. VCO was reportedly made by heating coconut milk using the microwave, this process diminishes free fatty acid production in some edible oil, including olive, canola, and soybean. Moreover, this technique can be used to produce the FVCO without significantly affecting the quality of moisture, free fatty acid, and peroxide value. The use of the microwave is a simple, accessible, low-cost, and modern method.

Generally, the VCO obtained from the fermentation, centrifugation, and microwave processes are colorless. It was reported that VCO does not contain non-saponified compounds, such as phytosterol, with an unsaponifiable matter value and phytosterol content (%) of 0 [1].

VCO is widely recognized as a functional food compared to other types of coconut oils because it is abundantly available, inexpensive, nontoxic, and has various health benefits. In tropical countries, VCO as an alternative food is abundant and is valuable from a health and economic perspective. The production which is convenient and low-cost from a natural product namely coconut fruit provides extra value. Moreover, various publications stated that VCO has an extraordinary antimicrobial activity against bacteria, fungi, and viruses [17–21]. The ability of its active compounds as an antimicrobial agent is also an important aspect to support the values as a functional food with incredible health benefits.

4 Chemical Perspective of VCO

VCO contains triglycerides and free fatty acids, the amount of free fatty acids is fairly low, ranging from 0.2–0.3 % of the maximum %FFA value expressed as lauric acid. Triglycerides in VCO are composed of various fatty acids that are bound as ester compounds. Therefore, triglycerides are also widely known as triester of glycerol or triacylglycerol.

Triglycerides from VCO are known as medium-chain triglycerides (MCT) because the fatty acids which bound as esters are dominated by medium-chain fatty acids (MCFA). The composition of fatty acid is usually determined using gas chromatography (GC) by converting triglycerides to fatty acid methyl ester (FAME) [3, 22, 23]. The conversion process involves the transesterification reaction of triglycerides with methanol using an inorganic base catalyst or lipase enzyme. Meanwhile, triglycerides and free fatty acids are known to have very high boiling points, hence, the conversion into their methyl ester ensures that the formation of gas-phase for GC separation in the column can be achieved. The determination of fatty acid content in the VCO using GC based on the initial conversion into the methyl ester has been demonstrated successfully by Kapally et al. [24] and the results are summarized in Tab. 1.

Table 1. Composition of fatty acids in VCO.

Fatty acids	Percentage [%]
Saturated:	
Lauric acid (C12:0)	45–52
Myristic acid (C14:0)	16–21
Palmitic acid (C16:0)	7–10
Caprylic acid(C8:0)	5–10
Capric acid (C10:0)	4–8
Stearic acid (C18:0)	2–4
Caproic acid	0.5–1
Palmitoleic acid	In traces
Unsaturated:	
Oleic acid (C18:1)	5–8
Linoleic acid (C18:2)	1–3
Linolenic acid (C18:3)	Up to 0.2

Medium-chain fatty acids have C atoms ranging from 6 to 12 and are categorized as saturated fatty acids [25, 26]. Tab. 1 indicates that there are three dominant MCFAs in VCO, namely lauric acid ranging from 45–52 %, capric acid 4–8 %, and caprylic acid 5–10 %. Therefore, the triglycerides in VCO can bind to the lauric acid (C12:0), capric acid (C10:0), and caprylic acid (C8:0), as shown in Fig. 1.

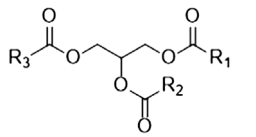


Figure 1. Medium chain triglyceride from VCO.

The structure of triglycerides in Fig. 1 shows that their hydrophobic property is due to the nonpolar functional groups namely -CH_2- from the MCFA. Meanwhile, the hydrophilic property is attributed to the oxygen atoms of the ester group, which is shielded by the hydrophilic groups. Therefore, VCO has no surfactant properties and is completely nonpolar, which implies that it can only dissolve in organic solvents and is difficult to dissolve in water.

Molecules from the lipid group with surfactant properties usually have both hydrophilic and hydrophobic components in their molecules [23, 27]. The surfactant properties possessed by lipid class compounds allow for effective interactions with pathogenic microbes such as bacteria, fungi, and viruses. Therefore, triglycerides from VCO have almost no antimicrobial activity due to the absence of surfactant or emulsifier prop-

erties. This poses the question about the compounds responsible for the extraordinary antimicrobial activity of VCO when they do not have surfactants or emulsifier properties.

The answer can be derived by understanding how VCO is digested in the human body, in the mouth, foods that contain fats are only physically digested and refined. Meanwhile, enzymatic digestion of triglycerides from VCO occurs in the stomach and small intestine with the help of gastric and pancreatic lipase. Lipase is an enzyme that specifically acts on lipid substrates. It includes sn-1,3 and sn-2 lipases which both have almost similar functions to remove the acyl group in the position of 1,3 on triglycerides and position 2 of the glycerol frame respectively.

An acidic environment in the human gastric is not adequately effective to support the hydrolysis process of fats. Meanwhile, the pancreatic fluid in the small intestine is known to have a pH between 7.0–8.8, which is a suitable environment for the effective hydrolysis of triglycerides by lipase enzymes. The hydrolysis process in the stomach and intestines by lipase enzymes produces diglycerides, monoglycerides, free fatty acids, and glycerol. Initially, the triglycerides are broken down into diglycerides by releasing one acyl group. Next, the diglycerides release one acyl group to produce 2-monoglycerides and 1-monoglycerides. When the breakdown process continues, the 2-monoglycerides and 1-monoglycerides release one acyl group to form free fatty acids and glycerol as by-products.

VCO contains high amount of lauric acid from its triglycerides, therefore, when consumed, its major components such as 2-monolaurin, 1-monolaurin, and lauric acid are abundantly present in the intestines and ready to be absorbed as well as transported throughout the body. Consequently, it is assumed that the ability of VCO to kill pathogenic microorganisms such as bacteria, viruses, and fungi, is due to the monoglycerides, 1-monolaurin, and 2-monolaurin, as well as the fatty acid, namely lauric acid.

5 Antimicrobial Activities of Lauric Acid

Lauric acid is widely known as a healthy saturated fatty acid [28], it is found in nature from the main sources such as VCO and palm kernel oil [29, 30]. Furthermore, lauric acid has been reported as the major component in VCO [22, 24]. The chemical structure is composed of 12 carbon (C), 24 hydrogens (H), and 2 oxygen (O) atoms with the molecular formula of $C_{12}H_{24}O_2$ and is categorized as a MCFA (Fig. 2). Lauric acid is present as a white solid with a melting point of 43–44 °C and a molecular weight of 200.32 g mol^{-1}. Moreover, it is a fatty acid that can be produced through the hydrolysis reaction of vegetable oils using an inorganic-base catalyst or a lipase enzyme, the base-catalyzed hydrolysis of pure fatty acid methyl ester, and the Colgate-Emery steam process [31].

Based on the chemical structure in Fig. 2, it appears that lauric acid has hydrophilic properties that are contributed by the presence of -OH group and the oxygen atom of the carbonyl group. Both functional groups allow the formation of hydrogen bonds with the polar part on the cell walls of pathogenic microorganisms. Meanwhile, its lipophilic properties are contributed by the lauryl groups, which potentially form Van der Waals interactions with the non-polar parts on the cell walls of microorganisms. The surfactant properties of lauric acid potentiate the interaction with cell walls to inhibit and even kill pathogenic organisms. Furthermore, lauric acid has been reported to have a broad spectrum of antimicrobial activities against viruses, bacteria, and fungi [22, 32–38]. Its antimicrobial activities including antibacterial, antifungal, and antiviral are presented comprehensively in Tab. 2.

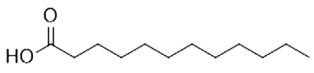


Figure 2. Chemical structure of lauric acid.

The antibacterial activity in vitro of lauric acid shows the ability to inhibit *P. acne* growth [34, 39] with a minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) of 20 and 80 µg mL^{-1} respectively [40]. Furthermore, lauric acid shows superb inhibition to *S. aureus* in vitro [19, 21, 34, 37, 41–44, 53, 54] with MIC and MBC values of 250 and 250 µg mL^{-1}, respectively [36]. Using the well dilution method, lauric acid inhibited *S. epidermidis* with MIC Value lower than those of benzoyl peroxide [34].

Lauric acid can also act as a potential antibacterial agent to the pathogenic bacteria such as Group A (GAS), Group B (GBS), and Group D Streptococci (GDS) [45, 46, 55]. An in vitro study on several clinical isolates of *Mycobacterium tuberculosis* and *Streptococcus pneumonia* was conducted by Anzaku et al. [37] using the Bauer-Kirby disc method. The result showed that lauric acid can inhibit the growth of *Streptococcus pneumonia* and *Mycobacterium tuberculosis* with an inhibition zone of 15.00 mm and 14.00 $\pm$ 14.41 mm, respectively.

Furthermore, Hovorková et al. [54] reported that lauric acid contained in coconut plants had inhibitory activity against *Listeriamonocytogeneses* and *Clostridium perfringens* bacteria. An assay using the broth microdilution method showed minimum inhibitory concentration (MIC) value to *Listeria monocytogeneses* and *Clostridium perfringens* of > 4.5 mg mL^{-1}. In addition, a Log reduction assay was carried out on *Helicobacter pylori* and the result indicated that lauric acid reduced the growth by 1 mM for 1 h [53]. Lauric acid can also inhibit the growth of *Enterococcus faecalis* [52] with a maximum inhibition at 24 h with a MIC value of 2.5794 µg and Clostridium difficile as determined by a reduction in colony-forming units per milliliter [18].

Antifungal activity of lauric acid also has been reported in several studies [45, 46, 52, 56, 57]. Devan et al. [52] reported that the antifungal activity of lauric acid against the growth of *C. albicans* was demonstrated by the MIC value of 0.4637 µg. The effectiveness of lauric acid on the inhibition of *Aspergillus niger* has also been investigated by Altieri et al [58] and the results showed that the inhibitory activity rises with the increasing minimum detection time (MDT) of 3.22 $\pm$ 0.34 days and lag times of 2.09 $\pm$ 0.70 days. The best inhibitory activity against *Fusarium spp* described by Altieri et al. [59] showed that lauric acid exhibited strong bioactivity compared to palmitic and myristic acids, as indicated by the absence of *Fusarium spp* growth in the presence of 20 ppm potato dextrose agar (PDA) for 30 days.

Table 2. Antimicrobial properties of lauric acid.

Inhibited microorganism	Method and activity	Ref.
Antibacterial properties		
Propionibacterium acnes	Well diffusion method	[34]
	Lauric acid shows the most inhibition *P. acnes* growth of other bacterial tests in EC_{50} value	
Propionibacterium acnes	The broth dilution method	[39]
	Lauric acid had stronger antimicrobial activity in vitro against *P. acnes* than capric acid	
Propionibacterium acnes	The two-fold serial dilution method	[40]
	Free lauric acid has good antimicrobial activity with minimum inhibitory concentration (MIC) and minimum bactericidal concentration (MBC) with the value of about 20 and 80 $\mu g\,mL^{-1}$, respectively	
S. aureus	Agar dilution method	[21]
	The phagocytosis of *S. aurues* improved by VCO presence at 0.102 % lauric acid	
S. aureus	Agar well diffusion method	[41]
	Lauric acid exhibited the inhibition of *S. aureus* growth at 5 % concentration	
S. aureus	Well dilution method	[34]
	Minimal inhibitory concentration (MIC) of lauric acid is 15 times less than benzoyl peroxide (BPO)	
S. aureus	Broth microdilution assay	[36]
	MIC and MBC value of lauric acid obtained at 250 $\mu g\,mL^{-1}$	
S. aureus	Agar disc diffusion method as described by Bauer-Kirby	[37]
	The inhibition zone of *S. aureus* is elevated by the lauric acid presence with a value about 15 ± 1.414 mm	
S. aureus MSSA and MRSA	Broth microdilution assay	[42]
	Lauric acid may be blocking methicillin-susceptible *S. aureus* (MSSA) and MRSA at 400 $mg\,mL^{-1}$	
S. aureus	In vitro analysis	[43]
	Lauric acid has successfully inhibited *S. aureus* growth	
Staphylococcus aureus, ATCC 2592	The disk diffusion method of Bauer with Mueller Hinton agar	[44]
	Lauric acid inhibits the *S. aureus* growth with MBC value of about 3.2 $mg\,mL^{-1}$	
S. epidermidis	Well dilution method	[34]
	Lauric acid yielded MIC values against *S. aureus* growth over 15 times lower than those of BPO	
Group A Streptococci (GAS) and group B (GBS)	In vitro analysis	[45]
	The colony forming unit (CFU) value of lauric acid activity was founded at 6.0 log10	
Group D Streptococci	In vitro analysis	[46]
	Lauric acid is likely blocking gram-positive bacteria	
Mycobacterium tuberculosis	Bauer-Kirby disc diffusion assay	[37]
	Lauric acid shows best antituberculosis activity with the inhibition zone of 14 ± 1.414 mm	
Streptococcus pneumonia	Bauer-Kirby disc diffusion assay	[37]
	Lauric acid demonstrated the highest zone of inhibition on *M. tuberculosis* at 15 ± 1.414 mm	
Listeria monocytogeneses	In vitro analysis	[42]
	Lauric in hydrolyzed coconut oil able to inhibit *Listeria monocytogenes* at 0.14–4.5 $mg\,mL^{-1}$	
Listeria monocytogeneses	In vitro analysis	[47]
	Lauric acid could block *Listeria monocytogenes* growth in neutral pH condition	

Table 2. Continued.

Inhibited microorganism	Method and activity	Ref.
Helycobacter pylori	Agar dilution method (brucella broth)	[48]
	Lauric acid discourages *H. pylori* extremely	
Helycobacter pylori	In vitro analysis	[32]
	Lauric acid has the best *H. pylori* inhibition at 10 mM with an incubation time during 10 min	
Helycobacter pylori	Agar dilution broth using Iso-Sensitest broth	[49]
	MBC value of lauric acid against *H. pyloryi* is 7.4 at neutral pH condition	
Bacteroides and Clostridium; Clostridium perfringens	In vitro analysis	[38]
	Lauric acid could destroy pathogenic Bacteroides and Clostridium growth	
Clostridium perfringens	Agar dilution on The Wilkins-Chargren Broth (Oxoid)	[50]
	Lauric acid has inhibition activity toward *Clostridium perfringens*	
Clostridium perfringens CNCTC 5459	In vitro analysis	[51]
	Lauric acid that obstructs *Clostridium perfringens* CNCTC 5459 at 0.1 mg mL^{-1}	
Enterococcus faecalis	Agar well–diffusion method using Muller–Hinton Agar medium	[52]
	Lauric acid is more inhibited *E. faecalis* type than NaOCl	
Clostridium difficile	In vitro analysis	[18]
	Lauric acid was discovered that have *Clostridium difficile* growth inhibitor	
S. aureus	Disk diffusion antibacterial test	[19]
	S. aureus growth is nicely inhibited by lauric acid	
S. aureus	Lauric acid has antibacterial activity toward *S. aureus*	[53]
S. aureus	Broth microdilution method	[54]
	Lauric acid in coconut oil is able to inhibit *S. aureus*	
S. aureus	In vitro analysis	[46]
	Lauric acid is properly discourages *S. aureus* growth	
S. aureus	Lauric acid was well inhibited Gram-positive bacteria	[55]
Antifungal properties		
C. albicans	In vitro analysis	[45]
	Lauric acid found *C. albican* inhibition at small concentrations and short incubation period	
C. albicans	In vitro analysis	[56]
	Lauric acid was found that have potential as a *C. albican* inhibitor	
C. albicans	The serial dilution method	[57]
	Lauric acid in VCO inhibits *C. albicans* at 25 % concentration during 2 days.	
C. albicans	In vitro analysis	[52]
	Lauric acid is superior to discouraging *C. albicans*	
Aspergillus niger	In vitro analysis assay using PDA-antimicrobial plates potato dextrose agar	[58]
	Mold growth inhibition by lauric acid undergoes in enhancing minimum detection time as well as lag times	
Fusarium spp	In vitro analysis assay using PDA-antimicrobial plates	[59]
	Lauric acid exhibited well inhibition to *Fusarium spp*	

Table 2. Continued.

Inhibited microorganism	Method and activity	Ref.
Antiviral properties		
Vesicular stomatitis virus (VSV)	The infectivity of cell with VSV was titrated by the serial dilution endpoint method	[60]
	Lauric acid is extremely potent to destroy VSV	
Vesicular stomatitis virus (VSV)	Plaque assay in Linbro plates	[61]
	Lauric acid leakages the host cell membrane of M protein	
Herpes simplex virus	Plaque assay in Linbro plates	[60]
	Lauric acid has the potential to destroy the enveloped virus in the amount of 20-fold	
Herpes simplex virus type 1 (HSV-1)	Viruses were titrated by inoculation of 10-fold dilutions into Vero cells	[62]
	Lauric acid shows antiviral activity against HSV-1 in milk and formula combination	
Herpes simplex virus type 2	In vitro analysis	[63]
	Lauric acid actively reduces HSV-2 activity activity at 4.5 log10 during 10 min	
Visna virus	Visna virus was titrated by inoculation of 10-fold dilutions into sheep choroid plexus cell cultures	[60]
	Lauric acid well destroyed the visna virus	
Visna virus	In vitro analysis	[5]
	Lauric acid combates Visna virus at 10 mM	
Respiratory syncytial virus (RSV)	Viruses were titrated by inoculation of 10-fold dilutions into Vero cells	[62]
	Lauric acid in milk and formula combination has excellently inhibited to respiratory syncytial virus (RSV)	
Junin virus (JUNV)	Cellular viability was measured with the 3-(4,5-dimethylthiazol-2-yl)-2,5-diphenyl tetrazolium bromide (MTT) method	[3, 64]
	Lauric acid could reduce JUNV growth without cell viability interfere	

Aside from its antifungal activity, lauric acid is also used as an antiviral agent, this is demonstrated by Hornung et al. who reported its ability to prevent the formation of M protein bonds in the host cell membrane, leading to the slow release of the virus [61]. At a concentration above 750 $\mu g\,mL^{-1}$, it was found that lauric acid suppressed the titer of the vesicular stomatitis virus (VSV) by 98%. Similarly, H. Thormar et al. [60] found that lauric acid decreased the growth of VSV and herpes simplex virus (HSV) at a concentration of 2 $mg\,mL^{-1}$ with a reduced value of virus titer (log_{10}) of > 4 and ≥ 3.2 for HSV and visna virus, respectively [60]. In a separate report, Isaacs et al. [62] investigated the antiviral activity against VSV in human and bovine milk. The results showed that lauric acid with a concentration of 5 mM had a log_{10} value of ≥ 4.25 in human milk and ≥ 3.25 in bovine milk. Furthermore, Hilmarsson et al. [5] reported better virucidal activity to the visna virus and herpes simplex virus type 2 at 10 mM, with the reduced virus activity value of 4.5 log10 after 10 min. Bartolotta et al. [64] also stated that lauric acid was effective in inhibiting the growth of the Junin virus (JUNV) from the Arenaviridae group that is known for its infectious effect on humans, widely recognized as Argentine hemorrhagic fever (AHF). The results indicated that lauric acid had a higher inhibitory profile against JUNV compared to other fatty acid groups. The IC_{50} values acid against several strains of JUNV such as IV4454, XJ, XJCl3, and Cl67 were 124, 188, 129, and 46 μM, respectively.

6 Antimicrobial Activity of Monolaurin

Monolaurin is a saturated monoglyceride from lauric acid, it is also called 1-monolaurin, α-monolaurin or α-glycerol monolaurate and is obtained by esterification reaction involving lauric acid and glycerol with accelerated H_2SO_4 [65], pTSA [66], sulfated zirconia loaded SBA-15 [67], Novozym 435 [68], and Rhizomucormiehei lipase [69]. Side products obtained by esterification reaction include dilaurin and trilaurin. Additionally, the ethanolysis of virgin coconut oil produces 2-monolaurin or β-monolaurin, or β-glycerol monolaurate. This reaction is catalyzed by lipozym TL IM [70]. With lauric acid as a starting material, 2-monolaurin is obtained from the ethanolysis of trilaurin using lipozym TL IM. Trilaurin is produced from an esterification reaction between glycerol and excess lauric acid [71].

As shown in Fig. 1, monolaurin structure has a lauryl group with lipophilic properties and two hydroxyl groups with hydro-

philic characteristics. Both lipophilic and hydrophilic groups allow monolaurin to have excellent amphiphilic or surfactant properties. The amphiphilic character probably occurs in chemical interaction between monolaurin and the cell wall. This leads to the organism's growth through hydrogen bond and van der Waals interaction. Tab. 3 provides the summary of monolaurin bioactivity which includes a broad spectrum as antibacterial, antifungal, and antiviral. The mechanism that best explains how monolaurin and lauric acid can inhibit the growth of bacteria, fungi, and viruses will be described in the following section.

Overall, monolaurin or glycerol monolaurate has incredible potency as a broad-spectrum antibacterial agent against *S. aureus, S. epidermidis, S.pyogenes, L. monocytogeneses, C. diphtheria, B. cereus, C. perfringens, P. aeruginosa, Enterobacteriaceae, H. pylori, E. coli*, and *P. Larvae*. It inhibits and kills various bacterial types at a particular concentration. Antibacterial assays to determine the inhibition diameter, minimum inhibition concentration (MIC), and minimal bactericidal concentrations (MBC) were executed in-vitro using a bacterial culture medium. Although the assay used different methods, the result shows that monolaurin actively inhibited and killed the bacteria (Tab. 3).

The antibacterial activity shown in Tab. 3 gives specific information that monolaurin is more active in killing Gram-positive than Gram-negative bacteria. Furthermore, the distinct thickness of the cell wall changed after the inhibitory and antibacterial activity of monolaurin. Monolaurin shows the highest inhibition activity towards *S. aureus* among other Gram-positive bacteria with a low concentration of 12.5 $\mu g\,mL^{-1}$ [43, 44, 76–78, 46, 60, 65, 70, 72–75]. Monolaurin has been reportedly effective to inhibit the *S. aureus* growth the concentrations of 100 $\mu g\,mL^{-1}$ [43], 500 $\mu g\,mL^{-1}$ [65], 12,5 $\mu g\,mL^{-1}$ [77], and 128 $\mu g\,mL^{-1}$ [78]. The MBC value reported by Tangwatcharin

Table 3. Antimicrobial activity of monolaurin.

Inhibited microorganism	Method and activity	Ref.
Antibacterial properties		
S. aureus	MIC determination using the broth microdilution method	[46]
	Monolaurin has great inhibition *S. aureus*	
S. aureus	In vitro assay: The broth microdilution method	[43]
	Monolaurin inhibits *S. aureus* growth at 100 $\mu g\,mL^{-1}$	
S. aureus	Agar disk diffusion and broth dilution assays with Mueller-Hinton broth	[44]
	Monolaurin has an MBC value against *S. aureus* about 0.1 $mg\,mL^{-1}$	
S. aureus	In vitro assay by perforation method	[65]
	Monolaurin is more inhibit *S. aureus* growth than dilaurin compound	
S. aureus FNCC 0047	Using Perforation method with nutrient agar as a media for bacteria	[70]
	2-monolaurin inhibits *S. aureus* with diameter zone 13.75 mm at 2500 ppm	
S. aureus FNCC 0047	Perforation method using nutrient agar as a media for bacteria	[66]
	1-monolaurin discourage *S. aureus* at 500 $\mu g\,mL^{-1}$	
S. aureus	Broth dilution method	[72]
	Monolaurin compound could inhibit *S. aureus*	
Staphylococcus aureus sub sp. aureus CCM 3953	Broth dilution method using Mueller-Hinton broth culture	[73]
	1-monolaurin inhibited *S. aureus* at 100 $mg\,L^{-1}$	
S. aureus MN8	Agar dilution method using Todd Hewitt broth	[74]
	Monolaurin has highly active against *S. aureus* with > 3 log reduction	
S. aureus RN6390	In vitro model of S. aureus biofilms culture	[75]
	Monolaurin has a bactericidal effect to combat *S. aureus* at 3 mM	
S. aureus	In vitro assay using Triptic soy broth with glucose as bacteria medium growth	[76]
	Monolaurin has effectively combated *S. aureus*	
S. aureus	A microtiter plate assay	[77]
	Monolaurin inhibits *S. aureus* with a MIC value of 12.5 $\mu g\,mL^{-1}$	

Table 3. Continued.

Inhibited microorganism	Method and activity	Ref.
S. aureus	Micro well dilution assay	[78]
	Monolaurin inhibits *S. aureus* with a MIC value of 128 μg mL^{-1}	
S. epidermidis 1093	Agar-well diffusion method	[79]
	Monolaurin inhibits *S. epidermidis* with diameter zone 28 mm and MIC 31.5 μg mL^{-1}	
S. epidermidis	Microbroth dilution technique to determine MIC and MBC	[80]
	1-monolaurin combats *S. epidermidis* with MIC and MBC value 1000 μg mL^{-1}	
S. epidermidis	In vitro assay to determine biofilm formation inhibition and eradiction activity	[81]
	1-monolaurin combats monospecies and polymicrobial biofilm (*S. epidermidis*) with MBIC80 value of 1.95 and 62.50 μg mL^{-1}, respectively	
S. pyogenes	Agar dilution method using Todd Hewitt Broth	[74]
	Monolaurin discourages *S. pyogenes* effectively	
S. pyogenes	Agar-well diffusion method	[79]
	Monolaurin inhibits *S. pyogenes* with diameter zone and MIC, 22.3 mm and 31.25 μg mL^{-1}, respectively.	
Listeria monocytogeneses	Agar-well diffusion method	[79]
	Monolaurin could inhibit *Listeria monocytogeneses* with diameter zone (23.3 mm) and MIC (62.5 μg mL^{-1})	
C. diphtheria	Agar-well diffusion method	[79]
	Monolaurin has diameter zone (21.3 mm) and MIC (62.5 μg mL) to fight *C. diphtheria*	
B. cereus	Agar-well diffusion method	[66]
	Monolaurin impede *B. cereus* growth with a diameter zone value of 10.83 mm at 1000 μg mL^{-1}	
B. cereus	Agar-well diffusion method	[79]
	Monolaurin has effectively inhibited *B. cereus* with a diameter zone value of 22 mm and MIC value of 125 μg mL^{-1}	
B. cereus	In vitro assay using rain heart infusion (BHI) broth	[82]
	Monolaurin is most active to inhibit *B. cereus* in ethanol as solvent	
Clostridium perfringens	Agar dilution method using Todd Hewitt Broth	[83]
	Monolaurin could destroy *C. perfringens* at 1 μg mL^{-1}	
Pseudomona aeruginosa & Enterobacteriaceae	Agar dilution method using Todd Hewitt Broth	[83]
	Monolaurin has the most active against *P. aeruginosa* and *Enterobacteriaceae* in acidic conditions as well ethylene diamine tetra acetic acid as cation chelator	
Helicobacter pylori	Agar dilution by the Turkey /Kramer method	[32]
	Monolaurin effectively combats *H. pylori*	
Helicobacter pylori	In vitro assay using Iso-Sensitest broth	[84]
	Monolaurin could inhibit *H. pylori* with an MBC and potency factor (Ki) value of 0.5 mM and 2, respectively	
Helicobacter pylori	In vitro analysis using microbroth dilution	[48]
	Monolaurin shows actively bactericidal properties to *H. pylori*	

Table 3. Continued.

Inhibited microorganism	Method and activity	Ref.
E. coli	Perforation method using nutrient agar as a media for bacteria	[66]
	1-monolaurin has been active against *E. coli* at 500 μg mL^{-1}	
E. coli	In vitro using a microtiter plate assay	[77]
	Monolaurin could fight *E. coli* with a MIC value of 25 μg mL^{-1}	
Paenibacillus larvae	Microdilution assay	[85]
	Monolaurin in nanocapsule form has active to destroy Paenibacillus larvae	
Antifungal properties		
C. albicans	In vitro analysis using the serial dilution method	[57]
	VCO containing monolaurin exhibits great discouragement to *C. albican* at 25 %	
C. albicans	In vitro using the inoculated broth dilutions (Trypticase Soy Agar plate)	[46]
	Monolaurin has effectively impeded *C. albican*	
C. albicans	In vitro analysis with the MBC concentration determination using Spectrophotometer	[86]
	Monolaurin could be an antifungal and anti-inflammatory activity. Monolaurin has actively inhibited *C. albicans* with MIC and MFC values of 62.5–125 μM and 125–250 μM, respectively	
C. albicans	In vivo analysis	[87]
	Monolaurin could inhibit *C. albican* in vivo	
C. albicans	The anti-biofilm assay	[85]
	Monolaurin in nanocapsule form deducts 31.94 % of formed biofilm during 48 h	
Aspergillus niger	In vitro analysis using PDA-antimicrobial plates	[58]
	Monolaurin could promote MDT and lag time enhancement	
Aspergillus niger DMF 0801	In vitro analysis using Malt Extract Broth	[88]
	Monolaurin has the most inhibition of *A. niger* at 0.2 and 1.8 mmol L^{-1}	
Candida tropicalis	The broth microdilution test method	[81]
	1-monolaurin could inhibit *C. tropicalis* growth at > 1000 μg mL^{-1}	
Fusarium spp	In vitro analysis	[59]
	Monolaurin shows antifungal properties toward *Fusarium spp*	
Antiviral properties		
Vesicular stomatitis virus (VSV)	In vitro assay with titrated by the serial dilution endpoint method	[60]
	Monolaurin exhibited greater antiviral activity than lauric acid	
Herpes simplex virus	In vitro analysis	[5]
	Monolaurin could deduce HSV-1 and HSV-2 growth at 1 min (3.5 log10) and acidic condition	
Respiratory syncytial virus (RSV)	Viruses were titrated by inoculation of 10-fold dilutions into Vero cells	[62]
	Monolaurin in milk and formula combination could inhibit respiratory syncytial virus (RSV)	
HIV-1	In vitro analysis	[89]
	Monolaurin can inhibit HIV-1 by means blocking HIV-1 into the host cell	

Table 3. Continued.

Inhibited microorganism	Method and activity	Ref.
HIV	Therapeutic VCO with monolaurion to patient	[7]
	VCO containing monolaurin diminished HIV activity in the third month	
Novel Corona Virus (nCov-19)	Monolaurin could inhibit severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) by being employed as an immunomodulator and protector virus	[90]
Novel Corona Virus (nCov-19)	In vitro assay	[91]
	Monolaurin was able to destroy virus including novel coronavirus (nCov-19) with preventing the ability of the virus to produce the syncytial formation	
Novel Corona Virus (nCov-19)	Therapeutic VCO to COVID-19 patient	[92]
	Monolaurin treatment shows good influence on participants with CRP levels normalized of $\leq 5\,mg\,dL^{-1}$ during the intervention period (14 days)	

and Khopaibool [44] was $0.1\,mg\,mL^{-1}$. With a concentration estimated to be 3 mM, monolaurin exhibited bactericidal activity against antibiotic-resistant *Staphylococcus aureus* biofilms [75].

Moreover, Kabara et al. [46] reported that monolaurin has good antimicrobial activity as demonstrated by the inhibition of *S. aureus* and *S. epidermis* with a MIC value of $0.09\,\mu mol\text{-}mL^{-1}$. Similarly, Nitbani et al. [66] reported that the ability of 1-monolaurin to inhibit the growth of *S. aureus* and *B. cereus* amounted to an inhibition zone of 13.75 and 10.44 mm at 2500 ppm, respectively. 2-monolaurin from coconut oil has also been reported to inhibit *S. aureus* growth at a concentration of 100 and 2500 ppm, respectively. Monolaurin was reported to have better antimicrobial activity compared to lauric acid [74]. An assay of monolaurin against *S. aureus* showed bactericidal activity with a minimum inhibitory value greater than 3 log CFU/mL at a concentration of 0.05 mM.

In an in vitro study, monolaurin also exhibited inhibition activity toward several bacterial growths such as *S. epidermidis, S. pyogenes, L. monocytogeneses, C. diphtheria, C. perfringens*, and *B. cereus* at a low level of $31.25\,\mu g\,mL^{-1}$ [79]. A study on the antimicrobial activity of monolaurin and lauric acid was reported by Botovska et al. [79]. The results showed that monolaurin had relatively better inhibitory abilities than lauric acid against *S. epidermis, S. pyogenes, L. monocytogenes, C. diphtheria*, and *B. cereus* with the MIC values of 31.25, 31.25, 62.5, 62.5, and $125\,\mu g\,L^{-1}$, respectively.

The growth of *H. pylori*, which is a common colony in the stomach or duodenum, can be inhibited by the presence of monolaurin. This was shown by the log reduction assay value, which demonstrated the ability of monolaurin to kill bacteria at 0.5–1.25 mL for 1 min to 1 h [32, 48, 49, 53]. Furthermore, a recent study reported that monolaurin can destroy *H. pylori* with an MBC value of 0.5 M and potency factors (Ki) value of 2 [84].

Monolaurin also exhibited broad-spectrum antibacterial activity against Gram-negative *E. coli* bacteria [93]. A study by Carpo et al. [93] showed that an increase in the concentration of monolaurin up to $20\,mg\,mL^{-1}$ can reduce the density of *E. coli* colony growth. Zhang et al. [77] also reported that monolaurin inhibits *E. coli* growth in vitro with a MIC value of $25\,\mu g\,mL^{-1}$. At a concentration of $500\,\mu g\,mL^{-1}$, the zone inhibition diameter was reportedly 10.55 mm [66]. For Gram-positive bacteria, monolaurin in nanocapsule form can kill Paenibacillus larvae as demonstrated through microdilution assay [85].

The presence of monolaurin in VCO contributes to its antifungal activity, as demonstrated by Tjin et al. [57] which reported that VCO inhibited the growth of *C. albicans* at a concentration of 25 % for 2 days of exposure. Moreover, Kabara et al. showed the ability of monolaurin to inhibit *C. albicans* with the MIC value of $2.49\,\mu mol/\,mL^{-1}$ [46]. The antifungal activity of monolaurin against *Aspergillus niger* was also studied by Řiháková et al. [88] through the inhibitory index (II) value to describe the inhibitory ability of spore germination using the gel cassette system. The results showed that a value of 100 % can be achieved at a concentration of $1.8\,mmol\,L^{-1}$. In this condition, the number of colonies observed was reduced to 50 which was smaller than that of the control namely 300. Several recent studies also showed that monolaurin or glycerol monolaurate is used as an antifungal agent. Monolaurin can inhibit *C. albicans* growth in vitro and in vivo [85–87].

The effectiveness of monolaurin to inhibit *Aspergillus niger,* in line with the *Gompertz* parameter, has been reported Altieri et al. [58]. The results showed that the maximum colony diameter (A) was 9.02 ± 0.86 cm, the maximum radial growth rate (μ_{max}) was $0.71 \pm 0.10\,cm\,day^{-1}$, the lag phase ($\lambda$) was 3.66 ± 1.11 days, and the MDT was 4.81 ± 0.68 days. For *Aspergillus niger* DMF 0801, monolaurin had the highest inhibition of spore outgrowths in the concentration ranging from $0.2–1.8\,mmol\,L^{-1}$ [88]. Meanwhile, with the broth microdilution assay, 1-monolaurin showed antifungal activities against *C. tropicalis* at a concentration above $1000\,\mu g\,mL^{-1}$ [81]. The measurement of the *Gompertz* parameter has also been performed by Altieri et al. [59] to show the inhibition of monolaurin against *Fusarium spp*. The results indicated that the effectiveness of monolaurin to inhibit *Fusarium spp*, was demonstrated by the smaller *Gompertz* parameter value than the control, such as the A value (7.41 ± 0.22 cm), μ_{max} ($1.05 \pm 0.10\,cm\,day^{-1}$), λ (4.33 ± 0.43 days), and MDT (5.05 ± 0.31 days) with a correlation coefficient value of 0.99.

A study on the antiviral activity of monolaurin against vesicular stomatitis virus (VSV) and herpes simplex virus type 1 (HSV-1) has been reported by Thormar et al. [60]. It was found that an effective antiviral activity of the monoglyceride groups such as monolaurin can be achieved at a concentration value 5 to 10 times less than the fatty acid groups. The Log_{10} values and the reduction of virus titer against VSV and HSV-1 were found to be ≥ 4.0 and ≥ 3.7 respectively at a concentration of $0.25\,mg\,mL^{-1}$. Furthermore, the effect of pH on the virucidal activity on visna virus (VV) was studied by Hilmarsson et al. [63]. The results showed that the activity of monolaurin was higher under an acidic environment compared to the neutral pH. The log_{10} value of monolaurin at a concentration of 5 mM at pH 7 and 4.2 was 4.57 ± 0.09 and ≤ 1.50, respectively. This indicates that the acidic pH influences the formation of ionic changes in the glycoproteins on the surface of the viral envelope membrane, thereby facilitating the penetration of monolaurin through the lipid membrane [63].

Monolaurin can also inactivate the respiratory syncytial virus (RSV) at a concentration of 4.5 mM with a log_{10} value of 0.5, and *H. influenza* at a concentration of 22.5 mM with a log_{10} value of ≥ 4.0 [62]. Another study by Dayrit and Newport [7] showed that VCO can provide a good therapeutic effect for HIV patients. The results demonstrated that the treatment until the third month caused a decrease in viral load and CD4 cell count, suggesting that the presence of VCO's compounds such as monolaurin and several fatty acids might have a significant role in the therapeutic effect. Moreover, Welch et al. [89] reported that monolaurin or glycerol monolaurate modestly reduced HIV-1 binding and dramatically inhibited the entry into permissive cells. Also, monolaurin offers broad-spectrum protection against enveloped viruses.

A study by Subroto and Indiarto found that monolaurin can act as an immunomodulator to increase the immune system and protect the body from virus attacks such as severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) [90]. It was proposed that the mechanism behind this process might be due to the increasing production of pro-inflammatory cytokines, modulating T-cell lymphocytes, and the control of cell proliferation. A recent study reported that monolaurin has the potential to destroy the novel coronavirus (nCov-19). Using an in-vitro method, monolaurin can kill the novel coronavirus (nCov-19) by preventing syncytial formation [91]. It was also discovered that monolaurin decreased the C-reactive protein level of several participants [92]. The average value of C-reactive protein achieved was less than $5\,mg\,dL^{-1}$ on the 14th day after the treatment with monolaurin.

7 Mechanism of Action of Lauric Acid and Monolaurin as Antibacterial Agents

The physicochemical properties of lauric acid and its ester form namely monolaurin significantly contribute to the effective antibacterial activity. Lauric acid is a type of saturated fatty acid with a medium carbon chain (C_{12}), which provides the lipophilic character to the structure. Meanwhile, the hydrophilic character is ascribed to the presence of the carboxylate group [31], hence, lauric acid possesses amphiphilic properties. Similarly, monolaurin also has amphiphilic properties, and the two hydroxyl groups that do not undergo an esterification reaction further increase this characteristic.

Amphiphilic properties are generally attributed to the binding mechanism of lipid molecules by detergents to form micelles. In a polar environment, micelles can move easily from their original place. Conversely, the outer layer of the bacterial cell membranes is composed of certain lipid molecules, hence, it is called a lipid bilayer. The polar part composed of the carboxylate groups is pointed toward the outer side of the cell, while the carbon chains are directed towards the center of the lipid bilayer. This creates a permeability of the membrane [94], which is a significant factor regarding the entry of antibacterial agents into the bacteria cell.

Lauric acid and monolaurin have also been reported to have antibacterial activity [37, 38, 66, 95]. Investigating their mechanisms of action in inhibiting bacterial growth is an interesting field to explore. The use of these two compounds as effective antibacterial can be explained by their chemical structure. The amphiphilic properties enable lauric acid and monolaurin to attack the structure of the cell membranes [96]. Consequently, the damaged cell membranes are exposed to the surrounding environment and the cytoplasmic fluid potentially leaks out. Meanwhile, the cytoplasmic fluid contains numerous organic compounds and enzymes that play a role in the cell metabolism of the bacteria. Therefore, leaking of the cytoplasmic fluid causes a decrease in the cell activity of the bacteria, leading to the death of the cells (Fig. 3).

The above-mentioned mechanism was proposed to explain the inhibitory effect of lauric acid and monolaurin for gram-negative bacteria. Due to the neutral nature of these two compounds, they can easily permeate through the bacterial membrane, without any steric hindrance. The bacterial membrane cannot cause any repulsion when these compounds interact with the outer layer. In contrast, the inhibitory mechanism of lauric acid and monolaurin against Gram-positive bacteria has also been commonly reported. The common target sites of antibacterial activity are well known and widely studied. The cell wall is the outermost part layer of Gram-positive bacteria. It is an important organelle that plays a role to maintain the structure of the cell and also prevents the entry of foreign compounds. The damage of the cell wall might potentially decrease the cellular activity and lead to the disruption of the metabolism by the incoming foreign compounds, causing cell death. The explanation regarding the breakdown of cell walls is discussed in this section.

The cell walls contain NAM and NAG compounds that are connected by glycoside bonds [98]. The formation of this bond produces a long chain to construct the cell walls, the hydroxyl group attached to the C_3 atom of NAM bound with 5 amino acid molecules (Fig. 4). Under normal conditions, the presence of the transpeptidase enzyme catalyzes the formation of new peptide bonds between amino acid chains called a cross-linking bond that produces a rigid structure for peptidoglycan (Fig. 5).

The mechanism of action for lauric acid and monolaurin in penicillin has been previously explained [99]. In penicillin, the

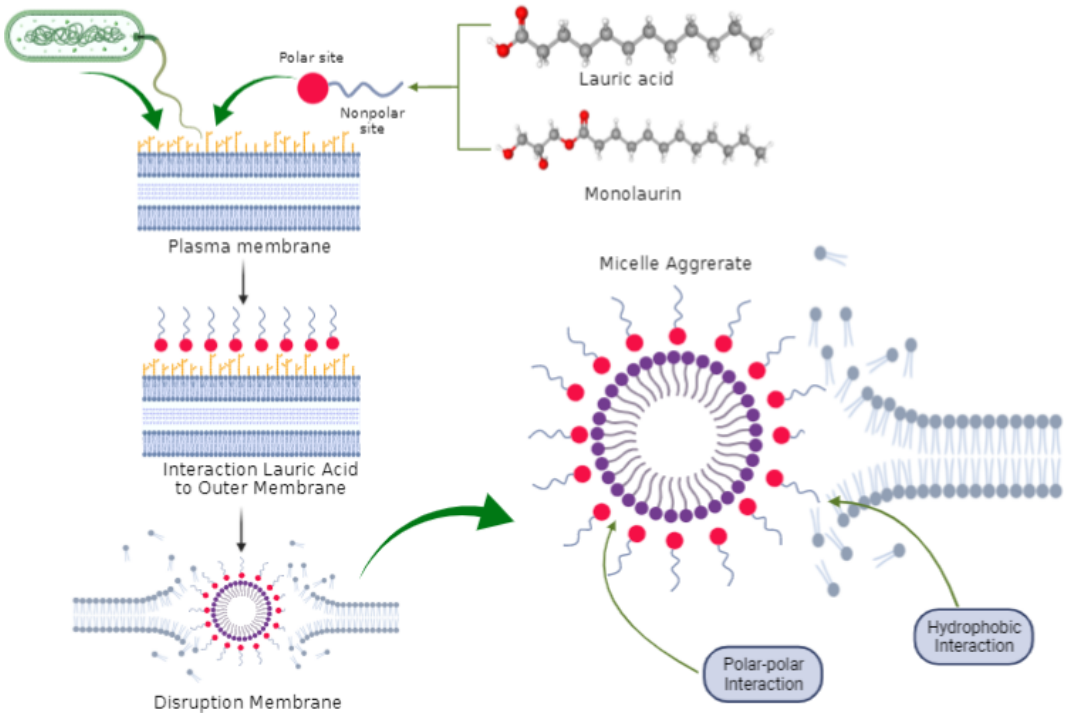


Figure 3. Disruption membrane by lauric acid and monolaurin.

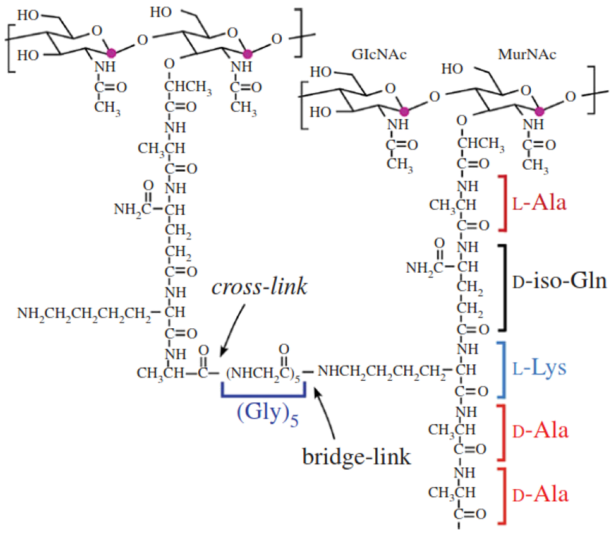


Figure 4. Structure of peptidoglycan of bacterial cells [97].

carbonyl carbon in the beta-lactam ring is utilized as an electrophilic source. This position is likely attacked by the nucleophilic side of the transpeptidase enzyme to form new irreversible ester bonds. Meanwhile, in lauric acid and monolaurin, the electrophilic property of the structure is due to the presence of carbonyl carbon in the carboxylic acid group, which opens the possibility to form bonds with the nucleophilic side of the transpeptidase enzyme. The formed connection potentially inhibits the active site of the enzyme to catalyze the formation of the cross-linking bond. Consequently, the rigid nature of peptidoglycan is lost, triggering the lysis of bacterial cells (Fig. 6).

8 Mechanism of Action of Lauric Acid and Monolaurin as Antifungal Agents

The development of antifungal agents is often related to the amphiphilic properties of the compounds. The amphiphilic properties of lauric acid and monolaurin ensure their interaction with the lipid membrane of fungi, causing cell lysis. Several studies have been conducted on different well-known antifungal agents with good amphiphilic properties, including Amphotericin B, Nystatin, and Natamycin [100–102].

A literature study indicated that lauric acid and monolaurin can inhibit the growth of different fungi as shown in Tab. 1 and 2. As described previously, the activity of these two compounds as antifungal agents is also associated with their amphiphilic properties. The presence of lauryl groups as lipophilic parts and carboxylic and hydroxyl groups as hydrophilic parts in lauric acid and monolaurin allow the chemical interactions with ergosterol, which is the main component of fungal cell membranes. Such interactions occur through the formation of Van der Waals and hydrogen bonds between lauryl, hydroxyl, and carboxyl groups with the components of the cell membrane, triggering the formation of pores. Consequently, these pores destabilize the cell membrane and damage the ion balance, ultimately leading to the death of the cells (Fig. 7) [100–102].

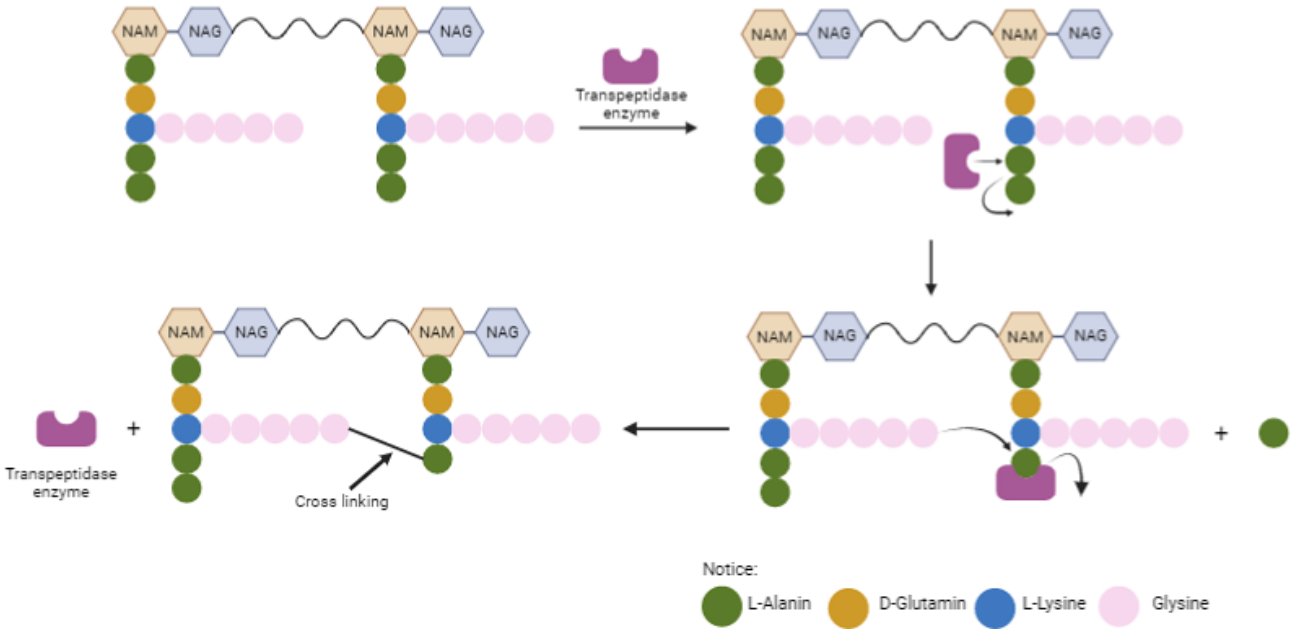


Figure 5. The mechanism of peptidoglycan synthesis.

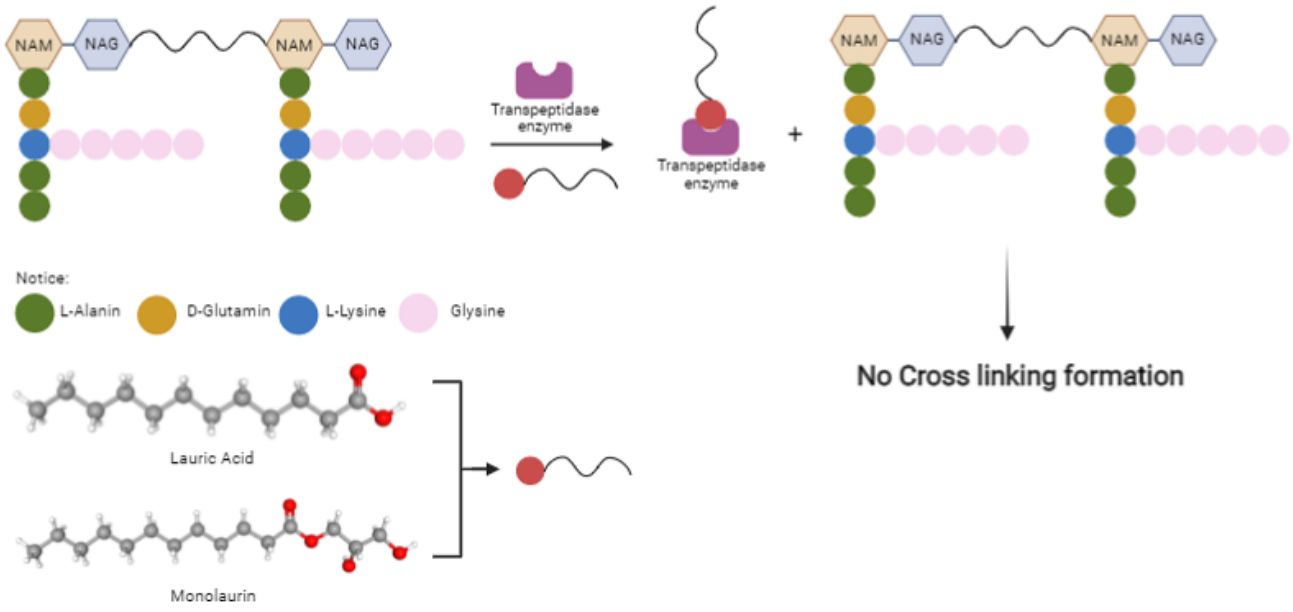


Figure 6. The inhibition mechanism of peptidoglycan synthesis.

9 Mechanism of Action for Lauric Acid and Monolaurin as Antiviral Agents

To date, the world is fighting the global pandemic caused by Coronavirus which has reportedly infected thousands of populations worldwide and even leads to death. Efforts to fight the spread of viral infections through several investigations are being developed. The mechanism of action for the inhibition of infection by the virus is one of the important study objectives. Several studies regarding the antiviral activity of fatty acids such as lauric acid have been reported. Similar bioactivity was also reported for monolaurin which is a monoester form of lauric acid glycerol.

In this section, the potential use of lauric acid and monolaurin as antivirals is described. These two compounds are reported to inhibit the final maturation stage in the viral replicative cycle [64]. This is supported by their amphiphilic properties that can change the characteristics of the cell membranes. The cell

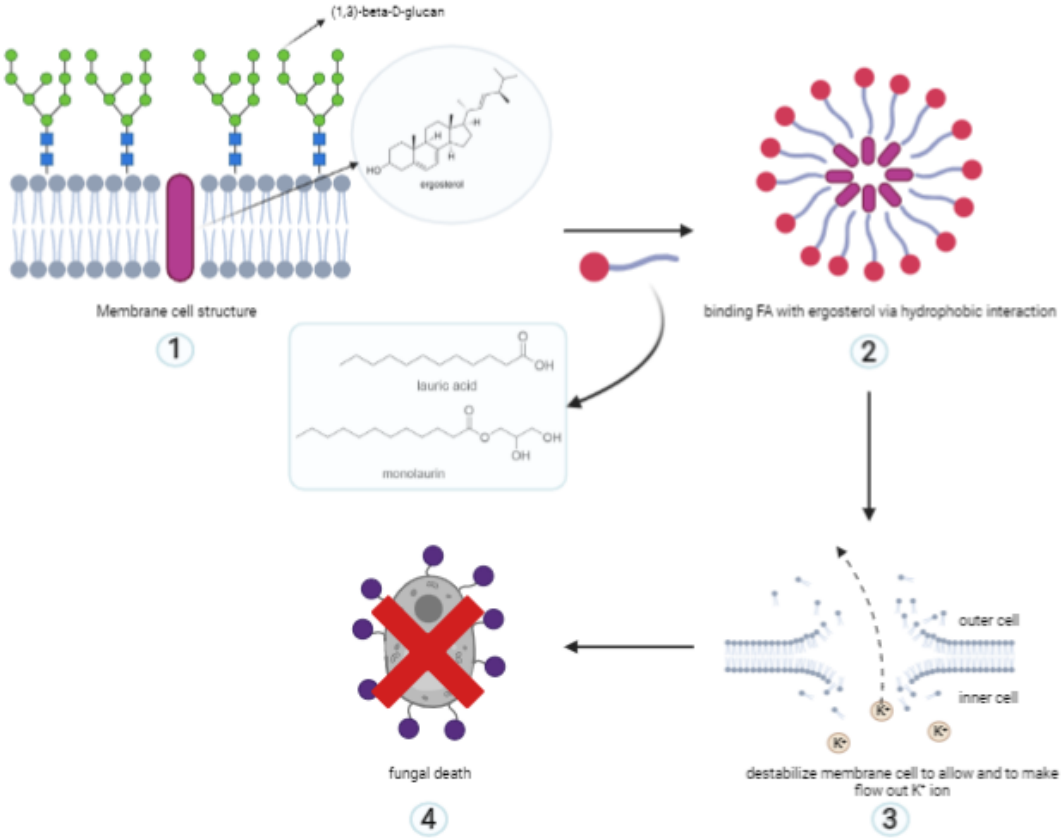


Figure 7. Antifungal mechanism of lauric acid and monolaurin.

membranes contain triacylglycerol (TAG) that contributes to its fluidity and permeability. In the presence of lauric acid and monolaurin, the hydrophobic properties of the aliphatic chain from both compounds can destabilize the interaction between glycoproteins of the virus and cell membranes (Fig. 8).

The treatment of Junin virus (JUNIV) using lauric acid for 24 h showed inhibition in the formation of the virus and stimulation of TAG synthesis by 54.1 and 26.1 %, respectively [64]. Consequently, the membrane permeability can be damaged, thereby disrupting the formation of bonds between the virus and the receptors of the cell.

The amphiphilic and lipophilic properties of lauric acid and monolaurin offer a virucidal mechanism [103]. The polar property of these compounds is due to the presence of the carboxylic group in lauric acid and the two hydroxyl groups in monolaurin. This is stabilized by the hydrophobic properties of both compounds due to the presence of the alkyl chain, which potentially causes the disintegration of the viral envelope. The disruption of the cell membranes triggers the cell opening and these compounds can dissolve both lipids and phospholipids in the envelope [103]. Finally, the formation of the vesicular aggregates in the aqueous medium occurs, leading to the destabilization of the lipid bilayer, this phenomenon causes lysis and the death of the cell [60].

Another antiviral mechanism of lauric acid is by preventing the binding of viral proteins to the host cells. Lauric acid can also break the RNA and DNA envelope of the virus by damaging the cholesterol membrane. Consequently, the permeability and fluidity of the membrane change, which interferes with the function of the virus by inhibiting the replication process and the binding of protein M to the host cell. This activity inhibits the release of the virus [61].

9 Conclusion

The coconut plant is well-known as the tree of life because all the parts have advantages to human life. Furthermore, coconut is among the primary exported commodities in tropical countries, such as Indonesia, Malaysia, the Philippines, and India. It is widely known that virgin coconut oil (VCO) is one of the primary products extensively produced from coconut and commonly utilized in a variety of human needs. VCO is typically an oil obtained from the coconut flesh using the wet processing technique which involves the extraction of coconut milk, followed by the preparation of cream, and finally, the degradation of emulsion to produce the oil. Moreover, coconut oil contains lauric acid (C12:0) as the primary component ranging from 45 to 52 %, along with myristic, palmitic, capric, and caprylic acids. Lauric acid which has been widely used as a base material for monolaurin production is present in two forms including 1-monolaurin and 2-monolaurin. These compounds together with dilaurin are produced in the stomach during VCO digestion by lipase. The amphiphilic character of

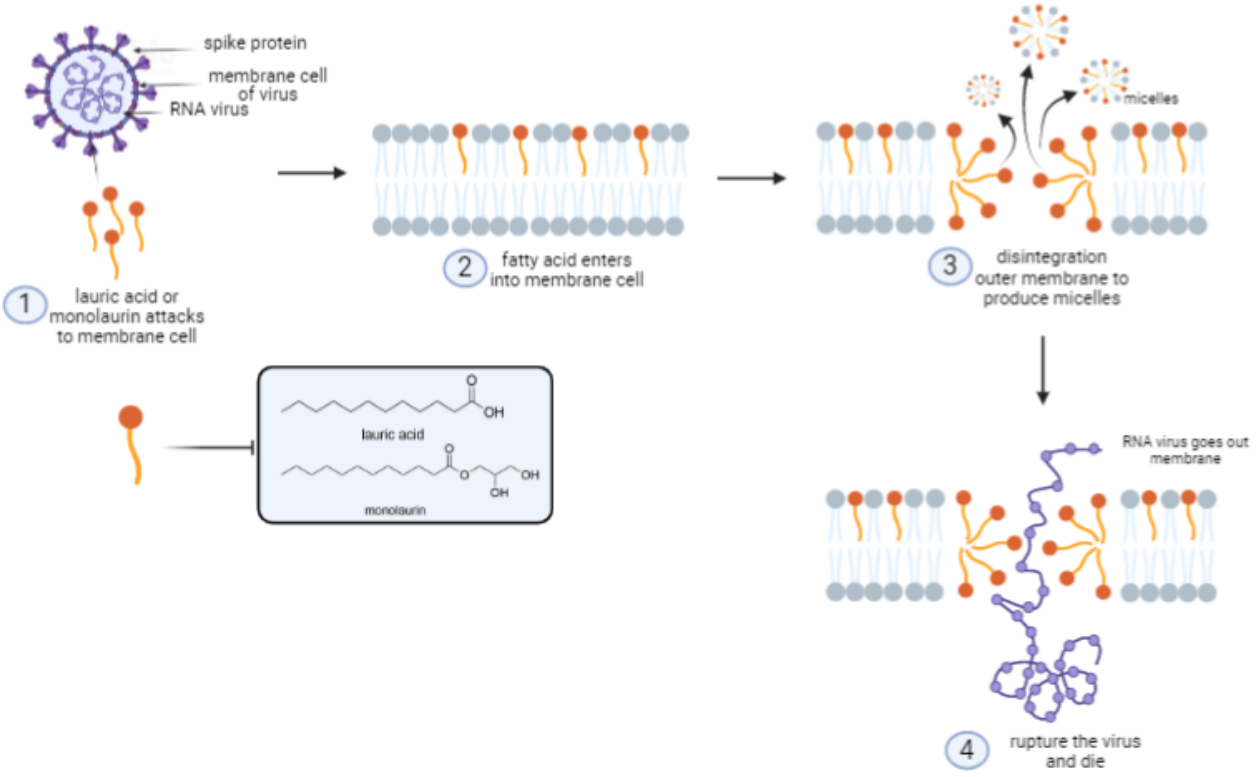
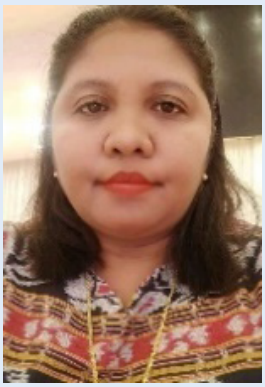


Figure 8. Antiviral mechanism of lauric acid and monolaurin.

lauric acid, 1-monolaurin, and 2-monolaurin reportedly contribute mainly to the broad spectrum of the VCO antimicrobial properties. Lauric acid and monolaurin are very effective in inhibiting and even killing gram-positive bacteria, especially *S. aureus*, fungi, especially *C. albicans* and certain viruses namely vesicular stomatitis virus (VSV), herpes simplex virus (HSV) and visna virus (VV). Monolaurin can also destroy very dangerous viruses such as Respiratory syncytial virus (RSV), human immunodeficiency virus (HIV), and novel coronavirus (nCov-19), while lauric acid has the potential to kill Junin virus (JUNV). Consequently, these compounds have been widely used as excellent antimicrobial lipids. According to the literature, the antimicrobial, antifungal, and antivirus properties can be attributed to the destruction of the cell membrane in bacteria, fungi, and viruses due to both hydrogen and hydrophobic interaction between antibacterial lipid compounds with functional groups present in the membrane. In conclusion, the antimicrobial effect of VCO is strongly associated with the presence of lauric acid and monolaurin as saturated medium-chain fatty acid and monoglyceride, respectively.

Conflicts of Interest

The authors declare no conflict of interest.

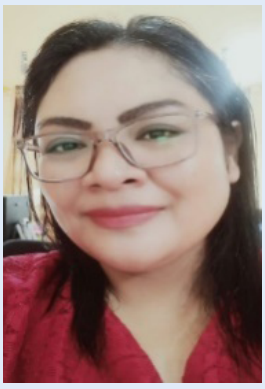


Febri Odel Nitbani completed her B.Sc. in organic chemistry at Gadjah Mada University in 2003. She obtained her M.Sc. at Gadjah Mada University in 2007 with research on the synthesis of epoxide compounds from methyl ricinoleate (isolated from castor oil). In 2017, she completed her doctoral studies on monoglyceride compounds synthesized from coconut oil at Gadjah Mada University. Currently, she is an Associate Professor at the Chemistry Department, Faculty of Science and Engineering, Universitas Nusa Cendana in Kupang. Her research is focused on the synthesis of monoglycerides and other derivatives from vegetable oils with antimicrobial properties and the development of surfactant compounds from vegetable oils.

Putra Jiwamurwa Pama Tjitda obtained his undergraduate degree in chemistry at the University of Nusa Cendana in 2012. He received his M.Sc. from Gadjah Mada University, Yogyarkata, Indonesia in 2015. His Master's research project was on the synthesis and antibacterial test of N1-hydrogen and N1-benzoyl pyrazoline from vanillin and veratraldehyde. Currently, he is a lecturer at the Department of Pharmacy, Health Polytechnic of Kupang. His research focuses on the utilization of the natural product for sunscreen agents, synthesis of organic compounds, QSAR, and molecular docking.

Fidelis Nitti completed his undergraduate degree in chemistry at the University of Nusa Cendana (Indonesia) in 2008. In 2021, he obtained his Ph.D. from the School of Chemistry, The University of Melbourne, Australia. His Ph.D. research was on the development of flow-through devices for passive sampling of zinc(II) in aquatic systems free from environmental effects. His current and main research interests include separation chemistry, polymer inclusion membrane, passive sampling, and paper-based analytical devices. He is currently a lecturer at the Department of Chemistry, University of Nusa Cendana in Kupang, Indonesia.

Jumina received his Ph.D. degree in Organic Chemistry from the University of New South Wales, Sydney-Australia in 1997. He has been working as a lecturer in the Department of Chemistry, Faculty of Mathematics and Natural Science, Universitas Gadjah Mada, Yogyakarta-Indonesia since 1989 and was appointed as a full professor in the same department in 2008. His research field is organic synthesis with a particular interest in drug development and medicinal chemistry.



Annytha I. R. Detha obtained her Ph.D. in Public Health Veterinary from IPB University in 2014. Her doctoral study was on the characteristics of antimicrobial compounds in mare's milk protein. Currently, she is an associate professor in Public Health Veterinary at the Faculty of Veterinary Medicine, Universitas Nusa Cendana. Her research focuses on the characteristics of antimicrobial compounds against pathogenic bacteria in animal diseases.

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References

[1] A. G. Krishna, *Inform* **2012**, *23 (6)*, 395–399.
[2] P. Shankar, S. Ahuja, A. Tracchio, *Agro Food Ind. Hi-Tech.* **2014**, *24 (5)*, 62–64.
[3] F. M. Dayrit, *J. Am. Oil Chem. Soc.* **2014**, *92 (1)*, 1–15. DOI: https://doi.org/10.1007/S11746-014-2562-7
[4] F. O. Nitbani, Jumina, D. Siswanta, E. N. Solikhah, *Procedia Chem.* **2016**, *18*, 132–140. DOI: https://doi.org/10.1016/j.proche.2016.01.021
[5] H. Hilmarsson, L. V. Larusson, *Arch. Virol.* **2006**, *151 (6)*, 1217–1224. DOI: https://doi.org/10.1007/S00705-005-0699-2
[6] S. Lieberman, M. G. Enig, H. G. Preuss, *Altern. Complementary Ther.* **2006**, *12 (6)*, 310–314. DOI: https://doi.org/10.1089/ACT.2006.12.310
[7] https://archium.ateneo.edu (accessed on September 26, 2021)
[8] S. Suryani, S. Sariani, F. Earnestly, M. Marganof, R. Rahmawati, S. Sevindrajuta, T. M. I. Mahlia, A. Fudholi, *Processes* **2020**, *8 (4)*, 402. DOI: https://doi.org/10.3390/PR8040402
[9] S. Kumalaningsih, M. Padaga, *J. Basic Appl. Sci. Res.* **2012**, *2 (3)*, 2286–2290.
[10] S. Neela, N. B. Prasad, *Asian J. Food Agro-Ind.* **2012**, *5 (5)*, 355–363.
[11] S. Redjeki, E. Kurniati, *J. Tek. Kim.* **2013**, *8 (1)*, 27–32.
[12] A. M. Marina, W. I. W. Rosli, S. L. Neoh, *Sains Malaysiana* **2014**, *43 (9)*, 1311–1315.
[13] Y. C. Wong, H. Hartina, *Orient. J. Chem.* **2014**, *30 (1)*, 2237–245. DOI: https://doi.org/10.13005/ojc/300129

[14] S. Harimurti, R. M. Rumagesan, Susanawati, *IOP Conf. Ser. Mater. Sci. Eng.* **2020**, *874*, 012004.
[15] B. Chen, L. L. Diosady, *Int. J. Appl. Sci. Eng.* **2003**, *1 (1)*, 55–61.
[16] R. Khathir, R. Agustina, S. Hartuti, Z. Fahmi, *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *425*, 012068.
[17] E. Carandang, *Indian Coconut J.* **2008**, *31*, 1–12.
[18] M. Shilling, L. Matt, E. Rubin, M. P. Visitacion, N. Haller, S. Grey, C. Woolverton, *J. Med. Food* **2013**, *16 (12)*, 1079–1085. DOI: https://doi.org/10.1089/JMF.2012.0303
[19] S. Nagase, M. Matsue, Y. Mori, M. Honda-Ogawa, K. Sugitani, *J. Wellness Heal Care* **2017**, *41 (1)*, 87–95. DOI: https://doi.org/10.24517/00048862
[20] L. Margata, J. Silalahi, U. Harahap, D. Suryanto, D. Satria, *Rasayan J. Chem.* **2019**, *12 (2)*, 987–993. DOI: https://doi.org/10.31788/RJC.2019.1225113
[21] D. C. Widianingrum, C. T. Noviandi, S. I. O. Salasia, *Heliyon* **2019**, *5 (10)*, 1–5. DOI: https://doi.org/10.1016/J.HELIYON.2019.E02612
[22] F. O. Nitbani, D. Siswanta, E. N. Sholikhah, *Int. J. Pharm. Sci. Rev. Res.* **2016**, *39 (16)*, 74–80.
[23] F. O. Nitbani, Jumina, in *Apolipoproteins, Triglycerides and Cholesterol* (Eds: V. Y. Waisundara, M. Z. Jovandaric), IntechOpen, London **2020**, 5.
[24] S. Kappally, A. Shirwaikar, A. Shirwaikar, *Hygeia* **2015**, *7 (2)*, 34–41. DOI: https://doi.org/10.15254/H.J.D.Med.7.2015.149
[25] N. Shah, B. Limketkai, *Nutr. Issues Gastroenterol.* **2017**, *160 (2017)*, 20–28.
[26] R. M. Venkateswar, G. Kumar, G. Mohanakrishna, S. Shobana, R. I. Al-Raoush, *Bioresour. Technol.* **2020**, *309*, 123400. DOI: https://doi.org/10.1016/J.BIORTECH.2020.123400
[27] F. O. Nitbani, Jumina, D. Siswanta, E. N. Solikhah, *Int. J. Pharm. Sci. Rev. Res.* **2015**, *35 (1)*, 126–136.
[28] S. Jadhav, S. Shirame, S. Kulkarni, S. B. Patil, S. K. Pasale, R. B. Bhosale, *Bioorganic Med. Chem. Lett.* **2013**, *23 (9)*, 2575–2578. DOI: https://doi.org/10.1016/j.bmcl.2013.02.105
[29] O. Ubgogu, R. Onyeagba, O. Chigbu, *African J. Biotechnol.* **2009**, *5 (11)*, 1045–1047. DOI: https://doi.org/10.4314/ajb.v5i11.42962
[30] J. Silalahi, L. K. Karo, S. M. Sinaga, Y. C. E. Silalahi, *Indones. J. Pharm. Clin. Res.* **2018**, *1 (2)*, 1–8. DOI: https://doi.org/10.32734/idjpcr.v1i2.605
[31] F. O. Nitbani, Jumina, D. Siswanta, E. N. Solikhah, *Procedia Chem.* **2016**, *18*, 132–140. DOI: https://doi.org/10.1016/j.proche.2016.01.021
[32] F. O. Nitbani, P. J. P. Tjitda, B. A. Nurohmah, H. E. Wogo, *J. Oleo Sci.* **2020**, *69 (4)*, 277–295. DOI: https://doi.org/10.5650/jos.ess19168
[33] G. Bergsson, O. Steingrímsson, H. Thormar, *Int. J. Antimicrob. Agents* **2002**, *20 (4)*, 258–262. DOI: https://doi.org/10.1016/S0924-8579(02)00205-4
[34] T. Thormar, H. Hilmarsson, *Chem. Phys. Lipids* **2007**, *150 (1)*, 1–11. DOI: https://doi.org/10.1016/J.CHEMPHYSLIP.2007.06.220
[35] T. Nakatsuji, M. C. Kao, J. Fang, C. C. Zouboulis, R. L. Gallo, C. M. Huang, *J. Invest. Dermatol.* **2009**, *129 (10)*, 2480–2488. DOI: https://doi.org/10.1038/jid.2009.93.Antimicrobial
[36] A. Desbois, V. Smith, *Appl. Microbiol. Biotechnol.* **2010**, *85 (6)*, 1629–1642. DOI: https://doi.org/10.1007/S00253-009-2355-3
[37] C. L. Fischer, D. R. Drake, D. V. Dawson, D. R. Blanchette, K. A. Brogden, P. W. Wertz, *Antimicrob. Agents Chemother.* **2012**, *56 (3)*, 1157–1161. DOI: https://doi.org/10.1128/AAC.05151-11
[38] A. A. Anzaku, J. L. Akyala, A. Juliet, E. C. Obianuju, *Ann. Clin. Lab. Res.* **2017**, *5 (2)*, 1–5. DOI: https://doi.org/10.21767/2386-5180.1000170
[39] M. Matsue, Y. Mori, S. Nagase, Y. Sugiyama, R. Hirano, K. Ogai, K. Ogura, S. Kurihara, S. Okamoto, *Cell Transplant.* **2019**, *28 (12)*, 1528–1541. DOI: https://doi.org/10.1177/0963689719881366
[40] J. Huang, Z. Yang, F. Guan, S. Zhang, D. Cui, G. Guan, Y. Li, *Process Biochem.* **2013**, *48 (12)*, 1899–1904. DOI: https://doi.org/10.1016/J.PROCBIO.2013.08.021
[41] T. Q. M. Tran, M. F. Hsieh, K. L. Chang, Q. H. Pho, V. C. Nguyen, C. Y. Cheng, C. M. Huang, *Polymers* **2016**, *8 (9)*, 321. DOI: https://doi.org/10.3390/POLYM8090321
[42] T. Kitahara, N. Koyama, J. Matsuda, Y. Aoyama, Y. Hirakata, S. Kamihira, S. Kohno, M. Nakashima, H. Sasaki, *Biol. Pharm. Bull.* **2004**, *27 (9)*, 1321–1326. DOI: https://doi.org/10.1248/BPB.27.1321
[43] J. A. Kelsey, K. W. Bayles, B. Shafii, M. A. McGuire, *Lipids* **2005**, *41 (10)*, 951–961. DOI: https://doi.org/10.1007/S11745-006-5048-Z
[44] P. Tangwatcharin, P. Khopaibool, *Shoutheast Asian J. Trop. Med. Public Heal.* **2012**, *43 (4)*, 969–985.
[45] G. Bergsson, J. Arnfinnsson, O. Steingrímsson, H. Thormar, *APMIS* **2001**, *109 (10)*, 670–678. DOI: https://doi.org/10.1034/J.1600-0463.2001.D01-131.X
[46] J. Kabara, D. Swieczkowski, A. Conley, J. Truant, *Antimicrob. Agents Chemother.* **1972**, *2 (1)*, 23–28. DOI: https://doi.org/10.1128/AAC.2.1.23
[47] J. Kinderlerer, H. Matthias, P. Finner, *J. Dairy Res.* **1996**, *63 (4)*, 593–606. DOI: https://doi.org/10.1017/S0022029900032131
[48] B. W. Petschow, R. P. Batema, L. L. Ford, *Antimicrob. Agents Chemother.* **1996**, *40 (2)*, 302–306.
[49] C. Sun, C. O'Connor, A. Roberton, *FEMS Immunol. Med. Microbiol.* **2003**, *36 (1)*, 9–17. DOI: https://doi.org/10.1016/S0928-8244(03)00008-7
[50] E. Skrivanová, M. Marounek, D. Dlouhá, J. Kanka, *Lett Appl Microbiol.* **2005**, *41 (1)*, 77–81. DOI: https://doi.org/10.21767/2386-5180.1000170
[51] E. Skrivanova, M. Marounek, V. Benda, P. Brezina, *Vet. Med.* **2006**, *51 (3)*, 81–88. DOI: https://doi.org/10.17221/5524-VETMED
[52] K. Devan, F. Peedikayil, T. Chandru, S. Kottayi, N. Dhanesh, K. Suresh, *J. Indian Soc. Pedod. Prev. Dent.* **2019**, *37 (3)*, 258–264. DOI: https://doi.org/10.4103/JISPPD.JISPPD_63_19
[53] C. Churchward, R. Alany, L. A. Snyder, *Crit. Rev. Microbiol.* **2018**, *44 (5)*, 561–570. DOI: https://doi.org/10.1080/1040841X.2018.1467875
[54] P. Hovorková, K. Laloučková, E. Skřivanová, *Czech J. Anim. Sci.* **2018**, *63 (3)*, 119–125. DOI: https://doi.org/10.17221/70/2017-CJAS

[55] B. K. Yoon, J. A. Jackman, E. R. Valle-González, N. J. Cho, *Int. J. Mol. Sci.* **2018**, *19 (4)*, 1–40. DOI: https://doi.org/10.3390/ijms19041114

[56] M. Takahashi, S. Inoue, K. Hayama, K. Ninomiya, S. Abe, *Med.Mycol.J.* **2012**, *53 (4)*, 255–261. DOI: https://doi.org/10.3314/MMJ.53.255

[57] L. D. Tjin, A. S. Setiawan, E. Rachmawati, *Padjadjaran J.Dent.* **2016**, *28 (2)*, 89–94. DOI: https://doi.org/10.24198/PJD.VOL28NO2.13718

[58] C. Altieri, D. Cardillo, A. Bevilacqua, M. Sinigaglia, *J.Food Prot.* **2007**, *70 (5)*, 1206–1212. DOI: https://doi.org/10.4315/0362-028X-70.5.1206

[59] C. Altieri, A. Bevilacqua, D. Cardillo, M. Sinigaglia, *Int. J. Food Sci. Technol.* **2009**, *44 (4)*, 242–245. DOI: https://doi.org/10.1111/j.1365-2621.2007.01639

[60] H. Thormar, C. Isaacs, H. Brown, M. Barshatzky, T. Pessolano, *Antimicrob. Agents Chemother.* **1987**, *31 (1)*, 27–31. DOI: https://doi.org/10.1128/AAC.31.1.27

[61] B. Hornung, E. Amtmann, G. Sauer, *J. Gen. Virol.* **1994**, *75 (2)*, 353–361. DOI: https://doi.org/10.1099/0022-1317-75-2-353

[62] C. Isaacs, R. Litov, H. Thormar, *J. Nutr. Biochem.* **1995**, *6 (7)*, 362–366. DOI: https://doi.org/10.1016/0955-2863(95)80003-U

[63] H. Hilmarsson, T. Kristmundsdóttir, H. Thormar, *APMIS* **2005**, *113 (1)*, 58–65. DOI: https://doi.org/10.1111/J.1600-0463.2005.APM1130109.X

[64] S. Bartolotta, C. García, N. Candurra, E. Damonte, *Arch. Virol.* **2001**, *146 (4)*, 777–790. DOI: https://doi.org/10.1007/S007050170146

[65] G. Widiyarti, M. Hanafi, W. P. Soewarso, *Indones J. Chem.* **2010**, *9 (1)*, 99–106. DOI: https://doi.org/10.22146/ijc.21569

[66] F. O. Nitbani, Jumina, D. Siswanta, E. Solikhah, D. Fitriastuti, *Orient. J. Chem.* **2018**, *34 (2)*, 863–867. DOI: https://doi.org/10.13005/ojc/340233

[67] A. Z. Abdullah, Z. Gholami, M. Ayoub, F. Gholami, *Chem. Eng. Commun.* **2016**, *203 (4)*, 496–504. DOI: https://doi.org/10.1080/00986445.2015.1039120

[68] P. Lozano, C. Gomez, S. Nieto, G. Sanchez-Gomez, E. García-Verdugo, S. V. Luis, *Green Chem.* **2017**, *19 (2)*, 390–396. DOI: https://doi.org/10.1039/c6gc01969b

[69] A. Mustafa, A. Karmali, W. Abdelmoez, *J. Clean. Prod.* **2016**, *137 (2016)*, 953–964. DOI: https://doi.org/10.1016/j.jclepro.2016.07.056

[70] F. O. Nitbani, Jumina, D. Siswanta, E. N. Sholikhah, D. Fitriastuti, *Orient. J. Chem.* **2016**, *32 (6)*, 3113–3120. DOI: https://doi.org/10.13005/ojc/320632

[71] F. O. Nitbani, Jumina, P. J. P. Tjitda, H. E. Wogo, A. I. R. Detha, B. A. Nurohmah, *AIP Conf. Proc.* **2021**, *2370*, 060005.

[72] A. Ruzin, R. Novick, *J. Bacteriol.* **2000**, *182 (9)*, 2668–2671. DOI: https://doi.org/10.1128/JB.182.9.2668-2671.2000

[73] L. Buňková, F. Buňka, R. Janiš, J. Krejčí, I. Doležálková, Z. Pospíšil, J. Růžička, B. Tremlová, *Acta Vet. Brno* **2011**, *80 (1)*, 29–39. DOI: https://doi.org/10.2754/AVB201180010029

[74] P. Schlievert, M. Peterson, *PLoS One* **2012**, *7 (7)*, e40350. DOI: https://doi.org/10.1371/JOURNAL.PONE.0040350

[75] H. J. Hess, M. J. Henry-Stanley, C. L. Wells, *Antimicrob. Agents Chemother.* **2014**, *58 (11)*, 6970–6973. DOI: https://doi.org/10.1128/AAC.03672-14

[76] J. Růžička, K. Velclová, R. Janiš, J. Krejčí, *Eur. Food Res. Technol.* **2003**, *217 (4)*, 329–331. DOI: https://doi.org/10.1007/s00217-003-0764-6

[77] H. Zhang, H. Wei, Y. Cui, G. Zhao, F. Feng, *J. Food Sci.* **2009**, *74 (7)*, 418–421. DOI: https://doi.org/10.1111/j.1750-3841.2009.01300.x

[78] A. M. Zare, R. S. M. Rohani, M. Raeisi, J. S. H. Hosseini, M. Hashemi, *J. Food Qual. Hazards Control* **2014**, *1 (2)*, 52–55.

[79] D. Botovska, I. Todorova, H. Najdenski, I. Tsvetkova, *Pol. J. Microbiol.* **2009**, *58 (1)*, 43–47. DOI: https://doi.org/10.3390/molecules2420377

[80] A. Krislee, C. Fadly, D. A. A. Nugrahaningsih, T. Nuryastuti, F. O. Nitbani, Jumina, E. N. Sholikhah, *BMC Proc.* **2019**, *13 (11)*, 19. DOI: https://doi.org/10.1186/S12919-019-0174-9

[81] C. Mochtar, E. N. Sholikhah, D. A. Nugrahaningsih, T. Nuryastuti, F. O. Nitbani, Jumina, *Int. J. Pharm. Res.* **2020**, *13 (1)*, 550–560. DOI: https://doi.org/10.31838/ijpr/2021.13.01.096

[82] L. N. Cotton, D. L. Marshall, *Food Sci. Technol.* **1997**, *30 (8)*, 830–833. DOI: https://doi.org/10.1006/fstl.1997.0281

[83] P. Schlievert, S. Kilgore, K. Seo, D. Y. Leung, *Sci. Rep.* **2019**, *9 (1)*, 14550. DOI: https://doi.org/10.1038/s41598-019-51130-y

[84] C. Q. Sun, C. J. O'Connor, A. K. H. MacGibbon, A. M. Roberton, *FEMS Immunol. Med. Microbiol.* **2007**, *49 (2)*, 235–242. DOI: https://doi.org/10.1111/j.1574-695X.2006.00185.x

[85] L. Lopes, C. Santos, R. D. A. Vaucher, L. Gende, R. P. Raffin, R. C. Santos, *Microb. Pathog.* **2016**, *97 (2016)*, 183–188. DOI: https://doi.org/10.1016/J.MICPATH.2016.05.014

[86] D. Seleem, E. Chen, B. Benso, V. Pardi, R. M. Murata, *PeerJ* **2016**, *4 (6)*, 1–17. DOI: https://doi.org/10.7717/PEERJ.2148

[87] D. Seleem, V. S. Freitas-Blanco, J. Noguti, B. R. Zancop, V. Pardi, R. M. Murata, *Biol. Pharm. Bull.* **2018**, *41 (8)*, 1299–1302. DOI: https://doi.org/10.1248/bpb.b18-00256

[88] Z. Řiháková, M. Plocková, V. Filip, J. Šmidrkal, *Eur. Food Res. Technol.* **2001**, *213 (6)*, 488–490. DOI: https://doi.org/10.1007/S002170100416

[89] J. Welch, J. Xiang, C. Okeoma, P. M. Schlievert, J. T. Stapleton, *Am. Soc. Microbiol.* **2020**, *11 (3)*, 1–17.

[90] E. Subroto, R. Indiarto, *Food Res.* **2020**, *4 (6)*, 2355–2365. DOI: https://doi.org/10.26656/fr.2017.4%286%29.324

[91] H. G. Preuss, O. I. Aruoma, *J. Am. Coll. Nutr.* **2021**, *40 (2)*, 95–97. DOI: https://doi.org/10.1080/07315724.2020.1779554

[92] I. Angeles-Agdeppa, J. S. Nacis, M. V. Capanzana, F. M. Dayrit, K. V. Tanda, *J. Funct. Foods.* **2021**, *83 (2021)*, 104557. DOI: https://doi.org/10.1016/j.jff.2021.104557

[93] B. Carpo, V. Verallo-Rowell, J. Kabara, *J. Drugs Dermatol.* **2007**, *6 (10)*, 991–998.

[94] E. London, in *Encyclopedia of Biological Chemistry*, 2nd Ed., Elsevier, Amsterdam **2013**, 733–735.

[95] N. Chinatangkul, C. Limmatvapirat, J. Nunthanid, M. Luangtana-Anan, P. Sriamornsak, S. Limmatvapirat, *Asian J. Pharm. Sci.* **2018**, *13 (5)*, 459–471. DOI: https://doi.org/10.1016/J.AJPS.2017.12.006

[96] J. Parsons, J. Yao, M. Frank, P. Jackson, C. Rock, *J. Bacteriol.* **2012**, *194 (19)*, 5294–5304. DOI: https://doi.org/10.1128/JB.00743-12

[97] J. Romaniuk, L. Cegelski, *Philos. Trans. R. Soc. B* **2015**, *370 (1679)*, 20150024. DOI: https://doi.org/10.1098/RSTB.2015.0024

[98] S. Porfírio, R. W. Carlson, P. Azadi, *Trends Microbiol.* **2019**, *27 (7)*, 653–654. DOI: https://doi.org/10.1016/j.tim.2019.04.007

[99] G. Soares, L. Figueiredo, M. Faveri, S. Cortelli, P. Duarte, M. Feres, *J. Appl. Oral Sci.* **2012**, *20 (3)*, 295–305. DOI: https://doi.org/10.1590/S1678-77572012000300002

[100] D. Sanglard, A. Coste, S. Ferrari, *FEMS Yeast Res.* **2009**, *9 (7)*, 1029–1050. DOI: https://doi.org/10.1111/J.1567-1364.2009.00578.X

[101] P. Vandeputte, S. Ferrari, A. T. Coste, *Int. J. Microbiol.* **2012**, 2012, 713687. DOI: https://doi.org/10.1155/2012/713687

[102] R. Prasad, A. H. Shah, M. K. Rawal, *Adv. Exp. Med. Biol.* **2016**, *892 (2016)*, 327–349. DOI: https://doi.org/10.1007/978-3-319-25304-6_14

[103] J. Hierholzer, J. Kabara, *J. Food Saf.* **1982**, *4 (1)*, 1–12. DOI: https://doi.org/10.1111/J.1745-4565.1982.TB00429.X

Virgin coconut oil (VCO) is a functional edible oil, rich with lauric acid. VCO can be converted into partial lipids, i.e., lauric acid, 1-monolaurin, and 2-monolaurin by lipase in the digestive system. These compounds are known as antimicrobial lipids based on their excellent activity in inhibiting the growth of broad-spectrum microbial. The inhibition mechanism of lauric acid and monolaurin as antibacterial, antifungal, and antiviral agents is also discussed

Antimicrobial Properties of Lauric Acid and Monolaurin in Virgin Coconut Oil: A Review

Febri Odel Nitbani*,
Putra Jiwamurwa Pama Tjitda,
Fidelis Nitti, Jumina,
Annytha Ina Rohi Detha

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