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CRITICAL REVIEW

A comprehensive review on the techniques for coconut oil extraction and its application

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Abstract

Virgin coconut oil is a useful substance in our daily life. It contains a high percentage of lauric acid which has many health benefits. The current industry has developed several methods to extract the oil out from the coconut fruit. This review paper aims to highlight several common extraction processes used in modern industries that includes cold extraction, hot extraction, low-pressure extraction, chilling, freezing and thawing method, fermentation, centrifugation, enzymatic extraction and supercritical fluid carbon dioxide. Different extraction methods will produce coconut oil with different yields and purities of lauric acid, thus having different uses and applications. Challenges that are faced by the industries in extracting the coconut oil using different methods of extraction are important to be explored so that advancement in the oil extraction technology can be done for efficient downstream processing. This study is vital as it provides insights that could enhance the production of coconut oil.

Keywords Virgin coconut oil · Lauric acid · Extraction process · Application

Introduction

Coconut is one of the most important tree crops in the tropical region of the world securing food and shelter for millions of people. Coconut tree is grown in more than 93 countries around the world in an area of 11.95 million hector producing 57,510 million coconuts annually [1]. Virgin coconut oil (VCO) was introduced to the world at the end of twentieth century. It is being considered as the greatest value derived from the fresh coconut [2]. VCO becomes one of the most prominent high-value coconut products in coconut producing countries because of its versatility. VCO gains worldwide popularity because of its wide range of applications in medication, food, cosmetics and hair care products [3]. VCO is a clear, high value oil obtained from the fresh mature kernel of coconut through mechanical or natural means [4]. Various methods have been employed to extract the coconut oil, but whichever method have been used it is still the best to avoid oil that has been refined, bleached or deodourized. This is because when the coconut oil undergo these processes, the health benefit, taste and the aroma will be reduced [3, 5]. As VCO contains large amount of high value compounds, its importance has been given more and more attention by the industry throughout the years. This results in the development of various extraction processes,

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each with its respective advantages and limitations. Therefore, it is crucial for the industry to choose the most suitable extraction process to avoid breaking down of the high value compounds.

VCO is believed to have medical qualities, including but not limited to antifungal, antioxidant, antibacterial, antiviral, hepatoprotective, low glycaemic index and immune system enhancement [6]. Coconut oil comprises 90–95% of saturated fatty acid [7]. Unlike long-chain fatty acid found in plant-based oil, medium-chain fatty acid is smaller in size, allowing higher cell permeability for immediate energy conversion instead of being stored as fat. When compared with long-chain fatty acids found in plant-based oil, medium-chain fatty acid can also be digested more easily and at the same time it is also antimicrobial and antifungal [8]. VCO contains 2.6% less calories as compared to other fats as it provides various health benefits to human body [9]. It helps in controlling blood sugar level as it preserves insulin action and insulin resistance. VCO also helps in preventing liver disease by reversing hepatosteatosis which is a type of fatty liver disease [10, 11]. Moreover, coconut oil also plays important roles in hair care and cosmetic products. When compared with mineral oils, it penetrates better to the dry and fizzy hair giving a shinier look of the hair due to the smaller particle sizes of VCO [12]. VCO is found to be a powerful antioxidant product which serve to fight against free radicals in the human body as it helps to slow down the ageing process [11].

The most popular traditional method of oil extraction are cold extraction and hot extraction process. The challenges faced by these two processes include low yield of oil and the heating process in the hot extraction technique will cause a reduction in the antioxidant properties in oil. Since the last decade, several extraction techniques have been introduced with the aim to improve the technology for coconut oil extraction. Table 1 shows the summary of various techniques available for coconut oil extraction. This review aims to let reader understand the difference between various extraction method of coconut oil and the applications of VCO. This paper will discuss various extraction processes in depth, including its respective advantages and limitations. The daily and industrial application of VCO will also be included in the end of this paper as well.

Properties of coconut oil

Physical properties

Coconut oil is a colourless liquid at a temperature of 30 °C and above. It will be solidified at a temperature of 25 °C. Solidified coconut oil is white in colour. Unrefined coconut oil reaches its smoking point at a temperature of 170 °C while refined coconut oil reaches its smoking point at 232 °C [32]. Coconut oil has a typical coconut smell to it only if it is not refined, bleached or deodourized. Coconut oil will form a white homogenous mixture when mixed with water and agitated. Without agitation, coconut oil will be insoluble in water. Coconut oil has a density of 924.27 kg/m^3 [33]. The density of an oil depends on its saponification value (molecular weight), iodine value (unsaturation), free fatty acid content, water content and temperature. Density of triglycerides in solid state is approximately 10% greater than in liquid state. However, there is no specific data that was reported on the specific heat for coconut oil. It is known that when in solid state, there is little change in the specific heat as the molecular weight varies. With the rise of iodine value, the specific heat of coconut oil will also be increased. Whereas in liquid state, the specific heat increases slightly with molecular weight but decreases with iodine value. Coconut oil shows the flow behaviour of true Newtonian liquids. When close to the melting point of coconut oil, non-Newtonian behaviour may occur due to the presence of fat crystals. Viscosity increases with molecular weight, but decreases with increasing unsaturation and temperature [5].

Chemical properties

The main composition in coconut oil is saturated fatty acids which is around 94%, with approximately 62% medium fatty acid [33]. Coconut oil contains of mainly saturated triglycerides, with medium chain acid which is lauric and myristic predominating [34]. Triglycerides oils are made predominantly of C_8 (caprylic) and C_{10} (capric) fatty acids which both of the acids are classified as medium-chain fatty acids, whereas the main fatty acid in coconut oil, lauric acid (C_{12}), can be classified as either medium-chain fatty acid or long-chain fatty acid. In terms of digestion, lauric acid behaves more like a long-chain fatty acid due to majority (70–75%) of it being absorbed with chylomicrons in comparison with 95% of medium-chain fatty acids are absorbed directly into the portal vein. Medium-chain fatty acids are weak electrolytes and are highly ionized at neutral pH which increases their solubility. This marks the difference in solubility that occurs at chain lengths of C:10 and less, which excludes lauric acid [35]. In a 100 g sample, there is 41.84 g of C_{12} (lauric) saturated fatty acid, 16.65 g of C_{14} (myristic) saturated fatty acid, 8.64 g of C_{16} (palmitic) saturated fatty acid, 6.80 g of C_8 (caprylic) saturated fatty acid and 2.52 g of C_{18} (stearic) saturated fatty acid [32]. The moisture content in the coconut oil extracted varies with the extraction method used to obtain the coconut oil. For example, coconut oil obtained from dried coconut copra will have significantly lower water content than that obtained from fresh coconut copra. Oil extracted by methods involving heating will also have less moisture content than those that was not exposed to

Table 1 Summary of various extraction methods of coconut oil

Method	Brief description	Advantages	Disadvantages	References
Cold Extraction Process	Chilling coconut milk and extracting solid phase then centrifuging to obtain oil	Reduction of production cost	Low yield	[13–15]
Hot Extraction Process	Coconut milk is heated and passed through a muslin cloth	Better hypolipidemic effect	Heated above 40 °C thus antioxidant properties reduced	[16–18]
Low Pressure Extraction	Coconut meat dried and placed into a low-pressure fabricated manual press then sent to centrifugation	By-products of this process may be used as fuel	Higher capital cost needed	[19]
Chilling, Freezing and Thawing	Coconut milk chilled to below 0 °C and warmed back to 25 °C then subject the cream to centrifugation process	Not heated above 40 °C thus antioxidant properties not reduced	Operating cost high as temperature needs to be reduced to below 0 °C	[13, 20]
Natural Fermentation	Hot water is added to coconut milk before container is covered and left for two days	Less effort is needed Maintains its natural flavour Nutrients retained	Requires long extraction time	[21]
Induced Fermentation	Microorganisms is mixed with coconut milk	Simple process High yield	Reduction in quality of coconut oil Long extraction time Fermented odour	[13, 22, 23]
Centrifugation	Coconut milk placed in centrifuge tube and centrifuged	Short period of time needed	Low yield	[13, 20]
Enzymatic Extraction	Mixing different types of enzymes into coconut milk	High yield	Enzymes very specific, may be hard to obtain	[24–27]
Supercritical Fluid Carbon Dioxide	Dried grated coconut meat charged with continuous flow of carbon dioxide	No heat involved	Apparatus needs to be able to withstand supercritical fluid, thus capital cost may increase	[28, 29]
Expeller Pressing	Coconut fruit squeezed by expeller	Able to use coconut fruit or coconut meat as raw feed	Lower yield	[16, 19, 30]
Wet Mill Method	Coconut milk used is not dried prior to extraction and is paired with other methods mentioned above	Can be used with other methods to combine advantages of both methods	Yield and purity depend on method paired with	[31]

heat. Among those vegetable oil used by consumers, coconut oil is slow to oxidize thus resistant to rancidity, resulting in a longer shelf life [33]. Table 2 shows the fatty acids compositions in coconut oil.

Nutrition value

In terms of the nutrition value, coconut oil contains 892 kcal of energy per 100 g, equivalent to 3730 kJ per 100 g. A total of 99.06 g of fat was found in a sample of 100 g of coconut oil. Coconut oil also contains 1 mg of calcium, 0.05 mg iron, 0.02 mg of zinc and 0.3 mg choline. In a 100 g sample, 0.11 mg of vitamin E was found [32]. Calcium is needed for humans to grow and maintain strong bones and teeth. Iron is essential for the formation of blood due to its function as oxygen carriers in red blood cells, while zinc is essential for the synthesis and stabilization of enzymes, proteins and genetic materials. Choline is important when it comes to the transmitting of nerve impulses as it is involved in the synthesis of neurotransmitters. Vitamin E is an antioxidant and it helps to keep the immune system strong [37].

Extraction techniques

Cold extraction process

Cold extraction process is a process where coconut oil is extracted from coconut milk without involving any heating processes to break the emulsion [13]. The fibrous outer husk of matured coconuts is removed to obtain the white coconut meat within the fruit. The reason to why matured coconuts is chosen over young coconuts is that the oil content in the fruit will increase when the fruit matures. The leftover solids in the mesh bag is the fibre of the coconut which can be dried and used in many other places [38]. Figure 1 illustrates the overall process of cold extraction technique. Benefits of this process includes reducing production cost as it does not require solvents and refining processes, such as deodourizing and bleaching. This also results in the reduction in the required amount of energy thus making this process more environmentally friendly. Furthermore, when the coconut oil is refined, phytonutrients and polyphenols within the oil will be lost. These components contribute to many health benefits, such as cancer prevention and anti-inflammatory properties [38]. However, the demerits of this cold extraction process is that the yield of coconut oil will be lower as compared to other methods of extraction [38]. Owing to the high tendency of manually cold pressed virgin coconut oil to

Table 2 Fatty acid contents of coconut oil [5, 36]

Acid name	Percentage by Malaysian standard (%)	Percentage by APCC standard (%)	Percentage by Codex standard (%)	Rough approximation (%)
Lauric acid (C_{12})	47.00–50.00	43.00–53.00	45.10–53.20	52
Myristic acid (C_{14})	17.00–18.50	16.00–21.00	16.80–21.00	19
Caprylic acid (C_8)	8.00–9.00	5.00–10.00	4.60–10.00	9
Palmitic acid (C_{16})	7.50–9.50	7.50–10.00	7.50–10.20	–
Capric acid (C_{10})	5.00–7.00	4.50–8.00	5.00–8.00	10
Stearic acid (C_{18}:1)	4.50–6.00	5.00–10.00	5.00–10.00	–
Stearic acid (C_{18}:0)	2.50–3.50	2.00–4.00	2.00–4.00	–
Caproic acid (C_6)	0.80–0.95	0.40–0.60	nd–0.70	–
Stearic acid (C_{18}:2)	0.70–2.50	1.00–2.50	1.00–2.50	–

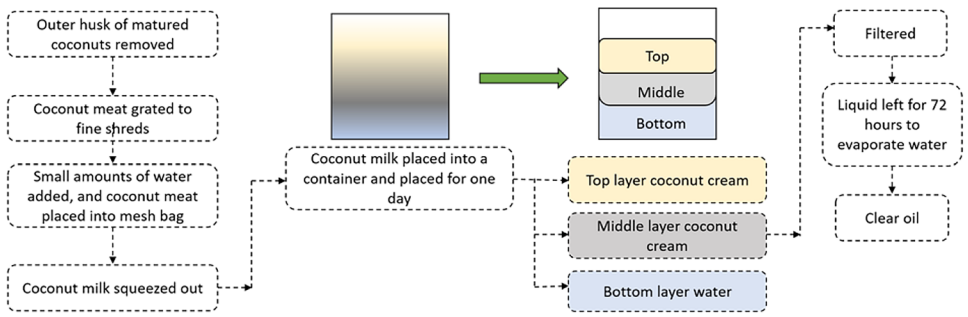

Fig. 1 Overall process of coconut extraction using cold extraction techniques

skip the killing step, an extra step was proposed to be introduced in the cold pressing extraction process. This step is to heat the coconut oil mildly or to use Ultraviolet-C(UV-C) irradiation rays to kill off *Salmonella enterica* found in the virgin coconut oil extracted. The logarithmic linear population of this pathogen has decreased by 2.07–2.39 log CFU/mL when the coconut oil was heated to 50–70 °C. After this an inactivation tail followed where the decrease in microbial population was minimal. The total inactivated cells ranged from 2.28 to 2.35 log CFU/mL by using this method when the sample was treated for 2 min to 100 min. However, by introducing heat into coconut oil, the antioxidant properties of coconut oil will be reduced, thus the effects of introducing UV-C irradiation rays were tested. By introducing UV-C irradiation at 1.25–3.99 mW/cm^2, similar behaviour was observed. The microbial population decreased in log-linear inactivation phase for 2.59 log CFU/mL when the sample was exposed to irradiation for 0.33 min and 4 log CFU/mL when the sample was exposed for 1.2 min. When the sample was exposed for more than 2 min, the total inactivated population started to range from 2.68 to 4.17 log CFU/mL. *Salmonella enterica* was not completely eliminated by using these methods however the result from this study provided baseline information for ensuring the safety of coconut oil [39].

Hot extraction process

Hot extraction process is an extraction process that involves heat. This heating step however will reduce the antioxidant properties of the coconut oil produced [17]. Hot extraction process is a process in which heat is used to break the emulsion between water and oil molecules. As the emulsion is being stabilized by proteins, the heating process aims to destabilize the emulsion by denaturing the proteins [13]. It was discovered that both cold extracted virgin coconut oil and hot extracted virgin coconut oil may be stored for 12 months with the percentage of fatty acids remained constant [16]. The hypolipidemic effect of coconut oil extracted by using hot extraction process and cold extraction process was studied. The coconut oil extracted by hot extraction process shows a higher decrease in Low Density Lipoprotein Cholesterol at all results obtained (i.e., 10 days, 20 days, 30 days) when tested on male Wistar albino rats. The coconut oil extracted by using hot extraction process also showed a higher increase in High Density Lipoprotein Cholesterol in all results obtained when compared with coconut oil extracted by using cold extraction process. When fed with hot extracted virgin coconut oil, the total change in cholesterol level of the male Wistar albino rats had decreased more when compared with cold extracted virgin coconut oil [18]. In an altered version of this method, the sample was treated with sonication after heating for 30 min at 60 °C. The sonication frequency used was at 2 MHz and energy densities of 44–349 kJ/kg. The coconut oil extraction yield was increased by 2.7% when the sample was treated with sonication after using heat extraction process. Li et al., (2018) concluded that this extra step has high potential to be introduced in large scale industrial production processes as the increase in yield will save a lot of production costs [40].

Low pressure extraction

Low pressure extraction technique is considered a fresh-dry technology. This process involves the principle of oil extraction utilizing low pressure approximately 460 psi and with a condition the moisture content of the seed/fruit/nut falls in the range of 10–13% [4]. Figure 2 exemplifies the process of low-pressure extraction. Virgin coconut oil yield with 92.54% was obtained when the centrifugation time was set to 60 min and the centrifugation speed was set to 2700 rpm [4]. Advantages of this method includes the by-products of this process, such as the coconut shells and husks may be used as fuel. Also, by changing the type of dryer used, the manufacturer may decide whether to use a continuous process, which is a relatively faster process but requires more labour or to use a batch process, which is a relatively slower process but only requires less labour. The disadvantages of this method includes this method requires higher capital cost as there are more equipment needed in this method than other methods [19].

Chilling, freezing and thawing

This method consists of a combination of a few separation methods, such as centrifugation and cold pressing.

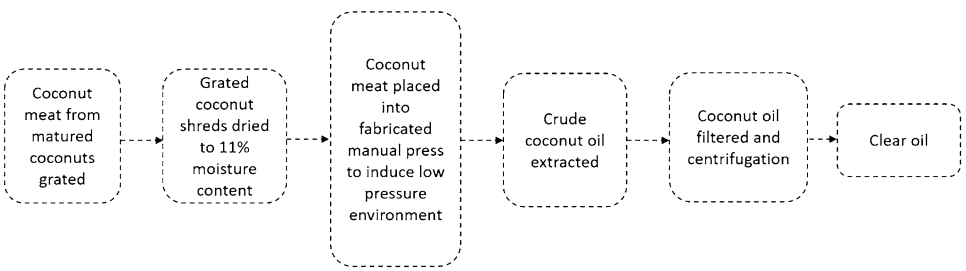

Fig. 2 Overall process of coconut extraction using low-pressure extraction techniques [19]

It makes use of the difference in freezing points of the components in coconut milk to extract coconut oil from coconut milk. Advantages of this method includes no heating above 40 °C is introduced to the coconut oil thus the antioxidant properties of coconut oil are not reduced by heat [17]. The coconut milk was centrifuged prior to being subjected to chilling and thawing to allow better packing of coconut oil globules. The centrifugation process helps to remove unwanted solids, which mainly consists of carbohydrates, proteins and fibrous materials from the coconut milk [13]. During this thawing process, the oil molecules clump together due to the loss of its spherical shape and this will result in the formation of large oil droplets in varying sizes [13]. A modified version of this process, the Robledano–Luzuriage process, is known to apply this method to extract coconut oil which is shown in brief in Fig. 3 [5]. Proteins from skim milk was also extracted out to produce protein concentrate by heating, filtering and drying [5]. In another alternative version of this method, the coconut milk was first hydrolyzed by partially purified seabass protease before being subjected to chilling or freezing treatment. [41]. It was observed that when the process was carried out for 150 min at 10 units g-PPSP(i.e., partially purified seabass protease), the highest oil recovery was obtained. However, in terms of yield there was no significant difference between hydrolysis carried out for 60 min and 150 min. This suggests that a hydrolysis time of 60 min is optimal for hydrolysis in terms of yield. After completing five cycles, the yield of coconut oil was at 91% for samples that underwent hydrolysis and 67.1% for samples that did not undergo hydrolysis. This method can also be carried out by substituting the chilling step with a freezing step, having a similar trend observed, but with higher oil yield observed when compared with chill–thaw method [5]. The highest oil recovery was obtained by hydrolyzing the sample for 150 min and at a PPSP concentration of 10 g^{-1} protein. After completing five cycles, the yield of coconut oil was observed to be at 98.6% with samples that was hydrolyzed and 81.45% for samples that was not hydrolyzed. These two processes showed a difference in terms of virgin coconut oil yield at which freeze–thawing process showed a higher yield which may be resulted in the difference in de-emulsification mechanism [41].

Fermentation

Natural fermentation

Natural fermentation is a low-cost process as it does not involve any expensive equipment and materials in this method. However, this method is time consuming as the process involves the reaction between enzyme and the cream [21]. This method surpasses other methods in ways, such as it requires almost no effort since it only needs to let the coconut milk to settle by its own. It also requires minimum amount of heat, thus preserving all its nutrients, such as when cold extraction method is used. Coconut oil produced from this method also maintains its natural coconut flavour as long as it is not fermented for extended period of times [21]. This method however requires a longer time to extract coconut oil as it needs to settle for days [21]. An automated coconut oil extraction machine applying this method of extraction is designed by Fabian in year 2018. Without using the automated machine, the maximum percent oil recovery of VCO is at 88.35% and a yield of 30–31%. However, with the use of this Automatic Virgin Coconut Oil Extractor, the oil recovery is at 89.84% and the yield is 31.27%. The extraction is also preferred to be carried out in areas at a temperature of 35–37 °C and feeding in good quality coconut kernel into the machine to ensure better extraction of coconut oil [42].

Induced fermentation

Coconut oil production through induced fermentation method is a method done by adding microorganisms to coconut milk to induce the separation of oil and protein components [13]. One of the microorganisms used for this method of extraction is *Lactobacillus plantarum* 1041 IAM [22, 23, 43]. Bacterial cultures alter the pH of the mixture to destabilize the coconut milk emulsion.

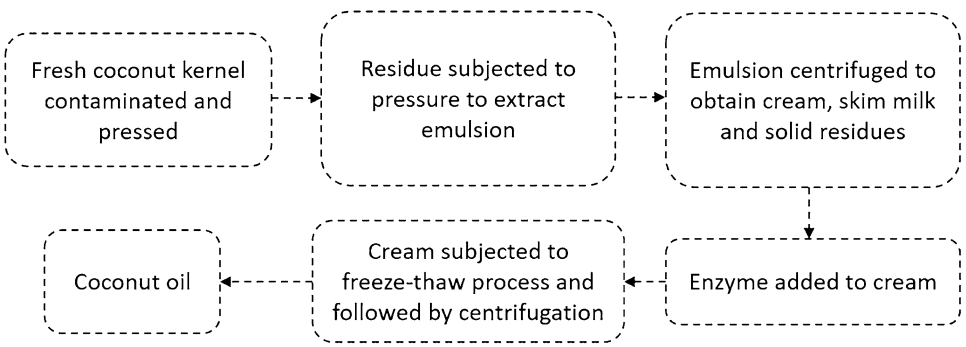

Fig. 3 Overall process of coconut extraction using modified chilling, freezing and thawing techniques [5]

Disadvantages of this method includes the reduction of quality of the oil and the long period of time used for this extraction (1–2 days). The oil produced from this method will be yellow in colour and there would be a fermented odour. This odour will mask the natural fragrance of coconut and it is caused by unwanted microorganisms [13]. In a modified version of this method, a pure culture of *Lactobacillus plantarum* 1041 IAM was also used. Solid starters were produced by using three types of enzymes, one of it being *Lactobacillus plantarum* 1041 IAM. The enzymes were incubated at room temperature for 4 days on 100 g of steamed rice that was submerged and mixed with 1% wood ash for 24 h. The starters were dried at 40 °C for 72 h and grinded. 1% solid starter was mixed with coconut cream and incubated for 43 °C for 10 to 15 h. The yield of coconut oil obtained using this enzyme was found to be 21.5% (v/v), which was the second highest when compared with the other two enzymes used [43].

Centrifugation

Centrifugation is a technique which can separate particles based on their respective size, shape, density, viscosity of medium and the rotor speed [29]. Several parameters for extraction of coconut oil by using the centrifugation method is studied including centrifugation time, speed and temperature. Yield of the coconut oil is used to optimize the parameters. For centrifugation speed, results showed that when increasing the speed, the coconut oil yield increases as well, reaching 9.27% when centrifuged for 15 min at 12,000 rpm. As for the centrifugation time, the longer the sample is centrifuged, the higher the yield of coconut oil is. At 12,000 rpm, the yield increased from 9.27% when the sample is centrifuged for 15 min to 13.53% when it was centrifuged for 120 min. Both parameters are tested at the same temperature, which is at 40 °C. When the centrifugation temperature is decreased from 40 to 20 °C, the result shows a decreasing trend. At 20 °C, coconut oil yield was at 3.1% when centrifuged at 12000 rpm. This method provides an alternative way to extract coconut oil in a short period of time when compared with the fermentation method along with providing a higher yield of coconut oil [13, 20]. Based on the research conducted by Wong in year 2010, a combination of microwave and centrifugation can be used to increase the yield of coconut oil extracted. At a microwave power of 720 W and a centrifugation speed of 12,000 rpm and a centrifugation time of 105 min, the yield of coconut oil extracted is at 46.88%. This result shows that when microwaving was implemented the yield of coconut oil extracted can be increased by 9.58%.

Enzymatic extraction

Coconut oil may be extracted by adding a mixture of several types of enzyme mixtures into coconut milk. The first mixture includes Cellules, Temramyl (endoamylase), Viscozyme L, neutrase and alcalase (protease) into coconut milk. This method is able to extract good quality coconut oil up to 83% yield [24]. By using a different mixture of enzymes, namely protease, α-amylase, cellulase, hemicellulose and pectinase, a different yield can be obtained, which is 65.5% [27]. It is also reported that by using a mixture of 2% hemicellulose, pectinase, cellulase and gamanase, coconut oil yield may reach 84% when this mixture is added into desiccated coconut kernel [26]. A mixture of 1% (w/w) cellulose, α-amylase, polygalacturonase and protease at a temperature of 60 °C and a pH of 7, the yield of coconut oil is at 73.8% when the mixture is added into grated coconut kernel [25]. It is also reported that when desiccated coconut kernel is first treated with cellulase, the fibrous content of the kernel may be reduced by 62% and when cellulase is added into fresh coconut kernel the fibrous content may be reduced by 17% [13]. A 80% yield of coconut oil is obtained when α-amylase, polygalacturonase and protease is added into diluted coconut paste even without undergoing any purification steps [44]. Senphan and Benjakul (2016) proposed a method to extract coconut oil by using only protease from hepatopancreas of Pacific white shrimp in year 2016 [45]. The amount of crude protease extract used and the time of hydrolysis was tested in this report. The yield of coconut oil only increased within the first six hours and did not show any increase when the time of extraction is increased. The effects of oxidation on lipids extracted by using this method is also negligible [45]. Table 3 compares the yield between different types of enzymes used for extraction.

Supercritical carbon dioxide

A substance at super critical condition is a substance which was subjected to a pressure and temperature that was higher than its critical point. When substances are in this condition, the substance will exhibit particular properties and has an intermediate behaviour between that of a liquid and a gas. For example, a substance under supercritical conditions may possess liquid-like densities and diffusivities intermediate to that of a liquid and a gas. Carbon dioxide is the most widely used supercritical fluid as carbon dioxide is low in cost while having steady chemical properties, such as chemically inert, non-flammable and non-toxic. The physical properties of carbon dioxide is also a reason to why it is the most widely used supercritical fluid, as the critical temperature of carbon dioxide is at 31 °C and the critical pressure of carbon dioxide is at 74 bar [29]. Coconut meat was first grated and dried with sun drying to reduce moisture content from 50

Table 3 Comparison of yield between different types of enzymes used for extraction

Enzyme	Operating conditions	Yield obtained (%)	References
Cellules, Temramyl, Viscozyme L, neutrase and alcalase	Temperature: 50 °C (Pectinolytic or cellulolytic enzyme) then 60 °C (Protease), 1 h at pH 7	83.0	[24]
Protease (Pr), α-amylase (A), cellulase + hemicellulose (HC) and pectinase (Pe)	Temperature: 37 °C, 6 h at pH 5.9	59.6–65.2	[27]
2% hemicellulose, pectinase, cellulase and gamanase	Temperature: 50 °C. Time: 5 h with gentle agitation then 15 h without agitation at pH 4.5	84.0	[26]
Amylase, polygalacturonases, proteases and cellulase	Temperature: 40 °C, Time: 30 min and pH 7.0	80.0	[44]
1% (w/w) cellulose, α-amylase, polygalacturonase and protease	Temperature: 60 °C, Time: 30 min and pH 7.0	73.8	[25]

to 3%. This is to prevent clogging of the capillary restrictor which is caused by frozen water by Joule–Thomson effect in the expansion valve. Samples ranging from 0.424 to 1.5 mm were obtained by sieving. This process is a semi-batch process with a continuous flow of carbon dioxide at a flow rate of 3 mL/mins. The coconut powder is charged into the extractor along with the carbon dioxide. The effect of temperature and pressure on the oil yield, antioxidant activity and total phenolic content is studied. At 24 MPa and 65 °C, the yield of oil is the highest. At high pressure, the increase in temperature will result in the decrease in yield, which is caused by the resistance of mass transfer in the matrices. For antioxidant activity, the highest antioxidant activity was found when the extraction process was carried out at a pressure range of 18–22 MPa and at 40–55 °C where temperature shows a more significant effect on antioxidant activity. Due to the tendency of antioxidants to oxidize at high temperatures, a high temperature extraction will result in a decrease in antioxidant activity. Total phenolic content extracted shows an increasing trend when the extraction temperature is increased. Studies have shown that phenolic compounds are more soluble when the pressure is high thus resulting in an increase in phenolic content yield [28].

Other methods

Expeller pressing

The expeller pressing is a mechanical method that extracts oil from nuts and seeds by using high pressure and high heat [16]. This method generally captures approximately 65% of the oil from the fruit [30]. This method may also be applied to coconut meat as raw feed material. Due to the coconut oil extracted by using this method will have a known rancid-acid odour, Ghosh et al. [46] proposed the implementation of usage of gamma irradiation to remove the odour. An irradiation at 4.2 kGy was found to be the appropriate irradiation dose to remove the rancid-acid odour of virgin coconut oil. It is also proven that the gamma irradiation treatment will not affect the antioxidation properties of coconut oil extracted [46]. However, it is recorded that the percentage free fatty acids and peroxide value of the VCO extracted via this method is the lowest among the four methods compared, which is centrifugation and fermentation with or without. It is proven in this study that expeller pressed coconut oil does not have an acidic and rancid smell as well heat damage [47].

Wet mill method

Coconut oil extracted by this method is extracted from coconut meat that is not dried prior to oil extraction. The coconut milk is first pressed out from the wet coconut meat and the coconut oil is then extracted from the coconut milk by separating the water from it. Methods used to separate the water from the coconut milk includes boiling, fermentation, refrigeration, centrifugation and enzymatic separations. Some manufactures choose to use fermentation to extract oil. This is because this process is very low tech and may be accomplished by small-scale producers. The coconut milk is allowed to settle overnight so that heavier water molecules may settle to the bottom of the container while lighter oil molecules remains on the top [31].

Application of coconut oil

Daily application

Coconut oil has many applications, mainly for health and beauty. First, coconut oil can help protect our skin from UV rays when applied on our skin. A study showed that coconut oil is able to block 20% of UV rays emitted from the sun [48]. It is also estimated that the sun protection factor of coconut oil is 7, which is lower than the minimum recommendation in some countries [48]. As coconut oil contains medium-chain triglycerides, it can increase our metabolism rate since these fatty acids can be absorbed rapidly and it increases the number of calories we burn [48, 49]. Studies

showed that fatty acids may boost our metabolic rate significantly temporarily [49–51]. An average of 120 cal may be burned over a 24 h period when 15–30 g of medium chain triglycerides are taken [49, 52]. As more than 80% of the fats in coconut oil is saturated, coconut oil is suitable to be used for high temperature cooking. Saturated fats will retain their structure even when heated to high temperatures unlike polyunsaturated fatty acids found in vegetable oils [53]. Coconut oil is also able to increase our dental health as it destroys bacteria in our month, such as *Streptococcus mutans*, the bacteria that causes many dental diseases, such as dental plaque, tooth decay and gum disease. When swished with coconut oil for 10 min, the bacteria in our mouth will be reduced as much as rinsing with an antiseptic mouthwash [49, 53]. The antifungal and anti-bacterial properties of coconut oil make it an excellent wound salve. A study found that when rats were treated with coconut oil on their wounds, inflammatory markers were decreased and there was an increase in the production of collagen which resulted in the enhanced healing speed of the wound [49, 54]. Eating coconut oil has also showed that it provides strong anti-inflammatory effects. This was proven on several animals [49, 55–57]. It is suggested when humans ingest coconut oil, there would be a reduction in the markers of oxidative stress and inflammation. However, this effect requires more research to be able to be commercialized [49]. For applications related to beauty, coconut oil is able to moisturize our skin when applied externally, especially for the limbs [49]. It is however, not recommended to be applied on the face for those with oily skin. The repair of cracked heels is also possible with the use of coconut oil [49]. A study compared the effects of coconut oil, mineral oil and sunflower oil on hair. Only coconut oil showed significant effects on hair as it reduced protein loss from hair when applied before or after shampooing. This applies on both healthy and damaged hair [49, 58]. Coconut oil may also be used as makeup removers, as it can remove even the most resistant waterproof mascara. For uses other than health and beauty, coconut oil is used in non-toxic insect repellents. By combining Thai essential oils with coconut oil, the insect repellent is able to provide over 98% protection from the bites of certain mosquitoes [49, 59]. Coconut oil is also suitable as a stain remover when mixed with the same amount of baking soda. The mixture is applied onto the stain and it is able to be wiped away after 5 min [49]. The strong antibacterial properties of coconut oil make it suitable to be made into deodorants. Coconut oil can be mixed with other natural ingredients, such as arrowroot powder, corn starch, baking soda and scented oil to form a natural deodorant [49]. Coconut oil is also used as a polish for wood furniture. It also acts as a dust repellent after applying it onto wood furniture. It also comes with a pleasant, delicate aroma [49]. Coconut oil can also be made into other everyday items, such as toothpastes, lip scrub, body scrub and shaving cream. Personal cleansing agents, such as shampoo [60], soaps [61] and detergents in body wash products [62] may also be produced from coconut oil as well. The daily applications of coconut oil mentioned is summarized in Table 4.

Industrial applications

In a study conducted in year 2011, it was found that coconut oil can be a potential feedstock for biodiesel production [63, 64]. With the aid of cellulose-Zn/SiO_2 nanocomposite, it was noted that the formation of biodiesel methyl esters can be formed more efficiently, further promising a future application of coconut oil in the fuel industry [65]. Catalysis activity may also be achieved with calcined marlstones to increase the biodiesel yield as well [66]. It is also found that virgin coconut oil has a potential in reducing cardiovascular risk factors [67]. To combat the pandemic caused by COVID-19 virus, studies were carried out on the antibacterial properties of coconut oil as well [68]. In year 2020, Joondan has found that by replacing the surfactant used to produce laundry detergent with new surfactants derived from coconut oil, the antibacterial properties of the resulting detergents are more effective than detergents produced by the conventional surfactant used for detergent production which may help in reducing the spread of the virus [68]. Coconut oil may also be applied as a health care item for preterm newborns in their skin maturity development. Studies were carried out on many newborns under randomized controlled conditions with results showing that coconut oil has positive effects over the newborns' health and with no undesired side effects [6, 69]. Studies are also being conducted on the feasibility

Table 4 Daily application of coconut oil

Category	Uses
Health	Protects our skin from UV rays
	Increasing metabolism rates
	Able to be cooked at high temperatures
	Increase in dental health
	Increase in wound healing
Beauty	Moisturizer
	Protects hair from damage
	Makeup remover
Others	Non-toxic insect repellent
	Stain remover
	Deodorant
	Quick energy source
	Wooden furniture shiner
	Makeup brush cleaner
	Manufacturing of everyday items
	Shampoos and detergents for body wash

Table 5 Industrial applications of coconut oil

Product	Uses
Coconut oil	Biodiesel production
	Reducing cardiovascular diseases
	Surfactant for laundry detergent
	Healthcare item for preterm newborns
	Edible packaging material
	Extraction of medium-chain triglyceride
	Potential cutting fluid and industrial bio-lubricant
Coconut oil composite material	Energy sensor
	Strain sensor
Coconut oil residue (Coconut oil cake)	Potential raw material for α-amylase synthesis
	Nutritious snack product

of using coconut oil to synthesis edible packaging material as an additive for starch-based films in food packaging as an enhanced edible film [70–72]. Further extraction of virgin coconut oil can be carried out to obtain medium-chained triglyceride, which was found to be a major component of coconut oil [73]. This medium-chained triglyceride can be used for applications on body fat accumulation control as well as cholesterol deposition control on tissues [74, 75]. In year 2020, it was found that when combined with sonicated graphene, coconut oil can serve as a phase change material for energy storage purposes. It was found that the best results for this application may be obtained at low concentrations of graphene at 0.3 wt% graphene [76]. In recent year, Lugoda found that combining coconut oil and carbon black, a strain sensor can be developed. This strain sensor can be used for several applications such as human activity recognition, health mentoring as well as soft robotics [77]. During the production of coconut oil, the coconut oil cake produced can also be sold as a potential by product. This is proven by Sumitra in year 2003 that coconut oil cake can be used as a potential raw material for the synthesis of α-amylase as a substrate [78]. Besides using the coconut oil cake as a raw material, the spent coconut oil cake can also be converted into a nutritious snack to increase the revenue of coconut oil plants as well as reduce the waste produced by the plants. This application is proven to be feasible as the cake is rich in protein as well as other nutrients such as polyphenols and antioxidants [79]. Coconut oil is used cutting fluid and lubricants in the industry as well. However, due to its poor thermal stability this application is limited [80]. Studies are being conducted to increase its thermal stability so that it can be applied more widely as industrial lubricants [81–84]. The industrial application of coconut oil and their utilization is shown at Table 5.

Conclusions

Virgin coconut oil has many uses in our daily life as well as industrial applications. This will give a positive result to the market demand and the industry may apply the methods mentioned above to extract coconut oil. Each extraction method has its benefits and disadvantages. Thus, the industry needs to determine which method to be use in order to meet the needs of the population. Coconut oil extracted from different methods can have different quality and usage. If the coconut oil were to be applied externally, the quality of the oil was not prioritised but the amount of oil being extracted was prioritised. Therefore, a method that provides high oil yield may be preferred. There will never be a "perfect" method to satisfy everyone in one method alone, thus multiple methods have been invented and tested.

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Declaration

Conflict of interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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