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Review

Virgin coconut oil: emerging functional food oil

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Virgin coconut oil (VCO) is growing in popularity as functional food oil and the public awareness of it is increasing. It is expected that VCO will experience a dramatic growth in the market. The introduction of VCO has open up new research that basically reveals new things besides what has already been known on commercial coconut oil. This paper mainly discusses on some of the findings associated with VCO up to date. Physicochemical properties, antioxidant activity, clinical and authentication studies of VCO were some of the topics addressed in this review.

Introduction

Coconut oil is extensively used for food and industrial purposes. The oil is rich in medium chain fatty acids (MCFA) and exhibits good digestibility (Che Man & Marina, 2006). Various methods have been developed to extract coconut oil, either through dry or wet processing. Dry processing is the most widely used form of extraction. Clean, ground and steamed copra is pressed by wedge press, screw press or hydraulic press to obtain coconut oil, which then goes through the refining, bleaching, and deodorizing (RBD) processes. During the RBD process, heating process is applied especially during deodorization process, which is carried out at high temperature between 204 and 245 °C (O'Brien, 2004). The copra industry also faced some problems such as contamination by aflatoxin in copra and cake and presence of high free fatty acids due to high moisture content (Guarte, Muhlbauer, & Kellert, 1996).

Recently, there is a trend towards producing coconut oil which does not have to go through the RBD process. Rather than going to the normal dry process, this oil is obtained by wet processing which entails the extraction of the cream from the fresh coconut milk and consequently breaking the cream emulsion. This process is more desirable as no chemical or high heat treatment is imposed on the oil. The coconut oil produced through the wet method is known as virgin coconut oil (VCO).

The term VCO refers to an oil that is obtained from fresh, mature kernel of the coconut by mechanical or natural means, with or without the use of heat and without undergoing chemical refining (Villarino, Dy, & Lizada, 2007). Unlike RBD coconut oil which is tailor-made for cooking purposes, VCO is marketed lately as functional oil. Since its first introduction, virgin coconut oil has captured the attention of vast majority of publics. The beneficial properties of VCO are fast spreading. The availability of VCO is increasing in the market especially in South East Asia involving the Philippine, Thailand, Indonesia and Malaysia.

This paper presents an overview of the current status and recent trend of on going research in VCO. Brief explanations on some of the methods used to produce VCO are described. The results of published works on VCO were further reviewed which focused on physicochemical properties, antioxidant activity and phenolic contents, clinical and authentication studies.

Methods of extraction of virgin coconut oil

Unlike refined coconut oil which is produced through dry method from copra, VCO is produced through wet method, *via* coconut milk. Through the wet process itself, many ways of producing coconut oil have been described. No specific requirement for producing VCO has been established. Based on the definition of virgin oil, it is understood that as long as the oil does not go through the RBD process and which does not lead to the alteration of the nature of the oil, the oil can be deemed as VCO.

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Wet extraction

Wet processing or aqueous processing is the term used for the extraction of coconut oil directly from coconut milk. This method eliminates the use of solvent which reportedly may lower the investment cost and energy requirements. Furthermore, it eliminates the RBD process (Villarino *et al*., 2007). Even though the concept appears potentially attractive, however, the method yields comparatively low content of oil, which has discouraged its commercial application (Rosenthal, Pyle, & Niranjan, 1996).

The wet processing can only be carried out by means of coconut milk by breaking the emulsion. This is rather difficult due to the high stability emulsion of the coconut milk. Destabilization can be done through three mechanisms. The first stage is creaming by the action of gravitational force resulting in two phases, with the higher specific gravity takes place at the top phase and the lower specific gravity phase moves downward. The second stage is flocculation or clustering in which the oil phase moves as a group which does not involve the rupture of the interfacial film that normally surrounds each globule and therefore does not change the original globule. The last stage, coalescence is the most critical phase in destabilization. During this stage, the interfacial area is ruptured; the globules joined together and reduced the interfacial area (Onsaard, Vittayanont, Srigam, & McClements, 2005).

The wet process appears more desirable due to the free usage of chemical solvents, thus more environmental friendly than the solvent extraction. The method is also much simpler, which can be carried out at home by anyone who are interested in producing their own natural oil.

Chilling, freezing and thawing techniques

Attempts have been made before to break the protein stabilized oil-in-water emulsion including heating and centrifugation, freezing and thawing, chilling and thawing the coconut cream obtained after centrifugation (Seow & Gwee, 1997). Emulsion was centrifuged before chilling and thawing to allow better packing of the coconut oil globules. According to the studies, the temperature used were 10 °C and −4 °C for chilling and freezing process, respectively while the thawing process was carried out in a water bath at 40 °C until the coconut cream reached room temperature (25 °C). In addition, this action also helps in removing undissolved solids after extraction. The removal of solids present in high percentages in the dispersion of oil seed was important for efficient recovery of oil by centrifugation (Rosenthal *et al*., 1996). The centrifugation step was followed to enable the packing of cream oil globule to crystallize on lowering the temperature. Centrifugation process was carried out from 2000 to 5000 G up to 6 min. During thawing, the oil coalesced due to loss of spherical shape and formed large droplets of varying sizes.

Robledano-Luzuriage and Krauss-Maffei were two processes known to apply freeze and thaw operation in the extraction of coconut oil (Marina, 2008). In the Robledano-Luzuriage process, fresh coconut kernel was comminuted and pressed to obtain approximately equal amounts of emulsion and residue. The residue was pressed again to obtain more emulsion and residue. The emulsion was centrifuged to obtain cream, skim milk and some solids or protein. The cream was subjected to enzymatic action under closely controlled temperature and pH conditions. After freeze-thaw operation, the cream was centrifuged again to obtain the oil. The protein in the skim milk was coagulated by heating, subsequently filtered and dried to produce protein concentrate.

The oil recovery reported in the Krauss-Maffei was 89%, which was less than the conventional expeller process (95%). In this technique, husked coconuts were autoclaved, shelled, and the coconut meat (the white solid endosperm inside the coconut fruit) first sent through cutter and subsequently through a roller mill. Then it was pressed in a hydraulic press and the emulsion was centrifuged to obtain the cream and skim milk. The cream was heated to 92 °C and then filtered to obtain high quality oil. The skim milk is heated to 98 °C in a flow heater to coagulate protein, which was separated by centrifuging and then drying. The residue from the hydraulic press was dried and ground to obtain edible coconut flour. The study shows that quite high recovery of oil was obtained but the temperature employed was slightly high which might destroy some of its minor components such as phenolic compounds.

Fermentation technique

Che Man, Abdul Karim, and Teng, (1997) investigated the use of pure culture, *Lactobacillus plantarum* 1041 IAM to extract coconut oil, which was able to extract as much as 95% of the oil. In the study, grated coconut meat and water at 30, 50 and 70 °C were mixed in ratio of 1:1, 1:2 and 1:3 and allowed to settle for 2 to 6 h. The most efficient coconut cream separation was obtained at the 1:1 ratio of grated coconut meat to water at 70 °C followed by 6 h settling time. *L. plantarum* has the ability to ferment sugar with the production of considerable amount of lactic acid. Coconut milk with *L. plantarum* strain IAM 1041 inoculation indicated a rapid breaking of the emulsion and the liberation of the oil compared to *Lactobacillus delbrueckii*. This was because *L. plantarum* strain could multiply faster in coconut milk at 40–50 °C under microaerophilic conditions which increased the fermentation process.

Coconut milk emulsion can also be separated by adjusting pH of the coconut milk emulsion between pH 3 and 5.6 and inoculated with bacteria cultures (Chen & Diosady, 2003). Che Man, Suhardiyono, Ali, and Azudin (1992) used acetic acid treatments to destabilize coconut cream in coconut oil extraction. Treatment of 25% of acetic acid at level of 0.1, 0.2, 0.3 and 0.4% on coconut cream from 10 to 14 h of reaction time at room temperature had improved the quality of the oil extracted, with oil recovery up to 60%. Other treatments to break the coconut milk emulsion included the use of heat, refrigeration, action of enzymes, acidification, the use of salt or brine, electrolyte action, short waves and

combination of these treatments (Seow & Gwee, 1997). These techniques were possible due to the fact the coconut milk proteins were easily coagulated and precipitated at pH 4 (Tangsuphoom & Coupland, 2008).

Enzymatic extraction technique

Extraction of oil can also be carried out by the use of enzymes in aqueous extraction process. This is due to the fact that plant cell walls consists of complex carbohydrate molecules such as cellulose, hemicellulose, mannans, galactomanans, arabinogalactans, pectin substances and protein (Christensen, 1991). Coconut meat contains about 10% of carbohydrate, in which 50% of this is cellulose and 75% of the cellulose is made up with α-cellulose (Rosenthal *et al*., 1996).

Oil can be found inside plant cells, linked with proteins and wide range of carbohydrate such as starch, cellulose, hemicellulose, and pectins. Cell-wall degrading enzymes can be used to extract oil by solubilizing the structural cell wall components of the oil seed. Che Man, Suhardiyono, Asbi, Azudin, and Wei (1996) also successfully extracted coconut oil with 1% enzyme mixture of cellulase, α-amylase, polygalacturonase, and protease with an oil yield of 74%. The polygalacturonase hydrolyses α-linkages of polygalacturonic acid of the polymer randomly from the ends. An α-amylase randomly hydrolyzed α-linkages to liquefy starch and produced maltose, whereas bacterial proteases were used to hydrolyze the plant protein. The study showed that different enzymes were required to degrade components of the structural cell wall including mannan, galactomannan, arabinoxylogactan and cellulose.

Physicochemical properties of virgin coconut oil

Since its appearance in the market, VCO is well accepted by consumer as functional food oil and the demand for this oil continues to increase. Due to that, the number of commercial VCO was increasing in the market. Marina, Che Man, Nazimah, and Amin (2009a) described the chemical properties of commercial VCO available in Malaysia and Indonesia. The results revealed that chemical properties of VCO did not vary much from the RBD coconut oil. The iodine, peroxide, saponification and free fatty acid values obtained for commercial VCO samples were well within the specification limit of Codex standard (2003) for refined coconut oil. The fatty acid composition was dominated by lauric acid with percentage ranging from 46 to 48%, which was within the limit of VCO standard according to Malaysian Standard (2007) and Asian and Pacific Coconut Community (APCC, 2003) (Table 1). According to the study, medium chain fatty acids ranged from 60 to 63%. The major triacylglycerol (TAG) in VCO samples consisted of 22–25% of LaLaLa, 14–16% of CCLa, 19–21% of CLaLa, 13–15% of LaLaM and 7–9% of LaMM with La, C and M are lauric, capric and mysristic acids, respectively. Generally, VCO from Malaysia had relatively higher contents of CpCpLa (Cp: caproic), CpCLa and LaOO while Indonesian VCO had more of LaMP.

Dia, Garcia, Mabesa, and Tecson-Mendoza (2005) compared the physicochemical properties of VCO produced by different methods. Three different processing methods were applied, namely incubated dessicated coconut meat, incubated coconut milk and freeze-thaw coconut milk. The results showed that there were some differences in the physicochemical properties of the VCO samples produced by different methods but the differences were not large enough to significantly affect the overall quality of the VCO. The levels of the physical and chemical qualities were within the Codex standard for coconut oil and the Philippine standards for VCO. In addition, the authors also determined the α-Tocopherol in the studied VCO. The result revealed that α-Tocopherol was actually found in the coconut testa (the thin brown layer that clings to the white coconut meat) and only trace amount in the VCO samples. Since coconut testa was removed in the production of VCO, it was logical that the VCO samples contain only trace amount in α-Tocopherol.

The quality of VCO is very much determined by its physicochemical properties. However, as established by Dia *et al*. (2005) and Marina *et al*. (2009a), the physicochemical quality of VCO was comparable to RBD coconut oil. An understanding of descriptive quality of VCO in terms of sensory evaluation was highly needed to better

Table 1. Fatty acid composition of virgin coconut oil (VCO) and refined, bleached and deodorized (RBD) coconut oil from various sources.

Fatty acid	Codex standard for RBD coconut oil	[a]APCC standard for VCO	Malaysian standard for VCO	Marina *et al.* (2009a)	Dia *et al.* (2005)
C6	nd–0.70	0.40–0.60	0.80–0.95	0.52–0.69	nd–0.60
C8	4.60–10.0	5.00–10.00	8.00–9.00	7.19–8.81	5.98–10.44
C10	5.0–8.0	4.50–8.00	5.00–7.00	5.65–6.59	5.37–6.60
C12	45.10–53.20	43.00–53.00	47.00–50.00	46.89–48.03	47.63–52.55
C14	16.80–21.00	16.00–21.00	17.00–18.50	16.23–18.90	16.79–20.08
C16	7.50–10.20	7.50–10.00	7.50–9.50	7.41–9.55	6.38–10.17
C18:0	2.00–4.00	2.00–4.00	2.50–3.50	2.81–3.57	7.45–10.73
C18:1	5.00–10.00	5.00–10.00	4.50–6.00	5.72–6.72	
C18:2	1.00–2.50	1.00–2.50	0.70–1.50	0.90–1.60	nd–0.12
C18:3	nd–0.20	<0.5	nd	nd	nd

[a] Asian and Pacific Coconut Community.

distinguish VCO from the refined coconut oil. This was accomplished by Villarino *et al*. (2007) who conducted a study to describe the sensory terms for VCO by using trained panelists. A total of 14 attributes were generated. VCO was found to be almost colourless while RBD coconut oil was described as having a distinct yellow colour. The RBD sample had no perceptible aroma while VCO samples were perceived to have an acid, cocojam (aroma associated with roasted coconut), latik (aroma of cooked coconut with sweet sensation), nutty and rancid aromas. In terms of flavour, VCO samples were found to have detectable sweet taste and nutty flavour. Since VCO is produced by natural methods without contamination by chemicals usage, it is no surprise that its sensory profiles reflected the natural way it is produced. Thus, descriptive sensory analysis provides as an important criteria to better discriminate VCO from refined coconut oil.

Antioxidant activity and phenolic compounds in virgin coconut oil

Recently, considerable interests in the possible impact of consuming certain foods to fight against several diseases have appeared. Numerous studies suggest that the consumption of foods containing dietary phenolics may significantly contribute to human health (Naczk & Shahidi, 2004). Beneficial effects resulting from phenolic antioxidants has creates a niche in finding of food worth of these phenolic compounds. Olive oil is one of the edible oils known for its high phenolic contents.

Attempts have been made by few investigators to determine the phenolic content in VCO. Dia *et al*. (2005) determined the total phenolic content in VCO produced from different methods. The results revealed that VCO contained higher total phenolic content compared to refined coconut oil. Marina *et al*. (2009a) conducted a study on commercial VCO in Malaysian and Indonesian markets, confirmed that VCO samples were significantly higher in total phenolic content compared to RBD coconut oil. It was suggested that the RBD process being applied through dry method had considerably destroyed some of the phenolic compound in the coconut oil. The total phenolic content in coconut oil produced by traditional and commercial methods (dry processing) were also compared by Seneviratne and Dissanayake (2008). The result indicated that the total phenolic content of traditional coconut oil was nearly seven times higher than that of commercial coconut oil. The authors did not use the term VCO for the traditional coconut oil, even though the oil was produced by wet method, probably because of the high temperature used, which was 100–120 °C.

The antioxidant activity in VCO was reported to be high in VCO compared to refined coconut oil (Dia *et al*., 2005 and Marina *et al*., 2009a). The results also indicated that VCO with the highest total phenolic content also possessed the highest antioxidant activity. The effect of different processing methods on antioxidant capacity of VCO was studied by Marina, Che Man, Nazimah, and Amin (2008). Two different methods of extraction, which were chilling and fermentation, were used to produce VCO. The VCO obtained was subjected to three different antioxidant assays, namely 1,1-diphenyl-2-picrylhydrazyl (DPPH) radical scavenging activity, β-carotene-linoleate bleaching activity and reducing power. A significant difference was observed in the total phenolic content, with fermentation method yielded the highest total phenolic content, followed by chilling and RBD methods (Fig. 1). The VCO produced through fermentation had the strongest scavenging effect on DPPH and the highest antioxidant activity based on β-carotene-linoleate bleaching method. However, VCO obtained through chilling method had the highest reducing power. Very high correlations were found between total phenolic content and each of scavenging activity and reducing power.

Determination of phenolic compounds in VCO was determined by Marina *et al*. (2008). Some of the phenolic acids identified in VCO were protocatechuic, vanillic, caffeic, syringic, ferulic and p-coumaric acids. The study suggested that the contribution of antioxidant activity in VCO could be due to phenolic compounds. Seneviratne and Dissanayake (2008) also reported the presence of caffeic, p-coumaric and ferulic acids as well as catechin in the commercial and traditional coconut oil.

It is believed that cold extraction condition employed in the processing of VCO preserves the thermally unstable antioxidant compound. However, in a recent study, Seneviratne, Hapuarachchl, and Ekanayake (2009) found that more phenolic substances were recovered in the coconut oil extracted under hot condition, compared to coconut oil extracted under cold condition. According to the study, the high temperature used in the hot extraction of coconut oil favoured the incorporation of more thermally stable phenolic antioxidants into coconut oil. It was hypothesized that the concentration of the phenolic substances increased when the water in the emulsion evaporated during the hot

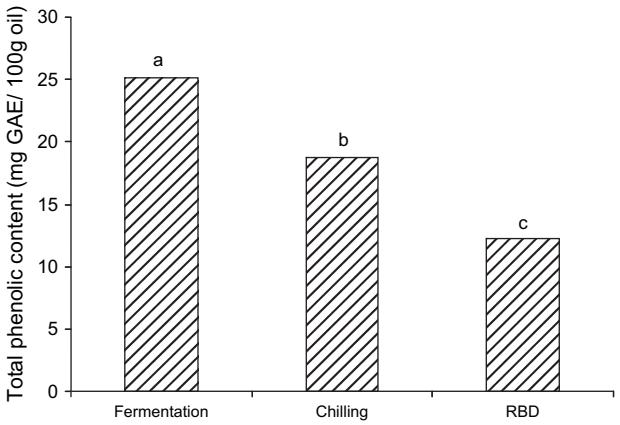

Fig. 1. Mean total phenolic content of virgin coconut oil, (fermentation and chilling methods) and RBD coconut oil. Values with different lower case letters are significantly different at $P < 0.05$ using SAS statistical software (Duncan's multiple range test). GAE, gallic acid equivalents. Source: Marina *et al*. (2008).

extraction method. The antioxidant activity in hot extraction coconut oil was superior than that of cold extraction as indicated by higher inhibition of the DPPH assay and deoxyribose assay. The serum trolox equivalent antioxidant capacity (TEAC) showed better improvement in the blood serum of rats fed with diets containing hot extraction coconut oil compared to blood serum of rats fed diets containing cold extraction coconut oil.. The hot extraction method used in the study was 100 °C, perhaps a little too high to indicate that the coconut oil as virgin. However, according to the Codex standard (2003), application of heat is permitted in producing virgin oil, but there is no definite temperature set as to how high the application of heat should be limited.

Animal and human *in vivo* studies on virgin coconut oil

It has been established that coconut oil is considered a saturated fat because it contains more than 90% of saturated fatty acids. Epidemiologic study suggests that the consumption of high amounts of saturated fat and cholesterol leads to high blood cholesterol (German & Dillard, 2004). Due to that, coconut oil has received bad reputation. However, in the past few years, clinical studies have been conducted on coconut oil and VCO and positive outcomes were obtained which might refute those arguments.

Coconut oil is rich in medium chain triacylglycerol (MCT). Extensive review has been made by Che Man and Marina (2006) and Marten, Pfeuffer, and Schrezenmeir (2006) on MCT. Having rich in MCT, consumption of coconut oil is associated with increase in the serum triacylglycerol but incorporation of structured lipid and other functional substances may improve the lipid profile. A study conducted on regular coconut consumers of Polynesian populations, revealed that consumption of coconut was not associated with heart attacks and other forms of cardiovascular disease (Prior, Davidson, Salmond, & Czochanska, 1981). Coconut oil is also rich in lauric acid; a fatty acid with strong antimicrobial property which inhibited various pathogenic bacteria such as *Listeria monocytogenes* (Wang & Johnson, 1992). There was also a study showing protective effect of coconut oil together with menhaden oil in reducing mammary tumor incidence in animal study (Craig-Schmidt, White, Teer, Johnson, & Lane, 1993).

The effects of consumption of VCO on various lipid parameters were conducted by Nevin and Rajamohan (2004). The findings indicated that triglycerides in serum and tissues were significantly lower in VCO-treated animals compared to copra oil and control animals. High density lipoprotein (HDL) cholesterol in VCO fed animals was increased while low density lipoprotein (LDL) cholesterol level were significantly decreased compared to copra oil. Polyphenol fraction of VCO was found to be more beneficial than polyphenol fractions of copra and groundnut oils in preventing the copper-induced oxidation of LDL as indicated by the low thiobarbituric acid reactive substance (TBARS) and reduced carbonyl formation.

In the subsequent study, Nevin and Rajamohan (2006) determined the antioxidant status of rats fed VCO. The results indicated that the activities of catalase (CAT), and superoxide dismutase (SOD) which were mutually supportive team of defense against reactive oxygen species (ROS) and preventing lipid peroxidation, were increased in VCO. The lipid peroxide levels were significantly less in the heart, liver and kidney of VCO fed animals compared to the other oil fed groups. Compared to groundnut and copra oils, VCO feeding was found to increase the total glutationine (GTN) content, a sensitive indicator of antioxidant status. The study concluded that consumption VCO was superior in antioxidant property than coconut oil extracted by dry process.

In a recent study, the influence of VCO on blood coagulation factors, lipid levels and LDL oxidation in cholesterol fed Sprague-Dawley rats were investigated by Nevin and Rajamohan (2008). The lipid levels and thrombotic risk factors as indicated by platelets, fibrin and fibrinogen levels were lower in rats fed VCO compared to copra oil and comparable to sunflower oil. The antioxidant vitamin levels were found to be higher in VCO fed animals compared to the other groups. The LDL isolated from VCO fed animals when subjected to oxidant *in vitro*, showed significant resistance to oxidation as compared to LDL isolated from the copra and groundnut oils.

VCO, just like coconut oil, is also known for its high MCT. MCT is unique due to its physicochemical properties such as having shorter chain length and smaller molecules compared to long chain triglyceride (LCT), making them more rapidly absorb and hydrolyze in the body. MCT has been using in the clinical area for enteral and parenteral nutrition in diverse medical conditions for treatment of patients suffering from fat malabsorption (Che Man & Marina, 2006). The relevance of the positive consequences of clinical studies on VCO has been widely contributed by its bioactive components. Apart from the physicochemical properties, the scientific investigation of VCO on health effect can further enhance the quality of VCO. Hence good knowledge on the molecular and bioactive components in VCO is highly desired.

Authentication studies on virgin coconut oil

The positive outcomes from previous clinical studies conducted on VCO further enhance its reputation as highly valuable oil. Some might take advantage by intentionally replacing VCO with oils of less value. Thus, adulteration issue might follow next. Methods have been developed by few researchers to detect adulteration in VCO.

Manaf, Che Man, Hamid, Ismail, and Abidin (2007) utilized Fourier transform infrared (FTIR) as a tool to detect adulteration in VCO. Palm kernel olein was used as an adulterant in the study because of its similarity with VCO in chemical composition. Detection of adulteration was possible down to 1% limit. Discriminant analysis using

10 principal components showed that pure and adulterated samples were successfully classified into its group. Discriminant analysis was also applied to distinguish between VCO and other vegetable oils such as walnut, extra virgin olive, soybean, sunflower, grapeseed, sesame, canola and corn oil (Fig. 2). The result showed that VCO samples fall into one group, separated from other vegetable oils. This indicated that FTIR spectroscopy is an efficient and accurate method to detect adulteration in VCO.

Although Manaf *et al*. (2007) has successfully discriminated between VCO samples and other vegetable oils, there was still opportunity for VCO to be adulterated by the refined coconut oil. Thus, Dayrit, Buenafe, Chainani, and Vera (2008) have proposed a method to detect adulteration in VCO with refined coconut oil by using NMR spectroscopy. According to the study, monolgycerides (MGs), diglycerides(DGs), sterols and free fatty acids (FFA) have been converted into phosphorus-containing dioxaphospholane derivatives and analyzed by Phosphorus-31 nuclear magnetic resonance spectroscopy (^{31}P NMR). On the average, VCO had 40% higher of 1-MG content than refined coconut oil. On the other hand, VCO had lower average of DG content (1.5%) than refined coconut oil (4.1%). Average total sterol contents in VCO samples was around 0.096%, slightly lower compared to refined coconut oil (0.032%). The FFA contents showed that VCO had 8 times as much as FFA contents than refined coconut oil. Principal component analysis showed that the 1,2-DG, 1,3-DG and FFA were the most important parameters for differentiating VCO from refined coconut oil.

Differential scanning calorimetry (DSC) was used by Marina, Che Man, Nazimah, and Amin (2009b) to detect adulteration in VCO. Three different oils, namely soybean, sunflower and palm kernel oil were used as adulterants, which represented oil from linolenic, oleic-linoleic and lauric acid group respectively. The heating curves of sunflower and soybean adulterated samples showed that adulteration peak appeared at the lower temperature region starting at 10% adulteration level. Regression analyses using stepwise multiple linear regression (SMLR) was used to predict the percent adulterant with R^2 of 0.9390 for sunflower oil and 0.9490 for soybean oil. For adulterant palm kernel oil, which belong to the same group as VCO, no adulteration peak was observed. Nevertheless, a good relationship between the main exothermic peak height of palm kernel oil and percentage of adulteration was established.

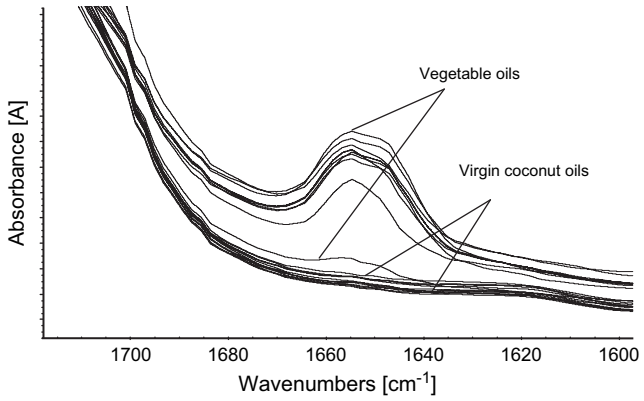

Fig. 2. The spectral variation between virgin coconut oil samples and other vegetable oil samples near wavenumber 1654 cm^{-1}. Source: Manaf *et al.* (2007).

The potential use of electronic nose in detecting adulteration in VCO oil was studied by Marina (2008). In the study, zNose™ electronic nose with surface acoustic wave was used to detect adulteration of palm kernel olein in VCO. Principal component analysis (PCA) was used to differentiate between pure and adulterated samples. The PCA provided good separation of samples with 74% of the variation accounted for the PC1 and 17% accounted for the PC2. Pure samples formed separated cluster from all adulterated samples.

With respect to adulteration in VCO, Mahmood Mat Yunus, Fen, and Yee (2009) determined the refractive index and FTIR spectra of VCO and virgin olive oil. Refractive index of aqueous solutions and oil is important in determination of purity and adulteration of oils. The results found that the refractive index of virgin olive oil was higher than those obtained for VCO. FTIR spectra indicated that virgin olive oil possessed stronger absorption compared to VCO in five important peaks associated with stretching of aldehyde (C═O) and esters (C−O), bending absorption of methylene (CH_2) and methyl (CH_3) groups and double absorption of (C═O).

Conclusion

Since its first appearance, VCO has gained wide attraction among the public and scientific community as functional food oil. Some studies pertinent to VCO have been described in this review article. From the health point of view, VCO has been documented as having more beneficial effects in clinical trials such as having more antioxidant potential compared to refined coconut oil. The underlying justification was based on the fact that VCO did not undergo the RBD process, which destroys some of the biologically active components such as phenolic compounds. A number of studies confirmed the higher content of phenolic contents, which correlated with higher antioxidant activity in VCO, compared with refined coconut oil. Attention was also addressed by investigators in developing methods for detection of adulteration in VCO. The overall knowledge improvement allowed the identification of suitable new techniques to better differentiate VCO from other vegetable oils, especially from refined coconut oil. Further studies are needed to establish effective purity criteria for VCO.

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