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Detection of oil adulteration in virgin coconut oil (VCO) through physical characterization

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Abstract
Substantiation of virgin coconut oil (VCO) is crucial for consumer protection. Using physical factors in conjunction with multiple linear regression models, an investigation was carried out to distinguished VCO from coconut oil (CO), palm oil (PO), and liquid paraffin. Various oil blends of VCO:PO, VCO:CO (both in 10% increments), VCO:CO:PO, VCO: liquid paraffin, and CO: liquid paraffin were created. The physical qualities of oil blends were tested, and the data was statistically analysed. Physical qualities such as colour, refractive index, smoke point, turbidity, and viscosity were persuasive in distinguishing the oil samples at different levels of adulteration. Even with as little as 10% adulteration, samples could be categorised. Multiple regression analysis produced predictive equation models with a high coefficient of determination (R^2) which could aid in the quantification of adulteration. As a result, this investigation revealed the usefulness of assessing physical features and their efficiency in discerning VCO from probable adulterants such as PO, CO, and liquid paraffin.

Keywords: Adulteration detection, food quality, regression analysis, virgin coconut oil

Introduction
Coconut (*Cocos nucifera* L.), one of the most significant plantation crops in the Palmae family, is grown throughout the world's tropical and subtropical regions. The crop is grown in 13 million hectares distributed across 90 countries, including the Philippines, Indonesia, Brazil, and Sri Lanka, with a total yield of 69836.36 million nuts. Coconut was grown in an area of 2173.28 thousand hectares in India in 2020 with a production of 20308.70 million nuts (https://coconutboard.gov.in/Statistics.aspx). One of the most important oils in the tropical region is coconut oil, a commercial product extracted from the endosperm of coconuts. Coconut oil has numerous uses, not just in cooking but also in industrial processes. Coconut oil is rich in medium-chain fatty acids (MCFAs) with great health benefits (Man and Manaf, 2006; Ramesh *et al*. 2019; Ramesh *et al*. 2021) [20, 27, 28].

Edible oils are the most abundant source of dietary lipids and fatty acids, which are required for human body development. Additionally, edible oils contain many antioxidants (tocopherol, oryzanol, carotenes, and tocotrienols), phytosterols, and minerals (Manchanda and Passi, 2016) [21]. Olive oil, avocado oil, pumpkin seed oil, walnut oil, peanut oil, sesame oil, sunflower seed oil, coconut oil, and many other plant-based edible oils are produced from vegetables. Among them, coconut oil stands out because, as a plant fat, it comprises more than 90% saturated fatty acids with traces of unsaturated fatty acids (MUFA and PUFA), has no cholesterol (Bharti *et al*., 2017) [10], and can significantly boost metabolism, immunity, and digestibility (Agarwal and Bosco, 2017) [2]. Virgin coconut oil (VCO) provides higher health advantages than the oil obtained from dried copra (Krishna *et al*., 2010) [18]. It has numerous applications in food, medicine, and business. Because it oxidises slowly, it is relatively resistant to rancidity. Coconut oil from dried copra (unrefined grade), Virgin coconut oil (VCO) from fresh kernel meat (unrefined grade), and refined, bleached, and deodorised (RBD) coconut oil are the most common edible coconut oils.

Virgin coconut oil (VCO), a superior version, has gained more relevance due to its nutritional and medicinal benefits and has been used as a functional food component (Marina *et al*., 2009) [24]. Furthermore, Nevin and Rajamohan (2004) [25] discovered that VCO could reduce low-density lipoprotein oxidation. VCO and CO promote metabolism, lower obesity, and have anti-inflammatory, anti-microbial, and antioxidant qualities that protect arteries from atherosclerosis and the human heart from cardiovascular disease, as well as stimulate the immune system. Furthermore, the increased concentration of medium-chain fatty acids (C8-

C12), whose structure is comparable to that of mother's milk, can be used as a substitute to help babies develop immunity against diseases.

VCO is one of the developing products in the Indian oil market, and it is in high demand in both domestic and international markets because of its health benefits and other significant features. India exported 818 MT of VCO to countries such as the United Kingdom, Japan, Australia, the United States, and the Middle East (Anonymous, 2020) [6]. The global market value of virgin coconut oil has risen to 1.15 billion US dollars in 2021, with a projected increase to 1.28 billion US dollars by 2022 (https://www.statista.com/statistics/875977/organic-virgin-coconut). Because of its nutritional benefits and business potential, VCO may be adulterated with ordinary coconut oil or other oils derived from crops or animal sources. Given the commercial potential and nutraceutical value of VCO, it is critical to create quality standards and examine the physico-chemical properties of oils while VCO is being adulterated with low-grade or cheaper oils.

Coconut oil has frequently been adulterated, either accidentally or intentionally due to its high price in comparison to most other oils on the market (Rohman *et al*., 2019) [31]. Food adulteration not only reduces its quality but also has a number of negative health consequences. Adulteration of high-priced premium oils such as Virgin Coconut Oil (VCO) has emerged as a major issue worldwide, in addition to conventional coconut oil. The food safety department banned 70 coconut oil brands in 2018 due to adulteration and false labelling (Anonymous, 2018) [5]. It is critical to determine if the oil sample is pure or contaminated. Because of its growing popularity, coconut oil has been found to be contaminated with a variety of inexpensive oils. Because of its physical and molecular similarities, palm kernel oil (PKO) is one of the most common CO adulterants. Because of their colourless, tasteless, and odourless properties, low price, and simple availability, palm oil and paraffin, as well as mineral oil derived from petroleum, are regarded the most common adulterants in coconut oil (Sheeba *et al*., 2005) [33]. It is also investigated that regular consumption of paraffin oil is hazardous because it promotes liver disorders or possibly cancer in the human system (Libish *et al*., 2011) [19]. To lower the expense of producing pure coconut oil, testa oil, another by product of coconut oil that might be utilised in soap manufacture, is blended with coconut oil. During the oil extraction process, inferior quality rotten copra may be blended with good quality copra. Argemone and cotton seed oil can likewise be employed as coconut oil adulterants. Given these realities, it is critical to comprehend and develop appropriate adulteration detection tools. As a result, detecting adulteration quickly and easily protects the coconut oil market and provides quality products for consumers.

Many analytical approaches could be used to differentiate between oils and discover adulteration. Chromatographic methods, differential scanning calorimetry, Fourier transform infrared spectroscopy, photopyroelectric detection, and others are examples. Although adulteration in VCO due to various oils such as CO and PKO was detected using expensive instruments such as FTIR (Fourier transform infrared spectroscopy) and differential scanning calorimetry, a baseline of information pertaining to changes in the biochemical features of VCO due to adulteration was not performed. Adulteration has been investigated utilising spectroscopy, electron-nose, gas chromatography (GC), FTIR, differential scanning calorimetry, and a variety of other equipment. The majority of these adulteration detection instruments are expensive and demand labour expertise as well as arduous interpretation skills. There is a need to create a simple and low-cost method for detecting adulteration in coconut oil and other oil-based food items. Hence, the purpose of this study is to explore the changes in the physical properties of VCO caused by adulterants such as low-grade vegetable oils or paraffin oil.

Material and Methods

Oil samples

Virgin coconut oil (VCO) extracted by the hot extraction process (Manikantan *et al*., 2016) [22] on the 7th of November 2020 was obtained from the post-harvest technology section of ICAR-CPCRI, Kasaragod, Kerala, India. On the 28th of October 2020, coconut oil (CO) that had just been extracted was purchased from the Kasaragod coconut oil mill. Commercially available palm olein (PO) manufactured during October 2020 was purchased from an open market. Paraffin was also bought from a chemical shop in Mangalore, Karnataka, India.

Preparation of oil blends

Treatment	VCO (%)	CO (%)	PO (%)	Paraffin (%)
T_1	100	0	0	-
T_2	80	20	0	-
T_3	70	30	0	-
T_4	60	40	0	-
T_5	40	60	0	-
T_6	20	80	0	-
T_7	80	0	20	-
T_8	70	0	30	-
T_9	60	0	40	-
T_{10}	40	0	60	-
T_{11}	20	0	80	-
T_{12}	0	80	20	-
T_{13}	0	70	30	-
T_{14}	0	60	40	-
T_{15}	0	40	60	-
T_{16}	0	20	80	-
T_{17}	60	20	20	-
T_{18}	50	25	25	-
T_{19}	40	30	30	-
T_{20}	0	100	0	-
T_{21}	0	0	100	-
T_{22}	90	0	0	10
T_{23}	0	90	0	10

Different levels of oil blends including VCO, CO, and PO, i.e., VCO+CO, VCO+PO, CO+PO, VCO+ liquid paraffin and CO+ liquid paraffin were prepared in addition to a combination with liquid paraffin. There were 23 treatment combinations of oil mixes (both adulterated and pure forms). Each blend was produced in three replicates, sealed in amber glass bottles, and kept at room temperature (25±2 °C) for further investigation. The oil mixes were physically shaken before storage to ensure uniform mixing of the components. The crude oil blends were evaluated without any pre-treatment or dilution with solvents.

Analysis of physical properties

The colour of the different oil blends was measured using the spectrophotometric method (Thimmaiah, 2004) [39]. The oil samples were analysed in a UV- visible recording spectrophotometer (Shimadzu UV-160 A), and the absorbance of the samples at 400 nm was recorded with water as the blank.

MX-50 moisture analyser was used for the analysis of moisture content in oils. The instrument works on the principle of thermo-gravimetric analysis, where the oil (5 g) in aluminium plates is dried due to the action of a halogen lamp, producing a temperature of 105 °C. The percentage of moisture content of the oil is estimated based on the differences between the samples' wet weight and dry weight (Ramesh *et al*., 2020) [29].

Lab Master-a_w neo water activity meter was used to measure the water activity (a_w) of oils. It works on the principle that once the water exchange between free water in the sample and the humidity in the air moves towards equilibrium, the net amount of water exchanged becomes smaller and smaller. The oil (2-3g) was fed to the analyser, and the analysis continued until the measurement value showed no more change than 0.001a_w. (www.novasina.ch)

The refractive index was measured using a hand-held refractometer, which worked on the principle of refraction. One or two drops of oil were placed in the instrument's well and run. A light source illuminated this well, and the light transmitted was interpreted into degree Brix. Those readings were then converted into a refractive index using the conversion table given by Ranganna (2012) [30].

The specific gravity of oils was measured by weighing 1 mL of oil. The pre-weighed 1 mL tip was used for pipetting out of the oil, the weight was measured along with the tip, and specific gravity was calculated using the formula given below (Siebel and Kott, 1937) [34].

$$\text{Specific gravity} = \frac{\text{Density of oil}}{\text{Density of water}}$$

Where,

Density = Mass/Volume

The melting point was determined by the AOCS open capillary tube method with a small modification. Capillary tubes having 1 mm internal diameter and 8 cm length were filled with oil up to 1 cm by capillary action and were kept in a freezer for an hour to allow the oil to solidify. The capillary tube with solidified oil was bound to the thermometer (the base of the capillary tube being equal to the base of the thermometer bulb) and immersed in a beaker with cool water. This beaker was placed on a magnetic stirrer at a medium stirring rate to maintain the uniform temperature while heating. The temperature at which the oil melts and moves upward was considered the melting point of oil (Deman *et al*., 1983) [12]. Oil in a beaker (20 mL oil) was subjected to continuous heating until a bluish smoke was emitted from the oil. The temperature was measured using an infrared contactless thermometer, and this temperature at which the oil emits smoke was considered the smoke point of the oil **(**Alzaa *et al*., 2018) [4].

The viscosity of oils was determined using Brookfield-Amtek, DV Next Rheometer. The instrument worked on the principle of rotational viscometry. It measures the viscosity sensing the torque required to rotate a spindle at a constant speed while immersed in the sample fluid. Oil (200 mL) was taken in a beaker, and the instrument spindle was immersed in the oil. Spindle number 61 was used for the analysis. Speed was set around 150 rpm depending on the maximum torque obtained for each oil sample. The instrument was run for about 5 minutes, and the constant value obtained at a maximum torque was noted.

Eutech TN-100 turbidimetry was used to measure the turbidity of oils, which works on the nephelometric principle of turbidity measurement. Infrared light was used to measure the amount of light scattered by particles suspended in oil samples. The oil was filled in the instrument vial up to the mark and allowed to settle for some time. Then, the vial was placed in the instrument sample well, covered with a cap and measured. Viscosity reading was noted when the value displayed remained constant.

Statistical analysis

The data were subjected to analysis of variance using SAS software version 9.3 (SAS Institute Inc. 2011). The experiment was conducted in a completely randomised design (CRD) followed by the application of Duncan's Multiple range Test (DMRT). Further, multiple linear regression analysis of the data was carried out using the statistical software IBM SPSS statistics version 26 (SPSS Inc., Chicago, IL).

Results and Discussion

Colour (absorbance at 400 nm)

The spectrophotometric measurement of absorbance to study the colour of the oil mixtures showed high absorbance values in T_{21} (PO) (1.668) followed by T_{20} (CO) (0.055) and T_1 (VCO) (0.027) among the pure oils (PO, CO, and VCO respectively). There was a very high significant difference between the absorbance of CO and VCO with PO, but the absorbances between VCO and CO were marginal. No significant differences in absorbance were observed among the blends of VCO+CO, whereas oil blends of VCO+PO and CO+PO showed significant differences among their respective treatments. Figure 1 depicts the increase in the absorbance with the increased level of adulteration in VCO and CO with PO, and also the increase in absorbance with the increased concentration of CO in VCO (Table 1). Also, the absorbance of the samples T_{17} (60VCO+20CO+20PO), T_{18} (50VCO+25CO+25PO), and T_{19} (40VCO+30CO+30PO) were recorded with an increase in adulteration of VCO with both CO and PO (Table 1). By analysing the effect of 10 per cent adulteration with paraffin oil in both VCO and CO oils individually, it was found that there was no significant difference in the absorbance of T_{22} (90VCO+10P) and T_{23} (90CO+10P) compared to T_1 (VCO) and T_{20} (CO) (Table 1).

The spectrophotometric measurement of the colour at 400 nm showed the least absorbance values for T_1 (VCO) (0.027), which supports the findings of Koh and Long (2012), who recorded a similar absorbance value (0.020) in VCO obtained from Malaysia Agriculture Research and Development Institute. The absorbance value obtained for T_{20} (CO) at 400 nm was 0.055, slightly higher than VCO. This difference can be attributed to the transparency or colourlessness of VCO compared to other oils, and also, the presence of testa during the processing of CO could attribute to the slightly higher absorbance. The colour of T_{21} (PO) seemed to be darker than

VCO and CO which could be attributed to the carotenoids present in PO; because of this, the absorbance was also higher (1.668) compared to other oil samples.

Moisture content

There was no significant difference between the moisture content of T_1 (VCO) (0.08%), T_{20} (CO) (0.09%) and T_{21} (PO) (0.08%). Thus, not much variations in the moisture content of different blends of these oil samples were observed (Table 1). Also, no significant differences were found in the moisture content of T_{22} (90VCO+10P) and T_{23} (90CO:10P) when compared to T_1 (VCO) and T_{20} (CO), respectively (Table 1).

The moisture content of pure T_1 (VCO) was 0.08 per cent, whereas T_{20} (CO) showed 0.09 per cent which was in alignment with the findings of Srivastava *et al.* (2016) [37], who observed that the moisture content of VCO and commercial coconut oil were 0.08-0.09 per cent and 0.08 per cent respectively. The values were also within the range of Asian and Pacific coconut community standards for VCO (Anonymous, 2009) [7] and Codex standards for CO (Anonymous, 2019) [8]. The level of moisture content in T_{21} (PO) (0.08%) had no variation from that of T_1 and T_{20}; as a result of which, the various blends of these oils showed no significant difference with respect to moisture content. The same trend was registered in treatments T_{22} (90VCO+10P) and T_{23} (90CO+10P).

Refractive index

The refractive index of T_1 (VCO) (0.1449) was within the range of APCC standards (Anonymous, 2009) and showed no significant difference with T_{20} (CO) (0.1456). However, the RI of T_1 (VCO) (significantly differed from T_{21} (PO) (1.462). On the other hand, among the blends of these oils, no clear significant difference in RI could be found (Table 1). Even with a ten per cent adulteration of VCO and CO with PO, the refractive index of the VCO and CO did not differ significantly (Table 1; Fig. 2).

The refractive index of T_1 (VCO) and T_{20} (CO) were within the range of APCC (Anonymous, 2009) [7] and codex (Anonymous, 2019) [8] standards, respectively. Also, in T_{21} (PO), the value observed was 1.462, which supports the findings of Ariponnammal (2012) [9]. This difference in the RI of PO compared to VCO and CO could be attributed to the higher degree of unsaturation in the fatty acids of PO. This relation was also earlier reported by Abdul-Hammed *et al.* (2020) [1]. The slight variations in the refractive index among the CO and VCO blends showed no significant differences, whereas when CO and VCO were blended with PO, there was a substantial increase in the refractive index with increased levels of PO. This supports the study conducted by Ariponnammal (2012) [9], where the refractive index of CO, when blended with 20 per cent PO, hiked from 1.4540 to 1.4555.

Specific gravity

The specific gravity of T_1 (VCO), T_{20} (CO), and T_{21} (PO) were 0.92, 0.90 and 0.89, respectively. No significant differences between the treatments concerning the specific gravity were documented except between T_1 (VCO) (0.92) and T_{21} (PO) (0.89) (Table 1).

The specific gravity of T_1 (VCO) and T_{20} (CO) was within the range of APCC (Anonymous, 2009) and codex (Anonymous, 2019) standards, respectively. This supports the findings of Dia *et al.* (2005) [13], who also reported the specific gravity of cold and hot pressed VCO samples of different coconut varieties to be ranging from 0.9169 to 0.9193. Also, in T_{21} (PO), it was in line with the findings of Akinola *et al.* (2010) [3], where the specific gravity of palm oils procured from different locations ranged from 0.853 to 0.911. The very small difference between the specific gravities of VCO, CO and PO rendered no much difference between their respective different blends.

Water activity

The water activity of T_{21} (PO) (0.552) was slightly higher than T_{20} (CO) (0.549) and T_1 (VCO) (0.543), although no significant differences among the water activities of any of the treatments were found (Table 1).

Water activity, the ratio of water vapour pressure in a food system to the saturation of water vapour pressure at the temperature of the food system (Shyamaladevi *et al.*, 2016) [38], could be used to predict the microbial activity, which could be the source of spoilage. The lower the water activity, the lesser the growth of microbes. The water activity of all three pure oils, i.e., T_1 (VCO); T_{20} (CO); and T_{21} (PO), were in the range of 0.5. The low water activity in these oils renders them the perk of less or no microbial activity. As there was no significant difference between the water activities of pure CO, VCO, and PO, no apparent difference in the water activity among their blends was observed.

Melting point

The melting points of T_1 (VCO), T_{20} (CO) and T_{21} (PO) were found to be 24 °C, 24˚C, and 19 °C, respectively. Although, a decreasing trend in the MP of CO and VCO blends was observed when they were adulterated with PO at different levels, but none of the treatments differed significantly (Table 1).

The melting point of both T1 (VCO) and T_{20} (CO) were the same, and this trend was also reported by Dia *et al.* (2005) [13], where the MP of cold and hot pressed VCO samples of different coconut varieties ranged from 24 to 25.7˚C and also that of the RBD coconut oil ranged from 24.5 to 25.5 °C. The MP of T_{21} (PO) was lower than that of VCO and CO. This could be attributed to the presence of more unsaturated fatty acids in PO compared to CO and VCO. As there was a minimal range of difference between the melting points of VCO, CO, and PO, no clear distinguishment between the blended samples was observed. It was also observed that the treatments T_{22} and T_{23} showed lower melting points than that of their respective pure oil samples. This might be due to the lower melting point of liquid paraffin.

Smoke point

The smoke point was recorded lowest in T_{20} (CO) (186.13˚C), whereas the treatments T_1 (VCO) (201.53˚C) and T_{21} (PO) (227.97˚C) showed higher smoke points than that of T_{20}. A significant difference in the smoke points of VCO, CO and PO were documented. The smoke points of VCO+CO and VCO+PO blends showed no significant differences, whereas, among the blends of CO+PO, the smoke point values differed significantly when the adulteration level exceeded the threshold of 20 per cent. The smoke point of VCO, CO and PO blends did not differ significantly (Table 1; Fig. 3). Paraffin adulteration at the level of 10 per cent did not show a significant difference, although the smoke point in the

adulterated sample slightly decreased than that of the pure oils (Table 1).

The smoke point of T_1 (VCO) was higher than that of T_{20} (CO). This indicates that the frying quality of VCO is better than CO. The smoke point of T_{21} (PO) was the highest, whose value was closer to the one mentioned by Fan *et al.* (2013) [14]. The decreasing trend in smoke points of different VCO+CO blends with an increase in CO concentration is due to the lower smoking point of CO. In the same way, the increase in smoke points of VCO and CO when blended with PO is because of the higher smoke point of PO. It was also observed that the blends with paraffin oil showed a lower smoke point than that of their pure forms, as the smoke point of liquid paraffin was lower.

Turbidity

The turbidity in T_{20} (CO) was found to be the highest (2.20 NTU), and the lowest (0.14 NTU) was observed in T_{21} (PO), whereas T_1 (VCO) showed turbidity of 0.56 NTU. The turbidity of oil blends at different levels of adulteration varied accordingly. The turbidity in VCO increased when it was adulterated with CO, whereas the turbidity among the blends of VCO+PO and CO+PO decreased with an increased level of adulteration with PO. Significant increases in the turbidity levels of the blends involving VCO+CO, CO+PO and VCO+CO+PO were observed, whereas, in VCO+PO blends, no significant difference was observed (Table 1; Fig. 4).

Turbidity of oil blends, i.e., T_{17} (60VCO+20CO+20PO), T_{18} (50VCO+25CO+25PO), and T_{19} (40VCO+30CO+30PO) showed a significant rise with an increase in CO and PO levels (Table 5). The treatments T_{22} (90VCO+10P), when compared to T_1 (VCO), showed decreased turbidity levels, although not significant, whereas T_{23} (90CO+10P) differed significantly from T_{20} (CO), indicating lower turbidity (Table 5). The turbidity of T_{20} (CO) was more followed by T_1 (VCO) and T_{21} (PO), respectively. This difference could be attributed to the difference in the number of colloidal particles present in the oil samples as a result of the difference in the filtering techniques used during the processing of different oil samples. Pereira *et al.* (2016) [26] also reported that the colour and appearance of purified moringa oil were visually excellent than crude oils, and hence, lower turbidity levels were observed in purified oils. The decreasing trend in the turbidity of different blends of CO with increasing levels of VCO and also among CO+PO blends with increasing levels of PO is due to the lower turbidity of T_1 (VCO) and T_{21} (PO) than T_{20} (CO). Similarly, the turbidity of VCO+PO blends decreased with an increase in the levels of PO. The oil samples of VCO and CO with paraffin oil also showed decreased turbidity levels, which could be attributed to the lower turbidity levels of liquid paraffin.

Viscosity

The treatment T_{21} (PO) (54.44 cP) was found to be more viscous than T_1 (VCO) (37.17 cP) and T_{20} (CO) (38.51 cP). A trend of increase in viscosity was found when VCO was adulterated with PO and CO. Also, no significant differences in the viscosity of oil blends of VCO+CO were observed. It was also found that the viscosity of CO increased significantly as that of VCO when adulterated with PO (Table 1; Fig. 5). The viscosity of blends involving VCO, CO, and PO, i.e., T_{17} (60VCO+20CO+20PO) (40.65 cP), T_{18} (50VCO+25CO+25PO) (41.76 cP), and T_{19} (40VCO+30CO+30PO) (42.73 cP), differed significantly, with an increase in viscosity when VCO was adulterated with a higher quantum of CO and PO (Table 5). A significant increase in the viscosity of the treatments T_{22} (90VCO+10P) and T_{23} (90CO+10P), in which VCO and CO were adulterated with paraffin oil up to 10 per cent, was observed when compared to T_1 (VCO) and T_{20} (CO) respectively (Table 1).

The viscosity of VCO (T_1) was less in this study than the one reported by Mansor *et al*. (2012) [23], where it was in the range of 48.73-50.93 Pa. s. This difference could be due to the environmental temperature difference as the viscosity decreases with the increase in temperature. Also, T_{20} (CO) showed slightly higher viscosity compared to T_1. A similar trend was observed by Singh *et al*. (2010) [35], where the viscosity of crude coconut oil (40.09 cP) was more compared to virgin coconut oil (39.49 cP). The viscosity of PO (T_{21}) was the highest among the different oil samples. De Almeida *et al*. (2021) [11] reported the viscosity of PO to be 43.79 cP at 40 degrees Celsius temperature, which explains that the high viscosity of PO in the present study is due to the lower atmospheric temperature of 31.1 degrees Celsius. Because of this variation in the viscosity of different oils, the trend of viscosity difference among different oil blends was observed to be in accordance with the concentration of different oils within the blends. The viscosity of CO and VCO increased with an increase in the concentration of PO, and the viscosity of VCO also increased with an increase in the concentration of CO among the blends. Similarly, the viscosity of T_{22} (90VCO+10P) and T_{23} (90CO+10P) increased due to the presence of 10 per cent liquid paraffin in VCO and CO, respectively.

Table 1: Physical properties of VCO, CO, PO and P blends at different ratios

Treatment	Colour (abs. at 400nm)	Moisture content (%)	Refractive index	Specific gravity	Water activity	Melting point (˚C)	Smoke point (˚C)	Turbidity (NTU)	Viscosity (cP)
T_1	$0.027^{m}\pm0.002$	$0.080^{c}\pm0.005$	$1.449^{h}\pm0.001$	$0.92^{a}\pm0.006$	0.543 ± 0.005	24.00 ± 0	$201.53^{hi}\pm1.6$	$0.56^{l}\pm0.03$	$37.17^{m}\pm0.28$
T_2	$0.033^{lm}\pm0.001$	$0.080^{c}\pm0.005$	$1.452^{defgh}\pm0.001$	$0.91^{ab}\pm0.006$	0.549 ± 0.006	24.00 ± 0	$199.13^{ij}\pm0.32$	$1.14^{i}\pm0.06$	$37.27^{m}\pm0.02$
T_3	$0.036^{lm}\pm0.003$	$0.093^{a}\pm0.006$	$1.453^{defgh}\pm0.002$	$0.91^{abc}\pm0.010$	0.550 ± 0.006	24.00 ± 0	$198.83^{ijk}\pm0.2$	$1.33^{h}\pm0.05$	$37.42^{lm}\pm0.02$
T_4	$0.040^{lm}\pm0.001$	$0.086^{abc}\pm0.003$	$1.451^{fgh}\pm0.001$	$0.91^{ab}\pm0.006$	0.548 ± 0.001	24.00 ± 0	$194.70^{kl}\pm0.44$	$1.54^{g}\pm0.01$	$37.62^{klm}\pm0.15$
T_5	$0.043^{lm}\pm0.002$	$0.082^{bc}\pm0.003$	$1.452^{defgh}\pm0.001$	$0.91^{ab}\pm0.011$	0.549 ± 0.006	24.00 ± 0	$190.60^{mn}\pm0.45$	$1.66^{f}\pm0.03$	$37.81^{kl}\pm0.06$
T_6	$0.048^{lm}\pm0.002$	$0.086^{abc}\pm0.003$	$1.454^{cdefg}\pm0.001$	$0.91^{abc}\pm0.00$	0.551 ± 0.003	24.00 ± 0	$187.20^{no}\pm0.91$	$1.89^{d}\pm0.01$	$38.06^{k}\pm0.05$
T_7	$0.288^{k}\pm0.007$	$0.093^{a}\pm0.006$	$1.450^{gh}\pm0.001$	$0.91^{abc}\pm0.010$	0.547 ± 0.001	24.00 ± 0	$203.63^{gh}\pm0.6$	$0.45^{m}\pm0.00$	$40.52^{i}\pm0.03$
T_8	$0.420^{i}\pm0.007$	$0.087^{abc}\pm0.004$	$1.452^{defgh}\pm0.001$	$0.90^{bc}\pm0.010$	0.546 ± 0.005	23.00 ± 0	$208.93^{de}\pm0.97$	$0.34^{n}\pm0.01$	$42.45^{g}\pm0.09$
T_9	$0.634^{f}\pm0.005$	$0.083^{bc}\pm0.003$	$1.455^{cdef}\pm0.001$	$0.91^{ab}\pm0.005$	0.547 ± 0.001	23.00 ± 0	$211.97^{cd}\pm0.95$	$0.24^{0}\pm0.02$	$44.12^{e}\pm0.01$
T_{10}	$0.989^{e}\pm0.007$	$0.083^{abc}\pm0.003$	$1.456^{bcd}\pm0.001$	$0.90^{bc}\pm0.00$	0.552 ± 0.004	21.00 ± 0	$214.70^{c}\pm0.66$	$0.21^{op}\pm0$	$47.62^{d}\pm0.10$
T_{11}	$1.325^{c}\pm0.005$	$0.087^{abc}\pm0.003$	$1.456^{bcd}\pm0.001$	$0.90^{bc}\pm0.006$	0.545 ± 0.001	20.00 ± 0	$221.10^{b}\pm0.98$	$0.17^{op}\pm0.06$	$51.62^{b}\pm0.35$
T_{12}	$0.364^{j}\pm0.004$	$0.093^{a}\pm0.003$	$1.455^{cdef}\pm0.001$	$0.91^{abc}\pm0.010$	0.548 ± 0.01	23.00 ± 0	$189.90^{mn}\pm0.72$	$2.08^{b}\pm0.006$	$41.58^{h}\pm0.07$
T_{13}	$0.518^{g}\pm0.010$	$0.083^{bc}\pm0.003$	$1.456^{bcde}\pm0.00$	$0.91^{ab}\pm0.010$	0.552 ± 0.002	22.00 ± 0	$193.23^{lm}\pm1.08$	$1.54^{g}\pm0.006$	$43.48^{f}\pm0.18$

T_{14}	0.652^{f}±0.010	0.093^{a}±0.006	1.457^{bc}±0.001	0.91^{abc}±0.010	0.550±0.01	22.00±0	197.30^{ijkl}±1.57	1.04^{j}±0.006	44.24^{e}±0.22
T_{15}	1.015^{d}±0.010	0.090^{ab}±0.00	1.459^{ab}±0.001	0.91^{bc}±0.010	0.549±0.003	21.00±0	206.53^{ef}±1.45	0.92^{k}±0.00	48.30^{c}±0.17
T_{16}	1.347^{b}±0.010	0.083^{bc}±0.006	1.462^{a}±0.001	0.90^{bc}±0.010	0.549±0.01	20.00±0	214.20^{c}±1.01	0.52^{lm}±0.01	51.56^{b}±0.10
T_{17}	0.358^{j}±0.006	0.090^{ab}±0.002	1.452^{efgh}±0.001	0.91^{ab}±0.005	0.550±0.002	23.00±0	196.67^{jkl}±0.61	1.15^{i}±0.1	40.65^{i}±0.26
T_{18}	0.446^{h}±0.004	0.090^{ab}±0.001	1.452^{defgh}±0.001	0.91^{ab}±0.010	0.548±0.006	22.00±0	199.23^{ij}±1.26	1.51^{g}±0.01	41.76^{h}±0.11
T_{19}	0.519^{g}±0.001	0.087^{abc}±0.004	1.456^{bcd}±0.001	0.90^{bc}±0.010	0.548±0.002	22.00±0	199.53^{hij}±0.72	1.75^{e}±0.01	42.73^{g}±0.04
T_{20}	0.055^{l}±0.004	0.090^{ab}±0.001	1.455^{bcdef}±0.001	0.90^{bc}±0.006	0.549±0.005	24.00±0	185.13^{o}±6.47	2.20^{a}±0.01	38.51^{j}±0.15
T_{21}	1.668^{a}±0.035	0.087^{abc}±0.003	1.462^{a}±0.001	0.89^{c}±0.005	0.552±0.004	19.00±0	227.97^{a}±2.05	0.14^{p}±0.03	54.44^{a}±0.4
T_{22}	0.027^{lm}±0.002	0.086^{abc}±0.003	1.450^{gh}±0.001	0.90^{bc}±0.005	0.540±0.001	22.00±0	199.76^{hij}±1	0.50^{lm}±0.037	41.50^{h}±0.43
T_{23}	0.045^{lm} ± 0.002	0.086^{abc}±0.003	1.456^{bcde}±0.005	0.89^{c}±0.005	0.545±0.003	22.00±0	183.40^{o}±2.19	1.97^{c}±0.06	42.83^{g}±0.30
CD at 1%	0.020	0.008	0.004	0.015	NS	NS	3.869	0.075	0.442

Treatments with significant differences are denoted with dissimilar notations, whereas those with no significant difference are denoted with the same notations as per Duncan's multiple range test (DMRT) at a 99 per cent level of confidence

T_1- 100 VCO: 0 CO: 0 PO T_2- 80 VCO: 20 COT_3- 70 VCO: 30 CO T_4- 60 VCO: 40 CO T_5- 40 VCO: 60 COT_6- 20 VCO: 80 CO T_7- 80 VCO: 20 PO T_8- 70 VCO: 30 PO T_9- 60 VCO: 40 PO T_{10}- 40 VCO: 60 PO T_{11}- 20 VCO: 80 PO T_{12}- 80 CO: 20 PO T_{13}- 70 CO: 30 PO T_{14}- 60 CO: 40 PO T_{15}- 40 CO: 60 PO T_{16}- 20 CO: 80 PO T_{17}-60 VCO: 20 CO: 20 PO T_{18}-50 VCO: 25 CO: 25PO T_{19}-40 VCO: 30 CO: 30 PO T_{20}-0 VCO: 100 CO: 0 PO T_{21}- 0 VCO: 100 PO T_{22}- 90 VCO: 10 P T_{23}- 90 CO: 10 P VCO- virgin coconut oil CO- Coconut oil PO-Palm oil P- Liquid paraffin

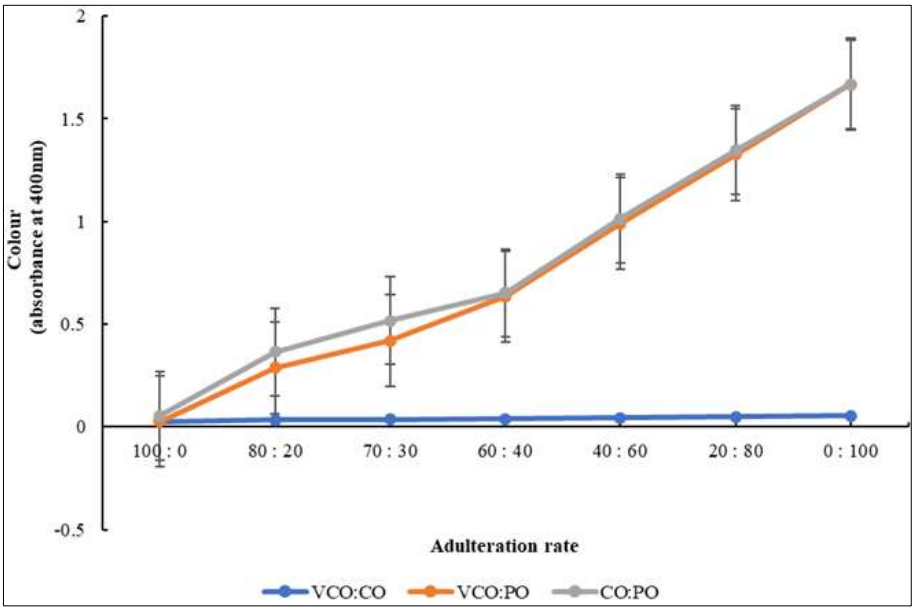

Fig 1: Changes in absorbance among the different VCO, CO, and PO blends

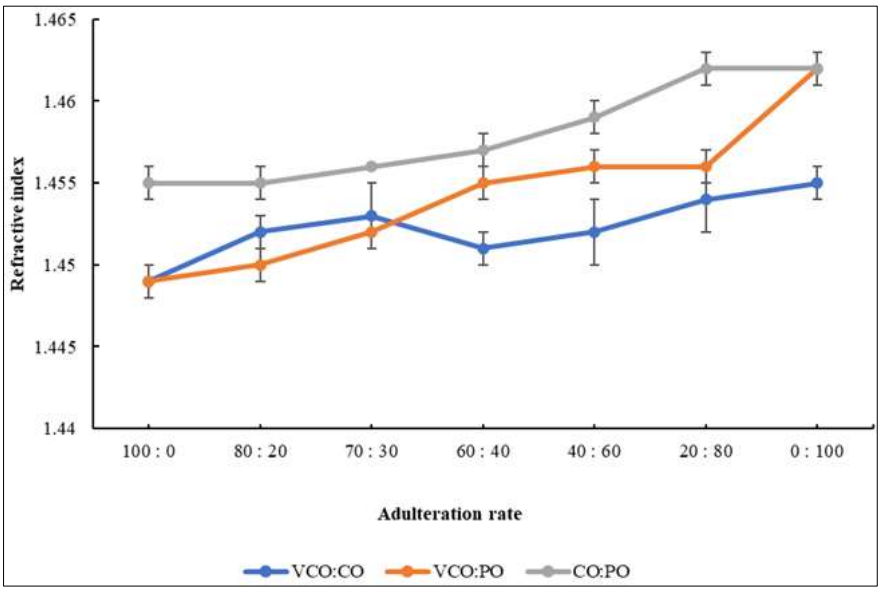

Fig 2: Changes in refractive index among the different VCO, CO, and PO blends

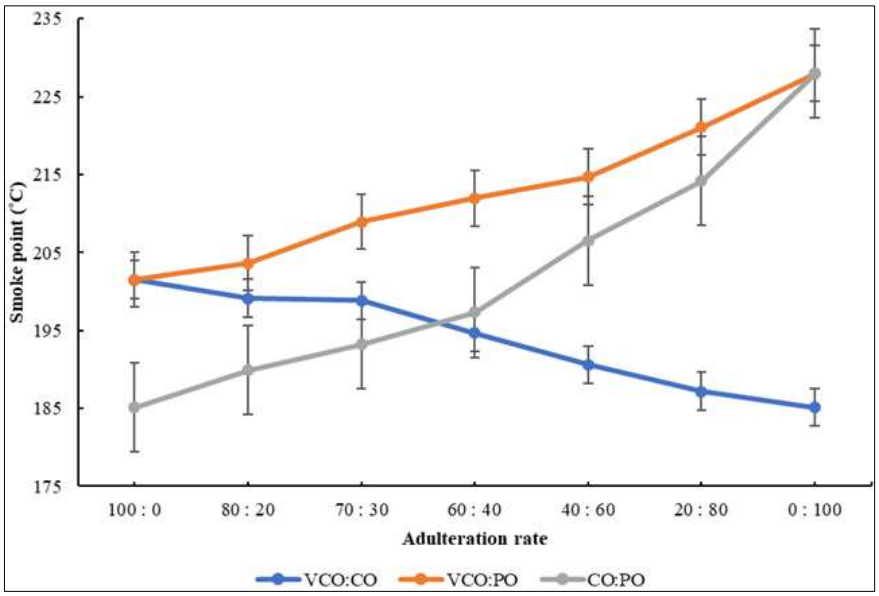

Fig 3: Changes in smoke point among the different VCO, CO, and PO blends

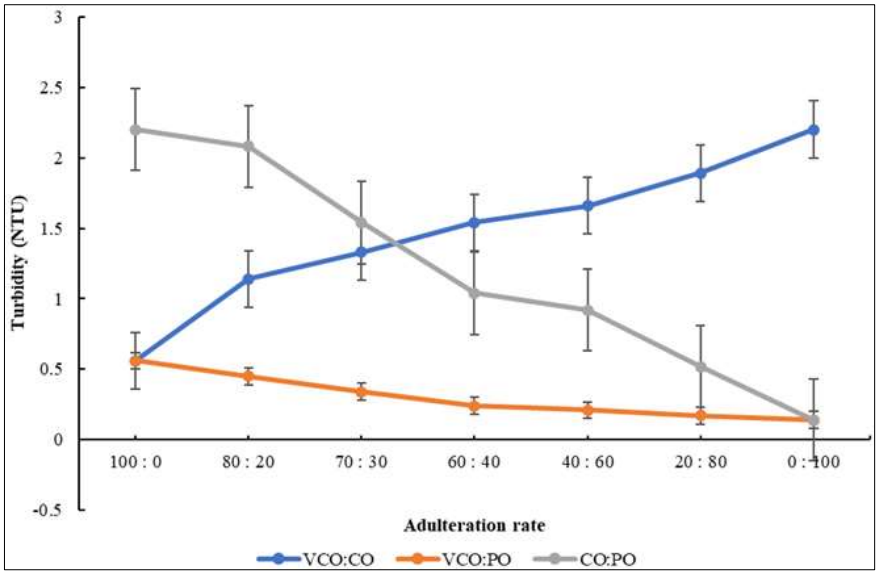

Fig 4: Changes in turbidity among the different VCO, CO, and PO blends

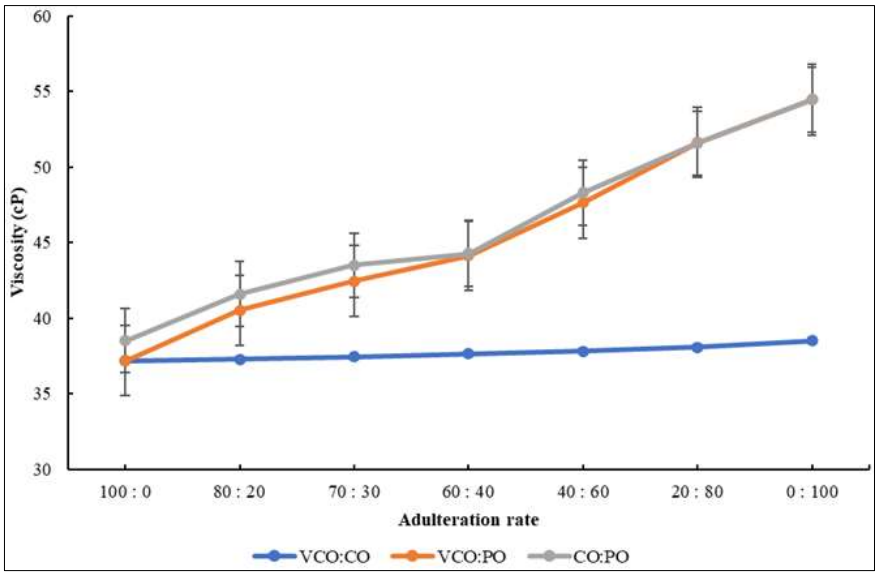

Fig 5: Changes in viscosity among the different VCO, CO, and PO blends

Multiple linear regression analysis

A multiple linear regression analysis was performed for various physical parameters. Colour, refractive index, smoke point, turbidity and viscosity collectively gave a fit regression model (model-5) for different blends of VCO+CO and VCO+PO each with an R^2 value of 1. For the blend of VCO+ liquid paraffin, viscosity alone provide a proper regression model with an R^2 value of 1. These regression models could be reflected as the best suitable fit to detect the levels of purity of the oil by exploiting the equations thus obtained (Table 2).

Table 2: Multiple linear regression models for physical properties of various blends

Model no.	Regression model (% purity)	R-square value	Dubrin-Watson value
VCO+CO			
1	$Y= 203.279 - X_1\ 3720.676$	0.987	3.082
2	$Y= 336.114 - X_1\ 3703.577 - X_2\ 91.929$	0.987	
3	$Y= 3130.475 - X_1\ 1410.213 - X_2\ 2453.257 + X_3\ 2.799$	0.998	
4	$Y= 3457.196 - X_1\ 2033.714 - X_2\ 2645.603 + X_3\ 2.613 + X_4\ 9.547$	0.999	
5	$Y= 7815.197 + X_1\ 7724.864 - X_2\ 3391.377 + X_3\ 2.876 - X_4\ 76.836 - X_5\ 95.430$	1.000	
VCO+PO			
1	$Y= 98.125 - X_1\ 59.20$	0.997	3.650
2	$Y= 227.790 - X_1\ 58.565 - X_2\ 89.481$	0.997	
3	$Y= 6.524 - X_1\ 54.511 + X_2\ 111.395 - X_3\ 0.348$	0.997	
4	$Y= - 337.349 - X_1\ 52.423 + X_2\ 329.374 - X_3\ 0.259 + X_4\ 20.882$	0.998	
5	$Y= 2643.918 + X_1\ 19.426 - X_2\ 1643.643 + X_3\ 0.687 - X_4\ 16.296 - X_5\ 7.851$	1.000	
VCO+ liquid paraffin			
1	$Y= 185.769 - X_5\ 2.308$	1.000	-

Where,

X_1: Colour X_2: Refractive index X_3: Smoke point X_4: Turbidity X_5: Viscosity

Conclusion

The purpose of this study was to investigate the viability of simple approach for detecting adulterants in virgin coconut oil (VCO). VCO is often blended with CO, palm oil, or paraffin oil, whereas CO is merged with PO or paraffin oil. According to the findings of this study, pure CO, VCO, and PO oils have distinct physical properties in terms of colour, moisture, specific gravity, refractive index, water activity, melting point, smoke point, turbidity, and viscosity. It is concluded that the assessment of colour, refractive index, smoke point, turbidity, and viscosity might be used to detect the level of adulteration in VCO and CO with PO and paraffin oil down to 10%. This study suggests that it could aid in the detection of adulteration in VCO and CO using simple technologies rather than expensive apparatus. However, all of these physical parameters may vary with processing methods, and hence variations in the biochemical properties of these oils owing to adulteration may also be encompassed.

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Compliance with Ethical Standards

Declaration of competing interest

The authors declare that they have no conflict of interest.

Author contribution statement

Study design and conceptualization: KBH, V & SVR; investigation: CMB, SVR; data analysis CMB, GSC, VJ, drafting of various sections of the manuscript: All authors and; Read and approved the final version of the manuscript: **All authors**

Data availability statement

All the data described in this research work is available within this manuscript.

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