Original Research Article

Effect of improved cultivars and maturity stage on physical parameters, chemical indices and fatty acid composition of virgin coconut oils from Ivorian coconut germplasm

ABSTRACT

Aims: This study was conducted to evaluate the effect of improved *Cocos nucifera* cultivars and maturity on the physical, chemical indices, and fatty acid composition of virgin coconut oils (VCOs) from Ivorian coconut germplasm for food purposes.

Methodology: Improved coconut cultivars were obtained from the experimental field West Tall African (WAT^+), Rennell Island Tall (RIT^+), and local hybrids ($PB\ 121^+$ and $PB\ 113^+$) were harvested at different stages of maturity :10, 11, and 12 months after pollination. VCOs from Low-heat extraction were obtained from freshly prepared coconut milk. A total of 12 VCOs samples were evaluated for various physico-chemical quality properties.

Place and Duration of Study: Genetics and Plant Breeding Department of the Marc Delorme Coconut Research Station, Southern Côte d'Ivoire 2023.

Results: The two-way ANOVA showed a significant effect ($p < 0.05$) of improved variety and maturity of VCOs on the parameters studied. A high value of yield (82.75%), melting point (24.89 °C), density (0.921), acid value (0.71 mg KOH/g), saponification value (262.83 mg KOH/g), and lauric acid (53.73%) were found for VCO from the improved cultivar WAT^+. Hybrid ($PB121^+$ and $PB113^+$) coconut virgin oils had higher iodine value (11.79 g I_2/100 g), oleic acid (6.61%), and linoleic acid (2.22%) fat compared to Tall (RIT^+ and WAT^+). All the physico-chemical parameters studied increased with full maturity of the coconut at 12 months. All extracted virgin coconut oils were clear in colour, which could be an important feature to attract consumers.

Conclusion: All chemical composition results meet the specifications of several standards, including the Asian Pacific Coconut Community (APCC) and Codex Alimentarius (CODEX STAN 210-1999). This suggests that Ivorian virgin coconut oils could be an effective source of food ingredients that could have a positive impact on the agricultural market, thereby contributing to increasing the income of farming households.

Keywords: improved cultivar, maturity virgin coconut oil, physicochemical, Côte d'Ivoire

1. INTRODUCTION

Cocos nucifera L. is a versatile traditional agroforestry crop in tropical areas that generates significant commercial value. The value of the global market for coconut products was nearly $13 billion in 2019 and could increase to $31 billion by 2024 (Zainol et al., 2023). Virgin coconut oil (VCO) is one of the most important derivatives. The coconut agro-industry plays a significant role in the economic and social development of rural communities, providing a source of food, employment opportunities, livelihoods and sustainable agricultural practices (Mifta et al., 2024). Côte d'Ivoire's coastal region is the main area of coconut production, where

the growth of other crops is inappropriate. Between 1962 and 2010, Côte d'Ivoire introduced a total of 125 coconut palm accessions from all coconut growing regions. The current area under coconut cultivation in Côte d'Ivoire is estimated at around 103,239 ha (FAOSTAT, 2020). The majority of the 53 cultivars developed by the National Agronomic Research Centre are maintained under living conditions in the experimental fields of the Marc Delorme Coconut Research Station, which converted in Genebank for Africa and the Indian Ocean (ICG-AIO). Research has been the main factor in increasing the productivity of coconut plantations. This has led to the development of high-yielding coconut tree varieties through genetic improvement to improve the resistance of the coconut palm to various diseases and to increase productivity and profitability for farmers (Konan et al., 2010). These genetic improvements have increased the kernel mass in the fruit of various cultivars. However, there are limited reports on the physicochemical properties of virgin coconut oil from the improved coconut kernel varieties for food purposes. Virgin coconut oil is a functional oil extracted from fresh mature coconut kernels recognised for its significant use in food and pharmaceuticals (Wickramasinghe & Wickramasinghe, 2023). The oil content in coconut kernel is one of the physical indicators used to assess the oil productivity of the fruit. Thus, the fatty acid composition, chemical and physical indices are the main parameters for evaluating the nutritional quality of virgin coconut oil and its stability to oxidation. The factors influencing the above physico-chemical parameters are related to the varieties, the stage of maturity, the conditions of oil extraction, the conditions of harvesting and the pedoclimatic conditions. In general, the liquid endosperm (coconut water) present in the internal cavity of the fruit transforms into solid endosperm (kernel) from 10 months after pollination, and this continues until the kernel becomes thicker and more solid, which affects the oil extraction yield, which decreases or increases depending on the maturity of the coconut fruit (Kouadio et al., 2023). Lauric acid (C12:0), the most abundant fatty acid in virgin coconut oil, varies from 40 to 63% (Deen et al., 2020) depending on variety and maturity, and this variation can be used to assess oil quality. In addition, within the same coconut variety, be it dwarf, tall or hybrid, there is an intra-variability in the physico-chemical properties of the kernel that influences the quality of the virgin coconut oil. For this reason, quantitative measurements of the physico-chemical parameters virgin coconut oils from four improved coconut varieties at three stages of maturity (10, 11 and 12 months) were subjected to analysis. Multivariate statistical analyses, such as principal component analysis (PCA), were used to study the interactions between multiple cultivars. PCA is widely used to physicochemical data to obtain useful information.

2. MATERIAL AND METHODS

2.1 Area of study

Samples were collected at the Marc Delorme Coconut Research Station of the CNRA (Centre National de Recherche Agronomique), (5°16'-5°15'N, 3°54'-3°55'E, altitude 7-10 m), southern Côte d'Ivoire. The meteorological of the study area has a tropical climate with an annual mean minimum temperature of 25.80 °C (rainy season in June) and a maximum of 28.30 °C (dry season in April). Relative humidity (87.23 ± 1.96%, cv = 2%) and sunshine duration (194.30 ± 40.66 hours, cv = 2.1%) vary slowly. Rainfall (154.60 ± 229.75 mm, cv = 14.9) and water deficit (58.98 ± 63.03 mm, cv = 10.7) are unevenly distributed throughout the year; water deficit is zero during the sampling period, rainfall was abundant enough to meet the water needs of the coconut tree. The geological environment of the study site belongs to the sedimentary basin of Côte d'Ivoire and consists mainly of Tertiary clayey sands and Quaternary coastal sands with a simple geology (Agoh et al., 2021). On the hydrogeological map, the aquifers present are continuous and characteristic of the sedimentary basin. They are the Quaternary aquifer and the Mio-Pliocene (Continental Terminal) and Upper Cretaceous (Maestrichtian) aquifers (Agoh et al., 2021).

2.1 Coconuts cultivar collection

Four improved coconuts cultivars such as West African Tall (WAT^+), Rennell Island Tall (RIT^+), hybrids $PB121^+$ (Malayan Yellow Dwarf × improved West African Tall) and $PB113^+$ (Cameroon Red Dwarf × improved Rennell Island Tall) at three maturity stages (10-11 and 12 months old from pollination) were obtained from the genetics and plant breeding division of the Marc Delorme Coconut Research station of CNRA (Centre National de Recherche Agronomique), Southern Côte d'Ivoire.

2.1 Virgin coconut oil (VCO) low hot extraction process

VCOs were produced from freshly extracted coconut milk of the same batch within 24 h after the harvest of coconuts. The coconut kernels (1000g) free from testa were crushed using a blender (Cleanblend). The crushed coconut kernel was then pressed and filtered through cheese cloth to remove the solid residue and milk was recovered. The solid residue was utilized for second and third milk extraction. The obtained milk was heated on a hot plate at 40°C until the oil appeared and the Maillard reaction began. The obtained oil was filtered through sterilized filter paper (Figure 1)

2.1.1 Calculation of oil recovery

The oil recovery were determined according to Muthukkannan & Balasaravanan (2020) modified method. Oil yield on wet basis percentage (Y %) was calculated as the ratio of the weight of oil recovered to the weight of the milk sample before oil extraction.

$$\text{Oil recovery (Y \%)} = \frac{W_2}{W_1} \times 100$$

*Where **W_2** = weight of oil (g) recovered; **W_1** = weight of coconut milk (g)*

2.1.2 Determination of density

Density bottle method was used in determining the specific gravity of the VCOs. A clean and dry stoppered bottle of 50 mL capacity was weighed (W_0) on analytic balance and then filled with the oil, stoppered and reweighed to give (W_1). The oil was then substituted with distilled water after washing and drying the bottle and weighed to give (W_2). The specific gravity was calculated thus;

$$\text{Density (g/cm}^3\text{)} = \frac{W_1 - W_0}{W_2 - W_0} \times 100$$

*Where **W_0** = weight of empty bottle; **W_1** = weight of bottle + oil; **W_2** = weight of bottle + distilled water.*

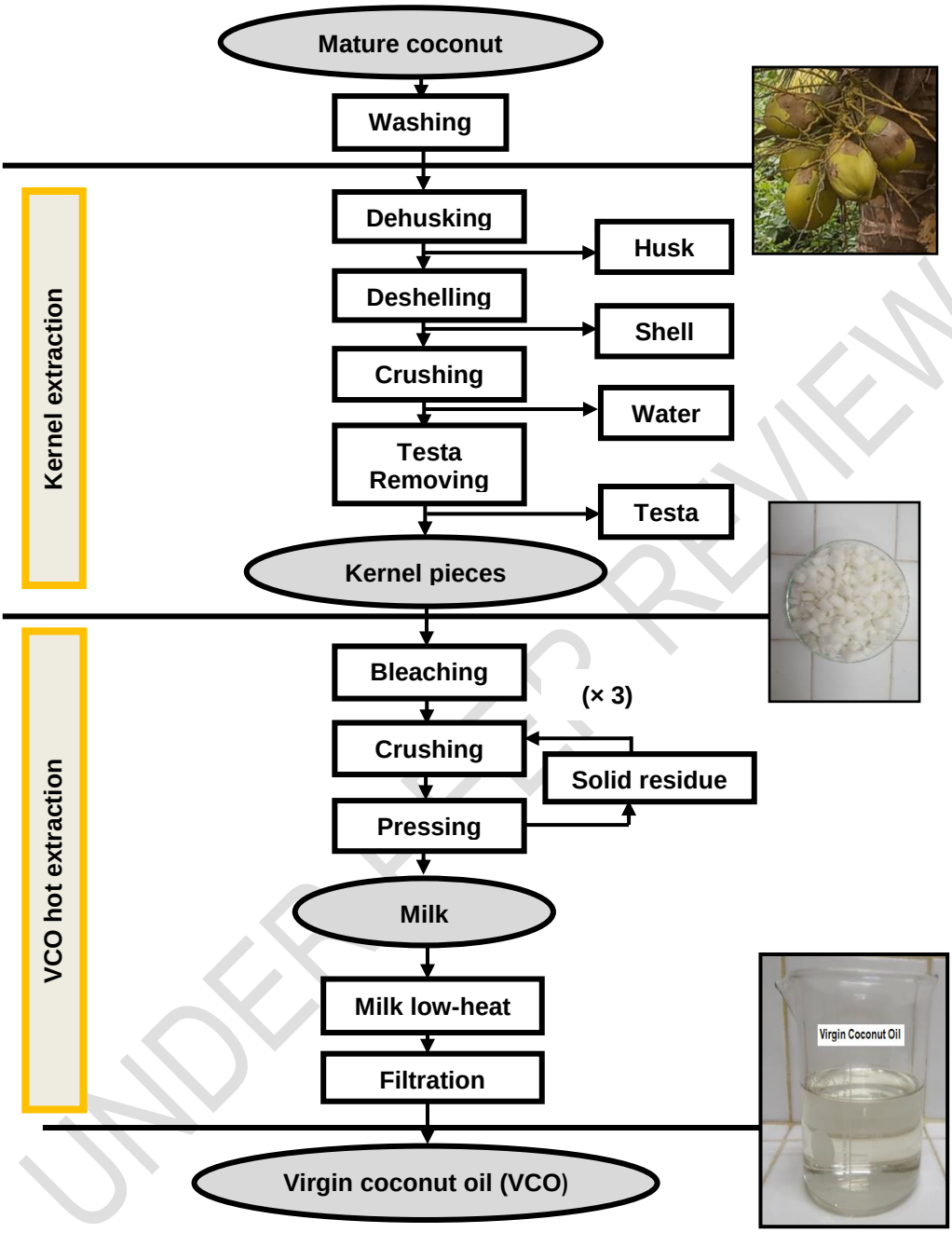

Fig. 1. Virgin coconut oil low-hot extraction process

2.1.3 Determination of acid and iodine values; moisture, free fatty acids, melting point, colour and insoluble impurities by Fourier transform near infrared spectroscopy (PIR-TF)

The Virgin Coconut Oils (VCOs) samples were analyzed using a Near Infrared Spectrometer (MPA BRUKER OPTICS GBMH Near Infrared Spectrometer (NIRS) equipped with OPUSLAB software, 2015 NIR-FTS, model MPA, Bruker, Gmbh, Ettlingen, Germany) (Yéo et al., 2022). This FT-NIR spectrometer is designed for transmittance analysis of a liquid sample. Thereby, 1 mL of VCOs were transferred into 8 mm disposable glass vials and submitted for

FT-NIR transmission analysis. All spectra were recorded in triplicate at 50°C after a thermal preconditioning for 10 min in a separate thermoblock to avoid turbid solutions. Spectra were obtained in transmission mode from 12,500 to 4000 cm^{-1}. Each spectrum was time-averaged based on 32 scans per sample at a resolution of 8 cm^{-1}. Calibration standards of the known oil composition was using as the reference calibration.

2.1.4 Determination of virgin oil peroxide value

Peroxide value of all VCO_S samples was determined by was determined according to the methods described by AOCS (2009). 1.0 g of each VCO_S sample was put in a 250 mL closed Erlenmeyer flask. Next, 15 mL of acetic acid, 10 mL of chloroform and 1 mL of saturated potassium iodide solution. The mixture was then incubated in the dark for 5 minutes at room temperature, followed by addition of 75 mL of distilled water. Finally, the solution was titrated with 0.01 N sodium thiosulfate solution ($Na_2S_2O_3$) with 0.5 mL of 1% starch solution as an indicator until the color just disappears. A blank test was carried out under the same conditions replacing VCO_S by distilled water. The calculation of peroxide index (meq O_2/kg of oil) was given by the following formula:

$$\text{Peroxide value} = \frac{(V_0 - V_1) \times N \times 1000}{\text{Weight of sample (g)}}$$

*Where V_0 = Volume of titration $Na_2S_2O_3$ of blank, V_1= Volume of titration $Na_2S_2O_3$ of sample; **N** = Normality of $Na_2S_2O_3$*

2.1.5 Determination of VCOs saponification value

The saponification value (SV) of the VCO_S was determined according to the AOCS method (AOCS, 2009). About 1.0 g of VCO_S sample was mixed with 25 mL of 0.5 N ethanolic KOH, and the mixture was boiled for 60 min in a reflux condenser. The mixture was then cooled down to room temperature and subsequently titrated with 0.5 N HCl using 1% phenolphthalein solution as an indicator until the color of the mixture changed from pink to colorless. The volume (V_1) of spent HCl was recorded. A control was carried out by mixing 1 mL of distilled water and 25 mL of ethanolic KOH in the same experimental conditions of the sample by determining the volume (V_0) of the titration. The calculation of the saponification index was carried out according to this equation:

$$\text{Saponification value} = \frac{(V_0 - V_1)\text{mL of HCL} \times M \times 56.1}{\text{Weight of sample (g)}}$$

*Where, V_0 = Volume of titration of blank, V_1 = Volume of titration HCl of sample, **M** = molarity of the HCl and **56.1** = molecular weight of KOH.*

2.1.6 Fatty acids (FAs) Composition

The quantitation method of FAs was performed as Laffargue et al. (2007) method. FAs, after being converted into methyl esters, were analysed by gas chromatography (Thermo Scientific Focus GC) using a capillary column of 30 mm length, 0.25 mm inner diameter and 0.32 mm thickness. The fatty acids were identified by comparison with the retention time of the corresponding standards. Integration of the chromatograms obtained was carried out using Chromcard Data System software version 2.4.1. The results are expressed as a percentage

of total FA. The conditions for chromatographic analysis were as follows: oven temperature ≤ 50 °C; injector temperature 165 °C; detector temperature 250 °C; carrier gas (N_2); flow rate 20 $mL.min^{-1}$. The relative contents of the main FAs in VCOs were calculated based on the peak area normalization method, expressed as percentages of total FAs (%).

2.1.7 Statistical Analysis

Measurements were carried out in triplicate. All data analyses including mean, standard deviation was calculated. The two-way analysis of variance ANOVA using full data set was performed to consider the main effects of cultivar, maturity stage and their interactions on physicochemical parameters. Analyses were run with the statistical software XLSAT. After rejecting the null hypothesis (P = 0.05), statistical differences between the groups were compared by post hoc test using the Student Newman Keuls test for multiple comparisons within mean. The correlation between the mean values of each parameter was expressed using Pearson's correlation coefficient. R-function "corrplot" was used to compute to plot a correlogram. A multivariate analysis approach using XLSTAT (Addinsoft, New York, USA) was applied to analyse the relationships between VCOs of different coconut varieties according to their maturity stage with the measured physicochemical variables.

3. RESULTS AND DISCUSSION

Edible vegetable oils are an essential part of the human diet. They contain triglycerides, a major component of lipids, which, when hydrolysed, produce fatty acids. These fatty acids are important components in the human body and play various structural, biological, and functional roles (Nagy et al., 2017). As the nutritional composition of edible vegetable oils varies according to their source, it is necessary to characterise these oils. Oil was extracted from the coconut kernel milk of the four improved cultivars according to three maturity levels in order to know their qualities. Various physical and chemical parameters were used to monitor the compositional quality of the edible oils (Ng et al., 2021). This study was then carried out to determine the physical properties, chemical indices, and fatty acid composition of these oils. According to Jack, virgin coconut oil (VCO) is the clear coconut oil obtained from fresh mature coconut kernel milk by wet or hot extraction without chemical refining, bleaching, or deodorisation, which is ready for consumption (Ng et al., 2021; Pathirana et al., 2021). In the present study, based on the analysis of variance results, a significant effect of improved cultivar and maturity stage was observed on all the physico-chemical parameters. The effect of cultivar can be explained by the existing genetic variability in coconut (COGENT, 2017). Regarding the effect of maturity stage, this is due to the fact that during coconut ripening, many enzymes and genes are associated with specific metabolic or biosynthetic pathways of carbohydrates, fatty acids, or secondary metabolites, which regulate and play an important role in the transformation of coconut liquid endosperm into solid endosperm present in the inner cavity of the fruit (Yousefi et al., 2023).

3.1. Virgin Coconut oil physical quality characteristics

The results of the analysis of the physical quality parameters of virgin coconut oil (VCO) obtained for the four cultivars considered are presented in Table 1.

3.1.1. Virgin coconut oil recovery

Virgin coconut oil (VCO) yield is generally one of the most important parameters in VCO extraction (Sundrasegaran & Mah, 2020). In this study, the results of oil yield in coconut milk showed a significant effect (P = 0.05) of cultivar and maturity stage according to the results of the analysis of variance test in Table 1. Oil recovery in milk was greater than 50% when extracted from 12-month-old kernels for all cultivars, particularly for oil from WAT^+, a tall coconut cultivar known for its high oil content. This is explained by the fact that at 12 months

the kernel becomes thicker and more fibrous, allowing the oil to accumulate in the kernel. This suggests that the resulting coconut milk emulsion from WAT$^+$ contains more oil droplets remaining after evaporation of the aqueous phase during heating (Patil et al., 2016; Penprapai & Intharit, 2017). The oil yields found (44.30 - 82.75%) are high compared to those of other cultivars (58.47 - 59.83) (Pathirana et al., 2021). Previous work by Patil et al. (2016) also showed a significant effect of maturity stage on oil yield using the enzymatic extraction method, with a yield of 84.45% for 12-month mature nuts. Other methods conducted by Ghani et al. (2018) resulted in lower yields, ranging from 9.43% to 47.92%. The improved cultivar WAT$^+$ would therefore be suitable for the production of virgin coconut oil due to its better oil extractability. In fact, the oil yield depends on the cultivar used, the maturity of the nut and the extraction method, which are the parameters that influence the oil yield. In this study, hot extraction of virgin coconut oil (VCO) at low temperature (40°C) by boiling the coconut milk evaporates the water to obtain the oil, avoiding the Maillard reaction. According to Sundrasegaran & Mah (2020) and Rohman et al. (2021), hot extraction of virgin coconut oil, as we have done, increases the oil yield in a shorter time, releases a large amount of phenolic compounds, gives a pleasant aroma, and allows a long shelf life.

3.1.2. Density

Density is a key factor influencing oil absorption, as it affects the drainage rate after frying, the mass transfer rate during the cooling phase of frying (Sahasrabudhe et al., 2017), and allows the determination of oil quality and purityl (Rodríguez-Blázquez et al., 2023). The density of the oil depends on its molecular weight, unsaturation, free fatty acid content, water and total solids content, and temperature (Alemayhu et al., 2019; Ng et al., 2021). Based on the results of the analysis of variance test, cultivar and maturity stage had a significant effect (P = 0.05) on moisture content in Table 1. The HVC density measured at ambient temperature varied between 0.901 and 0.921 g/cm^3. The similarity between hybrid PB113$^+$ and PB121$^+$ oils is probably due to their similar fatty acid content.

Table 1. Effect of cultivar and stage of maturity on yield, density, slip melting point, moisture of virgin coconut oil

Cultivar	maturity	Yield (%)	Density (g/cm^3)	SMP ºC	Moisture (%)
RIT$^+$	**10**	44.30 ± 1.46^{j}	0.905 ± 0.005^{bc}	23.09 ± 0.04^{d}	0.122 ± 0.004^{ab}
	11	58.21 ± 1.39^{gh}	0.914 ± 0.003^{ab}	23.06 ± 0.08^{d}	0.098 ± 0.001^{c}
	12	63.22 ± 1.12^{e}	0.919 ± 0.005^{a}	23.21 ± 0.07^{d}	0.095 ± 0.001^{c}
WAT$^+$	**10**	55.89 ± 2.27^{hi}	0.901 ± 0.001^{c}	23.65 ± 0.11^{c}	0.096 ± 0.001
	11	78.09 ± 2.24^{b}	0.915 ± 0.007^{ab}	24.68 ± 0.05^{ab}	0.094 ± 0.001^{c}
	12	82.75 ± 2.47^{a}	0.921 ± 0.005^{a}	24.89 ± 0.24^{a}	0.094 ± 0.001^{c}
PB113$^+$	**10**	49.02 ± 1.08^{i}	0.903 ± 0.003^{bc}	24.25 ± 0.35^{b}	0.123 ± 0.004^{a}
	11	55.76 ± 1.05^{hi}	0.913 ± 0.003^{abc}	24.59 ± 0.16^{ab}	0.119 ± 0.003^{ab}
	12	67.85 ± 0.50^{d}	0.916 ± 0.002^{ab}	24.51 ± 0.03^{ab}	0.118 ± 0.001^{ab}
PB121$^+$	**10**	50.26 ± 1.07^{i}	0.903 ± 0.001^{bc}	24.32 ± 0.15^{b}	0.118 ± 0.001^{ab}
	11	60.28 ± 1.72^{fg}	0.909 ± 0.002^{abc}	24.20 ± 0.14^{b}	0.117 ± 0.000^{ab}
	12	72.30 ± 1.70^{c}	0.913 ± 0.004^{abc}	24.13 ± 0.18^{b}	0.117 ± 0.002^{b}
Statistical significance from ANOVA					
Cultivar (C)		<0.0001	ns	<0.0001	<0.0001
Maturity (M)		<0.0001	<0.0001	<0.001	<0.0001
C×M		<0.001	ns	<0.0001	<0.0001

***(+):** improved, **WAT:** West African Tall, **RIT:** Rennell Island Tall, **PB:** Port-Bouët, **SMP:** slip melting point, **PB:** Port-Bouët, **ns:** Not Statistically Significant. Values are expressed as Mean ± Standard deviation. Mean values in the same column with different superscript letters were significantly different (P = 0.05).*

These established values are close to those of canola oil (913.3 kg/m^3), corn oil (915.3 kg/m^3), olive oil (908.7 kg/m^3), peanut oil (912.1 kg/m3), and soybean oil (915.7 kg/m^3) established by Sahasrabudhe et al. (2017) and are in line with the standard values (0.915 to 0.920 g/mL) of the Asian and Pacific Coconut Community (APCC, 2009). Based on the results of the analysis of variance test, only maturity stage had a significant effect on specific gravity ($p < 0.05$). The high density of VCO compared to some oils is due to its high saturation and polymerisation (Ghani et al., 2018), as established for VCO from WAT+. Oils with a low density value indicate a low total liposoluble content, which is suitable for the extraction of low-density oils. According to Zahir et al. (2017), oils with low density values are very noticeable to consumers.

3.1.3. Slip melting point

Based on the results of the analysis of variance test, cultivar and maturity stage had a significant effect on the melting point content ($P = 0.05$). The slip melting points (SMP) of the oil samples in this study (23.06 to 24.89 °C) in Table 1 are similar to those found by Patil et al. (2016), which ranged from 23.30 to 24.87. The slip melting point values were within the recommended CODEX standard of ≤2 4C for virgin coconut oil(Codex alimentarius commission, 1999). These values were within the recommended CODEX standard of ≤ 24 °C for virgin coconut oil. The slip melting point of an oil varies according to the structure of its fatty acids (chain length, number of double bonds, and type of isomer). Oils rich in saturated fatty acids, which have a higher melting point, are generally solid at room temperature, while those containing unsaturated fatty acids have low melting point values and are liquid at room temperature (Chouikh, 2016). For example, PB121$^+$ and PB113$^+$ hybrids, whose fatty acid profiles show a higher proportion of unsaturated fatty acids (oleic and linoleic), have lower melting point values than virgin oils from Grand cultivars (WAT$^+$ and RIT+). According to Martins et al. (2020), oils rich in lauric acid, such as coconut oil, are resistant to non-enzymatic oxidation and have a low melting temperature, unlike other oils and fats. This property helps to provide a good solid support for margarines and shortenings (Akusu & Wordu, 2019).

Table 2. of cultivar and stage of maturity on soluble impurity and lovibond colors of virgin coconut oils

Cultivar	maturity	Insoluble impurities	Lovibond	
			Red	Yellow
RIT$^+$	**10**	0.048 ± 0.001^{a}	0.106 ± 0.001^{abc}	0.481 ± 0.008^{b}
	11	0.046 ± 0.000^{ab}	0.107 ± 0.001^{ab}	0.487 ± 0.005^{b}
	12	0.045 ± 0.001^{abc}	0.108 ± 0.001^{ab}	0.491 ± 0.005^{b}
WAT$^+$	**10**	0.042 ± 0.003^{bcd}	0.105 ± 0.002^{abc}	0.486 ± 0.002^{b}
	11	0.039 ± 0.001^{cde}	0.106 ± 0.002^{abc}	0.506 ± 0.011^{a}
	12	0.039 ± 0.001^{de}	0.112 ± 0.002^{a}	0.514 ± 0.002^{a}
PB113$^+$	**10**	0.042 ± 0.000 ^{bcd}	0.094 ± 0.004^{e}	0.392 ± 0.001^{d}
	11	0.041 ± 0.001^{bcde}	0.100 ± 0.002^{cd}	0.418 ± 0.002^{c}
	12	0.035 ± 0.001^{e}	0.103 ± 0.001^{bc}	0.418 ± 0.001^{c}
PB121$^+$	**10**	0.043 ± 0.002^{bcd}	0.098 ± 0.001^{d}	0.306 ± 0.002^{e}
	11	0.040 ± 0.001^{cde}	0.106 ± 0.001^{abc}	0.315 ± 0.001^{e}
	12	0.039 ± 0.004^{de}	0.107 ± 0.000^{abc}	0.317 ± 0.001^{e}
Statistical significance from ANOVA				
Cultivar (C)		<0.0001	<0.0001	<0.0001
Maturity (M)		<0.001	<0.0001	<0.001
C×M		ns	<0.05	ns

(+): *improved,* ***WAT:*** *West African Tall,* ***RIT:*** *Rennell Island Tall,* ***PB:*** *Port-Bouët,* ***ns:*** *Not statistically significant. Values are expressed as Mean ± Standard deviation. Mean values in the same column with different superscript letters were significantly different (P = 0.05).*

3.1.4. Colour

Colour is an important quality parameter of edible oils, both during the refining process and when they are marketed. Each oil has its own characteristic colour, mainly due to the presence of carotenoids and/or chlorophyll pigments (Fengxia et al., 2001). he colours of the extracted VCOs at different stages of maturity, expressed as red and yellow values, are shown in Table 1. All analysed VCOs were clear with Lovibond red value (0.09 - 0.11) and yellow value (0.031 - 0.51) as mentioned by previous authors (Kamariah et al., 2008; Srivastava et al., 2016; Wickramasinghe & Wickramasinghe, 2023). Based on the results of the analysis of variance test, cultivar and maturity stage had a significant effect on colour content ($p < 0.05$). This is probably due to extraction at low temperature (Satheeshan et al., 2019; Wickramasinghe & Wickramasinghe, 2023). According to Patil et al. (2016), coconut oil in its virgin form is clear in colour with a distinct coconut flavour and aroma. However, excessive heat during the process of extracting the virgin oil can cause the oil to become more yellow in colour. The pale yellow colour of coconut oil is due to the beta-carotene present in the oil, which becomes more intense when the testa is added during extraction. This indicates that these oils are suitable for use and have not undergone any oxidation process. However, prolonged exposure to high heat during cooking could result in polymerisation, browning due to caramelisation, and Maillard reactions, and the oil would therefore have a less clear colour with pronounced colour indices (red and yellow) (Wickramasinghe & Wickramasinghe, 2023).

3.1.5. Moisture

Moisture content is a critical parameter for the quality of VCOs. A low moisture content in the oil indicates good stability and resistance to microbial degradation during storage (Alemayhu et al., 2019; Azevedo et al., 2020). In contrast, a large amount of water in the oil promotes a hydrolysis reaction. This hydrolysis contributes to the formation of free fatty acids that cause vegetable oils to become rancid. The moisture content of the VCO samples was found to be in the range of 0.094 to 0.122%. Based on the results of the analysis of variance test, cultivar and maturity stage had a significant effect on moisture content ($p < 0.05$). VCOs extracted by hot extraction methods have a low moisture content due to the hot conditions that significantly remove water components from the VCOs (Mohammed et al., 2021). The residual water content of VCOs in this study is slightly lower than that of VCOs extracted by Ghani et al. (2018) using cooling and centrifugation, fermentation, and drying methods (0.10-0.17%). Low water content is a prerequisite for long-term preservation of oils, as high water content leads to bacterial contamination, which can initially hydrolyse triglyceride molecules and subsequently cause rancidity (Asiah et al., 2019; Negash et al., 2019). In this study, the low water content indicates that oils from these cultivars are less susceptible to oxidation and rancidity processes, thus ensuring the long-term preservation of these oils. The moisture values obtained in this study are in line with the WHO/FAO guideline on the quality of edible oils, where the maximum moisture limit should be 0.2% (Codex alimentarius commission, 1999).

3.2. Edible virgin Coconut oil chemical quality characteristics

The determination of parameters such as iodine value (degree of unsaturation), peroxide value (formation of primary oxidation products), and acid value (formation of free fatty acids due to rancidity) are crucial parameters in assessing the quality of oils (Geng et al., 2023). The results of the analysis of the physical quality parameters of virgin coconut oil (VCO) obtained for the four cultivars at different stages of maturity are presented in Table 2.

3.2.1. The acid value and the free fatty acid

The acid value and the free fatty acid content are two parameters that are positively correlated. The acid value is a measure of the free fatty acids (FFAs) present in the fat (Arlee et al., 2013). FFAs are harmful to health due to their lipotoxic activity. The acid values (0.51 to 0.71% lauric acid) and free fatty acids (0.17 to 0.22 mg KOH/g) of the analysed VCOs were found to be lower. Based on the results of the analysis of variance test, only improved variety had a significant effect on FFA ($p < 0.05$), while both variety and maturity factors influenced oil acidity. FFAs in oils, resulting from the hydrolysis of triacylglycerols, are naturally present in oils at very low levels. During extraction and storage, these levels can increase due to residual moisture in the oil (Wickramasinghe & Wickramasinghe, 2023). FFA is an indicator of the hydrolytic rancidity of the oil; its high level is not acceptable as it causes undesirable flavour, taste, and aroma in the oil. Consumption of oil with high FFA content is harmful to the body due to lipotoxic activity. The FFA levels in this study (0.20-0.25%) are in line with the standard limit (<0.5%) for FFA according to APCC (2009). Although the APCC and Codex do not specify acid number, these values (0.58-0.71%) are similar to those (0.307-0.900) reported by Ramesh et al. (2020) using different extraction methods. The low free fatty acid content of the VCOs found here indicates the suitability of these VCOs for edible purposes, which are more stable and have a longer shelf life.

3.2.2. Iodine value

All oils are formed from molecules called fatty acids. These molecules can be divided into three categories according to their degree of saturation: saturated fatty acids, monounsaturated fatty acids, and polyunsaturated fatty acids. The iodine value is a parameter used to determine the overall degree of unsaturation of an oil sample. Its determination is important because it allows the quality and functionality of an oil to be assessed (Mohammed et al., 2021). In this study, the iodine values obtained for all the VCOs samples ranged from 7.54 to 11.73 g I2/100 g, which is within the limits (4 to 11 g I_2/100 g) of the APCC (2009). Based on the results of the analysis of variance test, cultivar and maturity stage had a significant effect on the iodine value ($p < 0.05$). The high iodine values of hybrid oils ($PB113^+$ and $PB121^+$) indicate that they contain more unsaturated fatty acids than others, which is beneficial for health. However, due to their unsaturated fatty acid content, virgin oils from hybrids may be susceptible to β-oxidative degradation due to their double bond (C=C), unlike oils from WAT^+ and RIT^+ cultivars, which are more resistant. Although coconut oil is high in saturated fats (92%), it also contains a significant amount of unsaturated fats (6% monounsaturated fats and 2% polyunsaturated fats) (Appaiah et al., 2014). The lower iodine value of VCOs oils indicates good resistance to oxidative damage compared to other seed oils, which could be an advantage for long-term storage. Ahmad et al. previous studies on West African Tall kernel oil in Malaysia had shown a higher iodine index of 12.28 ± 0.66 I_2/100 g (Ahmad et al., 2015).

Table 3. Effect of cultivar and stage of maturity on acid value, free fatty acids and iodine value of virgin coconut oils

Cultivar	maturity	Acid (mg KOH/g)	Free Fatty Acids (%)	Iodine (g of I_2/100g)
RIT^+	**10**	0.51 ± 0.02^{f}	0.17 ± 0.01^{d}	7.80 ± 0.23^{h}
	11	0.53 ± 0.01^{e}	0.19 ± 0.00	8.35 ± 0.16^{fg}
	12	0.55 ± 0.01^{e}	0.20 ± 0.00^{bc}	8.90 ± 0.02^{de}
WAT^+	**10**	0.65 ± 0.01^{c}	0.21 ± 0.01^{a}	7.54 ± 0.25^{h}
	11	0.69 ± 0.00^{b}	0.21 ± 0.01^{ab}	8.02 ± 0.19^{gh}

	12	0.71 ± 0.01^{a}	0.22 ± 0.01^{a}	8.64 ± 0.06^{ef}
PB113^{+}	**10**	0.56 ± 0.01^{de}	0.19 ± 0.01^{abc}	9.19 ± 0.19^{d}
	11	0.58 ± 0.01^{d}	0.20 ± 0.01^{cd}	10.20 ± 0.27^{c}
	12	0.59 ± 0.01^{d}	0.21 ± 0.00^{abc}	10.90 ± 0.26^{b}
PB121^{+}	**10**	0.54 ± 0.01^{e}	0.17 ± 0.00^{d}	9.95 ± 0.12^{c}
	11	0.56 ± 0.01^{de}	0.21 ± 0.00^{abc}	10.99 ± 0.16^{b}
	12	0.58 ± 0.00^{d}	0.22 ± 0.00^{a}	11.73 ± 0.14^{a}
Statistical significance from ANOVA				
Cultivar (C)		<0.0001	<0.0001	<0.0001
Maturity (M)		<0.0001	<0.001	<0.0001
C×M		<ns	<0.05	ns

(+): *improved,* ***WAT:*** *West African Tall,* ***RIT:*** *Rennell Island Tall,* ***PB:*** *Port-Bouët,* ***ns:*** *Not statistically significant. Values are expressed as Mean ± Standard deviation. Mean values in the same column with different superscript letters were significantly different (P = 0.05).*

3.2.3. Peroxyde value

The peroxide value (PV) is used to estimate the degree of rancidity of the oil caused by atmospheric oxygen. It is an oil quality criterion that also indicates primary oxidation, i.e., autoxidation (oxidation with triplet oxygen), photooxidation (oxidation with singlet oxygen), and enzymatic oxidation of the oil. This leads to the formation of unpleasant compounds (ketones, alcohols, aldehydes, acids, esters, epoxides, hydrocarbons, hydroperoxides, and free radicals) that affect the quality of the oil and cause a deterioration in its taste and smell, some of which are known to be harmful to health (Rodriguez-Amaya & Shahidi, 2021). The mean peroxide values of VCO samples in this study ranged from 1.15 to 1.35 meq O2/kg, which are lower compared to the values reported by Ghani et al. (2018) from different extraction methods, including cooling and centrifugation, fermentation, and direct microextrusion. Based on the results of the variance test, coconut variety and maturity stage had a significant effect ($p < 0.05$) on the peroxide value. According to Alemayhu et al. (2019), fresh oils typically have peroxide values well below 10 meq/kg. This shows that the VCO extraction method used in this study is suitable for long-term storage. Considering the peroxide value as an indicator of the degree of oxidation or rancidity of oils, the values found in the study are below the maximum acceptable limits of the WHO/FAO (10 meq O_2/kg) and the limit (<3 meq O_2/kg) of the APCC (2009) for virgin oils, indicating that these VCOs have a high oxidative stability, allowing them to be used for consumption. However, light, oxygen and metal content, and fatty acid composition affect the formation of peroxides in oils, so quality analysis during storage is necessary to check the formation of these peroxides over time (Wickramasinghe & Wickramasinghe, 2023).

Table 4. Effect of cultivar and stage of maturity on saponification value, peroxide value and deterioration of bleachability index of virgin coconut oils

Cultivar	maturity	Saponification (mg KOH/g)	Peroxide (meq O_2/kg)	DOBI
RIT^{+}	**10**	237.22 ± 3.14^{f}	1.15 ± 0.03^{f}	6.43 ± 0.21^{e}
	11	245.05 ± 1.78^{e}	1.24 ± 0.01^{cd}	6.83 ± 0.21^{d}
	12	257.47 ± 0.88^{b}	1.31 ± 0.01^{ab}	7.21 ± 0.15^{cd}
WAT^{+}	**10**	244.30 ± 2.40^{e}	1.20 ± 0.01^{efg}	7.57 ± 0.13^{bc}
	11	250.99 ± 1.40^{cd}	1.27 ± 0.01^{bc}	8.45 ± 0.18^{a}
	12	262.83 ± 0.50^{a}	1.35 ± 0.01^{a}	8.70 ± 0.16^{a}
PB113^{+}	**10**	244.90 ± 1.27^{e}	1.19 ± 0.04^{efg}	7.01 ± 0.15^{d}
	11	247.73 ± 0.75^{de}	1.23 ± 0.01^{cde}	7.64 ± 0.19^{bc}
	12	251.82 ± 0.87^{cd}	1.28 ± 0.01^{bc}	7.77 ± 0.11^{b}

PB121^{+}	**10**	243.60 ± 2.26^{e}	1.18 ± 0.02^{ef}	6.85 ± 0.07^{d}
	11	250.19 ± 1.14^{cd}	1.23 ± 0.01^{cde}	7.63 ± 0.11^{bc}
	12	254.64 ± 0.91^{bc}	1.27 ± 0.01^{bc}	7.82 ± 0.04^{b}
Statistical significance from ANOVA				
Cultivar (C)		<0.0001	<0.0001	<0.0001
Maturity (M)		<0.001	<0.0001	<0.0001
C×M		<0.05	ns	ns

***(+):** improved, **WAT:** West African Tall, **RIT:** Rennell Island Tall, **PB:** Port-Bouët, **DOBI :** Deterioration of bleachability index, **ns:** Not statistically significant. Values are expressed as Mean ± Standard deviation. Mean values in the same column with different superscript letters were significantly different (P = 0.05).*

3.2.4. Deterioration of bleachability index

The Deterioration of Bleachability Index (DOBI) is used to assess the quality of refined oils. It is also used to assess the degree of oxidation of oil from simple heating processes, as in this case where hot extraction was used to obtain virgin oil. The DOBI values found ranged from 6.43 to 8.70. A DOBI value higher than 3.3 indicates an excellent quality of VCOs (Yéo et al., 2022). Based on the results of the analysis of variance test, cultivar and maturity stage had a significant effect (P = 0.05) on the DOBI.

3.2.5. Saponification value

The saponification value (SV) is an indirect measure of the free and esterified acids present in oils (Ivanova et al., 2022). It indicates the average molecular weight or equivalent mass of the fatty acids in the oils and is inversely proportional to the chain length of the fatty acids of fats and oils. A lower saponification number indicates a higher molecular weight of the fatty acids and less hydrolysable oils (Almeida et al., 2020). The SV of all VCOs showed high values ranging from 237.22 to 262.83 mg KOH/g. Based on the results of the variance test, coconut cultivar and maturity stage had a significant effect on SV (P = 0.05). According to Aremu et al. (2015), high saponification value is an indicator of suitability of fat/oil for industrial use. The high saponification value of VCO from WAT^{+} at 12 months suggests that it is suitable for use in soap and shampoo, pharmaceuticals, and food processing.

3.2.6. Fatty acid Profiles

The main parameter used to differentiate vegetable oils is the fatty acid (FA) composition. Fatty acid analysis provided information on the fatty acid distribution in the VCO samples. The fatty acid composition of the VCO cultivars is shown in Table 3. The fatty acid profile of the VCO samples shows a preponderance of saturated fatty acids with a predominance of lauric acid (C12) (44.78 to 53.73%), followed by myristic acid (C14) (16.35 to 19.44%). Unsaturated fatty acids such as oleic acid (C18:1) (5.20 and 6.61) and linoleic acid (C18:2) (1.43 and 2.36) are also present. The significant effect (P = 0.05) of the cultivar found in this study on the fatty acid profile of oils was also highlighted by Wickramasinghe & Wickramasinghe (2023). The genetic diversity of the coconut palm could explain the effect of cutlivar. The increase in fatty acids during maturation could also be due to fatty acid synthesis during seed development, which reaches its maximum content at full seed maturity at 12 months of age. Its predominantly lauric acid composition is thought to be the result of the activity of the enzyme acyl-ACP thioesterase. Certain specific acyl-ACP thioesterase enzymes are thought to be responsible for interrupting the elongation of fatty acid chains, favouring the synthesis of medium fatty acid chains between C8 and C14 (Feng et al., 2017). Their activity in coconut kernels therefore promotes the synthesis of lauric acid. This activity is optimal when the fruit reaches 12 months of maturity in this study. The fatty acid contents of the VCOs in the present study are close to the standard values of the APCC (2009). The fatty acid composition of coconut oil is stable to

oxidation and has a low melting point, which allows it to stabilise emulsions. All these properties make coconut oil highly valued in the food and chemical industries (Félix et al., 2023). Coconut oil contains 92% saturated fat. This is significantly higher than other commonly consumed vegetable oils. The major saturated fatty acids in coconut oil are lauric acid (12:0) from 32 to 51%, myristic acid (14:0) from 17 to 21%, and palmitic acid (16:0) from 6.9 to 14% (Deen et al., 2020). Interest in the medium-chain fatty acids (MCFAs) found in vegetable oils has grown rapidly in recent years because of their health benefits. According to Nitbani et al. (2022), lauric acid in virgin coconut oil is broken down in the body by intestinal lipase into 1-monolaurine and 2-monolaurine. These molecules, which have both hydrophilic and lipophilic groups, are recognised as excellent broad-spectrum antibacterial, antifungal, and antiviral agents. Unlike long-chain fatty acids (LCFAs), MCFAs have smaller molecular sizes and lower melting points. In addition, MCFAs are liquid at room temperature and less energy dense. These different physicochemical properties facilitate the absorption and metabolism of MCFAs (Deen et al., 2020). Thus, they are directly absorbed from the intestine and sent to the liver for energy use without accumulating in adipose tissue (Pepe et al., 2023; Valente et al., 2018). They are also converted into ketone compounds, which are beneficial for brain function (Deen et al., 2020; Pepe et al., 2023; Shori & Al Zahrani, 2021). This gives virgin coconut oil numerous nutritional, functional, metabolic, physiological, and pharmacological properties such as cardioprotective, antidiabetic, hepatoprotective, ketogenic, and antimicrobial activity that are beneficial to health (Deen et al., 2020; Nitbani et al., 2022; Rohman et al., 2021; Silalahi, 2020)

Table 5. Effect of cultivar and stage of maturity on fatty acids profil of virgin coconut oils

Cultivar	maturity	Caprylic	Capric	Lauric	Myristic
RIT^{+}	**10**	5.41 ± 0.03^{g}	7.53 ± 0.06^{a}	46.03 ± 1.25^{ef}	16.99 ± 0.08^{d}
	11	6.18 ± 0.04^{b}	6.80 ± 0.04^{b}	46.97 ± 0.18^{def}	17.62 ± 0.06^{c}
	12	6.67 ± 0.03^{a}	5.09 ± 0.11^{h}	51.22 ± 0.04^{b}	17.84 ± 0.07^{c}
WAT^{+}	**10**	5.58 ± 0.13^{f}	5.63 ± 0.17^{f}	49.82 ± 0.03^{bc}	17.57 ± 0.17^{c}
	11	5.90 ± 0.10^{de}	5.29 ± 0.11^{g}	50.41 ± 0.52^{b}	17.55 ± 0.58^{c}
	12	5.11 ± 0.10^{h}	5.15 ± 0.06^{gh}	53.73 ± 1.47^{a}	16.89 ± 0.14^{d}
PB113^{+}	**10**	6.27 ± 0.05^{b}	6.46 ± 0.03^{c}	44.78 ± 1.46^{f}	19.44 ± 0.05^{a}
	11	5.75 ± 0.02^{ef}	6.12 ± 0.04^{d}	47.50 ± 0.84^{cde}	18.56 ± 0.04^{b}
	12	5.96 ± 0.03^{cd}	5.93 ± 0.02^{e}	49.25 ± 0.26^{bcd}	16.35 ± 0.22^{e}
PB121^{+}	**10**	5.20 ± 0.03^{h}	6.21 ± 0.02^{d}	45.47 ± 0.78^{ef}	18.92 ± 0.10^{b}
	11	5.65 ± 0.11^{f}	6.53 ± 0.03^{c}	47.61 ± 0.03^{cde}	16.47 ± 0.11^{de}
	12	6.11 ± 0.07^{bc}	5.76 ± 0.01^{f}	49.90 ± 0.11^{bc}	16.19 ± 0.12^{e}
Statistical significance from ANOVA					
Cultivar (C)		<0.0001	<0.0001	<0.0001	<0.0001
Maturity (M)		<0.0001	<0.0001	<0.0001	<0.0001
C×M		<0.0001	<0.0001	ns	<0.0001

***(+):** improved, **WAT:** West African Tall, **RIT:** Rennell Island Tall, **PB:** Port-Bouët, **ns:** Not statistically significant. Values are expressed as Mean ± Standard deviation. Mean values in the same column with different superscript letters were significantly different (P = 0.05).*

Table 6. Effect of cultivar and stage of maturity on fatty acids profil of virgin coconut oils

Cultivar	maturity	Palmitic	Stearic	Oleic	Linoleic
RIT^{+}	**10**	8.53 ± 0.08^{a}	3.01 ± 0.07^{bcd}	6.15 ± 0.16^{b}	1.43 ± 0.08^{g}
	11	7.92 ± 0.05^{bc}	3.21 ± 0.05^{b}	5.66 ± 0.04^{c}	1.65 ± 0.08^{efg}
	12	7.19 ± 0.11^{d}	2.44 ± 0.04^{ef}	5.20 ± 0.08^{e}	1.85 ± 0.07^{cde}
WAT^{+}	**10**	6.23 ± 0.07^{f}	3.47 ± 0.17^{a}	5.38 ± 0.05^{d}	1.58 ± 0.06^{fg}

	11	7.71 ± 0.02^{c}	2.82 ± 0.11^{d}	5.60 ± 0.02^{c}	1.71 ± 0.11^{def}
	12	6.10 ± 0.10^{f}	2.57 ± 0.04^{e}	5.74 ± 0.08^{c}	1.90 ± 0.01^{cd}
PB113^{+}	**10**	8.15 ± 0.23^{b}	3.05 ± 0.10^{bcd}	6.19 ± 0.01^{b}	2.01 ± 0.08^{bc}
	11	7.37 ± 0.11^{d}	3.02 ± 0.07^{bcd}	6.44 ± 0.08^{a}	2.11 ± 0.07^{bc}
	12	6.81 ± 0.16^{e}	3.11 ± 0.09^{bc}	6.55 ± 0.06^{a}	2.36 ± 0.10^{a}
PB121^{+}	**10**	8.71 ± 0.14^{a}	2.34 ± 0.06^{f}	6.03 ± 0.07^{b}	2.00 ± 0.13^{bc}
	11	8.61 ± 0.07^{a}	2.62 ± 0.08^{e}	6.45 ± 0.08^{a}	2.11 ± 0.06^{bc}
	12	7.34 ± 0.16^{d}	2.87 ± 0.06^{cd}	6.61 ± 0.12^{a}	2.22 ± 0.04^{ab}
***P* values statistical significance from ANOVA**					
Cultivar (C)		<0.0001	<0.0001	<0.0001	<0.0001
Maturity (M)		<0.0001	<0.001	ns	<0.0001
C×M		<0.0001	<0.0001	<0.0001	ns

***(+):** improved, **WAT:** West African Tall, **RIT:** Rennell Island Tall, **PB:** Port-Bouët, **ns:** Not statistically significant. Values are expressed as Mean ± Standard deviation. Mean values in the same column with different superscript letters were significantly different (P = 0.05).*

2.4. Multivariate analysis

2.4.1. Physico-chemical parameters correlation coefficient

The correlation matrix (Figure 2) between the physico-chemical properties of the virgin oils shows that there are significant Pearson correlations (r) between the parameters. Lauric acid has a positive and significant correlation with parameters such as density (r = 0.717), acid value (r = 0.744), free fatty acid (r = 0.802), saponification (r = 0.845), and a negative correlation (r≤-0.088) with the iodine value. This positive correlation between lauric acid and most of the properties of the oil studied can be explained by the fact that lauric acid, as the main medium-chain saturated fatty acid, influences the physico-chemical properties of coconut oil, giving it these unique properties.

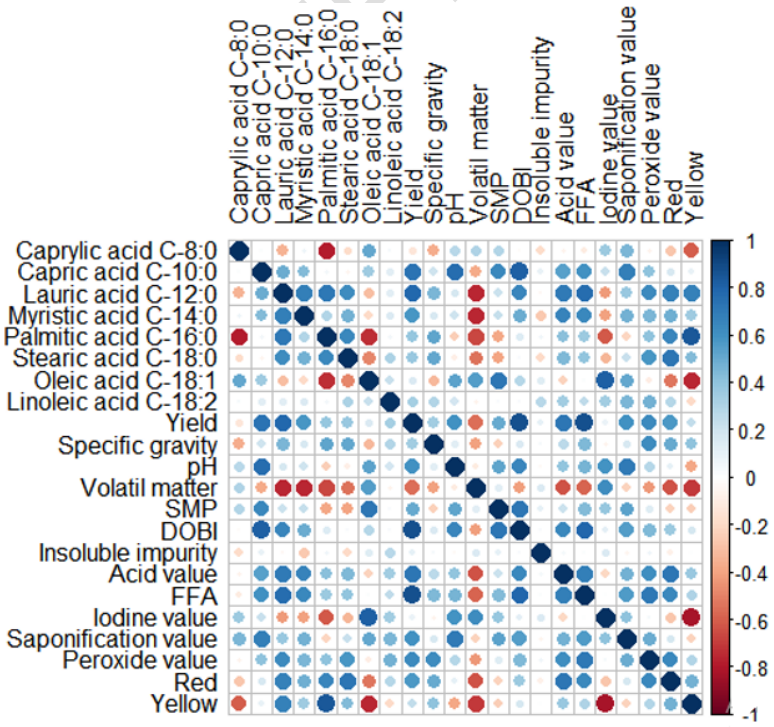

Fig. 2. Pearson correlation among physicochemical qualities of virgin coconut oils

2.4.1. Principal component analysis

Principal Component Analysis (PCA) was used to improve the correlation analysis and to differentiate the VCOs based on their physico-chemical properties, using the mean values of all four VCO cultivars according to maturity stages. The total parameters evaluated are significantly distributed around four (5) principal components (PC1 to PC5) from the Principal Component Analysis (PCA), with eigenvalues greater than 1 and supporting 93.17% of the total variance and therefore used to describe the PCA. Among these principal components, both PC1 and PC2 covered 68.68% (PC1 = 45.17% and PC2 = 23.51%) of all the data analysed, indicating a good representation of the correlation analysis (Figure 4). They were then used to plot the PCA. The biplot includes the loadings and the score plot, where the VCOs from cultivars are colour-coded in blue. The biplot consists of arrows representing the VCO physicochemical parameters considered for analysis. DOBI, SMP, recovery oil, peroxide, free fatty acids, acid, and density correlate with the VCO of WAT^{+}, $PB113^{+}$, and $PB121^{+}$ at 12 months. In addition, the VCO of WAT^{+} at 12 months had more oil density, acidity, and lauric acid than the other VCOs. The $PB121^{+}$ and $PB113^{+}$ hybrids have a positive correlation with iodine, linoleic acid, oleic acid, and moisture.

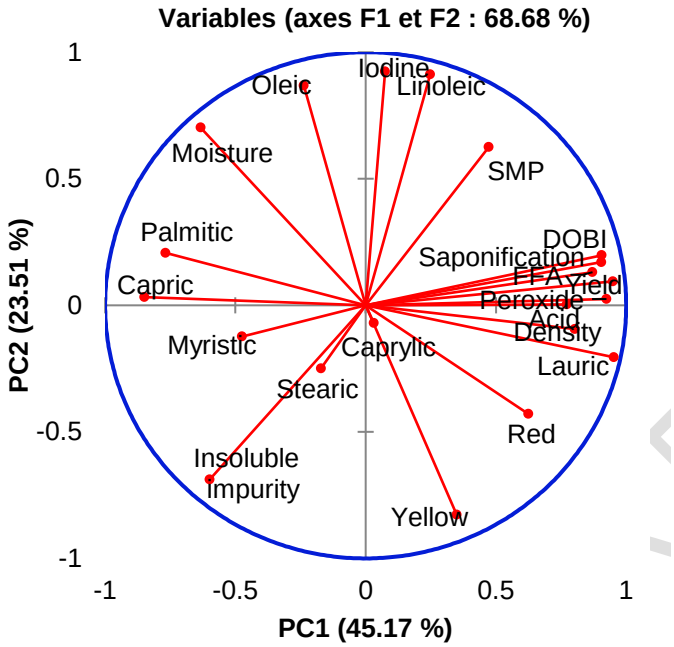

Fig. 3. Principal Component Analysis mean showing the relationship among physicochemical characteristics

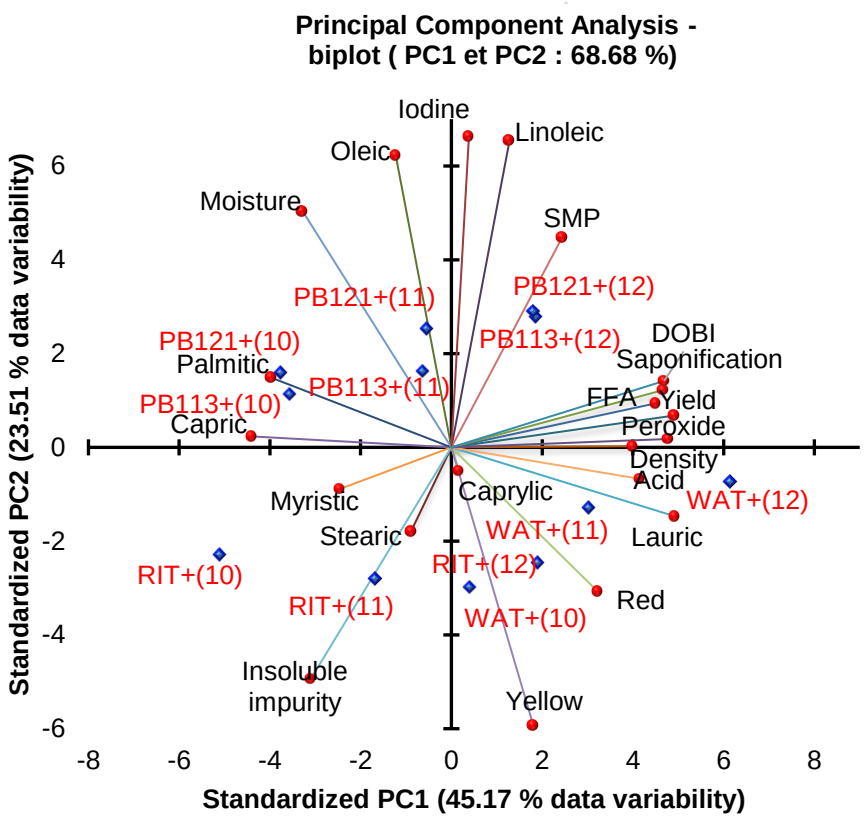

Fig. 4. Principal Component Analysis mean showing the relationship among physicochemical characteristics VCOs cultivars

4. CONCLUSION

In summary, the physical parameters, chemical indices, and fatty acid composition of virgin coconut oil hot extracted from four coconut cultivars at three maturity stages at the Coconut Research Station, Southern Côte d'Ivoire, were analysed in this study. It was found a significant effect of cultivar and maturity stage on virgin coconut oils the physical parameters, chemical indexes, and fatty acid composition. The lauric acid content, as the main fatty acid, influenced the chemical indices of the oil. It increased with increasing maturity of the coconut kernel. The oil obtained in the kernel milk of the WAT^+ cultivar was higher and denser, with high saponification, peroxide, and acidity indices. The hybrid ($PB121^+$ and $PB113^+$) virgin coconut oils had a higher iodine value and insaturated fat compared to Tall (RIT^+ and WAT^+). All extracted virgin coconut oils were clear in colour, which could be an important feature to attract consumers. This suggests that Ivorian virgin coconut oils could be an effective source of food ingredients that could have a positive impact on the agricultural market, thereby helping to increase the income of farming households.

REFERENCES

Agoh, C. F., Lekadou, T. T., Mahaman, M. B., Gala, B. T. J., Danumah, J., Coffi, P.-M. J., Koffi, E. B. Z., & Goula, B. T. A. (2021). Impact of climate variability on water resources : The case of Marc Delorme CNRA station, Southeast of Ivory Coast. *Journal of Water Resource and Protection*, *13*, 726-749. https://doi.org/10.4236/jwarp.2021.139038

Ahmad, Z., Hasham, R., Aman Nor, N., & Sarmidi, M. (2015). Physico-chemical and antioxidant analysis of virgin coconut oil using West African Tall variety. *Journal of Advanced Research in Materials Science*, *13*(1), 1-10.

Akusu, O. M., & Wordu, G. O. (2019). Physicochemical properties and fatty acid profile of Allanblackia seed oil and African pear pulp oils. *International Journal of Biotechnology and Food Sciences*, *7*(2), 14-22. https://doi.org/10.33495/ijbfs_v7i2.19.102

Alemayhu, A., Emire, S., & Tesfaye, B. (2019). Shelf-life prediction of edible cotton, peanut and soybean seed oils using an empirical model based on standard quality tests. *Cogent Food & Agriculture*, *5*, 1-18. https://doi.org/10.1080/23311932.2019.1622482

Almeida, C. A. S., Baggio, S. R., Mariutti, L. R. B., & Bragagnolo, N. (2020). One-step rapid extraction of phytosterols from vegetable oils. *Food Research International (Ottawa, Ont.)*, *130*, 108891. https://doi.org/10.1016/j.foodres.2019.108891

AOCS. (2009). *Official methods and recommended practices of the American oil chemists' society*.

APCC, A. and P. C. C. (2009). *Standards for virgin coconut oil*.

Appaiah, P., L., S., P K, P. K., & A.G., G. K. (2014). Composition of Coconut Testa, Coconut Kernel and its Oil. *Journal of the American Oil Chemists' Society*, *91*, 917-924. https://doi.org/10.1007/s11746-014-2447-9

Aremu, M., Ibrahim, H., & Bamidele, T. (2015). Physicochemical characteristics of the oils extracted from some Nigerian plant foods- A Review. *Chemical and Process Engineering Research*, *32*, Page 36-52.

Arlee, R., Suanphairoch, S., & Pakdeechanuan, P. (2013). Differences in chemical components and antioxidant-related substances in virgin coconut oil from coconut hybrids and their parents. *International Food Research Journal*, *20*(5), 2103-2109.

Asiah, N., Astuti, R., Cempaka, L., & Setiani, R. (2019). Physical and chemical characteristic of virgin coconut oil under Mix culture fermentation technique. *Journal of Physics: Conference Series*, *1364*, 012009. https://doi.org/10.1088/1742-6596/1364/1/012009

Azevedo, W., Oliveira, L., Alcântara, M., Cordeiro, A., Damasceno, K. S., Araújo, N., Assis, C., & Junior, F. (2020). Physicochemical characterization, fatty acid profile, antioxidant activity and antibacterial potential of cacay oil, coconut oil and cacay butter. *PLOS ONE*, *15*(4), 1-11. https://doi.org/10.1371/journal.pone.0232224

Chouikh, S. (2016). *Qualité des huiles à friture et effet des produits de dégradation sur la santé. Université Mohammed Seddik Ben Yahia Jijel,* pp 93*.*

Codex alimentarius commission. (1999). *Report Of The Sixteenth Session Of The Codex Committee On Fats And Oils, London, United Kingdom 8–12 March 1999; Food and Agriculture Organisation of the United Nations; World Health Organization : Rome, Italy, 1999.*

COGENT. (2017). *A global strategy for the conservation and use of coconut genetic resources 2018-2028*. https://cgspace.cgiar.org/handle/10568/96540

Deen, F., Visvanathan, R., Liyanage, R., & Marikkar, N. (2020). Chemical Composition and Health Benefits of Coconut oil : An Overview. *Journal of the Science of Food and Agriculture*, *101*(6), 2182-2193.

FAOSTAT. (2020). *Crops food and agriculture organization of the United Nations*. https://www.fao.org/faostat/en/#home

Félix, J. W., Granados-Alegría, M. I., Gómez-Tah, R., Tzec-Simá, M., Ruíz-May, E., Canto-Canché, B., Zamora-Briseño, J. A., Bojórquez-Velázquez, E., Oropeza-Salín, C., & Islas-Flores, I. (2023). Proteome landscape during ripening of solid endosperm from two different coconut cultivars reveals contrasting carbohydrate and fatty acid metabolic pathway modulation. *International Journal of Molecular Sciences*, *24*(13), 1-24. https://doi.org/10.3390/ijms241310431

Feng, Y., Wang, Y., Liu, J., Liu, Y., Cao, X., & Xue, S. (2017). Structural insight into Acyl-ACP thioesterase toward substrate specificity design. *ACS Chemical Biology*, *12*(11), 2830-2836. https://doi.org/10.1021/acschembio.7b00641

Fengxia, S., Dishun, Z., & Zhanming, Z. (2001). Determination of oil color by image analysis. *Journal of Oil & Fat Industries*, *78*, 749-752. https://doi.org/10.1007/s11746-001-0337-5

Geng, L., Zhou, W., Qu, X., Sa, R., Liang, J., Wang, X., & Sun, M. (2023). Iodine values, peroxide values and acid values of Bohai algae oil compared with other oils during the cooking. *Heliyon*, *9*(4), 1-10. https://doi.org/10.1016/j.heliyon.2023.e15088

Ghani, N., Channip, A.-A., Hwa, P., Ja'afar, F., Yasin, H., & Usman, A. (2018). Physicochemical properties, antioxidant capacities, and metal contents of virgin coconut oil produced by wet and dry processes. *Food Science & Nutrition*, *6*(5), 1298-1306. https://doi.org/10.1002/fsn3.671

Ivanova, M., Hanganu, A., Dumitriu, R., Tociu, M., Ivanov, G., Stavarache, C., Popescu, L., Ghendov-Mosanu, A., Sturza, R., Deleanu, C., & Chira, N.-A. (2022). Saponification Value of Fats and Oils as Determined from 1H-NMR Data : The Case of Dairy Fats. *Foods*, *11*(10), Article 10. https://doi.org/10.3390/foods11101466

Kamariah, L., Azmi, A., Rosmawati, A., Ching, M. G. W., Azlina, M. D., Tan, C. P., & Lai, O. M. (2008). Physico-chemical and quality characteristics of virgin coconut oil – A Malaysian survey. *Journal of Tropical Agriculture and Food Science*, *36*(2), 1-10.

Konan, K. J. L., Sié, R. S., N'guette, S. P., Lekadou, T. T., & Allou, K. (2010). Assessment of vegetative growth and production of new improved coconut (Cocos nucifera L.) hybrids. *Journal of Applied Biosciences*, *26*, 1664-1674.

Kouadio, M. K., Konan, K. J. L., Doubi, B. T. S., Soro, P. L., Djaha, K. E., & Koné, F. M. T. (2023). Fruit morphological characteristics at different maturity stages of coconut (Cocos nucifera L.) improved hybrids (PB113+, PB121+) and their parent males (RIT+, WAT+). *African Journal of Agricultural Research*, *19*(10), 987-993. https://doi.org/10.5897/AJAR2023.16461

Laffargue, A., De Kochko, A., & Dussert, S. (2007). Development of solid-phase extraction and methylation procedures to analyse free fatty acids in lipid-rich seeds. *Plant Physiology and Biochemistry*, *45*(3-4), 250-257. https://doi.org/10.1016/j.plaphy.2007.01.012

Martins, J. S., Santos, J. C. O., & Da Conceicao, M. M. D. (2020). Comparative study of physico-chemical properties of coconut Oil (Cocos nucifera L.) obtained by industrial and artisanal processes. *BioTechnology: An Indian Journal*, *16*(3), 1-8.

Mifta, E., Lilik, S., Didik, P., & Mochammad, M. M. (2024). Development of integrated coconut agroindustry from a circular economy perspective : A literature Review. *IOP Conference Series Earth and Environmental Science*, *1364*(1), 012001. https://doi.org/10.1088/1755-1315/1364/1/012001

Mohammed, N. K., Samir, Z. T., Jassim, M. A., & Saeed, S. K. (2021). Effect of different extraction methods on physicochemical properties, antioxidant activity, of virgin coconut oil. *Materials Today: Proceedings*, *42*(5), 2000-2005. https://doi.org/10.1016/j.matpr.2020.12.248

Muthukkannan, N., & Balasaravanan, T. (2020). Optimization of process variables for the production of virgin coconut oil from selected *Cocos nucifera* varieties under fresh-dry method. *International Journal of Scientific Research in Biological Sciences*, *6*(6), 1-12. https://doi.org/10.26438/ijsrbs/v6i6.112

Nagy, K., Tiuca, I.D., Nagy, K., & Tiuca, I.D. (2017). Importance of fatty acids in physiopathology of human body. In *Fatty Acids* (Angel Catala). IntechOpen. https://doi.org/10.5772/67407

Negash, Y. A., Amare, D. E., Bitew, B. D., & Dagne, H. (2019). Assessment of quality of edible vegetable oils accessed in Gondar City, Northwest Ethiopia. *BMC Research Notes*, *12*(1), 793. https://doi.org/10.1186/s13104-019-4831-x

Ng, Y. J., Tham, P. E., Khoo, K. S., Cheng, C. K., Chew, K. W., & Show, P. L. (2021). A comprehensive review on the techniques for coconut oil extraction and its application. *Bioprocess and Biosystems Engineering*, *44*(9), 1807-1818. https://doi.org/10.1007/s00449-021-02577-9

Nitbani, F., Tjitda, P., Nitti, F., Jumina, J., & Detha, A. (2022). Antimicrobial properties of lauric acid and monolaurin in virgin coconut oil : A review. *ChemBioEng Reviews*, *9*(5), 1-21. https://doi.org/10.1002/cben.202100050

Pathirana, H. P. D. T. H., Yalegama, L. L. W. C., Madusanka, J. A. D., & Senarathne, L. M. I. (2021). Physicochemical properties of virgin coconut oil extracted from different coconut (*Cocos nucifera* L.) varieties. *Cord*, *37*, 1-10. https://doi.org/10.37833/cord.v37i.440

Patil, U., Benjakul, S., Prodpran, T., Senphan, T., & Cheetangdee, N. (2016). Characteristics and quality of virgin coconut oil as influenced by maturity stages. *Carpathian Journal of Food Science and Technology*, *8*(4), 103-115.

Penprapai, P., & Intharit, S. (2017). Total phenolic content and antioxidant activity of coconut oil enriched with some extracts of curcuma species in Thailand. *Journal of Applied Science*, *16*, 48-54. https://doi.org/10.14416/j.appsci.2017.10.S07

Pepe, R. B., Lottenberg, A. M., Fujiwara, C. T. H., Beyruti, M., Cintra, D. E., Machado, R. M., Rodrigues, A., Jensen, N. S. O., Caldas, A. P. S., Fernandes, A. E., Rossoni, C., Mattos, F., Motarelli, J. H. F., Bressan, J., Saldanha, J., Beda, L. M. M., Lavrador, M. S. F., Del Bosco, M., Cruz, P., … Piovacari, S. M. F. (2023). Position statement on nutrition therapy for overweight and obesity : Nutrition department of the Brazilian

association for the study of obesity and metabolic syndrome (ABESO-2022). *Diabetology & Metabolic Syndrome*, *15*(1), 1-53. https://doi.org/10.1186/s13098-023-01037-6

Ramesh, S. V., Pandiselvam, R., Thushara, R., Ramarathinam, M., Hebbar, K., Beegum, S., Mathew, A., Neenu, S., & Shil, S. (2020). Engineering intervention for production of virgin coconut oil by hot process and multivariate analysis of quality attributes of virgin coconut oil extracted by various methods. *Journal of Food Process Engineering*, *43*, 1-10. https://doi.org/10.1111/jfpe.13395

Rodriguez-Amaya Delia B., F. S., & Shahidi, F. (2021). Oxidation of lipids. In D. B. Rodriguez-Amaya & J. Amaya-Farfan (Éds.), *Chemical Changes During Processing and Storage of Foods* (p. 125-170). Academic Press. https://doi.org/10.1016/B978-0-12-817380-0.00004-X

Rodríguez-Blázquez, S., Gómez-Mejía, E., Rosales-Conrado, N., León-González, M. E., García-Sánchez, B., & Miranda, R. (2023). Valorization of Prunus Seed Oils : Fatty Acids Composition and Oxidative Stability. *Molecules*, *28*(20), 7045. https://doi.org/10.3390/molecules28207045

Rohman, A., Irnawati, Erwanto, Y., Lukitaningsih, E., Rafi, M., Fadzilah, N. A., Windarsih, A., Sulaiman, A., & Zakaria, Z. (2021). Virgin Coconut Oil : Extraction, Physicochemical Properties, Biological Activities and Its Authentication Analysis. *Food Reviews International*, *37*(1), 46-66. https://doi.org/10.1080/87559129.2019.1687515

Sahasrabudhe, S. N., Rodriguez-Martinez, V., O'Meara, Meghan., & Farkas, B. E. (2017). Density, viscosity, and surface tension of five vegetable oils at elevated temperatures : Measurement and modeling. *International Journal of Food Properties*, *20*(2), 1965-1981. https://doi.org/10.1080/10942912.2017.1360905

Satheeshan, K., Seema, B., & Manjusha, A. M. (2019). Quality analysis of virgin coconut oil processed through different methods. *Ournal of Pharmacognosy and Phytochemistry*, *8*(3), 2119-2123.

Shori, A. B., & Al Zahrani, A. J. (2021). Non-dairy plant-based milk products as alternatives to conventional dairy products for delivering probiotics. *Food Science and Technology*, *42*, 1-14. https://doi.org/10.1590/fst.101321

Silalahi, J. (2020). Nutritional values and health protective properties of coconut oil. *Indonesian Journal of Pharmaceutical and Clinical Research*, *3*(2), 1-12.

Srivastava, Y., Semwal, A. D., & Majumdar, A. (2016). Quantitative and qualitative analysis of bioactive components present in virgin coconut oil. *Cogent Food & Agriculture*, *2*(1), 1-13. https://doi.org/10.1080/23311932.2016.1164929

Sundrasegaran, S., & Mah, S. H. (2020). Extraction methods of virgin coconut oil and palm-pressed mesocarp Oil and their Phytonutrients. *eFood*, *1*. https://doi.org/10.2991/efood.k.201106.001

Valente, F., Cândido, F., Lopes, L., Dias, D., Carvalho, S., Pereira, P., & Bressan, J. (2018). Effects of coconut oil consumption on energy metabolism, cardiometabolic risk markers, and appetitive responses in women with excess body fat. *European Journal of Nutrition*, *57*(4), 1627-1637. https://doi.org/10.1007/s00394-017-1448-5

Wickramasinghe, D. R., & Wickramasinghe, I. (2023). Comparison of physicochemical characteristics of virgin coconut oils from traditional and hybrid coconut varieties. *Journal of Agriculture and Food Research*, *12*, 1-7. https://doi.org/10.1016/j.jafr.2023.100554

Yéo, A. M., Niamketchi, G. L., Akely, P. M. thierry, & Konan, A. G. (2022). Quality assessment of crude palm oil from smallholders in Alepe department, Southeast Côte d'Ivoire. *International Journal of Advanced Research*, *10*(1), 6-11. http://dx.doi.org/10.21474/IJAR01/14003

Yousefi, K., Abdullah, S. N. A., Hatta, M. A. M., & Ling, K. L. (2023). Genomics and transcriptomics reveal genetic contribution to population diversity and specific traits in coconut. *Plants*, *12*(9), Article 9. https://doi.org/10.3390/plants12091913

Zahir, E., Saeed, R., Hameed, M. A., & Yousuf, A. (2017). Study of physicochemical properties of edible oil and evaluation of frying oil quality by Fourier Transform-Infrared (FT-IR) Spectroscopy. *Arabian Journal of Chemistry*, *10*, S3870-S3876. https://doi.org/10.1016/j.arabjc.2014.05.025

Zainol, F. A., Arumugam, N., Daud, W. N. W., Suhaimi, N. A. M., Ishola, B. D., Ishak, A. Z., & Afthanorhan, A. (2023). Coconut value chain analysis : A systematic review. *Agriculture*, *13*(7), 1379. https://doi.org/10.3390/agriculture13071379