# Effect of Improved Cultivars and Maturity Stage on Physical Parameters, Chemical Indices and Fatty Acid Composition of Coconut Oils from Ivorian Germplasm

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*Authors' contributions*

*This work was carried out in collaboration among all authors. Author MKK designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. All authors read and approved the final manuscript.*

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## 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 coconut oils (COs) 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 (PB121^{+} and PB113^{+}) were harvested at different stages of maturity :10, 11, and 12 months after pollination. COs from Low-heat extraction were obtained from ly prepared coconut milk. A total of 12 COs 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 COs 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 CO from the improved cultivar WAT[+]. Hybrid (PB121^{+} and PB113^{+}) coconut 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 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 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.

## 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). Coconut oil (CO) 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 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. These kernels could be converted into oils with significant food and pharmaceutical applications (Wickramasinghe & Wickramasinghe, 2023). However, there is a lack of reports on the physicochemical properties of oils from improved Ivorian coconut kernel cultivars for food purposes. In addition, the fatty acid composition, physical properties, and chemical indices of coconut kernel oils vary depending on several factors, among them kernel maturity. In general, the liquid endosperm (coconut water) present in the inner cavity of the fruit transforms into solid endosperm (kernel) 10 months after pollination, and this continues until the kernel becomes thicker and more solid, which affects the oil extraction yield (Kouadio et al., 2023). Lauric acid (C12:0), the most abundant fatty acid in coconut oil, also varies. For this reason, the aim of this study was to determine the physico-chemical properties of

coconut oils from four improved coconut cultivars at three stages of kernel maturity (10, 11, and 12 months), which were subjected to multivariate analysis. Principal Component Analysis (PCA) was used to study the interactions between different oil cultivars and their physicochemical characteristics.

## 2. MATERIALS 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).

### 2.2 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.

### 2.3 Coconut Oil (CO) Low Hot Extraction Process

Fresh coconut oils (COs) were produced from 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 (Fig. 1).

**Calculation of oil recovery**: Oil recoveries were determined using the 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.

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

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

**Determination of density:** Density bottle method was used in determining the specific gravity of the COs. 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;

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

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

**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 coconut oils (COs) 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 COs 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.

**Determination of oil peroxide value:** Peroxide value of all CO$_S$ samples was determined by was determined according to the methods described by AOCS (2009). 1.0 g of each CO$_S$ 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.
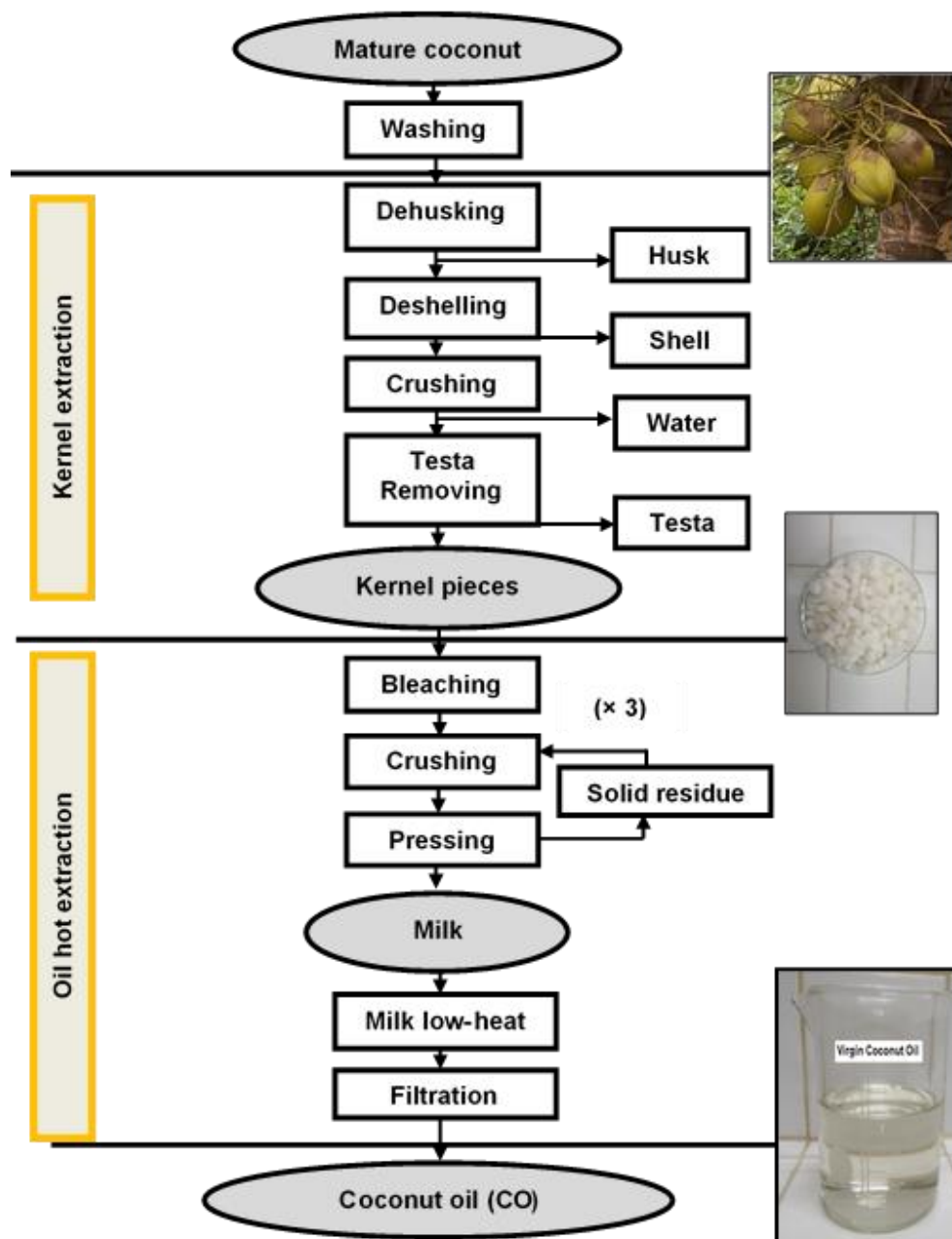


**Fig. 1. Coconut oil low-hot extraction process**

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 $CO_S$ 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 $Na_2S_2O_3$*

**Determination of COs saponification value**: The saponification value (SV) of the COs was determined according to the AOCS method (AOCS, 2009). About 1.0 g of $CO_S$ 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:

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

*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.*

**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 COs were calculated based on the peak area normalization method, expressed as percentages of total FAs (%).

## 2.4 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 COs 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, coconut oil (CO) is the clear coconut oil obtained from 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 Coconut Oil Physical Quality Characteristics

The results of the analysis of the physical quality parameters of coconut oil (CO) obtained for the four cultivars considered are presented in Tables 1 and 2.

**Coconut oil recovery:** Coconut oil (CO) yield is generally one of the most important parameters in CO 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 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 coconut oil (CO) 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 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.

**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 coconut oils densities measured at ambient temperature varied between 0.901 and 0.921 g/cm³. The similarity between hybrid PB113^{+} and PB121^{+} oils is probably due to their similar fatty acid content.

These established values are close to those of canola oil (913.3 kg/m³), corn oil (915.3 kg/m³), olive oil (908.7 kg/m³), peanut oil (912.1 kg/m3), and soybean oil (915.7 kg/m³) 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 CO compared to some oils is due to its high saturation and polymerisation (Ghani et al., 2018), as established for CO 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.

**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.

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

| Cultivar | Maturity | Yield (%) | Density (g/cm³) | 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).*

**Table 2. Effect of cultivar and stage of maturity on soluble impurity and lovibond colors of 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] |
| ***P* values 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).*

The slip melting point values were within the recommended CODEX standard of ≤2 4C for coconut oil (Codex alimentarius commission, 1999). These values were within the recommended CODEX standard of ≤ 24 °C for 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 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).

**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 COs at different stages of maturity, expressed as red and yellow values, are shown in Table 1. All analysed COs 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 form is clear in colour with a distinct coconut flavour and aroma. However, excessive heat during the process of extracting the 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).

**Moisture:** Moisture content is a critical parameter for the quality of COs. 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 CO 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 ($p < 0.05$). COs extracted by hot extraction methods have a low moisture content due to the hot conditions that significantly remove water components from the COs (Mohammed et al., 2021). The residual water content of COs in this study is slightly lower than that of COs 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 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 coconut oil (CO) obtained for the four cultivars at different stages of maturity are presented in Tables 3 and 4.

**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 COs 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 COs found here indicates the suitability of these COs for edible purposes, which are more stable and have a longer shelf life.

**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 COs samples ranged from 7.54 to 11.73 g $I_2$/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, 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 COs 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 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] |
| ***P* values 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).*

**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 CO samples in this study ranged from 1.15 to 1.35 meq $O_2$/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), oils typically have peroxide values well below 10 meq/kg. This shows that the CO 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 oils, indicating that these COs 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).

**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 oil. The DOBI values found ranged from 6.43 to 8.70. A DOBI value higher than 3.3 indicates an excellent quality of COs (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.

**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 COs 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 CO from WAT+ at 12 months suggests that it is suitable for use in soap and shampoo, pharmaceuticals, and food processing.

**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 CO samples. The fatty acid composition of the CO cultivars is shown in Table 5. The fatty acid profile of the CO 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 COs 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

**Table 4. Effect of cultivar and stage of maturity on saponification value, peroxide value and deterioration of bleachability index of 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] |
| *P* values 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).*

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 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 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).

## 3.3 Multivariate Analysis

**Physico-chemical parameters correlation coefficient:** The correlation matrix (Fig. 2) between the physico-chemical properties of the 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.

**Principal component analysis:** Principal Component Analysis (PCA) was used to improve the correlation analysis and to differentiate the COs based on their physico-chemical properties, using the mean values of all four CO cultivars

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

| Cultivar | maturity | Caprylic | Capric | Lauric | Myristic | Palmitic | Stearic | Oleic | Linoleic |
|---|---|---|---|---|---|---|---|---|---|
| RIT[+] | 10 | 5.41 ± 0.03[g] | 7.53 ± 0.06[a] | 46.03 ± 1.25[ef] | 16.99 ± 0.08[d] | 8.53 ± 0.08[a] | 3.01 ± 0.07[bcd] | 6.15 ± 0.16[b] | 1.43 ± 0.08[g] |
| | 11 | 6.18 ± 0.04[b] | 6.80 ± 0.04[b] | 46.97 ± 0.18[def] | 17.62 ± 0.06[c] | 7.92 ± 0.05[bc] | 3.21 ± 0.05[b] | 5.66 ± 0.04[c] | 1.65 ± 0.08[efg] |
| | 12 | 6.67 ± 0.03[a] | 5.09 ± 0.11[h] | 51.22 ± 0.04[b] | 17.84 ± 0.07[c] | 7.19 ± 0.11[d] | 2.44 ± 0.04[ef] | 5.20 ± 0.08[e] | 1.85 ± 0.07[cde] |
| WAT[+] | 10 | 5.58 ± 0.13[f] | 5.63 ± 0.17[f] | 49.82 ± 0.03[bc] | 17.57 ± 0.17[c] | 6.23 ± 0.07[f] | 3.47 ± 0.17[a] | 5.38 ± 0.05[d] | 1.58 ± 0.06[fg] |
| | 11 | 5.90 ± 0.10[de] | 5.29 ± 0.11[g] | 50.41 ± 0.52[b] | 17.55 ± 0.58[c] | 7.71 ± 0.02[c] | 2.82 ± 0.11[d] | 5.60 ± 0.02[c] | 1.71 ± 0.11[def] |
| | 12 | 5.11 ± 0.10[h] | 5.15 ± 0.06[gh] | 53.73 ± 1.47[a] | 16.89 ± 0.14[d] | 6.10 ± 0.10[f] | 2.57 ± 0.04[e] | 5.74 ± 0.08[c] | 1.90 ± 0.01[cd] |
| PB113^{+} | 10 | 6.27 ± 0.05[b] | 6.46 ± 0.03[c] | 44.78 ± 1.46[f] | 19.44 ± 0.05[a] | 8.15 ± 0.23[b] | 3.05 ± 0.10[bcd] | 6.19 ± 0.01[b] | 2.01 ± 0.08[bc] |
| | 11 | 5.75 ± 0.02[ef] | 6.12 ± 0.04[d] | 47.50 ± 0.84[cde] | 18.56 ± 0.04[b] | 7.37 ± 0.11[d] | 3.02 ± 0.07[bcd] | 6.44 ± 0.08[a] | 2.11 ± 0.07[bc] |
| | 12 | 5.96 ± 0.03[cd] | 5.93 ± 0.02[e] | 49.25 ± 0.26[bcd] | 16.35 ± 0.22[e] | 6.81 ± 0.16[e] | 3.11 ± 0.09[bc] | 6.55 ± 0.06[a] | 2.36 ± 0.10[a] |
| PB121^{+} | 10 | 5.20 ± 0.03[h] | 6.21 ± 0.02[d] | 45.47 ± 0.78[ef] | 18.92 ± 0.10[b] | 8.71 ± 0.14[a] | 2.34 ± 0.06[f] | 6.03 ± 0.07[b] | 2.00 ± 0.13[bc] |
| | 11 | 5.65 ± 0.11[f] | 6.53 ± 0.03[c] | 47.61 ± 0.03[cde] | 16.47 ± 0.11[de] | 8.61 ± 0.07[a] | 2.62 ± 0.08[e] | 6.45 ± 0.08[a] | 2.11 ± 0.06[bc] |
| | 12 | 6.11 ± 0.07[bc] | 5.76 ± 0.01[f] | 49.90 ± 0.11[bc] | 16.19 ± 0.12[e] | 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 | <0.0001 | <0.0001 | <0.0001 | <0.0001 |
| Maturity (M) | | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.0001 | <0.001 | ns | <0.0001 |
| C×M | | <0.0001 | <0.0001 | ns | <0.0001 | <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).*
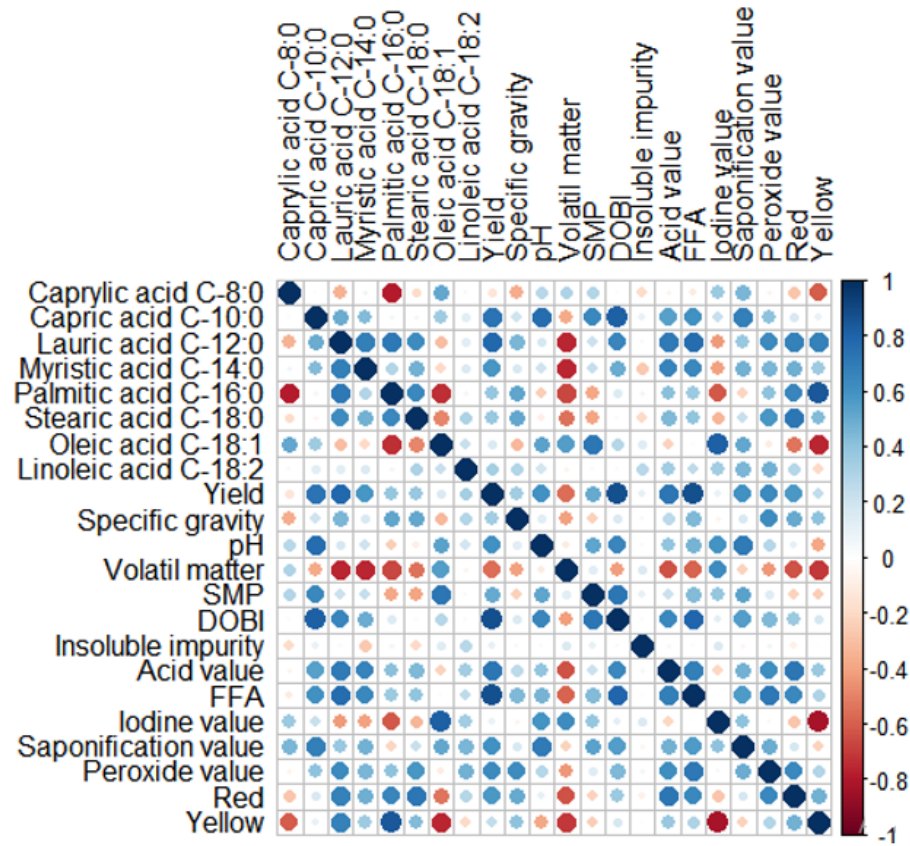
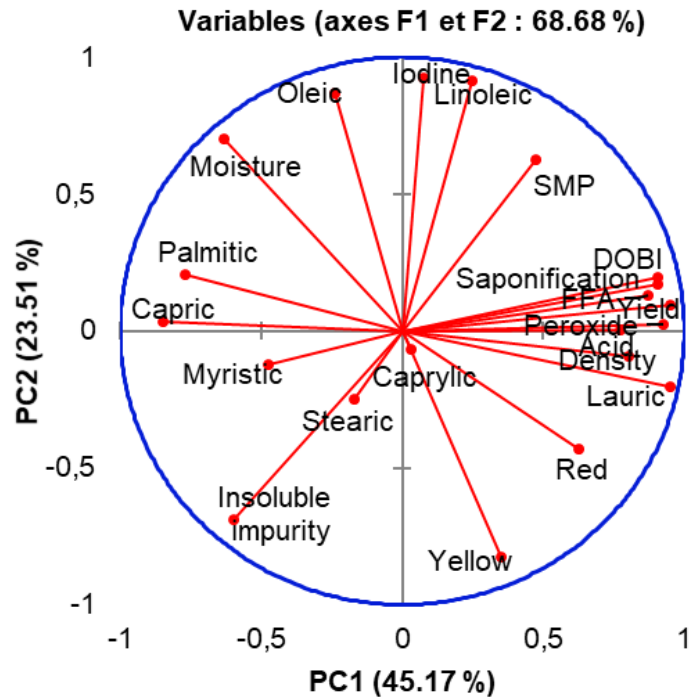**Fig. 2. Pearson correlation among physicochemical qualities of coconut oils**

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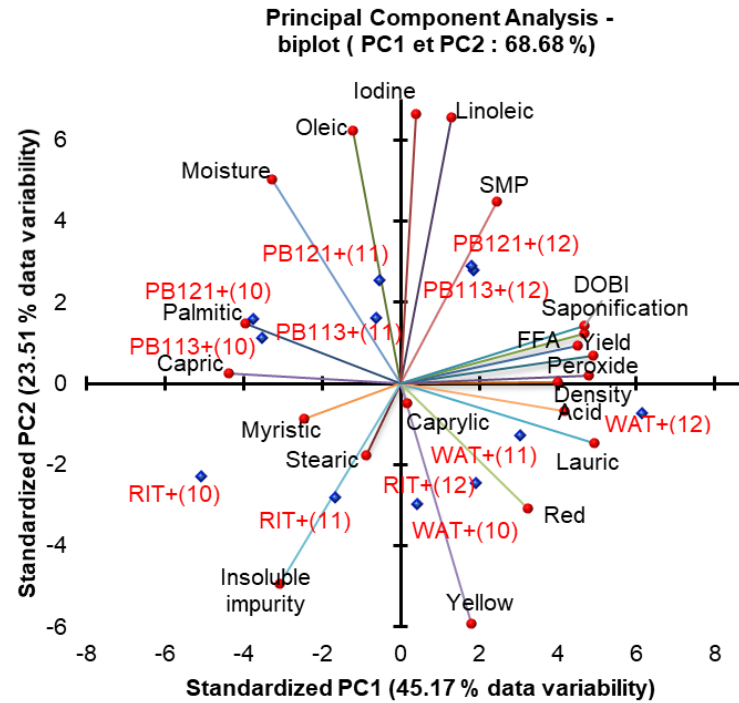


**Fig. 4. Principal Component Analysis mean showing the relationship among physicochemical characteristics COs cultivars**

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 (Fig. 4). They were then used to plot the PCA. The biplot includes the loadings and the score plot, where the COs from cultivars are colour-coded in blue. The biplot consists of arrows representing the CO physicochemical parameters considered for analysis. DOBI, SMP, recovery oil, peroxide, free fatty acids, acid, and density correlate with the CO of WAT[+], PB113^{+}, and PB121^{+} at 12 months. In addition, the CO of WAT[+] at 12 months had more oil density, acidity, and lauric acid than the other COs. The PB121^{+} and PB113^{+} hybrids have a positive correlation with iodine, linoleic acid, oleic acid, and moisture.

## 4. CONCLUSION

In summary, the physical parameters, chemical indices, and fatty acid composition of 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 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^{+}) coconut oils had a higher iodine value and unsaturated fat compared to Tall (RIT[+] and WAT[+]). All extracted coconut oils were clear in colour, which could be an important feature to attract consumers. This suggests that Ivorian 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.

## DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

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