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Study of some quality parameters of palm oils sold in Bujumbura markets in Burundi

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Abstract
People in and around Bujumbura city of Burundi use palm oil extensively, generally in both crude and refined forms. However, these oils sold in the markets are exposed to various factors affecting quality which include sunlight, unhygienic containers, and heat. This study aimed to assess some quality parameters of crude and refined palm oils sold in five markets in Bujumbura and to determine whether these parameters meet the standards. Furthermore, the crude and refined oils sold were compared in terms of these parameters, and a sample distribution was performed using Principal Component Analysis (PCA). After sampling, physical, chemical and spectroscopic methods were used to determine physicochemical parameters and total carotenoids. The average results for refined and crude palm oils, respectively were: relative density (RD) 0.892±0.001; 0.887±0.001, refractive index (RI) 1.463±0.001; 1.462±0.001, moisture and matter volatile (MVH) 0.974±0.527 % (m/m); 2.429±2.196% (m/m), impurity levels (TII) 4.642±1.228% (m/m); 9.468±1.703% (m/m), the acid value (AV) 4.581±0.591 mg KOH/g; 37.190±1.789 mg KOH/g, the free fatty acid contents (FFA) 2.165±0.757%; 18.671±4.947%, the iodine value (IV) 50.252±7.179 g I_2/100 g ; 54.3±10. 531 g I_2/100 g, the peroxide value (PV) 5.8±2.263 meq O_2/kg; 5.3±2.970 meq O_2/kg; the saponification value (SV) 200.371±3.834 mg KOH/g; 195.384±4.540 mg KOH/g; and the total carotenoid (TC) 10.574±3.801 ppm; 738.913±81.467 ppm. The results of the physicochemical analyses showed that only four (4) parameters met the Burundian and Codex Alimentarius standards. In addition, the total carotenoids contained in crude palm oils also complied with these standards. However, the high acid value (AV) or free fatty acid contents (FFA) and impurity levels (TII) are among the indicators of low quality of the crude oils. Based on these results, there is a need to further ensure the compliance to standards of the palm oils sold in different markets of the Bujumbura city.

Key words: *Bujumbura City; Markets; Palm oils; Physicochemical parameters; Standards; Total carotenoids*

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Introduction

Palm oil is consumed in two forms in Burundi: crude (CPO) also known as 'red oil' which is the most consumed and refined corresponding to palm olein (RPO) (N'guessan *et al.*, 2018). In its raw state, it contains vitamin E or tocopherol (864 - 1124 µg/g), a highly sought-after substance; carotenoids (832 - 3575 µg/g), which have the only real nutritional properties of an oil due to their pro-vitamin activity; and polyphenols (64.42-130.23 mg of gallic acid equivalent) (Adamu, 2023; N'guessan *et al.*, 2018).

Refining is the set of chemical or physical-chemical processes used to make a product suitable to standards. It is generally carried out by neutralising, decolourising and deodorising, giving the oil a light yellow colour (Pages *et al.*, 2010; Jahouache, 2002). However, compounds with antioxidant activity in crude palm oil are partially eliminated during refining, leaving palm olein light in antioxidant compounds (carotenes, tocopherols, etc.) (N'guessan *et al.*, 2018).

In Burundi, palm oil continues to be the most important source of fat. Palm oil yields can exceed five tonnes of oil per hectare. This is in contrast to other oil crops such as groundnut, cotton, soya and sunflower, which have lower yields (MAE, 2008). The main palm growing region remains Rumonge and Nyanza-Lac in the south west of Burundi. Relative to Bujumbura on the shores of Lake Tanganyika, Rumonge is located approximately 80 km to the south along the coastline, while Nyanza-Lac lies further south, near the Tanzanian border. These regions alone provide more than 85% of Burundi's palm oil production. Two major companies purchase the large amount of palm oil produced in Burundi: Savonor and Lite. These companies refine the oil into other products (Ngiye, 2015). According to the people of Bujumbura city and its environs, the particular colour and taste of crude palm oil makes it a special spice that is irreplaceable by other oils in the preparation of some "sauce leaves" (Cheyns, 2001; Sagna, 2023). In fact, refined palm oil is highly valued by the urban and rural population.

Oils produced using traditional methods may contain risk factors that could favour yeasts and moulds to proliferate (Ollivon *et al.*, 1992; Ribier and Rouzière, 1995). Similarly, free fatty acids and mono- and diglycerides accumulate in the oil as a result of enzymatic hydrolysis of triacylglycerols (lipolysis) by yeasts and moulds. These compounds can alter the organoleptic properties of the oil and its by-products (Fournier *et al.*, 2001). Furthermore, cardiovascular problems and obesity have been suggested in some consumers of this vegetable oil due to its unsatisfactory essential fatty acid composition, especially omega-6 (9.2%) and omega-3 (<0.5%) (Bamba, 2024; Lecerf, 2013).

The crude palm oil sold on the various markets in Bujumbura City is generally prepared in an artisanal manner. It is then transported to various storage and sales sites. Referring to the Ministry of Agriculture and Livestock reports, artisanal oil processing units (UATH) process more than 85% of the clusters produced, but deliver crude oil of dubious quality, obtained with a very low extraction rate (MAE, 2008). It then escapes specialised quality control. On the other hand, the quality of the refined oil delivered for consumption is first checked by the industry before it is marketed, and then by the Burundian Bureau of Standards and Quality Control (BBN) at the local or urban market where it is sold. These oils are exposed to various lipid degradation factors by retailers. In fact, they are generally stored in open containers, exposed to sunlight leading, to oxidation, and subjected to repeated heating for ease of measurement (Budju, 2012; M'Baye *et al.*, 2011). Furthermore, the three critical points (treatment, transport and storage) in their production do not seem to be given much importance by local production units or industries. Failure to control these points has led to acidity and high moisture in the samples (Olorunfemi *et al.*, 2014). Moreover, some of them even have rancid smell of deteriorated oil (Tay *et al.*, 2020).

In this context, this study analyses the quality of palm oils samples in some markets of Bujumbura city, in order to contribute to the verification of the compliance of palm oils with the Burundian Standards (NB EAS) and with the Codex Alimentarius Standards and to guarantee food safety for the population. The results could be used by hygiene and public health authorities for control, treatment or permanent monitoring. More specifically, the study aims to: (1) evaluate the physicochemical properties; (2) determine the total carotenoids with a view to assessing the intrinsic quality of the oils delivered to the Bujumbura City Council markets, in accordance with the relevant standards; (3) compare the characteristics of the crude palm oils (CPO) and the refined palm oils (RPO) sold in the markets of Bujumbura city; (4) divide markets into homogeneous or heterogeneous palm oil groups.

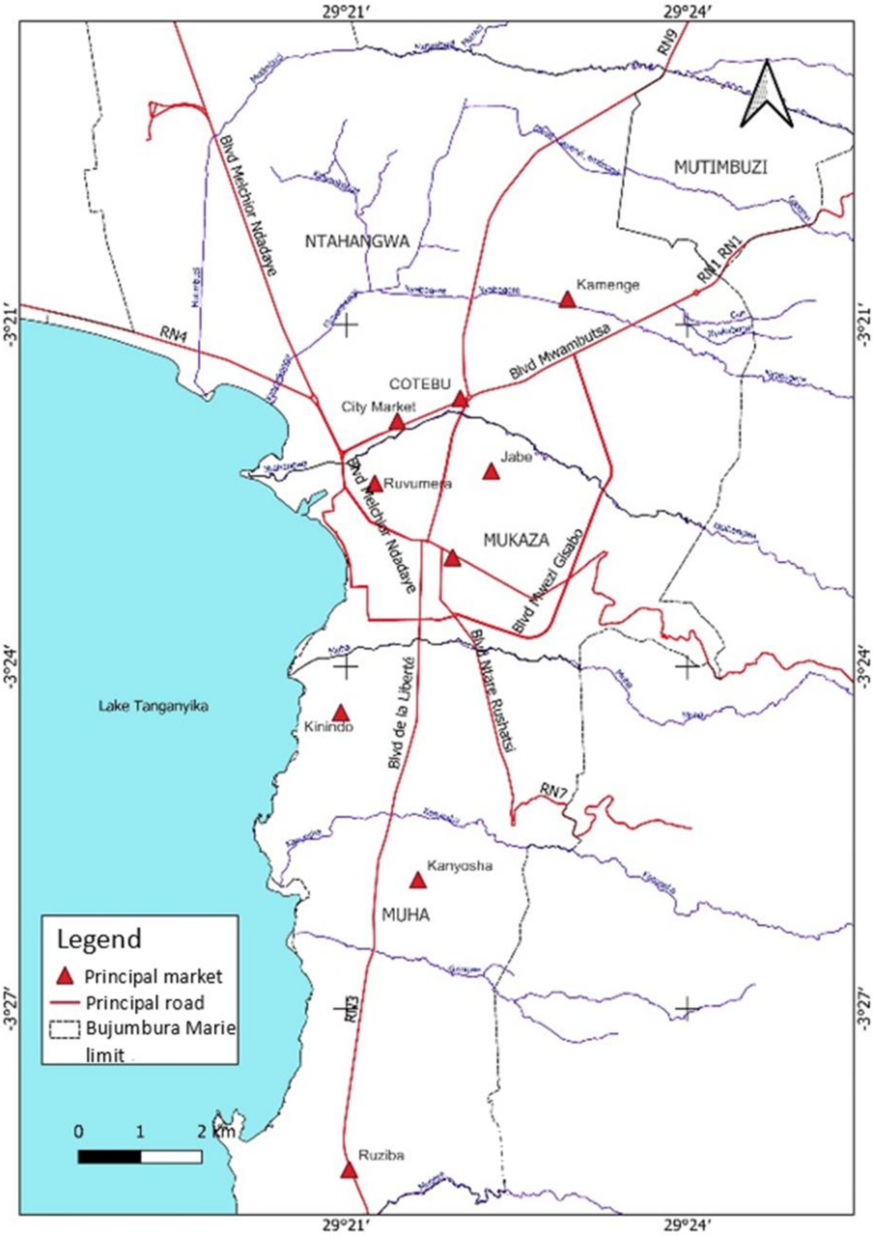
Materials and methods

Study area

This study was conducted in different markets in Bujumbura city (Fig. 1). Bujumbura is a macrocephalic city in the throes of change, due to its high population density (almost 7,500 inhabitants/km^2) (Nsabimana *et al*., 2023).

Figure 1

Location of the various study markets in the City of Bujumbura.



Study Materials

The material used in this study was palm oils (both crude and refined) collected from the commercial markets in Bujumbura, specifically

Ruvumera, Jabe, Siyoni (also referred to as City Market), Cotebu and Kamenge.

Laboratory equipment

The laboratory equipment used for this study included beakers, erlenmeyer flasks, test tubes, coolant, flasks, filter paper, burette, funnel, desiccator, quartz vat, oven (Memmert), spectrophotometer (Shimadzu Neo-Tech UV-Visible), magnetic stirrer (Ikamag), freezer (ZEC AB-180), boiling water bath (Heidolph), refractometer (Abbe Novex 98.490), pycnometer (VF2 series), thermometer (Spengler), flask heater (Electrothermal) and analytical balance 0.001g (Sartorius).

Analytical reagents

All solvents and reagents used were of analytical grade, including the following: pure acetone, 96% cyclohexane, 99% chloroform, 99% n-hexane, 99% sodium thiosulfate, 97% potassium iodide, starch, phenolphthalein, 99% sodium hydroxide, 99% potassium hydroxide, Wij's reagent which were purchased from Merck, Germany. 96% acetic acid, 96% diethyl ether, 36.5% hydrochloric acid, 95% petroleum ether were purchased from Rotipuran, p.a, Spain. 96% ethanol was purchased from BDOM-Bukavu, DRC.

Sampling

The samples analyzed were purchased in the five markets on October 12, 13 and 14, 2024. Purchases were made at random from each of these five markets. Analyses were carried out on 20 samples of refined and crude palm oil, including 10 samples of refined palm oil (RPO) and 10 samples of crude palm oil (CPO). The samples were stored in 600 ml "Kinju" brand plastic bottles, as they are chemically compatible with the oil matrix, cost-effective, and suitable for field conditions. Then labelled (oil type and market) and arranged in cartons and placed in the laboratory cupboard, at room temperature, protected from light and humidity as reported by Césaire *et al.* (2019). Indeed, the samples were stored protected from light and moisture to prevent carotenoid degradation and an increase in acidity and others parameters. Acidity is a fundamental parameter for assessing oil quality. These conditions enable samples to be securely carried up to the laboratory for further analysis. Analyses were carried out in the chemistry laboratory of the Faculty of Sciences at the University of Burundi.

Analysis of physicochemical parameters

In this study, nine physicochemical parameters were analyzed: refractive index (RI) at 50^0C according to ISO 6320:2017, relative density (RD) (50^0C/water at 20^0C) according to ISO 6883:2017, moisture and matter volatile (MVH) at 105^0C according to ISO 662:2016, impurity levels (TII) according to ISO 663:2017, iodine value (IV) according to ISO 3961:2018, acid value (AV) and free fatty acid contents (FFA) according to ISO 660:2020, peroxide value (PV) according to ISO 3960:2017 and saponification value (SV) according to ISO 3657:2020 (EAS, 2022; ISO, 2017).

Determination of total carotenoids (TC)

Total carotenoid concentration was calculated using Mackiney's simplified formula by taking into account all considerations (total chlorophyll concentration), where concentrations are given in (µg/ml or ppm) of extract solution (Lichtenthaler and Wellburn, 1983). The palm oil sample was melted by heating at a temperature between 60°C and 70°C and homogenized before a test sample was taken. It was then filtered through Whatman filter paper to remove impurities. In a 25 ml volumetric flask, 0.1 g of the sample was weighed out to obtain low absorbance values. The sample was dissolved in a few millilitres of 100% acetone at room temperature, then made up to the flask mark with the same solvent. Mix well. The quartz cell was rinsed three times with the pure acetone solution. The first cell was then filled with the pure acetone solution (serving as a blank) and the second with the solution to be analyzed. Measurements were taken against the solvent using a *Shimadzu Neo-Tech UV-Visible spectrophotometer* at 470, 644.8 and 661.6 nm (ISO, 2011).

In pure acetone:

$$C_{(x+c)} = \frac{(1000 \times A_{470}) + (243.2 \times A_{661.6}) - (1267.1 \times A_{664.8})}{214} \quad (1)$$

where $C_{(x+c)}$: concentration of total carotenoids (xanthophylls and carotenes).

$$\text{Finally, TC (ppm)} = \frac{C_{(x+c)} \times 25\ ml}{m} \quad (2)$$

Where m is the weighed oil sample and TC is the total carotenoids.

Statistical Analysis and Data Processing

Experiments were carried out twice for each parameter. The results obtained were expressed as means and standard deviations, and recorded in the results tables. Means and standard deviations were calculated using MS Excel 2013. These averages were then subjected to *Student's t* parametric hypothesis test (normal distribution) for two independent variables (crude and refined oils) for comparison at the 5% probability threshold ($p \leq 0.05$). This test was completed by the *Mann-Whitney U* test (distribution not following the Gaussian normal distribution) to establish a comparison between crude and refined oils. The distribution was checked using the Skewness/Kurtosis normality test. In order to search for homogeneous groups between the different markets where the oils were sampled, a principal component analysis (PCA) was carried out on the results of the physico-chemical parameters and total carotenoids using Past and Stata 15 software to check for variability between these different markets.

Results

Physicochemical parameters and total carotenoids

Analyses carried out on crude and refined palm oil samples taken from various markets (Ruvumera, Jabe, Siyoni, Cotebu and Kamenge) in the Bujumbura city were assessed for refractive index (RI), relative density (RD), moisture and matter volatile (MVH), impurity levels (TII), acid value (AV) or free fatty acid contents (FFA), iodine value (IV), peroxide value (PV), saponification value (SV) and total carotenoids (TC). The results are reported in Tables 1 and 2.

Table 1

Physicochemical parameters of crude and refined palm oils from different markets of Bujumbura

Market	RI (50℃)		RD (50℃/water at 20℃)		MVH at 105℃ (% m/m)		TII (% m/m)		AV (mg KOH/g)	
	CPO	RPO	CPO	RPO	CPO	RPO	CPO	RPO	CPO	RPO
Ruvumera	1.463±0.001	1.463±0.002	0.890±0.001	0.895±0.002	4.649±5.027	1.9405±0.292	11.3±0.113	2.89±0.269	49.992±2.135	2.925±1.403
Jabe	1.462±0.001	1.464±0.001	0.885±0.001	0.892±0.003	4.446±4.676	1.18±1.601	14.78±3.055	4.58±1.075	22.850±5.223	5.397±0.007
Siyoni	1.463±0.001	1.462±0.001	0.890±0.002	0.894±0.00	0.948±0.180	1.384±0.629	6.16±1.188	4.65±2.645	34.442±0.496	6.039±1.187
Cotebu	1.462±0.001	1.463±0.001	0.886±0.002	0.891±0.002	1.908±1.092	0.341±0.077	12.62±3.762	4.12±1.357	43.776±0.517	4.992±0.007
Kamenge	1.461±0.001	1.462±0.001	0.886±0.00	0.891±0.00	0.196±0.003	0.025±0.035	2.48±0.396	6.97±1.796	34.889±0.576	3.552±0.351
Mean	1.462±0.001	1.463±0.001	0.887±0.001	0.892±0.001	2.429±2.196	0.974±0.527	9.468±1.703	4.642±1.228	37.190±1.789	4.581±0.591

Note: *Values are expressed as Mean ± SD from duplicate samples. With: refractive index (RI), relative density (RD), moisture and matter volatile (MVH), impurity levels (TII), acid value (AV), Crude Palm oils (CPO) and Refined Palm Oils (RPO).*

Table 2

Physicochemical parameters and total carotenoids of crude and refined palm oils from different markets of Bujumbura

Market	FFA (% m/m)		IV (g I_2/100 g)		PV (meq O_2/kg)		SV (mg KOH/g)		TC (ppm)	
	CPO	RPO	CPO	RPO	CPO	RPO	CPO	RPO	CPO	RPO
Ruvumera	25.016±0.914	1.47±0.705	54.567±5.384	46.952±1.796	5.5±6.364	6.5±0.707	199.155±3.967	190.039±2.976	851.360±84.892	9.388±0.580
Jabe	11.486±2.625	2.7125±0.003	55.836±25.125	41.877±8.973	9±2.828	5.5±2.121	190.74±0.00	197.752±1.983	594.179±45.604	9.928±0.343
Siyoni	17.313±0.249	2.348±1.570	55.836±7.179	58.374±10.768	6±4.242	5±0.00	197.7525±5.950	199.155±11.900	725.801±71.285	8.351±2.070
Cotebu	22.005±0.260	2.509±0.003	59.643±16.152	44.415±5.384	1.5±0.707	4.5±2.121	198.999±8.154	207.57±0.00	819.926±195.628	18.081±10.362
Kamenge	17.537±0.290	1.785±0.177	45.618±14.450	59.643±8.973	4.5±0.707	7.5±6.364	190.2725±4.628	207.336±2.313	703.301±9.926	7.124±5.650
Mean	18.671±0.867	2.165±0.492	54.3±10.531	50.252±7.179	5.3±2.970	5.8±2.263	195.384±4.540	200.371±3.834	738.913±81.467	10.574±3.801

Note: *Values are expressed as Mean ± SD from duplicate samples. With: Free Fatty Acid Contents (FFA), iodine value (IV), peroxide value (PV), saponification value (SV) and total carotenoids (TC), Crude Palm oils (CPO) and Refined Palm Oils (RPO).*

Figure 2 summarizes the variations in the physicochemical parameters of crude and refined palm oils from different markets of Bujumbura city where they were sampled. There was minimal variations in the refractive index (RI), peroxide value (PV), iodine value (IV) and saponification value (SV) of the two categories of palm oil from different markets.

Figure 2

Physicochemical parameters of palm oil samples from different markets of Bujumbura city: refractive index (RI), relative density (RD), moisture and matter volatile (MVH), impurity levels (TII), acid value (AV), iodine value (IV), peroxide value (PV) and saponification value (SV).

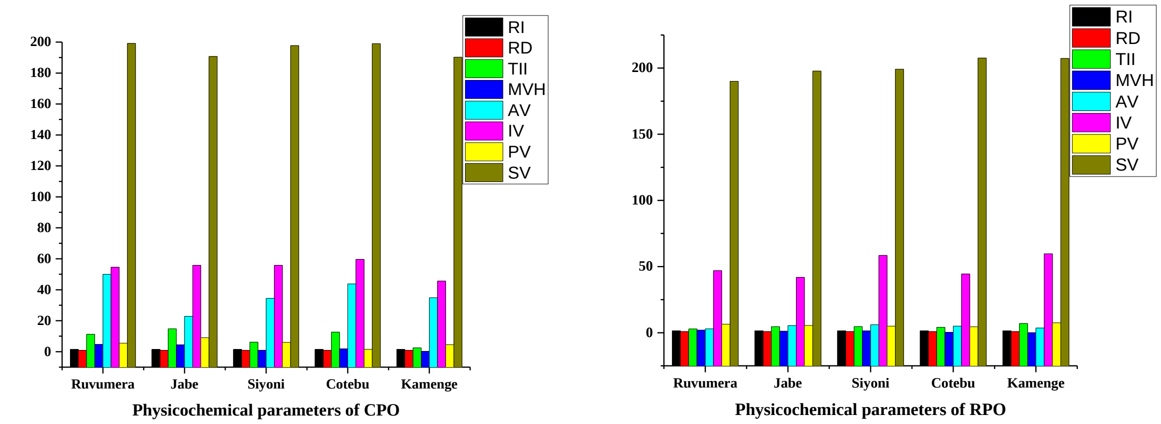
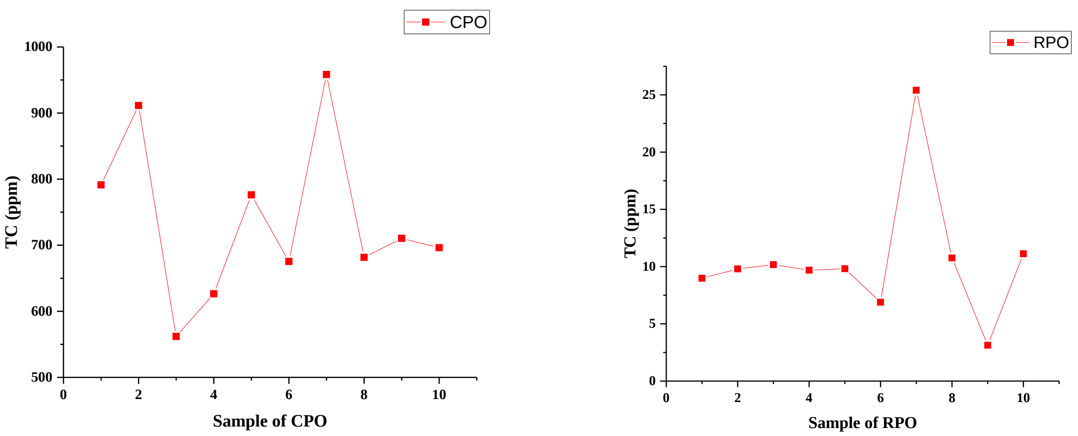


Figure 3 shows the variation in total carotenoid content in the different samples, with more variation in crude palm oils (CPO). On the other hand, in refined palm oils (RPO), the variation was minimal. Jabe crude oil samples (3 and 4) had low levels of total carotenoids.

Figure 3

Variation in total carotenoid content in crude (CPO) and refined (RPO) palm oils from different markets of Bujumbura city.



Comparison of the physicochemical characteristics and total carotenoid content of crude and refined palm oils from different markets of Bujumbura city

The average results of twenty (20) samples of crude and refined palm oils are reported in Table 3. This comparison between the two oil categories is made using the *Student's t*-test coupled with the *Man Whitney U*-test at the 5% probability threshold ($p \leq 0.05$).

Table 3

Physico-chemical parameters and total carotenoids content of crude and refined palm oil samples from different markets of Bujumbura city.

Parameter	Crude Palm Oils (CPO)	Refined Palm Oils (RPO)	p-value
RI	1.462±0.295[a]	1.463±0.001[a]	0.4299
RD	0.887±2.214[a]	0.892±0.002[b]	0.0001
MVH (% m/m)	2.429±5.412[a]	0.974 ±0.940[a]	0.273
TII (% m/m)	9.468±5.029[a]	4.642 ±1.851[b]	0.0107
AV (mg KOH/g)	37.190±14.043[a]	4.581±1.376[b]	p<0.0001
FFA (% m/m)	18.671±4.947[a]	2.165±0.757[b]	p<0.0001
IV (g I_2/100 g)	54.3±26.685[a]	50.2522±9.705[a]	0.4284
PV (meq O_2/kg)	5.3±3.743[a]	5.8±2.616[a]	0.5967
SV (mg KOH/g)	195.384±5.576[a]	200.371±8.101[a]	0.1304
TC (ppm)	738.913±117.783[a]	10.574±6.439[b]	0.0002

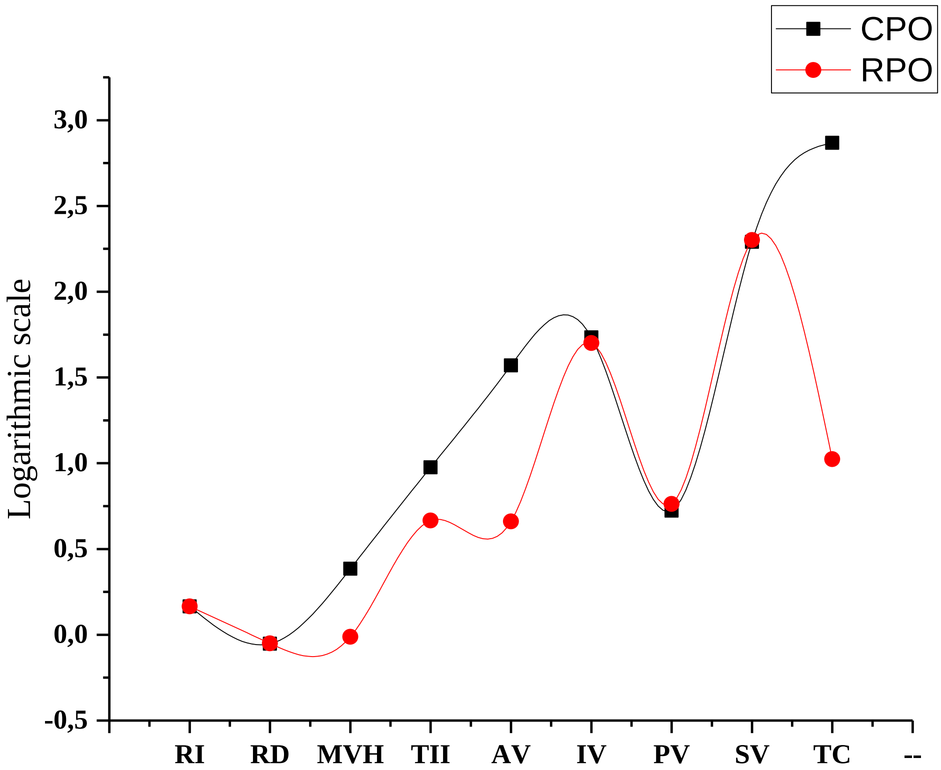
Note: *Values are expressed as Mean ± SD from duplicate samples. These on a line bearing the same letter are not significantly different (p >0.05).*

Results shown in Table 3 reveal that five (5) parameters varied significantly between the two palm oil categories. These are relative density (RD), impurity levels (TII), acid value (AV) or free fatty acid contents (FFA) and total carotenoid content (TC). However, other variations between certain parameters were not statistically significant.

Figure 4 shows the variations between physicochemical parameters and total carotenoid content. These variations are presented on a logarithmic scale to better visualise the differences between them. Refined oils are shown in red and crude oils in black. Relative density (RD), refractive index (RI), peroxide value (PV) and saponification value (SV) showed no variation. On the other hand, moisture and matter volatile (MVH), impurity levels (TII), acid value (AV) or free fatty acid contents (FFA) and total carotenoids (TC) showed variations.

Figure 4

Variation in total carotenoid content in crude (CPO) and refined (RPO) palm oils from different markets of Bujumbura city: refractive index (RI), relative density (RD), moisture and matter volatile (MVH), impurity levels (TII), acid value (AV), iodine value (IV), peroxide value (PV), saponification value (SV) and total carotenoids (TC).

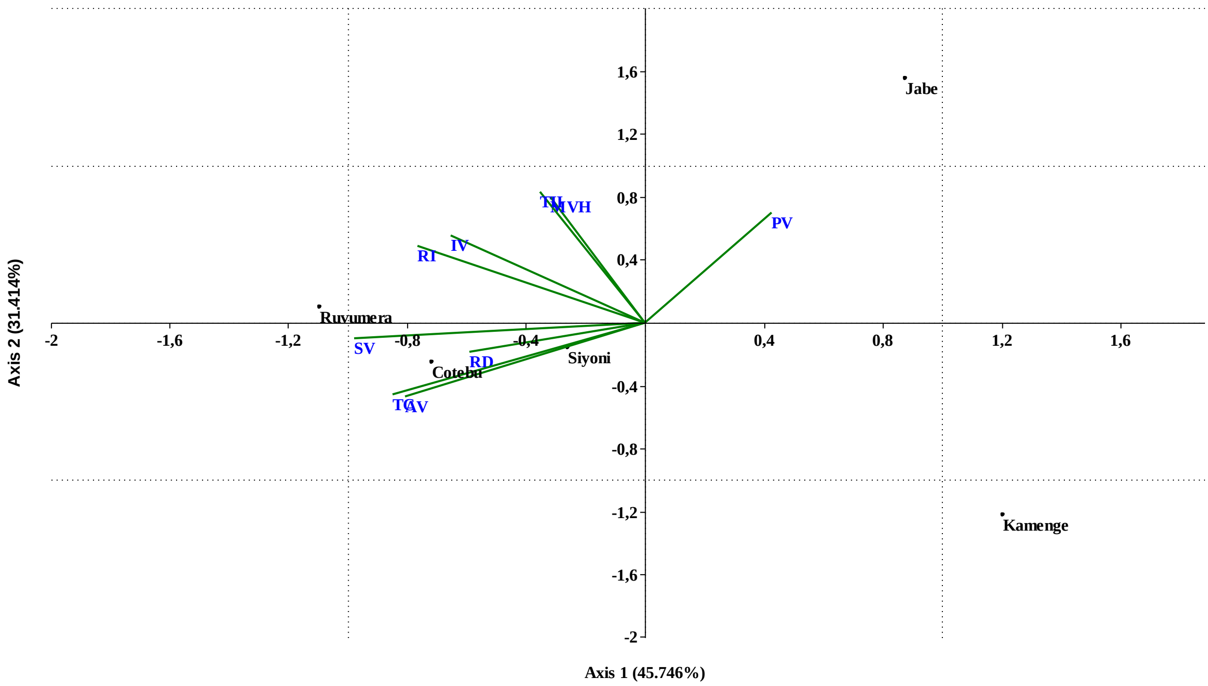


Grouping of markets according to physicochemical parameters and total carotenoids crude palm oil content

Principal Component Analysis (PCA) performed on the physicochemical parameters and total carotenoid content of crude palm oil samples from different markets in Bujumbura city enabled us to determine a scatter plot of the oil samples on two factorial axes. This representation explains 77.16% of the overall inertia (Figure 5). This analysis revealed three Groups (G) according to physicochemical parameters and total carotenoids crude palm oil content: the G1 made by the Siyoni, Cotebu and Ruvumera markets are homogeneous. On the other hand, the G2 made Jabe samples which shows a high peroxide value (PV). Lastly, the G3 Kamenge samples that showed more or less low values for physicochemical parameters and total carotenoid (TC.) content.

Figure 5

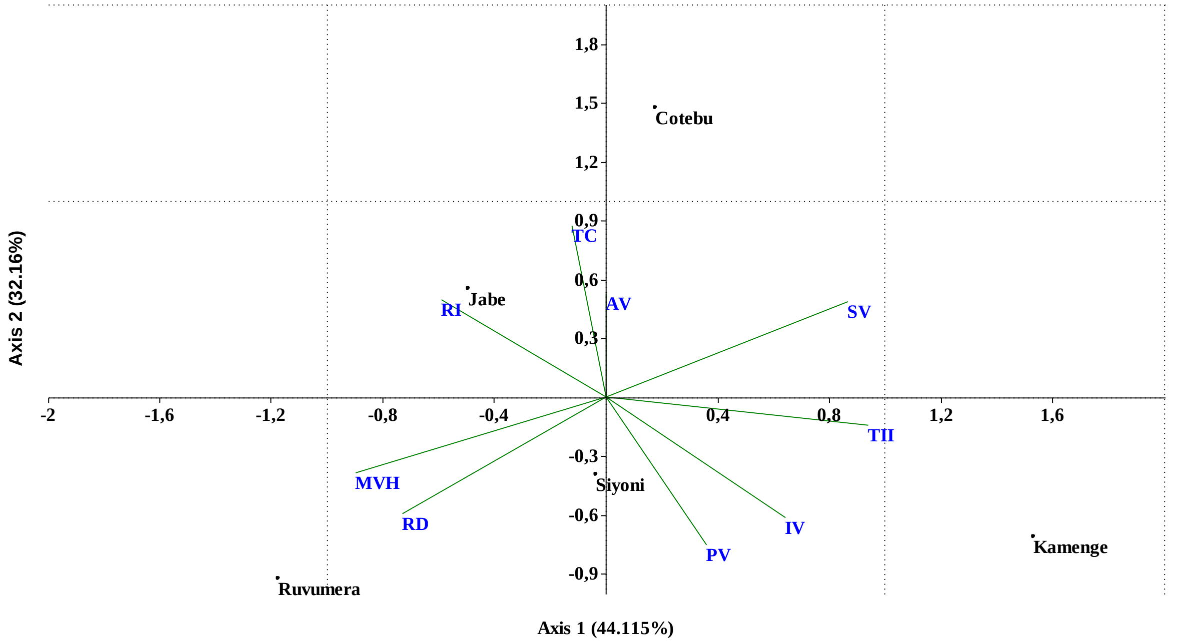
Clouds of individuals (Bujumbura city markets) and variables (physicochemical parameters and total carotenoid content), with: refractive index (RI), relative density (RD), moisture and matter volatile (MVH), impurity levels (TII), acid value (AV), iodine value (IV), peroxide value (PV), saponification value (SV) and total carotenoids (TC).



In order to understand the variations in different parameters between markets, a PCA was also carried out for refined palm oils. Physicochemical parameters, total carotenoids and the different markets in the Bujumbura city were projected on the same factorial plane (1× 2) (Figure 6). The analysis explains 76.276% of inertia and classifies markets into three Groups according to physicochemical parameters of refined palm oils. The G1 made by Kamenge, Cotebu and Jabe markets are homogeneous. For this G1: saponification value (SV), impurity levels (TII), iodine value (IV) and peroxide value (PV) are high, while moisture and matter volatile (MVH) and relative density (RD) are low. On the other hand, the G2 made by Ruvumera market seemed to be at the opposite end of the spectrum, with low values for moisture and matter volatile (MVH) and relative density (RD). Finally, the G3 made by Siyoni market seemed to have the best projection on the axis, with intermediate features for almost all parameters except for acid value (AV).

Figure 6

Clouds of individuals (Bujumbura city markets) and physicochemical parameters and total carotenoid content, with: refractive index (RI), relative density (RD), moisture and matter volatile (MVH), impurity levels (TII), acid value (AV), iodine value (IV), peroxide value (PV), saponification value (SV) and total carotenoids (TC).



In summary, these markets share a number of common features and are almost homogeneous.

Discussion

Few variations in physicochemical parameters of different palm oil types and deviation from standards compliance:

The refractive index (RI) values are almost equal to 1.462 and 1.463 for crude and refined oils respectively. These values exceed the maximum value set simultaneously by the Burundian standard bureau (NB EAS) and that of the Codex Alimentarius, which sets a value of between 1.454 and 1.456 specifically for palm oils (EAS, 2022; Codex, 2023). Therefore, 100% of the samples analyzed do not comply with these standards. Refractive index is considered an oil purity criterion (Novidzro *et al.*, 2019). It depends on the oil's chemical composition and temperature. When oils are not stored under the right conditions, quality can be lost through oxidation or hydrolysis (Diakite *et al.*, 2022). These high refractive index values are due to palm oils being exposed to the open air in various markets. In addition, they are stored in plastic bottles, which promotes and accelerates light-catalyzed oxidation (Drici Adil, 2019; Tay *et al.*, 2020). However, these values are consistent with those reported for red palm oils produced in the Mountains "Man" district in the Côte d'Ivoire, ranging from 1.449 to 1.463 (Kouassi *et al.*, 2017).

All crude palm oil relative density (RD) values were less than or equal to 0.891. Refined oils, on the other hand, have values between 0.889 and 0.896. Only the average relative density of refined palm oils falls within the range of the Burundian standard (NB EAS) and the Codex Alimentarius, which specifies a value between 0.891 and 0.899 for palm oils (Codex, 2023; EAS, 2022). This difference between the densities of these two types of oil can be explained primarily by the addition of ingredients during refining in refined palm oils (Budju, 2012). However, the determination of relative density also provides information on the purity of the oil (Diakite *et al.*, 2022). Crude palm oils are likely to contain many other undesirable elements due to rudimentary production techniques and less compliance to hygienic conditions. The average relative density of crude palm oil is lower than what was reported in district oils from the Mountains "Man" in the Côte d'Ivoire, ranging from 0.924 to 0.998 (Kouassi *et al.*, 2017).

Moisture and matter volatile (MVH) values range from 0 to 8.203% (m/m). However, the average values for these two types of oil are 0.974 and 2.429% (m/m), for refined and crude palm oil respectively. All these average values do not comply with Burundian (NB EAS) and Codex Alimentarius standards for a maximum of 0.2% (m/m) (Codex, 2023; EAS, 2022). For crude oil, moisture can result from the extraction stage, where the oils are not well separated from the water (Karleskind, 1992). On the other hand, poor drying or insufficient deodorization may be the cause of moisture in refined palm oil. Moisture content influences the deodorization stage, which, once well controlled, contribute to the stability and conservation of refined oil (Echioda *et al.*, 2018). The high moisture content in a fat constitutes a medium for microbial development, enzymatic actions contribute to the hydrolysis and oxidation phenomena of fats, and a shorter shelf life, and since a water activity > 0.3% favours enzymatic oxidation of the oil (Ollivon *et al.*, 1992; Ribier and Rouzière, 1995). The moisture and matter volatile values obtained for palm oil samples seem to be higher not only because of the conditions mentioned above, but also because of the poor hygiene conditions of the containers where the oils are stored, sometimes containing traces of water. Atmospheric water vapour and rainwater are also possible causes (Novidzro *et al.*, 2019). The best way to preserve oils is to dehydrate them before storing them away from heat and light (Karleskind, 1992).

The values for impurity levels (TII) are all above 2.2% (m/m) for all two palm oil categories. These values are all above the Burundi (NB EAS) and Codex Alimentarius quality standards, which set a threshold of 0.05% (m/m) (Codex, 2023; EAS, 2022). In crude oil, these impurities are significant, with considerable variation between samples, reaching a maximum of 14.78% (m/m) in the Jabe market. The origin of these impurities may generally be due to the poor exposure to air conditions of the oils during marketing. In fact, as the sampling was carried out during the dry season (almost at the end), dust prevails in the region. It has been reported that all impurities in palm oil come from residues in the raw material (Tarnagda, 2016). This explains their abundant presence in crude palm oils. During laboratory filtration of crude palm oils, these impurities were clearly visible on the filter paper. The high amount of insoluble impurities in the oil also increases the oxidation of free fatty acids and carbohydrates (sugars), making it unfit for consumption (Liyansan *et al.*, 2022). These values agree with those reported by Liyansan et *al.* (2022). They ranged from 0.145 to 15.618% (m/m) for palm oils purchased in the markets of Lagos, Nigeria.

Refined palm oils must have a maximum acid value (AV) of 0.6 mg KOH/g and crude or virgin oils a maximum of 10 mg KOH/g according to Burundian and Codex Alimentarius standards (Codex, 2023; EAS, 2022). With regard to the values obtained, all palm oil categories have an average of 4.581 and 37.190 mg KOH/g for refined and crude palm oils respectively. These values do not comply with. This AV plays an important role in refining operations, but above all, low acidity characterizes purity and stability at ambient temperature (Eze *et al*., 2021). Acidity also limits industrial applications, and oil that is too acidic should not be used in human nutrition (Japir *et al*., 2017). The more acidic the oil, the lower its quality (Abdulkadir and Jimoh, 2013). Our mean values are higher than those of N'guessan *et al*. (2018), who found a value of 1.11 mg KOH/g for refined palm oils produced in the Côte d'Ivoire. Eze *et al*. (2021) reported a mean value of 6.658 mg KOH/g while Liyansan et *al.* (2022) reported 4.497 mg KOH/g for crude palm oils produced in Nigeria.

The average of free fatty acid contents for two categories of palm oil are 2.165% and 18.671% respectively for refined and crude palm oils. This index even reached a maximum of 25.016% mg KOH/g for the Ruvumera market samples. The acidity of crude palm oils is justified by the presence of free fatty acids (citric acid, malic acid, malonic acid, oxalic acid, etc.) in significant proportions (M'Baye *et al*., 2011). However, during refining, precisely at the neutralization and deodorization stages, a large proportion of these free fatty acids are neutralized (Jahouache, 2002). As a result, the palm oils sold in Bujumbura markets are too acidic, and refining does not result in total neutralization of the free fatty acids. However, all refined oils have an acidity value below 3% as recommended by Onyeike and Acheru (2002) for edible oil. Crude oils, on the other hand, can be considered hard since their acidity exceeds 5% (Hyman, 1990). In addition, the long stay of oils in storage or markets can also cause an increase in acidity, as fats altered by ageing give rise, through enzymatic hydrolysis, to free fatty acids, which in turn are primary products of the oxidation of oils with peroxides, aldehydes and ketones (Drici Adil, 2019; Tay *et al*, 2020). The mean values in this study were higher than those by Eze et *al.* (2021), who found the value of free fatty acid ranges from 2.44% to 4.29% and Obahiagbon (2013), who ranges from 3.59% to 7.90% for crude palm oils produced at Nigeria. On the other hand, they agree with those of Olorunfemi (2014) ranging from 12.1 to 19.8% for crude palm oils sold at the Ibadan market in Nigeria.

The average iodine value (IV) for the two categories of palm oil are 50.252 and 54.3 g I_2/100 g for refined and crude palm oil respectively. These values are in line with Burundian standards (NB EAS), which require a minimum of 45 g I_2/100 g, and Codex Alimentarius standards, which range from 50 to 55 g I_2/100 g (Codex, 2023; EAS, 2022). The iodine value gives an indication of the unsaturated fatty acid content of the fat being analysed. The lower the iodine value, the more saturated the molecule and *vice versa* (Césaire *et al*., 2019). Moreover, this index gives an assessment of the susceptibility of the oil to rancidity, since the more unsaturation it contains, the more sensitive it is to oxygen (Kouadio, 2022). Based on these results, the palm oils sold in Bujumbura city have resistance to oxidation because they contain less unsaturation. These values are in line with those of Konan et *al*. (2018), N'guessan *et al.* (2018) and Adamu (2023), who found an average value of this index varying between 50 and 55 g I_2/100 g for palm oils produced in the Côte d'Ivoire and Nigeria.

The results obtained for peroxide value (PV) showed that average values oscillate between 5.3 and 5.8 meq O_2/kg for crude and refined palm oils respectively. These comply with Burundian (NB EAS) and Codex Alimentarius standards for a maximum of 10 meq O_2/kg (Codex, 2023; EAS, 2022). The peroxide value gives an assessment of the quantity of peroxides present in the sample. In fact, it indicates the quantity of already rancid fatty acids (Novidzro *et al*., 2019). It gives information about the oil's current or future state, not its past (Olorunfemi *et al*., 2014). Moreover, the peroxide value mainly provides information on the primary products of lipid oxidation, which are hydro peroxides (Eze *et al*., 2021). This would imply that the palm oil samples analysed have either not yet undergone oxidation (primary oxidation) or are already highly oxidized (secondary oxidation). Since these oils are not likely to remain on the markets for long and are obtained directly from industries and production units, they are probably not oxidized. This because the palm oils samples appear to be rich in the pigments that provide antioxidant power. These results corroborate those reported by Lecerf (2013), who stated that such palm oil would present low oxidizability and, therefore, good stability. These results are also close to those of Adamu (2023), who found an average value of 3.82 meq O_2/kg for oils produced in Nigeria.

Knowing the saponification value (SV) of a fatty substance gives the information about the carbon chain length of the fatty acids. The saponification index of a fatty substance is higher when the carbon chain of the fatty acids is short or of low molecular weight (M'Baye *et al.*, 2011). The average saponification value obtained for these oils, 195.384 and 200.371 mg KOH/g for crude and refined palm oils respectively, are within the range of the Burundian (NB EAS) and Codex Alimentarius standards, which set a value between 190 and 209 mg KOH/g (Codex, 2023; EAS, 2022). The saponification value results showed that the majority of the fatty acids in the refined oil samples were short chain or low molecular weight. This low molecular weight could be linked to the loss of certain macromolecules, such as carotenoids, during refining (Budju, 2012). The values obtained in this study are consistent with those of N'guessan *et al.* (2018), Césaire et *al.* (2019), Eze et *al.* (2021), Obibuzor *et al.* (2017) and Adamu (2023), which range from 190 to 215 mg KOH/g for palm oils produced in Côte d'Ivoire, Cameroon and Nigeria.

Total carotenoids (TC)

The average total carotenoid (TC) content in these samples ranged from 10.574 to 738.913 ppm for refined and crude palm oils respectively. For crude or red oil, this average value is within the range of Burundian (NB EAS), Nigerian (SON) and Codex Alimentarius standards, which stipulate a value in the 500 to 2000 ppm range (Codex, 2023; EAS, 2022). However, total carotenoid content can vary from 500 to 1000 ppm in red oil (Adamu, 2023). The palm oil produced in Burundi is of the *tenera* variety (Ngiye, 2015). This average for red oil agrees with that of Obibuzor *et al.* (2017), who found an average value of 701.85 ppm in crude or red oil of the *tenera* variety produced in Nigeria during a comparative study between various varieties. On the other hand, it is higher than that of Olorunfemi et *al.* (2014), who found values ranging from 269 to 355 ppm for crude or red oils sold at the Ibadan market in Nigeria.

In this study, the mean carotenoid content was on average 76 times higher in red oil than in refined oil. Thus, there is no standard value for refined oils, since they are very low in carotenoids. Studies by Bamba *et al.* (2024) have shown that refined palm oil or palm olein can be enriched with antioxidants such as Omega-3-rich hevea oil, since they are low in Omega-3s, to counter the carcinogenic and cardiovascular diseases to which consumers of this oil are exposed in the Côte d'Ivoire.

Palm oil is a rich source of carotenoids, they are widely known as provitamin A. Dietary beta-carotene and other provitamin A carotenoids such as α-carotene and cryptoxanthin can be obtained from a number of foods, such as fruits and vegetables (Mangels *et al.*, 1993). In higher plants or angiosperms, lutein and xanthophyll are the most available carotenoids whose presence in an individual's food intake plays a dominant role (Zielińska *et al.*, 2017). However, they play several preponderant roles in the prevention of many diseases as antioxidants in the prevention of certain types of cancer, cognitive, anti-inflammatory, neuro-protective. They are also involved in preventing eye and heart problems, and play an important role in pregnancy development (Roomi *et al.*, 2018; Zhou *et al.*, 2018).

It should be remembered that during refining, carotenoids and minor elements are almost totally eliminated from palm oil precisely during the deodorization stage, since their presence limits the oil's industrial applications (Mattea *et al.*, 2009). As a result, the carotenoid content of refined oil is very low (Tay *et al.*, 2020).

Conclusion

This study analysed the quality of crude (CPO) and refined (RPO) palm oils sold in Bujumbura city markets. The physicochemical properties were analysed and the determination of total carotenoids using UV-visible spectroscopy was done. The low iodine (50.252±7.179 and 54.3±10.531 g I_2/100 g) and peroxide (5.8±2.263 and 5.3±2.970 meq O_2/kg) values for refined et crude palm oils partly confirm that the palm oils sold in the markets of Bujumbura do not remain on the shelves for long; they are quickly sold due to high consumer demand. This is likely because they come directly from local production units and processing industries. However, the *Student's t*-test coupled with the *Mann-Whitney U*-test revealed that five (5) parameters (relative density, insoluble impurity levels, acid value or free fatty acid contents and total carotenoids) differed significantly. This means that these two categories of oil are very different in terms of nutrition and quality values. In addition, Principal Component Analysis (PCA) showed that all the markets in which they were sampled were almost homogeneous.

Recommendations

Based on the findings, it is recommended that crude palm oil consumption be approached with caution, given its high acid value (37.190±1.789 mg KOH/g) or free fatty acid contents (18.671±0.867% m/m) and impurity levels (9.468±1.703% m/m), which may indicate substandard hygienic practices in its production. In addition, refined palm oils need to be enriched with antioxidant compounds as they are very low in carotenoids (10.574±3.801 ppm). Consequently, local production units, industries and traders need to improve palm oil processing, transport, storage and sales techniques to provide consumers with products of the required quality.

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Conflict of interest

The authors declare no conflict of interest on the study.

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