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Physicochemical and sensory evaluation of the quality of crude palm oil (*Elaeis guineensis*) produced artisanally and industrially in Brazil

Avaliação físico-química e sensorial da qualidade do óleo de palma (*Elaeis guineensis*) bruto produzido no Brasil de forma artesanal e industrial

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Highlights

Quality and sensory parameters of seven Brazilian crude palm oils were analyzed.
Acidity and iodine values in palm oil were inadequate based on legislation.
Low results for carotenoids and positivity for Kreis reaction in all samples.
Artisanal production achieved high acceptance in terms of global impression.
Results show improvement possibilities in traditional palm oil production methods.

Abstract

Palm oil is primarily used in the crude form in northeastern Brazil's cuisine. Most of its production is carried out by small manufacturers, who use the profits from sales as a subsidy to supplement their family income. Evaluating the physicochemical and sensory quality of palm oil is essential to help producers develop higher-quality artisanal products. This study aimed to analyze samples of crude palm oil produced and sold in the city of Taperoá (BA) and other industrialized brands sold in Salvador (BA). Seven palm oil samples underwent physicochemical analysis (acidity, carotenoid content, instrumental color, iodine value, peroxide value, Kreis reaction, saponification value) and sensory analysis (acceptance and ranking tests). Our findings revealed significant variation in the evaluated parameters, with most samples showing inadequate results for the regulatory parameters of acidity and iodine values, as well as unsatisfactory results for carotenoids and the Kreis reaction across all samples. Variations in

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color analysis were likely associated with differences in carotenoid content among the samples. The acceptance tests showed that most samples scored above average for all evaluated characteristics, except for the industrial sample from Taperoá (sample 06), which showed the lowest averages for color (4.5), odor (5.2), viscosity (3.2), and overall impression (4.3). In the ranking test, sample 02 from artisanal production (Taperoá-BA) was the most preferred in all categories, while sample 06 from industrial production (Nazaré-BA) was the least preferred in all categories. These results indicate opportunities for improving both traditional and industrial crude palm oil production methods, which could lead to an increase in income for the population that depends on this product.
Key words: Quality control. Instrumental color. Palm oil. Artisanal product. Acceptance test.

Resumo

O óleo de palma é usado principalmente na forma bruta na culinária do nordeste brasileiro. A maior parte de sua produção é realizada por pequenos fabricantes, que usam os lucros das vendas como subsídio para complementar a renda familiar. Avaliar a qualidade físico-química e sensorial do óleo de palma é essencial para ajudar os produtores a desenvolver produtos artesanais de maior qualidade. Este estudo teve como objetivo analisar amostras de óleo de palma bruto produzido e vendido na cidade de Taperoá (BA) e outras marcas industrializadas vendidas em Salvador (BA). Sete amostras de óleo de palma foram submetidas a análises físico-químicas (acidez, teor de carotenoides, cor instrumental, índice de iodo, índice de peróxido, reação de Kreis, índice de saponificação) e análise sensorial (testes de aceitação e classificação). Nossos achados revelaram variação significativa nos parâmetros avaliados, com a maioria das amostras apresentando resultados inadequados para os parâmetros regulatórios de acidez e valores de iodo, bem como resultados insatisfatórios para carotenoides e reação de Kreis em todas as amostras. Variações na análise de cor provavelmente foram associadas a diferenças no teor de carotenoides entre as amostras. Os testes de aceitação mostraram que a maioria das amostras obteve pontuação acima da média para todas as características avaliadas, exceto a amostra industrial de Taperoá (amostra 06), que apresentou as menores médias para cor (4,5), odor (5,2), viscosidade (3,2) e impressão geral (4,3). No teste de classificação, a amostra 02 de produção artesanal (Taperoá-BA) foi a mais preferida em todas as categorias, enquanto a amostra 06 de produção industrial (Nazaré-BA) foi a menos preferida em todas as categorias. Esses resultados indicam oportunidades de melhoria dos métodos tradicionais e industriais de produção de óleo de palma bruto, o que pode levar ao aumento da renda da população que depende desse produto.
Palavras-chave: Controle de qualidade. Cor instrumental. Óleo de palma. Produto artesanal. Teste de aceitação.

Introduction

Palm oil is derived from the processing of the fruit of *Elaeis guineensis* Jacq., originating from West Africa. It can be refined into refined palm oil (RFO) or sold as crude palm oil (CPO). In 2019, global palm oil output reached 62 million tons, with cultivation spanning 17 million hectares, making it a vital component of the global vegetable oil market (Abazue et al., 2019). It holds significant economic value for the global food industry as the preferred raw material for food hydrogenation, due to the low cost of processing compared to other vegetable sources (Almeida et al., 2019). This advantage stems from its composition, which is predominantly saturated fatty acids, featuring a low degree of unsaturation.

In 2022, the production value of palm oil in Brazil was approximately USD 238,000. That year, the country produced 2,952,129 t of palm oil over a harvested area of 200,527 ha (Instituto Brasileiro de Geografia e Estatística [IBGE], 2023). In Brazil, much of the palm harvest is used to produce crude palm oil (CPO), a symbol of Afro-Brazilian culture due to its unique flavor and gastronomic uses in traditional recipes. The production of CPO in Brazil is a multifaceted industry, encompassing both artisanal and industrial processes. It is deeply intertwined with Brazilian culture, particularly in the Northeastern and Northern regions, where it holds significant cultural importance (Almeida et al., 2019).

The artisanal production of CPO often involves community-based activities, contributing to the socio-economic development of the region. On the other hand, semi-industrial and industrial production methods are essential for meeting the growing demand for high-quality processed products and ensuring supply chain efficiency. Understanding the differences in quality between artisanal and industrial CPO production is crucial for preserving cultural practices and supporting the livelihoods of small-scale producers, while also catering to global market demands (Sarpong et al., 2022). Given the importance of palm oil in various cultural and culinary contexts, assessing the physicochemical and sensory profiles of both artisanally and industrially produced palm oils is essential to understand the distinct characteristics of each production method and their implications for food quality and consumer preferences (Araújo et al., 2019).

Critical parameters commonly analyzed in CPO include acidity, carotenoids, color, iodine index, peroxide index, Kreis reaction (rancidity), saponification, and sensory profile (Almeida et al., 2019). Acidity content is a key indicator of oil quality and stability, with legislation often specifying maximum allowable levels (Agência Nacional de Vigilância Sanitária [ANVISA], 2021). Carotenoids, important for the oil's color and nutritional value, must be analyzed to meet regulatory standards (Food and Agriculture Organization of the United Nations and World Health Organization [FAO/WHO], 1999). Color assessment is crucial for the sensory appeal and marketability of natural or processed products (Rodrigues et al., 2023; Cafieiro et al., 2022). The iodine value indicates the oil’s unsaturation and suitability for various applications, while the peroxide value measures primary oxidation. The Kreis reaction assesses rancidity, and the saponification value indicates the oil’s purity and composition. Sensory analysis is also essential for overall quality assessment, ensuring that the oil meets specific sensory requirements (Almeida et al., 2019; Liu et al., 2020).

These parameters are governed by regulatory standards and industry specifications to ensure the quality and safety of CPO in the market. However, there is a notable gap in studies evaluating the differences between artisanal and medium/

large-scale production of CPO in the Northeast region of Brazil. Therefore, this study aims to investigate the physicochemical and sensory aspects of Brazilian artisanally and industrially produced palm oils to identify the distinct characteristics inherent to these two production methods and provide valuable insights for the food industry.

Materials and Methods

Sample collection and coding

A total of seven samples of palm oil were collected, one from artisanal production (A) and six of industrial output (I). Three of the samples were produced in São Paulo (SP) (samples ISP1, ISP2, ISP3) and four (samples ABA, IBA1, IBA2, and IBA3) were processed by communities in the municipalities of Valença, Taperoá, and Nazaré, in the state of Bahia (BA).

Physicochemical analysis

All samples underwent analysis for acidity, peroxide value, Kreis reaction, saponification value, and carotenoids according to the methodology of Instituto Adolfo Lutz [IAL] (2008). The iodine value was determined using a methodology modified by Edo et al. (2022). All analyses were conducted in triplicate.

The color parameters were analyzed using a Konica Minolta CR-5 colorimeter (Japan) in the CIELab space. The L* dimension, representing lightness as a percentage, ranges from 0 (black) to 100 (white). The a* and b* dimensions indicate the color varies from green to red (x-axis) and blue to yellow (y-axis), respectively, with values from -60 to +60. Based on the values of L* (lightness), a* (variation between green-negative and red-positive), and b* (variation between blue-negative and yellow-positive), both saturation (C) and hue (h) were calculated using a D65º illuminant and a 10º observation angle. Samples were analyzed in a 2-mm thick cuvette with a volume of 2 mL (Tavares et al., 2021).

Sensory analyses

The project received ethical approval from the Climério de Oliveira Maternity Hospital/UFBA research ethics committee (Resolution 196/96), with a favorable opinion for its conduct (62/2007).

The sensory acceptance test involved 62 assessors of crude palm oil, utilizing a nine-point structured hedonic scale ranging from "strongly dislike" (1) to "strongly like" (9), evaluating global impression, color, odor, and viscosity (Meilgaard et al., 2007). Samples, coded and randomized, were presented monadically to assessors.

Following the acceptance test, a ranking test was conducted with the same 62 evaluators according to ISO 8587 (International Organization for Standardization [ISO], 2006). In this test, coded and randomized samples were presented simultaneously to the evaluators to establish a preference order for color, odor, and viscosity. The results were calculated by summing the orders assigned by the assessors to each of the samples (Dutcosky, 2013).

Statistical treatment

The data from the physicochemical and sensory acceptance tests were analyzed using analysis of variance (ANOVA) and Tukey's test, considering $p \leq 0.05$. For the ranking test, data were analyzed using the Friedman test, and differences in order totals were quantified (Christensen et al., 2006). Principal component analysis (PCA) was conducted to correlate instrumental and sensory color data, and the statistical analysis was performed using XLMINER ANALYSIS software.

A heatmap was created in the ClustVis web app to correlate physicochemical data with the overall impression of the samples. The analysis applied unit variance scaling to rows and used imputation for missing value estimation. Both rows and columns were clustered by correlation distance and average linkage.

Results and Discussion

The measurement of acidity in edible oils is indicative of free fatty acids and relates to the oil's deterioration degree. Hydrolysis and oxidation reactions can increase acidity levels, particularly in oils like palm oil derivatives, which contain moderate to high percentages of unsaturated fatty acids. Palm oil is rich in C18:1 (Soto et al., 2020). High acidity in palm oil can signal processing flaws and negatively impact sensory characteristics such as flavor and aroma, as well as reduce the product's shelf life (Japir et al., 2017).

The acidity levels observed in this study (Table 1) ranged from 4.62 mg KOH g^{-1} (ISP1) to 36.88 mg KOH g^{-1} (ISP3), demonstrating high variability among crude palm oils produced and marketed in Brazil, particularly in the state of Bahia. For comparison, a study in Malaysia recorded crude palm oil acidity between 18.53 and 18.98 mg KOH g^{-1} (Hari et al., 2024), while in Ghana, acidity varied from 10.75 to 22.47 mg KOH g^{-1} (MacArthur et al., 2021), similar to the findings in this study.

Brazilian legislation IN 87/2021 (ANVISA, 2021) mandates that the maximum acidity for virgin palm oil should not exceed 10.0 mg KOH g^{-1}. Thus, only sample ISP1 from São Paulo adheres to this standard. The high acidity in the other samples suggests that both artisanal and industrial production processes, including extended fruit harvesting and processing times, require refinement to align with legal standards.

Carotenoid analysis, expressed as β-carotene (Table 1), revealed the lowest content in sample ABA at 63.56 ppm, an artisanally produced sample. In contrast, the highest value was recorded for sample 04 at 325.43 ppm. According to the Codex Alimentarius (FAO/WHO, 1999), recommended carotenoid levels in palm oil range from 500 to 2000 ppm, indicating that all samples fell below the minimum standard. Levels immediately after production by Almeida et al. (2019) were significantly higher at 766.83 ppm, only declining to figures comparable to this study (252.42 ppm) after 12 months of storage at 26 to 32 °C, suggesting compromised stability of the samples in this study, particularly in artisanal crude palm oil.

Table 1
Physicochemical parameters of the different crude palm oil samples

Sample	Acidity (mg KOH g^{-1})	Carotenoid Content (ppm)	Iodine value	Peroxide value (mEq 1000 g^{-1})	Saponification value (mg KOH g^{-1})
ABA	17.23 ±0.14^{c}	63.56 ±11.20^{c}	48,10 ±1.30^{bc}	4.81 ±0.36^{c}	192.85 ±1.09^{b}
IBA1	11.78 ± 0.05^{e}	145.44 ±15.30^{b}	52.60 ±8.30^{bc}	6.28 ±1.61^{cb}	197.37 ±2.77^{ab}
ISP1	4.62 ± 0.01^{g}	198.79 ±14.72^{ba}	76.08 ±2.11^{a}	69.78 ±1.51^{a}	202.47 ±1.35^{a}
ISP2	16.16 ± 0.55^{d}	325.43 ±114.73^{a}	58.38 ±4.24^{b}	5.07 ±0.20^{c}	201.72 ±1.79^{a}
ISP3	36.88 ± 0.06^{a}	118.00 ±8.34^{c}	44.70 ±2.87^{c}	4.94 ±0.14^{c}	200.18 ±1.78^{a}
IBA2	10.92 ± 0.01^{f}	249.48 ±19.41^{ba}	59.62 ±2.47^{b}	8.58 ±0.59^{b}	199.78 ±0.91^{a}
IBA3	26.33 ± 0.20^{b}	249.32 ±24.05^{ba}	47.91 ±4.15^{bc}	7.55 ±0.10^{b}	200.55 ±1.64^{a}

Different letters in the same column indicate statistical differences (Tukey test - $p \leq 0.05$). Sample ABA (artisanal; Taperoá, BA). Samples ISP1, ISP2, and ISP3 (industrial; São Paulo, SP). Samples IBA1, IBA2, and IBA3 (industrial; Valença, Taperoá, and Nazaré, BA).

The results also show significant variation in the carotenoid content among the samples. This difference could be attributed to the processing and packaging of the oils since carotenoids are photosensitive compounds that degrade upon exposure to sunlight. Therefore, analyzing the carotenoid content helps assess the impact of processing and storage conditions on the stability of these compounds (Almeida et al., 2019).

The iodine value is a measure that depends on the intrinsic characteristics of the oil related to the level of unsaturation present. Palm oil is reported in the literature to have a low iodine value, typically between 44.37 and 49.33 g 100 g^{-1} (Ruswanto et al., 2021), indicating a high degree of saturation (Birnin-Yauri & Garba, 2011). Consequently, this result suggests a lower percentage of unsaturated fatty acids and a reduced risk of rancidity.

The iodine value range, as determined by the Codex Alimentarius, is from 50.00 to 55.00 g 100 g^{-1} (FAO/WHO, 1999). Sample ISP1 showed values of 76.02 g 100 g^{-1}, exceeding the maximum limit. This result may indicate adulteration of the product with other oils possessing a higher degree of unsaturation (Salah & Nofal, 2020).

Variations in the iodine value may also result from harvesting oil palm fruit at different ripeness levels (Ruswanto et al., 2021). During ripening, there is intense metabolism involved in the formation of both saturated and unsaturated fatty acids. In contrast, immature fruits exhibit less intense metabolism, producing fewer unsaturated fatty acids. Finally, over-ripe fruits show a decrease in iodine value due to prolonged exposure to oxygen, leading to the oxidation of unsaturated fatty acids into peroxides and free fatty acids (Ruswanto et al., 2021).

Ruswanto et al. (2021) note that the iodine value tends to decrease during storage, likely due to oxygen exposure causing the breakdown of double bonds in unsaturated fatty acids.

The peroxide value is an indicator of oil deterioration (Dokun et al., 2021). Brazilian legislation and the Codex Alimentarius set a peroxide limit of up to 15 mEq 1000 g-1 for non-refined oils (FAO/WHO, 1999). The results of this study were within these recommendations, except for sample ISP1, which exhibited a much higher value of 69.78 mEq 1000 g^{-1}. According to Singh et al. (2022), the peroxide value increases as the oil becomes more oxidized. As also mentioned by these authors, peroxide values between 30 and 40 mEq 1000 g^{-1} are typically found in rancid oils.

With respect to the Kreis test, all samples tested positive. Samples ABA (artisanal), ISP2, and IBA3 showed less intense coloration compared to others, potentially indicating a lower presence of degradation compounds, which characterize rancidity, as the intensity of the red color is proportional to the degree of lipid oxidation in the oil (Mehta et al., 2018).

Overall, this test provides qualitative results on the presence of elements indicative of the onset of lipid oxidation and can be used to assess the quality of oil processing. Quality control methods are thus essential to protect the studied samples more effectively from initial degradation processes, which can occur during the harvesting, handling, processing, packaging, and storage of crude palm oil (Mehta et al., 2018).

The saponification value indicates the amount of alkaline base required to saponify a given amount of sample and serves as an indicator of the molecular weight of triglycerides present in oils. Elevated saponification values suggest a high content of short-chain fatty acids in the sample. Therefore, it can be inferred that shorter fatty acid chain lengths (C4-C12) result in higher saponification values (Muangrat & Pongsirikul, 2019; Edo et al., 2022).

According to Nwakodo et al. (2019), the variation for this parameter in crude palm oils produced by different extraction methods ranges between 250.89±4.84 and 260.50±3.35 mg KOH g^{-1}. In this study, the results ranged from 192.852 mg KOH g^{-1} (Sample ABA) to 202.474 mg KOH g^{-1} (Sample ISP1), which are within the range of 190 to 209 mg KOH g^{-1} set by the Codex Alimentarius (FAO/WHO, 1999). In this case, the artisanal sample (ABA) exhibited a lower saponification value, statistically similar to sample IBA1, thereby indicating a lower concentration of short-chain fatty acids compared to other samples.

The color results, as shown in Table 2, indicate a variation in the L* values from 54.07 for sample IBA2 to 80.37 for sample ABA (artisanal). According to Almeida et al. (2019), a high L* value in palm oil may be associated with pigment degradation or low levels of carotenoids of the pigments in the unused oil, which could explain the higher results for the artisanal sample in this study.

Table 2
Results for the color parameters analyzed in the different crude palm oil samples

Sample	L*	a*	b*	C*	h
ABA	$80.37^{g} \pm 0.01$	$23.93^{b} \pm 0.02$	$82.37^{f} \pm 0.04$	$85.78^{f} \pm 0.04$	$73.83^{g} \pm 0.06$
IBA1	$75.53^{d} \pm 0.03$	$32.43^{f} \pm 0.01$	$75.81^{d} \pm 0.06$	$82.45^{d} \pm 0.05$	$66.84^{d} \pm 0.02$
ISP1	$79.30^{f} \pm 0.01$	$26.36^{c} \pm 0.02$	$82.45^{f} \pm 0.06$	$86.56^{g} \pm 0.06$	$72.28^{f} \pm 0.01$
ISP2	$77.94^{e} \pm 0.02$	$27.29^{e} \pm 0.04$	$79.77^{e} \pm 0.01$	$84.31^{e} \pm 0.01$	$71.12^{e} \pm 0.02$
ISP3	$74.60^{c} \pm 0.01$	$33.49^{g} \pm 0.03$	$74.08^{c} \pm 0.02$	$81.30^{c} \pm 0.02$	$65.67^{c} \pm 0.02$
IBA2	$54.07^{a} \pm 0.09$	$21.73^{a} \pm 0.01$	$37.58^{a} \pm 0.14$	$43.42^{a} \pm 0.11$	$59.96^{a} \pm 0.10$
IBA3	$60.96^{b} \pm 0.06$	$26.51^{d} \pm 0.02$	$51.77^{b} \pm 0.04$	$58.16^{b} \pm 0.04$	$62.88^{a} \pm 0.02$

Different letters in the same column indicate statistical differences (Tukey test, $p \leq 0.05$). Sample ABA (artisanal; Taperoá, BA). Samples ISP1, ISP2, and ISP3 (industrial; São Paulo, SP). Samples IBA1, IBA2, and IBA3 (industrial; Valença, Taperoá, and Nazaré, BA).

The a* values in this study ranged between 21.73 and 33.49, indicating a red hue present in all the samples. The b* values were lower for sample IBA2 at 37.58 and higher for sample ABA at 82.37, confirming the presence of a yellow hue in the palm oils analyzed.

Variations in these color parameters may be linked to the presence of carotenoids or traces of pigments and tocopherols and tocotrienols, which are prone to forming brownish polymers (Almeida et al., 2019).

Regarding the sensory analyses, the hedonic scores for each attribute analyzed are presented in Figure 1. The hedonic scale is divided into two areas: the acceptance area, with values from 6 to 9, and the product rejection area, with values from 1 to 4. The category "neither liked nor disliked," assigned a value of 5, is considered an area of neutrality regarding the product (Xia et al., 2020).

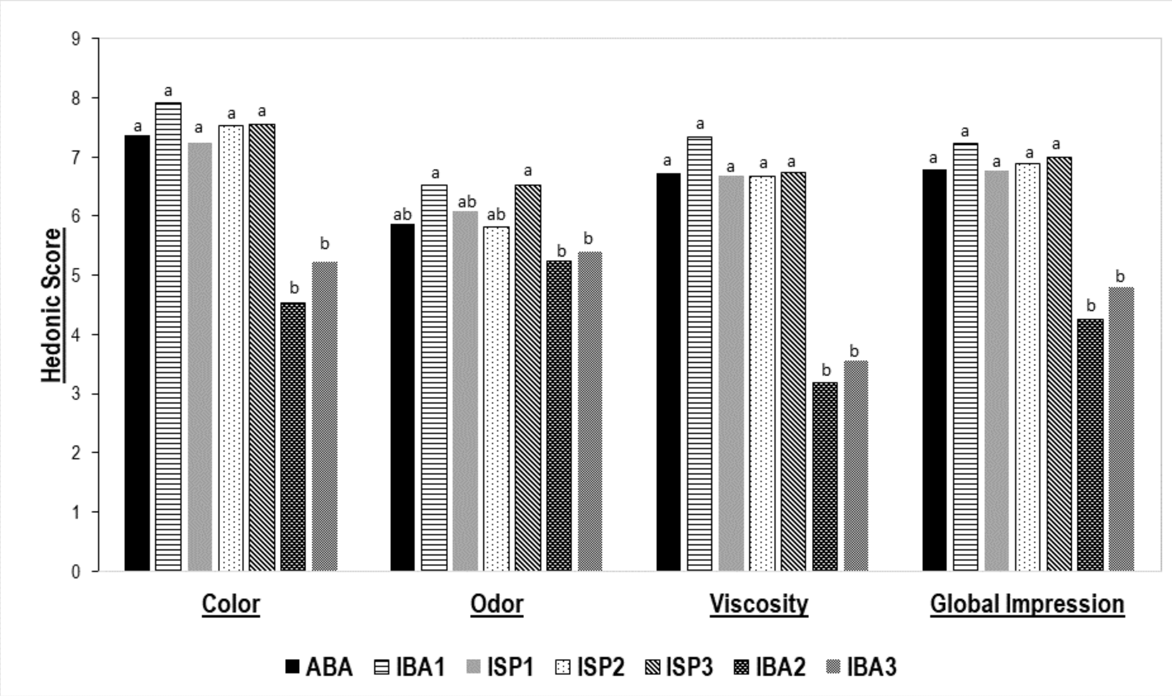

Figure 1. Hedonic score of crude palm oil samples for each attribute analyzed. Different letters in the same attribute indicate a statistical difference (Tukey test - $p \leq 0.05$). Sample A = 01 (artisanal; Taperoá, BA, Brazil). Sample ABA (artisanal; Taperoá, BA). Samples ISP1, ISP2, and ISP3 (industrial; São Paulo, SP). Samples IBA1, IBA2, and IBA3 (industrial; Valença, Taperoá, Nazaré, BA).

It is evident that the samples were generally well-accepted by the tasters, with average global impression scores above 5, except for sample IBA3, which had an average within the rejection values (4.79). Odor scores ranged from 5.39 (IBA3) to 6.19 (IBA1), indicating general approval for this attribute, and the artisanal sample (ABA) statistically matched the industrial ones in terms of odor. In addition, samples with the lowest odor scores were those with high peroxide levels, as high peroxide content can compromise the sensory odor of the oil due to the rancidification process (Destiana & Safitri, 2023).

The results for the color attribute ranged from 4.53 (IBA2) to 7.92 (IBA1). This shows that, unlike the others, this attribute faced rejection, specifically for samples IBA2 and IBA3. The color attribute that displayed the greatest statistical difference in the instrumental analysis was lightness (L*), where samples with the lowest color scores were those with the lowest measured L* values. According to Destiana and Safitri (2023), there is a consumer preference for lighter oils, likely due to expectations about the relationship between this visual parameter and the overall quality of the product.

Finally, viscosity ranged from 3.56 (sample IBA3) to 7.34 (sample IBA1), with sample IBA3 showing rejection for sample IBA3 possibly due to its semi-solid state at room temperature, unlike the liquid state of the other samples. Overall, these sensory results suggest that sample IBA1 scored highest for global impression and other analyzed attributes. Although this sample exhibited acidity slightly above the legal limit, it recorded low values for peroxides and saponification, indicating stability and minimal oxidative processes, factors likely contributing to its positive evaluation. The artisanally processed sample ABA showed similar results for all analyzed characteristics compared to sample IBA1, suggesting no correlation between the type of processing facility and sensory acceptance.

Conversely, samples IBA2 and IBA3 scored poorly across all attributes, with statistical significance. These samples had acidity above the legal limit and high peroxide values, alongside intermediate saponification values, indicating more intense oxidative processes. According to Peng et al. (2017), the oxidation process in crude palm oil can degrade certain volatile compounds and form new ones, including aldehydes, which compromise its sensory characteristics.

Figure 2 illustrates the results of multivariate analysis as a heatmap, correlating physicochemical data with the global impression of the crude palm oil samples. The analysis reveals two major clusters. The first cluster subdivides into one group isolating sample ABA and another comprising samples IBA1 and ISP3, which share similarities such as higher global impression scores and close values for saponification, iodine, and peroxide indicators.

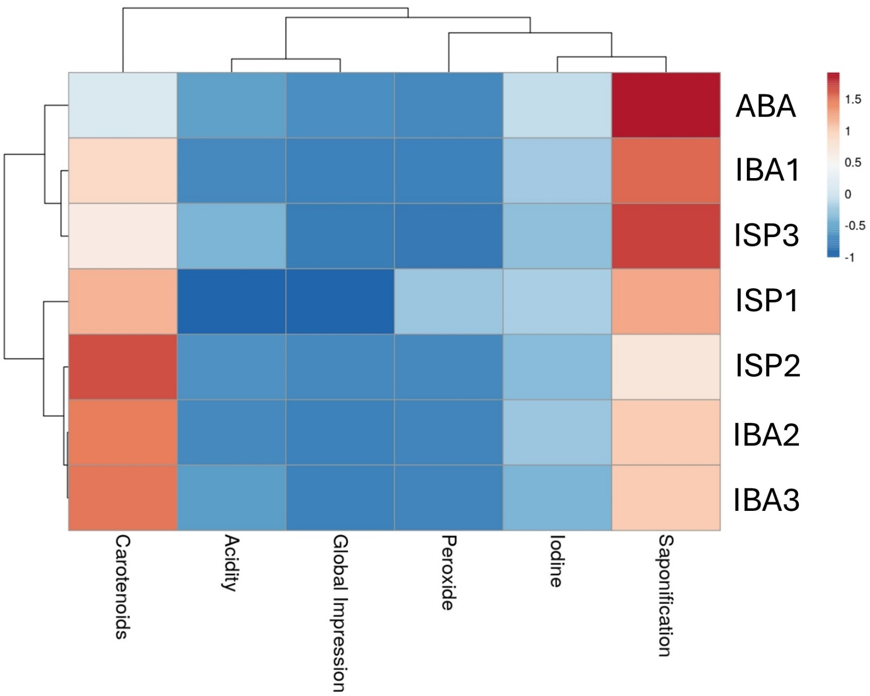

Figure 2. Heatmap multivariate analysis of physicochemical parameters and global impression of crude palm oil samples. Unit variance scaling is applied to rows. Rows and columns are clustered by correlation distance and average linkage. Sample ABA (artisanal; Taperoá, BA). Samples ISP1, ISP2, and ISP3 (industrial; São Paulo, SP). Samples IBA1, IBA2, and IBA3 (industrial; Valença, Taperoá, Nazaré, BA).

The second large cluster includes sample ISP1 alone; samples IBA2 and IBA3 grouped together; and sample ISP2 alone. This clustering indicates that samples IBA2 and IBA3 are grouped due to their low global impression scores and higher values for peroxides, iodine, and carotenoids. In terms of the parameters analyzed, there are two distinct clusters: one exclusively comprising carotenoids, and the other subdivided into groups for acidity and global impression; saponification and iodine; and peroxide. These clustering patterns may provide insights into the parameters relevant to the sensory acceptance of palm oil.

Figure 3 illustrates the correlation between the color parameters from instrumental and sensory analyses. Samples ISP3 and IBA1 exhibit the highest correlation with sensory color acceptance parameters, L* (lightness) and a* (green/red), located in the upper right quadrants. Conversely, samples ISP2, ISP1, and ABA correlate most strongly with parameters b* and L. Samples IBA3 and IBA2 show a negative correlation with the analyzed parameters. The color acceptance of the samples correlates with the CIELAB color values, showing greater acceptance for samples with higher lightness and red color intensity.

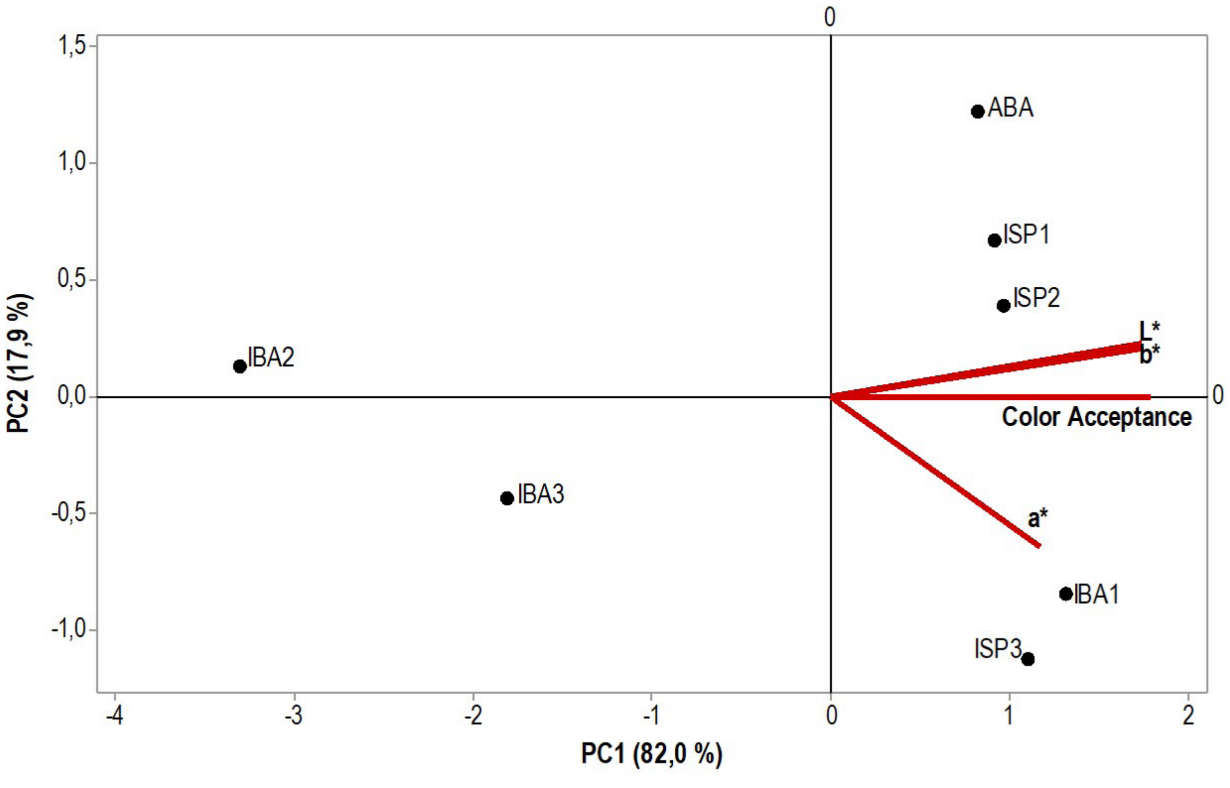

Figure 3. Principal component analysis (PCA) between instrumental color parameters and acceptance of the color (attribute) of crude palm oil samples. Sample ABA (artisanal; Taperoá, BA). Samples ISP1, ISP2, and ISP3 (industrial; São Paulo, SP). Samples IBA1, IBA2, and IBA3 (industrial; Valença, Taperoá, Nazaré, BA). Line red represent the analyzed parameters of color acceptance, L* = lightness, a* = variation between green-negative and red-positive, b*= variation between blue-negative and yellow-positive. Black dots represent crude palm oil samples.

The sensory ranking test results, shown in Table 3, reveal that samples IBA1, ISP2, and ISP3 are statistically similar and score the highest sum for the color attribute. Samples ABA and ISP1 displayed intermediate results, while samples IBA2 and IBA3 scored the highest. This ranking partially aligns with the mean values from the acceptance test but differentiates the samples into more distinct groups based on statistical similarities.

Table 3
Ranking test values for each attribute evaluated of the different crude palm oil samples

Sample	Attribute		
	Color	Odor	Viscosity
ABA	250^{b}	240^{abc}	285^{a}
IBA1	349^{a}	309^{a}	314^{a}
ISP1	272^{b}	258^{abc}	298^{a}
ISP2	288^{ab}	237^{bc}	304^{a}
ISP3	345^{a}	286^{ab}	301^{a}
IBA2	129^{c}	214^{c}	116^{b}
IBA3	131^{c}	220^{bc}	146^{b}

Rank are sums of values from 62 assessors. Different letters in the same column indicate significant differences ($p \leq 0.05$; MDS = 70) according to the critical values of differences proposed by Christensen et al. (2006). Sample ABA (artisanal; Taperoá, BA). Samples ISP1, ISP2, and ISP3 (industrial; São Paulo, SP). Samples IBA1, IBA2, and IBA3 (industrial; Valença, Taperoá, and Nazaré, BA).

For the odor attribute, samples ABA, IBA1, ISP1, and ISP3 achieved the highest scores, with statistical similarities. Samples ISP2 and IBA3 showed intermediate results but were statistically similar to ABA, ISP1, and IBA2 the lowest-ranked sample. Thus, Sample IBA1 exhibited the best performance for this ranking.

In terms of viscosity, samples ABA, IBA1, ISP1, ISP2, and ISP3 ranked the highest and were statistically distinct from samples IBA2 and IBA3, which were the lowest-ranked. This pattern also emerged in the acceptance test for the same attribute.

Overall, the results suggest that the ranking test provides a more precise measurement of parameters, as also observed by Mamede and Benassi (2016). The ranking test findings align with those of the acceptance test, where samples IBA1 and ISP3 demonstrated the most positive outcomes, and samples IBA2 and IBA3 showed lower sensory acceptance. In this sample set, the artisanal sample ABA displayed intermediate results for color, but comparable results for odor and viscosity with the highest-scored sample (IBA1), further affirming the high sensory quality of artisanally produced crude palm oil.

Conclusion

This study conducted physicochemical and sensory analyses of samples of crude palm oil produced in Brazil, encompassing both artisanal and industrial production methods. The quality of the analyzed samples was found to be below the standards mandated by current Brazilian legislation, particularly concerning acidity and iodine values. Additionally, the carotenoid content was lower than that reported in other studies, and signs of initial oxidation were observed in all samples. This indicates a need to revise production methods to enhance the overall quality of palm oil sold, regardless of whether it is produced artisanally or industrially/semi-industrially.

In terms of sensory aspects, the samples demonstrated good acceptance overall. Correlations between sensory acceptance and the physicochemical parameters analyzed were identified, providing valuable insights for producers and researchers to make informed decisions about critical factors in the production of crude palm oil. Artisanal crude palm oil holds great importance in Brazil, particularly valued for its use in the cuisines of the North and Northeast regions. By considering the results obtained from this sample set, traditional crude palm oil production methods could be improved, potentially benefiting the local economy and, consequently, increasing the income of populations reliant on this product.

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