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New insights into the oil from the seeds of Cerrado passion fruit (*Passiflora cincinnata*): physicochemical characterization and stability during storage

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SUMMARY: This study aimed to investigate the chemical composition, rheological behavior, and photostability of Cerrado passion fruit seed oil during 225 days of storage. To this end, the quality indices, fatty acid composition, rheological behavior, and photostability were evaluated. The findings revealed that the oil is notably rich in unsaturated fatty acids. It showed a high concentration of polyunsaturated fatty acids, particularly linoleic acid. Furthermore, the oil showed lower viscosity compared to other vegetable oils. The oil also exhibited better physical-chemical stability when stored under light protection, retaining its color intensity and remaining suitable for consumption for an extended period of up to 135 days. These results highlight the importance of Cerrado passion fruit seed oil as a sustainable and versatile material with potential applications in the food, cosmetic, and pharmaceutical industries.

KEYWORDS: *Co-products; Fatty Acid Profile; Oxidative Stability; Rheology.*

RESUMEN: ***Nuevos conocimientos sobre el aceite de semillas de maracuyá del Cerrado* (Passiflora cincinnata)*: caracterización fisicoquímica y estabilidad durante el almacenamiento***. En este estudio se investigó la composición química, el comportamiento reológico y la evaluación de fotoestabilidad durante 225 días de almacenamiento del aceite de semilla de maracuyá del Cerrado. Para ello se evaluaron los índices de calidad, composición de ácidos grasos, comportamiento reológico y fotoestabilidad. Los resultados revelaron que el aceite es notablemente rico en ácidos grasos insaturados y triacilgliceroles de bajo peso molecular. Mostró una alta concentración de ácidos grasos poliinsaturados, particularmente ácido linoleico. Además, el aceite mostró una viscosidad más baja en comparación con otros aceites vegetales. El aceite también exhibió una mejor estabilidad físico-química cuando se almacena bajo protección de la luz, conservando su intensidad de color y permaneciendo apto para el consumo durante un período prolongado de hasta 135 días. Estos resultados destacan la importancia del aceite de semilla de maracuyá del Cerrado como un material sostenible y versátil con aplicaciones potenciales en las industrias alimentaria, cosmética y farmacéutica.

PALABRAS CLAVE: *Coproductos; Estabilidad Oxidativa; Perfil de Ácidos Grasos; Reología.*

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1. INTRODUCTION

Passion fruit (*Passiflora* spp.) is a tropical fruit, known for its various species such as *P. edulis*, *P. alata, P. quadrangularis, P. cincinnata, P. setacea* e *P. nitida* (Lopes *et al.,* 2010; Pereira *et al.,* 2017; Souza *et al.,* 2022). Brazil is the world's largest producer, with the 2021 harvest yielding ~684 thousand tons of passion fruit (IBGE, 2023). Passion fruit processing

generates huge amounts of waste residues, including peel, bagasse and seeds, which account for around 75% of the total fruit weight (Francischini *et al.,* 2020). Consequently, finding suitable strategies for food waste valorization becomes a global issue.

Passion fruit seeds can be exploited as a source of oil and bioactive substances. The fatty acid (FA) composition of passion fruit seed oil consists of approximately 8.73 to 11.62% palmitic (C16:0), 2.71 to 4.23% stearic (C18:0) acids; 13.47 to 31.21% oleic acid (C18:1; ω-9) and 52.93 to 75.09% linoleic acid (C18:2; ω-6) (Lee *et al.,* 2015). The presence of the saturated fraction, along with oleic acid, contributes to the physicochemical stability of the oil.

Among the passion fruit species that can offer many benefits, *Passiflora cincinnata*, also known as the 'mato' passion fruit, exists in various Brazilian states (Souza *et al.,* 2022). However, it is particularly noticeable in the Cerrado (Lopes *et al.,* 2010), where it has significant environmental value due to the vulnerability to deforestation of the area, which is one of the most intensely deforested biomes in the country. Therefore, valorizing native species, such as *P. cincinnata*, can play an important role in conserving the local flora, increasing the income of the population, and facilitating the preparation of new food products, among other benefits.

P. cincinnata appears to be a valuable resource for applications within the food, cosmetic, and pharmaceutical industries. Moreover, the importance of conserving the Cerrado species and effectively utilizing their byproducts becomes increasingly evident. One particularly promising opportunity is the extraction of oil from *P. cincinnata* seeds. Given the limited availability of studies in this area, our research aimed to evaluate the physicochemical composition, rheological characteristics, and photostability of cold-pressed Cerrado passion fruit seed oil (CPFO). More importantly, our investigation incorporates innovative analyses which shed new light on the properties of oil derived from this unique species.

2. MATERIALS AND METHODS

2.1. Plant material and oil extraction

The passion fruit seeds (*P. cincinnata*) used to carry out the experiments were obtained from ripe fruits of uniform size and without injuries, collected from Cerrado, in the town of Grão Mogol, located in the state of north of the Minas Gerais, Brazil (coordinates: 16°33'27"S, longitude 42°53'38"W, and altitude 829 m). The procedure described below was carried out according to the processes used for extraction in local communities where the collection and sustainable management of passion fruit are common practices.

The fruits were sanitized in a chlorinated solution of 50 $mg \cdot L^{-1}$ for 15 min. After that, the fruits were de-pulped through a pulper (Bonina - NB 30, Brazil) to separate the seeds. Subsequently, the samples were washed under running water and dried naturally in the sun for 2 days (27 ± 2 °C). It is important to emphasize that the local producers had already established the practice of drying, observing whether the seeds were properly dried and suitable for the next steps. After drying, the material was packed in a low-density polyethylene plastic bag until oil extraction.

For oil extraction, seeds were crushed with a knife mill (MF32150, Scott Tech, Brazil) and then cold-pressed in a helical-type mechanical press ("Expeller") (MPE-100 TI, Ecirtec, Brazil) with an extraction capacity of 200 mL of oil/min. After extraction, coarse particles were removed by sedimentation for 12 h and the oil was filtered through a filter press (FPE-25/10 PI, Ecirtec, Brazil). The oil was inerted with gaseous nitrogen, packed in hermetically sealed bottles of 250 mL and stored (7 ± 1 °C) until use.

2.2. Oil quality parameters

The iodine value (Tg 1-64 method), saponification index (Cd 3-25 method), moisture and volatile matter (Ca 2b-38 method), and color (Cc 13e-92 method) were determined according to the Official Methods of the American Oil Chemist's Society (AOCS, 2009).

2.2.1. Determination of the fatty acid profile

The analysis of fatty acid methyl esters (FAME) was conducted using capillary gas chromatography (CGC 68650 Series GC System, Agilent, USA) equipped with a flame ionization detector and autoinjector. Briefly, the separation of the compounds was performed on an Agilent DB-23 fused silica capillary column (60 m x 0,25 mm x 0,25 μm).

The carrier gas was helium at a constant flow rate of 3.0 mL · min^{-1}. The injector temperature was 250 ºC. The oven temperature program of the column was held at 110 °C for 5 min, then increased to 250 °C. Identification of the peaks was performed by comparison with the retention time of corresponding FAME standards (Supelco 37 component FAME Mix, Sigma-Aldrich). The relative percentage (%) of individual fatty acids was calculated by comparing retention time and unit area of the FAME standards with the unit area of the fatty acid methyl ester peak investigated.

2.2.2. Rheological behavior

The rheological behavior of the oil was evaluated on a rotational rheometer (MCR 102, Anton-Paar, Germany) equipped with a Peltier heating system and cone plate geometry (2°/35 mm, gap 0.5 mm) using three flow curves to eliminate thixotropy from 1 to 200 s^{-1} at 25 ± 2 ºC.

2.2.3. Photostability over time

CPFO was evaluated for its physicochemical stability to light (photostability) at time intervals for 225 days under two light conditions: the first treatment was to expose oil samples stored to artificial and natural light in hermetically-sealed transparent glass containers (Ø 6.5 cm × 9 cm height; 2 cm headspace); in the second treatment, the samples were conditioned in the same way as in the first treatment, but they were externally coated with aluminum foil to prevent the incidence of light on the oil. Both treatments were at room temperature (25 ± 2 ºC). To assess photostability, acidity (Ca 5a-40 method) and peroxide (Cd 8-53 method) indices were evaluated (AOCS, 2009). In addition, the oil samples were analyzed in a colorimeter (CR-400, Konica Minolta, Japan) with the CIELAB system defined by the coordinates L^* (white/black coordinate), a^* (red/green coordinate), and b^* (yellow/blue coordinate). The chroma and whiteness index (WI) were calculated as shown in Equations (1) and (2), respectively:

$$Chroma = \sqrt{(a^2 + b^2)} \quad \text{(Eq. 1)}$$

$$Whiteness\ index = 100 - ((100 - L)^2 + a^2 + b^2)^{1/2} \quad \text{(Eq. 2)}$$

2.3. Statistical analysis

All results are presented as a mean value ± standard deviation (n = 3). The storage stability experiments were carried out in a completely randomized design in a 2 x 6 factorial design (two storage conditions: with and without exposure to light, and six analysis times: 0, 45, 90, 135, 180, and 225 days). Analysis of variance (ANOVA) followed by the Tukey test was performed at the statistically significant level $p < 0.05$ for comparison of means. Flow curve data were subjected to linear regression analysis. The statistical analyses were carried out using the SAS University Edition software (SAS Institute Inc, USA).

3. RESULTS AND DISCUSSION

3.1. Quality characteristics

The quality parameters of CPFO are shown in Table 1. According to the iodine index, *P. cincinnata* oil was classified as a semi-drying oil, that is, it undergoes mild alteration when placed in a thin layer and exposed to the atmosphere, similar to other edible oils (Delvar *et al.,* 2019). The iodine index of *P. cincinnata* oil was comparable to that found in *P. edulis* seed (136 g·100g^{-1}) (Delvar *et al.,* 2019). Furthermore, the value found in this work was in line with the range reported for other oils, such as soy (124–139 g·100g^{-1}), and sunflower (118–141 g·100g^{-1}) (FAO, 2019). These differences are associated with the composition of FA since the iodine value is related to the amount of unsaturation present in the oil. Thus, the greater the number of unsaturation, the greater the iodine value.

The saponification value for *P. cincinnata* (Table 1) was close to those found by Souza *et al.* (2022) for *P. setacea* (191.01 mg KOH·g^{-1}) and *P. alata* (194.3 mg KOH·g^{-1}) seed oils. According to the Codex Alimentarius (FAO, 2019), the saponification values are 185–197, 188–194, and 187–194 mg KOH·g^{-1} for flaxseed, grape seed, and sunflower oils, respectively, which have degrees of unsaturation similar to that of CPFO. These values for saponification index indicate the average molecular weight of the fatty acids present in the oil. Therefore, this result suggests that CPFO has predominantly long-chain fatty acids.

TABLE 1. Quality parameters of Cerrado passion fruit seed oil

Parameter	Cerrado passion fruit seed oil[a]
Iodine value ($g \cdot 100g^{-1}$)	137.67 ± 0.58
Saponification value (mg $KOH \cdot g^{-1}$)	193.00 ± 0.00
Moisture and volatile matter (%)	0.09 ± 0.00
Color (Y + R) value	70Y + 3.5R

[a]Values are taken in triplicate and expressed as Mean ± standard deviation.

For moisture and volatile matter, CPFO showed lower levels (Table 1) compared to that reported by Wilhelm *et al*. (2014), whose value was 0.11%. This difference may be because the residue from different passion fruits has, even in small amounts, other components in addition to the seeds, like pulp fragments, which can affect the moisture content. Moreover, this amount of water may be related to the extraction process involving pressing, wherein some small amounts of unbound water could be transferred to the oil samples (Wilhelm *et al.*, 2014). In addition, the volatile matter obtained in this study complies with the standards established by Codex Alimentarius (FAO, 2019) for cold-pressed oils, giving values which are in line with the recommended maximum limit (0.2%).

The color parameters demonstrated shades for the yellow (Y) and red (R) colors. As seen in Table 1, CPFO showed a more intense yellow shade than chia seed oil (20–50) but was within the red shade attributed to the same oil (2–5) (Imran *et al.,* 2016). According to Borges *et al.* (2022), carotenoids are the main constituents associated with the yellow/red color in oils. Thus, the intense yellow color and the red nuances of CPFO can be associated with the presence of these compounds.

3.2. Fatty acids profile

CPFO mainly contained polyunsaturated fatty acids (PUFA), followed by saturated fatty acids (SFA) and a considerable amount of monounsaturated fatty acids (MUFA) (Table 2). Regarding the unsaturated fraction, the majority are linoleic and oleic acids. The significant content of PUFA may contribute to lipid oxidation due to the presence of double bonds that affect oil stability. Compared to other studies, Reis *et al*. (2023) found higher levels of linoleic acid (78.34%) and lower levels of oleic acid (8.43%) in *P. cincinnata* oil obtained from the Caatinga biome, Brazil. In addition, the FA profile is close to those obtained for other passion fruit species (Takam *et al*., 2019; Santana *et al*., 2015). Cultivar type, edaphoclimatic conditions, maturation degree, oil processing, analysis protocol, and other factors might affect FA biosynthesis. Comparing the FA profile determined by Codex Alimentarius with other vegetable oils, it is noted that soy and corn oils have lower linoleic acid contents (48–59 and 34–65.6%, respectively) and higher oleic contents (17–30 and 20–42.2%, respectively) (FAO, 2019).

As seen in Table 2, the main SFAs present in CPFO were palmitic and stearic. Similarities were verified in the palmitic acid contents regarding *P. cincinnata* (10.20%), *P. edulis* (9.40%) and *P. alata* (11.17–11.50%) oils, as well as in the stearic acid contents, which were slightly lower, at 2.90, 2.50 and 2.47–2.57%, respectively, for the mentioned species (Delvar *et al.,* 2019; Lopes *et al.,* 2010; Pereira *et al.,* 2017). It is important to note that oils with SFA have improved stability, as these compounds make products less susceptible to oxidation processes because these FAs are more resistant to thermal degradation.

The PUFA/SFA ratio is used to evaluate the nutritional quality of oils and fats. It hypothesizes that PUFA in the diet can decrease low-density lipoprotein cholesterol (LDL-c) and lower levels of serum cholesterol; whereas SFA contributes to high levels of serum cholesterol. According to the Department of Health and Social Security of England (DHSS, 1994), a PUFA/SFA ratio higher than 0.45 is a desirable index. Hence, the PUFA/SFA ratio of CPFO (Table 2) was consistent with the recommended value. Therefore, the composition of *P. cincinnata* oil may present benefits in the prevention of metabolic diseases.

3.3. Rheological behavior

The rheological evaluation is crucial to determine the flow behavior of liquid foods. In the oil and fat industry, knowing the rheological properties of oils is particularly valuable for sizing equipment such as heat exchangers, reactors, extraction columns, and extractors (Valeri and Meirelles, 2007). To this end, the rheological behavior of CPFO was evaluated,

and its flow curve (Figure 1) demonstrated a linear relationship between shear stress and shear rate (R^2 = 0.999), which classifies it as a Newtonian fluid. Furthermore, no hysteresis area was observed between the flow curves (ascent, descent, and ascent), indicating the absence of thixotropy, which is expected of the behavior of oils.

The viscosity of CPFO was 32.99 ± 2.75 mPa·s. This value is different from that of other edible oils with comparable linoleic acid content, such as melon seed oil (90.75 mPa·s) (Mallek-Ayadi *et al*., 2019) and safflower seed oil (42.97 mPa·s) (Aydeniz *et al*., 2013) at 25 °C. This difference can be attributed to the higher proportion of linoleic acid and lower concentrations of monounsaturated and saturated long-chain fatty acids in passion fruit seed oil. The presence of double bonds in the fatty acid chain induces torsion, preventing the tight packing of the molecules, resulting in a less rigid and more flexible structure with higher fluidity (Kim *et al*., 2010).

The lower viscosity of CPFO, compared to other edible oils, offers several advantages. First, it results in cost savings for the implementation and maintenance of a flowline, as a lower viscosity leads to a reduced pressure drop. This, in turn, requires less robust equipment and lowers the energy input needed for the oil to flow.

3.4. Photostability

3.4.1. Acidity and peroxide indexes

CPFO was evaluated for light stability. One of the parameters evaluated was the acidity value, which indicates the presence of free fatty acids resulting from the hydrolysis of triacylglycerols in the oil, either by temperature, moisture, or enzymes (Almeida *et al.,* 2019; Chen *et al.,* 2019). The acidity value increased over time in both stored oils, with and without exposure to light (Figure 2). At 225 days, higher acidity values were found for samples stored away from light (1.84 mg KOH·g^{-1}) and for those exposed to light (3.09 mg KOH·g^{-1}). No significant difference was observed ($p > 0.05$) in the acidity value when

Table 2. Fatty acid profile of Cerrado passion fruit seed oil and other species

Common name	Systematic names	Carbon numbers	Chemical formula	Cerrado passion fruit seed oil (%)[a]	*Passiflora edulis* seed oil (%)[b]	*Passiflora alata* BRS Doce Mel seed oil (%)[c]
Myristic acid	Tetradecanoic acid	C14:0	$C_{14}H_{28}O_2$	0.17 ± 0.01	0.10	—
Pentadecylic acid	Pentadecanoic acid	C15:0	$C_{15}H_{30}O_2$	0.05 ± 0.01	—	—
Palmitic acid	Hexadecanoic acid	C16:0	$C_{16}H_{32}O_2$	10.17 ± 0.15	11.72	10.38 ± 0.03
Palmitoleic acid	9-Hexadecenoic acid	C16:1	$C_{16}H_{30}O_2$	0.20 ± 0.00	0.34	0.66 ± 0.00
Margaric acid	Heptadecanoic acid	C17:0	$C_{17}H_{34}O_2$	0.08 ± 0.10	—	—
Stearic acid	Octadecanoic acid	C18:0	$C_{18}H_{36}O_2$	3.52 ± 0.18	2.84	2.72 ± 0.02
Oleic acid	Octadec-9-enoic acid	C18:1	$C_{18}H_{34}O_2$	12.42 ± 0.21	14.31	13.58 ± 0.05
Linoleic acid	9, 12-Octadecadienoic acid	C18:2	$C_{18}H_{32}O_2$	72.09 ± 0.60	68.39	71.54 ± 0.34
Linolenic acid	9, 12, 15-Octadecatrienoic acid	C18:3	$C_{18}H_{30}O_2$	0.62 ± 0.01	0.54	0.80 ± 0.01
Arachidic acid	Eicosanoic acid	C20:0	$C_{20}H_{32}O_2$	0.22 ± 0.01	0.16	—
Gondoic acid	11-Eicosanoic acid	C20:1	$C_{20}H_{38}O_2$	0.15 ± 0.02	0.15	—
Lignoceric acid	Tetracosanoic acid	C24:0	$C_{24}H_{48}O_2$	0.09 ± 0.01	—	—
∑ MUFA	—	—	—	12.86	—	14.83 ± 0.08
∑ PUFA	—	—	—	72.71	—	72.07 ± 0.13
∑ SFA	—	—	—	14.30	—	13.10 ± 0.05
∑ UFA	—	—	—	85.48	—	—
PUFA/SFA	—	—	—	5.09	—	—

[a]Values are taken in triplicate and expressed as Mean ± standard deviation. [b]Takam *et al*. (2019). [c]Santana *et al*. (2015). Abbreviations: ∑MUFA, total monounsaturated fatty acids; ∑PUFA, total polyunsaturated fatty acids; ∑SFA, total saturated fatty acids; ∑UFA, total unsaturated fatty acids; PUFA/SFA, ratio between polyunsaturated and saturated fatty acids

comparing samples stored without light exposure for the duration of 90 to 180 days (Figure 2). However, significant differences ($p < 0.05$) in acidity values were observed for samples exposed to light in the same period. Significant differences ($p < 0.05$) were also detected between the two storage conditions from 135 days until the end of the experiment. The acidity values for the oil exposed to light (1.94–3.09 mg $KOH \cdot g^{-1}$) were statistically higher than the values for the oil protected from light (1.65–1.84 mg $KOH \cdot g^{-1}$).

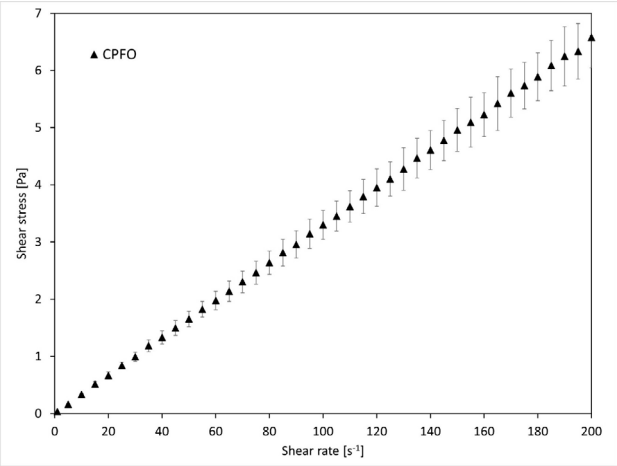

Figure 1. Flow curve of Cerrado Passion Fruit Oil at 25 °C in a shear rate range from 1 to 200 s^{-1}. Mean value ± standard deviation (n=3).

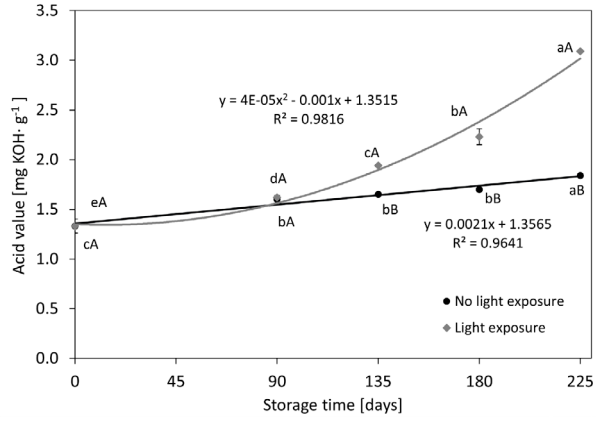

Figure 2. Acidity value changes in Cerrado Passion Fruit Oil samples during 225 days of storage with (♦) and without (●) exposure to light. Values are taken in triplicate and expressed as Mean. Different lowercase letters among timepoints for the same treatment and uppercase letters among treatments for the same time point indicate significant differences according to Tukey's test ($p < 0.05$).

Exposing oils to light can lead to issues of oxidative rancidity (Ayu *et al.,* 2016). However, in this study, it was observed that exposure of the oil samples to light also led to an increase in the acidity value, which measures the level of hydrolytic rancidity compared to samples that were not exposed to light. Possibly, the aluminum sheets used to protect the oil from light exposure acted as thermal insulators. Their mirrored surface reduced the absorption of heat transmitted by light, creating a barrier that impeded the transfer of heat from the environment to the samples. However, unprotected samples may have absorbed light heat, increasing their temperature and promoting the activity of lipase enzymes (Chen *et al.,* 2019), which were possibly liberated from the matrix after the extraction process from seeds. Despite the variations observed in the acidity value between the different treatments at all evaluated times, all of them comply with the maximum acidity value recommended by the Codex Alimentarius (FAO, 2019), which is 4.0 mg $KOH \cdot g^{-1}$ for cold-pressed and unrefined vegetable oils.

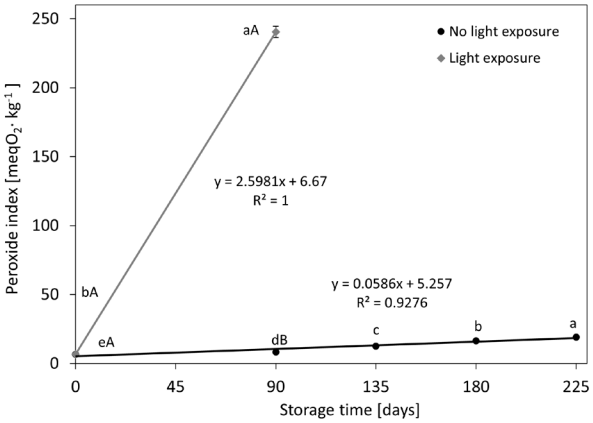

Figure 3. Peroxide index of Cerrado Passion Fruit Oil samples stored for 225 days with (♦) and without (●) light exposure. Values are taken in triplicate and expressed as Mean. Different lowercase letters among timepoints for the same treatment and uppercase letters among treatments for the same timepoint indicate significant differences according to Tukey's test ($p < 0.05$).

The peroxide index (Figure 3) indicates the presence of primary products of oxidative rancidity in lipids. This process requires the presence of triacylglycerols or free fatty acids with unsaturation in the product. In treatment without exposure to light, the peroxide index increased over time, ranging from 6.67 to 19.14 $meqO_2 \cdot kg^{-1}$. On the other hand, the light-exposed treatment started at the same initial value but rapidly increased to 240.50 $meqO_2 \cdot kg^{-1}$ by the second analysis time (Figure 3). According to the Codex Alimentarius (FAO, 2019), the recommended

maximum peroxide index is 15 $meqO_2 \cdot kg^{-1}$. Therefore, oil samples not exposed to light can be safely consumed for up to 135 days of storage (12.52 $meqO_2 \cdot kg^{-1}$). Likewise, the consumption of CPFO stored away from light is not recommended since its peroxide content became very high in just 90 days. Due to this, the decision was made to discontinue the peroxide analysis for this treatment.

Over a period of 90 days, CPFO, when exposed to both artificial and natural light, exhibited high levels of peroxides (240.50 $meqO_2 \cdot kg^{-1}$). This increase in peroxides is attributed to the photo-oxidation process which occurs in the presence of light and catalysts like photosensors or photosensitizers, such as chlorophylls and pheophytins, commonly found in vegetable oils (Ayu *et al.,* 2016). During this process, reactive oxygen species, such as triplets and singlets, are formed, initiating the degradation of lipids. The oxidation process generates free radicals that combine with oxygen molecules, leading to the formation of peroxides and hydroperoxides. These compounds can further decompose due to interactions with free radicals and external factors, giving rise to volatile compounds responsible for rancid flavors and odors (Gorji *et al.,* 2016).

Samples that were not exposed to light also experienced oxidative rancidity. The occurrence of this process is more likely when there is a higher number of PUFA. In this case, oxidative rancidity may have been triggered by pro-oxidants such as free fatty acids, higher ambient temperature, and endogenous enzymes like lipoxygenase, or the presence of oxygen (Almeida *et al.,* 2019).

Based on the evaluation of the peroxide index, it becomes evident that the most effective method for storing CPFO is by protecting it from light sources. This precautionary measure helps to prevent photo-oxidation processes and slows down other forms of oxidation. It is crucial to protect the oil's content of PUFA, as their reduction could lead to a loss in oil bioactivity and the development of undesirable aroma and flavor compounds (Lee *et al.,* 2015). According to the analyses performed, it is recommended to consume CPFO within 135 days of storage without the addition of antioxidants. When adhering to this recommendation, the quality of the oil and beneficial properties can be preserved for an extended period.

3.4.2. Color

The color variations in the samples are shown in Figured 4A and B. The whiteness index (WI) increased during the storage period for both treatments, and the most significant difference between the treatments was observed on day 225, with light-exposed samples being lighter than the non-exposed ones. The chroma of the treatments remained consistently low, with values close to zero. These values fluctuate with time and show statistical differences. Specifically, the samples protected from light exhibited significantly higher values (indicating more intense colors) compared to the samples exposed to light, starting on day 90 ($p < 0.05$).

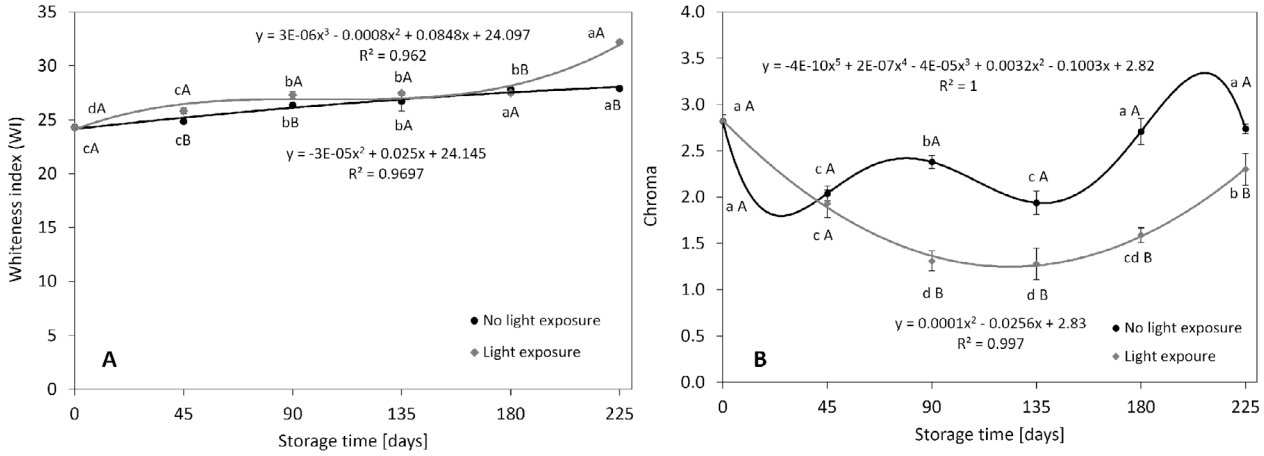

Figure 4. Color parameters of Cerrado Passion Fruit Oil samples stored for 225 days with (♦) and without (●) exposure to light: Whiteness index (A) and Chroma (B). Values are taken in triplicate and expressed as Mean. Different lowercase letters among timepoints for the same treatment and uppercase letters among treatments for the same time point indicate significant differences according to Tukey's test ($p < 0.05$).

The increase in the WI might be attributed to the consumption of the pigment β-carotene, which is commonly present in this type of product. This component possibly acted as an antioxidant photoprotector in light-exposed samples. β-carotene contains numerous conjugated double bonds that absorb light energy, thereby limiting the capture of excessive energy by UFA and the formation of hydroperoxides (Ayu *et al.,* 2016). Additionally, chlorophyll may have catalyzed the photo-oxidation reactions in the oil, as suggested by Ayu *et al*. (2016). Investigating the presence of chlorophyll in CPFO is a prospective goal for future studies. Even in treatments not exposed to light, which experienced oxidative rancidity possibly induced by heat and/or enzymes, β-carotene may have acted as an antioxidant by scavenging free radicals and singlet oxygen, according to Almeida *et al*. (2019). Consequently, the oil maintained a lighter appearance over time.

The low chroma indices result from the low values of the coordinates a^* and b^*, indicating an opaque coloration of CPFO. These values are close to the axis, where color intensity is reduced. Lee *et al*. (2015) proposed a grayer color intensity for passion fruit oil with chroma values ranging from 12.07 to 15.09, which are higher than those found in the current study. Therefore, CPFO typically exhibits a predominantly grayish color with limited color intensity. However, it is known to be rich in carotenoid pigments, such as β-carotene. Over time, these pigments may degrade due to oxidative reactions, leading to a lighter appearance. Thus, it is essential to store this oil protected from light and preferably under refrigeration to preserve its quality.

4. CONCLUSIONS

P. cincinnata oil is a promising material for use in product development because of its ability to consistently meet quality standards, with a rich content of polyunsaturated fatty acids, primarily linoleic acid, and a variety of health-enhancing compounds. Its lower viscosity compared to other vegetable oils, further enhances its appeal. Additionally, the oil exhibited better stability when stored under light protection, ensuring the preservation of its physical and chemical quality for up to 135 days. However, there is room for further exploration in the form of studies that incorporate *P. cincinnata* oil into food matrices, such as emulsions. These investigations could yield intriguing insights into its versatility and applicability. Thus, *P. cincinnata* oil is a valuable raw material for the development of new products in the food, pharmaceutical, and cosmetic industries.

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DECLARATION OF COMPETING INTEREST

The authors of this article declare that they have no financial, professional or personal conflicts of interest that could have inappropriately influenced this work.

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