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Bocaiuva (*Acrocomia aculeata*) nut oil: composition and metabolic impact in an experimental study

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Abstract

This study aimed to obtain physicochemical characteristics and the fatty acid profile of bocaiuva nut oil and to evaluate the impact of its daily consumption on glucose, lipid, and energy metabolism in mice. The acidity content in the bocaiuva nut oil exceeded the maximum limit for crude oils (5.68 mg KOH g^{-1}). However, the peroxide value is within the standard considered adequate for crude oils (3.33 mEq O_2 kg^{-1}). In the fatty acid profile, lauric (42.25%) and oleic (23.96%), saturated and monounsaturated, respectively, stand out. After 90 days of *in vivo* experimentation, the administered oil doses had not influenced the animals' food intake and body weight. Regarding the biochemical parameters, only the non-HDL fraction showed a significant difference, considering that this parameter represents the sum of atherogenic lipoproteins directly linked to atherogenic cholesterol. However, there was no statistical difference between the groups regarding histological changes in the liver, showing that the bocaiuva oil does not cause considerable damage to the liver, even though it is saturated oil. Results show that daily consumption of bocaiuva nut oil did not produce metabolic changes in mice.

Keywords: Brazilian Cerrado; fatty acids; lauric acid; biochemical parameters.

Practical Application: Some vegetable oils are gaining recognition for their positive metabolic effects due to their fatty acids composition. For example, both the pulp and the nut of the bocaiuva (*Acrocomia aculeata*) are rich in oils. Thus, it becomes relevant to provide information to promote the commercialization and use of this species' oils as a supplementary nutrient source.

1 Introduction

The quality of oils and fats for consumption depends on their source, influencing their composition. It relates to the amount of saturated and unsaturated fatty acids content (van den Bremt et al., 2012), which ranges from the extraction process to ingestion (Redondo-Cuevas et al., 2018). After consumption, this quality will interfere with the body fat distribution, negatively affecting the metabolism (Hammad & Jones, 2017). For example, the intake of medium-chain fatty acids (MCFAs) has been shown to promote greater fat oxidation as they are catabolized before long-chain fatty acids (LCFAs), providing energy spending, decreasing adipocyte size, and leading to further visceral fat reduction (Zhou et al., 2017).

Vegetable oil options from non-traditional sources have emerged as a promising way to ease the challenges of environmental sustainability issues experienced by traditional vegetable oil production (Henderson et al., 1997).

Coconut oil is among the nine most produced oils worldwide, behind palm oil, soybean oil, canola, sunflower, palm kernel, peanut, and cotton (Figueiredo et al., 2018). The coconut oil lipid composition differs from other vegetable oils since SFAs predominate (90%). Much of these acids are lauric acid (C12:0). In contrast, other saturated sources of animal origin, such as butter and lard, are rich in palmitic acid (C16:0), which has reinforced the role of lipid constitution, and not only the presence of double bonds for modulation in inflammation and overall health (Khaw et al., 2018).

Olive oil (*Olea europaea*) is considered an excellent lipid source, being associated with the primary and secondary prevention of cardiovascular disease outcomes, the improvement of the lipid profile and insulin sensitivity, increased oxidative stability, improvement of inflammatory markers, and control of arterial pressure (Hohmann et al., 2015). Such benefits are attributed to its nutritional composition, which is predominantly monounsaturated fatty acids (MUFA), with oleic acid (C18:1) being the fraction representing 55% to 83%, followed by polyunsaturated fatty acids (PUFA), representing 4% to 20%, such as linoleic (C18:2) and alpha-linolenic (C18:3) acids, and saturated fatty acids (SFA), representing 8% to 14%, such as palmitic (C16:0) and stearic (C18:0) acids. It also contains minor

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compounds, with the phenols oleuropein and hydroxytyrosol standing out nutritionally (Marcelino et al., 2019).

Bocaiuva (*Acrocomia aculeata*) is a good MCFA source, and it is abundantly found both in the Pantanal and Brazilian Cerrado. Its fruit and oil are traditionally consumed by indigenous and rural people (Nunes et al., 2015).

Monounsaturated fatty acids are found in more than 50% of the total composition of *Acrocomia aculeata* nut oil (Lescano et al., 2015), with a predominance of lauric and oleic fatty acids (Munhoz et al., 2018; Nunes et al., 2018). Therefore, even though there is a lack of research showing the effect of oil on body weight and metabolic parameters, this study aimed to evaluate the physicochemical characteristics and the fatty acid profile of bocaiuva nut oil and to verify the impact to effect of its daily consumption on glucose, lipid, and energy metabolism in mice.

2 Materials and methods

2.1 Raw material

The crude oil from the *Acrocomia aculeata* nut was supplied by Sr Ouro Verde Produtos e Óleos Especiais LTDA®. Andorinha® olive oil and Natural Life coconut oil from Kodilar®, both extra virgin, were purchased commercially in the city of Campo Grande, Mato Grosso do Sul - MS.

2.2 Quality and identity of crude oil from Acrocomia aculeata *nuts*

The oil was evaluated for acidity (Ca 5a-40 method), peroxide (Cd 8-53 method), refraction (Cc 7-25 method), iodine (Cd 1-25 method), and relative density (Cc 10a-25 method) (American Oil Chemists' Society, 1990). All analyses were performed in triplicate.

Coloration

A colorimeter CM-2300d, Konica Minolta, Ramsey, NJ, USA, was used for color analysis. This parameter was expressed on the CIE-L *, a *, b *, classification scale, L * values indicate the brightness, a * represents the red-green axis, and b * the yellow-blue axis.

Fatty acid profile

Fatty acid methyl esters (FAMEs) were prepared according to the Maia & Rodriguez-Amaya (1993) method with a derivatization solution of ammonium chloride, methanol, and sulfuric acid. They were analyzed by gas chromatography (GC 2010, Shimadzu) to obtain their peaks. We identified the individual FAMEs peaks by comparing their relative retention time with 37 FAMEs standard (Supelco C22, 99% pure).

Nutritional quality indexes

The oil's nutritional quality was determined according to the atherogenic index (AI), thrombogenic index (TI) (Ulbricht & Southgate, 1991), and the hypocholesterolemic:hypercholesterolemic (HH) ratio considering monounsaturated fatty acids (MUFA) (Santos-Silva et al., 2002). In other words, it was determined based on fatty acid composition.

2.3 Animal experiment

Animals

The project was conducted according to the ethical standards and guidelines, and the experimental protocol was approved by the Ethics Committee on Animal Use of the Universidade Federal de Mato Grosso do Sul (UFMS) (Protocol No. 1.089/2019). Adult male Swiss (*Mus musculus*) mice were kept under a temperature of 22 ± 2 °C, relative humidity of 50-60%, with a light/dark cycle of 12 hours, fed with pelleted AIN-93M diet and water *ad libitum*. Before starting the experiment, they underwent seven days of adaptation to the new environment and then were divided into experimental groups according to the experimental protocol.

Experimental protocol

We used 108 mice distributed into six groups with similar weight means. After the adaptation period, the experiment was initiated. For 90 days, the supplementation through gavage of different lipidic sources was performed: olive oil, coconut oil, and oil from *Acrocomia aculeata* nuts. The different doses were adjusted weekly according to the animal's weight. The Control Group (CG) received water (2000 mg/kg/day). The Olive Oil Group (OO) was supplemented with extra-virgin olive oil (2000 mg/kg/day). The Coconut Oil Group (CO) received coconut oil (2000 mg/kg/day). The Crude Bocaiuva Oil Group (CBO1 and CBO2) received crude oil from the bocaiuva nut at 1000 mg/kg/day and 2000 mg/kg/day, respectively. The Olive Oil + Crude Bocaiuva Oil Group (OO + CBO) contained olive oil (1000 mg/kg/day) associated with bocaiuva nut oil (1000 mg/kg/day), adapted from Silva et al. (2020).

In order to control morphometric parameters, the animals were weighed weekly, and feed consumption was measured in grams of feed/day. Feed Efficiency Coefficient (FEC) was also calculated, following the Nery et al. (2011) and Salerno (2014) protocol. After 90 days of treatment and an 8-hour fast, the animals were sedated with Isofluorane® and euthanized by exsanguination through the inferior vena cava. The blood samples were centrifuged at 3000 rpm for 5 minutes, and the serum was separated and stored for further analysis.

Five adipose tissue sites (epididymal, retroperitoneal, perirenal, mesenteric, and omental) were removed and weighed on an electronic analytical balance (Bel Diagnóstica®), with subsequent determination of the animal's fat (percentage of adipose tissue at each site compared to body weight) (Chau et al., 2014; White et al., 2016).

The liver was extracted, weighed, and fixed in a 10% formalin solution. After 24 hours, the tissue was transferred to a 70% ethyl alcohol solution until the histological slides were prepared (Mello & Alves, 2010).

Serum profile

In the serum obtained after the blood centrifugation, triacylglycerols (TG), total cholesterol (TC), high-density lipoprotein cholesterol (HDL-c), very low-density lipoprotein cholesterol (VLDL-c), non-high-density lipoprotein cholesterol (non-HDL-c), and fasting glucose were quantified. The CT, TG, and HDL parameters were determined by the enzymatic-colorimetric method, following the manufacturer's instructions (Labtest™, Lagoa Santa, Minas Gerais, Brazil). The cholesterol of the atherogenic fractions (LDL-c, VLDL-c, and IDL-c) was calculated by the difference between total cholesterol and HDL-c.

2.4 Statistical analysis

Results were expressed as mean ± standard error of the mean. Analysis of Variance (ANOVA) was used for multiple comparisons of parametric results, followed by Tukey's post-test. The chi-square test was applied to evaluate associations in histological analyses, followed by Bonferroni's test. A significance level of $p < 0.05$ was adopted. Jandel Sigma Stat, version 3.5 (Systat software, Incs., San Jose, CA, USA) was used for statistical analyses.

3 Results and discussion

Table 1 shows the results of the quality and identity indexes of the bocaiuva nut oil.

The acidity index at a high value makes the oil more prone to rancidity, indicating the presence of free fatty acids (FAs) (Aremu et al., 2017). In this study, the acidity content found in bocaiuva nut oil exceeds the maximum allowable limit for crude oils (< 4 mg KOH g^{-1}) (Food and Agriculture Organization, 1999), which differs from that found by Lescano et al. (2015) in bocaiuva nut oil (0.07 mg KOH g^{-1}), a result possibly explained by a storage error or the difference in the titration method.

The peroxide index showed values within the standard considered for crude oils (< 15 mEqO_2kg^{-1}) (Food and Agriculture Organization, 1999). The oil's low unsaturation degree favors this result since peroxidation occurs in unsaturation, resulting from oxidative stress, through mechanisms that include reversible addition of oxygen to carbon radicals, rearrangement and cyclization of allyl and pentadienyl peroxyl radicals, and homolytic substitution of carbon radicals at the peroxide bond (Porter, 2013). The iodine index indicates the amount of unsaturated FAs in the triglyceride composition. This study's result was higher than that found in another study conducted with bocaiuva nut oil (26.59 ± 0.83 gI_2 100 g^{-1}) (Nunes et al., 2018). In Oliveira et al. (2017), when using the EN 14111 method (Lôbo et al., 2009), in which the sample is dissolved in a cyclohexane mixture with glacial acetic acid and titrated with Wijs' reagent, the iodine index in the bocaiuva nut oil was 36.00±3.00 g I_2 100g^{-1}. In the pulp oil, it was 75.00 ± 9.00 g I_2 100g^{-1}. This result is due to the higher amounts of unsaturated FAs in the pulp (65.8%) compared to the nut (19.7%).

Table 1. Quality and identity indexes of bocaiuva nut oil.

Indexes	Values
Acidity index (mg KOH g^{-1})	5.68 ± 0.04
Peroxide index (mEq O_2 kg^{-1})	3.33 ± 1.15
Iodine index (g I_2 100g^{-1})	32.40 ± 0.49
Saponification index (mg KOH g^{-1})	246.30 ± 4.06
Refraction index at 20 °C	1.46 ± 0.00
Relative density	0.92 ± 0.001
*L**	49.66 ± 0.10
*a**	-1.08 ± 0.02
*b**	4.41 ± 0.02

The means were taken in triplicate. Values are expressed as mean ± standard deviation.

The saponification index indicates triglyceride's molecular weight or chain length and is inversely proportional to the lipid molecular weight (Xu et al., 2018). The result (246.30 ± 4.06) was considered high when compared to that recommended by the Food and Agriculture Organization (1999) for olive oil (184.00-196.00 mg KOH g^{-1}). It indicates that the oil from bocaiuva nuts contains more low molecular weight fatty acids. In other words, it corresponds to the observed profile of FAs, with a prevalence of medium-chain fatty acids (MCFAs). The result observed in this study was similar to that found by Nunes et al. (2018) (255.42 ± 8.65 mg KOH g^{-}) and agrees with standard values established for palm nut (*Elaeis guineenses*) oils with 248.00 mg KOH g^{-1} and coconut (*Cocos nucifera* L.) oil with 265.00 mg KOH g^{-1} (Food and Agriculture Organization, 1999). The obtained refractive index is within the range established for olive oil (1.4677-1.4705) and relative density (0.910-0.916) (Food and Agriculture Organization, 1999). When considering the L* parameter, the oil showed medium brightness in the colorimetric analysis, closer to the black color (brightness scale: 0 - black; 100 - white). The chromaticity coordinates indicated a negative value for the a* axis ranging from red (+a*) to green (-a*) and a positive value for the b* axis ranging from yellow (+b*) to blue (-b*). Thus, the results indicate a slightly green and yellow coloration for this oil.

The fatty acid profile of bocaiuva nut oil (Table 2) showed high values of saturated FAs (72.39%), with lauric acid standing out (45.25%), followed by monounsaturated oleic (23.99%). The saturated FAs profile was similar to that found by Lescano et al. (2015), Río et al. (2016), and Lieb et al. (2019). Compared to coconut oil, it has a high content of saturated fatty acids (92%) being 47% of lauric acid (Eyres et al., 2016). Both oils comprise lauric acid as the major fatty acid. Olive oil has 19% of the saturated fatty acids, mainly palmitic acid C16 (15%) and 68% of the monounsaturates, with the main component being oleic acid C18:1n9 (64%), according to Khaw et al. (2018).

The predominant fatty acid in bocaiuva nut oil and coconut oil, the lauric acid (C12:0), is a medium chain fatty acid. This acid is rapidly absorbed, taken up by the liver, and oxidized to increase energy expenditure, which is a possible explanation for why those oils may have different effects compared with other saturated fats (DeLany et al., 2000). Moreover, it has been suggested that medium chain saturated fatty acids oil does not raise total cholesterol (TC) or low-density lipoprotein cholesterol (LDL-C). They significantly increased HDL-C concentrations in experimental rats (Santana et al., 2016). Furthermore, there is evidence that consumption of monounsaturated oils (olive oil and nuts) led to improved lipid profiles and a decreased risk of cardiovascular disease (Khaw et al., 2018).

The AI and TI are important tools to verify the nutritional quality of dietary fat because the lower the values of these indexes, the greater the amount of anti-atherogenic fatty acids present in a given oil/fat and, consequently, the greater the potential for preventing the onset of cardiovascular diseases (Javardi et al., 2020). The AI and IT found in this study presented values of 3.14 and 1.21, respectively. In other words, higher than 1.0 due to more than 60% saturated FAs. Munhoz et al. (2018) also reported this in the AI of bocaiuva nut oil (2.08). The H/H ratio showed a value of 1.92, and it is worth noting that higher values of this ratio are desirable since they indicate that the hypocholesterolemic FAs values are higher than the hypercholesterolemic values (Munhoz et al., 2018). In the experimental study, Table 3 shows the results obtained for the animals' body weight, food intake, the weight of adipose tissue sites, liver, and adiposity index. Regarding weight gain (Final weight minus Initial weight), the CBO2000 group obtained a significantly lower gain compared to the CBO1000 group ($p \leq 0.05$), a similar result when looking at the average weight of the collected adipose tissue sites and the adiposity index, even without statistical difference. It can be justified by the evidence presented in the literature indicating MCFAs. In other words, FAs whose carboxyl chain is within 6 to 12 carbons, such as lauric acid, reduce total cholesterol levels and decrease weight and body mass index (BMI) (Airhart et al., 2016). In Nunes et al. (2018), bocaiuva nut oil, rich in lauric acid, added to the diet of diabetic rats as a partial carbohydrate replacement also contributed to reduced weight gain.

Table 2. Fatty acid profile of *Acrocomia aculeata* nut oil.

Fatty acids	Values (% in area)
Saturated	
Butyric, C4:0	0.04 ± 0.01
Caprylic C8:0	6.05 ± 0.10
Capric C10:0	4.89 ± 0.18
Lauric C12:0	45.25 ± 0.88
Tridecanoic C13:0	0.02 ± 0.00
Myristic, C14:0	7.92 ± 0.03
Palmitic, C16:0	5.73 ± 0.14
Heptadecanoic, C17:0	0.02 ± 0.00
Stearic, C18:0	2.25 ± 0.13
Arachidic, C20:0	0.14 ± 0.01
Behenic, C22:0	0.03 ± 0.00
Tricosanoic C23:0	0.02 ± 0.00
Lignoceric, C24:0	0.03 ± 0.00
TOTAL	72.39
Monounsaturated	
Palmitoleic, C16:1	0.02 ± 0.00
Oleic, C18:1 (ω-9)	23.96 ± 1.25
Cis-11- eicosenic, C20:1	0.01 ± 0.00
TOTAL	23.99
Polyunsaturated	
Linoleic, C18:2 (ω-6)	2.31 ± 0.12
Dihomo- γ-Linolenic, C20:3	0.04 ± 0.00
TOTAL	2.35

The means were taken in duplicate. Values are expressed as mean ± standard deviation.

Schönfeld & Wojtczak (2016) point out that the MCFAs metabolic pathway is likely linked to specific uptake, transport, and mitochondrial metabolism mechanisms, which differ from long-chain fatty acids. MCFAs have an entry into the mitochondrial matrix that bypasses the chylomicron lymphatic route and are independent of L-carnitine mediated transport. Furthermore, the transport is not under metabolic control of L-malonyl-CoA and has low deposition in adipose tissue.

Supplementation with the oils did not influence the animals' food intake since there was no statistical difference between the study groups, which the FEC also evidenced. Santana et al. (2016) showed similar results regarding food intake, with no difference in food intake between the control group and the groups supplemented with different lipid sources. However, it showed a significant difference in FEC between the groups treated with lard and soybean oil.

Maher & Clegg (2019) reviewed the effect of medium-chain triglyceride (MCT) consumption on satiety hormones. Cholecystokinin (CCK), an intestinal hormone responsible for influencing satiety, has its secretion associated with lipid consumption. However, the FAs chain length in these lipid sources influences this secretion.

Most MCTs do not increase CCK levels, although emulsions of either capric acid (C10) or lauric acid (C12) infused into the intestine of healthy volunteers demonstrated CCK release, being greater with C12. In addition, C12 significantly decreased hunger and food consumption perceptions. Even though FAs with chain lengths below 12 carbons cause CCK secretion, it does not appear to affect appetite sensation, unlike GAs with chains of 12 carbons or more (Maher & Clegg, 2019).

Table 3. Bodyweight, food intake, visceral fat weight, liver, adiposity index of control, and supplemented animals with different lipid sources.

Parameters	CG (n = 18)	OO2000 (n = 18)	CO2000 (n = 18)	CBO1000 (n = 18)	CBO2000 (n = 18)	OO + CBO (n = 18)
Initial weight (g)	35.39 ± 1.16	36.06 ± 1.10	36.22 ± 0.81	35.94 ± 0.85	35.89 ± 0.73	36.44 ± 0.65
Final weight (g)	41.72 ± 1.47	40.94 ± 1.59	42.61 ± 1.34	42.53 ± 1.08	39.89 ± 1.15	42.67 ± 1.16
Weight gain (g)	6.33 ± 0.57	5.88 ± 0.85	6.39 ± 0.72	7.50 ± 0.80	4.00 ± 0.65*	6.22 ± 0.66
Food Intake (g/day)	4.78 ± 0.16	4.61 ± 0.12	4.93 ± 0.15	5.06 ± 0.09	4.90 ± 0.10	4.91 ± 0.07
FEC	0.02 ± 0.001	0.01 ± 0.002	0.01 ± 0.002	0.02 ± 0.002	0.01 ± 0.002	0.014 ± 0.00
Omental fat (g)	0.04 ± 0.005	0.03 ± 0.004	0.04 ± 0.01	0.05 ± 0.007	0.032 ± 0.01	0.033 ± 0.003
Epididymal fat (g)	1.15 ± 0.13	1.41 ± 0.17	1.17 ± 0.16	1.36 ± 0.15	1.01 ± 0.10	1.33 ± 0.15
Mesenteric fat (g)	0.51 ± 0.04	0.52 ± 0.05	0.60 ± 0.08	0.62 ± 0.06	0.45 ± 0.05	0.63 ± 0.08
Retroperitoneal fat (g)	0.54 ± 0.07	0.52 ± 0.06	0.49 ± 0.07	0.53 ± 0.07	0.41 ± 0.04	0.53 ± 0.06
Perirenal fat (g)	0.16 ± 0.02	0.18 ± 0.03	0.14 ± 0.03	0.18 ± 0.03	0.11 ± 0.01	0.20 ± 0.06
Adiposity index (%)	5.81 ± 0.39	6.42 ± 0.59	5.40 ± 0.62	6.66 ± 0.67	5.00 ± 0.37	6.23 ± 0.53
Liver (g)	1.51 ± 0.08	1.51 ± 0.05	1.69 ± 0.08	1.73 ± 0.06	1.56 ± 0.04	1.64 ± 0.05

CG: control group, received water; OO2000: group supplemented with olive oil 2000 mg/kg; CO2000: group supplemented with coconut oil 2000 mg/kg; CBO1000 and CBO2000: groups supplemented with crude oil from bocaiuva nuts, 1000 mg/kg and 2000 mg/kg, respectively; OO + CBO: group received simultaneously olive oil 1000 mg/kg with crude oil from bocaiuva nuts 1000 mg/kg; FEC: feed efficiency coefficient. Values are represented as mean ± standard error of the mean. *In the same row, $p \leq 0.05$, vs. CBO 1000. One-way ANOVA, with Tukey's post-test.

Table 4 shows the results of the animals' serum profiles after 90 days of supplementation with different lipid sources. There was a statistical difference for the Non-HDL-c parameter in groups OO2000, CO2000, and CBO1000, with lower values than in the OO + CBO group ($p \leq 0.05$).

The sum of atherogenic lipoproteins, including LDL-c and VLDL-c, is named Non-HDL-c. Thus, atherogenic cholesterol can be understood as either LDL-c or Non-HDL-c (Grundy, 2013). It is worth noting that regarding supplementation with the crude bocaiuva nut oil, the 1000 mg/kg concentration achieved a better response in this parameter normally associated with atherosclerosis (Morita, 2016). One of the hypotheses justifying the result for the BOD1000 group is that there is some evidence in the literature indicating that MCFAs are not stored in the adipose tissue and decrease fat mass, which is related to the higher energy expenditure and smaller fat depots. Furthermore, the diet containing MCT oil reduced hepatic lipid synthesis by decreasing the activity of lipogenic enzymes and increasing hepatic lipolytic enzymes, consequently lowering serum TG (Schönfeld & Wojtczak, 2016). Higher levels of serum HDL-C in animals fed with MCT oil is related to the functionality of LDL receptors (Fernandez & West, 2005). These receptors are glycoproteins that recognize apoprotein B and are controlled by the glycosylation mechanism (Betteridge, 1989).

Still, on the biochemical parameters, a 28-day study with a different method, in which bocaiuva nut oil was added to the diet of rats previously induced to diabetes with a hyperlipidic diet plus streptozotocin, showed a decrease in LDL-c levels and an increase in HDL-c levels (Nunes et al., 2020), which could be a protective factor against the risk of atherosclerosis.

Another study using fruit from the Cerrado obtained good results on total cholesterol, LDL-c, and non-HDL-c parameters when supplementing Swiss mice with pequi pulp oil (Silva et al., 2020).

Regarding histological changes in the liver (Table 5), there was no statistical difference in the degree of steatosis,

Table 4. Biochemical parameters of animals after 90 days of supplementation with different lipid sources.

Parameters (mg dL^{-1})	CG (n = 18)	OO2000 (n = 18)	CO2000 (n = 18)	CBO1000 (n = 18)	CBO2000 (n = 18)	OO + CBO (n = 18)
Total Cholesterol	164.73 ± 5.36	168.84 ± 3.84	157.68 ± 5.89	176.33 ± 5.21	168.86 ± 4.57	177.41 ± 5.94
HDL-c	103.19 ± 3.14	113.22 ± 4.25	102.90 ± 4.26	117.03 ± 4.04	107.65 ± 3.01	107.96 ± 4.82
Non-HDL-c	61.54 ± 3.56	55.62 ± 2.96*	54.77 ± 2.74*	56.79 ± 2.63*	60.57 ± 2.76	69.39 ± 3.23
VLDL-c	37.46 ± 1.11	37.81 ± 2.07	39.13 ± 1.52	42.56 ± 2.77	38.78 ± 1.43	44.97 ± 2.40
LDL-c	23.15 ± 2.31	19.13 ± 3.80	16.13 ± 4.04	19.13 ± 4.89	20.73 ± 6.15	25.28 ± 5.34
Triglycerides	191.93 ± 6.97	189.07 ± 10.36	195.67 ± 7.58	212.79 ± 13.85	193.88 ± 7.14	224.84 ± 12.02
Glucose	204.25 ± 16.23	169.63 ± 12.58	168.47 ± 18.58	212.74 ± 15.15	218.34 ± 16.95	205.83 ± 17.71

CG: control group, received water; OO2000: group supplemented with olive oil 2000 mg/kg; CO2000: group supplemented with coconut oil 2000 mg/kg; CBO1000 and CBO2000: groups supplemented with crude oil from bocaiuva nuts, 1000 mg/kg and 2000 mg/kg, respectively; OO + CBO: group received simultaneously olive oil 1000 mg/kg with crude oil from bocaiuva nuts 1000 mg/kg. Values are represented as mean ± standard error of the mean. *In the same row, $p \leq 0.05$, vs. OO + CBO One-way ANOVA, with Tukey's post-test.

Table 5. Histological changes in animals' livers after 90 days of supplementation with different lipid sources.

Variable	CG (n = 12)	OO2000 (n = 12)	CO2000 (n = 12)	CBO1000 (n = 11)	CBO2000 (n = 12)	OO + CBO (n = 11)
Changes in the liver						
Steatosis (p > 0.999)						
< 5%	100.0(12)	91.7(11)	100.0(12)	100.0(11)	91.7(11)	100.0(11)
5-33%	-	8.3(1)	-	-	8.3(1)	-
34 to 66%	-	-	-	-	-	-
> 66%	-	-	-	-	-	-
Microvesicular steatosis (p = 0.654)						
Absent	66.7(8)	66.7(8)	66.7(8)	81.8(9)	58.3(7)	45.5(5)
Present	33.3(4)	33.3(4)	33.3(4)	18.2(2)	41.7(5)	54.5(6)
Lobular inflammation (p = 0.052)						
Absent	41.7(5)	66.7(8)	100.0(12)	72.7(8)	75.0(9)	72.7(8)
< 2 foci	58.3(7)	33.3(4)	-	27.3(3)	25.0(3)	27.3(3)
Ballooning (p = 0.352)						
Absent	-	16.7(2)	16.7(2)	9.1(1)	-	-
Few	100.0(12)	83.3(10)	83.3(10)	90.9(10)	100.0(12)	100.0(11)
Mallory's hyaline (p = 1.0)						
Absent	100.0(12)	100.0(12)	100.0(12)	100.0(11)	100.0(12)	100.0(11)
Present	-	-	-	-	-	-
Apoptosis (p > 0.999)						
Absent	91.7(11)	100.0(12)	100.0(12)	100.0(11)	100.0(12)	100.0(11)
Present	8.3(1)	-	-	-	-	-
Glycogen core (p = 0.642)						
None/Rare	100.0(12)	100.0(12)	100.0(12)	100.0(11)	91.7(11)	90.9(10)
Some	-	-	-	-	8.3(1)	9.1(1)

CG: control group, received water; OO2000: group supplemented with olive oil 2000 mg/kg; CO2000: group supplemented with coconut oil 2000 mg/kg; CBO1000 and CBO2000: groups supplemented with crude oil from bocaiuva nuts, 1000 mg/kg and 2000 mg/kg, respectively; OO + CBO: group received simultaneously olive oil 1000 mg/kg with crude oil from bocaiuva nuts 1000 mg/kg. The data are presented in relative frequency (absolute frequency). P-value in the Fisher's exact test extension.

microvesicular steatosis, lobular inflammation, ballooning, Mallory's hyaline, apoptosis, and glycogen core, showing that the oil from bocaiuva nut did not cause considerable changes to the liver, even though it is an oil with a higher concentration of saturated FAs. Similar to coconut oil, the oil from bocaiuva nuts has a higher composition of lauric fatty acid. Dayrit (2015) points out in a review that lauric acid is a medium-chain fatty acid directly transported to the liver and quickly converted into energy instead of being stored as fat.

4 Conclusion

The bocaiuva nut oil shows a predominance of saturated fatty acids in its composition, especially lauric acid. However, regarding the nutritional quality, the oil was within the desired parameters for consumption.

The results presented in the experimental design show that the CBO2000 group had less weight gain compared to CBO1000, and the non-HDL was lower in OO2000, CO2000, and CBO1000 compared to OO + CBO. However, in the other analyses, even though it is a saturated oil, the daily offer of bocaiuva nut oil did not cause any negative metabolic changes in mice, nor in the olive oil and coconut oil control groups. It is worth noting that the high content of lauric acid may have contributed to this result because it is a medium-chain fatty acid that is easily metabolized by the body. Furthermore, we emphasize a need for new studies addressing the possible metabolic effects of bocaiuva nut oil, especially in experimental models with induced physiological alterations, such as dyslipidemia, obesity, and others.

The oil from bocaiuva nuts proved to be a good alternative to broaden the options of oils obtained from non-traditional sources for human consumption. According to the parameters analyzed, after 90 days of daily consumption, bocaiuva nut oil did not cause negative metabolic effects, even though it is a predominantly saturated oil. It can even be compared to olive oil and coconut oil, which in the same study showed no negative effects and are often used in human food.

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