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Supercritical CO₂ assisted extraction of freeze-dried sinami fruit pulp (*Oenocarpus mapora* H. karst) oil: An experimental optimization approach

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ABSTRACT

Sinami (*Oenocarpus mapora* H. karst) is the fruit of a native palm from the Amazon region. Sinami is a source of bioactive compounds and, mainly, vegetable oil rich in unsaturated fatty acids and phenolic compounds. In the present study, supercritical-CO₂ (SC-CO₂) extraction was applied to obtain the Sinami oil. Parameters such as pressure (P) and temperature (T) were optimized to determine the extraction conditions to allow the highest yield of oil. Also, quality values of oils such as peroxide value index (POV), free fatty acids (FFA), dienes, and trienes were assessed, the fatty acid and phenolic compounds profiles were characterized, and color parameters were observed. The maximum oil yield was reached at 43.5 °C and 27.07 MPa (30.4 g 100 g⁻¹). Quality parameters indicate that Sinami oil exhibits good stability per resistance to oxidation and presents low levels of hydrocarbons. The oleic > palmitic > linoleic acids were predominant in the oil composition, and vainillin acid was the phenolic with the highest concentration. These characteristics suggest future research about possible applications of Sinami oil as a potential ingredient with nutraceutical benefits.

1. Introduction

The fruit of *Oenocarpus mapora* H. Karst palm, usually known as Sinami, of the botanical family Arecaceae, is widely employed and consumed by different communities in all the Amazonic region in countries as Bolivia, Brazil, Colombia, Ecuador, and Peru, and also in forest areas of Costa Rica and Venezuela (Smith, 2015). The palm tree has a height between 8 and 20 m. Under the palms, flowers grow as clusters. From each one grown between 500 and 700 fruits, that in maturity state has a purple dark color. Each fruit has a single hard-coated, dark-colored single seed (Best et al., 2021; Smith, 2015; Zambrana, Bussmamann & Macía, 2012).

One of the principal uses of these fruits is for making beverages that can be consumed as soft drinks. An alcoholic drink, known in the Amazon region of Peru, such as chicha, can also be made. However, one

of its most common uses is to produce oil, for cosmetic purposes (for skin and hair care) (Zambrana, Bussmamann, & Macía, 2012). Raw material can also be employed as an exfoliant ingredient in cosmetic products (Romero-Orejon, Huaman, Lozada, Ramos-Escudero, & Muñoz, 2023).

The Sinami fruits, have great potential for industrial use due to their high content of polyunsaturated fatty acids, mainly oleic acid and linoleic acid (Vargas-Arana, Merino-Zegarra, Aricari, & Ipushima, 2022). In addition, high content of phenolic compounds and antioxidant capacity was determined in Sinami sub-product as oil (Muñoz et al., 2022), also this content is higher than other palm fruit oils. The Sinami fruit oil can be obtained by different methods, the most used the mechanical procedures. This kind of procedure uses large amounts of organic solvents, making the oil obtained have a limited application.

Currently, the use of environmentally friendly technologies has allowed to development and study of the application of less invasive

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methods in samples, with better performance and sustainable use of the product and its bioactive compounds. One of the recently studied methods for obtaining oil from palm fruits is supercritical fluids extraction with CO₂ (Cunha et al., 2019; Muñoz et al., 2022; Phan Tai & Brunner, 2019; Pinto et al., 2018; Turola Barbi et al., 2020). The application of this technology favors the yield and the obtaining of a better-quality oil, free of organic solvent, and with better stability, since no separation step is needed, because CO₂ is gaseous at ambient conditions of pressure and temperature (Mouahid et al., 2022). However, the study of the effect of the SC-CO₂ parameters in Sinami oil yield, and optimal operating conditions is limited. The optimization and assessment of the extraction process with a mathematical model as Response surface methodology (RSM) is essential for process improvement and allows for analysis the possible effects of the independent variables and to improve the processing operations.

For this reason, a process of optimization using CO₂ as a supercritical fluid, to obtain oil from the Sinami fruit is carried out, to evaluate the effects in yield (Y), POV and FFA, of the extraction parameters employing the RSM. Also, a polyphenol and fatty acid profile were characterized in Sinami oil, as well as dienes and trienes level and color parameters.

2. Materials and methods

2.1. Plant materials

Sinami fruits supplied by Haktone Wabakae Kate'dapi Uruanda/Wara (HAWAKAUR E.I.R.L; Tambopata, Madre de Dios, Peru), were harvested manually in January 2021. The samples were transported in boxes by air from the origin to Lima and were immediately taken to the laboratory. The fruits free of signs of over-ripening, bird bites and the presence of molds was separated. Selected fruits were washed and subsequently heat-treated at 100 °C during 15 min in order to easily obtain the pulp. Pulping was performed manually using a stainless-steel knife according to Muñoz et al. (2022). The fresh pulp fruits (3.74 kg) were pulverized by a Labconco freeze-dryer, at 106.5 °C, for 24 h, under a pressure of 17.7 Pa. The particle size was between 350 and 500 μm with less than 6% humidity. The samples were stored at -20 °C (A54546, Infracva, Valencia, Spain) until oil extraction.

2.2. Chemicals

Acetic acid, acetonitrile, starch, chloroform, potassium iodide, diethyl ether, ethyl acetate, ethanol, hexane, isooctane, methanol, orthophosphoric acid, potassium hydroxide, sodium thiosulfate, turmeric oleoresins, and standards of gallic acid, chlorogenic acid, vanillic acid, caffeic acid, syringic acid, vainillin acid, ferulic acid, sinapic acid, rutin were purchased from Merck KGaA (Sigma-Aldrich), Darmstadt, Germany.

2.3. Supercritical-CO₂ extraction of sinami oil

The trials were carried out in a multi-solvent extractor equipment Model 2802.000 (Top Industrie, Vaux le Pénil, France) with an extraction cell of 1 L capacity that had a volume reducer device (87 cm³, internal diameter = 2.8 cm, internal height = 14.1 cm), according to the method proposed by Barriga-Sánchez & Rosales-Hartshorn (2022) with some modifications. Samples of 19.5 ± 0.4 g of freeze-dried sinami fruit pulp were weighed and put into the extraction vessel. Each extraction run lasted for 2 h with a CO₂ flow rate of 39 g min⁻¹, at 33.5 °C and 18.8 MPa. The extraction yield was expressed on a dry basis according to the following formula:

$$\text{Sinami oil yield (\%)} = (W_1/W_2) \times 100 \quad (1)$$

where: W₁ is the oil mass and W₂ is Sinami fruit mass.

2.4. Peroxide value index

The determination of the POV index is based on the measurement of the oxidation state of a compound, using the method of the AOAC (2012) with a small change. Turmeric oleoresins were dissolved in a mixture of acetic acid and chloroform (3:2). Then, a potassium iodide solution was added to liberate iodine. The titration was carried out with a standardized solution of sodium thiosulfate in an automatic titrator (TitroLine® 7000, SI Analytics, Germany). The titration endpoint corresponded to the final volume of sodium thiosulfate needed to get the maximum slope in the titration curve.

2.5. Free fatty acids

FFA was determined by the method of titration according to AOCS (1998). Briefly, 0.25 g of oleoresin was weighed into 100 mL beaker and mixed with 50 mL of ethanol. Solution was titrated with 0.02 mol/L NaOH using and automatic titrator equipped with a glass electrode Pt 62 RG and Cable L 1 A (TitroLine® 7000, SI Analytics, Germany). The results were expressed as a percentage of oleic acid.

2.6. Experimental design

RSM was applied to evaluate the effects of P (MPa) and T (°C) on the sinami oil yield and its POV and FFA. The experimental design and statistical analysis were accomplished by Statistica® software, version 14.0.1.25 (TIBCO Software Inc). The experimental design was based on the central composite design (CCD) to evaluate the effects of the extraction conditions and their impacts on the oil yield. The variables used in the design and their respective units and codes included 10 experimental points as follows: 2 axial points (2n) (run 1–4) with an axial distance of 4 (runs 5–8) and 2 replicates at the center point of the design (runs 9, 10). The P low, medium, and high levels were 15, 20, and 25 MPa respectively. In the case of T, the low, medium, and high level were 35, 40, 45 °C, respectively. The relationship between the Sinami oil yield and the extraction conditions (P and T) was obtained by fitting a model into experimental data. The predicting response is given by the following second-order polynomial regression model:

$$R = \beta_0 + \beta_1.P + \beta_2.T + \beta_{11}.P^2 + \beta_{22}.T^2 + \beta_{12}.P.T + \text{ERROR} \quad (2)$$

Where R, is the response variable, β₀ is the intercept term, β₁ and β₂ are linear coefficients, β₁₂ are interactions coefficients, β₁₁ and β₂₂ are quadratic coefficients, and P – T are the coded independent parameters. Table 1 shows the standard order, experimental design, oil recovery, and 10 experimental runs.

Table 1

Differences between predicted values of yield extraction by Response Surface Methodology design and observed results of Sinami oil yield.

Runs	P	T	Y		
	(MPa)	(°C)	Predicted	Observed	Difference
Run 1	15.00	35.0	17.73	18.81 ± 0.01	1.08
Run 2	25.00	35.0	28.19	31.90 ± 0.07	3.71
Run 3	15.00	45.0	10.00	7.33 ± 0.03	-2.67
Run 4	25.00	45.0	29.77	29.73 ± 0.04	-0.04
Run 5	12.93	40.0	8.37	9.71 ± 0.02	1.34
Run 6	27.07	40.0	29.73	27.35 ± 0.06	-2.38
Run 7	20.00	32.9	25.97	22.81 ± 0.02	-3.16
Run 8	20.00	47.1	21.60	23.73 ± 0.02	2.13
Run 9	20.00	40.0	25.82	25.10 ± 0.13	-0.72
Run 10	20.00	40.0	25.82	26.53 ± 0.01	0.71

Values are expressed in raw weight (RW). Each observed value is the mean ± the standard deviation (SD) of triplicate determinations (n = 3), P: pressure, T: temperature, Y: yield (g 100 g⁻¹).

2.7. Dienes and trienes conjugated analysis

The determination of conjugated dienes and trienes was carried out following the procedure described by the [International Olive Council \(2019\)](#). An approximate amount of 50 mg of oil was weighed into a glass flask and made to volume with 5 mL of isooctane. Absorbance readings were then collected from a UV spectrum curve from 200 to 300 nm. The extinction coefficients K232 and K270 were calculated from the absorbance values at 232 and 270 nm respectively.

2.8. Phenolic compounds analysis by HPLC-DAD

The procedures used to separate the polyphenols from sinami oil and its characterization by HPLC-DAD were based on the method reported by [Ramos-Escudero, Morales, et al. \(2021\)](#). Approximately 1.25 g of oil was weighed and then 1 mL of *n*-hexane was added. The mixture was stirred in vortex for a few seconds and subsequently 1.25 mL of 80% MeOH was added. The extraction was conducted in an ultrasound bath at a frequency of 40 kHz and 15 min of extraction at 20 °C. It was subsequently centrifuged (Eppendorf 5810 R, Germany) at 18.8×g for 15 min. The supernatant was filtered (FilterBio® PTFE-L Syringe Filter, diameter 13 mm, pore size 0.22 µm) and placed in amber (2 mL). The analysis was carried out with a High-Performance Liquid Chromatograph Chromaster with a diode array detector (Hitachi High-Technologies Corporation, Tokyo, Japan). The analytes were separated using a LiChrospher® 100 RP-18 end-capped, 5 µm, 4.0 × 250 mm cartridge (Millipore, Darmstadt, Germany) column. The column was maintained at 30 °C, the injection volume was 20 µL and the flow was 1 mL min⁻¹. The solvent elution was a mix of 0.5% of orthophosphoric acid in water as mobile phase A and another mixture of MeOH:acetonitrile (50:50 v/v) as mobile phase B. The gradient program used was as follows: 0–25 min, lineal from 95 to 70% A; 25–35 min, lineal from 70 to 62% A; 35–40 min, isocratic 62% A, 40–45 min, lineal from 62 to 55% A; 45–50 min, lineal from 55 to 47.5% A; 50–55 min, lineal from 47.5 to 95% A; 55–60 min, isocratic 95% A. The identification of the phenolic compounds was carried out using the retention times and UV spectra of the extracts with the standards.

2.9. Fatty acids profile analysis

Fatty acids were identified according to the method described by [Ramos-Escudero, Casimiro-Gonzales, et al. \(2021\)](#) as follows. A PerkinElmer Clarus® 690 gas chromatograph (PerkinElmer, Shelton, CT) equipped with a SPTM-2380 fused silica capillary column (60 m × 0.25 mm i. d.: 0.2 µm film thickness, Supelco®) and a flame ionization detector (FID) was used. Approximately 25 mg of sinami oil was dissolved in 1.5 mL hexane and then transesterified using 300 µL 2 N methanolic potassium hydroxide solution. After vigorous shaking and centrifugation, the upper phase (methyl ester fatty acids) was transferred to a 250 µL vial insert micro conical glass for analyses. The injector and detector temperature were set at 250 °C, the oven temperature was maintained at 170 °C for 10 min and then programmed to increase from 170 to 200 °C at 1.5 °C min⁻¹ intervals, after being kept in an isotherm for 8 min. The temperature of the injector, detector and oven temperature program were similar to those described by [Ramos-Escudero et al. \(2019\)](#). Helium was used as the carrier gas at a flow rate of 1.0 mL min⁻¹. The injection volume was 1 µL. The results of the fatty acid composition were expressed in relative percentage.

2.10. Color index

Color parameters were carried out following the method described by [Muñoz et al. \(2022\)](#) with some modifications. Aliquots of 800 µL oil samples were placed in a liquid adapter (nix™ color sensor). Each sample was then placed in a portable photographic studio (40 cm³) (Puluz Technology Limited, Shenzhen, China) containing 2 light boards

each with 32 LED lights (output power: 30 W, color temperature: 5500 K), under these conditions the photographs were taken using a digital camera. Subsequently, the photographs were analyzed using the ImageJ –1.51 k software program. Chromatic parameters L^* , a^* , and b^* were calculated from RGB values using a color converter (Color Sensor App). The chroma (C^*ab) and pitch angle (hab) were calculated from $C^*ab = \sqrt{a^{*2} + b^{*2}}$ and $hab = \arctan(b^*/a^*)$.

2.11. Statistical analysis

Experimental results were tested for significant differences in ANOVA analysis and F-test to obtain the mathematical-statistical relationship between input and output parameters. All analyses were carried out with Statistica® software, version 14.0.1.25 (TIBCO Software Inc). The experiments were conducted in triplicate (n = 3) and data was reported as mean ± standard deviation (SD) and, the significance of all the terms in the model was assayed statistically by calculating corresponding P-values (significance confirmed if $P \leq 0.05$). The reliability of the model was evaluated by the coefficient of determination (R^2 model) and adjusted R^2 . Finally, the lack-of-fit of the model was determined to better fit the second-order polynomial to the observed data of sinami oil yield.

3. Results and discussion

3.1. Model optimization and validation

As was proposed, RSM was employed to optimize the SC-CO₂ extraction conditions. The variables temperature and pressure were assessed to determine its effect on sinami (*O. mapora* H. Karst) oil yield. Central composite design (CCD) was used to evaluate the effects of pressure and temperature and their impacts on the dependent variables. The observed results of sinami oil yield (listed in [Table 1](#)) were analyzed to get a regression model. Besides the experience of the researches on supercritical extraction systems and optimization methods, the most important interest was to design an efficient supercritical extraction operation process method to allow the solubility in the supercritical fluid of pure compounds of interest or their mixtures in the sinami oil. At selected process variables, the sinami oil yield varied from 9.71% to 31.90% (w/w) and yield was maximum at 25 MPa and 35 °C. The predicted values were calculated using the regression model and compared with the experimental values. The estimated coefficients of the regression model are given in [Table 2](#). ANOVA test for sinami oil yield revealed that, among the linear effects, pressure had the most significant effect ($P < 0.01$), followed by temperature which significantly affects free fatty acid values ($P < 0.01$) ([Table 2](#)). The model R^2 value of 0.924 implies that 92 % of the variations associated with

Table 2

Regression coefficients of the fitted quadratic equation and standard errors for Sinami oil yield.

	SS	df	MS	F	P
Linear					
P (MPa)	456.5868	1	456.5868	446.5615	0.030
T (°C)	18.9678	1	18.9678	18.5513	0.145
Interaction					
P (MPa) × T (°C)	21.6690	1	21.6690	21.1932	0.136
Quadratic					
P (MPa) ²	52.3012	1	52.3012	51.1528	0.088
T (°C) ²	4.7124	1	4.7124	4.6089	0.277
Lack of fit	44.0626	3	14.6875	14.3650	0.191
Pure error	1.0224	1	1.0224		
Total	595.6944	9			
R^2 model	0.92432				
Adj R^2	0.82971				

SS: sum of squares; P: pressure, T: temperature. * $P < 0.05$; ** $P < 0.01$. The data is related to runs 1–10.

extraction yield are attributed to the selected independent variables (pressure and temperature). This design indicates that the model adequately represents the experimental data of sinami oil yield and permits the response to be modeled by fitting with the following second-order polynomial equation:

$$Y = -36.3862 + 3.2049X_1 + 1.0596X_2 - 0.1354X_1^2 - 0.0404X_2^2 + 0.093X_1X_2 \quad (3)$$

where X_1 and X_2 are the independent variables, pressure, and temperature, respectively. Additionally, no significant ($P > 0.05$) lack of fit at the 95% confidence level was observed for the final reduced model. It is recommended not to extrapolate beyond the studied independent variable ranges, because the final reduced model and recommended optimum region is only a valid statistical empirical model with these ranges (Montgomery, 2017).

The optimization process showed that the parameters to maximize the oil yield were 27.07 MPa and 43.55 °C (Fig. 1A), being the desirability value 0.94 (Fig. 2). Also, it was observed that an increase in the extraction pressure increased the Sinami oil yield significantly. This can be explained because with increasing the extraction pressure, it leads to a higher fluid density, which increases the solubility of the analytes and finally its extraction (Ara, Jowkarderis & Raofie, 2015). As is can be observed in Fig. 1B, at the 40 °C isotherm, when the pressure increased from 12.93 to 20, there was a significant increase (3.08 times) of oil yield. However, at 27 MPa the yield remained practically constant. And at 45 °C isotherm, at increase of oil yield, in 4.06 times, was observed, when the pressure increases from 15 to 25 MPa. This shows that the first increase in pressure for each temperature selected is enough to enhance the oil yield in Sinami fruits. The Sinami oil yield obtained in this study was higher than Muñoz et al. (2022) who showed 7.45% as the maximum level of Sinami oil yield at 60 °C and 35 MPa by SC-CO₂ extraction. It should be added that, the principal limitation identified during the develop of the study is the limited information related the *Oenocarpus mapora* L. fruit and an optimized extraction oil model. In this way, information of different varieties of palm fruit oil were used to compare the results obtained. Also, the maximum yield observed in this study was higher than those indicated by other authors as Cunha et al. (2019), who obtained a maximum oil yield of 45.90% at 60 °C and 27 MPa in Bacaba-de-leque (*Oenocarpus distichus* Mart.). While, with conventional extractions, were determined a 41.78 and 38.3% yield of patauá (*Oenocarpus bataua*) (Rodrigues, Darnet, & Silva, 2010) and (*Oenocarpus bacaba*) oil (Santos, Marmesat, Brito, Alves, & Dobarganes, 2013), respectively. A higher oil yield (60.39%) was obtained by Pinto et al. (2018) with Bacaba (*Oenocarpus bacaba*) fruit, by SC-CO₂ at 60 °C

and 42 MPa, they observed that the results showed direct relationship among the global yield, the pressure, and the CO₂ density. Also, Phan Tai and Brunner (2019) observed a range of palm oil yield between 10 and 50%, having the maximum value at 65 °C and 40 MPa.

3.2. Quality parameters

As is observed in Table 3, in the present study POV values in sinami oil ranged from 1.76 to 3.92 meq O₂ kg⁻¹, indicating that exhibits a good oxidative stability. Barriga-Sánchez, Campos Martinez, Cáceres Yparaguire and Rosales-Hartshorn (2022) reports from 1.06 to 1.91 meq O₂ kg⁻¹ in grape seed oil obtained by supercritical CO₂. The good quality of the oil and its good state of preservation is possibly due to the oil extraction technique with SC-CO₂ used (Barriga-Sánchez & Rosales-Hartshorn, 2022). Likewise, Coelho, Pereira, Rodrigues, Teixeira & Pintado (2020) affirm that CO₂ generates cleaner extracts than other conventional extraction techniques. Also, the method applied constitutes a strength, since CO₂ is a safe, non-toxic and easy-to-recycle solvent.

FFA is an index of oil hydrolysis that exhibit the resistance to oxidation when the values are lower. The results of sinami oil shown ranged from 1.00 to 1.86 g 100 g⁻¹, indicating that presents higher resistance to oxidation. Recently, Muñoz et al. (2022) obtained a main value of 1.05 g 100 g⁻¹. Also, Varas-Condori et al. (2020) evaluated the useful life of linseed oil with lycopene and considered the maximum acceptable values of 2 g 100 g⁻¹ oleic acid for FFA.

Alkenes are a part of the endogenous hydrocarbon fraction of oils (Giuffrè, 2021) that allows the assessment of the quality of oils. According to the European Agency for the Evaluation of Medicinal Products, the intake of biogenic hydrocarbons is normally within the range of 10–100 mg per person per day (0.17–1.7 mg kg⁻¹ of body weight per day), and the intake of hydrocarbons by all sources has been estimated at around 240 mg per person per day (4 mg per kg body weight, per day) if a 60 kg person is considered (The European Agency for the Evaluation of Medicinal Products, 1995). In this way, dienes (1.84–2.31) and trienes (0.26–0.44) quantities in Sinami oil samples are in the range of hydrocarbons consumed per day.

3.3. Phenolic compounds

The phenolic compounds composition of Sinami oil is shown in Table 3. Eight kinds of phenolic acids were detected in Sinami oil samples, being the most abundant the vainillin acid in concentrations ranging from 45.12 to 164.2 mg kg⁻¹. Also, rutin was quantified in a

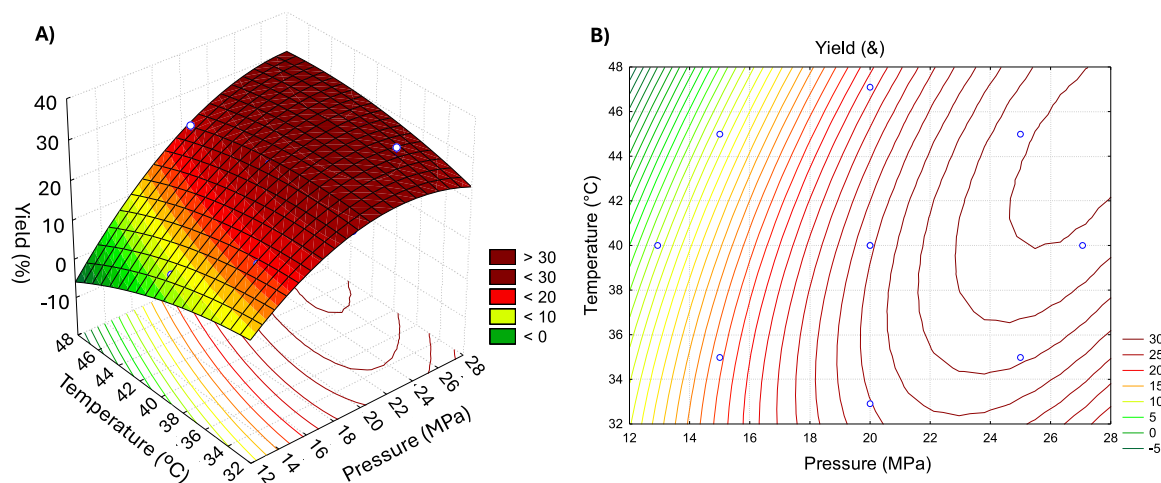


Fig. 1. Response surface (A) and contour (B) plot graphs of Sinami oil yield obtained by Supercritical CO₂ assisted extraction.

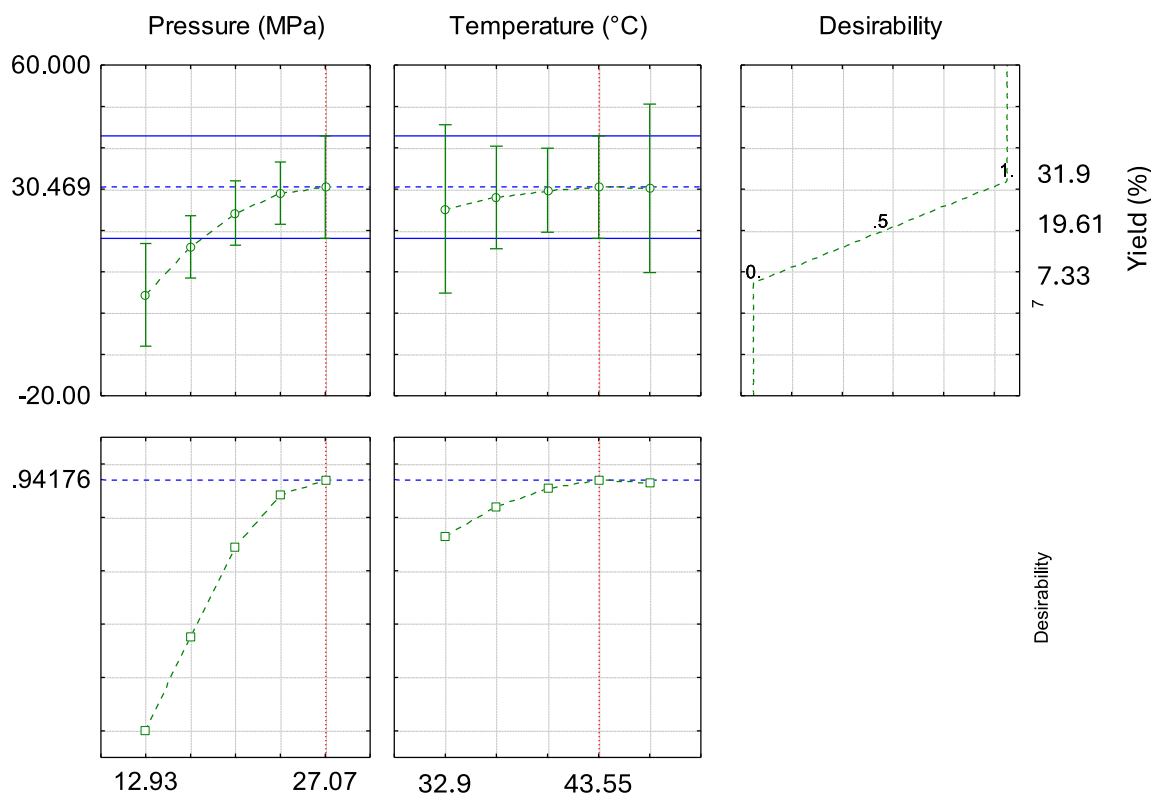


Fig. 2. Profiles for predicted values and desirability of Sinami oil yield during Supercritical CO₂ assisted extraction.

range from 3.99 to 16.90 mg kg⁻¹. These results indicate that Sinami oil can be considered as a potential source of phenolic acids, being attractive for different industries such as cosmetics and pharmacy, improving the antioxidant properties of products. In the same line, in ultrasonic extracts of *Oenocarpus distichus* Mart. fruits some phenolic compounds were detected, being the main compounds 3,4-dihydroxybenzoic acid, chlorogenic acid, cyanidin derivative, cyanidin 3-O-rutinoside, syringic acid, rutin, flavonol derivative and ferulic acid (Brabo de Sousa, de Andrade Mattietto, Campos Chisté & Carvalho, 2018).

Additionally, the total content of phenolic compounds is ranged from 61.94 to 225.8 mg kg⁻¹. This is due to Muñoz et al. (2022) who determined 200.49 mg kg⁻¹ of total phenolic compounds in Sinami oil samples obtained by SC-CO₂. Also, recent studies have shown that other species of the *Oenocarpus* genus are a potential source of phenolic compounds. In this way, Borges et al. (2019) determined higher concentrations of phenolic compounds in samples of *Oenocarpus distichus* Mart. seed oils extracted by SC-CO₂, at 60° and 27 MPa. Different concentrations were reported in some types of seed oils (Barriga-Sánchez & Rosales-Hartshorn, 2022; Sodeifian, Saadati Ardestani, Ali Sajadian & Moghadamian, 2018). For his part, Cunha et al. (2019) did not observe significant changes in the phenolic composition of *Oenocarpus distichus* Mart. fruit before and after SC-CO₂ extraction treatment.

3.4. Fatty acids

The fatty acid composition of Sinami oils (Table 3) includes seven kinds of fatty acids. Results revealed that the oil was mainly characterized by unsaturated fatty acids (UFA ≈ 77%) in contrast to saturated fatty acids (SFA ≈ 22%), and the monounsaturated fatty acids (MUFA ≈ 61%, mainly oleic acid) were more predominant than polyunsaturated (PUFA ≈ 16%). As is indicated in several studies, oils with high concentrations of MUFAs, are considered with high quality and healthier, in terms of beneficial effects of PUFAs and MUFAs concentration, mainly

against cardiovascular diseases, controlling the blood cholesterol levels, mainly the low density lipoprotein (LDL), controlling the metabolic system (Innocenti, Franzoni & Pruneti, 2014; Ozen et al., 2023; Zhi-hao et al., 2022), also oleic acid is associated with the improvement of hepatic lipotoxicity injury (Liu et al., 2023). On the other hand, Wang, Zhao, Yang, and Zhang (2020) suggested that palm oils cannot induce an increase of cardiovascular diseases. The most abundant fatty acid in Sinami oil was oleic acid (C18:1) ranging from 57.48 to 61.12 g 100 g⁻¹, being approximately more than 50% of the total fatty acid composition. Followed by palmitic acid (C16:0) (16.45–21.03 g 100 g⁻¹) and linoleic acid (C18:2) (15.70–16.60 g 100 g⁻¹), as also was reported by Borges et al. (2019) and Cunha et al. (2019) in samples of *Oenocarpus distichus* Mart oil extracted by SC-CO₂. In addition, similar results were obtained by Pinto et al. (2018) who used SC-CO₂ for oil extraction of *Oenocarpus bacaba* being oleic > palmitic > linoleic acid the most abundant fatty acids. Turola Barbi et al. (2020) extracted, from palm oil (*Maximiliana maripa*), a high content of oleic acid (58.2 g 100 g⁻¹), followed by palmitic acid (21.8 g 100 g⁻¹). They observed the same content of linoleic and linolenic acid (5.6 g 100 g⁻¹) in samples obtained by SC-CO₂. Based on the extraction parameters of supercritical extraction, fatty acid values in palm oils varied according to the changes in pressure and temperature. This is also observed by Pinto et al. (2018) and Ramos-Escudero, Gómez-Coca, Muñoz, Fuente-Carmelino, and Pérez-Camino (2022). However, Borges et al. (2019) determined no significant changes in oleic acid content according to the variations of pressure and temperature by SC-CO₂. By conventional extraction, more than 70 g 100 g⁻¹ of oleic acid was determined by Rodrigues et al. (2010) in Patawa (*Oenocarpus bataua*) oils obtained. In contrast, Santos et al. (2013) obtained 46.2 g 100 g⁻¹ of oleic acid in Bacaba (*Oenocarpus bacaba*) oil.

3.5. Color index

The color index is an important parameter to evaluate the quality of

Table 3
Quality parameters, bioactive compounds, and color index values of Sinami oil samples.

Resource	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10
Quality parameters										
POV (meq O ₂ .kg ⁻¹)	2.43 ± 0.13	2.64 ± 0.46	3.92 ± 0.04	3.56 ± 0.58	2.24 ± 0.24	2.04 ± 0.22	1.76 ± 0.22	3.24 ± 0.03	3.60 ± 0.14	3.48 ± 0.21
FFA (g.100 g ⁻¹ oleic acid)	1.16 ± 0.04	1.15 ± 0.07	1.72 ± 0.00	1.82 ± 0.01	1.66 ± 0.00	1.86 ± 0.00	1.07 ± 0.04	1.74 ± 0.08	1.20 ± 0.05	1.00 ± 0.02
Diene K232 (g.100 mL ⁻¹ cm ⁻¹)	2.13 ± 0.00	2.07 ± 0.00	2.31 ± 0.01	1.84 ± 0.01	2.19 ± 0.00	2.01 ± 0.00	2.01 ± 0.02	2.01 ± 0.01	2.09 ± 0.00	2.28 ± 0.00
Triene K270 (g.100 mL ⁻¹ cm ⁻¹)	0.39 ± 0.00	0.31 ± 0.00	0.44 ± 0.01	0.26 ± 0.01	0.40 ± 0.00	0.30 ± 0.00	0.28 ± 0.02	0.28 ± 0.01	0.30 ± 0.00	0.31 ± 0.00
Phenolic compounds (mg.kg ⁻¹)										
Gallic acid	1.27 ± 0.03	1.85 ± 0.03	3.16 ± 0.01	0.41 ± 0.10	1.52 ± 0.14	0.78 ± 0.02	1.49 ± 0.05	0.73 ± 0.05	0.86 ± 0.05	1.36 ± 0.02
Chlorogenic acid	8.85 ± 0.56	4.44 ± 0.19	11.39 ± 0.15	2.26 ± 1.11	4.44 ± 0.04	2.73 ± 0.37	4.88 ± 0.07	1.83 ± 0.87	5.81 ± 0.22	7.11 ± 0.11
Vanillic acid	2.71 ± 0.02	1.82 ± 0.12	2.50 ± 0.06	0.28 ± 0.02	1.13 ± 0.02	0.45 ± 0.08	2.29 ± 0.03	0.79 ± 0.03	1.19 ± 0.11	2.62 ± 0.03
Caffeic acid	2.51 ± 0.06	1.97 ± 0.06	2.88 ± 0.10	1.21 ± 0.02	1.98 ± 0.04	1.59 ± 0.04	2.59 ± 0.01	1.10 ± 0.03	2.79 ± 0.04	1.97 ± 0.02
Syringic acid	3.10 ± 0.67	2.64 ± 0.39	4.13 ± 0.18	1.14 ± 0.16	2.43 ± 0.13	1.11 ± 0.00	2.99 ± 0.15	1.09 ± 0.23	2.40 ± 0.17	2.97 ± 0.11
Vanillin acid	129.7 ± 0.48	88.06 ± 0.31	164.2 ± 1.15	64.84 ± 0.12	74.34 ± 0.41	48.48 ± 0.15	78.48 ± 0.08	45.12 ± 0.41	97.89 ± 0.88	97.17 ± 0.96
Ferulic acid	15.67 ± 0.00	13.86 ± 0.05	19.80 ± 0.19	5.10 ± 0.11	11.31 ± 0.20	5.89 ± 0.05	16.93 ± 0.04	6.92 ± 0.00	16.29 ± 0.16	18.46 ± 0.55
Sinapic acid	1.13 ± 0.10	0.90 ± 0.07	0.82 ± 0.00	0.21 ± 0.05	0.87 ± 0.00	0.36 ± 0.02	1.16 ± 0.04	0.37 ± 0.01	0.21 ± 0.05	1.31 ± 0.05
Rutin	12.79 ± 0.18	8.20 ± 0.03	16.90 ± 0.16	4.50 ± 0.10	8.55 ± 0.23	5.23 ± 0.36	9.95 ± 0.11	3.99 ± 0.12	13.17 ± 0.18	10.14 ± 0.05
Fatty acids (g.100 g ⁻¹)										
Palmitic acid	20.64 ± 0.00	20.64 ± 0.03	20.80 ± 0.01	16.45 ± 6.09	20.91 ± 0.02	21.03 ± 0.03	20.73 ± 0.02	20.44 ± 0.02	20.51 ± 0.02	20.26 ± 0.01
Palmitoleic acid	1.01 ± 0.00	0.98 ± 0.00	1.03 ± 0.00	1.01 ± 0.07	1.00 ± 0.01	1.02 ± 0.00	0.97 ± 0.00	0.93 ± 0.00	0.94 ± 0.01	0.93 ± 0.00
Stearic acid	2.04 ± 0.01	2.09 ± 0.00	1.99 ± 0.01	2.23 ± 0.16	2.01 ± 0.00	1.98 ± 0.01	2.06 ± 0.01	2.18 ± 0.01	2.13 ± 0.01	2.19 ± 0.01
Oleic acid	57.74 ± 0.04	57.89 ± 0.02	57.76 ± 0.01	61.12 ± 4.45	57.48 ± 0.03	57.55 ± 0.02	57.95 ± 0.01	58.29 ± 0.02	58.24 ± 0.04	58.24 ± 0.00
Isomer oleic acid	1.86 ± 0.01	1.86 ± 0.01	1.82 ± 0.01	1.98 ± 0.14	1.85 ± 0.01	1.84 ± 0.00	1.85 ± 0.00	1.90 ± 0.00	1.89 ± 0.00	1.90 ± 0.00
Linoleic acid	16.13 ± 0.04	15.98 ± 0.01	16.02 ± 0.00	16.60 ± 1.23	16.13 ± 0.00	16.00 ± 0.01	15.87 ± 0.01	15.70 ± 0.01	15.77 ± 0.01	15.89 ± 0.01
α-linolenic acid	0.58 ± 0.01	0.55 ± 0.01	0.57 ± 0.01	0.61 ± 0.05	0.61 ± 0.01	0.58 ± 0.01	0.56 ± 0.01	0.57 ± 0.00	0.52 ± 0.06	0.58 ± 0.01
Color index										
L*	54.81 ± 0.60	59.38 ± 0.74	57.26 ± 0.58	60.25 ± 0.45	60.14 ± 0.37	56.96 ± 0.76	62.10 ± 0.28	61.77 ± 0.47	63.95 ± 0.35	63.54 ± 0.20
a*	-13.14 ± 0.18	-15.16 ± 0.53	-15.29 ± 0.26	-15.37 ± 0.24	-15.96 ± 0.09	-12.99 ± 0.47	-17.53 ± 0.17	-16.14 ± 0.33	-18.59 ± 0.37	-17.76 ± 0.51
b*	58.95 ± 0.30	62.66 ± 0.65	60.38 ± 0.78	63.34 ± 0.40	63.30 ± 0.32	60.78 ± 0.63	64.85 ± 0.20	64.58 ± 0.37	60.57 ± 0.44	63.76 ± 0.20
Chroma (C* _{ab})	60.40 ± 0.27	64.48 ± 0.63	62.29 ± 0.79	65.19 ± 0.35	65.28 ± 0.32	62.15 ± 0.68	67.18 ± 0.23	66.57 ± 0.38	63.36 ± 0.43	66.19 ± 0.23
Hue angle (h _{ab})	77.45 ± 0.21	76.40 ± 0.50	75.80 ± 0.22	76.36 ± 0.27	75.85 ± 0.08	77.94 ± 0.36	74.87 ± 0.12	75.97 ± 0.28	72.94 ± 0.34	74.44 ± 0.43
Color										

Values are expressed in raw weight (RW). Each value is the mean ± the standard deviation (SD) of triplicate determinations (n = 3). S: sample, POV: Peroxide value index, FFA: free fatty acids (oleic acid %). Extraction parameters can be observed in [Table 1](#).

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