The addition of essential oils increases the oxidative stability of sacha inchi (*Plukenetia volubilis*) oil

La adición de aceites esenciales incrementa la estabilidad oxidativa del aceite de sacha inchi (*Plukenetia volubilis*)

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ABSTRACT

Essential oils are known for their antioxidant properties, which make them a natural alternative for preventing oxidative rancidity in fixed oils. The aim of this research was to analyze the effects of adding essential oils of *Mespilodaphne quixos* or *Citrus limon* on the shelf life of sacha inchi (*Plukenetia volubilis*) oil. We determined oxidative stability using the Rancimat method at 80 and 100°C. We extrapolated the results to 30°C to estimate the oil shelf life under real storage conditions. Analysis of variance was used to evaluate the effects of oil type and dose (200-800 mg kg^{-1}) on shelf life. The optimal conditions were identified using an optimal design. The oil of sacha inchi is rich in unsaturated fatty acids, mainly cis-13,16-docosadienoic acid (47.16%) and linolenic acid (35.13%), which may undergo reactions that alter the degrees of unsaturation and alter the properties of the oil. The addition of *M. quixos* and *C. limon* essential oils significantly increased the oxidative stability of sacha inchi oil. We obtained the best results with the 800 mg kg^{-1} dose. The *M. quixos* oil performed better than the *C. limon* oil, increasing the shelf life of sacha inchi oil by 2.29 years and 2.07 years, respectively, compared to the control.

Keywords: Amazonian cinnamon oil, lemon oil, oxidative stability, Rancimat, shelf life.

RESUMEN

Los aceites esenciales son reconocidos por sus propiedades antioxidantes, lo que los convierte en una alternativa natural para prevenir la rancidez oxidativa en aceites fijos. El objetivo de esta investigación fue analizar los efectos que tiene la adición de aceites esenciales de *Mespilodaphne quixos* o *Citrus limon* sobre la vida útil del aceite de sacha inchi (*Plukenetia volubilis*). La estabilidad oxidativa se determinó mediante el método Rancimat a 80 y 100°C, y los resultados se extrapolaron a 30°C para estimar la vida útil en condiciones reales de almacenamiento. Se aplicó un análisis de varianza para evaluar el efecto del tipo de aceite y la dosis (200-800 mg kg^{-1}) sobre la vida útil. Las condiciones óptimas se identificaron usando un diseño optimo. El aceite de sacha inchi es rico en ácidos grasos insaturados, principalmente ácido cis-13,16-docosadienoico (47,16%) y ácido linolénico (35,13%), que pueden sufrir reacciones que provoquen cambios en los grados de insaturación y alteren las propiedades del aceite. Con la adición de aceites esenciales de *M. quixos* y *C. limon*, se observó un aumento significativo de la estabilidad oxidativa del aceite evaluado. Los mejores resultados se obtuvieron con la dosis de 800 mg kg^{-1}. El aceite de *M. quixos* se comportó mejor que el de *C. limon*, aumentando la vida útil del aceite de sacha inchi en 2,29 años y 2,07 años respectivamente en comparación con el control.

Palabras clave: aceite de canela amazónica, aceite de limón, estabilidad oxidativa, Rancimat, vida útil.

Introduction

Plukenetia volubilis, known as sacha inchi (SI), is a plant species broadly distributed in the Peruvian Amazon whose potential has been seldom explored (Adal & Eren, 2019). It is particularly of interest given that consumer demand for natural cosmetics (free of traditional synthetic chemicals) has increased in recent years. For example, in 2024, the global eco-cosmetics market was valued at $46.8 billion USD, with projections to reach $54.5 billion USD by 2027 (Trif, 2024). Additionally, 70% of consumers prefer natural cosmetic products, 47% are willing to pay more for them, and 29% would pay extra for eco-friendly packaging (Amberg & Fogarassy, 2019).

SI seed oil is rich in essential fatty acids (78.2-84.5% polyunsaturated and 6.7-7.7% monounsaturated) (Lourith *et al*., 2023). This oil is also a natural source of sterols and

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tocopherols, which are known to have protective effects against diseases such as diabetes and heart disease.

More than 48% of the SI oil's content is α-linolenic acid (Romero-Hidalgo *et al*., 2019). Indeed, the oxidative rancidity of SI oil can be ascribed to long-chain polyunsaturated fatty acids (PUFAs) such as α-linolenic and linoleic acids. Hence, this oil is liable to undergo structural modifications due to the influence of air, heat, and moisture (Adal & Eren, 2019). Rancidity caused by the oxidative degradation of fatty acids during storage generally produces low-quality fats. As a result, the oil's shelf life is reduced due to changes in its organoleptic properties, which release unpleasant odors and flavors from volatile substances (ketones, aldehydes, and hydrocarbons) (Adal & Eren, 2019).

The presence of undesirable compounds reduces nutritional value, making it necessary to apply new industrial technologies. Susceptibility to oxidation is assessed using accelerated techniques, such as the Rancimat method, to determine oxidative stability. This method accelerates the oxidation of the oil sample by continuously measuring water conductivity to record the induction time at which volatile acids form and establish the sample's resistance to oxidation (Esmaeili *et al*., 2018). Di Rauso-Simeone *et al*. (2020) report that the oxidative degradation of fatty acids is a problem in the industrialization of vegetable oils, attributed to the presence of PUFAs in their composition, which influences shelf life and product quality. Some methods of preserving vegetable oil may involve the addition of synthetic antioxidants, such as butylated hydroxyanisole (BHA), butylated hydroxytoluene (BHT), and tert-butylhydroquinone (TBHQ), which have been shown to have carcinogenic effects.

On the other hand, natural antioxidants such as essential oils (EOs) extracted from plants can be a good alternative due to their phenolic compounds, which neutralize free radicals by inhibiting (Baj *et al*., 2023). Given the promising antioxidant potential of EOs, their application in lipid-rich matrices is of scientific and industrial interest. Pino *et al*. (2018) find that EOs extracted from the plants of Amazonian cinnamon (*Mespilodaphne quixos* (Lam.) Rohwer) have a high antioxidant capacity. They studied how this capacity was influenced by the plant's place of origin, the time of harvesting, storage conditions, and the extraction technology used. This EO has antifungal, anti-inflammatory, and antimicrobial properties, which support its use for treating skin infections (Sosa *et al*., 2023) and as a natural preservative in foods, where it helps prevent the growth of microorganisms and delays oxidation (Bermúdez del Sol *et al*., 2024; Falleh *et al*., 2020).

Conversely, Wang *et al*. (2020) report the highest phenolic content in the peels and seeds of lemon (*Citrus limon* L.). They find that they had high antioxidant activity. The EO from its leaves is rich in limonene and phenolic compounds, which provide a remarkable antioxidant capacity and antimicrobial activity against pathogens such as *Staphylococcus aureus* and *Salmonella enterica* (Kačániová *et al*., 2024; Valarezo *et al*., 2025; Yeasmin *et al*., 2024). These properties enable this oil to act as a natural preservative in foods, inhibiting oxidation and microbial growth (Yeasmin *et al*., 2024). In this way, it extends product shelf life without altering their organoleptic characteristics (Kačániová *et al*., 2024).

Oils with a higher content of unsaturated fatty acids tend to have a higher level of oxidation that affects their quality (Rezvankhah *et al.,* 2020). The oxidation pathway of oils involves the structural modification of carbon-carbon bonds driven by oxygen-mediated autocatalysis, leading to the formation of oxygenated compounds (Pisoschi *et al*., 2021). These compounds exhibit organoleptic changes that lead to rancidity, so the current search for natural antioxidants is an interesting alternative that can help preserve chemical properties for longer.

Currently, we have found no published reports on the application of essential oils, such as those of *M. quixos* and *C. limon,* to improve the oxidative stability of fixed oils such as SI oil. In view of the benefits of SI oil and the high antioxidant capacity of essential oils, a new alternative emerges to counteract the oxidative deterioration of fatty acids due to environmental factors. Consequently, the aim of this study was to evaluate the effect of adding the essential oils of *M. quixos* and *C. limon* on the shelf life of *P. volubilis* oil by evaluating the oxidative stability index (OSI).

Materials and methods

Samples

The sacha inchi (SI) seeds were acquired in San Miguel de los Bancos, located on Calacalí Road, 104 km from Quito, Ecuador. The oil was then extracted by cold pressing using a Cgoldenwall screw press with a 1500 W motor, maintaining a constant temperature of 40°C. The EOs of *C. limon* and *M. quixos* leaves were obtained using the steam distillation technique in an oil distiller (Figmay, Buenos Aires, Argentina). The leaves of *C. limon* and *M. quixos* were collected from the trees grown on the campus of Universidad Estatal Amazónica (Puyo, Ecuador). The collection was carried out during the early morning hours (between 8:00 and 10:00 am), selecting mature and visibly healthy leaves from plants approximately 3 years old. The EOs were stored in dark containers and refrigerated at 4 ± 0.5°C until further analysis.

Sample preparation

Two hundred fifty µl of *C. limon* and *M. quixos* oil was added to a 5 ml flask and diluted to volume with HPLC-grade hexane. The samples were filtered before analysis using a 13 mm/25 mm Millipore hydrophilic needle microfilter (PTFE, Luer) with a 0.22/0.45/1.2 µm membrane.

Esterification of the SI oil was performed according to the AOCS (2022). Five tenths ml of 2 M KOH in methanol (KOH/MeOH) and 4 ml of HPLC-grade n-hexane were added to 200 mg of oil, and the mixture was vortexed for 30 s. Subsequently, the samples were centrifuged at 4000 rpm for 5 min at 30°C. The upper n-hexane layer was collected and filtered for further analysis.

GC-MS analysis

The samples were analyzed using QP2020 NX gas chromatography-mass spectrometry (GC-MS) equipment (Shimadzu, Japan). Chromatographic conditions for oil analysis were set using a Thermo Fisher Scientific TG-1MS column (USA) with the following specifications: thickness 0.5 µm, inner diameter 0.32 mm, length 30 m, injection volume 1 µl, injector temperature 250°C, split ratio of 25:1 and oven temperature program starting at 50°C for 4 min with an increase of 10°C min^{-1} up to 220°C and held for 2 min. Helium was used as the carrier gas at a constant flow of 1 ml min^{-1}. The mass spectra of the samples were corroborated using the Wiley Online Library, which was installed in the equipment software.

Estimation of shelf life using the oxidative stability index (OSI)

The Rancimat method (Metrohm model 892, Herisau, Switzerland) was used in accordance with AOCS international standards. A filtered, dry airflow of 15 L h^{-1} was set up and passed through a 5±0.2 g sample of oil contained in a reaction tube. This tube was then placed in a heating block at temperatures of 80 and 100°C. The volatile organic acids in the effluent air were collected in a polycarbonate container containing 60 ml of distilled water, whilst the water's conductivity (µS cm^{-1}) was continuously recorded. The oxidative stability index (OSI) was determined in h and the shelf life was estimated by means of the extrapolation method at a storage temperature of 30°C, establishing a mathematical correlation between the OSI and the temperatures (80 and 100°C) used in the Rancimat method according to Equation 1, which is derived from the Arrhenius model and has been widely used in studies of vegetable oils using the Rancimat technique (Aktar & Adal, 2019; Chabni *et al*., 2024):

$$Log(OSI) = B + AT \quad (1)$$

where

OSI is expressed in h; *A* indicates the temperature coefficient (°C^{-1}), which reflects the sensitivity of the oil to the increase in temperature during the accelerated oxidation test and is calculated as the slope of the straight lines obtained by plotting the logarithm of OSI according to temperature; B represents an empirical dimensionless value with no physical relevance; and T indicates the temperature (°C) needed to calculate the OSI.

Statistical analysis

An optimal design was employed using Design Expert software version 10 (Trial version, Stat-Ease Inc., Minneapolis, MN, USA). All assays were performed in triplicate, and results were expressed as mean ± standard deviation. For each experiment, the EO was incorporated into the SI oil, followed by homogenization with a vortex mixer for 2 min at 2000 rpm to ensure complete mixing. For all oxidative stability experiments, a control treatment with pure SI oil, without any added essential oils, was included. This control served as the baseline for comparing the effects of adding *C. limon* or *M. quixos* essential oils on the oil's shelf life. First, 5±0.2 g of sample were placed in each reaction tube according to the proposed design (Tab. 1). The effect that the dosage of the essential oil of each species had on the shelf life of the SI oil was evaluated using an analysis of variance (ANOVA). Optimal conditions for extending shelf life were determined using response surface methodology. The experimental data were fitted using the following polynomial equation:

$$y = \beta_0 + \sum_{i=1}^{n} \beta_{ii} x_i + \sum_{i=1}^{n} \beta_{ii} {x_i}^2 + \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \beta_{ij} xixj \quad (2)$$

TABLE 1. Optimal experimental design.

Factor	Type	Subtype	Minimum (-1)	Maximum (+1)
Dose (mg kg^{-1})	Numeric	Continuous	200	800
Essential oil	Categoric	Nominal	*C. limon*	*M. quixos*

* The dose was expressed in mg of essential oil per kg of sacha inchi oil.

Results

GC-MS characterization of the essential oils of sacha inchi, *Citrus limon*, and *Mespilodaphne quixos*

The major fatty acids in SI oil were found to be cis-13,16-docosadienoic acid and linolenic acid, representing 47.16% and 35.13%, respectively (Fig. 1). As for the *C. limon* EO, 22.88% of its composition corresponded to D-limonene, followed by α-phellandrene (16.12%) and citronellal (11.77%). These three components accounted for 50.77% of the total volatile oils in *C. limon* oil (Fig. 2). In *M. quixos* oil, 43.33% of the total mixture was made up of cinnamaldehyde and caryophyllene, with values of 32.73% and 10.6%, respectively (Fig. 3).

Effect of the dosage of the essential oils on the shelf life of sacha inchi oil

C. limon and *M. quixos* oils had a significant effect on the shelf life of SI oil. These results are indicated by the ANOVA presented in Table 2. The model found that the relationship between oil type and dosage on the oxidative stability of fixed oil was significant ($P \leq 0.05$). The third-order polynomial model showed the best results for the oxidative stability of SI oil, with an R^2 coefficient of determination of 0.9999, suggesting good model validity. The predicted R^2 of 0.9985 agreed reasonably well with the adjusted R^2, differing by less than 0.2, indicating that the selected model was adequate. All essential oil doses showed superior results compared to the control, with *M. quixos* EO producing the greatest effect.

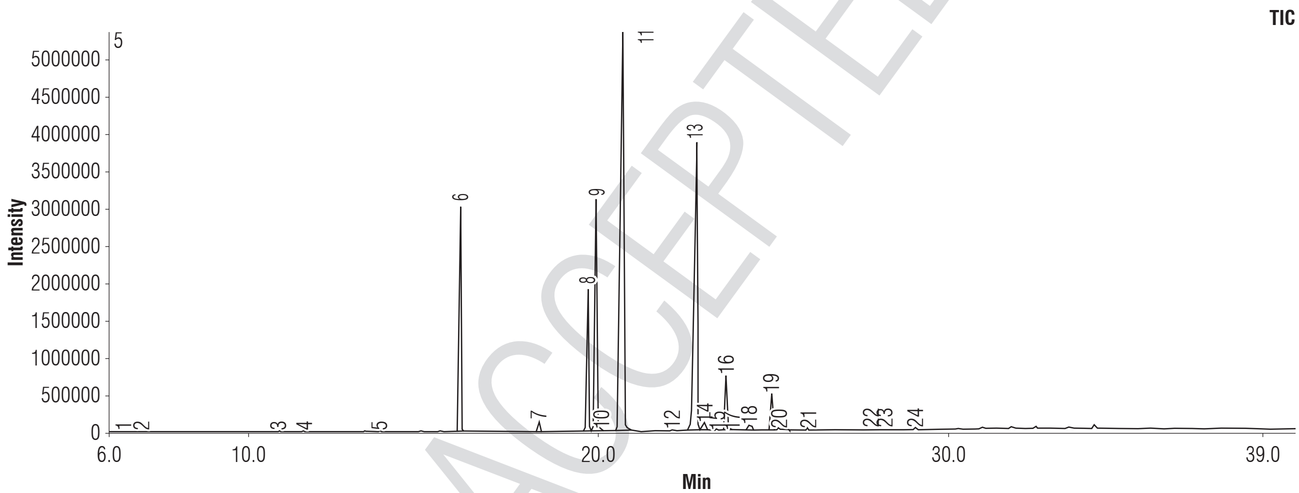

FIGURE 1. GC-MS chromatogram of sacha inchi seed oil. Major compounds: 11: cis-13,16-docosadienoic acid (47.16%); 13: linolenic acid (35.13%); and 9: hexadecanoic acid methyl ester (7.65%).

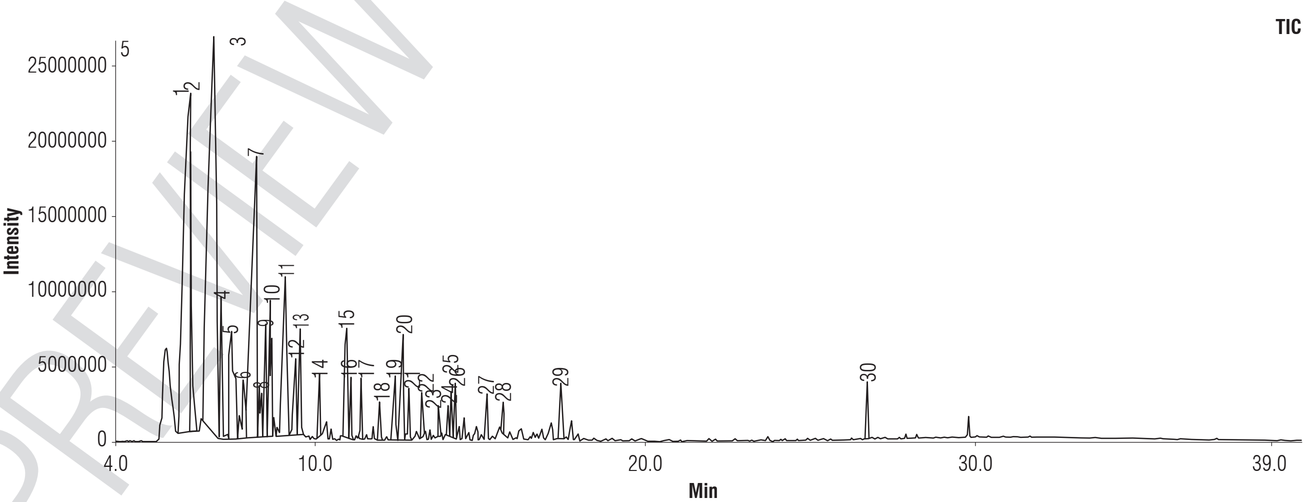

FIGURE 2. GC-MS chromatogram of *Citrus limon* leaf oil. Major compounds: 3: D-limonene (22.88%); 2: α-phellandrene (16.12%); and 1: citronellal (11.77%).

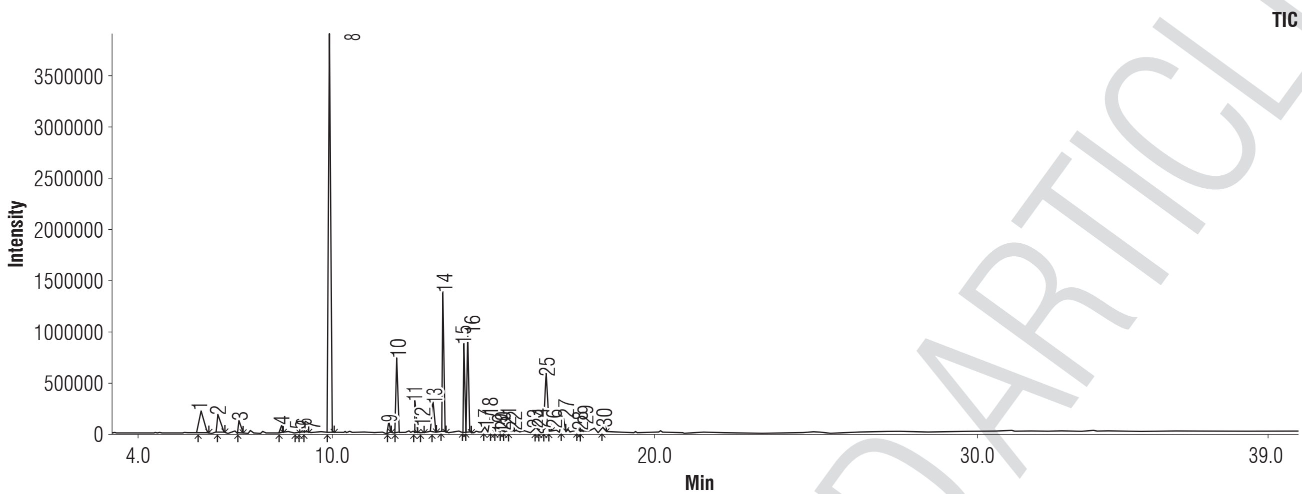

FIGURE 3. GC-MS chromatogram of *Mespilodaphne quixos* leaf oil. Major compounds: 8: cinnamaldehyde (32.73%); 14: caryophyllene (10.6%); and 16: isoeugenol (7.63%).

TABLE 2. Analysis of variance for the selected factorial model.

Source	Sum of squares	df	Mean square	F-value	*P-value*	
Model	7.33	6	1.22	15648.09	< 0.0001	significant
Dose (A)	0.4647	1	0.4647	5948.52	< 0.0001	
EO (B)	0.1164	1	0.1164	1490.38	< 0.0001	
AB	0.0014	1	0.0014	17.62	0.0085	
A^2	0.3132	1	0.3132	4009.78	< 0.0001	
A^2B	0.0076	1	0.0076	96.96	0.0002	
A^3	0.0020	1	0.0020	25.02	0.0041	
Residual	0.0004	5	0.0001			
Lack of fit	0.0002	2	0.0001	2.41	0.2380	not significant
Pure error	0.0001	3	0.0000			
Cor. total	7.33	11				
R^2	0.9999					
R^2 adjusted	0.9999					
R^2 predicted	0.9985					

*df: degrees of freedom.

Meanwhile, the F-value for lack of fit (2.41) suggested that the lack of fit was not significant compared to the pure error. A non-significant lack of fit was observed, indicating that the model can accurately represent the experimental data.

The predictive equations in terms of real factors for the EO of *C. limon* and *M. quixos* were as follows:

$$\text{Shelf life } (\textit{C. limon}) = -0.074895 + 0.004997D + 8.21011*10^{-7}D^2 - 2.87941*10^{-9}D^3 \quad (3)$$

$$\text{Shelf life } (\textit{M. quixos}) = -0.153972 + 0.006394D - 4.67215*10^{-7}D^2 - 2.87941*10^{-9}D^3 \quad (4)$$

where D represented the dosage of essential oil.

The experimental results and those predicted by the third-order polynomials were calculated and shown in Table 3 and Figure 4A. The results showed that the predictive models adequately captured the entire range of experimental results, suggesting that they could be successfully applied. As shown in Figure 1B, the experimental data met the assumption of normal distribution.

The optimal levels recommended by the model (Fig. 4C-D) to maximize the shelf life of the SI oil were 800 mg kg^{-1} of *M. quixos* EO, achieving a shelf life of 3.18 years, which was 2.29 years longer than the control. Likewise, the best shelf life was achieved with a *C. limon* EO concentration of 800 mg kg^{-1} with a shelf life of 2.97 years, which exceeded the control by 2.07 years.

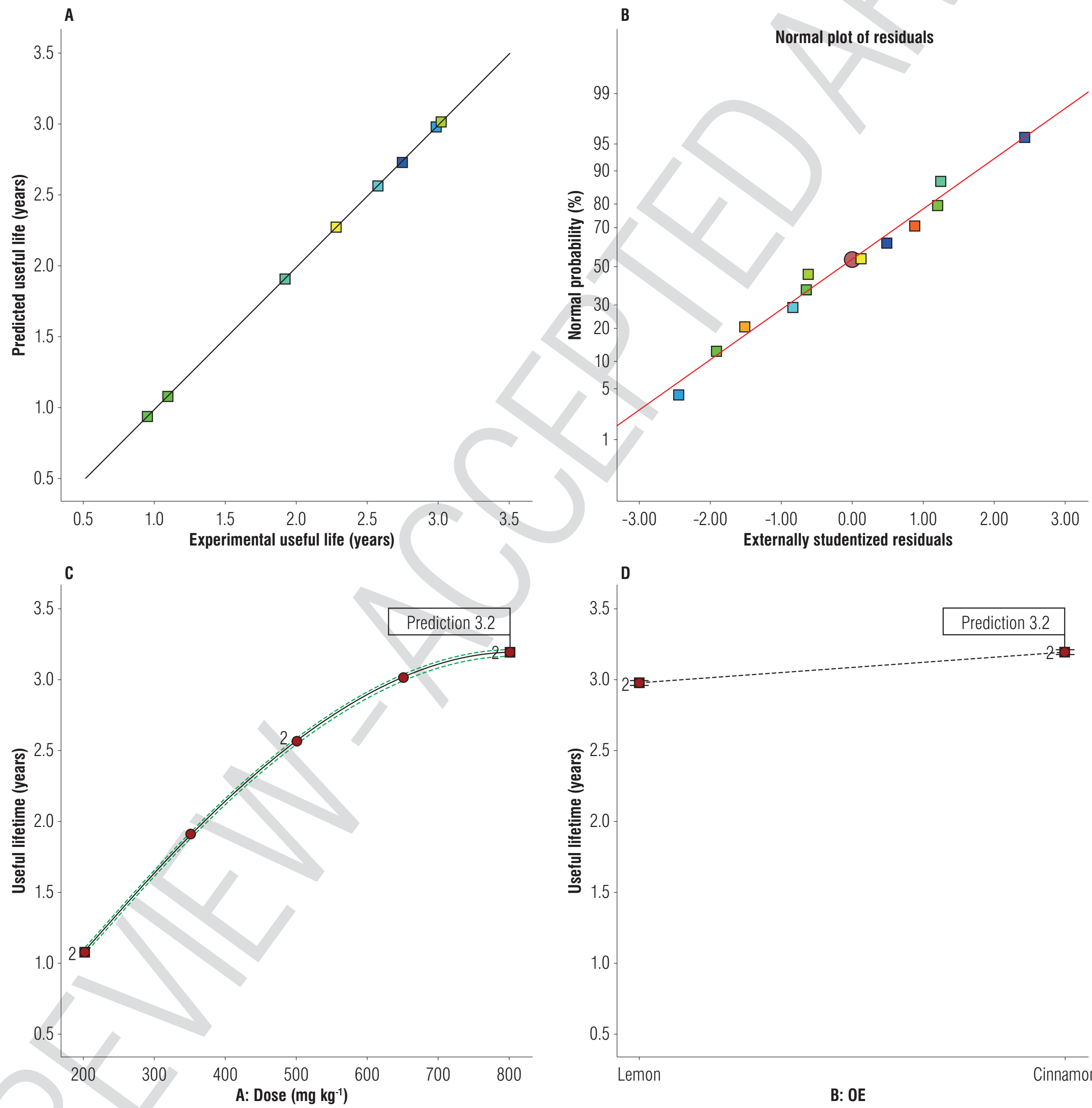

FIGURE 4. A) Experimental and predicted shelf life of the sacha inchi oil, B) normal distribution of results, C and D) optimum values recommended by the polynomial model. EO – essential oil, Lemon – *Citrus limon* L., Cinnamon – Amazonian cinnamon *Mespilodaphne quixos* (Lam.) Rohwer.

TABLE 3. Shelf life of the sacha inchi oil with addition of *M. quixos* or *C. limon* essential oils.

Run	Dose (mg kg^{-1})	Essential oil	Shelf life (Experimental) (years)	Shelf life (Predicted) (years)
1	500	*M. quixos*	2.57 ± 0.02	2.57
2	650	*C. limon*	2.74 ± 0,01	2.73
3	800	*C. limon*	2.97 ± 0,04	2.97
4	500	*M. quixos*	2.56 ± 0.02	2.57
5	350	*M. quixos*	1.91 ± 0.05	1.90
6	200	*C. limon*	0.93 ± 0,07	0.93
7	200	*M. quixos*	1.08 ± 0.06	1.08
8	800	*M. quixos*	3.18 ± 0.02	3.19
9	650	*M. quixos*	3.01 ± 0.04	3.01
10	500	*C. limon*	2.27 ± 0.06	2.27
11	500	*C. limon*	2.26 ± 0.06	2.27
12	200	*C. limon*	0.94 ± 0.07	0.93
Control	0	-	0.90	-

* Shelf life was expressed as mean values ± standard deviation for three measurements.

Discussion

The use of EOs in the oxidative stability of fixed oils has been demonstrated in previous studies. Adal and Eren (2019) use the Rancimat method, based on OSI values, to study the effect of the addition of *Salvia rosmarinus* and *Origanum vulgare* EOs on the shelf-life extension of pistachio oil. They evaluate concentrations of 150, 300, and 600 ppm for each EO, and the results indicate that EO improves pistachio oil by preventing lipid oxidation. Both *S. rosmarinus* and *O. vulgare* EOs at 600 ppm extract exert more antioxidant activity than 150 ppm of a synthetic antioxidant, butylated hydroxytoluene. In a similar vein, Esmaeili *et al*. (2018) report the effect of adding *S. rosmarinus* and *Mentha piperita* EO on the oxidative stability of pistachio oil. Doses of 1,500 or 3,000 ppm were added to the fixed oil, which is then incubated for 80 d in the dark at 60°C. The authors conclude that the EO of *S. rosmarinus* is more efficient than that of *M. piperita*. Both EOs (3,000 ppm) show greater antioxidant effects in inhibiting lipid oxidation than 100 ppm of butylated hydroxytoluene (BHT).

The EOs of *M. quixos* and *C. limon* increased the shelf life of SI oil by 2.29 and 2.07 years, respectively. This increase was greater than that reported for other oils treated with different additives. For example, the addition of BHT and lycopene extract increases the shelf life of linseed oil by 0.08 and 0.10 years, respectively (Condori *et al*., 2019). The shelf life of refined olive oil increases by 0.81 years with the addition of BHT (Morsy *et al*., 2022). The longer shelf life reported in our study may be attributed to the presence of natural antioxidant compounds in the EOs, such as terpenes and phenols, which neutralize free radicals and inhibit lipid peroxidation of SI oil during accelerated oxidation in the Rancimat assay.

The antioxidant potential of *C. limon* EO has already been evaluated. For example, Di Rauso Simeone *et al*. (2020) publish Trolox equivalent antioxidant capacity data of *C. limon* cultivars. The radical scavenging activity of the EOs of four citrus species is also determined using DPPH (2,2-diphenyl-1-picrylhydrazyl), ABTS (Ferric Reducing Antioxidant Power), and FRAP (1,1-difenil-2-picrilhidrazilo; acid 2,2'-azino-bis(3-etilbenzotiazolina-6-sulfónico). The antioxidant and ion protective effects of *C. limon* EO in nanoemulsions have also been reported in the literature (Liu *et al*., 2022). Similarly, this EO improves the antioxidative quality of Prima Sole cheese (Busetta *et al*., 2022). Likewise, Moosavy *et al*. (2017) record the antioxidant and antibacterial activities of this EO on barley soup using the FRAP method.

The antioxidant activity of *C. limon* EO could be related to the presence of its main components, including limonene, α-phellandrene, and citronellal. The FRAP, ABTS, and DPPH methods also indicate that limonene strongly inhibits free radicals, with limonene highly inhibiting them (Shah & Mehta, 2018). One study reported that limonene could scavenge up to 93.1% of DPPH free radicals (Yang *et al*., 2012). In contrast, Wang *et al*. (2020) find that the incorporation of 17.4 mg kg^{-1} limonene inhibits the oxidation of sunflower oil during the cooking process at high temperatures. The other main component of *C. limon* EO was α-phellandrene, whose antioxidant activity has also been demonstrated using diverse methods, such as ABTS, ORAC, and FRAP (Scherer *et al*., 2019).

The third main constituent of *C. limon* EO was identified as citronellal. Baj *et al*. (2023) test its antioxidant activities using several methods (DPPH, H_2O_2 scavenging, FRAP, and ferrous ion chelating activity).

Mespilodaphne quixos EO has been hailed for its spectrum of stimulant, antiseptic, and antioxidant properties. In particular, its antioxidant capacity has been shown by Pino *et al*. (2018) and Ortiz-Calderón *et al*. (2018). These articles supported the antioxidant efficacy of *M. quixos* EO using various tests, *e.g*., ABTS, FRAP, DPPH, and ORAC. Its antioxidant properties are due to the two main compounds of EO: cinnamaldehyde and caryophyllene. The antioxidant properties of cinnamaldehyde have already been reported using NO radical scavenging, ABTS, and FRAP by Suryanti *et al*. (2018) and Ormachea-Ferretti (2022). López-Mata *et al*. (2018) observe that the antioxidant activity of chitosan films increases with the addition of 1% cinnamaldehyde. Oral cinnamaldehyde is also time-dependent in its influence on serum antioxidants in rat kidneys due to an increased level of antioxidants: superoxide dismutase, glutathione peroxidase, and glutathione-S-transferase in response to the delayed carcinogenesis (Gowder & Devaraj, 2006). Molania *et al*. (2012) demonstrate that introducing cinnamaldehyde to gamma-irradiated rats enhances salivary antioxidant activity. Naveena *et al*. (2014) observe that the incorporation of cinnamaldehyde enhances the antioxidant activity of ground chicken meat. Calleja *et al*. (2013) report that the antioxidant properties of cinnamaldehyde reduces oxidative stress in arthritic rats.

The free radical scavenging activity of β-caryophyllene was demonstrated in the study conducted by Neta *et al*. (2017) using DPPH and FRAP assays. Furthermore, Flores-Soto *et al*. (2021) report that this compound exerts protective antioxidant effects by activating quinone oxidoreductase (NQO1) in a 1-methyl-4-phenyl-1,2,3,6-tetrahydropyridine (MPTP) model of Parkinson's disease.

Various scientists describe the chemical constituents of *C. limon* and *M. quixos* EOs, as well as the fat profile of SI. Liu *et al*. (2022) report that limonene (48.54%) and α-pinene (30.9%) are the predominant constituents in *C. limon* EO. Citral (3.65%) is the next most abundant compound. On the other hand, Odjo *et al*. (2022) find that geranial (29.30%), limonene (21.29%), and neral (8.68%) are its main constituents, while Hung *et al*. (2023) observe that limonene (45.55%) is the principal component, followed by γ-terpinene (16.87%) and geranial (7.32%). In the EO of *M. quixos*, Arteaga-Crespo *et al*. (2021) detect cinnamyl acetate (36.44%) as the main component, followed by cinnamaldehyde (27.03%) and methyl isoeugenol (4.18%). Similarly, Bruni *et al*. (2004) discover that cinnamaldehyde (27.91%) and methyl ester (21.65%) are the most important components.

Our results partially agreed with previous studies regarding the fatty acid profile of SI oil. Lourith *et al*. (2023) observe that α-linolenic (51.72%) and linoleic (24.3%) are the most dominant fatty acids. Meanwhile, α-3 linolenic acid (38.84%) and α-6 linoleic acid (34.67%) proved to be the most predominant fatty acids for Romero-Hidalgo *et al*. (2019). Linoleic acid and cis-13,16-docosadienoic acid from our study are from the omega-3 series, whereas linoleic acid is from the omega-6 series.

Variability in the amounts of the main compounds of *C. limon*, *M. quixos,* and SI oils could be attributed to several factors, including extraction method, plant age, climate, and soil.

Conclusions

Both *M. quixos* and *C. limon* essential oils significantly affected the oxidative stability of the sacha inchi oil. *Mespilodaphne quixos* oil showed better results than *C. limon* oil. The dose with the most noticeable effect was 800 mg kg^{-1} for both oils, increasing the shelf life by 2.29 years and 2.07 years, respectively, compared to the control. The oxidative protection properties were attributed to cinnamaldehyde and caryophyllene, the main constituents of *M. quixos* oil, and to the limonene, phellandrene, and citronellal present in *C. limon* oil. Our study demonstrated the potential of Amazonian essential oils as natural antioxidants to extend the shelf life of high-nutritional-value oils such as sacha inchi oil. Given that a significant portion of the seed remained after oil extraction, future research could explore its use as a functional ingredient in animal feed, as a source of dietary fiber, or as a substrate in biotechnological processes, thereby providing added value to the entire production chain.

Conflict of interest statement

The authors declare that there is no conflict of interest regarding the publication of this article.

Author's contributions

SBLF designed the research, conducted the experiments, analyzed and interpreted the results, and wrote the manuscript; YAC designed the research, conducted the experiments, analyzed and interpreted the results, and wrote the manuscript; YGQ designed the research, analyzed and interpreted the results, and wrote the manuscript; DMGM analyzed and interpreted the results, wrote and corrected the manuscript. All authors have read and approved the final version of the manuscript.

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