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Comparative chemical composition and antioxidant capacity of essential oil and oleoresin from *Eucalyptus globulus* Labill. leaves

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SUMMARY: The *Eucalyptus globulus* is a tree which is cultivated in Peru for its wood, while its leaves are often discarded. This study compared the extraction yield, chemical composition, and antioxidant capacity of essential oil and oleoresin obtained from the leaves. The essential oil was extracted by hydrodistillation (1.62 % yield), and oleoresins were obtained using supercritical CO_2, with and without ethanol as a co-solvent (yield up to 8.96 %). GC-MS analysis identified 1,8-cineole as the major compound in the essential oil and in the oleoresin extracted with supercritical CO_2+ethanol. The essential oil showed a higher monoterpene content (80.33 %), while the oleoresins were richer in sesquiterpenes (up to 63.68 %). The total phenolic content was significantly higher in the oleoresin (5.05-11.30 mg GAE/g) than in the essential oil (0.25 mg GAE/g). Antioxidant capacity was also significantly higher in the oleoresins. These findings highlight the potential of *E. globulus* oleoresin as a natural antioxidant for food and pharmaceutical applications.

KEY-WORDS: *Antioxidant capacity; Eucalyptus; Hydrodistillation; Supercritical CO_2; Terpenes.*

RESUMEN: ***Composición química comparativa y capacidad antioxidante del aceite esencial y oleorresina de hojas de* Eucalyptus globulus *Labill.*** *Eucalyptus globulus* es un árbol cultivado en Perú por su madera, y sus hojas suelen ser descartadas. Este estudio comparó el rendimiento de extracción, la composición química y capacidad antioxidante del aceite esencial y la oleorresina obtenidos de las hojas. El aceite esencial se extrajo por hidrodestilación (1.62 %), y las oleorresinas mediante CO_2 supercrítico, con y sin etanol (hasta 8.96 %). El análisis por GC-MS identificó al 1,8-cineol como compuesto principal en el aceite esencial y en la oleorresina extraída con CO_2+etanol. El aceite esencial mostró mayor contenido de monoterpenos (80.33 %) y las oleorresinas, mayor contenido de sesquiterpenos (hasta 63.68 %). Los compuestos fenólicos totales fueron mayores en las oleorresinas (5.05–11.30 mg EAG/g) que en el aceite esencial (0.25 mg EAG/g). La capacidad antioxidante también fue significativamente superior en las oleorresinas. Estos resultados destacan el potencial de la oleorresina de *E. globulus* como antioxidante natural para aplicaciones alimentarias y farmacéuticas.

PALABRAS CLAVE: *Capacidad antioxidante; CO_2 supercrítico; Eucalipto; Hidrodestilación; Terpenos.*

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1. INTRODUCTION

The *Eucalyptus* spp. is a tall, evergreen tree which is native to Australia and Tasmania which has around 900 species and subspecies which are cultivated in subtropical and warm temperate regions such as Bolivia, Brazil, Chile, China, India, Paraguay, Portugal, Spain and Uruguay (Surbhi *et al*., 2023). In Peru, *Eucalyptus globulus* Labill. is distributed in the regions of Puno, Apurímac, Ayacucho, Cusco and Huancavelica (Laura-Ticona *et al*., 2024).

Essential oil and oleoresin can be obtained from the leaves of *E. globulus*, two different products with applications in the perfume, pharmaceutical and food industries (Rodrigues *et al*., 2021). The essential oil contains a wide range of chemical substances such as monoterpenes, sesquiterpenes, esters, aldehydes, and ketones, a composition which is involved in defence mechanisms against pests and microorganisms (Čmiková *et al*., 2023). On the other hand, oleoresins exhibit a more complete aromatic and flavor profile, providing aroma, flavor, color and pungency, characteristics of interest to the food industry (Procopio *et al*., 2022).

Traditionally, hydrodistillation has been described as a classic method for the extraction of eucalyptus essential oil due to its high extraction yield, cost-effectiveness and ease of implementation. Hydrodistillation mainly extracts the volatile compounds of *E. globulus*, characterized by its high content of 1,8-Cineole (Immaroh *et al*., 2021); while for extracting the non-volatile components, such as those with higher molecular weight, organic solvents such as ethanol or hexane are commonly used (Zhou *et al*., 2021). Among alternative extraction techniques, supercritical CO_2 extraction, either alone or combined with a polarity modifier such as ethanol, is able to extract natural mixtures of essential oils and resins responsible for the total flavor profile of the plants (Shahidi and Hossain, 2018). The main advantage of supercritical CO_2 extraction is the reduction of thermal degradation of essential oil compounds, while being environmentally friendly (Sethunga *et al*., 2022). Other compounds described in oleoresin include sugars, waxes, phenolic compounds, sterols, terpenes, triglycerides and free fatty acids, which impart either a liquid or solid consistency under ambient conditions (Rodrigues *et al*., 2021). The effectiveness of natural antioxidants in eucalyptus, including bioactive compounds such as terpenes, plays a crucial role in preventing reactions that lead to food spoilage (Khaiper *et al*., 2024).

Although essential oils from different eucalyptus species have been studied and characterized, there are few studies comparing the chemical composition and antioxidant capacity of essential oil and oleoresin from eucalyptus leaves, particularly from eucalyptus grown in Peru, where its leaves are often wasted and incinerated (Laura-Ticona *et al*., 2024). For this reason, the aim of this research was to compare the extraction yield, chemical composition and antioxidant capacity of the essential oil and oleoresin obtained using the hydrodistillation and supercritical extraction techniques.

2. MATERIALS AND METHODS

2.1. Plant material

Fresh eucalyptus leaves from the Huancayo region, Peru, were used. The identification of the leaves was carried out at the Herbarium Amazonense (AMAZ) of the Natural Resources Research Center (CIRNA) of the Universidad Nacional de la Amazonía Peruana (No. 096-2024 AMAZ-UNAP). The leaves were collected in April 2023, under ambient temperatures ranging from 3 to 13 °C and a relative humidity of approximately 89%. They were then transported to the laboratories of the Instituto Tecnológico de la Producción, where they were air-dried for 24 hours. The dried leaves, with a moisture content of 4.5%, were pulverized using a mill (IKA A11 basic, Germany) and sieved to obtain a fine powder with a particle size of 0.35-0.5 mm.

2.2. Extraction of oleoresin and essential oil

Oleoresin extraction by supercritical CO_2 (SCO_2) and supercritical CO_2 + Ethanol (SCO_2+Et): Oleoresin was extracted from eucalyptus leaves using multi-solvent extraction equipment (2802 0000, Top Industrie,

France) as described by Barriga-Sánchez *et al*. (2022). A total of 75 g of ground eucalyptus leaf sample was placed in the extraction cell, interspersed with 8 layers of glass beads.

The SCO_2 extraction was carried out at 250 bar and 33 °C, with a constant flow rate of 35 g/min. The oleoresin was collected for 2 hours, ending when no variation in the recovered weight was observed.

The SCO_2+Et extraction was carried out at 250 bar and 33 °C. A CO_2 flow of 35 g/min. Absolute ethanol (99.8%) was used as a co-solvent at a sample:solvent ratio of 1:10.5 (w/v), corresponding to approximately 10% ethanol by mass relative to CO_2. The extraction time of 3.5 h was used. The collected ethanolic extract was taken to a rotary evaporator and the ethanol was recovered (Buchi, R-300, Switzerland). Traces of ethanol were eliminated with a nitrogen flow. Finally, the oleoresin was stored at -20 °C until further analysis. Oleoresin extraction was performed in duplicate. Extraction yields were calculated according to Equation 1.

$$Oleoresin\ yield\ (\%) = \frac{Oleoresin\ weight\ (g)}{Leaves\ weight\ (g)}\ x\ 100 \quad \text{Eq. (1)}$$

Essential Oil Extraction by Hydrodistillation: The methodology of Rodrigues *et al*. (2021) was followed using a Clevenger-type apparatus. A total of 100 g of ground eucalyptus leaves was placed in a 2000-mL round-bottom distillation flask. Glass beads were added in a 1:1 proportion, and distilled water at 100 °C was added in a 1:12 ratio relative to the sample weight. The extraction was conducted for 3.5 hours and performed in duplicate. The essential oils obtained were collected in vials and stored at freezing temperature (-20 °C) until further analysis. The extraction yield was calculated according to Equation 2 (Khaiper *et al*., 2025).

$$Essential\ Oil\ Yield\ (\%) = \frac{Essential\ oil\ volume\ (mL)}{Leaves\ weight\ (g)}\ x\ 100 \quad \text{Eq. (2)}$$

2.3. Chemical analysis

2.3.1. Total phenolic compounds

The methodology described in the study by Barriga-Sánchez *et al*. (2021) was followed. A total of 71 µL of sample diluted in ethanol was reacted in the dark for 8 minutes with 71 µL of Folin-Ciocalteu reagent. Subsequently, 1430 µL of 6% (w/v) sodium carbonate and 2000 µL of distilled water were added. The tubes were stirred and incubated for 1 hour in the dark. Absorbance was measured at 750 nm using a UV-VIS spectrophotometer (Genesys 180, Thermo Scientific, USA). Results were expressed in milligrams of gallic acid equivalent (GAE) per gram of sample. A 5-point calibration curve of gallic acid (50-400 mg/L) was prepared. Analyses were performed in triplicate.

2.3.2. Gas chromatography-mass spectrometry (GC-MS)

The analysis of volatile compounds was performed according to the methodology of Yáñez Rueda and Cuadro Mogollón (2012) using a gas chromatograph (Thermo scientific Trace 1310, USA) coupled to a triple quadrupole mass spectrometer (Thermo scientific TSQ 8000 EVO, USA). A TG-5SILMS capillary column with a length of 30 m x 0.25 mm x 0.25 µm was used. Helium was used as carrier gas with a pressure of 40 psi and a flow rate of 1.0 mL/min. The oven temperature was initially set at 50 °C for 4 min, increased at a rate of 3 °C/min up to 200 °C and held for 2 min. The temperatures of the injector, the transfer line and the ion source were 250, 280 and 180 °C, respectively. Mass spectra were obtained by electron ionization (70 eV) with automatic scanning in the mass range m/z 20-550 Da, with a scan time of 0.2 s. The percentage composition of the identified compounds was expressed as a percentage of the peak area relative to the total peak area. The run time was 56 min. The identity of the components was assigned by comparison of the experimentally obtained mass spectra for each component with those reported in the National Institute of Standards and Technology (NIST) mass spectra database. The terpenes α-Pinene, Limonene, Eucalyptol and α-Terpineol were identified using analytical standards.

2.3.3. In vitro antioxidant capacity

ABTS: The free radical scavenging capacity was determined according to the methodology of Prior *et al*. (2005). Briefly, 30 µL of sample diluted in ethanol were reacted with 3 mL of ABTS radical and incubated for 30 minutes. After the reaction time, the absorbance was measured at 734 nm. A 5-point Trolox calibration curve was performed (0.1 to 2.0 mM). The results were expressed as µmol of Trolox equivalent (TE)/g of sample. Analyses were performed in triplicate.

Ferric Reducing Antioxidant Power (FRAP): The determination was performed following the methodology described by Benzie and Strain (1996). A total of 90 µL of sample diluted in ethanol was reacted with 270 µL of distilled water and 2.7 mL of FRAP reagent (0.3 M acetate buffer at pH 3.6, 10 mM TPTZ, and 20 mM FeCl3 in a 10:1:1 ratio). The mixture was incubated in the dark for 30 minutes, and the absorbance was subsequently measured at 595 nm. A 6-point Trolox calibration curve (50 to 600 µM) was prepared. Results were expressed as µmol TE/g of sample. Analyses were performed in triplicate.

2.4. Statistical analyses

An analysis of variance (ANOVA) and a mean comparison using Tukey test were performed, with a significance level of 0.05. The analyses were conducted using Statgraphics Centurion software, version 18.

3. RESULTS AND DISCUSSION

3.1. Extraction yield of essential oil and oleoresin

A higher extraction yield was obtained for oleoresin compared to essential oil (Table 1). This result was expected, as oleoresins are more complex extracts which, unlike essential oils, include non-volatile compounds such as pigments and phenolic compounds in their composition (Procopio *et al*., 2022). The SCO_2+Et extraction likely extracted these non-volatile components from eucalyptus leaves, increasing the extraction yield compared to SCO_2 extraction.

TABLE 1. Yield, total phenolic compounds, and antioxidant capacity (FRAP and ABTS) of essential oil and oleoresins from *E. globulus* Labill., obtained by hydrodistillation, SCO_2 and SCO_2+Et

Extraction type	Sample	Yield (%)	TPC (mg GAE/g)	ABTS (µmol TE/g)	FRAP (µmol TE/g)
Hydrodistillation	Essential oil	1.62 ± 0.16 ^{b}	0.25 ± 0.02 ^{c}	10.28 ± 0.20 ^{c}	2.58 ± 0.18 ^{c}
SCO_2	Oleoresin	1.05 ± 0.06 ^{b}	5.05 ± 0.13 ^{b}	469.59 ± 7.88 ^{b}	788.06 ± 16.62 ^{b}
SCO_2+Et	Oleoresin	8.96 ± 0.39 ^{a}	11.30 ± 0.18 ^{a}	1601.92 ± 88.39 ^{a}	808.82 ± 32.16 ^{a}

SCO_2: supercritical CO_2, SCO_2+Et: supercritical CO_2 + ethanol, TPC: Total phenolic compounds, GAE: Gallic acid equivalent, TE: Trolox equivalent. Results are expressed as mean ± standard deviation (n = 3). Different letters in the same column indicate significant difference ($p < 0.05$) according to Tukey's test.

The extraction yields of essential oil from *E. globulus* have been reported from 0.74 % in leaves from Tunisia (Jerbi *et al*., 2017), 0.43 - 0.54 % in leaves from Nigeria (Usman *et al*., 2020), and up to values of 2.53 % (Harkat-Madouri *et al*., 2015) in leaves from Algeria. The essential oil yield from *E. globulus* Labill. obtained in this study fall within an intermediate range compared to the values mentioned above. Differences in yields have been attributed to different factors such as leaf age, harvest date, geographical origin and extraction method (Chahomchuen *et al*., 2020). Another difference is mentioned by Rodrigues *et al*. (2021), who reported a higher essential oil yield from ground *E. globulus* leaves (3.09 %) compared to unground leaves (2.10%).

The oleoresin extraction yield (SCO_2+Et) reached 8.96 % (Table 1), a value higher than those reported by Rodrigues *et al*. (2021) for *E. globulus* oleoresin from Portugal, with yields of 3.86 and 4.64% for SCO_2+Et (5 %, w/w) and ethanol (10 %, w/w) extraction, respectively. On the other hand, SCO_2 extraction showed a significantly lower yield (1.05 %), a similar trend to that reported by Rodrigues *et al*. (2018), who

obtained yields of 1.52 and 2.02 % from *E. globulus* leaves using supercritical CO_2, increasing to 3.16% when using SCO_2+Et. Similar results have been observed for other eucalyptus species when extracted with only SCO_2. Abbas *et al*. (2022) reported yields of less than 1.32 % from *E. camaldulensis* L., while Zhao and Zhang (2014) reported a yield of 4.78 % from *E. loxophleba* ssp. *Lissophloia* with SCO_2+Et extraction. The differences can be attributed to variations in extraction parameters and eucalyptus varieties used in each study.

3.2. Total phenolic compounds (TPC)

The TPC contents of essential oil and oleoresins showed significant differences ($p < 0.05$). The TPC value in the eucalyptus essential oil in this study (Table 1) was lower than the range of 17.7 - 28.3 mg EAG/g reported by Chahomchuen *et al*. (2020) in the essential oil from different species of eucalyptus leaves from Thailand, and the contents of 43.85 and 60.19 mg GAE/g from the leaves of *E. cinerea* and *E. camaldulensis*, respectively (Herzi *et al*., 2013). The TPC content in the essential oil of *E. globulus* was significantly lower compared to the oleoresins. As mentioned previously, oleoresin obtained with organic solvents, SCO_2 or SCO_2+Et, contains a mixture of volatile and non-volatile compounds, which may include polyphenols or other compounds that can reduce Folin's reagent. Nadeem *et al*. (2016) identified and quantified vitamin E, quercetin and phenolic acids such as gallic, ferulic, m-coumaric, myricetin, p-coumaric and caffeic acid in *Eucalyptus citriodora* oleoresin obtained with methanol. Furthermore, Rodrigues *et al*. (2018) reported a higher triterpenic acid content in *E. globulus* oleoresin when extracted with SCO_2+Et, compared to SCO_2 extraction. Based on the above, it could be assumed that oleoresins obtained through SCO_2+Et and SCO_2 extraction, contain compounds similar to those reported by Nadeem *et al*. (2016), and that SCO_2+Et extraction may yield a greater number of bioactive compounds, which may exhibit reducing capacity for the Folin reagent.

3.3. Gas chromatography-mass Spectrometry (GC-MS) analysis

The identified terpenes were grouped into families of hydrocarbon monoterpenes, oxygenated monoterpenes, hydrocarbon sesquiterpenes, and oxygenated sesquiterpenes (Table 2). The essential oil and oleoresins obtained with SCO_2 and SCO_2+Et extraction from *E. globulus* showed different compositions. A total of 13 and 11 terpenes were identified in the essential oil and oleoresins, respectively.

The essential oil was characterized by a higher content of total monoterpenes (80.33 %) with the predominant compound being the oxygenated monoterpene 1,8-Cineole (67.01 %), similar to those reported in previous studies on *E. globulus* essential oil (Harkat-Madouri *et al*., 2015; Jerbi *et al*., 2019). 1,8-Cineole (eucalyptol) is commonly used in flavorings, fragrances, and cosmetics due to its pleasant aroma and spicy taste (Almas *et al*., 2021). On the other hand, the oleoresins obtained by SCO_2+Et and SCO_2 presented a higher relative content of total sesquiterpenes, with 63.68 and 54.23 %, respectively. The main identified hydrocarbon sesquiterpenes were aromadendrene (19.26 and 18.92 %) and viridiflorene (24.48 and 17.17 %), which were predominant in the oleoresins obtained with SCO_2 and SCO_2+Et, respectively.

The oleoresin was characterized by a high content of higher molecular weight terpenes, and no hydrocarbon monoterpenes were even identified in its composition. In this regard, Zhao and Zhang (2014) mentioned that the oil extracted by hydrodistillation contained only volatile compounds, while the oil obtained by supercritical extraction contained both volatile and high molecular weight compounds. Mann *et al*. (2011) reported that, with SCO_2 extraction, the content of hydrocarbon monoterpenes was close to zero, in contrast to the essential oil of *Eucalyptus cinerea* obtained by hydrodistillation. They attribute this difference to the different polarities and solvating capacities between the water used in hydrodistillation and supercritical CO_2. The highest content of viridiflorene was found in the oleoresin obtained with supercritical SCO_2, a compound reported in small amounts (2.9-6.7 %) in the essential oil of different species of eucalyptus (Polito *et al*., 2023) and 0.7 % in *E. globulus* (Jerbi *et al*., 2017).

The essential oil contained α-Pinene (5.48 %), Limonene (2.24 %) and sesquiterpene γ-Gurjunene (1.34%), compounds that were not identified in the oleoresins. Other studies have reported variable levels of α-Pinene contents, from 0.1 % (Usman *et al*., 2020) to 16.1 % (Jerbi *et al*., 2017), as well as D-limonene contents, from

0.3 to 23.5 %, in *E. globulus* essential oil harvested in different seasons (Usman *et al*., 2020). On the other hand, γ-Gurjunene has been reported in low amounts in eucalyptus essential oil, with 0.9 % in *E. globulus* essential oil (Usman *et al*., 2020), 0.2 % in *E. alba* and 1.2 % in *E. paniculata* (Elaissi *et al*., 2020), with contents lower than those found in the essential oil of this study.

TABLE 2. Terpenoid composition in essential oil and oleoresin obtained with supercritical SCO_2 and SCO_2+Et of *E. globulus* Labill

Compounds	RT (min)	Relative content (%)		
		Essential oil	Oleoresin - SCO_2	Oleoresin - SCO_2+Et
Hydrocarbon monoterpenoids				
α-Pinene	9.17	5.48 ± 0.01	-	-
Limonene	13.47	2.24 ± 0.05	-	-
Oxygenated monoterpenoids				
Eucaliptol (1,8 Cineol)	13.97	67.01 ± 0.49 ^{a}	19.59 ± 0.35 ^{c}	29.66 ± 0.17 ^{b}
α-Terpineol	21.7	1.26 ± 0.01 ^{c}	2.61 ± 0.09 ^{b}	2.89 ± 0.09 ^{a}
α-Terpineol acetate	28.45	4.34 ± 0.00 ^{c}	9.62 ± 0.04 ^{a}	9.43 ± 0.06 ^{b}
Hydrocarbon sesquiterpenoids				
α-Gurjunene	30.79	2.04 ± 0.01 ^{b}	2.95 ± 0.26 ^{a}	3.23 ± 0.00 ^{a}
γ-Muurolene	31.75	0.60 ± 0.22 ^{a}	0.86 ± 0.13 ^{a}	0.88 ± 0.08 ^{a}
Aromadendrene	32.07	8.23 ± 0.08 ^{c}	19.26 ± 0.04 ^{a}	18.92 ± 0.09 ^{b}
Alloaromadendrene	32.94	2.29 ± 0.02 ^{b}	5.77 ± 0.13 ^{a}	5.76 ± 0.04 ^{a}
β-Selinene	34.13	0.58 ± 0.05 ^{b}	1.08 ± 0.11 ^{a}	1.00 ± 0.04 ^{a}
γ-Gurjunene	34.26	1.34 ± 0.04	-	-
Viridiflorene	38.15	3.09 ± 0.05 ^{a}	24.48 ± 0.25 ^{a}	17.17 ± 0.12 ^{b}
Isoledene	38.4	-	5.99 ± 0.08 ^{a}	4.51 ± 0.07 ^{b}
Oxygenated sesquiterpenoids				
Guaiol	39.58	0.62 ± 0.07 ^{c}	3.29 ± 0.03 ^{a}	2.76 ± 0.11 ^{b}
Hydrocarbon monoterpenoids		7.72	0	0
Oxygenated monoterpenoids		72.61	31.82	41.98
Hydrocarbon sesquiterpenoids		18.17	60.39	51.47
Oxygenated sesquiterpenoids		0.62	3.29	2.76
Total		99.12	95.5	96.21

SCO_2: Supercritical CO_2, SCO_2+Et: Supercritical CO_2 + ethanol. Results are expressed as mean ± standard deviation (n = 2). Different letters in the same row indicate significant difference ($p < 0.05$) according to Tukey's test.

The presence of other terpenes in *E. globulus* which were not identified in this investigation has been reported, such as sesquiterpene spathulenol, with contents of 7.44 % (Harkat-Madouri *et al*., 2015) and 14.10% (Bendaoud *et al*., 2009); and monoterpene p-Cymene, with contents of 20.24% (Bendaoud *et al*., 2009) and 8.8 % (Jerbi *et al*., 2017). Usman *et al*. (2020) reported a content of 24.8 % m-Cymene in eucalyptus essential oil harvested in the rainy season, but no m-Cymene content was found when the eucalyptus was harvested in the dry season. The variability among studies may be caused by differences in eucalyptus origin, genetic variation, and environmental conditions. Other factors include the extraction method, harvest year, and season (Koursaoui *et al*., 2023; Zhou *et al*., 2021).

3.4. *In vitro* antioxidant capacity

Different methods have been used to evaluate the *in vitro* antioxidant capacity of eucalyptus essential oils. The ability of *E. globulus* essential oil to neutralize the $ABTS^{\bullet+}$ radical and reduce ferric iron (Fe^{+3}) to ferrous ion (Fe^{+2}) has been previously described (Ayed *et al*., 2024).

The order of antioxidant capacity from highest to lowest for ABTS and FRAP was as follows: oleoresin obtained with SCO_2+Et > oleoresin obtained with SCO_2 > essential oil (Table 1). The difference in antioxidant capacity is explained by differences in chemical composition (Liu *et al*., 2023). 1,8-Cineole was the major component in both the essential oil (67.01 %) and oleoresin obtained with SCO_2+Et (29.66 %). This oxygenated monoterpene has been described for its *in vitro* antioxidant capacity (Hoch *et al*., 2023) and as the main terpene that provides the antioxidant capacity in the essential oils of eucalyptus species (Koursaoui *et al*., 2023). The oleoresins presented a higher content of sesquiterpenes and TPC, and this difference may influence the antioxidant capacity results. Bendaoud *et al*. (2009) mention that essential oils with a higher content of monoterpenes are less effective as antioxidants. On the other hand, Liu *et al*. (2023) mention that phenols contribute greatly to the antioxidant capacity of essential oils. The combination and interaction of the different components of the essential oil could explain its antioxidant properties (Ayed *et al*., 2024), as well as the possible synergistic effects that could lead to the enhancement of the antioxidant properties (Luís *et al*., 2016). The results suggest that the greater presence of TPC and the possible interactions of the compounds present in the *E. globulus* oleoresins contribute to the greater ABTS and FRAP antioxidant capacity.

In addition to the difference in composition, the extraction process can influence the content and bioactivity of the compounds. Harkat-Madouri *et al*. (2015) mention that hydrodistillation, an extraction process that uses water at 100 °C, can cause thermal degradation and hydrolysis of the compounds obtained in the extraction of essential oil, thus changing its antioxidant capacity. On the other hand, SCO_2 extraction of essential oils and oleoresin uses lower temperatures, above the critical temperature of CO_2 (32 °C), reducing the thermal degradation caused by hydrodistillation (Yousefi *et al*., 2019). This could also explain the greater antioxidant capacity of the compounds found in the *E. globulus* oleoresin.

4. CONCLUSIONS

This study highlights the differences between essential oil and oleoresins obtained with SCO_2 and SCO_2+Et from *E. globulus*, with emphasis on their distinct terpene compositions and antioxidant capacities. Extraction with SCO_2 and SCO_2+Et resulted in the highest molecular weight components present in the essential oil obtained by hydrodistillation. Compounds that are only present in the essential oil such as α-Pinene, Limonene and γ-Gurjunene were identified, while the oleoresins had a higher content of higher molecular weight compounds such as sesquiterpenes. A marked difference was observed between the total phenolic compound contents and the antioxidant capacity of the oleoresins compared to the essential oil. The high antioxidant capacity of the oleoresin makes it a natural antioxidant additive of interest for the food industry, emphasizing the use of green technologies such as supercritical extraction for obtaining food additives. Understanding the differences in the various products that can be obtained from *E. globulus* becomes a solid starting point for obtaining useful products with applications in the pharmaceutical and food 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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AUTHORSHIP CONTRIBUTION STATEMENT

M. Barriga-Sánchez: Conceptualization, Formal analysis, Methodology, Project administration, Writing – review & editing. E. Arpi: Investigation. P. M. Cueva-Martínez: Conceptualization, Formal analysis, Investigation, Writing – review & editing. E. Medina Cáceres: Investigation.

M. A. Varas Condori: Formal analysis, Investigation, Writing – original draft.

REFERENCES

Abbas A, Anwar F, Alqahtani SM, Ahmad N, Al-Mijalli SH, Shahid M, Iqbal M. 2022. Hydro-distilled and supercritical fluid extraction of *Eucalyptus camaldulensis* essential oil: Characterization of bioactives along with antioxidant, antimicrobial and antibiofilm activities. *Dose-Response* **20** (3). https://doi.org/10.1177/15593258221125477

Almas I, Innocent E, Machumi F, Kisinza W. 2021. Chemical composition of essential oils from Eucalyptus globulus and *Eucalyptus maculata* grown in Tanzania. *Sci. Afr*. **12**, e00758. https://doi.org/10.1016/j.sciaf.2021.e00758

Ayed A, Caputo L, De Feo V, Elshafie HS, Fratianni F, Nazzaro F, Hamrouni L, Amri I, Mabrouk Y, Camele I, Polito F. 2024. Antimicrobial, anti-enzymatic and antioxidant activities of essential oils from some Tunisian *Eucalyptus species*. *Heliyon* **10**, e34518. https://doi.org/10.1016/j.heliyon.2024.e34518

Barriga-Sánchez M, Castro-Rumiche CF, Sanchez-Gonzales G, Rosales-Hartshorn MU. 2021. Functional and chemical qualities of Vitis labrusca grape seed oil extracted by supercritical CO_2. *Rev. Colomb. Quim.* **50**, 3-9. https://doi.org/10.15446/rev.colomb.quim.v50n3.95469

Barriga-Sánchez M, Varas Condori MA, Churata Huanca AC, Aranda Pariasca DM. 2022. Supercritical Fluid Extraction of Lipids and Astaxanthin Optimization from Munida (*Pleuroncodes monodon*) and its Characterization. *J. Aquat. Food Prod. Technol.* **31**, 615-624. https://doi.org/10.1080/10498850.2022.2082903

Bendaoud H, Bouajila J, Rhouma A, Savagnac A, Romdhane M. 2009. GC/MS analysis and antimicrobial and antioxidant activities of essential oil of *Eucalyptus radiata*. *J. Sci. Food Agric.* **89**, 1292-1297. https://doi.org/10.1002/jsfa.3585

Benzie IFF, Strain JJ. 1996. The ferric reducing ability of plasma (FRAP) as a measure of "antioxidant power": The FRAP assay. *Anal. Biochem.* **239**, 70-76. https://doi.org/10.1006/abio.1996.0292

Chahomchuen T, Insuan O, Insuan W. 2020. Chemical profile of leaf essential oils from four Eucalyptus species from Thailand and their biological activities. *Microchem J.* **158**, 105248. https://doi.org/10.1016/j.microc.2020.105248

Čmiková N, Galovičová L, Schwarzová M, Vukic MD, Vukovic NL, Kowalczewski PL, Bakay L, Kluz MI, Puchalski C, Kačániová M. 2023. Chemical composition and biological activities of Eucalyptus globulus essential oil. *Plants* **12**, 1076. https://doi.org/10.3390/plants12051076

Elaissi A, Moumni S, Roeleveld K, Larbi Khouja M. 2020. Chemical characterization of five Tunisian *Eucaliptus* essential oils species. *Chem. Biodiversity* **17**, e1900378. https://doi.org/10.1002/cbdv.201900378

Harkat-Madouri L, Asma B, Madani K, Bey-Ould Si Said Z, Rigou P, Grenier D, Allalou H, Remini H, Adjaoud A, Boulekbache-Makhlouf L. (2015). Chemical composition, antibacterial and antioxidant activities of essential oil of *Eucalyptus globulus* from Algeria. *Ind. Crops Prod.* **78**, 148-153. https://doi.org/10.1016/j.indcrop.2015.10.015

Herzi N, Bouajila J, Camy S, Cazaux S, Romdhane M, Condoret JS. 2013. Comparison between supercritical CO_2 extraction and hydrodistillation for two species of Eucalyptus: Yield, chemical composition, and antioxidant activity. *J. Food Sci.* **78**, C667-C672. https://doi.org/10.1111/1750-3841.12113

Hoch CC, Petry J, Griesbaum L, Weiser T, Werner K, Ploch M, Verschoor A, Multhoff G, Dezfouli AB, Wollenberg B. 2023. 1,8-cineole (eucalyptol): A versatile phytochemical with therapeutic applications across multiple diseases. *Biomed. Pharmacother.* **167**, 115467. https://doi.org/10.1016/j.biopha.2023.115467

Immaroh NZ, Kuliahsari DE, Nugraheni SD. 2021. Review: Eucalyptus globulus essential oil extraction method. *IOP Conf. Ser.: Earth Environ. Sci.* **733**, 012103. https://doi.org/10.1088/1755-1315/733/1/012103

Jerbi A, Derbali A, Elfeki A, Kammoun M. 2017. Essential oil composition and biological activities of *Eucalyptus globulus* leaves extracts from Tunisia. *J. Essent. Oil-Bear. Plants* **20**, 438-448. https://doi.org/10.1080/0972060X.2017.1304832

Khaiper M, Poonia PK, Dhanda SK, Beniwal R, Verma P, Nasir M. 2025. Seasonal variation in chemical composition and bioactivity of *Eucalyptus tereticorni*s leaf essential oil. *Biochem. Syst. Ecol.* **121**, 104988. https://doi.org/10.1016/j.bse.2025.104988

Khaiper M, Poonia PK, Redhu I, Verma P, Sheokand RN, Nasir M, Tiwari A, Kumar V. 2024. Chemical composition, antifungal and antioxidant properties of seasonal variation in *Eucalyptus tereticornis* leaves of essential oil. *Ind. Crop. Prod.* **222**, 119669. https://doi.org/10.1016/j.indcrop.2024.119669

Koursaoui L, Badr S, Ghanmi M, Jaouadi I, Chibani A, Chahboun N, Aouane EM, Chaouch A, Zarrouk A. 2023. Phytochemical analysis, antioxidant and antimicrobial activity of three Eucalyptus species essential oils from the Moroccan Maâmora Forest: *Eucalyptus cladocalyx* F.Muell, *Eucalyptus grandis* W.Hill ex Maiden and *Eucalyptus botryoides* Sm. *Chem. Data Collect.* **48**, 101101. https://doi.org/10.1016/j.cdc.2023.101101

Laura-Ticona J, Chambi-Rodriguez AD, Coaquira-Quispe JJ. 2024. Efecto antimicrobiano in vitro de aceite esencial de eucalipto (*Eucalyptus globulus* labill) y muña (*Minthostachys mollis*). *Rev. investig. Altoandin.* **26**, 36-45. http://dx.doi.org/10.18271/ria.2024.586

Liu S, Zhao C, Cao Y, Li Y, Zhang Z, Nie D, Tang W, Li Y. 2023. Comparison of chemical compositions and antioxidant activity of essential oils from Litsea cubeba, cinnamon, anise, and eucalyptus. *Molecules,* **28**, 5051. https://doi.org/10.3390/molecules28135051

Luís Â, Duarte A, Gominho J, Domingues F, Duarte AP. 2016. Chemical composition, antioxidant, antibacterial and anti-quorum sensing activities of *Eucalyptus globulus* and *Eucalyptus radiata* essential oils. *Ind. Crops Prod.* **79**, 274-282. https://doi.org/10.1016/j.indcrop.2015.10.055

Mann TS, Babu GDK, Guleria S, Singh B. 2011. Comparison of *Eucalyptus cinerea* essential oils produced by hydrodistillation and supercritical carbon dioxide extraction. *Nat. Prod. Commun.* **6**, 107-110.

Nadeem R, Mumtaz S, Hanif MA, Shahzadi I, Jilani MI. 2016. BIOCHEMICAL CHARACTERISATION OF OLEORESIN OF *Eucalyptus citriodora*. *Oxid. Commun.* **39**, 3065-3078.

Polito F, Fratianni F, Nazzaro F, Amri I, Kouki H, Khammassi M, Hamrouni L, Malaspina P, Cornara L, Khedhri S, Romano B, Maresca DC, Ianaro A, Ercolano G, De Feo V. 2023. Essential oil composition, antioxidant activity and leaf micromorphology of five Tunisian *Eucalyptus species*. *Antioxidants,* **12**, 867. https://doi.org/10.3390/antiox12040867

Prior RL, Wu X, Schaich K. 2005. Standardized methods for the determination of antioxidant capacity and phenolics in foods and dietary supplements. *J. Agric. Food Chem.* **53**, 4290-4302. https://doi.org/10.1021/jf0502698

Procopio FR, Ferraz MC, Paulino BN, do Amaral Sobral PJ, Hubinger MD. 2022. Spice oleoresins as value-added ingredient for food industry: Recent advances and perspectives. *Trends Food Sci. Technol.* **122**, 123-139. https://doi.org/10.1016/j.tifs.2022.02.010

Rodrigues VH, de Melo MMMR, Tenberg V, Carreira R, Portugal I, Silva CM. 2021. Similarity analysis of essential oils and oleoresins of *Eucalyptus globulus* leaves produced by distinct methods, solvents and operating conditions. *Ind. Crops Prod.* **164**, 113339. https://doi.org/10.1016/j.indcrop.2021.113339

Rodrigues VH, de Melo MMR, Portugal I, Silva CM. 2018. Extraction of Eucalyptus leaves using solvents of distinct polarity. Cluster analysis and extracts characterization. *J. Supercrit. Fluids* **135**, 263-274. https://doi.org/10.1016/j.supflu.2018.01.010

Sethunga M, Ranaweera K, Gunathilake K, Munaweera I. 2022. Recent advances in the extraction methods of essential oils and oleoresins from plant materials and its potential applications: A comprehensive review. *J Food Bioprocess Eng.* **5**, 151-167.

Shahidi F, Hossain A. 2018. Bioactives in spices, and spice oleoresins: Phytochemicals and their beneficial effects in food preservation and health promotion. *Journal of Food Bioactives,* **3**, 8-75. https://doi.org/10.18805/ag.R-2519

Surbhi, Kumar A, Singh S, Kumari P, Rasane P. 2023. Eucalyptus: phytochemical composition, extraction methods and food and medicinal applications. *Adv. Tradit. Med.* **3**, 369-380. https://doi.org/10.1007/s13596-021-00582-7

Usman LA, Oguntoye OS, Ismaeel RO. 2020. Effect of seasonal variation on chemical composition, antidiabetic and antioxidant potentials of leaf essential oil of *Eucalyptus globulus* L. *J. Essent. Oil-Bear. Plants* **23**, 1314-1323. https://doi.org/10.1080/0972060X.2020.1862710

Yáñez Rueda X, Cuadro Mogollón OF. 2012. Composición química y actividad antibacteriana del aceite esencial de las especies *Eucalyptus globulus* y *E. camaldulensis* de tres zonas de Pamplona (Colombia). *Rev. Fac. Cienc. Bás.,* **10**, 52-61.

Yousefi M, Rahimi-Nasrabadi M, Pourmortazavi SM, Wysokowski M, Jesionowski T, Ehrlich H, Mirsadeghi S. 2019. Supercritical fluid extraction of essential oils. *TrAC, Trends Anal. Chem.*, **118**, 182-193. https://doi.org/10.1016/j.trac.2019.05.038

Zhao S, Zhang D. 2014. Supercritical CO_2 extraction of Eucalyptus leaves oil and comparison with Soxhlet extraction and hydro-distillation methods. *Sep. Purif. Technol.* **133**, 443-451. https://doi.org/10.1016/j.seppur.2014.07.018

Zhou L, Li J, Kong Q, Luo S, Wang J, Feng S, Yuan M, Chen T, Yuan S, Ding C. 2021. Chemical composition, antioxidant, antimicrobial, and phytotoxic potential of *Eucalyptus grandis* × *E. urophylla* leaves essential oils. *Molecules,* **26**, 1450. https://doi.org/10.3390/molecules26051450