

Yield, kinetics, and composition of essential oil from *Schinus molle* inflorescence

Rendimiento, cinética y composición del aceite esencial de la inflorescencia de Schinus molle

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ABSTRACT

Schinus molle is known for its essential oil (EO) content, but knowledge about the composition of EO from inflorescences is limited. Therefore, the present study evaluated the extraction yield of the EO from the inflorescence of *S. molle*. Also, the composition of the EO was determined by gas chromatography-mass spectrometry (GC-MS). The extraction of EO was carried out by hydrodistillation (HD) with dried *S. molle* inflorescences (DSMI). A yield of 2.13 % was observed during a 190 min extraction period. The compounds .tau.-Muurolol (11.26 %), 1,4-Dimethyl-7-(prop-1-en-2-yl)decahydroazulen-4-ol (8.77%), 5-Azulenemethanol, 1,2,3,4,5,6,7,8-octahydro-.alpha.,.alpha.,3,8-tetramethyl-, acetate, [3S-(3.alpha.,5.alpha.,8.alpha.)]- (8.53%), 1,5-Cyclodecadiene, 1,5-dimethyl-8-(1-methylethenyl), [S-(Z,E)]- (8.52%), cyclohexanemethanol, 4-ethenyl-.alpha.,.alpha.,4-trimethyl-3-(1-methylethenyl)-, [1R-(1.alpha.,3.alpha.,4.beta.)]- (7.48%), and .alpha.-phellandrene (5.96%) were found in higher concentration in the EO of DSMI. The results show that DSMI is a potential source of EO with an interesting composition for the natural and functional products industry.

Keywords: Aromatic inflorescences; *Schinus*; essential oil; hydrodistillation; high andean aromatic plants; extraction kinetic; phytochemicals.

RESUMEN

El *Schinus molle* es conocido por su contenido en aceite esencial (AE), pero los conocimientos sobre la composición del AE procedente de las inflorescencias son limitados. Por ello, el presente estudio evaluó el rendimiento de extracción del AE a partir de las inflorescencias de *S. molle*. Asimismo, se determinó la composición del AE mediante cromatografía de gases-espectrometría de masas (GC-MS). La extracción del AE se llevó a cabo mediante hidrodestilación (HD) con inflorescencias secas de *S. molle* (DSMI). Se observó un rendimiento del 2,13 % durante un periodo de extracción de 190 minutos. Los compuestos .tau.-Muurolol (11,26 %), 1,4-dimetil-7-(prop-1-en-2-il)decahidroazulen-4-ol (8,77 %), 5-azulenmetanol, 1,2,3,4,5,6,7,8-octahidro-.alfa.,.alfa.,3,8-tetrametil-, acetato, [3S-(3.alfa.,5.alfa.,8.alfa.)]- (8,53 %), 1,5-ciclododecadieno, 1,5-dimetil-8-(1-metiletilenil), [S-(Z,E)]- (8,52 %), ciclohexanometanol, 4-etenil-.alfa.,.alfa.,4-trimetil-3-(1-metiletilenil)-, [1R-(1.alfa.,3.alfa.,4.beta.)]- (7,48 %), y alfa-felandreno (5,96 %) se encontraron en concentraciones más elevadas en el EO del DSMI. Los resultados muestran que el DSMI es una fuente potencial de aceite esencial con una composición interesante para la industria de productos naturales y funcionales.

Palabras clave: Inflorescencias aromáticas; *Schinus*; aceite esencial; hidrodestilación; plantas aromáticas de las altas Andas; cinética de extracción; fitoquímicos.

INTRODUCTION

Some properties of *S. molle* EO were recently reported, such as antimicrobial (Belloumi et al., 2024), insecticidal (Baccari et al., 2024; Belloumi et al., 2024), anti-inflammatory (Belloumi et al., 2024), antileishmanial (da Silva et al., 2024), antifungal activity (da Silva et al., 2024), among others. The properties of *S. molle* EO described in the current literature show that this species is a source of important bioactive compounds with potential to be used in the elaboration of products with functional properties. *S. molle* grows naturally in the city of Tarma, Peru, considered a native species in Peru (Royal Botanic Gardens Kew, n.d.). Studies on the extraction and composition of the EO of *S. molle* growing wild in Tarma, Peru, are still limited.

Technological advances have allowed the improvement of EO extraction methods, these emerging methods are more efficient, environmentally friendly, and allow obtaining EO with better quality compared to conventional methods (Huo et al., 2024). Some emerging methods recently reported are microwave-assisted hydrodistillation (Peng et al., 2022), ultrasound-assisted extraction (Khalid et al., 2024), field-assisted extraction (Ferraz and Silva, 2025), and supercritical fluid extraction (Yousefi et al., 2019), among others. Although emerging technologies show an interesting potential for the modernization of the EO production process, their application is still limited compared to conventional technologies, due to their complexity and accessibility. Hydrodistillation (HD) is one of the most commonly used conventional methods for EO extraction (Katekar et al., 2023). The HD method was applied for the extraction of EO from leaves and fruits of *S. molle*, yielding 2.97 and 2.67%, respectively (Belhoussaine et al., 2022). Limonene was the major component in the EO of leaves and fruits. In the case of the EO of leaves, other components (β -myrcene, α -terpinene and γ -terpinene) were also found with a composition greater than 10% (Belhoussaine et al., 2022). The composition and bioactive properties of *S. molle* EO may vary depending on the geographical area of production,

as observed in a study conducted with leaves collected in different regions of Algeria (Kouachi et al., 2025). On the other hand, studies conducted with *S. molle* observed different HD times, such as two (Herrera-Calderon et al., 2022), three (Hussein et al., 2021; Morales-Rabanales et al., 2022; Phiri et al., 2021), and four hours (Volpini-Klein et al., 2021), suggesting the need to evaluate the EO HD kinetics of the raw materials to determine a suitable operating time of the hydrodistiller. The scientific literature consulted shows that there is limited information on the extraction and composition of EO from the inflorescences of *S. molle*; therefore, the objective of this study was to evaluate the kinetics of HD of EO from the inflorescences of *S. molle* collected in the province of Tarma, Peru. The composition of the EO was also evaluated by gas chromatography to demonstrate the potential of this raw material as a source of bioactive compounds.

Materials and Methods

Sample

The study was carried out with inflorescences of *S. molle* (Figure 1) collected in the district of Tarma, Junin, Peru. The collection of the samples was authorized by the Servicio Nacional Forestal y de Fauna Silvestre – SERFOR (RA N° D000260-2024-MIDAGRI-SERFOR-ATFFS-SELVA CENTRAL y RA N° D000543-2024-MIDAGRI-SERFOR-ATFFS-SELVA CENTRAL). The sample collection area and botanical identification were reported in another study by the research group (Paucarchuco-Soto et al., 2025).

Figure 1

The *Schinus molle* plant (A) and inflorescence (B).



Sample preparation

S. molle inflorescences were subjected to drying under ambient conditions protected from light for a period of 5 days. Dried inflorescences were subjected to grinding for 15 s in a 400 W home immersion blender (Oster, FPSTHB460A-053, China).

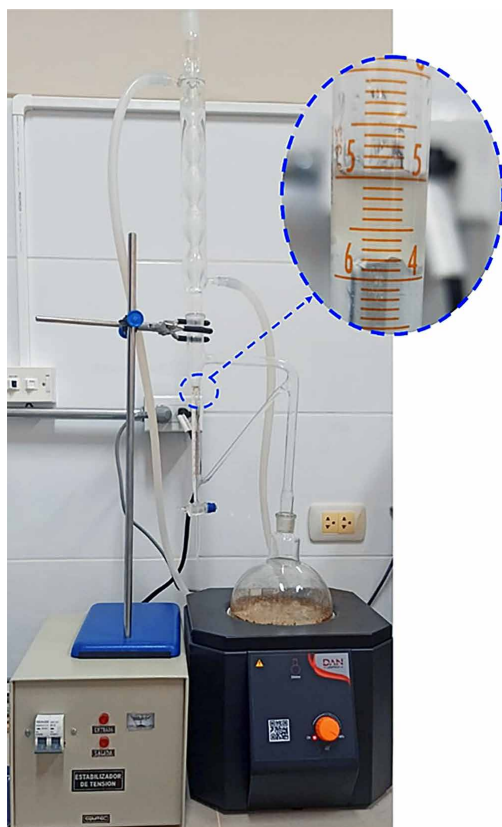
Curva cinética de la hidrodestilación (HD)

HD of EO was performed for 190 min in a Clevenger apparatus (Figure 2). Thirty g of DSMI and 600 mL of distilled water were fed to the hydrodistiller. The kinetic curve was constructed by recording the volume of EO retained in the hydrodistiller trap, as shown in Figure 2. The cumulative EO extraction yield was calculated using Equation 1, where EO is the essential oil yield in percent (%), EO_V is the volume (mL) of EO extracted at each time, and MP is the mass (g) of DSMI.

$$EO \left(\%, \frac{v}{w} \right) = \frac{EOV(v)}{MP(g)} \times 100 \quad (1)$$

Figure 2

Clevenger apparatus for the extraction of essential oils.



GC-MS Analysis

The analysis was performed by gas chromatography coupled to a mass spectrometer (Agilent Technologies, 5977C Inert Plus/8890), with an Agilent 19091S-433UI capillary column (30 m × 250 μm × 0.25 μm). The oven temperature was programmed from 40-250 °C at a rate of 5 °C/min and held for 15 min, and an equilibration time of 3 min at 350 °C. Helium was used as the carrier gas at 1 mL/min. The injector and detector temperatures were 250 °C. The inflorescence EO was diluted to a 207.6 mg EO/mL concentration with hexane. The injected sample volume was 1 μL, with a split ratio of 30:1. The MS conditions were, ionization energy of 70 eV, electron impact (EI) ion source temperature of 230 °C, transfer line 280 °C, and a mass range of 50–550 AMU. Data were obtained and processed using MassHunter software. Compound identification was based on retention time and mass spectra using the Wiley 12th library.

Results and Discussions

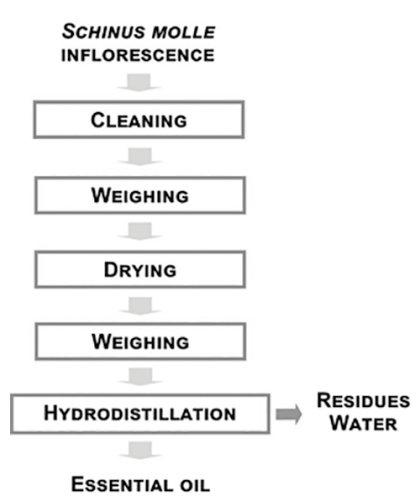
SMI essential oil processing

A proposal for the implementation of EO processing of *S. molle* inflorescence is illustrated in Figure 3. Our article does not provide information on the harvesting of *S. molle* inflorescences; this stage requires further study because it can affect the quality and yield of the EO. The inflorescences are usually collected with plant residues of leaves and branches, but it is also possible to find insects. We suggest using water to remove these residues. Before recording the weight of fresh inflorescences, they should be aerated to remove residual water from cleaning. The drying of inflorescences is described in section 2.2 of this article. The dried inflorescences of *S. molle* are conditioned according

to section 2.2, under these conditions they are fed to the hydrodistiller with water in a ratio of 1:20. The HD time is suggested to be set according to a production cost analysis, in our study we show the kinetics of EO extraction from inflorescences, which suggests the variation of the rate of extraction of EO from inflorescences during HD.

Figure 3

Proposed flowchart for the processing of EO from S. molle inflorescences by HD.



SMI essential oil yield

Figure 4 shows the EO obtained from the inflorescences of *S. molle*. After 190 min of HD in a Clevenger apparatus, a yield of 2.13 % could be obtained. The yield obtained in the present study was higher than the yield of EO from *S. molle* leaves (1.1 %) reported by (Irahal et al., 2021). In other studies, yields of 0.73 % (Herrera-calderon et al., 2022), 1.20 % (Volpini-klein et al., 2021), 1.91 % (Phiri et al., 2021), and 0.60 % (Morales-Rabanales et al., 2022) EOs obtained from *S. molle* leaves by the HD method were reported. On the other hand, a yield of 1.8 % of EO was observed in the fruits of this species (Volpini-klein et al., 2021). The extraction yields of *S. molle* EO by applying other technologies showed differences from our results. In the case of ultrasound-assisted hydrodistillation a yield of 2.33 % was reported (Phiri et al., 2021), and when microwave-assisted microdistillation was applied, 0.79 % was obtained (Landero-valenzuela et al., 2022). As it is evident when comparing our results with those reported in the literature, there are differences between the yields obtained by applying HD and by applying other technologies, which suggests that the EO extraction process has to be standardized, taking into account the origin of the raw material and the technology to be applied.

Figure 4

S. molle inflorescences EO obtained by HD.

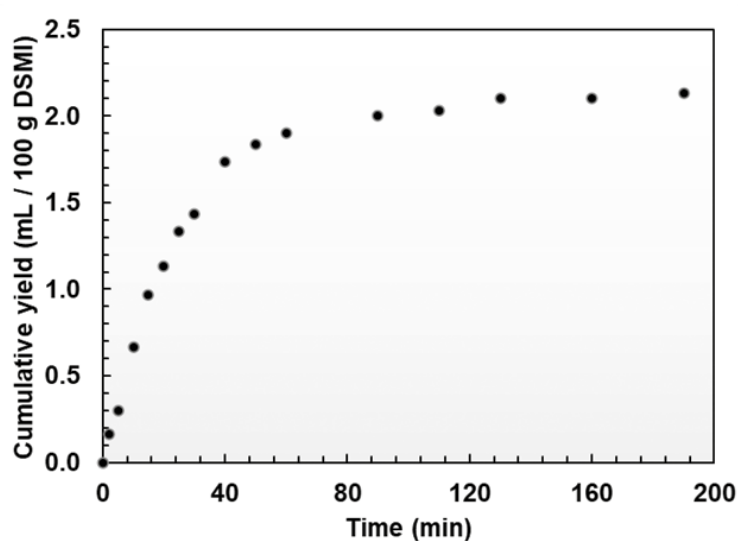


Extraction kinetics

Figure 5 shows the extraction kinetics of the HD of DSMI EO. Overall, it is observed that up to 50 min of HD, the yield was 1.83 %, which is approximately 86 % of the total EO extracted during the HD process, this means that 14 % (0.3 % DSMI) of the remaining EO is obtained during the next 140 min of operation of the hydrodistiller. The study of HD kinetics of *S. molle* inflorescences is limited in the scientific literature consulted, some reports suggest different HD times, for example: for fruits 120 and 240 min (Volpini-klein et al., 2021), for leaves 120 min (Herrera-calderon et al., 2022; Volpini-klein et al., 2021), 180 min (Hussein et al., 2021; Morales-Rabanales et al., 2022; Phiri et al., 2021), and 240 min (Volpini-klein et al., 2021). Our results highlight the importance of evaluating the HD process of EO from *S. molle* inflorescences, aiming to determine the kinetic behavior and establish an adequate HD time for the production line of EO from this raw material.

Figure 5

Extraction kinetics of DSMI essential oil extraction.



SMI essential oil composition

Table 1 shows the composition profile of the EO of DSMI; a total of 29 compounds were identified. The major constituent was α -Muurolol (11.26 %), other major components were 1,4-Dimethyl-7-(prop-1-en-2-yl)decahydroazulen-4-ol (8.77 %), 5-Azulenemethanol, 1,2,3,4,5,6,7,8-octahydro- α , α ,3,8-tetramethyl-, acetate, [3S-(3. α ,5. α ,8. α .)]- (8.53 %), and 1,5-Cyclodecadiene, 1,5-dimethyl-8-(1-methylethenyl)-, [S-(Z,E)]- (8.52 %). α -Muurolol was found in significant concentrations in other EO from other raw materials, such as leaves of *Rothmannia macrophylla* (Salleh and Khamis, 2020), wood of *Tectona grandis* (Vargas Suarez et al., 2019), leaves of *Guarea macrophylla* (Lago et al., 2006), flowers of *Diospyros discolor* (Su et al., 2015), twig of *Chamaecyparis formosensis* Matsum (Ho et al., 2012), fruits of *Liquidambar formosana* (Su and Ho, 2017), flowers of *Amomum muricarpum* (Huong et al., 2015), and heartwood of *Calocedrus formosana* (Hsu et al., 2021). Essential oils rich in α -Muurolol exhibited moderate lipoxygenase activity (Salleh and Khamis, 2020), in vitro cytotoxic activities (Su et al., 2015)(Su and Ho, 2017), antimicrobial activities (Hsu et al., 2021; Su et al., 2015), inhibitory activity of phytopathogenic fungi (Ho et al., 2012), anti-mildew activity (Su and Ho, 2017), and antifungal activity (Su and Ho, 2017). The composition of the EO of *S. molle* inflorescences (Table 1) and the advances reported in the current scientific literature show that *S. molle* can be an interesting source of bioactive molecules for various industries.

Table 1

Composition of DSMI EO determined by GC-MS.

Peak	RT (min)	CAS number	Compounds	Area (%)	Score
1	1.888	61141-71-7	6-Hepten-3-one, 5-hydroxy-4-methyl-	3.18	83.31
2	2.077	126750-34-3	3,4-Pentadien-2-d-1-ol	1.60	75.89
3	7.124	13466-78-9	3-Carene	4.02	95.24
4	7.525	60223-07-6	2-Methylbicyclo[4.3.0]non-1(6)-ene	1.13	93.56
5	8.709	127-91-3	2(10)-Pinene	2.64	89.12
6	9.104	99-83-2	.alpha.-phellandrene	5.96	95.4
7	9.665	535-77-3	Benzene, 1-methyl-3-(1-methylethyl)-	2.47	95.33
8	9.796	499-97-8	Cyclohexane, 1-methylene-4-(1-methylethenyl)-	3.80	92.91
9	20.462	489-40-7	1H-Cycloprop[e]azulene, 1a,2,3,4,4a,5,6,7b-octahydro-1,1,4,7-tetramethyl-, [1aR-(1a.alpha.,4.alpha.,4a.beta.,7b.alpha.)]-1	1.39	93.59
10	20.72	87-44-5	Isocaryophyllene	4.55	95.14
11	21.584	990080-17-3	1,4,7-Cycloundecatriene, 1,5,9,9-tetramethyl-, Z,Z,Z-1H-Cycloprop[e]azulene, decahydro-1,1,7-trimethyl-4-methylene-, (1aR,4aS,7R,7aR,7bS)-(-)- (1S,2E,6E,10R)-3,7,11,11-Tetramethylbicyclo[8.1.0]undeca-2,6-diene	1.08	88.69
12	21.767	25246-27-9	1,5-Cyclodecadiene, 1,5-dimethyl-8-(1-methylethenyl)-, [S-(Z,E)]-Naphthalene, 1,2,3,4,4a,5,6,8a-octahydro-7-methyl-4-methylene-1-(1-methylethyl)-, (1.alpha.,4a.beta.,8a.alpha.)-Cyclohexanemethanol, 4-ethenyl-.alpha.,.alpha.,4-trimethyl-3-(1-methylethenyl)-, [1R-(1.alpha.,3.alpha.,4.beta.)]- (3S,3aR,3bR,4S,7R,7aR)-4-Isopropyl-3,7-dimethyloctahydro-1H-cyclopenta[1,3]cyclopropa[1,2]benzen-3-ol	0.61	87.46
13	22.659	24703-35-3	(3S,3aR,3bR,4S,7R,7aR)-4-Isopropyl-3,7-dimethyloctahydro-1H-cyclopenta[1,3]cyclopropa[1,2]benzen-3-ol	2.53	96.61
14	22.871	75023-40-4	1,4-Dimethyl-7-(prop-1-en-2-yl)decahydroazulen-4-ol	8.52	92.08
15	23.071	39029-41-9	1H-Cycloprop[e]azulen-4-ol, decahydro-1,1,4,7-tetramethyl-, [1aR-(1a.alpha.,4.beta.,4a.beta.,7.alpha.,7a.beta.,7b.alpha.)]-Ledol	1.47	86.31
16	23.918	639-99-6	2-Naphthalenemethanol, 1,2,3,4,4a,5,6,7-octahydro-.alpha.,.alpha.,4a,8-tetramethyl-, (2R-cis)-2-Naphthalenemethanol, 2,3,4,4a,5,6,7,8-octahydro-.alpha.,.alpha.,4a,8-tetramethyl-, [2R-(2.alpha.,4a.beta.,8.beta.)]-2-Naphthalenemethanol, 2,3,4,4a,5,6,7,8-octahydro-.alpha.,.alpha.,4a,8-tetramethyl-, [2R-(2.alpha.,4a.beta.,8.beta.)]-	7.48	93.9
17	24.559	23445-02-5	.tau.-Muurolol	0.95	87.11
18	24.559	483-76-1	Agarospinol	0.95	97.18
19	24.765	21698-41-9	Cyclohexanol, 3-ethenyl-3-methyl-2-(1-methylethenyl)-6-(1-methylethyl)-, [1R-(1.alpha.,2.alpha.,3.beta.,6.alpha.)]-Benzyl Benzoate	8.77	77.04
20	24.954	552-02-3	5-Azulenemethanol, 1,2,3,4,5,6,7,8-octahydro-.alpha.,.alpha.,3,8-tetramethyl-, acetate, [3S-(3.alpha.,5.alpha.,8.alpha.)]-	1.37	88.57
21	25.211	577-27-5		0.92	77.48
22	25.864	1209-71-8		3.37	88.59
23	26.304	63891-61-2		2.74	81.74
24	26.304	1474790		2.74	81.74
25	26.379	19912-62-0		11.26	90.19
26	26.716	1460-73-7		1.51	91.39
27	27.226	35727-45-8		3.25	93.31
28	28.759	120-51-4		1.21	93.53
29	29.062	134-28-1		8.53	88.32

RT: Retention time.

CONCLUSIONS

The inflorescences of *S. molle* are a raw material with potential for the production of EO. A yield of 2.13 % DSMI was observed in the present study from dehydrated inflorescences. The HD kinetics showed that in the 50 minutes of the operation of the hydrodistiller, 86 % of the EO extracted during the whole process was obtained. The EO of *S. molle* inflorescences has significant potential for the industry due to its composition, which consists mainly of τ -Muurolol (11.26%). The prospects for the use of *S. molle* inflorescence as a raw material source of bioactive compounds are interesting for different industries, but more scientific studies are needed to improve the extraction of these compounds and to evaluate their application.

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