Brazilian Journal of Biology®

ISSN 1519-6984 (Print)
ISSN 1678-4375 (Online)

Original Article

Chromatography of *Solanum habrochaites* extracts with the first record of the docosanoate, hexadecanoate and octadecanoate ethyls in this plant and in Solanaceae

Cromatografia de extratos de *Solanum habrochaites* com o primeiro registro de etil docosanoato, hexadecanoato e octadecanoato nesta planta e em Solanaceae

C. A. M. Santos[a], D. L. Teixeira[a*], G. Salgado-Neto[b], C. F. Wilcken[c], P. G. Lemes[d], W. S. Tavares[e], J. A. Sabattini[f] and J. C. Zanuncio[a]

[a]Universidade Federal de Viçosa – UFV, Instituto de Biotecnologia Aplicada à Agricultura, Departamento de Entomologia, Viçosa, MG, Brasil

[b]Universidade Federal de Santa Maria – UFSM, Departamento de Defesa Fitossanitária, Programa de Pós-graduação em Agronomia, Santa Maria, RS, Brasil

[c]Universidade Estadual Paulista "Júlio de Mesquita Filho" – UNESP, Faculdade de Ciências Agronômicas, Departamento de Proteção Vegetal, Botucatu, SP, Brasil

[d]Universidade Federal de Minas Gerais – UFMG, Instituto de Ciências Agrárias, Laboratório de Entomologia Aplicada a Área Florestal, Montes Claros, MG, Brasil

[e]PT. ITCI Hutani Manunggal - IHM, Balikpapan, East Kalimantan, Indonesia

[f]Universidad Nacional de Entre Ríos, Fuacultad de Ciencias Agropecuarias, Consejo Nacional de Investigaciones Científicas y Técnicas, Departmento de Ecología, Oro Verde, Argentina

Abstract

The increasing need for sustainable alternatives to synthetic insecticides has driven the analysis of extracts from *Solanum habrochaites*, a wild tomato, through fractionated column chromatography. Potential bioactive compounds for pest management, a clean and promising biotechnological solution, have been reported from this plant. The objective is to provide detailed gas chromatography data, including peaks, structural formulas, and retention indices for the extracts of *S. habrochaites* aerial parts. Column chromatographic analysis was conducted with five fractions (F1, F2, F5, F3, and F4) of *S. habrochaites* extracts. Long-chain hydrocarbons such as hexadecanoic acid and docosano were identified in the F1 fraction; fatty acid esters, including hexadecanoate and octadecenoate ethyls in the F2 and methyl ketones, with tridecan-2-one as the major component in the F5, while no identifiable compounds were disclosed in the F3 and F4 fractions. The column chromatography provided valuable insights into compounds in the F1, F2, and F5 fractions of *S. habrochaites* extracts, highlighting fatty acid esters, long-chain hydrocarbons, and methyl ketones. The bioactive compounds, from extracts of this plant, including the first record of the docosanoate, hexadecanoate and octadecanoate ethyls in *S. habrochaites* and Solanaceae, reinforces their promising biological application in different areas of science.

Keywords: botanical, bioactive, compound, control, insecticide, pest.

Resumo

A crescente necessidade por alternativas sustentáveis no manejo de pragas motivou a análise de extratos de plantas do tomate silvestre, *Solanum habrochaites*, por cromatografia em coluna de fração. O objetivo foi detalhar resultados da cromatografia gasosa, incluindo picos, fórmulas estruturais e índices de retenção para compostos de extratos de partes aéreas de *S. habrochaites*. A análise cromatográfica em coluna foi realizada para cinco frações (F1, F2, F5, F3 e F4) dos extratos de *S. habrochaites*. Hidrocarbonetos de cadeia longa, como ácidos hexadecanóico e docosanoato, foram identificados na fração F1; ácidos graxos, incluindo hexadecanoato de etila e octadecanoato de etila na F2 e metilcetonas, com tridecan-2-ona como o composto majoritário, na F5 e nenhum composto nas frações F3 e F4. A análise dos extratos de *S. habrochaites*, por cromatografia em coluna, identificou compostos nas frações F1, F2 e F5, desta planta, destacando ésteres de ácidos graxos, metilcetonas e hidrocarbonetos de cadeia longa e o primeiro relato dos docosanoato, hexadecanoato e octadecanoato nessa planta e em Solanaceae.

Palavras-chave: botânico, bioativo, composto, controle, inseticida, praga.

*e-mail: david.l.teixeira@ufv.br
Received: December 19, 2023 – Accepted: March 18, 2024

1. Introduction

Chemical compounds from the secondary metabolism of plants are part of their communication, defense, and growth (Uranga et al., 2016). Fraction column chromatography identifies chemical compounds in plant extracts (Prasathkumar et al., 2022), with the potential for cosmetic (Popova et al., 2020), botanical deterrents, insecticides, and repellents (Santos et al., 2023), herbicides (Menezes et al., 2014), and treatment of human diseases (Bahgat et al., 2023).

Problems associated with synthetic pesticides misuse, such as ecological risks, intoxication, and high costs increase the need for alternative strategies in pest management programs (Leach and Mumford, 2008). Plant extracts with insecticidal secondary metabolites are a clean biotechnology approach (Attia et al., 2013). These extracts are biodegradable and pose lower environmental risks and potential insect resistance compared to conventional synthetic insecticides (Petacci et al., 2012).

Solanum habrochaites (Solanaceae), a wild tomato, is less preferred by various insect pests (Sánchez-Peña et al., 2006; Santos et al., 2023). The insecticidal potential of compounds from the aerial parts of this plant has been demonstrated (Santos et al., 2023). The tridecan-2-one induces midgut cytochrome P450 activity in insects, which may explain this plant's non-preference (Santos et al., 2023). This makes necessary to identify the chemical composition, gas chromatography peaks, structural formula, and retention indices of molecules from *S. habrochaites* extracts.

The aim of this work was to provide gas chromatography peaks, structural formula, and retention indices of compounds in the extract of aerial parts of *S. habrochaites* to contribute to existing studies on insect-plant interaction, plant communication and ecology, and on the application of its extract in the management of arthropod pests.

2. Methods

2.1. Experimental site

The experiment was carried out at the Supramolecular and Biomimetic Chemistry Laboratory of the Department of Chemistry at the Federal University of Viçosa (UFV) and at the Insect Biological Control Laboratory (LCBI) of the Institute of Biotechnology Applied to Agriculture (BIOAGRO) in Viçosa, Minas Gerais state, Brazil.

Seeds of *S. habrochaites* were collected in the *campus* of the UFV and cultivated in a greenhouse using standard practices (Kubond and St. Clair, 2023). The aerial parts (stems and leaves) were harvested from the cultivated plants and processed (Tavares et al., 2013).

2.2. Extractions and chromatographic procedures

Extractions and chromatographic procedures used analytical-grade solvents under vacuum and in open columns with silica gel 60 (70-230 mesh) as the stationary stage. Analytical thin-layer chromatography was performed using silica gel 60 G F254 plates (0.25 mm thickness) and revealed under ultraviolet light (254 and 366 nm), followed by immersion in a vanillin acid solution. The gas chromatography analyses were conducted in a Shimadzu GCMS QP-5000A chromatograph, equipped with a DB-5 Supelco capillary column (30 m × 0.25 mm × 0.25 µm) under the following conditions: electron impact method (70 eV); scan mode, 30 to 700 m/z; carrier helium (He) gas flow of 1.6 mL min^{-1}; split ratio 1:2. The temperature program was: T1= 40 ºC for 2 min, with a gradient of 20 ºC min^{-1} to T2= 300 ºC; injector and detector temperatures were set at 290 ºC.

2.3. Obtention and fractioning the extracts of the aerial parts

Stems and leaves of *S. habrochaites* were dried in a drying oven at 40 °C, followed by cold maceration extraction in pure ethanol (3 L) for seven days, a process repeated twice. The ethanolic extracts were combined, dried with anhydrous sodium sulfate (Na_2SO_4), and the solvent removed using a rotary evaporator, resulting in 58.936 g of crude extract, initially fractionated by vacuum chromatography using silica gel 60 (70-230 mesh) as the stationary phase and 2.5 L of dichloromethane (DCM) as the solvent (Figure 1) (Coll and Bowden, 1986). The DCM extract was fractionated by column chromatography using silica gel 60 (70-230 mesh) as the stationary phase, and elution performed with a hexane-dichloromethane gradient of 1:0 to 0:1 (v v^{-1}) to identify the chemical constituents of its fractions. Fractions of 10 mL were collected in test tubes (2 × 12 cm) and grouped based on the analytical change-coupled device (CCD) profile, resulting in five fractions and the crude extract (48.936 g) divided into:

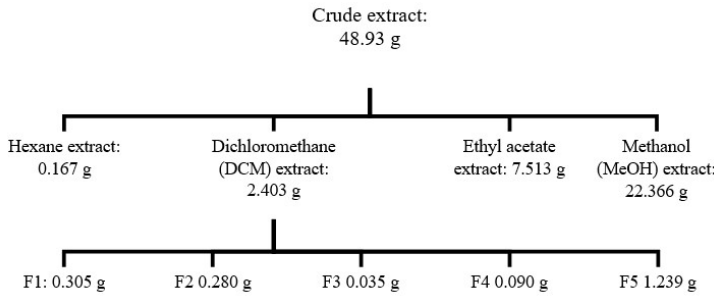

Figure 1. Fractioning of the crude extract of *Solanum habrochaites* (Solanaceae) in grams (g) by vacuum chromatography.

hexane-dichloromethane extract 1:0 to 0:1 (v v^{-1}) (2.403 g) [with the fractions of F1 (0.305 g), F2 (0.280 g), F3 (0.035 g), F4 (0.090 g), and F5 (1.239 g)], which were analyzed using Gas Chromatography-Mass Spectrometry (GC-MS) besides hexane (0.167 g), ethyl acetate (7.513 g), and methanol (22.366 g) extracts (Figure 1). The extraction process employed ethanol as the solvent to isolate compounds from the aerial parts of *S. habrochaites*. The ethanol esterifies fatty acids under certain conditions, and, for this reason, it is crucial to confirm that the identified esters in the extracts are not artifacts resulting from the esterification of fatty acids during the extraction process (Coll and Bowden, 1986).

Constituents were identified by comparing *S. habrochaites* extract mass spectra to chromatograph library data, with matches confirmed when retention and similarity indices values were over 90%. These indices were calculated using hydrocarbon standards $LRI = 100 \times \{[(t_c - t_n) \div (t_{n-1} - t_n)] + n\}$ (Viegas and Bassoli, 2007) with the equation: LRI= linear retention index; t_c= retention time of the compound of interest; t_{n+1}= retention time of the subsequent hydrocarbon; t_n= retention time of the preceding hydrocarbon; n= number of carbon atoms in the preceding hydrocarbon.

3. Results

3.1. Chromatography of the F1, F2, F3, F4 and F5 fractions

Fraction F1 from column chromatography identified the long-chain hydrocarbons docosane, heptacosane, hexadecanoic acid, octacosane, pentacosane, squalene, and tricosane (Figures 2, 3, Table 1).

Fraction F2 from column chromatography revealed the long-chain fatty acid esters docosanoate, hexadecanoate, and octadecenoate ethyls (Figure 3, Table 1).

Fractions F3 and F4 from column chromatography did not yield compounds with a similarity index >90% or in sufficient quantity for identification.

Methyl ketones tridecan-2-one, pentadecan-2-one, and 6,10,14-trimethylpentadecan-2-one, and the aldehyde 9,12,15-ocadecatrienal were identified in the F5 fraction of

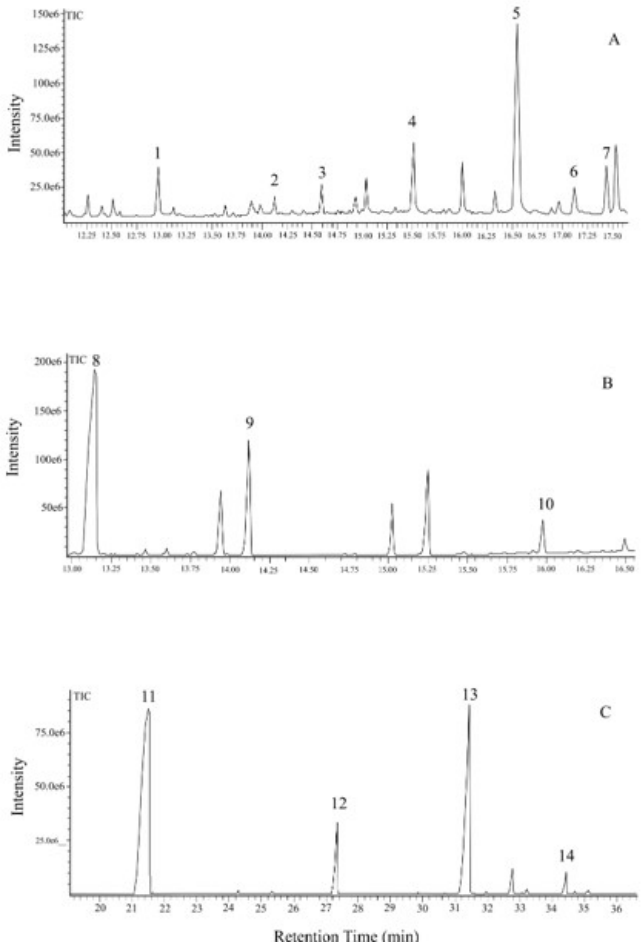

Figure 2. Gas chromatogram of total ions retention time and carbon index (TIC) from the F1 (A), F2 (B), and F5 (C) fractions of *Solanum habrochaites* (Solanaceae) extracts. 1- Hexanoic acid, 2- Docosane, 3- Tricosane, 4- Pentacosane, 5- Heptacosane, 6- Octacosane, 7- Squalene, 8- Ethyl hexadecanoate, 9- Ethyl octadecanoate, 10- Ethyl docosanoate, 11- Tridecan-2-one, 12- Pentadecan-2-one, 13- 6,10,14-Trimethylpentadecan-2-one, 14-9,12,15-Ocadecatrienal.

Table 1. Chemical composition (Comp.) of the F1, F2, and F5 fractions of *Solanum habrochaites* (Solanaceae) extract in hexane by gas chromatography-mass spectrometry and references (Ref.).

Comp.		Compound	Area	RI	RI*	Ref.
Factions	1	Hexadecanoic acid	2.23	1975	1973	1
	2	Docosane	0.99	2205	2200	2
	3	Tricosane	2.70	2305	2302	1
Fraction F1	4	Pentacosane	5.31	2506	2500	2
	5	Heptacosane	11.54	2712	2700	3
	6	Octacosane	1.58	2806	2800	4
	7	Squalene	2.97	2855	2847	2
	8	Ethyl hexadecanoate	8.91	2010	2013	5
Fraction 2	9	Ethyl octadecanoate	2.71	2204	2207	6
	10	Ethyl docosanoate	0.56	2601	2596	7
	11	Tridecan-2-one	38.02	1512	1512	8
Fraction 5	12	Pentadecan-2-one	4.46	1705	1705	9
	13	6,10,14-Trimethylpentadecan-2-one	20.05	1856	1846	10
	14	9,12,15-Ocadecatrienal	1.18	1973	1979	11

RI= Retention Index.*reported in literature. 1- Hosseinihashemi et al. (2013), 2- Samejo et al. (2013), 3- Silva et al. (2013), 4- Naquvi et al. (2014), 5- Selli et al. (2006), 6- Ansorena et al. (2000), 7- Heinrich et al. (2002), 8- Owens et al. (1997), 9- Souza et al. (2009), 10- Shi-Dong et al. (2014), 11- Yang et al. (2012).

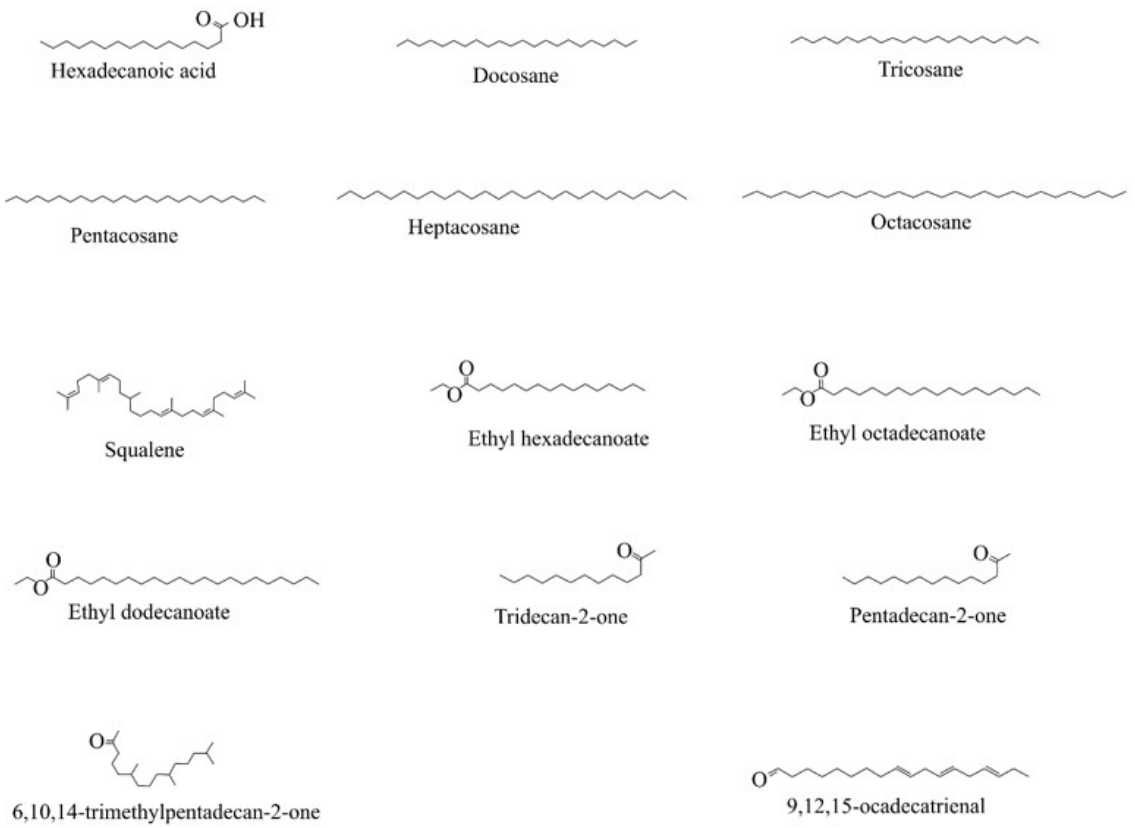

Figure 3. Structural formula of the molecules identified in the F1, F2, and F5 fractions of *Solanum habrochaites* (Solanaceae) extract in dichloromethane. Tridecan-2-one, pentadecan-2-one, 6,10,14-trimethylpentadecan-2-one, and 9,12,15-ocadecatrienal have been reported for this plant (Santos et al., 2023).

the *S. habrochaites* extract (Figure 3, Table 1), with tridecan-2-one constituting 38.02% of its total content (Table 1).

4. Discussion

4.1. Chromatography of the F1, F2, F3, F4 and F5 fractions

The long-chain hydrocarbons, docosane, heptacosane, hexadecanoic acid, octacosane, pentacosane, squalene acid, and tricosane identified in the chromatography of the F1 fraction from *S. habrochaites* extracts confirm a high diversity of compounds in this plant. This is the first record of docosane in Solanaceae. This compound, from *Sargassum fusiforme* (Sargassaceae), reduced respiratory syncytial virus (RSV) infection, one of the leading causes of bronchiolitis and pneumonia in infants (Chathuranga et al., 2021). The hexadecanoic acid can decrease the volatility of plant defense monoterpenes (Dell and McComb, 1981) and oviposition by *Tetranychus evansi* (Trombidiformes: Tetranychidae) on *Solanum sarrachoides* plants (Murungi et al., 2013). Squalene, also identified in the F1, may have a role in plant chemical defense (Kanmani et al., 2021). This compound, in *Nicotiana tabacum* (Solanaceae) leaf extracts, was linked to the toxicity against *Sitophilus oryzae* (Coleoptera: Curculionidae) (Kanmani et al., 2021). The toxicity of heptacosane and pentacosane to insects needs further study, but these compounds are of pharmaceutical relevance (Radulović et al., 2006; Satyal et al., 2015; Popova et al., 2020). Tricosane is one of the main volatile compounds attracting euglossine bees (Hymenoptera: Apidae) to *Cyphomandra* spp. (Solanaceae) plants (Sazima et al., 1993).

This is the first identification of the ethyl esters docosanoate, hexadecanoate and octadecanoate in a Solanaceae. These compounds are important, particularly, for the pharmaceutical industry (Radulović et al., 2010; Asgarpanah and Haghighat, 2012; Chung et al., 2011). Docosanoate is one of the volatile compounds found in grapes (Vitaceae) (Radulović et al., 2010), while hexadecanoate and octadecenoate ethyls are antioxidants (Chung et al., 2011), and aromatics and pharmacologicals (Asgarpanah and Haghighat, 2012), but they lack documented insecticidal activity.

The lack of identification of compounds in the F3 and F4 fractions of *S. habrochaites* may be due to factors such as inadequate resolution, contamination, or impurities, non-ideal chromatographic and variations in experimental conditions, and the complexity of the sample matrix. The similarity index, usually expressed in percentage, reflects how much the compound retention pattern is similar to a reference standard. Values below 90% indicate differences in retention periods of the unknown compound compared to the reference standard (Li et al., 2022).

The identification of the methyl ketones 6,10,14-trimethylpentadecan-2-one, pentadecan-2-one, tridecan-2-one, along with the aldehyde 9,12,15-ocadecatrienal, expands the known chemical profile of *S. habrochaites*. Further investigation of these compounds is warranted for potential applications, including insect pest management (Sánchez-Peña et al., 2006; Santos et al., 2023).

5. Conclusion

Chemical compounds with potential applications, such as the development of cosmetic products, botanical acaricides and insecticides, herbicides, and treatment of human diseases, were identified in the extracts of *S. habrochaites* plants through chromatography. Key compounds identified across fractions of these plants include aldehydes, fatty acid esters and methyl ketones. This is the first report of the hexadecanoate, octadecanoate, and docosanoate ethyls in this plant and in Solanaceae.

Acknowledgements

The final version was proofread by Adam Batten from Get It Right in Jakarta, Indonesia. This work was financially supported by the Brazilian Institution "Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG)". The compounds of *Solanum habrochaites* were identified by Prof. E.V.V. Varejão of the "Departamento de Química da Universidade Federal de Viçosa".

References

ANSORENA, D., ASTIASARÁN, I. and BELLO, J., 2000. Influence of the simultaneous addition of the protease flavourzyme and the lipase novozyme 677BG on dry fermented sausage compounds extracted by SDE and analyzed by GC-MS. *Journal of Agricultural and Food Chemistry*, vol. 48, no. 6, pp. 2395-2400. http://doi.org/10.1021/jf990931y. PMid:10888557.

ASGARPANAH, J. and HAGHIGHAT, E., 2012. Phytochemistry and pharmacologic properties of *Ziziphus spina christi* (L.) Willd. *African Journal of Pharmacy and Pharmacology*, vol. 6, no. 8, pp. 2332-2339. http://doi.org/10.5897/AJPP12.509.

ATTIA, S., GRISSA, K.L., LOGNAY, G., BITUME, E., HANCE, T. and MAILLEUX, A.C., 2013. A review of the major biological approaches to control the worldwide pest *Tetranychus urticae* (Acari: Tetranychidae) with special reference to natural pesticides. *Journal of Pest Science*, vol. 86, no. 1, pp. 361-386. http://doi.org/10.1007/s10340-013-0503-0.

BAHGAT, D.M., GAD, H.A., AL-SAYED, E., MAHMOUND, S.H., MOSTAFA, A., MAHFOUZ, N.M., ELDAHSHAN, O.A. and SINGAB, N.B., 2023. Essential oil of *Cestrum diurnum* L.: GC/MS analysis, *in vitro* and in *silico* Anti-HCoV-229E effects and inhibitory activity against LPS-induced inflammation. *Chemistry & Biodiversity*, vol. 20, no. 4, pp. e202201045. http://doi.org/10.1002/cbdv.202201045. PMid:36811152.

CHATHURANGA, K., WEERAWARDHANA, A., DODANTENNA, N., RANATHUNGA, L., CHO, W.K., MA, J.Y. and LEE, J.S., 2021. Inhibitory effect of *Sargassum fusiforme* and its components on replication of respiratory syncytial virus *in vitro* and *in vivo*. *Viruses*, vol. 13, no. 4, pp. 548. http://doi.org/10.3390/v13040548. PMid:33806073.

CHATHURANGA, K., WEERAWARDHANA, A., DODANTENNA, N., RANATHUNGA, L., CHO, W.K., MA, J.Y. and LEE, J.S., 2021. Inhibitory effect of *Sargassum fusiforme* and its components on replication of respiratory syncytial virus *in vitro* and *in vivo*. *Viruses*, vol. 13, no. 4, pp. 548. http://doi.org/10.3390/v13040548. PMid:33806073.

COLL, J.C. and BOWDEN, B.F., 1986. The application of vacuum liquid chromatography to the separation of terpene mixtures.

Journal of Natural Products, vol. 49, no. 5, pp. 934–936. https://doi.org/10.1021/np50047a033.

CHUNG, I.M., NAGELLA, P., AHN, Y.S., KIM, S.J. and AHMAD, A., 2011. Composition of the essential oil and petroleum ether extract of *Lycium chinense* Miller fruits and antioxidant activity of its several extracts. *Journal of Medicinal Plants Research*, vol. 5, no. 4, pp. 5973-5981. https://doi.org/10.5897/JMPR11.285.

DELL, B. and MCCOMB, A.J., 1981. Plant resins–their formation, secretion, and possible functions. *Advances in Botanical Research*, vol. 6, no. 1, pp. 277-316. http://doi.org/10.1016/S0065-2296(08)60332-8.

HEINRICH, G., PFEIFHOFER, H.W., STABENTHEINER, E. and SAWIDIS, T., 2002. Glandular hairs of *Sigesbeckia jorullensis* Kunth (Asteraceae): morphology, histochemistry and composition of essential oil. *Annals of Botany*, vol. 89, no. 4, pp. 459-469. http://doi.org/10.1093/aob/mcf062. PMid:12096807.

HOSSEINIHASHEMI, S.K., SAFDARI, V. and KANANI, S., 2013. Comparative chemical composition of n-hexane and ethanol extractives from the heartwood of black locust. *Asian Journal of Chemistry*, vol. 25, no. 2, pp. 929-933. http://doi.org/10.14233/ajchem.2013.13159.

KANMANI, S., KUMAR, L., RAVEEN, R., TENNYSON, S., ARIVOLI, S. and JAYAKUMAR, M., 2021. Toxicity of tobacco *Nicotiana tabacum* Linnaeus (Solanaceae) leaf extracts to the rice weevils *Sitophilus oryzae* Linnaeus 1763 (Coleoptera: curculionidae). *Journal of Basic & Applied Zoology*, vol. 82, no. 1, pp. 10. http://doi.org/10.1186/s41936-021-00207-0.

KUBOND, B.A. and ST. CLAIR, D.A., 2023. Bin mapping of water stress tolerance-related, fruit quality, and horticultural traits in tomato introgression lines derived from wild *Solanum habrochaites*. *Crop Science*, vol. 63, no. 2, pp. 568-584. http://doi.org/10.1002/csc2.20869.

LEACH, A.W. and MUMFORD, J.D., 2008. Pesticide environmental accounting: a method for assessing the external costs of individual pesticide applications. *Environmental Pollution*, vol. 151, no. 1, pp. 139-147. http://doi.org/10.1016/j.envpol.2007.02.019. PMid:17604888.

LI, L., SHUO, L., HAIYAN, W. and LEI, S., 2022. Influence of chromatographic column selection on the determination of 23 preservatives. *Se Pu*, vol. 40, no. 2, pp. 190-197. http://doi.org/10.3724/SP.J.1123.2021.05006. PMid:35080166.

MENEZES, C.W.G., TAVARES, W.S., DE SOUZA, E.G., SOARES, M.A., SERRÃO, J.E. and ZANUNCIO, J.C., 2014. Effects of crude extract fractions of *Adenocalymma nodosum* (Bignoniaceae) on duration of pupa stage emergence of *Tenebrio molitor* (Coleoptera: Tenebrionidae) and phytotoxicity on vegetable crops. *Allelopathy Journal*, vol. 33, no. 1, pp. 141-149.

MURUNGI, L.K., KIRWA, H. and TORTO, B., 2013. Differences in essential oil content of berries and leaves of *Solanum sarrachoides* (Solanaceae) and the effects on oviposition of the tomato spider mite (*Tetranychus evansi*). *Industrial Crops and Products*, vol. 56, no. 1, pp. 73-79. http://doi.org/10.1016/j.indcrop.2013.01.022.

NAQUVI, K.J., ANSARI, S.H., ALI, M. and NAJMI, A.K., 2014. Volatile oil composition of *Rosa damascena* Mill. (Rosaceae). *Journal of Pharmacognosy and Phytochemistry*, vol. 2, no. 5, pp. 177-181.

OWENS, J.D., ALLAGHENY, N., KIPPING, G. and AMES, J.M., 1997. Formation of volatile compounds during *Bacillus subtilis* fermentation of soya beans. *Journal of the Science of Food and Agriculture*, vol. 74, no. 1, pp. 132-140. http://doi.org/10.1002/(SICI)1097-0010(199705)74:1<132::AID-JSFA779>3.0.CO;2-8.

PETACCI, F., TAVARES, W.S., FREITAS, S.S., TELES, A.M., SERRÃO, J.E. and ZANUNCIO, J.C., 2012. Phytochemistry and quantification of polyphenols in extracts of the Asteraceae weeds from Diamantina, Minas Gerais State, Brazil. *Planta Daninha*, vol. 30, no. 1, pp. 9-15. http://doi.org/10.1590/S0100-83582012000100002.

POPOVA, V., IVANOVA, T., STOYANOVA, A., NIKOLOVA, V., HRISTEVA, T. and ZHELJAZKOV, V.D., 2020. GC-MS composition and olfactory profile of concretes from the flowers of four *Nicotiana* species. *Molecules (Basel, Switzerland)*, vol. 25, no. 11, pp. 2617. http://doi.org/10.3390/molecules25112617. PMid:32512824.

PRASATHKUMAR, M., ANISHA, S., KHUSRO, A., ESSA, M.M., CHIDAMBARAM, S.B., QORONFLEH, M.W., SADHASIVAM, S., SAHIBZADA, M.U.K., ALGHAMDI, S., ALMEHMADI, M., ABDULAZIZ, A., KHANDAKER, M.U., FARUQUE, M.R.I. and EMRAN, T.B., 2022. Anti-pathogenic, anti-diabetic, anti-inflammatory, antioxidant, and wound healing efficacy of *Datura metel* L. leaves. *Arabian Journal of Chemistry*, vol. 15, no. 9, 104112. http://doi.org/10.1016/j.arabjc.2022.104112.

RADULOVIĆ, N., BLAGOJEVIĆ, P. and PALIĆ, R., 2006. Chemical composition of the ether and ethyl acetate extracts of Serbian selected *Tobacco* types: Yaka, Prilep and Otlja. *The Journal of Essential Oil Research*, vol. 18, no. 5, pp. 562-565. http://doi.org/10.1080/10412905.2006.9699168.

RADULOVIĆ, N., BLAGOJEVIĆ, P. and PALIĆ, R., 2010. Volatiles of the grape hybrid cultivar othello (*Vitis vinifera* × (*Vitis labrusca* × *Vitis riparia*)) cultivated in Serbia. *The Journal of Essential Oil Research*, vol. 22, no. 6, pp. 616-619. http://doi.org/10.1080/10412905.2010.9700415.

SAMEJO, M.Q., MEMON, S., BHANGER, M.I. and KHAN, K.M., 2013. Comparison of chemical composition of *Aerva javanica* seed essential oils obtained by different extraction methods. *Pakistan Journal of Pharmaceutical Sciences*, vol. 26, no. 4, pp. 757-760. PMid:23811454.

SÁNCHEZ-PEÑA, P., OYAMA, K., NÚÑEZ-FARFÁN, J., FORNONI, J., HERNÁNDEZ-VERDUGO, S., MÁRQUEZ-GUZMÁN, J. and GARZÓN-TIZNADO, J.A., 2006. Sources of resistance to whitefly (*Bemisia* spp.) in wild populations of *Solanum lycopersicum* var. Cerasiforme (Dunal) Spooner G.J. Anderson et R.K. Jansen in Northwestern Mexico. *Genetic Resources and Crop Evolution*, vol. 53, no. 1, pp. 711-719. http://doi.org/10.1007/s10722-004-3943-9.

SANTOS, C.A.M., VAREJÃO, E.V.V., CASTRO, B.M.C., WILCKEN, C.F., LEMES, P.G., SERRÃO, J.E. and ZANUNCIO, J.C., 2023. Chemical composition of leaf and branch extracts of the wild tomato *Solanum habrochaites* (Solanaceae). *Brazilian Journal of Biology = Revista Brasileira de Biologia*, vol. 83, e274992. http://doi.org/10.1590/1519-6984.274992. PMid:37585935.

SATYAL, P., MAHARJAN, S. and SETZER, W.N., 2015. Volatile constituents form the leaves, fruits (berries), stems and roots of *Solanum xanthocarpum* from Nepal. *Natural Product Communications*, vol. 10, no. 2, pp. 361-364. http://doi.org/10.1177/1934578X1501000239. PMid:25920284.

SAZIMA, M., VOGEL, S., COCUCCI, A. and HAUSNER, G., 1993. The perfume flowers of *Cyphomandra* (Solanaceae): pollination by euglossine bees, bellows mechanism, osmophores, and volatiles. *Plant Systematics and Evolution*, vol. 187, no. 1, pp. 51-88. http://doi.org/10.1007/BF00994091.

SELLI, S., RANNOU, C., PROST, C., ROBIN, J. and SEROT, T., 2006. Characterization of aroma-active compounds in rainbow trout (*Oncorhynchus mykiss*) eliciting an off-odor. *Journal of Agricultural and Food Chemistry*, vol. 54, no. 25, pp. 9496-9502. http://doi.org/10.1021/jf0619582. PMid:17147438.

SHI-DONG, L., YUAN-SHUANG, W., JIANG-SHENG, Z., MING, L. and QING-XIONG, M., 2014. Analysis of aroma components of dark teas from five different production regions by fully automatic headspace solid-phase microextraction coupled with gas

chromatography-mass spectrometry. *Journal of Chemical and Pharmaceutical Research*, vol. 6, no. 1, pp. 246-253.

SILVA, E.B.P., SOARES, M.G., MARIANE, B., VALLIM, M.A., PASCON, R.C., SARTORELLI, P. and LAGO, J.H.G., 2013. The seasonal variation of the chemical composition of essential oils from *Porcelia macrocarpa* R.E. Fries (Annonaceae) and their antimicrobial activity. *Molecules* , vol. 18, no. 11, pp. 13574-13587. http://doi.org/10.3390/molecules181113574. PMid:24189296.

SOUZA, P.P., CARDEAL, Z.D.E.L., AUGUSTI, R., MORRISON, P. and MARRIOTT, P.J., 2009. Determination of volatile compounds in Brazilian distilled cachaca by using comprehensive two-dimensional gas chromatography and effects of production pathways. *Journal of Chromatography. A*, vol. 1216, no. 14, pp. 2881-2890. http://doi.org/10.1016/j.chroma.2008.10.061. PMid:19004451.

TAVARES, W.S., GRAZZIOTTI, G.H., DE SOUZA JÚNIOR, A.A., FREITAS, S.S., CONSOLARO, H.N., RIBEIRO, P.E.A. and ZANUNCIO, J.C., 2013. Screening of extracts of leaves and stems of *Psychotria* spp. (Rubiaceae) against *Sitophilus zeamais* (Coleoptera: Curculionidae) and *Spodoptera frugiperda* (Lepidoptera: Noctuidae) for maize protection. *Journal of Food Protection*, vol. 76, no. 11, pp. 1892-1901. http://doi.org/10.4315/0362-028X.JFP-13-123. PMid:24215693.

URANGA, C.C., BELD, J., MRSE, A., CÓRDOVA-GUERRERO, I., BURKART, M.D. and HERNÁNDEZ-MARTÍNEZ, R., 2016. Fatty acid esters produced by *Lasiodiplodia theobromae* function as growth regulators in tobacco seedlings. *Biochemical and Biophysical Research Communications*, vol. 472, no. 2, pp. 339-345. http://doi.org/10.1016/j.bbrc.2016.02.104. PMid:26926564.

VIEGAS, M.C. and BASSOLI, D.G., 2007. Linear retention index for characterization of volatile compounds in soluble coffee using GC-MS and HP-INNOWAX column. *Quimica Nova*, vol. 30, no. 8, pp. 2031-2034. http://doi.org/10.1590/S0100-40422007000800040.

YANG, Z., ZHU, S. and YU, Z., 2012. Comparison of terpene components from flowers of *Artemisia annua. Bangladesh Journal of Pharmacology*, vol. 7, no. 2, pp. 114-119. http://doi.org/10.3329/bjp.v7i2.10815.