



Chemical and biological properties of *Mentha* × *villosa* Huds. (mojito mint) and its parental species—*Mentha spicata* L. (spearmint) and *Mentha suaveolens* Ehrh. (apple mint)—a review

Szilvia Tavaszi-Sárosi · Ameni Sfaxi · Ákos Juhász · Péter Radácsi · Katalin Patonay



Received: 11 June 2024 / Accepted: 1 May 2025 / Published online: 6 June 2025
© The Author(s) 2025, modified publication 2025

Abstract Chemistry, in vitro antioxidant, and antimicrobial effects of *Mentha* × *villosa* and its parental species, *Mentha spicata* and *Mentha suaveolens*, are discussed. This is the first review of the terpene and phenolic composition of *M. × villosa*. The volatile chemistry of *M. × villosa* is evaluated in the mirror of the parental species, discussed based on structural-biogenetical groups of their terpenoids. In spearmint, there is a wide diversity, involving multiple groups of monoterpenes (such as linalool or cymyl

compounds). The main volatile components in *M. suaveolens* are usually rotundifolone or carvone, and these compounds also determine the chemotype in *M. × villosa*. However, contrary to the parental taxa, *M. × villosa* chemotypes seem connected to geographical origin. The polyphenol profile of the three taxa is also surveyed, in the framework of shikimate metabolism of genus *Mentha*. This means especially the high amounts of rosmarinic acid accompanied by flavanones and a variety of flavones. Even flavonols are major components, although they are considered atypical in *Mentha*. The preparation and extraction methods are also presented for better comparison

Supplementary Information The online version contains supplementary material available at <https://doi.org/10.1007/s11101-025-10136-3>.

S. Tavaszi-Sárosi (✉) · A. Sfaxi · P. Radácsi
Institute of Horticultural Science, Department of
Medicinal and Aromatic Plants, Hungarian University of
Agriculture and Life Sciences (MATE), Villányi St.
29-35, Budapest 1118, Hungary
e-mail: tavaszi-sarosi.szilvia@uni-mate.hu

A. Sfaxi
e-mail: amenisfaxi0@gmail.com

P. Radácsi
e-mail: radacsi.peter@uni-mate.hu

Á. Juhász
Institute of Genetics and Biotechnology, Department of
Microbiology and Applied Biotechnology, Hungarian
University of Agriculture and Life Sciences (MATE),
Szent-Györgyi A. St. 4, Gödöllő 2100, Hungary
e-mail: juhasz.akos@uni-mate.hu

K. Patonay
Food and Wine Knowledge Centre, Eszterházy Károly
Catholic University (EKKE), Leányka St 8 (Building G),
Eger 3300, Hungary
e-mail: patonay.katalin@uni-eszterhazy.hu

between compositional data and a survey of methods for the extraction of polyphenols. Regarding bioactivity, much less experimental work has been done on *M. × villosa* than on the parental taxa. *M. × villosa* can be a prospective medicinal plant not only used for flavoring. It can be a substitution for carvone-type spearmint. However, much more work is necessary to optimize its cultivation, focusing on different types of components and defining its biological activity properly.

Keywords *Mentha × villosa* · *Spicata* · *Suaveolens* · Antioxidant · Antimicrobial

Introduction

Mints are perennial herbaceous plants belonging to the *Lamiaceae* family. Mint (genus *Mentha*) is one of the plant genera with major global industrial and culinary applications. They are widespread in many countries, but the majority are in Europe and Africa, mainly in humid and temperate regions (Jullien 2007; Bakkali et al. 2008). They have a quadrangular stem and opposite, lanceolate, oblong-ovate, or ovate leaves with dentate or serrate margins. The leaves' color ranges from dark green to grey-green. Essential oil components, which provide the characteristic aromas of mint taxa, are produced in glandular hairs both on the flowering stems and the leaves. The structure of these glandular organs is specific to *Lamiaceae*. Leaves can be haired. The density and structure (stellate or non-branched) of these white covering hairs are often considered taxonomical markers. The flowers' color ranges from white to purple. After blooming, fertile mint taxa produce nutlets including 1–4 brownish or black-brown seeds. Furthermore, all (both fertile and infertile) mint taxa propagate effectively by their stolons. These are 2–4 mm in diameter, white or anthocyanic purplish, and develop vegetative shoots at their nodes and ends. Thus, they are tools for propagating and sustaining mint genotypes with desirable compositional and/or decorative value. They run on the surface or at 1–3 mm depth.

Nowadays, plants are used to produce pharmaceuticals. Among the most significant pharmaceuticals with an herbal origin are immunomodulatory, antispastic, anti-inflammatory, anti-cancer, and

antibacterial medications. The essential oil (EO) of mint species is considered one of the most significant pharmaceuticals that have these properties (Tafrihi et al. 2021). Among mint species, peppermint is only official in the European Pharmacopeia, as well as in the European Union Herbal Monographs, where the following description can be read: “Mint can be used for digestive disorder, coughs, cold, muscle pain, and inflammation of skin”. It is also used all over the world to flavor tea as well as provide flavor to savory and sweet foods (EMA 2018).

Because of the hybridization of the natural mint populations, the proper number of existing mint species is hard to define. According to Tucker and Naczi (2007), the genus *Mentha* includes 18 species and 11 hybrids. Some mint taxa have different names, but considering their taxonomy, they are the same species. For example, *M. suaveolens* and *M. rotundifolia* are synonym names, as well as *M. spicata* and *M. viridis*. There is a confusing detail that a hybrid species also exists with the name of ‘*rotundifolia*’—*Mentha × rotundifolia*—that is a hybrid species of *M. longifolia* and *M. suaveolens*. The only difference is the sign “×”. Therefore, it would be important to give not only the name of the evaluated plant species but also a short morphological description in the scientific articles. It is very important to study the taxa considering the complicated taxonomy of the genus *Mentha* (Moetamedipoor et al. 2021).

In the previous review articles, the whole genus has been evaluated from a chemical and pharmacological point of view. Several species were involved in the studies (Kumar et al. 2011; Salehi et al. 2018; Eftekhari et al. 2021). In the present study, we follow a different approach. Comparative evaluation of a less well-known taxon, mojito mint (*M. × villosa*), and its parental species apple mint and spearmint. What is common, and what is different in these species? What type of active compounds are they accumulating, especially focusing on terpenes and polyphenols? Based on the literature data, can it be proven that mojito mint holds both advantageous characteristics of the parental species? To the best of our knowledge, there is no detailed review article on *M. × villosa*, completed with the important data of its parental species as well.

Since all represented mint species are found in the gene bank of the Department of Medicinal and Aromatic Plants, Hungarian University of Agriculture

and Life Sciences, in the botanical descriptions, our data and pictures are given. Proper taxonomical and botanical description here is considered to bear paramount importance. Besides this, their chemistry is discussed in detail. A systematic review is undertaken on the essential oil composition and chemotaxonomy of the three taxa, along with their polyphenol profile, within the broader context of the polyphenol chemistry of the genus, as this latter seems to be not totally in the common focus. Furthermore, the study covers the *in vitro* antioxidant, antibacterial, and antifungal effects of the three taxa, highlighting some contradictions in the literature data.

Materials and search strategy

Studies were primarily collected from journal databases of Springer, Elsevier, American Chemical Society, Thieme, Taylor, and Francis, along with the archives *JSTOR* and *HAL*. Systematic searching on

PubMed, Google Scholar, and ResearchGate was also performed. These forums, especially ResearchGate, were useful in searching reliable but less cited and/or non-English sources like the work of Il Idrissi and Bellakhdar (1989) on the essential oil chemotaxonomy of *M. suaveolens* (written in French). References in available publications were also screened for further sources, e.g., PhD theses (like Kapp 2015; González-Martínez 2016; Medeiro Gomez, 2022) or lesser-known research articles. Comprehensive reviews on the different areas of chemistry and usage of the genus *Mentha* or family *Lamiaceae* were also used. These were, e.g., Ulubelen et al. (2005), Mimica-Dukić et al. (2008), Pereira and Cardoso (2013), and Salehi et al. (2018). Regarding taxonomy, morphology, plant geography, essential oil (EO) chemistry, and EO chemotaxonomy of *Mentha* spp., the monography of Lawrence (2007a, b) was also used.

In the discussion of essential oil (EO) chemistry, constituents at or above 5 area% are considered as major components, similar to the works of Başer et al.



Fig. 1 *Mentha* × *villosa* in the experimental field of the Hungarian University of Agriculture and Life Sciences, Soroksár (Photo: Tavaszi-Sárosi 2023)

(1999; 2012) on chemosystematics of *Mentha* taxa in Türkiye.

Taxonomy and botanical aspects of mojito mint, spearmint, and apple mint

Mentha × villosa Huds. (mojito mint)

Mentha × villosa, commonly known as mojito mint, is the hybrid of *Mentha spicata* L. and *Mentha suaveolens* Ehrh ($2n = 36$). Three varieties are known: var. *villosa*, var. *alopecuriodes*, and var. *nicholsoniana* (Tucker and Naczi 2007). In the study of the Australian-Egyptian author Hanafy and her coworkers, *M. × villosa* var. *alopecuriodes* and *M. × niliaca* (Egyptian mint) are given as synonyms (Hanafy et al. 2017). *M. × villosa* is native to the Mediterranean region and western Asia (Bezerra et al. 2019). It is a perennial herb that grows up to 1 m tall. It has a square stem that is covered with fine hairs. The leaves are greenish, opposite, ovate to lanceolate, serrated, and densely covered with fine hairs. The leaf length is approximately 4 cm. The flowers are 1–3 mm long

and arranged in whorls on a spike-like inflorescence. The color of the flowers is pink to lavender. The essential oil has a refreshing minty aroma and is used in the production of perfumes, cosmetics, and flavorings, especially in mojito cocktails in South America. A picture of the flowering plant can be seen in Fig. 1.

Mentha spicata L. (spearmint)

Mentha spicata ($2n = 48$), spearmint, is probably an ancient natural hybrid of *M. longifolia* and *M. suaveolens* (Tucker and Naczi 2007; Wilson 2016), however, the botanical name is not signed. Its synonym name is *M. viridis*. It can naturally occur next to streams, lake shores, wet fields, and roads in the temperate and Mediterranean regions of Eurasia and Northern Africa. As a domesticated plant, it is one of the economically most important *Mentha* taxa (Lawrence 2007a, b). Its well-known variety is *crispata*. It is a rhizomatous, perennial plant species (Kedia et al. 2014). The plant varies in height from 40 to 130 cm, and it tends to extend the branches, especially in bloom. Similar to other mint species, *M. spicata* has a quadrangular stem and opposite leaves. It



Fig. 2 *Mentha spicata* in the experimental field of the Hungarian University of Agriculture and Life Sciences, Soroksár (Photo: Tavaszi-Sárosi 2023)



Fig. 3 *Mentha suaveolens* in the experimental field of the Hungarian University of Agriculture and Life Sciences, Soroksár (Photo: Tavaszi-Sárosi 2023)

has middle-green colored leaves (5–6 cm long, serrated or entire) and pink to purple-colored flowers arranged in whorls. It is fertile and produces further hybrids easily. It has a very characteristic sharp, strong, minty, and/or carvonaceous taste and smell (Chrysargyris et al. 2017). Nevertheless, its EO composition shows extreme diversity (see Chapter 4). Spearmint plantation and flowering shoots can be seen in Fig. 2.

Mentha suaveolens Ehrh. (apple mint)

Mentha suaveolens ($2n = 24$), or so-called apple mint, is also an herbaceous, perennial species (Fig. 3) (Tucker and Naczi 2007). It is split into three subspecies, *suaveolens*, *insularis*, and *timija* (Oumzil et al. 2002; Tucker and Naczi 2007; Benayad et al. 2012). The name “*suaveolens*” is divided into two parts, “*suaveo*” from the Latin name “*suavis*” meaning sweet and “*olens*” from “*oleo*” meaning smell. The height of the plant can reach 100 cm (Božović et al. 2015). It is naturally found in Europe, North Africa, Canary Islands, Balears, and Corsica next to

roads, streambanks, and in wet fields (Tucker and Naczi 2007; Sutour et al. 2010). The stem is quadrangular and straight. The leaves are sessile. They are round, dentated, and covered by fine white hairs. The flowers are almost white, arranged in whorls, like the other two species. Apple mint has a fruity smell and flavor. It is also involved in cultivation, primarily as an aromatic plant.

Active constituents of mojito mint, spearmint, and apple mint—Essential oil components

In chapters 4 and 5, which deal with EO and polyphenol chemistry of the three taxa, the order of the subsections will be different as it was in the chapter on botany. Although the mojito mint is the focus of the review, the chemistry of her parent taxa is discussed first, beginning with *M. spicata*, which is the most studied and, regarding volatile chemistry, the most diverse. This was arranged because, as it was mentioned earlier, the chemistry of mojito mint here is derived from/compared to the chemistry of the parent

Table 1 Essential oil composition and grouping of *Mentha spicata*: groups based on open-chain terpenes, limonene, and limonene 2-oxo-derivatives

Group	References	1	Area%	2	Area%
Open chain	Góra and Kalembe, (1979)	Linalool	75.60–85.30	NA	
	Mimica-Dukić et al. (1991)	Linalool	81.25	Nothing else	
	Kofidis et al. (2004)	Linalool	85–94	Nothing else	
	Kokkini, Vokou et al. (1989)	Linalool	62.50–75.30	Myrcene I.N	4.70–5.90
	Telci et al. (2004)	Linalool	81.70–82.80	Carvone I. N	4.98–8.80
Carvone and limonene without other majors	dos S. Franciscato et al. (2018)	Linalool	58.51	Carvone I. N	15.10
	Rasooli et al. (2008)	Carvone I. N	78.90	Nothing else	
	Chowdhury et al. (2007)	Carvone I. N	73.29	Nothing else	
	Fitsiou et al. (2016)	Carvone I. N	85.41	Limonene	8.41
	Benomari et al. (2018)	Carvone I. N	79.30	Limonene	8.41
	Shahbazi and Shavisi (2016)	Carvone I. N	78.76	Limonene	11.50
	Chauhan et al. (2011)	Carvone I. N	76.55	Limonene	9.57
	de Sousa Barros, (2015)	Carvone, D-	54.94	Limonene	28.10
	Boukhebt et al. (2011)	Carvone I. N	59.40	Limonene	6.13
	Verma et al. (2011)	Carvone I. N	52.06	Limonene	22.32
	Benomari et al. (2018)	Carvone I. N	54.10	Limonene	21.30
	Nikšić et al. (2018)	Carvone I. N	56.40	Limonene	16.20
	Chauhan et al. (2011)	Carvone I. N	64.00	Limonene	8.40
	Narasimhamoorthy et al. (2015)	Carvone I. N	53.99	Limonene	12.62
	Piras et al. (2021)	Carvone, D-	62.90	Limonene	8.50
	Hussain et al. (2010a)	Carvone I. N	59.50	Limonene	10.44
	Sertkaya et al. (2010)	Carvone I. N	57.90	Limonene	9.87
	Kehili et al. (2020)	Carvone I. N	52.60	Limonene	24.99
	Snoussi et al. (2014)	Carvone I. N	40.80	Limonene	20.80
Limonene 2-oxo (carvone) derivatives and miscellaneous majors	Shahbazi (2015)	Carvone I. N	78.76	Limonene	11.50
	Hussein et al. (2010b)	Carvone I. N	51.70	c-Carveole	24.30
	Govindarajan et al. (2011)	Carvone I. N	48.60	c-Carveole	21.30
	Vian et al. (2008)	Carvone I. N	45.50	c-Carveole	16.90
	Znini et al. (2011)	Carvone I. N	29.00	t-Carveole	14.00
	Buleandra et al. (2016)	Carvone I. N	36.90	Dihydrocarveole	11.50
	Bishr and Salama, (2018)	Carvone I. N	31.33	p-Cymene	24.44
	Başer et al. (1999)	Carvone I. N	41.00	1,8-Cineole	18.80
	Sivropoulou et al. (1995)	Dihydrocarveole	34.80	Carvone I. N	33.34
	Laggoune et al. (2016)	c-Carvone oxide	44.06	1,8-Cineole	15.32

See also Supplements 1 & 4, main compounds are in bold

I.N. isomer *not* provided, *c* *cis*, *t* *trans*, *Nothing else* no further major constituents are present

taxa, along with (in the case of phenolics) a comparison to the entire genus.

An outlook on the essential oil typology of *Mentha spicata*

The main volatile compounds of spearmint are summarized in Tables 1 and 2. Supplement 1 provided

Table 2 *M. spicata* essential oil groups, reference, area% of the first 2 major components (continued)

Group	References	1	Area%	2	Area%
Limonene-3-oxo ketones	Teixeira et al. (2014)	Piperitone	81.18	Piperitenone	14.57
	Gonçalves et al. (2009)	Pulegone	55.49	1,8-Cineole	9.23
	Tayarani-Najaran et al. (2013)	Pulegone	56.28	α-Terpineol***	8.91
	Başer et al. (1999)	Menthone	62.00	Isomenthone	17.00
	Clark (1994)	Menthone	57.82	Isomenthone, d-	18.20
	Omar et al. (2009)	Menthone	32.43	1,8-Cineole	18.79
Limonene-3-oxo epoxides	Sartoratto et al. (2004)	Rotundifolone	94.10	Nothing else	
	Chauhan et al. (2011)	Rotundifolone	79.20	Nothing else	
	Azeem et al. (2019)	Rotundifolone	47.10	1,8-Cineole	12.00
	Koliopoulos et al. (2010)	Rotundifolone	35.70	t-Calamenene	6.40
	Kokkini et al. (1997)	t-Piperitone oxide	89.20	N.A	
	Kokkini et al. (1997)	t-Piperitone oxide	53.80	1,8-Cineole	17.60
	Karousou et al. (1998)	t-Piperitone oxide	44.95	Piperitenone oxide	15.68
	Kokkini et al. (1997)	t-Piperitone oxide	42.80	Piperitone	23.60
	Pavela et al. (2014)	Piperitone oxide I.N	34.10	Menthol, L-(-)	14.90
	Cook et al. (2007)	t-Piperitone oxide	33.50	Piperitenone oxide	26.20
	Cook et al. (2007)	t-Piperitone oxide	19.80	Piperitenone oxide	19.70
Cymyl compounds	Zeinali et al. (2005)	Carvacrol	49.60	1,8-Cineole	6.70
	Zeinali et al. (2005)	p-Cymene	48.90	t-Carvylacetate	31.90
	Zeinali et al. (2005)	p-Cymene	48.60	t-Carvylacetate	32.20
	Kizil and Tonçer, (2006)	p-Cymene	9.60–20.70*	Carvone I. N	48.6–57.9*
	Stoeva and Iliev, (1997)	1,8-Cineole	26.33–32.36**	p-Cymene	19.72–20.24**
Others	Cook et al. (2007)	1,8-Cineole	40.50	Piperitenone oxide	20.60
	Narasimhamoorthy et al. (2015)	α-Cubebene	25.70	β-Caryophyllene	15.51
	Narasimhamoorthy et al. (2015)	Mint lactone	30.24	Myrcene, I.N	15.07
	Chauhan et al. (2011)	α-Humulene	29.90	Rotundifolone	24.40
	Başer et al. (1999)	t-Sabinene hydrate	21.90	Carvone	18.60

See Suppl. 1 & 4, main compounds are in bold

I.N. isomer *not* provided, *c cis*, *t trans*, *Nothing else* no further major constituents are present

*Interval in samples taken consecutively at pre-flowering, flowering, and post-flowering

**Different cytokinin treatments

***Structure: see 45 in Supplement 4

much more precise detail, including the concentration of the first five major components, along with important data on the plant material (organ,

domestication status, phenophase, country). In supplement 4, structural formulae of essential oil components described from all the discussed taxa are

provided. All structures in this supplement have a number, which is placed into the text where the component is first mentioned. Numbering begins with (I) to geraniol as it is closest to the common monoterpene precursor geranyl pyrophosphate.

M. spicata is known for its high essential oil chemodiversity (Lawrence 2007a; Németh-Zámboriné 2016; Salehi et al. 2018; Mahendran et al. 2021a, b), likely due to its genetic diversity. The widest variety of composition can be observed primarily in wild-growing accessions. Cultivated spearmint usually belongs to limonene-2-oxo or limonene-3-oxo chemotypes, although some cultivars, such as CS87 in Bulgaria (Stoeva and Iliev 1997), represent other chemotypes. Recent reviews of *M. spicata* provide a vast amount of compositional data from 1995 to 2020, but this is not provided in a structured, chemotaxonomical, or geographical grouping. As mentioned earlier, we intend to discuss composition on a structural and biogenetical basis. Therefore, spearmint oils can be divided into the following groups. **I)** EOs based on open-chain monoterpenes, primarily linalool (4), which can be escorted by myrcene (3, isomer not indicated). **II)** carvone (7)-limonene (6) type oils. It is the combination of volatiles to which the spearmint scent is usually associated. **III)** oils based on carvone and related compounds, namely: *cis*-carvone oxide (8), *cis*- and *trans*-dihydrocarvone (9,10), *cis*- and *trans*-carveole (11,12) their acetates (13,14), neodihydrocarveole (15) and its acetate (16).

IV) oils based on limonene-3-oxo ketones: isopiperitenone (17), pulegone (18), menthone (19), isomenthone (20), piperitenone (22), piperitone (23).

V) limonene-3-oxo-1,2-epoxide based oils: piperitenone oxide syn. rotundifolone (24), piperitone oxide isomers (25, 26). Regarding limonene-3-oxo-type spearmint oils (groups IV and V), menthol (31), or other alcohols along with menthofuran (37), are usually absent. However, menthyl acetate isomers (see structure 33 depicting (-)-menthyl acetate) may accompany limonene-3-oxo epoxides as major components (Lawrence 2007a, b). In a USA-originated breed, a further limonene-3-oxo derivative, mint lactone (35) is reported as a major component, together with myrcene (Narasimhamoorthy et al. 2015).

VI) oils rich in cymyl compounds: thymol (39), carvacrol (41), p-cymene (42), escorted by their probable precursor γ -terpinene (38).

VII) oils based on other cyclic monoterpenes, like sabinene hydrate isomers (51).

All the abovementioned monoterpenes are frequently escorted by 1,8-cineole syn. eucalyptol (44) in larger (5–40%) ratios. Besides this wide variety of monoterpenes, an array of sesquiterpenes also can be majors in spearmint EO, in highly variable ratios (5–29.9 area %, see Table 2). These are derivatives of humulyl cation: α - and β -caryophyllene (55, 56), or derivatives of germacryl cation, representing multiple structural groups. Germacrene D (59), bicyclogermacrene (58), γ -muurolene (60), α -cadinol (61), *trans*-calamenene (62), α -cubebene (63), β -bourbonene (64), and longifolene (65) are the volatiles from *M. spicata* belonging to the germacryl cation. Most of them occur seldom as a major component, while germacrene D is relatively more frequent. For their structural formulae, see Suppl. 4, Fig. S4.8. Germacrene D and β -caryophyllene are often reported from *M. spicata*'s parental taxon, *Mentha longifolia*, as major EO components (Patonay and Németh-Zámboriné, 2021). The sesquiterpenes listed here can bear scent or flavor notes different from the usual minty aromas.

It is important to note that both sabinene derivatives (thujane backbones) and cymyl compounds (thymol, carvacrol, and their esters), along with γ -terpinene, are atypical in the genus *Mentha*. The exact steps of their biosynthetic pathway in this genus are not known yet. (Neither the biosynthesis of sesquiterpenes in the genus is studied in detail.)

An outlook on the essential oil typology of *Mentha suaveolens*

The main volatiles of apple mint are summarized in Tables 3 and 4. In Supplement 2, it is provided more deeply detailed, the same as in the case of spearmint. For structural formulae of these volatiles, see Supplement 4.

Németh-Zámboriné (2016) summarizes *M. suaveolens* as a mint species with a low extent of chemodiversity. This is distinctive if this species is compared to *M. spicata*. Only one single reference reports non-limonene-derived composition from apple mint: Linalool, 35.32%; p-Menth-1 en-8-ol (β -terpineol,

Table 3 Essential oil composition and grouping of *Mentha suaveolens*. Groups based on piperitone epoxide alone, limonene-3-oxo-1,2-epoxides mixed, and limonene-3-oxo-1,2-epoxides + non-limonene originated majors. Group based on limonene-3-oxo ketones

Group	References	1	Area%	2	Area%
Piperitenone epoxide (rotundifolone)	Zekri et al. (2014)	Piperitenone epoxide	74.69	Nothing else	
	Zekri et al. (2014)	Piperitenone epoxide	81.67	Nothing else	
	Vining et al. (2019)	Piperitenone epoxide	88.50	Nothing else	
	Vining et al. (2019)	Piperitenone epoxide	84.97	Nothing else	
	Vining et al. (2019)	Piperitenone epoxide	88.80	Nothing else	
	Vining et al. (2019)	Piperitenone epoxide	77.80	Nothing else	
	Vining et al. (2019)	Piperitenone epoxide	80.56	Nothing else	
	Vining et al. (2019)	Piperitenone epoxide	86.72	Nothing else	
	Vining et al. (2019)	Piperitenone epoxide	84.82	Nothing else	
	Vining et al. (2019)	Piperitenone epoxide	77.75	Nothing else	
	Pietrella et al. (2011)	Piperitenone epoxide	90.00	No other majors reported	
	Nagell et al. (1974)	Piperitenone epoxide	81.25	No other majors reported	
Limonene-3-oxo-1,2-epoxides	Başer et al. (1999)	Piperitenone epoxide	47.00	<i>t</i>-Piperitone epoxide	26.00
	Vining et al. (2019)	Piperitenone epoxide	71.83	<i>t</i>-Piperitone epoxide	16.70
	Vining et al. (2019)	Piperitenone epoxide	75.06	<i>t</i>-Piperitone epoxide	7.81
	Vining et al. (2019)	<i>t</i>-Piperitone epoxide	59.65	Piperitenone epoxide	19.34
	Vining et al. (2019)	<i>t</i>-Piperitone epoxide	56.35	<i>c</i>-Piperitone epoxide	18.23
Limonene-3-oxo-1,2-epoxides and other derivatives	El Moussaoui (2013)	Piperitenone epoxide	41.84	(-)-Isopulegol	11.95
	Başer et al. (2012)	Piperitenone epoxide	63–77	Limonene	2 to 6
	Lawrence (2007a, b)	<i>t</i>-Piperitone epoxide	40.50	Hydroxy-<i>p</i>-menth-3-one*	29.30
	Lawrence (2007a, b)	<i>t</i>-Piperitone epoxide	50.80	1,2-Epoxyneomenthyl ac	26.40
	Lawrence (2007a, b)	1,2-Epoxyneomenth. ac	66.50	<i>t</i>-Piperitone oxide	15.00
Limonene-3-oxo-1,2-epoxides and non-limonene-derived majors	Bengali et al. (2020)	Piperitenone epoxide	39.11	Germacrene D	13.60
	Elansary et al. (2013)	Piperitenone epoxide	35.14	Germacrene D	22.65
	Oumzil et al. (2002)	Piperitenone epoxide	56.00	<i>p</i>-Cymen-8-ol	20.60
	Vining et al. (2019)	Piperitenone epoxide	77.72	<i>t</i>-Sabinene hydrate	5.60
	Il-Idrissi et al. (1989)	Piperitenone epoxide	58.00	Geraniol	12.60
	Il-Idrissi et al. (1989)	Piperitenone epoxide	56.00	<i>p</i>-Cymen-8-ol	20.60
	Il-Idrissi et al. (1989)	Piperitenone epoxide	65.00	<i>p</i>-Cymen-8-ol	9.00
	Il-Idrissi et al. (1989)	Piperitenone epoxide	50.00	<i>p</i>-Cymen-8-ol	6.00
	Il-Idrissi et al. (1989)	Piperitenone epoxide	26.00	Piperitone epoxide I. N	26.00
Limonene-3-oxo ketones	El Arch et al. (2003)	Pulegone	85.47	Nothing else	
	Vining et al. (2019)	Pulegone	86.20	Nothing else	
	Oumzil et al. (2002)	Pulegone	50.00	<i>p</i>-Cymen-8-ol	10.40
	Vining et al. (2019)	Piperitenone	82.00	Nothing else	
	Benayad et al. (2012)	Piperitenone	33.03	Pulegone	17.61
Limonene-3-oxo ketones and alcohols	Derwich et al. (2010)	Menthol I.N	40.50	Menthone	5.00
	Handa et al. (1964)	Neoiso(iso)pulegol	52.30	Isopiperitenone	13.40
	Pérez Raya et al. (1990)	Piperitol	57.60	Rotundifolone	10.40

Table 3 continued

Group	References	1	Area%	2	Area%
<i>cis</i> , <i>cis</i> -p-Menthenolide rich types	Petretto et al. (2014)	Pulegone	46.52	Piperitone I.N	18.29
	Poli et al. (2018)	Pulegone	44.4	<i>c,c</i>-p-Menthenolide	12.23
	Sutour et al. (2010)	Pulegone	15.70–61.60	<i>c,c</i>-p-Menthenolide	5.90–57.90

See Suppl. 2 & 4, main compounds are in bold

I.N. isomer not provided, *c cis*, *t trans*, *ac* acetate, *Nothing else* no further major constituents are present

*Hydroxy-p-menth-3-one syn. 1-Hydroxymenthone: for structure, see **21** in Suppl. 4

structure: **49**), 11.08%; 1,8-cineole, 8.46%; myrcene (isomer not indicated) 5.3%. This was grown in Egypt; the breeding material is from Massachusetts. All other apple mint EO batches found in the literature are based on different limonene-oxo derivatives. Substances from other pathways only accompany them. A further difference from spearmint is that 1,8-cineole, as a major component, was found to be unusual.

Here, we intend to expand the previous review of apple mint (Božović et al. 2015) with new sources and the systematic biogenesis/structure-based view mentioned earlier. Ratios of the different epoxides, ketones, and/or substances accompanying them may influence the aroma and bioactive (e.g., antibacterial) activity of EO. Thus, it is proposed that groups of apple mint oils be established as follows: **I**) based on piperitenone epoxide (rotundifolone) alone, **II**) limonene-3-oxo-1,2-epoxides mixed (= rotundifolone + piperitone epoxide isomers in variable ratios), and **III**) limonene-3-oxo-1,2-epoxides along with non-limonene originated majors. **IV**) rich in limonene-3-oxo ketones, **V**) rich in limonene-3-oxo ketones + alcohols (like neoiso(iso)pulegol (**28**), etc.), **VI**) *cis,cis*-p-Menthenolide-based EOs, as this lactone appears as a determinative constituent in an array of ssp. *insularis* samples (Sutour et al. 2010). According to the structure of *cis,cis*-p-menthenolide (**36**), it is an isomer of mint lactone (**35**). **VII**) Apple mint oils rich in carvone, its related compounds (carveols, dihydrocarveols, their esters, dihydrocarvones), and/or limonene. This type is not as widespread in *M. suaveolens* as in *M. spicata*.

In many cases, piperitenone epoxide (rotundifolone) or a related ketone alone covers 70–90% area%. Apple mint EOs dominated only by piperitenone epoxide are reported from multiple points in

Europe, Northern Africa, and the USA in 1974–2022. These findings are in the focus of scientific interest because of the multifaceted bioactivity of **rotundifolone** (e.g., Lima et al. 2014; Božović et al. 2015). Llorens-Molina et al. (2017) studied the diurnal changes in the composition of two accessions from Spain. One was indicated as 'pure piperitenone epoxide chemotype', demonstrating 80.7–91.3% piperitenone epoxide content in EO in dependence on time and plant organ. Limonene-oxo alcohols like menthol are not abundant, and menthofurane (**37**) is found to be absent. Lawrence (2007a, b) reports about batches rich in 1,2-epoxymethyl acetate (**34**) isomers.

Important to note, batches based on epoxides accompanied by miscellaneous major constituents were reported primarily from Northern African wild-growing accessions till now and provide some unusual constituents above 5 area% (see Supplement 2 in detail). For example, *para*-cymen-8-ol (**43**), a γ -terpinene derivative representing some other (probably also unknown) pathway than of thymol isomers in *Mentha*, was found as major constituent in Moroccan batches: 20.60% by Il-Idrissi and co-author (1989), from ssp. *timija*, and by Oumzil et al. (2002) 10.40%. *para*-Cymen-8-ol was not found to be mentioned from any other *Mentha* sp. till May 2024. Regarding its structure, it may be a rarity in the entire genus. It is not known if it is a specialty of *M. suaveolens* and/or if it is bound to ssp. *timija*. Moroccan ssp. *timija* accessions bearing geraniol (12.6%) or δ -fenchol (?) (9.8%) beside piperitenone oxide were also found (Il-Idrissi and co-author, 1989). For the volatile terpenoid assigned as δ -fenchol, no structural data were found till 1 March 2025. Both fenchane-backbone volatiles and geraniol are atypical in *Mentha* spp.

Table 4 *M. suaveolens* essential oil groups, reference, area% of the first 2 major components (continued): groups based on limonene-2-oxo volatiles

Group	References	1	Area%	2	Area%
Carvone/limonene rich	Moetamedipoor (2021)	Carvone I.N	55.10	Limonene	17.40
	El-Kashoury et al. (2014)	Carvone I.N	50.59	Limonene	31.25
	Vining et al. (2019)	Carvone I.N	65.30	Limonene	18.10
	Vining et al. (2019)	Carvone I.N	72.30	Limonene	11.30
	Vining et al. (2019)	Carvone I.N	64.60	Limonene	22.10
	Vining et al. (2019)	Carvone I.N	79.20	Limonene	9.70
	Vining et al. (2019)	Carvone I.N	66.13	Limonene	14.97
	Vining et al. (2019)	Carvone I.N	74.51	Limonene	10.70
	Vining et al. (2019)	Carvone I.N	73.61	Limonene	10.95
	Galambosi et al. (1997)	Carvone I.N	62.30	Limonene	15.80
Carvone and derivatives	Aldogman et al. (2022)	Carvone I.N	43.65–64.36	<i>t</i>-Carveole	1–5.50
	Hendriks and van Os (1976)	<i>c</i>-Dihydrocarvone	43.20	Neodihydrocarvyl ac	17.00
	Lawrence et al. (2007a, b)	<i>c</i>-Dihydrocarvone	38.40	<i>c</i>-Dihydrocarvone	10.40
	Lawrence et al. (2007a, b)	Carvone I.N	48.50	<i>c</i>-Carvyl acetate	22.50

See also Supplements 2 & 4, main compounds are in bold

I.N. isomer *not* provided, *c* *cis*, *t* *trans*, *ac.* acetate

An outlook on the essential oil typology of *Mentha × villosa*

The essential oil chemistry of *M. × villosa*, a common spice plant and ethnomedicine in Brazil and some European countries, is not yet reviewed. Its main volatile compounds and their grouping are presented in Table 5 and Supplement 3. This is built up the same way as Suppl. 1–2. For structural formulae, see Supplement 4.

Mojito mint is similar to apple mint in several aspects, including the absence of non-limonene derived composition patterns, piperitenone epoxide (**rotundifolone**) rich accessions, carvone/limonene types, and types based on different carvone derivatives. Note that, according to the monography of the genus (Maffei et al. 2007), the escorting of carvone and related volatiles by higher concentrations of limonene is a common trait in limonene-2-oxo type mints, independent of their taxon. Maffei and co-authors (2007) suggest that limonene-6-hydroxylase leading to limonene-2-oxo products is less efficient than its analogue limonene-3-hydroxylase, thus, the quantity of the leftover limonene is higher than in limonene-3-oxo type mints.

However, the composition of mojito mint differs significantly from apple mint in several important characteristics. Sesquiterpenes are more frequent in mojito mint, accounting for 5–20% of the EO and represented by a couple of hydrocarbons. Germacrene D, which occurs as a major component in spearmint and horsemint, is also found to be relatively frequent in mojito mint.

1,8-Cineole emerges as a major component in mojito mint, providing 5–20% of the EO in many cases. This is a similarity to spearmint and a sheer difference from apple mint.

Furthermore, the extent of variety in limonene-derived constituents observable in apple mint is not found in mojito mint, although the main compound types are common in the two taxa. The groups established to this taxon include types **I**) based on limonene-3-oxo-1,2-epoxides, **II**) piperitenone epoxide (rotundifolone), **III**) limonene-3-oxo ketones and alcohols, **IV**) carvone and limonene, without other major constituents, and **V**) carvone and other limonene-2-oxo derivatives together. Note that thymol acetate (**40**) was found in a Northeastern Brazilian EO batch, the only record of a cymyl compound above 5 area% in a mint oil not from horsemint or spearmint.

Table 5 *M. × villosa* essential oil groups, reference, area% of the first 2 major components

Group	References	1	Area%	2	Area%
Piperitenone epoxide (rotundifolone)	Lahlou et al. (2001)	Piperitenone oxide	95.87	Nothing else	
	Sousa (1999)	Piperitenone oxide	79.03	Nothing else	
Rotundifolone/limonene	Lima et al. (2014)	Piperitenone oxide	70.96	Limonene	8.75
	Guerra et al. (2015)	Piperitenone oxide	70.20	Limonene	6.20
Limonene-3-oxo-1,2-epoxides and miscellaneous majors	Matos et al. (1999)	Piperitenone oxide	61.18	1,8-Cineole	7.31
	Teles et al. (2013)	Piperitenone oxide	64.53–72.50*	Germacrene D	9.00–9.67*
	Teles et al. (2013)	Piperitenone oxide	61.83–74.03*	Germacrene D	4.60–8.00*
	Teles et al. (2013)	Piperitenone oxide	64.80–70.83*	Germacrene D	5.07–11.20*
	Lahlou et al. (2001)	Piperitenone oxide	62.32	γ-Murolene	16.02
	Matos et al. (1999)	Piperitenone oxide	55.40	γ-Murolene	11.30
	de Martins et al. (2007)	Piperitenone oxide	35.35	Piperitone	9.64
	Benabdallah et al. (2018)	Piperitenone oxide	52.17	Bicyclogermacrene	16.79
Miscellaneous C ₁₀ Carvone/limonene	Moetamedipoor (2021)	Neomenthol***	22.80	1,8-Cineole	18.60
	Bortoluzzi et al. (2020)	Carvone I.N	83.87	Limonene	6.81
	de Pooter and Schamp, (1987)	Carvone I.N	74.70	Limonene	6.50
	de Pooter and Schamp, (1987)	Carvone I.N	72.60	Limonene	5.60
	Bortoluzzi et al. (2020)	Carvone I.N	68.80	Limonene	17.49
	Pavela et al. (2014)	Carvone I.N	67.30	R(+)-Limonene**	5.30
	González-Martínez, (2016)	Carvone I.N	51.20	Limonene	18.98
Carvone and derivatives	Matos et al. (1999)	Carvone I.N	Nothing else		
	Kapp (2015)	Carvone I.N	55.90	Dihydrocarvyl ac	15.50

See Suppl. 3 & 4

I.N. isomer not provided, c cis, t trans, ac acetate, Nothing else no further major constituents are present

*Depends on the cultivation site

**Isomer unusual in *Mentha* spp

***For structure, see 32 in Suppl. 4

Based on the literature data (in detail, see Suppl. 3), a question emerges – is it possible that the EO composition of mojito mint can be strongly connected to the geographical origin? In contrast with its two parental species, a clear geographical grouping is

observable in *M. × villosa*. In the mirror of the literature, carvone/carvone derivatives/limonene-based batches are abundant in Europe but rare in Brazil (González-Martínez 2016). Matos et al. (1999), in the study of one carvonaceous and one

Table 6 Methods of extraction applied to *M. × villosa* batches

References	Taxon	Herb weighed in	Solvent; volume	Extraction method
de Medeiros Gomes et al. (2021)	<i>M. × villosa</i>	500 g, crushed	Ethanol 96%; N.A	Maceration in 3 stages, 1 stage = 3 days. Room temperature
Čavar Željkočić et al. (2021)	<i>M. × villosa</i>	50 mg, powdered	Methanol, aqueous, 80%; 1 mL	Sonication in 1 stage, 10 min., frequency: N. A., room temperature
Kapp (2015)	<i>M. × villosa</i> Hudson	N.A	Water; vol: N.A	Infusion by boiling water stands for 5 min
Shen et al. (2011)	<i>M. × villosa</i> “apple mint”	25 mg, powdered	Methanol 100%; 50 mL	Sonication in 1 stage, 20 min., frequency: N. A, temperature N.A
Shen et al. (2011)	<i>M. × villosa</i> “Egyptian mint”	25 mg, powdered	Methanol 100%; 50 mL	Sonication in 1 stage, 20 min., frequency: N. A., temperature N.A
Bittner-Fialová et al. (2020)	<i>M. × villosa</i> cv. ‘Šněžná’	N.A	Water; vol: N.A	Infusion by boiling water, no details provided.*
Fialová et al. (2015)	<i>M. × villosa</i> cv. ‘Šněžná’	N.A	Water; vol: N.A	Infusion by boiling water, no details provided.*
Hanafy et al. (2017)	<i>M. × villosa</i> var. <i>alopecuroides</i>	1 g, powdered	Methanol, aqueous, 50%; 10 mL	Stirring 30 min.; 20–22 °C

rotundifolone/cineole type of mojito mint, also note this. However, as we have seen earlier in the examples from Greece, Algeria, and Iran, limonene-3-oxo types also emerge in Europe/Eurasia, where both carvone and limonene-3-oxo types can spread in the wild and, thus, may be involved in cultivation. A possible background of this disjunction between the Brazilian and European mojito mints may be in the history of cultivation of this taxon in Brazil: further study would be necessary to elucidate if limonene-3-oxo-1,2-epoxide-rich types of this taxon produced a more favorable aroma for the consumers in Brazil. Opinions on the aroma and scent properties of epoxide-rich and carvone/carvone derivative-rich mint essential oils are not uniform. Karousou and co-authors (2007) associate musty aromas with piperitone oxide (isomer not annotated) and/or piperitenone oxide, while sweet scent is associated with them with carvone/dihydrocarvone (isomer not annotated). In contrast, database Pubchem (2024) characterizes piperitenone epoxide (rotundifolone) as a liquid bearing herbaceous minty aroma.

Another important question is the difference in the preparation of plant material. In Europe and the East, (natural) drying is common, and the collected plant part is the flowering shoot. In Brazil, however, mainly fresh leaves are used (e.g. González-Martínez 2016), therefore, essential oil is mainly coming from fresh leaves’ distillation.

Active compounds of mojito mint, spearmint, and apple mint—phenolic compounds

Viewpoints and problems in the study of polyphenol composition in *Mentha* taxa

The chemistry, physiology, and agrotechnology of *Mentha* polyphenol production is far less studied than the background of volatile terpenoids’ production. A couple of authors in the 1990s (Guédon and Pasquier 1994) and 2010s (Pereira and Cardoso, 2013) have already emphasized that *Mentha* phenolics are much less studied. This tendency of a major focus on essential oils is also visible in some recent reviews on *Mentha* spp. (Salehi et al. 2018; Sevindik 2018; Mamadalieva et al. 2020; Tafrihi et al. 2021). It is an interesting contradiction as phenolics contribute to the therapeutic effects of mints (Guédon and Pasquier 1994, Mimica-Dukić et al. 2008) or can serve with industrial raw material (Dudai et al. 2006). There is a lack of screenings performed on large numbers of samples belonging to the same taxon and grown under the same circumstances, unveiling genetically determined diversity in a taxon. Thus, the factors aggravating the evaluation of phenolic chemodiversity of the three taxa are:

- 1) Lack of large-sample screenings—data is sporadic, especially for *M. × villosa*.

- 2) Different plant parts in the investigation
- 3) Phenophase is not given in the study
- 4) In an array of cases, inadequate categorization of constituents
- 5) Concentrations given in different units of measurement
- 6) Different extraction methods, influencing yields of phenolics.

In Sects. “Extractability and polyphenol composition of *M. spicata*”, “Polyphenol composition and extractability of *Mentha suaveolens*”, “Extractability and polyphenol profile of *Mentha × villosa*” and their supplements, we survey phenolics of the discussed taxa in the framework of the shikimate metabolism of their genus. Cinnamates (highlighting rosmarinic acid, RA), benzoates, flavanones, flavones, flavonols, catechins, and anthocyanins are discussed. Name(s), structure, concentrations of phenolic acids and flavonoids, along with the data of the mother plant (organ, phenophases, domestication status, origins), and extraction parameters of each taxon are collected there for future research endeavors.

A summary of major shikimate compound groups in the genus *Mentha*

Cinnamates, represented often in high (up to ca. 35,000 mg/kg) or even extremely high (ca. 58,000–120,000(?) mg/kg) concentrations of rosmarinic acid (**74**) are a leading group of phenolics in the genus.

They are accompanied by highly variable amounts of benzoates, such as para-hydroxybenzoic (**99**) and gallic (**103**) acids. Supplement 5 provides structural formulae of all phenolic acids and lignans (compounds **66–107**) detected in the three taxa.

Another dominant group of mint polyphenols comprises hydroxy- and hydroxy-methoxy-flavonoids originating from three major branches of the naringenin chalcone pathway; see Fig. 4A and B.

The main flavonoids in mints are primarily flavanones and flavones. However, in some cases, other related flavonoids occur: flavonols, anthocyanins, or (seldom) catechins.

In supplement 6, the authors collected names, synonyms, and structures of all flavonoids (**111–179**) discussed in this study. This may make the structure–activity relationships of *Mentha* flavonoids easier to

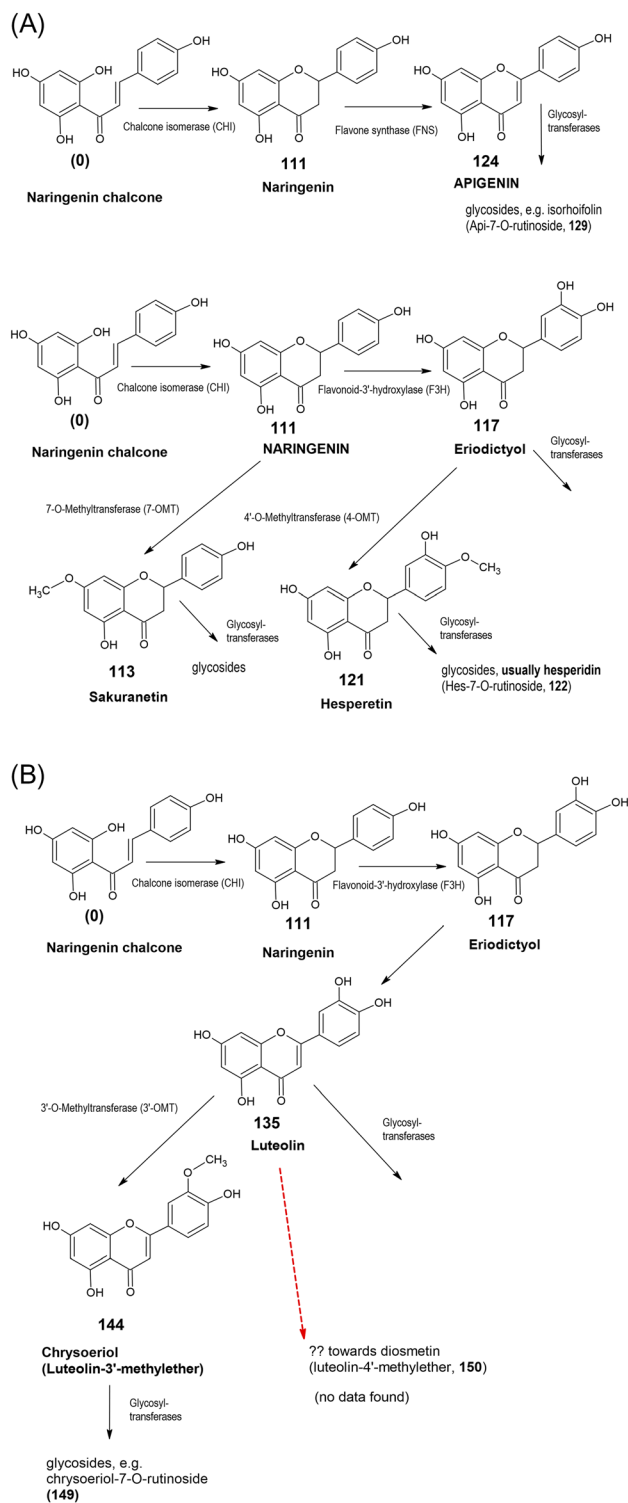
evaluate. For example, the presence of free C3'—OH and C4'—OH is observed to be crucial for high antiradical activity in vitro in the case of flavonoids (Bors et al. 1990; Csepregi et al. 2016) while other structural traits may enhance further, or fine-tune it but not become determinative (free —OH at C3, C5, C7, conjugated double bonds at the C2—C3—C4—O region of the flavonoid backbone; see Fig. 5). Thus, 3',4'-dihydroxyflavonoids abundant in mints, like glycosides of luteolin (**135**) and eriodictyol (**117**) deserve attention. Their contribution to, e.g., activity against DPPH has been demonstrated previously (Damien-Dorman et al. 2003).

Among flavanones, glycosides of hesperetin (**121**) and eriodictyol are usually major components in *Mentha* spp., especially hesperidin (hesperetin-7-O-rutinoside, **122**) and eriocitrin (eriodictyol-7-O-rutinoside, **118**). As an example, in the screening of 40 *M. × piperita* batches grown under the same conditions (Guédon and Pasquier, 1994) eriocitrin contents varied between 6.6–14.8 m/m% dry herb a.k.a. 66,000–148,000(!) mg/kg. Nevertheless, there are also examples, when hesperidin was given as the main constituent, however eriocitrin were not detected in different spearmint and mojito mint samples (Hanafy et al 2017).

Hydroxyflavones show a wide variety in *Mentha* taxa. Luteolin (**135**) and apigenin (**124**) bear the leading role. Their glycosides veronicastroside (luteolin-7-O-rutinoside, **145**) and cynaroside (luteolin-7-O-glycoside, **137**) often are present as main constituents. They are escorted by luteolin glucuronides (**139–141**) isorhoifolin (apigenin-7-O-rutinoside, **129**), and/or apigetrin (apigenin-7-O-glucoside, **125**) or apigenin-7-O-glucuronide (**127**) in variable concentrations depending on the genetically determined composition of the plant, environmental factors, and extraction methods. Hydroxy-monomethoxyflavones: diosmetin (**150**) and chrysoeriol (**148**) glycosides, especially diosmin (diosmetin-7-O-rutinoside, **151**) are often present in mints. Chrysoeriol glycosides and diosmin are sometimes escorted by apigenin monomethyl ethers genkwanin (Api-7-methylether, **134**) and acacetin (Api-4'-methylether, **132**) along with their glycosides e.g. linarin (acacetin-7-O-rutinoside, **133**).

Polymethoxy-flavones (PMFs) usually are minors in mints, in contrast to hydroxyflavones. Some studies show a decreasing concentration of mint leaf PMFs

Fig. 4 A and 4B The three major routes (the apigenin, naringenin and luteolin routes) to *Mentha* flavonoids, according to Winkel-Shirley et al. (2001), e Freitas et al. (2019), and MetaCyc. Sakuranetin (**113**) is not reported in the taxa discussed here. Instead, glycosides of its 4'-methoxy analogue isosakuranetin (**114**) were found in the late 2010s in *M. spicata* (see Sections 5.3-5.5 and their supplements.) Regarding diosmetin (**150**), no data was found on that if in mints it is derived from luteolin, or it is a derivative of hesperetin as in rosemary.



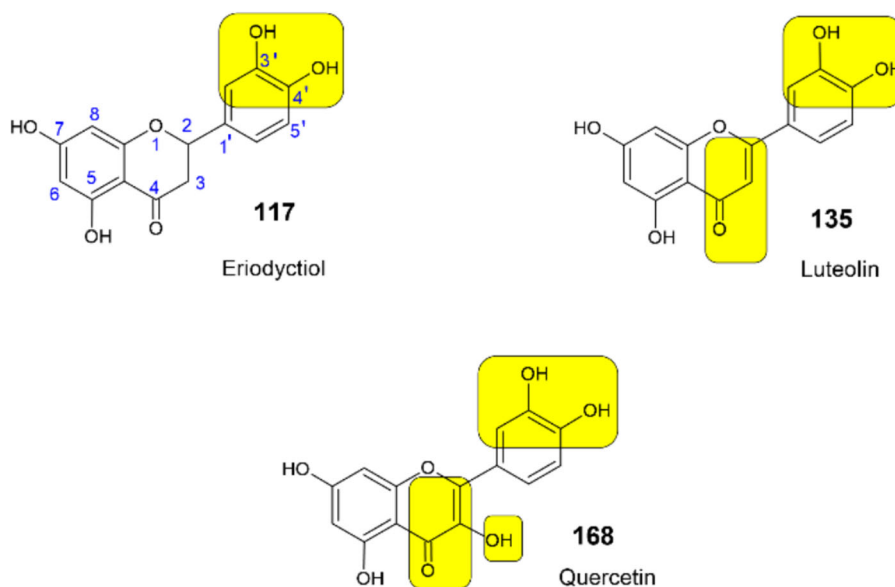


Fig. 5 Functional groups taking part in the radical scavenging of flavonoids, illustrated on eriodictiol, luteolin, and quercetin. Quercetin (**168**) possesses all the structural traits previously observed to be necessary for high antioxidant (AO) activity and

is known as a strong AO (along with its glycosides). Nevertheless, the other two 3',4'-dihydroxyflavonoids (and their glycosides) may also contribute to the antiradical properties of polar mint extracts as teas and tinctures

according to their degree of methoxylation. In the Japanese *M. spicata* batch investigated by Yamamura et al. (1998), thymonin (5,6,4'-trihydroxy-7,8,3'-trimethoxyflavone, **159**) and its isomer sideritoflavone (5,3',4'-trihydroxy-6,7,8-trimethoxyflavone) were present at 371 and 440 mg/kg, respectively; while thymonin-4'-methyl ether syn. pebrellin (**160**) at 145.7 mg/kg, and 5-hydroxy-6,7,8,5',4'-pentamethoxyflavone (5-desmethylnobiletin, **162**) at 34.29 mg/kg.

The PMF profile of mints seems to be not species-dependent, just like their main hydroxyflavones (Lut-7-glycosides, Api-7-glycosides) are common in the genus. The PMFs of the aforementioned Japanese *M. spicata* batch partially overlap with the leaf surface PMF composition of an Algerian wild-growing *M. suaveolens* sample. Zaidi and co-authors detected (qualitatively) the following substances from it: 5,6,7,4'-tetrahydroxy-3'-methoxy-flavone (nodifloretin syn. batatifolin; **152**); 5,7,4'-trihydroxy-6-methoxy-flavone (hispidulin, **153**), 5,6-dihydroxy-7,4'-dimethoxy-flavone (ladanein, **154**), 5,7,4'-trihydroxy-6,3'-dimethoxy-flavone (jaceosidin, **155**); 5,6,4'-trihydroxy-7-methoxy-flavone, (sorbifolin, **156**) 5,6,4'-trihydroxy-7,8-dimethoxy-flavone (thymusin, **157**); 5,6,4'-trihydroxy-7,3'-dimethoxy-

flavone (sorbifolin-3'-methylether, **158**); thymonin and thymonin-4'-methylether syn. pebrellin. Furthermore, overlapping in PMF composition with a Japanese *M. × piperita* var. *citrata* batch is also observable, as in that thymusin, thymonin, and thymonin-4'-methyl ether syn. pebrellin were present, 177.7, 278.0, and 179.7 mg/kg mint, respectively. (Sato and Tamura 2015). Noteworthy to mention that luteolin, thymusin, and pebrellin were observed to be antiallergenic according to the Japanese authors (Yamamura et al 1998; Sato and Tamura 2015), and the PMFs were more active and safer than luteolin (Sato and Tamura 2015). However, the usually low concentration and the hydrophobicity (low extractability to teas/tinctures, demand for apolar solvents) make the industrial and/or therapeutic exploitation of bioactive PMFs in *Mentha* taxa difficult.

Flavonols in mints: these are primarily glycosides of quercetin (**168**) and kaempferol (**163**), derived from naringenin-chalcone via dihydroflavonols; not considered to be characteristic in the genus. However, higher (up to ca. 12 000 mg/kg) concentrations of certain flavonols were reported from some *M. longifolia* batches (reviewed: Patonay and Németh-Zámboriné, 2021). Similar reports are available on the taxa

discussed here (see Sects. “Extractability and polyphenol composition of *M. spicata*”, “Polyphenol composition and extractability of *Mentha suaveolens*”, “Extractability and polyphenol profile of *Mentha × villosa*”).

Catechins and anthocyanins: these are also generated via dihydroflavonols (Winkel-Shirley et al. 2001). Some mints such as *M. × piperita* f. *rubescens* or certain lines of *M. aquatica* consistently produce anthocyanins. However, this is not common in the genus. *M. suaveolens* and *M. × villosa* do not synthesize them continuously.

Glycan parts of flavonoids in *Mentha* spp. usually are rutinose, glucose, or glucuronic acid. Generally, they build up O-glycosides like eriocitrin. C-glycosides like vicenin II (**131**) are not frequent. Kapp (2015) reports vicenin II (apigenin-6,8-C-diglucoside, **131**) from *M. × villosa* and it can occur as a minor constituent in its ancestor *M. longifolia* (Patonay and Németh-Zámboriné, 2021). The site of O-glycosidic bonds is usually C7 in flavones and flavanones. C5-O-glycosides as galuteolin (luteolin-5-O-glucoside, **136**) are not abundant. Ozer (2018), reports galuteolin from a batch of *M. spicata* ssp. *spicata* as a minor constituent: 13.8 and 283.9 mg/kg dry mint depending on extraction method. Galuteolin can also occur as a minor in spearmint’s parental taxon *M. longifolia*. In flavonols reported from mints, the site of O-glycosidic bond is usually C3 and less frequently C7: Moldovan et al. (2014) reports isoquercitrin (quercetin-3-O-glucoside, **169**) and quercitrin (quercetin-7-O-glucoside, **170**) in a Rumanian *M. spicata* ssp. *crispata* sample. Their concentrations were 160.6 and 22.3 mg/kg, respectively.

Extractability and polyphenol composition of *M. spicata*

The detailed data on plant organs, phenophases, extraction methods, and polyphenol composition of *M. spicata* are provided in tables of Supplement 7 discussed here in the text, for reasons of the clarity and total length of the section. Regarding polyphenols, spearmint is relatively the most studied one among the taxa discussed here. Furthermore, it has breeds specialized to phenolics: lines developed in the USA and Canada for extremely high rosmarinic acid (RA) production.

Supplement 7 (Table S7.1) summarizes the extraction parameters applied to different spearmint plant parts. Sonication and maceration were applied in most cases, which may be useful to avoid the thermodegradation of flavonoids. This is not common to every mint taxon. Literature on horsemint (a parental taxon of spearmint) shows samples are often processed by Soxhlet extraction, especially using methanol (Patonay et al. 2019 and 2020).

Regarding composition, most focus in the literature is on RA content. Supplement 7, Table S7.2. provides all data. Non-specialized breeds of spearmint show a wide variability in their RA contents, ranging from 26.47 mg/kg (Park et al. 2019) to around 33,000–36,000 mg/kg (Fatiha Brahmi et al. 2014; by densitometry). Specialized breeds can accumulate RA in the range of 84,000–104,000 mg/kg (Fletcher et al. 2010; Narasimhamoorthy et al. 2015). Important to note that, the earliest records on these lines (RA 51,000–122,000 mg/kg, Fletcher et al. 2005) were determined by photometry, not by HPLC.

Technological factors like drying and extraction also influence RA contents along with other polyphenols. Papageorgiou et al. (2008) found that air drying was gentler towards RA and other hydroxycinnamic acids, gallic acid, luteolin, and rutin in spearmint than lyophilization. For details, the concentration data of cinnamates (apart from RA), benzoates, flavanones, flavones, and flavonols are provided in tables S7.3–8 included in Supplement 7.

The study of mint plants, especially of *M. spicata*, has shown the paramount importance of keeping phenophases in sight. RA content fluctuates significantly according to phenophases (Fletcher et al. 2010). Changes in caffeic acid (**70**), ferulic acid (**71**), protocatechuic acid (**102**), and luteolin follow a similar rhythm as RA. According to Papageorgiou et al. (2008), quercetin and rutin contents reached their maximum levels in the blooming stage. Luteolin contents were also elevated. Thus, shikimate metabolism of spearmint may turn towards producing flavonoids instead of RA when inflorescences are in intense development.

Flavanones, such as eriocitrin and hesperidin, are present in high quantitative variability, while lower quantities of naringenin and its glycosides like narirutin (**112**) were detected. Note that, these latter are less extractable by polar solvents. Neoponcirin syn. didymin (isosakuranetin-7-O-rutinoside, **115**) is

also present (Hanafy et al. 2017; Erenler et al. 2018). It was first detected from spearmint only in 2017. Flavones, such as apigenin, luteolin, and their 7-O-glycosides, have a leading role, followed by various others, especially monomethoxyflavones. In addition, Erenler and co-authors (2018) in a screen of mint flavonoids bearing high therapeutic value, determine 5-hydroxy-6,7,3',4'-tetramethoxyflavone (5-desmethylinensetin, **161**) in an array of Turkish spearmint clones, 460–2050 mg/kg dry weight. It is higher than usual for polymethoxyflavonoids in mints.

Certain flavonols, rutin (**171**), free kaempferol (**163**), and quercetin (**168**), seem to be abundant in spearmint (Table S7.7). Their concentration is highly variable, from minor quantities to the magnitude of 1000 mg/kg. High concentrations of quercetin glycosides may enhance antiradical activity. Rutin in vivo provides an anti-permeability effect in the cardiovascular system and synergism with vitamin C. Further flavonols, which are probably atypical in genus *Mentha*, were detected earlier from a couple of spearmint batches. These were myricetin (**172**) (Bimakr et al 2011), penduletin (**176**) quercetagenin-3,6-methylether (**175**) (Ozer 2018), at concentrations 10–2200 mg/kg, strongly depending on extraction method (for details, see Table S7.7 in Supplement 7).

Catechin and epicatechin (**177,178**), rarities in the genus, were determined in a spearmint batch by Bimakr et al (2011), in quantities depending on the extraction method (Supplement 7, Table 7.8). Anthocyanins: although *M. spicata* usually does not produce anthocyanins continuously, Ozer (2018) reported pelargonin (pelargonidin-3,5-diglucoside, **179**) in a sample from Türkiye (Table S7.8).

The genetically determined variability of flavonoid composition in *M. spicata* is not unrevealed in full detail due to the lack of a large sample number of screenings. However, insights into the infraspecific variability of hesperidin, didymin, and some flavones can be obtained from work by Hanafy et al. (2017) and Erenler et al. (2018). Both components show wide concentration intervals. Hanafy et al. (2017) report a batch containing 19.62 mg/g (19,620 mg/kg) hesperidin. It is high not only in *M. spicata* but also in comparison with relative taxa investigated previously (*M. × piperita*, 0.37 w/w% dw–1.31w/w% viz. 3700–13,100 mg/kg dw [Guédon and Pasquier, 1994], *M. longifolia*, 1985–29,815 mg/kg dw [Patonay et al. 2020]). Erenler et al. (2018) also report a

high concentration of hesperidin in one clone (11,830 mg/kg dw). Furthermore, the Turkish authors report three linarin-rich clones (16,310–42,210 mg/kg dw). These findings may refer to that in *M. spicata* unconventionally flavonoid-rich chemotaxa occur. However, these are barely known, and unexploited as industrial raw materials.

Polyphenol composition and extractability of *Mentha suaveolens*

Detailed data on *M. suaveolens* are provided in tables of Supplement 8 and discussed here in the text. Table S8.1 summarizes the extraction method applied to different *M. suaveolens* batches, demonstrating that sonication and maceration are used in most cases. The data on rosmarinic acid contents (Table S8.2), minor phenolic acids (Table S8.3 and 4), and flavonoid profile (Tables S8.5–7) are relatively plentiful but are obtained from max. 2 batches in the same study. Quantitative data on flavanones and flavones in *M. suaveolens* is extremely scarce, which is similar to the tendency found previously in related wild-growing taxon *M. longifolia* (Patonay and Németh-Zámboriné, 2021). It is an interesting contradiction considering the difference between the domestication status and volume of cultivation between the two species. When data of polyphenol composition in *M. suaveolens* is surveyed, severe losses in multiple polyphenols are observable after drying. Rosmarinic acid content in dried leaves is approximately half of the fresh material, with the original caffeic, ferulic, and anisic acid (**99**) losing 99% of its original concentration in the dried leaf material (Aldogman et al. 2022). In rutin content, there is also a serious loss, as it changes from 3384 mg/kg fresh weight to 194.7 mg/kg dry weight. Quercetin and luteolin content also decreased significantly. In stems and whole aerial parts, the changes are unambiguous, with a significant loss of rutin but an increase in quercetin, possibly due to the decomposition of rutin to its aglycone in stems. Regarding rosmarinic acid as the dominant polyphenol in this batch, there is a pattern difficult to explain. The exact steps of changes in polyphenol profile during natural drying would be useful to elucidate not only for *M. suaveolens* but also for other *Mentha* taxa. Despite the small pool of data, two atypical, flavonol-rich samples are reported in the literature. One is the material investigated by Aldogman et al. (2022), while the

other is reported by Park et al. (2019), containing 9486 mg/kg of quercetin and 1920 mg/kg of rutin.

Extractability and polyphenol profile of *Mentha × villosa*

Among the three taxa, it is the least investigated to polyphenols. Quantitative data are obtained from single batches of cultivated *M × villosa*, often in screening samples of multiple taxa. Only two studies (Fialová et al. 2015; Bittner Fialová et al. 2020) were found which directly aim to investigate it. These valuable works study a Czechoslovakian cultivar 'Šněžná'. One of them (Bittner Fialová et al. 2020) processes rhizomes, noting that no previous study on this particular area was ever conducted. However, no possible usage of rhizome extracts was mentioned. As these studies also investigated single batches, it is not proposed to draw direct conclusions from them to the whole species. As it was mentioned, the quantitative diversity in the polyphenol composition of mints is large. This is clear also to *M. × villosa*, even in the small pool of data.

Infusions were made, or an appropriate polar solvent with a gentle extraction method was applied (maceration, sonication) which helps to avoid thermodegradation of flavonoids (Table 6).

Rosmarinic acid (RA) content is displayed in Table 7, minor phenolic acids in Table 8, and flavonoids in Table 9.

Hanafy et al. (2017) detect 70 mg/kg dw RA in a *M. × villosa* var. *alopecuroides*/*M. × niliaca* batch. This is unconventionally low, especially if the spring vegetative phase at sampling is taken into account. Since a single sample was investigated, it is not possible to decide whether this is caused by some extraction problem or the polyphenol chemotaxon of the mint. The same sample was, however, relatively rich in flavonoids, primarily in eriocitrin and luteolin glycosides (Tables 9 and 10). J. de Medeiros Gomes (2021) investigated RA content in an *M. × villosa* accession in Brazil monthly. A clear yearly cycle is visible here, with a minimum, of 7350 mg/kg in winter (June) and a 39,280-mg/kg maximum in mid-summer (January). Unfortunately, the phenophases were not given. The RA maximum here is considerable. It is worth to compare with the interval found to *M. × piperita* as the most widely cultivated mint taxon (40 batches of *M. × piperita*, not specialized to

rosmarinic acid production, sampled in full bloom): 0.96–3.98 m/m% dw., viz., 9600–39,800 mg/kg dw. (Guédon and Pasquier 1994). A mojito mint sample from the Czech Republic (Čavar Željković et al. 2021) demonstrated another particular acid and flavonoid profile. RA was accompanied here by salicin (97), salicylic acid (96), and 2,3-dihydroxybenzoic acid (100) as minors, instead of cinnamates: only ferulic acid (71) was reported but in lower concentration (as hydroxybenzoates). This sample was found to be low in flavonoids but luteolin, luteolin-7-O-rutinoside, and rutin were present in the same concentration interval (22.20, 26.50, and again, 26.50 mg/kg dw, respectively). Detection of various polyphenols from *M. × villosa* without quantitative data is also available in a couple of studies. Grayer et al. (2003) reported the presence of nepetoidin A and B (87 and 88) in the diethyl ether soluble surface exudates from leaves of many *Lamiaceae*. In *M. × villosa* (one batch) both nepetoidins were present. They are considered by the authors as markers of the subfamily *Nepetoideae*. In the Brazilian accession mentioned above, J. de Medeiros Gomes (2022) identified polyphenols beyond RA as follows (structures: see Suppl. 5 and 6.). Cinnamates and cinnamoylquinic acids: caffeic acid, a RA hexoside (no structural data provided), along with RA-related oligomers salvianolic acid A (76) and D (77), lithospermic acid Isomer I and II (no structural data provided to them—lithospermic acid itself is depicted in Suppl.5, under No. 80); free quinic acid (89), chlorogenic acid (91), neochlorogenic acid (93). Benzoates: a protocatechuic acid hexoside, a syringic acid hexoside (no structural data provided—their aglycones are depicted in Suppl.5., under No. 102 and 105). Flavanones: eriodictiol rutinoside (not assigned as eriocitrin, 119), isosakuranetin rutinoside (116, not assigned as neoponcirin, site of glycosidic bond is not given), narirutin and hesperidin. Flavones: Vicenin II, a luteolin rutinoside (not assigned as veronicastroside), a luteolin hexoside, luteolin glucuronides I and II (140–141), diosmin, 3',5-dihydroxy-4',6,7-trihydroxyflavone (syn. eupatorin). Flavonols: rutin. R. Kapp (2015) investigated three *M. × villosa* batches from Estonia and two batches from The Netherlands. Unfortunately, a detailed quantitative polyphenol composition of them was not provided. Here, two lignans, medioresinol (106) and its sulfate (107) were also identified. These compounds are not typical in the

Table 7 Rosmarinic acid content in *M. × villosa* batches

Taxon	Status	Organ	Phenophase	Quantity	Quantity, mg/kg dw	Country	Refs.
<i>M. × villosa</i>	Cult	L, fresh	N.A	7.35–39.28 mg/g	7350–39,280	Paraíba, Brazil	de Medeiros Gomes et al. (2021)
<i>M. × villosa</i>	Cult	L	Bl	2299 µg/g dw	2299	Czech Rep	Čavar Željković et al. (2021)
<i>M. × villosa</i> “apple mint”	Cult	L + S	Bl	12.21 mg/g dw	12,210	NJ, USA	Shen et al. (2011)
<i>M. × villosa</i> “Egyptian mint”	Cult	L + S	Bl	7.66 mg/g dw	7660	NJ, USA	Shen et al. (2011)
<i>M. × villosa</i> cv. ‘Šněžná’	Cult	Rh	Bl 2nd +	55.7 µg/mL infusion	N. A	Slovakia	Bittner-Fialová et al. (2020)
<i>M. × villosa</i> cv. ‘Šněžná’	Cult	L	Bl	17.9 mg/g extract	1847	Slovakia	Fialová et al. (2015)
<i>M. × villosa</i> var. <i>alopecuroides</i> (syn. <i>M. × niliaca</i>)	Cult	L + S	Spring vg	0.07 mg/g dw	70.00	NSW, Australia	Hanafy et al. (2017)

Geography: NJ New Jersey, NSW New South Wales, calculated quantity, mg/kg dw in bold

genus *Mentha*. From *M. × villosa*, this data is the only one found about their presence. The components identified by R. Kapp were as follows. Cinnamates: salvianic acid A (danshensu A, **72**), free RA, RA sulfate (**74** and **75**), salvianolic acids B, E, H, I (**81,83,79,84**, respectively) Benzoates: no mention. Flavanones: eriocitrin, narirutin. Flavones: an apigenin glucoside (**126**; not assigned as apigetrin, site of glycosidic bond not given) an apigenin rutinoside (**130**, not assigned as isorhoifolin, site of glycosidic bond not given), luteolin glucuronides I and II (no site/s of glycosidic bond/s given), a luteolin rutinoside (not assigned as veronicastroside, site of glycosidic bond not given, **146**) and diosmin. Flavonols: no mention. Kapp also lists protolithospermic acid and isosalvianolic acid A. About these, no structural data were found till March 2025. These small but noticeable gaps in the literature of mint taxa indicate the difficulties in the identification of hydroxycinnamic acid oligomers.

Both de Medeiros Gomes and Kapp list some jasmonates (**108–110**) among phenolics, although these are polyketide-originated, cyclic ketocarboxylic acids. 12-hydroxyjasmonic acid (tuberonic acid, **109**) was detected by both of them. 12-hydroxyjasmonate sulfate (**110**) and a tuberonic acid hexoside were present in the Brazilian sample. Note that the flavonoids and phenolic acids listed by these two

authors are in good accordance with the other findings on the polyphenol composition of mojito mint.

Biological activities of mojito mint, spearmint, and apple mint

Antioxidant effect

An antioxidant can be defined as a reductant, which means any substance that exhibits reductive properties by reacting with an oxidant. Alternatively, a broader definition, as described in the Encyclopedia Britannica, encompasses substances that possess the ability to undergo reduction reactions. Antioxidants are a class of chemical compounds that are incorporated into specific food products, as well as natural and synthetic rubbers, types of gasoline, petrol-derived lubricants, and other substances. Their primary function is to impede the occurrence of autoxidation, a chemical reaction in which these substances react with oxygen in the ambient air at ordinary room temperature (Franco et al. 2019). An example of autoxidation occurs via vitamin C when it decomposes into dehydroascorbic acid with the interference of the ascorbate oxidase enzyme (Carocho et al. 2018).

Antioxidants also play a crucial role in the cellular environment by counteracting the detrimental effects of free radicals and reactive oxygen species (ROS)

Table 8 Minor hydroxycinnamic, hydroxycinnamoylquinic, and benzoic acids in *M. × villosa*

Subclass	Component	Taxon	Status	Organ	Phenophase	Quantity	Quantity, mg/ kg dw	Country	Ref
Cinnamic and hydroxycinnamoylquinic acids	Cinnamic acid	<i>M. × villosa</i>	Cult	L	Bl	0.68 µg/g dw	0.68	Czech Rep	Čavar Željković et al. 2021
	p-Coumaric acid	<i>M. × villosa</i>	Cult	L	Bl	5.04 µg/g dw	5.04	Czech Rep	Čavar Željković et al. 2021
	p-Coumaric acid methyl ester	<i>M. × villosa</i>	Cult	L	Bl	2.20 µg/g dw	2.20	Czech Rep	Čavar Željković et al. 2021
	Caffeic acid	<i>M. × villosa</i> cv. 'Šnežná'	Cult	L	Bl	0.7 mg/g extract	72.24	Slovakia	Bittner-Fialová et al. 2020
	Caffeic acid	<i>M. × villosa</i> cv. 'Šnežná'	Cult	Rh	Bl 2nd +	traces		Slovakia	Bittner-Fialová et al. 2020
	Caffeic acid	<i>M. × villosa</i> var. <i>alopecuroides</i> syn. <i>M. × niliaca</i>	Cult	L + S	spring vg	traces		NSW, Australia	Hanafy et al. 2020
	Ferulic acid	<i>M. × villosa</i>	Cult	L	Bl	6.19 µg/g dw	6.19	Czech Rep	Čavar Željković et al. 2021
	Lithospermic acid	<i>M. × villosa</i> cv. 'Šnežná'	Cult	L	Bl	0.6 mg/g extract	61.92	Slovakia	Fialová et al. 2015
	Lithospermic acid	<i>M. × villosa</i> cv. 'Šnežná'	Cult	Rh	Bl 2nd +	55.7 µg/mL infusion	N.A	Slovakia	Bittner-Fialová et al. 2020
	Salvianolic acid A	<i>M. × villosa</i> cv. 'Šnežná'	Cult	L	Bl	1.4 mg/g extract	144.5	Slovakia	Fialová et al. 2015
	Salvianolic acid A	<i>M. × villosa</i> cv. 'Šnežná'	Cult	Rh	Bl 2nd +	4.00 µg/mL infusion	N.A	Slovakia	Bittner-Fialová et al. 2020
	Salvianolic acid B	<i>M. × villosa</i> cv. 'Šnežná'	Cult	Rh	Bl 2nd +	9.00 µg/mL infusion	N.A	Slovakia	Bittner-Fialová et al. 2020
	Salvianolic acid D ester	<i>M. × villosa</i> cv. 'Šnežná'	Cult	Rh	Bl 2nd +	4.80 µg/mL infusion	N.A	Slovakia	Bittner-Fialová et al. 2020
	Caffeic acid tetramer	<i>M. × villosa</i> cv. 'Šnežná'	Cult	Rh	Bl 2nd +	10.70 µg/mL infusion	N.A	Slovakia	Bittner-Fialová et al. 2020
	Quinic acid free	<i>M. × villosa</i> cv. 'Šnežná'	Cult	L	Bl	0.8 mg/g extract	82.56	Slovakia	Fialová et al. 2015
Chlorogenic acid	p-Coumaroylquinic acid	<i>M. × villosa</i> cv. 'Šnežná'	Cult	L	Bl	0.8 mg/g extract	82.56	Slovakia	Fialová et al. 2015
	Chlorogenic acid	<i>M. × villosa</i>	Cult	L	Bl	24.03 µg/g dw	24.03	Czech Rep	Čavar Željković et al. 2021
	Chlorogenic acid	<i>M. × villosa</i> cv. 'Šnežná'	Cult	L	Bl	0.6 mg/g extract	61.92	Slovakia	Fialová et al. 2015
		<i>M. × villosa</i>	Cult	L	Bl	1.7 µg/g dw	1.70	Czech Rep	

Table 8 continued

Subclass	Component	Taxon	Status	Organ	Phenophase	Quantity	Quantity, mg/ kg dw	Country	Ref
Hydroxybenzoic acids	p-Hydroxybenzoic acid	<i>M. × villosa</i>	Cult	L	Bl	2.32 µg/g dw	2.32	Czech Rep	Čavar Željković et al. 2021
	m-Hydroxybenzoic acid								
	Salicylic acid	<i>M. × villosa</i>	Cult	L	Bl	6.46 µg/g dw	6.46	Czech Rep	Čavar Željković et al. 2021
	Salicin	<i>M. × villosa</i>	Cult	L	Bl	108.5 µg/g dw	108.5	Czech Rep	Čavar Željković et al. 2021
	2,3- dihydroxybenzoic acid	<i>M. × villosa</i>	Cult	L	Bl	8.49 µg/g	8.49	Czech Rep	Čavar Željković et al. 2021
	Gallic acid	<i>M. × villosa</i>	Cult	L	Bl	0.20 µg/g	0.20	Czech Rep	Čavar Željković et al. 2021

Status: *Cult* Cultivated. Organ: *L* leaves, *S* stem, *Rh* rhizomes. Phenophase: *vg*, vegetative, *Bl* in bloom, *Bl 2nd* + after 2nd flowering. Geography: *NSW* New South Wales (Australia), *Rep*. Republic. *N.A.* in the Quantity, mg/kg dw column: conversion/recalculation to mg/kg dw was not possible as extraction yield is missing, calculated quantity, mg/kg dw in bold

(Abuajah et al. 2015). The classification of antioxidants can be broadly categorized into two main groups; synthetic antioxidants that can be toxic and expensive such as propyl gallate (PG), tertiary butylhydroquinone (TBHQ), butylated hydroxyanisole (BHA), and butylated hydroxytoluene (BHT) (Aher 2011; Koksall et al. 2011) and natural antioxidants such as vitamin C (Ascorbic acid), vitamin E, carotenoids, phenolic compounds such as flavonoids.

Antioxidants can be categorized into two main groups based on their sources: *endogenous* and *exogenous*.

They can be further classified as *enzymatic* (e.g., superoxide dismutases [SOD-s] and peroxidases) and *non-enzymatic* antioxidants (e.g., tocopherols, many alkylphenols, phenolic acids, and flavonoids; certain carotenoids; riboflavin; ascorbate isomers; some peptides, etc.).

A different classification defines *primary* and *secondary* antioxidants, making a distinction between direct intervention into a redox reaction (such as rosmarinic acid reacts) and the inhibition of oxidative deterioration in different matrices by removing/binding a partner or a catalyst that can take part in oxidation. For example, a chelator of Fe(III)/(II) ions in the presence of lipids and proteins (e.g., meat) may inhibit their oxidation, eliminating Fe(III)/(II) as the catalyst of the process (Kanatt et al. 2007). Thus, the chelator here acts as a secondary antioxidant. However, some compounds can act both as primary and secondary AOs. For example, quercetin and rutin are known as radical scavengers and chelators in parallel.

Moreover, another important distinction of antioxidants can be made based on their solubility (Gülçin 2012; Balasaheb Nimse and Pal 2015), with antioxidants being either *water-soluble* (e.g., gallic acid) or *lipid-soluble* (e.g., thymol isomers).

Nowadays, antioxidants have high importance in food technology as they are commonly incorporated into various food products to enhance their nutritional value and their preservation. Ongoing research efforts are being devoted to investigating the antioxidant properties of various natural foods and their constituent compounds. In recent encapsulation studies, researchers have explored the substitution of antioxidants to preserve and stabilize various food elements. From a functional perspective, it is noteworthy to mention that these elements exhibit antioxidant properties. Consequently, it is intriguing to observe a

Table 9 Flavonoids in *M × villosa*

Subclass	Component	Taxon	Status	Organ	Phenophase	Quantity	Quantity, mg/ kg dw	Country	Refs.
Flavanones	Naringenin	<i>M. × villosa</i>	Cult	L	Bl	1.50 µg/g dw	1.50	Czech Rep	Ćavar Željko et al. (2021)
	Neoponcirin (didymnin)	<i>M. × villosa</i> var. <i>alopecuroides</i>	Cult	L + S	spring vg	0.31 mg/g dw in naringenin eq	310	NSW, Australia	Hanafy et al. (2017)
	Eriocitrin	<i>M. × villosa</i> cv. 'Šněžná'	Cult	L	Bl	10.80 mg/g extract	1115	Slovakia	Fialová et al. (2015)
	Eriocitrin	<i>M. × villosa</i> var. <i>alopecuroides</i>	Cult	L + S	spring vg	1.19 mg/g dw	1190	NSW, Australia	Hanafy et al. (2017)
	Hesperidin	<i>M. × villosa</i>	Cult	L	Bl	3.87 µg/g dw	3.87	Czech Rep	Ćavar Željko et al. (2021)
	Hesperidin	<i>M. × villosa</i> cv. 'Šněžná'	Cult	Rh	Bl 2nd +	8.90 µg/mL infusion	N.A.**	Slovakia	Bittner-Fialová et al. (2020)
Flavones	Apigenin	<i>M. × villosa</i>	Cult	L	Bl	2.15 µg/g dw	2.15	Czech Rep	Ćavar Željko et al. (2021)
	Isorhoifolin	<i>M. × villosa</i> var. <i>alopecuroides</i>	Cult	L + S	spring vg	0.29 mg/g dw in apigenin eq	290	NSW, Australia	Hanafy et al. 2017
	Luteolin	<i>M. × villosa</i>	Cult	L	Bl	22.20 µg/g dw	22.20	Czech Rep	Ćavar Željko et al. (2021)
	Cynaroside	<i>M. × villosa</i> var. <i>alopecuroides</i>	Cult	L + S	spring vg	0.80 mg/g dw	800	NSW, Australia	Hanafy et al. (2017)
	Luteolin-7-O-glucuronide	<i>M. × villosa</i> var. <i>alopecuroides</i>	Cult	L + S	spring vg	1.23 mg/g dw in cynaroside eq	1230	NSW, Australia	Hanafy et al. (2017)
	Luteolin-7-O-glucuronide	<i>M. × villosa</i> cv. 'Šněžná'	Cult	L	Bl	9.90 mg/g extract	1022	Slovakia	Fialová et al. (2015)
	Veronicastroside	<i>M. × villosa</i> var. <i>alopecuroides</i> *	Cult	L + S	spring vg	3.51 mg/g dw in cynaroside eq	3510	NSW, Australia	Hanafy et al. (2017)
	Veronicastroside	<i>M. × villosa</i> cv. 'Šněžná'	Cult	L	Bl	10.80 mg/g extract	1115	Slovakia	Fialová et al. (2015)
	Veronicastroside	<i>M. × villosa</i> cv. 'Šněžná'	Cult	Rh	Bl 2nd +	9.10 µg/mL infusion	N.A.**	Slovakia	Bittner-Fialová et al. (2020)

Table 9 continued

Subclass	Component	Taxon	Status	Organ	Phenophase	Quantity	Quantity, mg/ kg dw	Country	Refs.
Flavonols	Kaempferol	<i>M. × villosa</i>	Cult	L	BI full	26.50 µg/g dw	26.50	Czech Rep	Čavar Željković et al. (2021)
	Astragalin	<i>M. × villosa</i> cv. 'Šněžná'	Cult	L	BI full	1.60 mg/g extract	165	Slovakia	Fialová et al. 2015
	Quercetin	<i>M. × villosa</i>	Cult	L	BI full	2.15 µg/g dw	2.15	Czech Rep	Čavar Željković et al. (2021)
	Rutin	<i>M. × villosa</i>	Cult	L	BI full	26.50 µg/g dw	26.50	Czech Rep	Čavar Željković et al. (2021)

Status: *Cult* Cultivated, Organ: *L* leaves, *S* stem, *Rh* rhizomes. Phenophase: *vg.* vegetative, *Bl* in bloom, *Bl* 2nd + after 2nd flowering. Geography: NSW New South Wales (Australia), Rep. Republic. N.A. in the Quantity, mg/kg dw column: conversion was not possible (missing yield data). *M. × villosa* var. *dolopeturoides* = *M. × niliaca*, calculated quantity, mg/kg dw in bold

certain paradox arising when contemplating the negative perception of preservatives on human health compared with the widely acknowledged benefits associated with antioxidants (Franco et al. 2019). However, in the research of Zehiroglu and Ozturk Sarikaya (2019), it is mentioned that they are additives that pose no harm to consumers' health and may even have the potential to contribute positively to overall health. The implementation of these functional elements has been of significant importance due to several compelling reasons. These substances have the potential to serve as coloring agents, antioxidants, preservatives, and additives within the realm of medicinal applications (Zehiroglu and Ozturk Sarikaya 2019). Antioxidants are abundant in the genus *Mentha* and other therapeutic plants. The essential oil (EO) compounds extracted from medicinal plants, such as thymol and carvacrol, are considered the best antioxidants to be used (Raeisi et al. 2019; Tafrihi et al. 2021). Phenolics such as phenolic acids, complex flavonoids, and anthocyanins also have good antioxidant capacity, as per the research of Lin et al. (2016).

The antioxidant capacity can be studied and investigated in vitro and in vivo.

In vitro tests are considered easier and simpler since in vivo tests are normally conducted on animals (Alam et al. 2013). From in vitro tests we can mention some of the most used and known methods; DPPH (1,1-diphenyl-2-picrylhydrazyl) scavenging activity to determine the concentration needed to reach 50% inhibition (IC₅₀) (Olugbami et al. 2014), Ferric reducing-antioxidant power (FRAP) assay in which the capacity of the antioxidant to reduce the ferric ion is studied (Benzie and Strain 1996), β-carotene linoleic acid method with measuring the inhibition of free radical formation in β-carotene resulting from the oxidation of linoleic acid (Alam et al. 2013), and ABTS radical cation decolorization (Alam et al. 2013). Ferrous ions catalyze the production of free radicals via Fenton reactions. Ferrozine quantitatively chelates Fe²⁺. The introduction of additional chelating agents led to the disruption of complex formation, resulting in a reduction in the intensity of the red hue shown by the complexes. This reaction provides the base of ferrozine assays as a further type of photometric AO tests.

Polar extracts of *Mentha* spp. usually show variable or strong in vitro antiradical effects connected to the phenolics in presence: in multiple cases, the

Table 10 Summary of the reviewed results of the antioxidant capacity of the three *Mentha* taxa

Taxon	Organ	Extract	Leading compound	AO assay	IC ₅₀ µg/mL	Positive control& IC ₅₀ µg/mL	References
<i>M. spicata</i>	L	n-BuOH fract	N/A	DPPH	7.47	C. E., 17.46	Kumar et al. (2007)
<i>M. spicata</i>	L	n-BuOH fract	N/A	ABTS	4.05	C. E., 11.90	Kumar et al. (2007)
<i>M. spicata</i>	L	n-BuOH fract	N/A	O ₂ ^{•−}	57.80	Quercetin, 58.33	Kumar et al. (2007)
<i>M. spicata</i>	L	WE	N/A	DPPH	25.8	BHT, 10.1	Kanatt et al. (2007)
<i>M. spicata</i>	L	WE	N/A	OH•	498.3	N/A	Kanatt et al. (2007)
<i>M. spicata</i>	L	EO	carvone	DPPH	26.64	AA, 12.03	Alsaraf et al. (2021)
<i>M. spicata</i>	AP	EE	N/A	DPPH	87.89	N/A	Bahman et al. (2008)
<i>M. spicata</i>	AP	EE	N/A	ABTS	173.80	N/A	Bahman et al. (2008)
<i>M. spicata</i>	AP	EO	carvone	DPPH	3450	AA 2.22; BHT 15.20	Bardaweel et al. (2018)
<i>M. spicata</i>	AP	EO	carvone	ABTS	40.2	AA, 0.82 BHT, 1.42	Bardaweel et al. (2018)
<i>M. spicata</i>	AP	EO	carvone	FRAP	215	AA, 2.2 BHT, 18.2	Bardaweel et al. (2018)
<i>M. spicata</i>	AP	EO	carvone	DPPH	79 IC%*	none	Elansary et al. (2013)
<i>M. spicata</i>	AP	EO	carvone	β-carotene	85 IC%*	none	Elansary et al. (2013)
<i>M. suaveolens</i>	AP	EO	rotundifolone	DPPH	215.59	AA, ~ 50. BHT, ~ 50	El Hachlafi et al. (2023)
<i>M. suaveolens</i>	AP	EO	rotundifolone	FRAP	144.38	AA, ~ 50. BHT, ~ 50	El Hachlafi et al. (2023)
<i>M. suaveolens</i>	AP	EO	rotundifolone	β-carotene	168.50	AA, BHT	El Hachlafi et al. (2023)
<i>M. suaveolens</i>	AP	EO	rotundifolone, germacrene D	DPPH	6 IC%*	none	Elansary et al. (2013)
<i>M. suaveolens</i>	AP	EO	rotundifolone, germacrene D	β-carotene	20 IC%*	none	Elansary et al. (2013)
<i>M. suaveolens</i>	L, F	EO	rotundifolone	DPPH	16.32	AA, 8.849	Zekri et al. (2023)
<i>M. × villosa</i>	AP	ME	N/A	DPPH	44.66	BHT 6.1, Trolox 5.8	Benabdallah et al. (2016)
<i>M. × villosa</i>	AP	ME	N/A	FRAP	1500	no data provided	Benabdallah et al. (2016)
<i>M. × villosa</i>	AP	ME	N/A	β-carotene	939	no data provided	Benabdallah et al. (2016)

Extraction: *C.E.* crude extract (as positive control compared to a fraction), *fract.* Fraction, *n-BuOH* n-buthanolic, *EE* ethanolic, *ME* methanolic, *WE* aqueous extract; *EO* essential oil

Plant organs: *L* Leaves, *F* Flowers, *AP* Aerial parts, *AA* ascorbic acid

* no IC₅₀ values have been given in the source

correlation between total polyphenol content and activity against DPPH or ABTS is proven. For spearmint's parent taxon *M. longifolia*, we conducted previously (2017–19) a large-sample screening on extractability, total polyphenol contents, and DPPH and FRAP values. It resulted in significant correlations between total polyphenol content (Folin-Ciocalteu's) and AO properties (Patonay et al. 2019). Damien-Dorman, Koşar, and co-workers (2003 and 2004) in a study of aqueous hydrodistillation residues of 9 batches of different mint taxa (including one item of spearmint) described that total polyphenol contents and DPPH values are in strong significant correlations. Regarding individual compounds, rosmarinic acid is considered to be the key antioxidant in *Mentha* spp. (Dudai et al. 2006). The aim of the exploitation of this compound has been the background in the breeding of *Mentha* (*spicata* and *piperita*) lines producing extreme concentrations of RA (for details on RA content of specialized spearmint lines, see Chapter 5.3). Additionally, (as it was referred in Chapter 5.1) Damien-Dorman, Koşar, and co-workers (2003 and 2004) demonstrated a strong significant correlation between DPPH values and eriocitrin contents of the extracts. A similar connection was found in this study between DPPH results and the concentration of one luteolin glycoside.

Contrary to polyphenol-rich polar (aqueous, hydroalcoholic, methanolic, ethanolic, etc.) extracts of *Mentha* taxa, their essential oils often demonstrate low or variable antioxidant efficacy. Compared to the correlation between AO activity and total polyphenols or RA, it is much more difficult to connect the AO properties of a *Mentha* essential oil to a component or a group of constituents. Only thymol and its isomers can be exceptions as monoterpenes with alkylphenolic rings capable of radical scavenging, but they are rare in the genus. The typical limonene-oxo components, linalool, and the alicyclic mono- and sesquiterpenes of various origins (see Chapter 4 and Supplement 4) in an essential oil provide highly variable results in the different antioxidant assays, and their rank in activity is currently ambiguous. Their structure-AO activity relations are less known (Sitzmann et al. 2014). Nevertheless, their additional, synergistic, or other effects on each other are not clarified yet.

Among the investigated mint taxa in this review, *M. spicata* has the highest number of experimental data

referring to the antioxidant effect determined by different methods (Table 10).

A valuable research study (Kanatt et al. 2007) aimed to assess the potential of *M. spicata* leaves, a widely used herb in Indian cuisine, as a natural antioxidant for lamb meat that has undergone radiation processing. The DPPH assay, β -Carotene bleaching assay, superoxide scavenging activity, iron chelating activity (ferrozine assay), and hydroxyl radical-scavenging activity assay were applied to the extract (*M. spicata* leaves were washed, refluxed with distilled water, filtered, and extracted; the residue was extracted with more water; the extracts were pooled, centrifuged, and concentrated). This was completed by a TBARS (thiobarbituric acid) assay to investigate lipid peroxidation of meat and to evaluate the effect of spearmint extract as a natural conservation agent. In foods, lipid peroxidation means rancidification and later, even in parallel, oxidative decay of proteins and other constituents such as vitamin E, A, carotenoids, flavonoids (especially anthocyanins), ascorbate, etc. by the secondary free radicals formed in this chain reaction(s) (Shahidi and Ambigaipalan 2015).

The DPPH assay results by Kanatt et al. (2007) show the IC₅₀ value of *M. spicata* extract at 25.8 $\mu\text{g/mL}$ despite BHT with 10.1 $\mu\text{g/mL}$. This finding was in accordance with the previous results demonstrating that extracts of *Mentha* spp. against DPPH (depending on polyphenol chemotaxon, phenophases, and extraction process) gave relatively high activity, however the effect was never stronger than BHT (Damien-Dorman et al 2003; Dudai et al 2006; Patonay et al 2019). Additionally, Kanatt and co-workers corroborate the earlier findings on the correlation of activity against DPPH and the total polyphenol contents (Folin and Ciocalteu's assay) in the investigated *M. spicata* extract. The results of the β -Carotene bleaching assay were considered by the authors to demonstrate *M. spicata* extract as a potent antioxidant in its high dilution (1 ppm). It provided an antioxidant activity coefficient (AAC) = 682 while BHT has shown AAC = 900. They conclude that BHT cannot be used with more than 200 ppm, so a natural competitive antioxidant (antiradical-AO) such as *M. spicata*, in our case, can be a good substitute.

Both the site-specific and non-site-specific assays of hydroxyl radicals were effectively quenched by the *M. spicata* extract in the experiments by Kanatt et al. (2007). Within the applied concentrations, there was a

linear association between the concentration of mint extract and the $\text{OH}^\bullet$ -scavenging activity. In the non-site-specific test, 50% inhibition was achieved with 498.3 $\mu\text{g/mL}$ of mint extract. In the mint extract, there was a strong association between the total flavonoid content and hydroxyl radical scavenging, and this proves the statement of Bravo that the flavonoids are potent hydroxyl radical scavengers (Bravo 1998).

Regarding iron chelator properties, the spearmint extract at Kanatt and co-authors' work did not show high activity (contrary to its activities against different radicals such as DPPH, hydroxyl, superoxide, etc.). Unfortunately, detailed data on the polyphenol composition of the extract has not been given, thus, we do not know whether this controversy is rooted in the individual flavonoid profile of the extract.

TBARS assays on the lamb meat samples show a nuanced picture of autoxidation. In every sampling time (0,1,2,3,4 weeks), the meat irradiated but free of preservatives has shown the far most advanced lipid peroxidation, more than the non-preserved non-irradiated control. This is probably due to the initiation/enhancement of radical formation by the ionizing radiation. After two weeks, data from the non-treated non-irradiated control are not shown anymore. Treatment with mint extract (0.1% in the meat) or BHT (0.02% in the meat) inhibited lipid peroxidation significantly, almost with uniform efficacy. Even in lower concentration (0.05% mint extract), significant difference could be detected compared to the untreated meat, even after 4 weeks.

In further work (Bahman et al. 2008), samples of five different mint species (one batch of each taxon) have been evaluated using their ethanol extract. Two methods were applied: the DPPH and the ABTS assays. Referring to their potential antioxidant effect, *M. spicata* showed the weakest DPPH scavenging activity IC_{50} among the five mint species with IC_{50} : 87.89 $\mu\text{g/mL}$ in connection with the lowest total phenolic content 150.9 $\mu\text{g/mg}$ (Bahman et al. 2008). However, it showed the second highest IC_{50} with the ABTS assay with 173.80 $\mu\text{g/mL}$ after *M. longifolia*.

In the study of Bardaweel et al. (2018), three different assays were conducted to investigate the antioxidant properties of *M. spicata* essential oil from the Algerian Saharan Atlas: DPPH, ABTS, and FRAP. The sample (carvone 49.5%, limonene 16.1%, 1,8-cineole 8.7%, no further majors present) has shown an IC_{50} value of 3450 $\mu\text{g/mL}$ against DPPH, which

means low antioxidant capacity compared to ascorbic acid (IC_{50} 2.22 $\mu\text{g/mL}$) and BHT (15.20 $\mu\text{g/mL}$). Bardaweel and co-authors compared the antioxidant capacity of the essential oil to previously investigated, carvonaceous spearmint oils from Turkey and Egypt. The referred Turkish spearmint oil (Kizil et al., 2010; carvone 50.33%, limonene 16.47%, no further majors present) produced IC_{50} = 77.40 $\mu\text{g/mL}$, while ascorbic acid in this study was characterised by IC_{50} = 45.43 mg/L .

If we compare the IC_{50} data provided by Bardaweel et al (2018) and the Turkish authors to whom they refer (Kizil et al., 2010), the severe difficulty of evaluating in vitro AO properties of mint essential oils comes into focus again. The Algerian and the Turkish spearmint oils are highly similar in their main components: the ratio of limonene and carvone are almost the same. However, their AO activity was rather different. The only common point is that none of the oils reached the activity of ascorbic acid. At the moment, it is not known whether it is a consequence of the unstandardized DPPH assay (the Algerian and the Turkish authors use different protocols for it), or, it may be an effect of the other constituents of the investigated EO-s besides carvone and limonene.

In the case of apple mint, less literature data can be found (see Table 10), and in some cases, rather different conclusions were reached by the authors.

According to the study of Park et al. (2019), eight mint populations, chocolate mint, eau de cologne mint, horse mint, peppermint, pennyroyal mint, pineapple mint, water mint, and apple mint (*M. suaveolens*) appeared to possess no antioxidant capacity. This statement is a result of the study of the correlation between the composition of the metabolite and the antioxidant activity by the use of chemometrics.

The findings of this examination showed that *M. suaveolens* contained a high amount of riboflavin and a low concentration of some carotenes. On the contrary, Straumite et al. (2015) showed that it has a higher level of carotenoids in the stem after the determination of the carotenoids and chlorophyll pigments of nine mint species in Latvia. Carotenoids are important in inhibiting ROS. However, neither carotenoids nor riboflavin are major constituents in genus *Mentha* as their major non-volatile constituents are different shikimates (see Chapter 5) and, as a less studied group, pentacyclic non-steroid triterpenoids as

oleanolic acid, ursolic acid (Shen et al. 2011) in some cases accompanied by some phytosterols as in *M. longifolia* (Patonay and Németh-Zámboriné, 2021).

Moreover, Aldogman et al. (2022) proved that *M. suaveolens* is a promising natural antioxidant because the ethanolic extracts for both fresh and dry plants showed a 90% antioxidant activity that was determined by the DPPH method. As it was previously mentioned (see Chapter 5) these samples have shown high rosmarinic acid contents (up to ca. 28,000 mg/kg) but it was strongly dependent on plant organs and losses caused by drying.

Research of Bichra et al. (2013a, b) discussed the antioxidant capacity of six plants cultivated in Morocco using their aqueous and ‘phenolic’ (water 4: ethanol 1) extracts. Regarding antioxidant activity, they conducted DPPH assay, ABTS assay, ferrous/ferric chelator ability (ferrozine) assay along with determination of total polyphenol content (Folin and Ciocalteu’s), total flavonoid content (AlCl_3 /nitrite assay) and ratio of nonflavonoid phenolics (precipitation of flavonoids by formaldehyde, then repeating Folin and Ciocalteu’s on the supernatant). These were followed by HPLC–DAD screening of the polyphenol profile of the plants. One batch of *M. suaveolens* and one of *M. viridis* were evaluated. For their detailed polyphenol profile, see tables of Suppl. 8 (*suaveolens*) and 7 (*viridis*) (ericiotrin, rosmarinic acid, ferulic, and p-coumaric acid were major components). The authors provide DPPH, ABTS, and ferrozine assay results in $1/\text{EC}_{50}$ units, which is a bit unconventional. The *M. suaveolens* batch has shown higher AO activity than the *M. viridis* sample. DPPH: 0.35–0.40, ABTS 0.20–0.25; ferrozine 0.30–0.38 $1/\text{EC}_{50}$ to *suaveolens*, while to *viridis*, DPPH has given 0.25–0.40, ABTS 0.20–0.25 and ferrozine 0.25–0.30 $1/\text{EC}_{50}$, respectively. To both two batches of mint, extraction by ethanol–water mixture has resulted in higher AO activity and higher yield in ericiotrin, luteolin, rosmarinic acid, and its related cinnamates than water extraction. As we referred to this problem in Chapter 5.1, from these data, we can not conclude whether *M. suaveolens* is a better raw material than *M. viridis* for the extraction of antioxidants as single samples of both taxa were taken.

As mentioned earlier, limonene-oxo-type mint oils usually provide variable or weak antioxidant activity. The data found on the antioxidant properties of apple mint essential oils may corroborate this observation.

El Hachlafi et al (2023) studied the antioxidant properties of a *M. suaveolens* essential oil batch rich in rotundifolone (74.55%; no further major constituents were present). DPPH radical scavenging, ferric reductive power (ferricyanide assay), and β -carotene bleaching tests were conducted. The EO of *M. suaveolens* demonstrated an IC_{50} value of $215.59 \pm 5.28 \mu\text{g/mL}$ against DPPH. Ferrous-reducing activity was characterized by $\text{IC}_{50} = 144.38 \mu\text{g/mL}$. The IC_{50} result for *M. suaveolens* for the β -carotene bleaching inhibition technique was $168.50 \pm 3.20 \mu\text{g/mL}$. The evaluated EO was nevertheless significantly ($p < 0.05$) less efficient than the usual antioxidants ascorbic acid and BHT.

The antioxidant activity of *M. pulegium*, *M. suaveolens*, and *M. spicata* essential oils was studied in Morocco (Zekri et al. 2023). *M. pulegium* showed the highest antioxidant activity and was rich in pulegone (68.86%), and *M. spicata* showed the lowest activity and was rich in carvone (71.56%) and limonene (10.50%). *M. suaveolens* EO was rich in piperitenone oxide and showed the second-strongest DPPH• inhibition ($\text{IC}_{50} = 16.32 \text{ mg/mL}$). However, all EOs studied were less active than ascorbic acid ($\text{IC}_{50} = 8.849 \text{ mg/L}$).

Aldogman et al. (2022) demonstrated that the EOs taken from different parts of the apple mint (stems, leaves, whole plant) were less active than BHT at the DPPH assay. Both for fresh and dried plant parts, $\text{IC}\%$ values at DPPH assay were 31–53%, while BHT reached 95%. These EOs mainly consisted of carvone (43.65–64.36%) and trans-carveole (1.00–5.50%). Note that EOs extracted from fresh plant parts exerted the lower IC values (31–33 IC %).

Elansary and co-authors (2013) studied the samples of four mint taxa (one sample of each) collected from natural populations near Cairo. *M. spicata* and *M. suaveolens* were among the investigated species. EO of the *M. spicata* sample was carvone/limonene/cis-dihydrocarvone type (53.90%, 21.01%, and 6.67%, respectively), while the EO of *M. suaveolens* studied here demonstrated a composition slightly diverging from the conventional types (especially the domesticated apple mints), as it was peculiarly rich in different sesquiterpenes which escorted rotundifolone (rotundifolone 35.14%; ortho-menth-8-ene (structure: **50** in Fig. 4.6., Suppl.4.) 8.98%; germacrene D 22.65%; trans- β -farnesene (structure: **54** in Fig. 4.7., Suppl.4) 6.92%). The studied *M. suaveolens* essential oil

exhibited low AO activity at DPPH and β -carotene assays: IC% values at the two assays were 6% and 20%, respectively. Unfortunately, there was no positive control mentioned. Nevertheless, 6 IC% at the DPPH assay means that the sample in question is practically inactive towards this radical. On the contrary, the results of the carvonaceous *M. spicata* EO in this study are unconventionally high (79 IC% at DPPH and 85 IC% at β -carotene assay).

Regarding *M. × villosa*, literature on the AO properties of its extracts and EO is not rich, similar to *M. suaveolens*.

In the research of Benabdallah et al. (2016), DPPH, β -carotene bleaching, and ferrozine assays were conducted on the methanolic extracts derived from the samples of six different *Mentha* species found in Algeria (one batch of each taxa). The results of the assay indicated that the range of DPPH scavenging activity varied from IC₅₀ 7.50 μ g/mL for *M. aquatica* to IC₅₀ 44.66 μ g/mL for *M. × villosa*. The findings of the study revealed that *M. aquatica* exhibited the highest level of efficiency. However, *M. × villosa* produced the weakest results. Nevertheless, none of the extracts reached the activity of BHT and Trolox at this assay (IC₅₀-s 6.1 μ g/mL to BHT and 5.8 to Trolox).

At β -carotene bleaching assay, the rank of AO activity among the mint extracts was similar. *M. aquatica* exhibited the most prominent results, with an IC₅₀ value of 425.00 μ g/mL. *M. arvensis* and *M. piperita* followed suit in terms of antioxidant activity. Therefore, the efficacy of *M. pulegium*, *M. rotundifolia*, and *M. × villosa* was found to be lower, with a value of 939.00 μ g/mL. Ferrous ion chelating activity of the mint extracts provided similar tendencies to the antiradical properties, viz., *M. aquatica* was the most (IC₅₀: 700 μ g/mL), while *M. × villosa* was the less effective (IC₅₀: 1500 μ g/mL). According to the authors, all of the studied antioxidant strong ($|R| \geq 0.8$ in all cases); significant correlation with total polyphenols (Folin and Ciocalteu's), total flavonoid contents (aluminum chloride assay) and, surprisingly, with total condensed tannin contents (vanillin assay). Significance levels are $p < 0.05$ in all cases except β -carotene assay/total flavonoids ($p < 0.10$) and chelator ability/total flavonoids ($p < 0.10$). The strong and significant correlation between the AO properties and total condensed tannin contents may be some unconventional result as

condensed tannins, viz., catechins (flavan-3-ols) and their oligomers, are atypical in *Mentha* taxa. Here, the result of the vanillin assay shows a relatively low quantity of them, as may be expected (< 2.71 – 8.67 mg catechin eq/g dry herb, while total polyphenol contents are 14.66–43.21 mg gallic ac eq./g). Thus, in these samples, some catechin derivatives seem to be present as minors and contribute to their AO properties.

Sitzmann et al. (2014) evaluated the antioxidant activity in fourteen different mint essential oils, among them *M. × villosa* and *M. suaveolens*. ABTS⁺ scavenging activity (expressed in Trolox equivalent antioxidant capacity, viz., TEAC value) and Cu(II)-induced lipid peroxidation assays were conducted. The essential oil of *M. suaveolens* showed the second-highest activity (TEAC 10 mM), while *M. × villosa* was the third in the rank (TEAC 8 mM). The main compound of *M. suaveolens* essential oil was piperitenone oxide (88%), while in the essential oil of *M. × villosa*, carvone (57%) was presented in the highest ratio. Authors conducted TEAC assay also on a couple of standards, and (concerning the fact that piperitenone epoxide along with germacrene D was not available commercially for them as standards) they performed multivariate regression calculations on TEAC and composition data of the EOs in the study. According to their results, carvone and limonene had no significant activity towards ABTS⁺, linalool, 1,8-cineole, and dihydrocarvone may exhibit a prooxidant effect, while germacrene D possibly reacts with ABTS⁺ as a potent antioxidant. Nevertheless, the individual role of piperitenone epoxide (rotundifolone) is not clarified here. Regarding Cu(II)-induced lipid peroxidation assay (which is a less widely used method of studying AO activity), the carvonaceous apple mint oil has shown moderate activity. The mojito mint oil has provided a significant activity in the inhibition of lipid peroxidation.

Thus, these results are in accordance with multiple others showing the AO abilities of limonene-oxo compounds, miscellaneous cyclic terpenes (as 1,8-cineole), and sesquiterpenes are weak, variable, or even not clarified yet.

Antibacterial effect

The widespread application of antibacterial agents for both therapeutic and preventative reasons in numerous

domains, such as animal farming and agriculture, has resulted in antibiotic resistance, now recognized as a profound global health crisis. In the past two decades, there has been a growing awareness of the risks associated with the overuse of antibiotics, leading to increased regulations and a reduction in their usage. For example, the risk of using antimicrobial agents has led to the prohibition of antibiotics as feed additives since 2006 in the European Union (European Commission, 2005). Since then, many additional restrictions have been introduced (European Parliament and the Council of the European Union, 2018), including a 20% reduction in the amount of antibiotics used in human medicine by 2030 (European Health Union). As the ongoing demand for antimicrobials persists, researchers are dedicating more attention to exploring potential alternatives, including the utilization of plant extracts.

A search in the PubMed database reveals a notable trend: before the year 2000, only five articles were focused on investigating the antibacterial properties of *Mentha* species. However, this number saw a substantial rise, with 51 articles published between 2001 and 2010, followed by 149 articles between 2011 and 2020. Notably, within the last four years, there has been a significant surge in interest, resulting in the publication of 162 additional articles specifically addressing this subject. Although an increasing number of researchers are investigating the essential oils of mint and their main components, their focus remains primarily on the examination of extracts derived from the most commonly used species, such as *M. × piperita* and *M. spicata*. Conversely, almost no data can be found for the less studied species (like *M. × villosa*) from a microbial perspective.

The in vitro effect of antimicrobial agents is usually demonstrated by measuring the minimum inhibitory concentration (MIC), the minimum bactericidal concentration (MBC), or the zones of inhibition determined by the agar diffusion method. The repeatability and comparison of these methods largely depend on standardization, which is why many internationally accepted protocols (CLSI, M02, 2018; CLSI M07, 2018; EUCAST, 2023; EUCAST, 2022) define the standardized parameters for testing the antimicrobial effect (applied media, solvents, the concentration of microbes to be tested, parameters of incubation, etc.). For example, in the case of non-fastidious aerobic bacteria the standard parameters of in vitro MIC

determination are the following: broth dilution method, Mueller–Hinton media, constant and maximum 1% solvent concentration, 5×10^5 CFU/mL concentration of the tested bacteria, and incubation at 35 ± 1 °C for 18 ± 1 h (CLSI M07, 2018). In the case of testing the antimicrobial effect of mint essential oils (EO) the most common difference is the use of certain solvents in different concentrations (e.g. DMSO, ethanol, hexane, Tween-80) to facilitate the dissolution of the EO, which, when used in higher concentrations, can even have an antimicrobial effect by themselves (Ansel et al. 1969), and the airtight sealing of microplates or test tubes to reduce evaporation (Bassolé et al. 2010).

In many cases, the concentration of the used culture media and the tested microbes also differ, which is why very large differences can be observed between the individual results (Supplement 9, Table S9.1). For example, the same author determined the antimicrobial effect of carvone (78.76%) and limonene (11.50%) type EO of *M. spicata* with two different methods and reported 10 µL/mL (Shahbazi 2015) and 0.005 µL/mL (Shahbazi and Shavisi 2016) against *Escherichia coli* O157:H7 (2000-fold difference). Other authors (Chrysargyris et al. 2017) investigated similar EOs (carvone content ranged from 69.23 to 74.25%, and limonene content ranged from 10.42 to 11.39%) against *E. coli* ATCC 11775 and reported MIC from 6.25 to 12.5 mg/mL, which is more than one million-fold more than the previously mentioned 0.005 µL/mL (the tester strains were different but belonged to the same species). Therefore, the results of the antimicrobial effect tests are difficult to compare due to the differences in the testing techniques, especially if we take into account that the exact chemical composition of the tested essential oils and the tester strains are usually not the same. Depending on the research topic, the antimicrobial effect of essential oils has been tested for many different bacteria, but the two most commonly used species are *E. coli* and *Staphylococcus aureus* because both bacteria are significant human pathogens and representative indicators of antimicrobial resistance in food safety (Cain 2013; Loayza et al. 2020).

In addition to methodological differences, researchers usually focus on examining only one or a few plant extracts, and it is rare to find articles where more plant species (and more than one sample per species) have been tested. As long as there is no uniformly accepted

technique for testing the antimicrobial effects of EOs, the best comparable results are provided by those complex studies where the antimicrobial effect of several EOs against several microbes is investigated. With relevance to mint species, the research work of Kowalczyk et al. (2021) can be regarded as a good basis for comparing the possible antibacterial effects of different mint species. Altogether, fifteen commercial mint cultivars belonging to four species (*M. × piperita*, *M. arvensis*, *M. suaveolens*, and *M. spicata*) have been tested against three bacterial strains.

Regarding *M. spicata*, they compared six different cultivars, and the main compounds in essential oils were p-menthone (one case), piperitenone (one case), and carvone (four cases). In general, the piperitenone-type spearmint had the strongest antimicrobial effect against the tested bacteria, and the p-menthone-type was close to the carvone-type cultivars. The carvone content in three different mints was quite similar, ranging from 63.09% to 66.55%, and their MIC values against *S. aureus* were identical (0.39% v/v). However, there were significant differences in MIC values for *E. coli* (ranging from $\leq 0.098\%$ to 0.39%) and *P. aeruginosa* (ranging from 0.78% to 12.5%). This variance may be attributed to the presence of other essential oil components in smaller proportions, which can exert additive, synergistic, or even antagonistic effects (Kwiatkowski et al. 2019).

Another common question regarding antimicrobial activity is whether Gram-negative or Gram-positive bacteria are more sensitive to EO. General findings outlined that Gram-positive bacteria are more sensitive to plant essential oils than Gram-negatives because of the different cell membrane structure (Benali et al. 2020), but there can be significant differences between bacterial species or plant extracts. Kowalczyk et al. (2021) reported *P. aeruginosa* was resistant to most extracts (MIC 6.5–25%), except two (MIC 0.39% and 0.78%). *E. coli*, another Gram-negative bacterium, was more sensitive: MIC values were $< 0.098\%$ to 1.56% against the 15 mint EOs. The MIC values were between $< 0.098\%$ and 3.125% in the case of *S. aureus*. In six cases, the extracts inhibited the two bacteria at the same concentration; in five cases *S. aureus* (Gram-positive), while in four cases *E. coli* (Gram-negative) proved to be more sensitive after testing the fifteen EOs, while in four cases, *E. coli* (Gram-negative) proved to be more

sensitive. In a study conducted by Chrysargyris et al. (2017), five carvone-type spearmint essential oils, ranging from 69.23% to 74.24% in carvone content, were tested against both Gram-positive bacteria (*S. aureus* and *Listeria monocytogenes*) and Gram-negative bacteria (*E. coli* and *Salmonella enteritidis*). The MIC values were the same in the case of *L. monocytogenes* and *S. enteritidis* (3.125 mg/mL) and ranged from 6.25 to 12.5 mg/mL against *E. coli* and *S. aureus*. This suggests that there were no significant differences in MIC values between Gram-positive and Gram-negative bacteria. Furthermore, the study also determined LD₉₀ (90% lethal dose) values, and it was 50 mg/mL against Gram-positive bacteria, and they were not able to determine it in the case of Gram-negative bacteria, therefore, they concluded that the essential oils were more effective against Gram-positive bacteria. In another study (Sfaki et al., 2025), six *Mentha* taxa encompassing 11 cultivars were analyzed, focusing, among other aspects, on the antibacterial activity of their EOs against two Gram-positive and two Gram-negative bacteria. For *M. spicata*, five chemotypes were examined. The carvone-type essential oil exhibited identical MIC values (0.5% v/v) across all four bacterial strains. In contrast, the piperitenone oxide-rich oil showed greater efficacy against Gram-positive bacteria (MIC: 0.25–0.50% v/v) compared to Gram-negative ones (MIC: 0.50–1.00% v/v). The dihydrocarvone-type essential oil demonstrated slightly better inhibition of Gram-negative bacteria, although the differences were modest (MIC for Gram-negatives: 0.50–1.00% v/v; for Gram-positives: 1.00% v/v). The most effective EO against all tested microbes was the carvacrol- and thymol-containing EO, with the same MIC value of 0.06% v/v. Carvacrol and thymol are well-known for their potent antimicrobial properties, but they are rarely found in essential oils derived from *Mentha* species. The study also revealed that when using the agar diffusion method, all essential oils were equally or more effective against Gram-positive bacteria. However, the MBC values were generally lower for Gram-negative bacteria. Notably, in the case of *Bacillus cereus*, none of the EOs, even at the highest tested concentration (2% v/v), were able to achieve complete bactericidal activity. Ranjbar et al. compared the antibacterial activity of four mint species (*M. spicata* – carvone-type, *M. aquatica*, *M. longifolia*, and *M. × piperita*) against two Gram-negative

(including *E. coli*) and two Gram-positive (including *S. aureus*) bacteria (Ranjbar et al. 2023). The inhibition zones determined by agar diffusion methods were always greater in the case of Gram-positive bacteria. The MIC values of the spearmint essential oil ranged from 30 to 60 µg/mL, and the MBC values ranged from 50 to 120 µg/mL. Gram-positive bacteria were slightly more sensitive than Gram-negative ones. Based on these studies and the data presented in Supplement 9 (Table S9.1.), it can be assumed that Gram-negative bacteria can be more resistant to mint EO, but in many cases, their sensitivity is the same or higher than that of Gram-positive ones. In the case of the studies presented in Supplement 9 (Table S9.1.), *E. coli* was more sensitive in eight cases, more resistant in ten cases, and the same sensitivity as *S. aureus* in thirteen cases.

M. suaveolens has received less attention in research regarding its antibacterial properties when compared to *M. spicata*. In addition to twelve other mints, Kowalczyk et al. (2021) investigated the antimicrobial effects of three *M. suaveolens* cultivars (Kowalczyk et al. 2021). The main component of EOs was *trans*-piperitenone-oxide (ranged from 73.05 to 85.14%), and the MIC values were determined against *S. aureus* (from ≤ 0.098 to 3.125%), *E. coli* (from 0.39 to 1.56%), and *P. aeruginosa* (from 6.25 to $> 25\%$). Interestingly, the oil with the highest *trans*-piperitenone-oxide content (85.14%) was the least effective for all three bacteria. Ludwiczuk et al. (2016) also tested the EO of *M. suaveolens* (*trans*-Piperitenone-oxide, 89.5%) against *Staphylococcus epidermidis* ATCC 35984, and the MIC was 0.5% (significantly less than the previously mentioned MIC values of *M. spicata*). In another study (Oumzil et al. 2002), the antimicrobial effect of *M. suaveolens* was investigated, but unlike those presented above, the main active component of OE was pulegone (50%) in this case. They tested several bacterial strains, and the MIC ranged from 0.69 ppm to 1.38 ppm for both *E. coli* and *S. aureus* (which is a significantly smaller value compared to the one presented earlier). They also tested a piperitenone-oxide-only-type (56%) and a mixed type, piperitenone oxide (25%) and piperitone oxide (26%) containing *M. suaveolens* EO. The MIC values ranged from 0.69 to 5.55 ppm; therefore, these essential oils generally had a lower antibacterial effect than the pulegone-type oil. Sfafi et al. (2025) also investigated the antibacterial activity of EOs derived

from *M. suaveolens* with two distinct chemotypes: pulegone (87.51%) and *cis*-piperitenone-epoxide (63.50%). Both oils demonstrated equal inhibitory effects against the two studied Gram-negative bacteria (*E. coli* and *S. enterica*), with an MIC of 0.50% v/v. However, both oils exhibited slightly stronger activity against the Gram-positive bacteria tested, with the pulegone-type EO showing MIC values of 0.25–0.50% v/v and the *cis*-piperitenone-epoxide-type oil demonstrating greater efficacy with MIC values of 0.13–0.25% v/v.

In the case of *M. × villosa*, most studies focus on antiparasitic and antifungal effects (see later), and only a single study reports MIC values (Sfafi et al., 2025). The main active compounds in the examined EO were L-carvone (64.61% v/v) and limonene (18.81% v/v). The strongest antibacterial activity was observed against *E. coli*, while for the other three bacterial strains analyzed in the study (*B. cereus*, *S. enterica*, *S. aureus*), the MIC values were identical at 0.50% v/v. Even the antimicrobial activity determined using the agar diffusion method is reported in only a few studies. Arruda Thúlio et al. (2006) investigated the antimicrobial effect of the EO of *M. × villosa* by agar diffusion methods. The EO inhibited the growth of *S. aureus* (inhibition zones ranged from 13 to 16 mm), but there was no inhibition in the case of *E. coli* and *P. aeruginosa*.

Antibacterial activity of *Mentha* spp. EOs against *E. coli*, *S. aureus* and other bacteria are presented in Supplement 9 (Table S9.1).

Antifungal effect

Antifungal agents have been widely used in the treatment and prevention of fungal infections in humans and animals. However, the overuse and misuse of antifungal agents have led to the emergence of drug-resistant fungal strains, posing a significant challenge to the management of fungal infections (Pappas et al. 2016). Very similar to the antibacterial tests, antifungal activity can be defined by giving the MIC values as well as measuring the inhibition zones on agar plates. International guidelines to test the antifungal activity of different compounds are also available (CLSI M27, 2017; CLSI M38, 2017; CLSI M44, 2018; CLSI M51, 2016; EUCAST, 2023), but despite this, many deviations from the standard protocols can also be observed during the

investigation of the antifungal effect. Comparing the antifungal effect is further complicated due to the considerably smaller amount of scientific data available on this subject in contrast to the antibacterial effect.

Terpenes and terpenoids are the major chemicals responsible for the antifungal effect in mint species (Oumzil et al. 2002; Ait-Sidi-Brahim et al. 2019). Pulegone, a highly active oxygenated monoterpene, was found at high concentrations in the EO of *M. pulegium* (Ait-Ouazzou et al. 2012), but the EO of other mints can contain pulegone in high concentrations too (e.g., *M. suaveolens*, 50% [Oumzil et al. 2002]). The MIC value of the OE of this pulegone-type *M. suaveolens* was determined against three *Candida* isolates, which ranged from 0.34 to 0.69 ppm. In this study, two other types of *M. suaveolens* EO were analysed. One of them contained mainly piperitenone oxide (56%), while the other contained piperitenone oxide (25%) and piperitone oxide (26%). None of them were as effective as the pulegone-type EO (MIC ranged from 1.38 to 2.77 ppm and from 1.38 to 5.55 ppm).

Supplement 9 (Table S9.2.) summarizes the MIC values obtained from several studies, although, in addition to these, the antifungal effect of mint EOs was also tested with several other (non-standardized) methods. In the research of Giménez-Santamarina et al. (2022), the antifungal activity of *M. suaveolens*, along with *M. spicata* and *M. × piperita*, was studied against four fungal pathogens (*Fusarium oxysporum*, *Botryotinia fuckeliana*, *Verticillium dahlia*, and *Curvularia hawaiiensis*). In this study, the main compounds of the EOs were 40.2% piperitone oxide and 31.4% piperitenone oxide (*M. suaveolens*), 47.0% menthol and 23.1% menthone (*M. × piperita*), 41.1% carvone (*M. spicata*) and the oils were added into the media at different concentrations (from 200 to 400 µg/mL). The results revealed that the EO derived from *M. suaveolens* exhibited the most potent antifungal activity, inhibiting the mycelial growth of *F. oxysporum* by 94.21%, and the other three fungal pathogens were unable to grow (100% inhibition) when exposed to this EO at 400 µg/mL. *B. fuckeliana* was particularly susceptible, with even a concentration of 300 µg/mL resulting in complete inhibition. The other two essential oils were less effective and were not capable of 100% inhibition even at a concentration of 400 µg/mL but still displayed substantial antifungal activity.

B. fuckeliana remained the most sensitive among the tested fungal pathogens, with inhibition of 92.12% and 99.91% compared to the control for *M. × piperita* and *M. spicata*, respectively. The inhibition ranged from 44.27% to 74.05% (*M. spicata*) and from 56.33% to 76.80% (*M. piperita*) against the other three fungi.

Other studies have also confirmed that piperitone oxide, piperitenone oxide, and carvone-containing essential oil are effective against various fungi. Božović et al. (2015) reported that the major compounds piperitone oxide and piperitenone oxide are responsible for the possible antifungal effect of *M. suaveolens*. On the other hand, Soković et al. (2009) reported that the presence of carvone (besides piperitenone oxide) in the essential oil of *M. suaveolens* raises the antifungal activity of the oil. Angioletti et al. (2010) reported the MIC of a piperitenone oxide-type (92.66%) *M. suaveolens* against four *Cryptococcus neoformans* (MIC 0.03%) and seven dermatophyte strains (MIC ranged from 0.06 to 0.5%). Several others (Pietrella et al. 2011; Stringaro et al. 2014; Scazzocchio et al. 2016; Spagnoletti et al. 2016) investigated the antifungal effect of the piperitenone oxid-type OE of *M. suaveolens* against *Candida* spp. and reported similar MIC values ranging from 0.39 to 1.56 mg/mL. They tested almost the same EO using the same methods and obtained similar results, which confirms that comparable results can be obtained with standardized methods.

Besides the above-mentioned results, numerous other research studies have explored the antifungal properties of *M. spicata*. Ismaili et al. (2023) reported that the essential oil of *M. spicata* caused a total inhibition of the growth of *Trichophyton rubrum* at only 0.10% of essential oil in the experimental medium, however, the exact composition of the EO was not given, and the MIC was not determined. In another study (Hussain et al. 2010a, b), a carvone-type (51.7%) EO of *M. spicata* also showed an important antifungal effect against five pathogenic fungi: *Aspergillus niger*, *Mucor mucedo*, *Fusarium solani*, *Botryodiplodia theobromae*, and *Rhizopus solani*. *Aspergillus niger* proved to be the most sensitive both by disc diffusion (inhibition zone 26.9 mm) and microdilution (MIC 0.07 mg/mL) methods, but the diameter of the inhibition zones (between 23.0 and 26.3 mm) and the MIC values (ranged from 0.08 to 0.11 mg/mL) was similar in the case of the other four fungi as well.

Ranjbar et al. (2023) also investigated the antifungal activity of a carvone-type *M. spicata* with disc diffusion and microdilution methods against *P. oryzae*, *C. albicans* and *A. niger*. The diameters of the inhibition zones were 12 to 24 mm, and the MIC values ranged from 30 to 70 µg/mL. Powers et al. 2018 reported the MIC values of sixty EOs, including *M. spicata*. In this case, the main EO components were carvone (62.3%), and limonene (20.1%) and the MIC values were 313 µg/mL (*A. niger* and *C. neoformans*) and 625 µg/mL (*C. albicans*). Similar MIC (512 µg/mL) results were reported by (Khouri et al. 2016) against *Tricophytum rubrum*, while (Nardoni et al. 2015) reported high values of MIC ranging from 2 to 3% v/v (but in this latter case menthol and menthon were the main EO compounds, which is not typical for *M. spicata*).

Soković et al. (2009) investigated the antifungal effect (against 17 species) of *M. spicata*, where the main components of EO were carvone (49.5%) and menthone (21.9%) and reported significantly lower MIC values compared to those presented above. The essential oil of *M. spicata* showed fungistatic activity with MICs of 1.0–2.5 µL/mL, and the minimum fungicidal concentrations were the same (1.0–2.5 µL/mL). Another study reported even lower MIC values against human pathogenic fungi (0.25 µL/mL) in the case of a carvone-type (59.12%) EO and noted that carvacrol (and thymol) exhibited the highest levels of antifungal activity among the tested EOs (Adam et al. 1998). Piras et al. (2021) also reported very low MIC (0.16 to 0.32 µL/mL) values of a carvone-type (62.9%) OE against several fungal pathogens (*Cryptococcus neoformans*, *Tichophyton* spp., and *C. albicans*).

Compared to the previous ones, only a few articles discussed the antifungal effect of *M. × villosa*. In addition to the antibacterial effect, Arruda Thúlio et al. (2006) investigated the antifungal effect of the EO of *M. × villosa* by agar diffusion methods. The main compound of *M. × villosa* was piperitenone oxide, but the exact amount and the composition of the essential oil were not given. In this study, the antifungal effect of piperitenone oxide and four analogues, limonene oxide, pulegone oxide, carvone epoxide, and (+)-pulegone, were also investigated. The EO inhibited the growth of *C. albicans* (18 mm inhibition zone), and the pure compounds were also effective (inhibition zones ranged from 15 to 18 mm). It is worth noting that in this article, the antibacterial

effect was also investigated, as previously mentioned. Their findings indicated that the essential oil of *M. × villosa* (as well as the pure compounds) exhibited greater efficacy against fungi compared to bacteria. Guerra et al. 2015 investigated the effect of coating with shrimp chitosan and/or *M. × piperita*, *M. × villosa* against *Aspergillus niger*, *Botrytis cinerea*, *Penicillium expansum*, and *Rhizopus stolonifera*. The article is primarily about the combination of essential oils and chitosan and their use in the food industry, but MIC values, determined by broth macrodilution methods, were also given. The MIC for both *M. × piperita* and *M. × villosa* EO was 5.0 µL/mL against all tested fungi.

Toxicological data of extracts, essential oils, or individual constituents of spearmint, apple mint, and mojito mint

Since the beneficial effects of the presented mint species were given in the previous sections, it is necessary to summarize the possible adverse effects, data referring to the toxicity of the extracts, and main compounds of spearmint, apple mint, and mojito mint.

In this section, the authors have intended to review the available sources from two viewpoints.

On one side, the adverse effects of different preparations (polar extracts via various solvents and essential oils) of the three mint taxa are surveyed by using the available literature (Table 11). Data of each taxon were arranged based on the type of the preparations discussed: beginning with teas or infusions, continuing with other solvent extracts, and, after them, essential oils. It is important to premise that much more data is available on the toxicology of spearmint than on the other two taxa. Studies were often conducted to establish oral acute toxicity, as it provides the data most often used and shared at hazard assessment and hazard communication in the chemical, pharmaceutical, and food industry. Furthermore, other individual effects, such as the supposed antian-drogenic effects of aqueous extracts of *Mentha spicata*, are also studied, however less frequently. Nevertheless, the results of these are often difficult to evaluate and compare (Lasrado et al. 2017).

On the other hand, the oral toxicological data (LD₅₀ or toxic-dose-lowest [TD-Lo] values) and GHS (Globally Harmonized System of Classification and

Table 11 Adverse effects of different preparations (polar extracts via various solvents, essential oils) of the three mint taxa according to the literature data

Plant species	Extract	Main compound	Dosage	In vivo/ human	Results	References
<i>M. spicata</i>	Tea	Not given	20 g/L, 40 g/L	Male rats	Decreased testosterone, increased LH and FSH	Akdogan et al. (2004)
<i>M. spicata</i>	Tea	Not given	20 g/L, 40 g/L	Male rats	Decreased testosterone, LH, and FSH. Dose-dependent antiandrogenic effect and development of oxidative stress	Kumar et al. (2008)
<i>M. spicata</i>	Tea	Not given	Not given	Human	Decreased testosterone, increased LH and FSH	Grant (2010)
<i>M. spicata</i>	Dried water extract	Rosmarinic acid (15%)	422, 844, 1948 mg/kg bw/day	Rats	No significant changes in body weight, feed consumption, neurological parameters, hematology, clinical chemistries, gross pathology, histopathology	Lasrado et al. (2015)
<i>M. spicata</i>	Dried water extract	TPC (24–32%, gallic acid equivalent), rosmarinic acid (14.5–17.5%), carvacrol (20 ppm)	600 mg spearmint extract/day (87 mg RA/day), 900 mg spearmint extract/day (130.5 mg RA/day)	Human	Dry extract was well-tolerated and had no significant effect on the thyroid or pituitary function	Lasrado et al. (2017)
<i>M. spicata</i>	Tea	Not given	559.36, 1118.72 and 2237.44 mg/kg bw	Rats	Elevated serum AST, CK, and LDH levels	Musa et al. (2022)
<i>M. spicata</i>	Aqueous extract	Rosmarinic acid (15.2%)	900 mg extract/day (2 capsules)	Human	Extract is well-tolerated and may improve certain aspects of cognitive function	Niemann et al. (2014)
<i>M. spicata</i>	Crude methanol extract (80 v/v %)	Not given	500, 1000 and 2000 mg/kg	Mice	Safe at all test doses	Yousuf et al. (2013)
<i>M. spicata</i>	Methanolic extract (80 v/v %)	Not given	Single dose of 5000 mg/kg extract by oral gavage (with the volume of 10 ml/kg bodyweight of the rats) after an overnight fast	Rats	LD ₅₀ > 5000 mg/kg bw	Naidu et al. (2014)
<i>M. spicata</i>	Ethanol–water (70–30:v/v)	Not given	10,000, 12,000, 14,000, 16,000 and 18,000 mg/kg bw	Mice, rat	LD50 = 13,606 mg/kg bw (mice)	Mugisha et al. (2014)
<i>M. spicata</i>	Ethanollic extract (yield of the solution 9.6% (g/g))	Not given	10, 20, and 40 mg/kg extract	Male rats	No significant effect on the reproductive system, fertility, number of offspring of male rats	Nozhat et al. (2014)

Table 11 continued

Plant species	Extract	Main compound	Dosage	In vivo/ human	Results	References
<i>M. spicata</i>	Essential oil	Limonene (21.56%), Carvone (60.37%)	500; 1000; 1500; 2000; 3000; and 5000 mg/kg	Rats	No major behavioral anomalies, clinical signs of toxicity, or mortality were noted. LD ₅₀ > 5000 mg/kg bw (rats)	Mekkaoui et al. (2022)
<i>M. spicata</i>	Aqueous extract	Rosmarinic acid (15.2%)	900 mg extract/day (2 capsules)	Human	Extract is well-tolerated and may improve certain aspects of cognitive function	Niemann et al. (2014)
<i>M. suaveolens</i>	Tea	Not given	2000 mg/kg, 5000 mg/kg	Mice	Clinical signs of local or systemic toxic effects were not observed. LD ₅₀ > 5000 mg/kg bw (mice)	Wafa et al. (2025)
<i>M. × villosa</i>	Essential oil	Rotundifolone (piperitenone oxid) 35.4%	10, 25, or 50 µg/kg/day of the essential oil prepared in 2% Tween 80 (20 µL Tween 80 for 1 mL distilled water) solution	Pregnant rats	Not toxic to pregnant rats and does not impair gestation at the applied doses employed when administered during the organogenesis period. Haemorrhagic points are mainly in the kidney, liver, and vessels near the heart—fetal toxic effect	da Silva et al. (2012)

LH Luteinizing hormone, FSH Follicle-stimulating hormone, TPC Total phenolic content, bw body weight

Labelling of Chemicals, see at: UNECE, 2023) hazard statements to a selection of individual compounds frequently detected in the three taxa in higher ratios, along with thymol and carvacrol, are also surveyed. (These latter were included here about that among the less abundant major EO constituents in the three taxa, thymol and carvacrol may have the most multifaceted bioactivity, industrial and therapeutic usage [see e.g., Nieto 2020]).

This is intended to provide concise, informative material on the toxicological properties of the leading components in the discussed *Mentha* taxa in their pure form. This survey is based on the safety data sheets (MSDS) of the selected components.

Although GHS is used in most UN member states (UNECE, 2023), its integration is different in the individual states' or unions' methods of toxicological classification (Morris-Schaffer and McCoy 2021), risk assessment, hazard communication, or labeling of chemicals. Therefore, the authors considered the MSDS-s published by two major fine chemicals distributors accessible from their home country; one of which (*Merck*) provides toxicological data and hazard statements according to EU directives and one of which (*Caymanchem*) provides toxicological data and hazard statements according to US Occupational Safety and Health Administration (OSHA) regulations.

Additionally, the recent and valuable review by Morris-Schaffer and McCoy (2021) on the calculation methods of LD₅₀ values, as well as the explanation and integration into GHS, is also presented in this chapter (Table 12). This may facilitate the assessment and comparison of toxicological data for both complex extracts and individual compounds.

The toxicity of spearmint tea (20 g/L, 40 g/L) was tested in rats in the study of Akdogan et al. (2004). Spearmint tea consumption resulted in decreased plasma testosterone and increased plasma luteinizing hormone (LH) and follicle-stimulating hormone (FSH). Extensive degenerative changes could be seen in the germinal epithelium of the testicles. Higher concentrations caused more significant damage.

Kumar et al. (2008) also evaluated the possible toxic effect of spearmint tea applied in the same concentration in rats. They also found a decreased level of testosterone, which possibly indicates the dose-dependent antiandrogenic nature of spearmint. Moreover, they found a correlation between the

Table 12 Categories of toxicity based on oral LD₅₀ by GHS, and the classification of intoxicants by two different major authorities, based on Morris-Schaffer and McCoy (2021)

GHS category	Interval of LD ₅₀ , mg/kg bw, oral	Classification in EU (ECB) and in USA (OSHA)
1	≤ 5	ECB: Very toxic OSHA: Highly toxic (Labelling: <i>Danger/Fatal if swallowed</i>)
2	5 < LD ₅₀ ≤ 50	ECB: ≤ 25 mg/kg bw, Very toxic, 25–50 mg/kg bw, Toxic OSHA: Highly toxic (Labelling: <i>Danger/Fatal if swallowed</i>)
3	50 < LD ₅₀ ≤ 300	ECB: ≤ 200 mg/kg bw Toxic 200 mg/kg and up: Harmful OSHA: Toxic (Labelling: <i>Danger/Fatal if swallowed</i>)
4	300 < LD ₅₀ ≤ 2000	ECB: 200–2000 mg/kg: Harmful OSHA: ≤ 500 mg/kg bw, Toxic (<i>Danger/Toxic if swallowed</i>), 500–2000 mg/kg: not classified as toxic, but labelled as <i>Warning/Harmful if swallowed</i>
5	2000 < LD ₅₀ ≤ 5000	ECB: Not classified as toxic or harmful OSHA: Not classified as toxic, but labelled as <i>May be harmful if swallowed</i> . No <i>Warning</i> or <i>Danger</i> labels and symbols

ECB European Chemical Bureau, OSHA US Occupational Safety and Health Administration, bw body weight

dosage and the emerging oxidative stress in the hypothalamus.

In 2010, Grant presented his findings on the antiandrogenic effect of spearmint tea in polycystic ovarian syndrome in a 30-day, randomized controlled trial. Similar to the two above-mentioned studies, the composition of the tea is not given. In the spearmint tea group, free and total testosterone levels decreased, while LH and FSH levels increased. However, because of the length of the study, these results can be regarded only as preliminary findings, and much longer future studies are necessary.

The toxicity of dried water extract of two different spearmint lines was tested in rats (Lasrado et al. 2015). The main compound of the extract was rosmarinic acid (RA) (15%) – volatile compounds were not detected. None of the tested extract dosages (422, 844, 1948 mg/kg bw/day) caused significant changes in the evaluated parameters (body weight, feed consumption, neurological parameters, haematology, clinical chemistries, gross pathology, and histopathology). Based on the results, the acceptable daily intake (ADI) was calculated for the dried aqueous extract of spearmint 19.48 mg/kgbw/day (1363 mg/day for a

70 kg human). With relevance to the main compound of the extract (rosmarinic acid), the ADI is 3 mg/kg bw/day.

Another clinical evaluation was conducted by Lasrado et al. (2017) as a randomized, double blind, placebo-controlled study. The total phenolic content of the applied dried water extract was between 24–32% expressed as gallic acid equivalent, and rosmarinic acid (RA) content was between 14.5–17.5%. Carvacrol was also present in the samples in a concentration of 20 ppm. Healthy subjects were randomized into three groups: placebo, 600 mg spearmint extract/day (87 mg RA/day), and 900 mg spearmint extract/day (130.5 mg RA/day). The following safety and tolerability characteristics were determined: complete blood count (CBC), hepatic function, Luteinizing Hormone (LH), Follicular Stimulating Hormone (FSH), Thyroid Stimulating Hormone (TSH), vital signs, lipid panel, and adverse events. According to the results, the tested dry extract was well-tolerated and had no significant effect on the thyroid or pituitary function. Therefore, according to the authors, spearmint and spearmint extracts can be regarded as safe food additives (Lasrado et al. 2017).

This finding may be highly relevant if the in vitro radical scavenging effect of extracts rich in rosmarinic acid and/or polyhydroxyflavonoids is considered. The in vitro AO/antiradical effects may serve as a basis of development of plant-originated antirancidity/preservative agents. The study of Kanatt et al. (2007) was already referred earlier (Chapter 6.1) as a demonstration of the efficacy of spearmint extract as a potent lipid peroxidation inhibitor in lamb meat.

Similarly to the previous works, in the study of Musa et al. (2002), rats given an herbal tea from *M. spicata* leaves demonstrated no significant toxicity or death. However, the highest possible dose of 2237.44 mg/kg elevated serum aminotransferase (AST), creatine kinase (CK), and lactate dehydrogenase (LDH) levels in both sexes, reflecting somewhat mild organ stress. The liver, kidney, and pancreas showed minor lesions without significant histological change. The study suggests that spearmint tea is safe at tested dosages but calls for further research on chronic and reproductive toxicity (Musa et al. 2022).

Dried material of a spearmint water extract was clinically evaluated in the study of Nieman et al. (2014). The spearmint extract material was packed in 450 mg capsules. The extract contained 15.2 m/m% rosmarinic acid. Subjects consumed 900 mg extract/day (2 capsules) for 30 days. Evaluation of gastrointestinal (GI) tolerability and adverse effects was done completed with laboratory tests. Serious adverse effects were not detected. Based on the results, the tested spearmint extract is well-tolerated and may improve certain aspects of cognitive function.

It is necessary to note that the results on the supposed antiandrogenic effects of aqueous spearmint preparations are difficult to compare, and they are not assigned to either leading or minor components in the extract. Currently, these studies have not been followed by official contraindications or prohibitions on the regular consumption of spearmint tea.

The research of Yousuf et al. (2013) on mice has shown no mortality or signs of toxicity after oral administration of different doses of the methanolic extract of *M. spicata* up to 2000 mg/kg bw dosage.

Naidu et al. (2014) examined the acute toxicity of methanol–water extract (80 v/v %) of spearmint on aquatic life and rats. The brine shrimp lethality essay resulted in $LC_{50} = 1701 \mu\text{g/ml}$. Looking at the acute toxicity test results, in rats, even 5000 mg/kg extract did not show any toxicity or mortality. During the

14 days of observation, significant changes in the behaviour of the animals (apathy, hyperactivity, morbidity, etc.) were not detected. Body weight, respiration rate, and heart rate did not change as well. With relevance to the histopathological examination results, no signs of toxicity have been revealed. According to the authors, the material of methanol extract of spearmint seems to be safe at a dose level of 5000 mg/kg bw, therefore, the LD_{50} is more than 5000 mg/kg bw. If GHS (see Table 11) are regarded here, this extract may be evaluated neither toxic, nor harmful.

Mugisha et al. (2014) investigated the acute and subacute toxicity of the ethanol–water extract (70–30: v/v) of spearmint in Swiss mice and Wistar albino rats. The composition of the extract was not evaluated. The acute toxicity experiment was illustrated with the highest dose of 18,000 mg/kg body weight of the 70% ethanolic extract in mice. This resulted in a 100% death rate. Subacute toxicity using ethanol leaves extract with the highest dose of 1500 mg/kg body weight showed no mortality or signs of toxicity but increased hemoglobin concentration, lymphocytes, blood cells count, and aspartate transferase levels in rats. According to the authors, the high LD_{50} value is considered to be experimentally safe.

The possible toxic effect of ethanolic extract of spearmint was tested on the reproductive system, fertility, and number of offspring of male rats (Nozhat et al. 2014). Three experimental groups received 0, 10, 20, and 40 mg/kg spearmint extract orally for 45 days. In the applied dosages, significant changes in the examined characteristics were not detected.

The research carried out by Mekkaoui et al. (2022) investigated the acute and subacute toxicity of spearmint essential oil on Swiss mice and rats. The main compounds of the essential oil were limonene (21.56%) and carvone (60.37%). During the acute toxicity investigation, no major behavioral anomalies, clinical signs of toxicity, or mortality were noted. All the rats displayed uniform health conditions and stability, encompassing heart rates and breathing. The median lethal dose (LD_{50}) value was found to surpass 5000 mg/kg body weight. This signifies that *M. spicata* EO can be employed safely at a dosage of 5000 mg/kg body weight in rats. Interestingly, in the case of Japanese mint (*M. arvensis*) essential oil, LD_{50} was 2070.4 $\mu\text{l/kg}$ body weight after 10 days of oral treatment in the case of mice. In the brine shrimp

lethality assay, the result was 139.73 µl/ml (Yousuf et al. 2021). Unfortunately, the main compounds of the tested essential oil are not given, however, it is a well-known fact that Japanese mint is mainly characterised by a higher amount of menthol, which is usually not present in spearmint, apple mint, and mojito mint.

In the document of the „European Union list entry on *Mentha x piperita* L., aetheroleum” single dosage of cutaneous use of peppermint oil for children (4–11 age) is semi-solid preparations 2–10%, hydroethanolic preparations 2–4%, for adults semi-solid preparations 5–15%, hydroethanolic preparations 3–6%, for elderly semi-solid and oily preparations 5–20, hydroethanolic preparations 5–10%. Nasal ointments can contain 1–5% essential oil. The limit of 0.75 mg/kg bw should not be exceeded in the case of pulegone and menthofuran.

More details are available in “Public statement on the use of herbal medicinal products containing pulegone and menthofuran” (EMA/HMPC/138386/2005 Rev. 1 2005). Since there is a pulegone chemotype of apple mint (see the tables in Chapter 4 and supplements 1–3) and it also can be major EO component in spearmint and mojito mint too, it is very important to note, that this compound is rather toxic in higher concentrations. The highest known recommended daily dose in the EU is 1.2 ml in the case of peppermint oil (EU herbal monograph EMEA/HMPC/349466/2006) that contains a maximum 32.97 mg pulegone. For a 50 kg person, this would correspond to a daily intake of 0.66 mg/kg bw of pulegone.

With relevance to apple mint and mojito mint, toxicity results are scarce. The water extract (tea) of *M. suaveolens* was assessed for acute toxicity in Swiss mice by Wafa et al. (2025). The results demonstrated that apple mint tea possesses a considerable safety margin with LD₅₀ higher than 5000 mg/kg, with no fatalities recorded at modest dosages. Nevertheless, particular LD₅₀ values for *M. suaveolens* EO in animals are not uniformly documented across investigations, warranting additional research (see Table...). Behavioral assessments in treated animals (e.g., mice and rats) revealed no significant abnormalities at lower dosages, indicating minimal acute toxicity under regulated conditions.

Da Silva Bezerra Guerra et al. (2012) investigated the embryo and fetal toxicity of mojito mint essential oil on pregnant rats. Tested concentrations were as follows: 10, 25, or 50 µg/kg/day of the essential oil

prepared in 2% Tween 80 (20 µL Tween 80 for 1 mL distilled water) solution. The treatment did not alter body weight gain, water and food intake, litter weight, the number and weight of fetuses, reabsorptions, and implantations. Visceral analysis showed mild hemorrhagic points at the brain, kidney, liver, and blood vessels near the heart. The essential oil did not promote impairment to pregnant rats or gestation. According to the authors, in Brazil, 100 g of fresh leaves are used to make mojito mint infusion/day. This means 1.7 g leaves/body weight kg. If the mean body weight is 60 kg and 1 kg of fresh leaves yields 1 mg of essential oil, the average daily intake is 1.7 µg/kg. The applied concentrations were much higher, therefore, the consumption of *M. × villosa* tea can be considered safe.

If the toxicological or hazard assessment data of the individual compounds of the three taxa is surveyed, the first (and possibly the most important) comment is that none of them can be categorized upon their known LD₅₀s as acutely very toxic (US: Highly toxic) or acutely toxic, except pulegone (Supplement 10, Table S10.1., Table S10.3.). However, a shortcoming in the toxicological data is observable: for many flavonoids, LD₅₀ values are not available till nowadays. Their classification, hazard communication/labelling (especially in the European practice) seems to be based primarily on an empirical consensus that they are not hazardous.

By the European distributor, the polyphenols in question are not treated as hazardous materials at all, except p-hydroxybenzoic (syn. anisic) acid as an irritant (Supplement 10, Table S10.1., Table S10.3.). The evaluation of potential hazards of contacting these compounds is somewhat stricter at the US-originated distributor (e.g., luteolin is labelled as an irritant). Rosmarinic acid is assigned as toxic (H301) and rutin as harmful (H302) when swallowed, even though toxicological indices (LD₅₀ or TD-Lo) to rutin are not provided.

Note that TD-Lo of rosmarinic acid (100 ml/kg, rat) at the US-based distributor is given in an unconventional unit as this chemical is a solid crystalline one; this is a rather confusing detail. For comparison: The European distributor has given LD₅₀ of RA higher than 10 000 mg/kg bw, on rat. This can be classified as neither toxic nor harmful, according to the ECB. Therefore, the overall picture of the human

toxicology of RA and some flavonoids seems to be ambiguous.

In the case of the volatile terpenoids, much more toxicological data are available (Supplement 10, Table S10.4., Table S10.5.). Usually, the hazards associated with them can be flammability or combustibility, harms of ingestion, and topical irritative, allergizing, or damaging effects to skin and mucous membranes: eyes, respiratory tract, etc. Note that neither of the essential oils containing these compounds are advised for use in undiluted form, e.g., for cosmetic purposes, or intentionally ingested. Pulegone is exceptional regarding its HS-s, as it is suspected as a carcinogen (H351) agent. The actual acute oral toxicity among the discussed terpenoids is variable in connection with their structural variety.

According to their LD₅₀-s, linalool, limonene, piperitone, β -caryophyllene, and 1,8-cineole can be classified as neither toxic nor harmful agents, based on the classifications of both ECB and OSHA.

The LD₅₀ data of carvone is not uniform in the different sources. If Merck's data is considered, carvone may be classified as harmful (ECB, OSHA). If additional data is searched, another main European distributor, C. Roth, provides LD₅₀ = 3,561 mg/kg bw (rat) to carvone (source: MSDS sheet, reference number *SDB-8811-MT-EN*), which falls far over the upper limit of the harmful category (ECB, OSHA).

LD₅₀ values under 2000 mg/kg bw are assigned to the following terpenoids: thymol (LD₅₀ 980 mg/kg bw, rat), carvacrol (LD₅₀ 810 mg/kg bw, rat), isomenthone (LD₅₀ 500.1 mg/kg bw, rat), menthone (LD₅₀ NA or 500 mg/kg bw), pulegone (LD₅₀ 470 mg/kg bw, rat).

These data show that the substances in question are *harmful* (ECB, OSHA) if orally administered. The data on menthone are not in total accordance with the different sources and are difficult to evaluate. At Merck (see Supplement 10, Table S.10.5), its LD₅₀ is 500 mg/kg bw (undefined test animal). Additional data was found concerning menthone in the database Pubchem. Here, LD₅₀ is 500 mg/kg bw to rat. Despite the aforementioned, at Caymanchem, toxicological data of menthone are not provided on the MSDS; it seems to be treated as a non-hazardous material.

For pure thymol and carvacrol, they can cause burns when they come into contact with the skin and mucous membranes.

Regarding pulegone in its pure form, it can be considered as *harmful* (ECB) but also can be categorized as *toxic* (OSHA, LD₅₀ < 500 mg/kg). Based on the known adverse effects of pulegone (EMA/HMPC/138386/2005 Rev. 1 2005; Anderson et al. 1996), it may be more suggestable to consider it as *toxic* when risk assessment or hazard communication of it is required.

LD₅₀ values and hazard statements have not been found in MSDS-s and database Pubchem to: piperitenone, piperitenone epoxide, germacrene D and piperitone epoxides till 1 March 2025.

Additionally, it is necessary to consider that rosmarinic acid and an array of the terpenoids (limonene, linalool, pulegone, menthone, thymol, carvacrol, caryophyllene) are labelled as toxic or harmful to aquatic life in various degrees of severity (see the list of hazard statements in Supplement 10), independently from their human health-related properties.

The severity (H400-413) of the ecotoxic or harmful effect claimed on the label also depends on the regulations of authority with which the classification, hazard communication, and labelling is in accordance, and these incongruencies may also hamper the proper handling of the substances in question.

This is the case of rosmarinic acid (an MSDS according to the regulations of EU: No statement of environmental hazard, an MSDS based on OSHA regulations: H400, *Very toxic to aquatic life*).

Summarizing the toxicity results, we can conclude that the consumption of mojito mint and its parental species can be regarded safe for humans; however, chemotypes rich in pulegone should be avoided.

Conclusion

We aimed to present a less well-known mint species, *M. × villosa*, by summarizing the previous literature data referring to its botanical, chemical, and biological (in vitro antioxidant, antibacterial, and antifungal) effects. For a better understanding, not only mojito mint but its parental species—*Mentha spicata* and *Mentha suaveolens* have also been evaluated from the same aspects.

Looking at the morphological characteristics, mojito mint has some common features of both parental species. The leaf shape is more similar to

spearmint, however, the fur on the surface is an inherited characteristic of apple mint. The growing vigor is also between these two species; the plants can reach approximately 1 m in height. The color of the flowers is similar to spearmint.

The essential oil composition of different spearmint populations has been analyzed for much more time than in the other two mint species. As we highlighted, the composition is determined by many factors—genetics, collected plant part, phenophase, way of sample preparation, distillation method, etc. In most cases, spearmint contains carvone as the main EO compound, however, several other chemotypes have also been described. Less variability can be seen in apple mint, where most of the samples contained piperitenone oxide (rotundifolone). In the case of mojito mint, it is interesting that both main compounds of the parental species can be observed, and this difference shows a strong connection to different geographical zones. European samples are usually rich in carvone, while South American plants are characterized by a higher ratio of piperitenone oxid.

Regarding the non-volatile-phenolic compounds, rosmarinic acid (RA) is one the most important ones present in all mint species. To give more understandable, comparable data, we converted the different units into mg/kg. Similar to the essential oil composition, spearmint is the most heterogeneous species again since the RA content varies between 180 and 104,000 mg/kg d.w. Smaller average RA content results can be seen in the case of apple mint (19–28,000 mg/kg dw). Only a few data are available in the case of mojito mint (data ranged between 70 and 39,000 mg/kg d.w.); however, in this plant species, we can find the highest values (de Medeiros Gomez et al. 2021). As we presented, rather different sample preparations, extraction, and measuring methods can be found in the literature.

In all three species, there were reported batches found to be outstandingly rich in peculiar flavonoids: hesperidin, linarin, quercetin, or rutin. The same results were obtained in the cases of *M. × piperita* (Guédon and Pasquier 1994) and *M. longifolia* (Patonay et al. 2020); therefore, deeper investigations in the three discussed mint taxa are proposable. Wide screenings of many genotypes of *M. spicata*, *M. suaveolens*, or *M. × villosa* in parallel (raised in the same plot) are advised to be implemented. Regarding bioactive properties of eriocitrin (Yao et al. 2022),

hesperidin and related flavonoids such as apigenin, luteolin (Mimica-Dukic et al. 1999) linarin (Erenler et al. 2018; Pryzyska 2022) along with the well-known bioactivity of rutin, the searching, breeding, and exploitation of flavonoid-rich chemotaxa in the three discussed taxa is proposable.

Regarding flavonols, they are found to be regularly present in all discussed mint taxa, even in such a small pool of data as that which was found in *M. × villosa*. Considering these findings, it is advisable to re-evaluate the presence of flavonols in the genus *Mentha*.

The extraction methods applied to samples of the three mint taxa have shown a wide variety. It is aligned with the multiple goals and potential uses of mint phenolics in medicine [e.g. in treating ischemia (Fialová et al. 2015), Alzheimer's (Hanafy et al. 2017) or mitigating harms by nicotine intake (ben Saad et al. 2019)], in agronomy (Puig et al. 2023) in the food industry (Igoumenidis et al. 2016)]. However, the comparative evaluation of the composition from different extracts and the efficacy of the various methods are seriously hampered by the yield of extraction, which is often not provided. Thus, it is proposed to assess and provide the yield of dry extract material when polyphenol extraction is discussed.

The amount of phenolic compounds usually indicates the possible antioxidant power of a plant extract. Since the RA content of the above-mentioned mint species varied between rather wide ranges, it is not surprising that clear consequences cannot be drawn from the literature data referring to the in vitro antioxidant power of these plant species. In the cases of *M. spicata* and *M. suaveolens*, fewer fluctuating data can be seen, while *M. × villosa* exhibits inconsistent effectiveness. Nevertheless, much less experimental work focused on mojito mint than the other two species. Rosmarinic acid, the key antioxidant of *Mentha* taxa, can also be found in mojito mint. Furthermore, polyhydroxyflavonoids are also present in it. Therefore, additional research on the topic of the contribution of different constituents to the antioxidant properties of a complex extract should be continued in this plant species. The same point is valid for the open chain and alicyclic terpenoids (linalool, 1,8-cineole, limonene-oxo compounds) in the essential oils and their role in the AO activity of essential oils.

The overuse of antibacterial substances has caused a worldwide problem of antibiotic resistance, leading to a transition towards alternative remedies. *Mentha* species, specifically *M. spicata* and *M. suaveolens*, are being studied for their possible antibacterial characteristics. Methodological differences in assessing antibiotic effects complicate result comparisons, highlighting the necessity for standardization.

The rising volume of papers on *Mentha* species highlights a growing interest, although the absence of globally recognized testing methods presents obstacles. Kowalczyk et al. (2021) research demonstrates differences in antibacterial effectiveness within the same species, particularly with Gram-negative bacteria displaying various reactions. *M. suaveolens* shows diverse antimicrobial activities according to its chemical composition, however, the antibacterial evidence for *M. × villosa* is scarce. Resolving methodological inconsistencies and investigating less-researched species is essential for progressing our comprehension. A systematic approach is crucial in exploring the full potential of mint extracts as efficient antibacterial agents as we look for alternatives to antibiotics.

Excessive usage of antifungal medications has caused the development of drug-resistant fungal strains, presenting a major concern. This study highlighted the antifungal characteristics of mint species, with a particular focus on the significance of terpenes and terpenoids. Mint species such as *M. suaveolens* and *M. spicata* demonstrated positive outcomes, while chemicals like pulegone, piperitone oxide, and carvone displayed potent antifungal properties.

Standardized testing methodologies are essential for precise comparisons, as demonstrated by the differing MIC values in several investigations. *M. suaveolens* showed outstanding effectiveness, while *M. spicata* and *M. × villosa* exhibited significant antifungal properties. Further investigation of these natural chemicals could provide useful insights for combating drug-resistant fungal diseases.

Since all mint species are consumed not only for medicinal but other purposes too (as simple food as well), the available toxicity of the extracts and main compounds of spearmint, apple mint, and mojito mint have also been presented. In conclusion, we can state that the usage of these mint species can be regarded as safe for humans. However, more research is necessary to reveal the detailed pharmacokinetics and establish the exact human and environmental toxicity indices of

the solvent extracts along with their main compounds: phenolic acids, especially RA, and many flavonoids.

The toxicological classification of the individual compounds related to the discussed taxa in some cases may be hampered by the fact that the sources provide different data (e.g., as it was found to the oral LD₅₀ of carvone and menthone). If a risk assessment is required and multiple LD₅₀ values for a compound are found for the same method of administration and the same test animal, the lowest LD₅₀ (i.e., the highest potential harm) may be suggested to take into consideration.

Additionally, the pulegone-rich breeds/chemotypes of the three discussed taxa need to be avoided as medicinal, aromatic, or food crops because this ketone is known to exhibit severe adverse effects. The avoidance of harm by pulegone consumption is guaranteed only if the wild collection of *M. spicata*, *M. suaveolens*, and *M. × villosa* is replaced with cultivation, using their selected pulegone-free lines/breeds/chemotypes at domestication, further breeding, and propagation.

Summarizing our findings, mojito mint can be regarded as a prospective medicinal plant not only used for drink flavouring. It can be a good substitution of carvone-type spearmint; however, much more scientific experiments would be necessary to optimize its cultivation technique focusing on different types of active agents as well as to define its proper in vitro biological activity.

Acknowledgements This work has been supported by the János Bolyai Research Scholarship of the Hungarian Academy of Sciences (BO/00585/22/4), TKP2021-NKTA-16 “Research and Development to Improve the Competitiveness and Environmental Adaptability of Viticulture and Oenology at the Eszterházy Károly Catholic University” and by the Research Excellence Programme of the Hungarian University of Agriculture and Life Sciences.

Author contributions SzTS: conceptualization, editing, author of chapters 1, 2, 3; 7, 8. KP: conceptualization, author of chapters 4, 5, 6.1, 7, 8, editing, table, graphs editing, revision, visualization. ÁJ: conceptualization, author of chapters 6.2, 6.3. and 8. AS: author of chapter 6.1., editing. PR: author of chapter 3; table, graph editing, revision, visualization.

Funding Open access funding provided by Hungarian University of Agriculture and Life Sciences. Magyar Tudományos Akadémia, BO/00585/22/4, Szilvia Tavaszi-Sárosi, Nemzeti Kutatási, Fejlesztési és Innovációs Alap, TKP2021-NKTA-16, Katalin Patonay, Magyar Agrár- és

Élettudományi Egyetem, Research Excellence Programme, Ákos Juhász, Research Excellence Programme, Péter Radácsi.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Abuajah CI, Ogbonna AC, Osuji CM (2015) Functional components and medicinal properties of food: a review. *J Food Sci Technol* 52:2522–2529. <https://doi.org/10.1007/s13197-014-1396-5>
- Adam K, Sivropoulou A, Kokkini S et al (1998) Antifungal activities of *Origanum vulgare* subsp. *hirtum*, *Mentha spicata*, *Lavandula angustifolia*, and *Salvia fruticosa* essential oils against human pathogenic fungi. *J Agric Food Chem* 46:1739–1745. <https://doi.org/10.1021/jf9708296>
- Adam M, Dobiaš P, Eisner A, Ventura K (2009) Extraction of antioxidants from plants using ultrasonic methods and their antioxidant capacity. *J Separ Sci* 32:288–294. <https://doi.org/10.1002/jssc.200800543>
- Aher VD, Wahi A, Pawdey AM, Sonawan A (2011) Antioxidants as an immunomodulator: an expanding research avenue. *Int J Curr Pharm Res* 3:8–10
- Ait-Ouazzou A, Lorán S, Arakrak A et al (2012) Evaluation of the chemical composition and antimicrobial activity of *Mentha pulegium*, *Juniperus phoenicea*, and *Cyperus longus* essential oils from Morocco. *Food Res Int* 45:313–319. <https://doi.org/10.1016/j.foodres.2011.09.004>
- Ait-Sidi-Brahim M, Markouk M, Larhsini M (2019) Moroccan medicinal plants as anti-infective and antioxidant agents. New look to phytomedicine. Elsevier, Amsterdam, pp 91–142
- Akdogan M, Ozguner M, Kocak A, Oncu M, Cicek E (2004) Effects of peppermint teas on plasma testosterone, follicle-stimulating hormone, and luteinizing hormone levels and testicular tissue in rats. *Urology* 64:394–398. <https://doi.org/10.1016/j.urology.2004.03.046>
- Alam MdN, Bristi NJ, Rafiquzzaman MD (2013) Review on *in vivo* and *in vitro* methods evaluation of antioxidant activity. *Saudi Pharm J* 21:143–152. <https://doi.org/10.1016/j.jsps.2012.05.002>
- Aldogman B, Bilel H, Moustafa SMN et al (2022) Investigation of chemical compositions and biological activities of *Mentha suaveolens* L. from Saudi Arabia. *Molecules* 27:2949. <https://doi.org/10.3390/molecules27092949>
- Alsaraf S, Hadi Z, Akhtar MJ, Khan SA (2021) Chemical profiling cytotoxic and antioxidant activity of volatile oil isolated from the mint (*Mentha spicata* L.) grown in Oman. *Biocatal Agric Biotechnol* 34:102034. <https://doi.org/10.1016/j.bcab.2021.102034>
- Anderson IB, Mullen WH, Meeker JE, Khojasteh-Bakht SC, Oishi S, Nelson SD, Blanc PD (1996) Pennyroyal toxicity: measurement of toxic metabolite levels in two cases and review of the literature. *Ann Intern Med* 124:726–734. <https://doi.org/10.7326/0003-4819-124-8-199604150-00004>
- Angiolella L, Vavala E, Sivric S et al (2010) Letter: In vitro activity of *Mentha suaveolens* essential oil against *Cryptococcus neoformans* and dermatophytes. *Int J Essent Oil Ther* 4:35–36
- Ansel HC, Norred WP, Roth IL (1969) Antimicrobial activity of dimethyl sulfoxide against *Escherichia coli*, *Pseudomonas aeruginosa*, and *Bacillus megaterium*. *J Pharm Sci* 58:836–839. <https://doi.org/10.1002/jps.2600580708>
- Arruda Thúlio A, Antunes RMP, Catão RMR et al (2006) Preliminary study of the antimicrobial activity of *Mentha × villosa* Hudson essential oil, rotundifolone and its analogues. *Rev Bras Farmacogn* 16:307–311. <https://doi.org/10.1590/S0102-695X2006000300005>
- Azeem M, Zaman T, Tahir M, Haris A, Iqbal Z, Binyameen M, Nazir A, Shad SA, Majeed S, Mozūraitis R (2019) Chemical composition and repellent activity of 30 native plants essential oils against dengue mosquito. *Aedes Aegypti Ind Crops Prod* 140:111609. <https://doi.org/10.1016/j.indcrop.2019.111609>
- Bahman N, Alinaghi A, Kamalinejad M (2008) Evaluation of the antioxidant properties of five *Mentha* species. *Iran J Pharm Res* 7:203–209
- Bakkali F, Averbeck S, Averbeck D, Idaomar M (2008) Biological effects of essential oils—a review. *Food Chem Tox* 46:446–475. <https://doi.org/10.1016/j.fct.2007.09.106>
- Balasaheb Nimse S, Pal D (2015) Free radicals, natural antioxidants, and their reaction mechanisms. *RSC Adv* 5:27986–28006. <https://doi.org/10.1039/C4RA13315C>
- Bardaweel SK, Bakchiche B, AlSalamat HA, Rezzoug M, Gherib A, Flamini G (2018) Chemical composition, antioxidant, antimicrobial and Antiproliferative activities of essential oil of *Mentha spicata* L. (Lamiaceae) from Algerian Saharan atlas. *BMC Complement Altern Med* 18:201. <https://doi.org/10.1186/s12906-018-2274-x>
- Başer KHC, Kürkçüoğlu M, Tarımcılar G, Kaynak G (1999) Essential oils of *Mentha* species from Northern Turkey. *J Essent Oil Res* 11:579–588. <https://doi.org/10.1080/10412905.1999.9701218>
- Başer KHC, Kürkçüoğlu M, Demirci B, Özek T, Tarımcılar G (2012) Essential oils of *Mentha* species from Marmara region of Turkey. *J Essent Oil Res* 24:265–272. <https://doi.org/10.1080/10412905.2012.676775>
- Bassolé IHN, Lamien-Meda A, Bayala B, Tirogo S, Franz C, Novak J, Nebié RC, Dicko MH (2010) Composition and antimicrobial activities of *Lippia multiflora* Moldenke, *Mentha × piperita* L. and *Ocimum basilicum* L. essential oils and their major monoterpene alcohols alone and in

- combination. *Molecules* 15:7825–7839. <https://doi.org/10.3390/molecules15117825>
- Ben Saad A, Rjeibi I, Brahmi N, Elaloui E, Zouari N (2019) Nicotine-induced oxidative stress, testis injury, AChE inhibition and brain damage alleviated by *Mentha spicata*. *Inflammopharmacology*. <https://doi.org/10.1007/s10787-019-00650-0>
- Benabdallah A, Rahmoune C, Boumendjel M, Aissi O, Messaoud Ch (2016) Total phenolic content and antioxidant activity of six wild *Mentha* species (Lamiaceae) from northeast of Algeria. *Asian Pac J Trop Biomed* 6:760–766. <https://doi.org/10.1016/j.apjtb.2016.06.016>
- Benabdallah A, Boumendjel M, Aissi O, Rahmoune C, Boussaid M, Messaoud Ch C (2018) Chemical composition, antioxidant activity and acetylcholinesterase inhibitory of wild *Mentha* species from northeastern Algeria. *South Afr J of Bot* 116:131–139. <https://doi.org/10.1016/j.sajb.2018.03.002>
- Benali T, Bouyahya A, Habbadi K, Zengin G, Khabbach A, Achbani EH, Hammami K (2020) Chemical composition and antibacterial activity of the essential oil and extracts of *Cistus ladaniferus* subsp. *ladanifer* and *Mentha suaveolens* against phytopathogenic bacteria and their ecofriendly management of phytopathogenic bacteria. *Biocatal Agric Biotechnol* 28:101696. <https://doi.org/10.1016/j.cbab.2020.101696>
- Benayad N, Ebrahim W, Hakiki A, Mosaddak M (2012) Chemical characterization and insecticidal evaluation of the essential oil of *Mentha suaveolens* L. and *Mentha pulegium* L. growing in Morocco. *Food Ind* 13:27–32
- Benomari FZ, Andreu V, Kotarba J, Dib MEA, Bertrand C, Muselli A, Costa J, Djabou N (2018) Essential oils from Algerian species of *Mentha* as new bio-control agents against phytopathogen strains. *Environ Sci Pollut Res* 25:29889–29900. <https://doi.org/10.1007/s11356-017-9991-4>
- Benzie IF, 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>
- Bezerra AC, da Barbosa LS, Zuza JFC et al (2019) Structural characterization of mint (*Mentha × villosa* Huds) stem and leaf. *J Exp Agric Int*. <https://doi.org/10.9734/jeai/2019/v36i230232>
- Bichra M, El-Modafar Ch, El-Boustani E-s, Benkhalti F (2012) Antioxidant and anti-browning activities of *Mentha suaveolens* extracts. *Afr. J. Biotechnol.* 11:8722–8729. <https://doi.org/10.5897/AJB11.3528>
- Bichra M, El Modafar C, El Abbassi A et al (2013a) Antioxidant activities and phenolic profile of six Moroccan selected herbs. *J Microbiol Biotechnol Food Sci* 2:2320–2338
- Bichra M, El-Modafar Ch, El-Abbassi A, Bouamama H, Benkhalti F (2013b) Antioxidant activities and phenolic profile of six Moroccan selected herbs. *J Microbiol Biotechnol Food Sci* 2:2320–2338
- Bimakr M, Rahman RA, Taip FS et al (2011) Comparison of different extraction methods for the extraction of major bioactive flavonoid compounds from spearmint (*Mentha spicata* L.) leaves. *Food Bioprod Process* 89:67–72. <https://doi.org/10.1016/j.fbp.2010.03.002>
- Bishr MM, Salama OM (2018) Inter and intra GC-MS differential analysis of the essential oils of three *Mentha* species growing in Egypt. *Future J Pharm Sci* 4:53–56. <https://doi.org/10.1016/j.fjps.2017.08.003>
- Bittner Fialová S, Kurin E, Trajčiková E, Jánošová L, Šušaničková I, Tekel'ová D, Nagy M, Mučaji P (2020) *Mentha* rhizomes as an alternative source of natural antioxidants. *Molecules* 25:200. <https://doi.org/10.3390/molecules25010200>
- Bors W, Heller W, Michel C, Saran M (1990) Flavonoids as antioxidants: determination of radical-scavenging efficiencies. *Meth Enzymol.* 186:343–55. [https://doi.org/10.1016/0076-6879\(90\)86128-i](https://doi.org/10.1016/0076-6879(90)86128-i)
- Bortoluzzi BB, Buzatti A, Chaaban A, Pritsch IC, Dos Anjos A, Cipriano RR, Deschamps C, Molento MB (2020) *Mentha villosa* Hubs *M. × piperita* and their bioactives against gastrointestinal nematodes of ruminants and the potential as drug enhancers. *Vet Parasitol.* <https://doi.org/10.1016/j.vetpar.2020.109317>
- Boukhebbi H, Chaker AN, Belhadj S, Sahli F, Ramdhani M, Laouer H, Harzallah D (2011) Chemical composition and antibacterial activity of *Mentha pulegium* L. and *Mentha spicata* L. essential oils. *Pharm Lett* 3:267–275
- Božović M, Piroli A, Ragno R (2015) *Mentha suaveolens* Ehrh. (Lamiaceae) essential oil and its main constituent piperitone oxide: biological activities and chemistry. *Molecules* 20:8605–8633. <https://doi.org/10.3390/molecules20058605>
- Bravo L (1998) Polyphenols: chemistry, dietary sources, metabolism, and nutritional significance. *Nutr Rev* 56:317–333. <https://doi.org/10.1111/j.1753-4887.1998.tb01670.x>
- Buleandra M, Oprea E, Popa DE, David IG, Moldovan Z, Mihai I, Badea IA (2016) Comparative chemical analysis of *Mentha piperita* and *M. spicata* and a fast assessment of commercial peppermint teas. *Nat Prod Commun.* 11:19345781601100. <https://doi.org/10.1177/1934578x1601100433>
- Cain CL (2013) Antimicrobial resistance in *Staphylococci* in small animals. *Vet Clin North Am Small Anim Pract* 43:19–40. <https://doi.org/10.1016/j.cvsm.2012.09.003>
- Carocho M, Morales P, Ferreira ICFR (2018) Antioxidants: reviewing the chemistry, food applications, legislation and role as preservatives. *Trends Food Sci Technol* 71:107–120. <https://doi.org/10.1016/j.tifs.2017.11.008>
- Čavar Zeljković S, Šišková J, Komzáková K, De Diego N, Kaffková K, Tarkowski P (2021) Phenolic compounds and biological activity of selected *Mentha* species. *Plants* 10:550. <https://doi.org/10.3390/plants10030550>
- Chauhan SS, Prakash O, Padalia RC, Vivekanand Pant AK, Mathela CS (2011) Chemical diversity in *Mentha spicata*: antioxidant and potato sprout inhibition activity of its essential oils. *Nat Prod Commun* 6:1934578X1100600. <https://doi.org/10.1177/1934578x1100600938>
- Chowdhury JU, Nandi NC, Uddin M, Rahman M (2007) Chemical Constituents of Essential Oils from Two Types of Spearmint (*Mentha spicata* L. and *M. cardiaca* L.) Introduced in Bangladesh. *Bangladesh j sci ind res* 42(1):79–82. <https://doi.org/10.3329/bjsir.v42i1.359>
- Chrysargyris A, Xylia P, Botsaris G, Tzortzakakis N (2017) Antioxidant and antibacterial activities, mineral and

- essential oil composition of spearmint (*Mentha spicata* L.) affected by the potassium levels. *Ind Crops Prod* 103:202–212. <https://doi.org/10.1016/j.indcrop.2017.04.010>
- Clark GS (1994) An aromatic profile. *Menthone*. *Perfum Flavor* 19:41–45
- Cook CM, Kokkini S, Lanaras T (2007) *Mentha spicata* essential oils rich in 1,8-cineole and 1,2-epoxy-p-menthane derivatives from Zakynthos (Ionian Island, W Greece). *J Essent Oil Res* 19:225–230. <https://doi.org/10.1080/10412905.2007.9699266>
- Csepregi K, Neugart S, Schreiner M, Hideg É (2016) Comparative evaluation of total antioxidant capacities of plant polyphenols. *Molecules* 21:208. <https://doi.org/10.3390/molecules21020208>
- da Silva Bezerra Guerra KS, Silva RLC, Souza Maia MB, Schwarz A (2012) Embryo and fetal toxicity of *Mentha × villosa* essential oil in Wistar rats. *Pharm Biol* 50(7):871–877. <https://doi.org/10.3109/13880209.2011.641024>
- de Pooter HL, Schamp NM (1987) The essential oil of *Mentha × villosa* nm. *alopecuroides*. *Flav Fragr J* 2:163–165. <https://doi.org/10.1002/ffj.2730020405>
- de Martins PA, Craveiro AA, Machado MIL, Raffin FN, Moura TF, Novák Cs, Éhen Zs (2007) Preparation and characterization of *Mentha × villosa* Hudson oil–cyclodextrin complex. *J Therm Anal Calorim* 88:363–371. <https://doi.org/10.1007/s10973-005-7407-z>
- de Matos FJA, Machado MIL, Craveiro AA, Alencar JW, Barbosa JM, da Cunha EVL, Hiruma CA (1999) Essential oil of *Mentha × villosa* Huds. from Northeastern Brazil. *J. Essent. Oil Res.* 11:41–44. <https://doi.org/10.1080/10412905.1999.9701066>
- de Medeiros Gomes J, Cahino Terto MV, do Golzio Santos S, da Sobral Silva M, Fachine Tavares J (2021) Seasonal variations of polyphenols content, sun protection factor and antioxidant activity of two *Lamiaceae* species. *Pharmaceutics* 13:110. <https://doi.org/10.3390/pharmaceutics13010110>
- de Medeiros Gomes J (2022) Atividade fotoprotetora e antioxidante do extrato otimizado de *Mentha × villosa* e estudo sazonal de suas atividades e metabólitos secundários. Universidade Federal da Paraíba, João Pessoa, Paraíba, Brazil. PhD Thesis, in Portuguese (Brazil). (Accession: 19 April 2024) https://repositorio.ufpb.br/jspui/bitstream/123456789/26502/1/JulianaDeMedeirosGomes_Tese.pdf
- de Sousa BA, de Moraes SM, Ferreira PAT, Vieira ÍGP, Craveiro AA, dos Santos Fontenelle RO, Silva JE, de Menezes A, Ferreira FW, da Silva FWF, de Sousa HA (2015) Chemical composition and functional properties of essential oils from *Mentha* species. *Ind Crop Prod* 76:557–564. <https://doi.org/10.1016/j.indcrop.2015.07.004>
- Derwich EZ, Benziane Z, Taouil R, Senhaji O, Touzani M (2010) Comparative essential oil composition of leaf of *Mentha rotundifolia* and *Mentha pulegium* a traditional herbal Medicine in Morocco. *Am-Eur J Sustain Agric* 4:47–54
- Dorman HJD, Koşar M, Kahlos K, Holm Y, Hiltunen R (2003) Antioxidant properties and composition of aqueous extracts from *Mentha* species, hybrids, varieties, and cultivars. *J Agric Food Chem* 51:4563–4569. <https://doi.org/10.1021/jf034108k>
- dos Santos Franciscato LMS, da Silva MR, Andrich F, Sakai OA, Doyama JT, Fernandes Júnior A, Moritz Mengue Feniman C (2018) Chemical characterization and antimicrobial activity of essential oils of mint (*Mentha spicata* L.) and Surinam cherry (*Eugenia uniflora* L.). *Orbital Electron J Chem.* 10:475–481. <https://doi.org/10.17807/orbital.v10i6.1008>
- Dudai N, Segev D, Havkin-Frenkel D, Eshel A (2006) Genetic variation of phenolic compounds content, essential oil composition and anti-oxidative activity in Israel-grown *Mentha longifolia* L. *Acta Hortic.* 709:69–78. <https://doi.org/10.17660/ActaHortic.2006.709.8>
- eFreitas JRL, Vendramini PH, Melo JOF, Eberlin MN, Rodinei A (2019) Assessing the spatial distribution of key flavonoids in *Mentha × piperita* leaves: an application of desorption electrospray ionization mass spectrometry imaging (DESI-MSI). *J. Braz. Chem. Soc.* 30:1437–1446. <https://doi.org/10.21577/0103-5053.20190039>
- Eftekhari A, Khusro A, Ahmadian E et al (2021) Phytochemical and nutra-pharmaceutical attributes of *Mentha* spp.: a comprehensive review. *Arab J Chem* 14:103106. <https://doi.org/10.1016/j.arabjc.2021.103106>
- El Arch M, Satrani B, Farah A, Bennani L, Boriky D, Fechtal M, Blaghen M, Talbi M (2003) Composition chimique et activités antimicrobienne et insecticide de l'huile essentielle de *Mentha rotundifolia* du Maroc. *Acta Bot Gallica* 150:267–274. <https://doi.org/10.1080/12538078.2003.10515996>
- El Hachlafi N, Benkhaira N, Al-Mijalli SH, Mrabti HN, Abdnim R, Abdallah EM, Jeddi M, Bnouham M, Lee LH, Ardianto C, Ming LC, Bouyahya A, Fikri-Benbrahim K (2023) Phytochemical analysis and evaluation of antimicrobial, antioxidant, and antidiabetic activities of essential oils from Moroccan medicinal plants: *Mentha suaveolens*, *Lavandula stoechas*, and *Ammi visnaga*. *Biomed Pharmacother* 164:114937. <https://doi.org/10.1016/j.biopha.2023.114937>
- El Moussaoui N, Sanchez G, Ouardy Khay E, Idaomar M, Ibn Mansour A, Abrini J, Aznar R (2013) Antibacterial and antiviral activities of essential oils of Northern Moroccan plants. *Biotech J Int* 3:318–331. <https://doi.org/10.9734/BBJ/2013/3596>
- El-Akhal J, Oliveira AP, Bencheikh R, Valentão P, Andrade PB, Morato M (2022) Vasorelaxant mechanism of herbal extracts from *Mentha suaveolens*, *Conyza canadensis*, *Teucrium polium* and *Salvia verbenaca* in the aorta of Wistar rats. *Molecules* 27:8752. <https://doi.org/10.3390/molecules27248752>
- Elansary HO, Ashmawy NA (2013) Essential oils of mint between benefits and hazards. *J Essent Oil Bear Plants* 16:429–438. <https://doi.org/10.1080/0972060X.2013.813279>
- Elansary HO, Mahmoud EA (2014) Egyptian herbal tea infusions' antioxidants and their antiproliferative and cytotoxic activities against cancer cells. *Nat Prod Res* 29:474–479. <https://doi.org/10.1080/14786419.2014.951354c>
- El-Kashoury EA, El-Askary HA, Kandi ZA, Ezzat SM, Salem MM, Sleem AA (2014) Chemical and biological study of

- Mentha suaveolens* Ehrh. cultivated in Egypt. J Med Plants Res 8:747–755. <https://doi.org/10.5897/JMPR2014.5324>
- EMA (2018) *Menthae piperitae aetheroleum*. In: Eur. Med. Agency. <https://www.ema.europa.eu/en/medicines/herbal/menthae-piperitae-aetheroleum> Accessed 21 Mar 2023
- Erenler R, Telci İ, Elmastaş M, Akşit H, Gül F (2018) Quantification of flavonoids isolated from *Mentha spicata* in selected clones of Turkish mint landraces. Turk J Chem 42:1695–1705. <https://doi.org/10.3906/kim-1712-3>
- Fatiha B, Didier H, Naima G, Khodir M, Martin K, Léocadie K, Caroline S, Mohamed C, Pierre D (2015) Phenolic composition, in vitro antioxidant effects and tyrosinase inhibitory activity of three Algerian *Mentha* species: *M. spicata* (L.), *M. pulegium* (L.) and *M. rotundifolia* (L.) Huds (Lamiaceae). Ind Crops Prod 74:722–730. <https://doi.org/10.1016/j.indcrop.2015.04.038>
- Fatiha Brahmi B, Madani K, Stévinny C, Chibane M, Duez P (2014) Algerian mint species: HPTLC quantitative determination of rosmarinic acid and in vitro inhibitory effects on linoleic acid peroxidation. J Coast Life Med. 2:986–992. <https://doi.org/10.12980/JCLM.2.2014APJTB-2014-0027>
- Fitsiou E, Mitropoulou G, Spyridopoulou K, Tiptiri-Kourpeti A, Vamvakias M, Bardouki H, Panayiotidis MI, Galanis A, Kourkoutas Y, Chlichlia K, Pappa A (2016) Phytochemical profile and evaluation of the biological activities of essential oils derived from the Greek aromatic plant species *Ocimum basilicum*, *Mentha spicata*. Pimpinella Anisum Fortunella Margarita Mol 21:1069. <https://doi.org/10.3390/molecules21081069>
- Fialová S, Veizerova L, Nosalova V, Drabikova K, Tekelova D, Tekelova D, Tekelova R (2015) Water Extract of *Mentha × villosa*: Phenolic Fingerprint and Effect on Ischemia-Reperfusion Injury. Nat Prod Commun 10(6):937–940. <https://doi.org/10.1177/1934578X1501000636>
- Fletcher R, Slimmon T, Kott L (2010) Environmental factors affecting the accumulation of rosmarinic acid in Spearmint (*Mentha spicata* L.) and Peppermint (*Mentha piperita* L.). Open Agric J 4:10–16. <https://doi.org/10.2174/1874331501004010010>
- Franco R, Navarro G, Martínez-Pinilla E (2019) Antioxidants versus food antioxidant additives and food preservatives. Antioxidants 8:542. <https://doi.org/10.3390/antiox8110542>
- Galambosi B, Aflatuni A, Sorvari K (1998) Effect of cultivation techniques on mint oils in Northern Finland. Perfum Flavor 23(5):27–31
- Giménez-Santamarina S, Llorens-Molina J-A, Sempere-Ferre F, Santamarina C, Roselló J, Santamarina MP (2022) Chemical composition of essential oils of three *Mentha* species and their antifungal activity against selected phytopathogenic and post-harvest fungi. Life 15:64–73. <https://doi.org/10.1080/26895293.2021.2022007>
- Gökbulut A, Şarer E (2010) Simultaneous determination of phenolic compounds in *Mentha spicata* L. subsp. *spicata* by RP-HPLC. Turk J Pharm Sci 7:249–254
- Gonçalves RS, Battistin A, Pauletti G, Serafini LA (2009) Antioxidant properties of *Mentha* species evidenced by electrochemical methods Rev. Bras Plantas Med 11:372–382. <https://doi.org/10.1590/S1516-05722009000400004>
- González-Martínez CA (2016) Principais componentes do óleo essencial de acessos de *Mentha* spp em Brasília e estudo da propagação vegetativa. 2016. xiv, 64 f., il. Dissertação (Mestrado em Agronomia)—Universidade de Brasília, Brasília, 2016. Thesis (MSc), in Portuguese (Brazil). Not available. Full text: Repositório Institucional da UnB: Principais componentes do óleo essencial de acessos de *Mentha* spp em Brasília e estudo da propagação vegetativa Accession 19 April 2024
- Góra J, Kalembe D (1979) Chemical composition of essential oil from *Mentha spicata* L. Herba Polonica 25:269–275
- Govindarajan M, Sivakumar R, Rajeswari M, Yogalakshmi K (2011) Chemical composition and larvicidal activity of essential oil from *Mentha spicata* (Linn.) against three mosquito species. Parasitol Res 110:2023–2032. <https://doi.org/10.1007/s00436-011-2731-7>
- Grant P (2010) Spearmint herbal tea has significant anti-androgen effects in polycystic ovarian syndrome. A randomized controlled trial. Ovaryther Res. 24:186e188. <https://doi.org/10.1002/ptr.2900>
- Grayer RJ, Eckert MR, Veitch NC, Kite GC, Marin PD, Kokubun T, Simmonds MJ, Paton AJ (2003) The chemotaxonomic significance of two bioactive caffeic acid esters, nepetoidins A and B, in the *Lamiaceae*. Phytochemistry 64:519–528. [https://doi.org/10.1016/S0031-9422\(03\)00192-4](https://doi.org/10.1016/S0031-9422(03)00192-4)
- Guedon DJ, Pasquier BP (1994) Analysis and distribution of flavonoid glycosides and rosmarinic acid in 40 *Mentha × piperita* clones. J Agric Food Chem 42:679–684. <https://doi.org/10.1021/jf00039a015>
- Guerra ICD, de Oliveira PDL, de Souza Pontes AL, Lúcio ASSC, Tavares JF, Barbosa-Filho JM, Madruga MS, de Souza EL (2015) Coatings comprising chitosan and *Mentha piperita* L. or *Mentha × villosa* Huds essential oils to prevent common postharvest mold infections and maintain the quality of cherry tomato fruit. Int J Food Microbiol 214:168–178. <https://doi.org/10.1016/j.ijfoodmicro.2015.08.009>
- Gülçin İ (2012) Antioxidant activity of food constituents: an overview. Arch Toxicol 86:345–391. <https://doi.org/10.1007/s00204-011-0774-2>
- Hanafy DM, Prenzler PD, Burrows GE, Ryan D, Nielsen S, Al Sawi SA, El Alfy TS, Abdelrahman EH, Obied HK (2017) Biophenols of mints: antioxidant, acetylcholinesterase, butyrylcholinesterase and histone deacetylase inhibition activities targeting Alzheimer's disease treatment. J Funct Foods. 33:345–362. <https://doi.org/10.1016/j.jff.2017.03.027>
- Handa KL, Smith DM, Nigam IC, Levi K (1964) Essential oil and their constituents. XXIII. Chemotaxonomy of the genus *Mentha*. J Pharm Soc 53:1407–1409. <https://doi.org/10.1002/jps.2600531129>
- Hawryl MA, Niemiec M, Słomka K, Waksmundzka-Hajnos M, Szimczak G (2016) Micro-2D-TLC Separation of phenolics in some species of mint and their fingerprints on diol bonded polar stationary phase. Acta Chrom 28:119–127. <https://doi.org/10.1556/ACHrom.28.2016.1.9>
- Hendriks H (1974) The essential oil of a new chemotype of *Mentha suaveolens* and a hybrid with *Mentha longifolia*. Ph.D. Thesis, State University, Groningen, Netherlands

- (data reported in: Lawrence BM (ed) (2007) Mint: The Genus *Mentha*. CRC Press, Boca Raton)
- Horváth P, Koščová J (2015) *In vitro* antibacterial activity of *Mentha* essential oils against *Staphylococcus aureus*. Folia Vet 61:71–77. <https://doi.org/10.1515/fv-2007-0030>
- Hussain AI, Anwar F, Shahid M, Anwar F, Shahid M, Ashraf M, Przybylski R (2010a) Chemical composition, and antioxidant and antimicrobial activities of essential oil of spearmint (*Mentha spicata* L.) from Pakistan. J Essent Oil Res 22:78–84. <https://doi.org/10.1080/10412905.2010.9700269>
- Hussain AI, Anwar F, Nigam PS, Ashraf M, Gilani AH (2010b) Seasonal variation in content, chemical composition and antimicrobial and cytotoxic activities of essential oils from four *Mentha* species. J Sci Food Agric 90:1827–1836. <https://doi.org/10.1002/jsfa.4021>
- Igoumenidis PE, Lekka EG, Karathanos VT (2016) Fortification of white milled rice with phytochemicals during cooking in aqueous extract of *Mentha spicata* leaves. An Adsorption Study. LWT-Food Sci Technol 65:589–596. <https://doi.org/10.1016/j.lwt.2015.07.012>
- Il Idrissi A, Bellakhdar J (1989) Étude chimiotaxonomique de diverses populations de *Mentha suaveolens* Ehrh. du Maroc: nouvelles données. (Written in French.) Al-Biruniya. 5:79–90.
- Jullien F (2007) Mint. In: Pua E-C, Davey MR (eds) Transgenic crops IV. Springer, Berlin, Heidelberg, pp 435–466
- Kanatt SR, Chander R, Sharma A (2007) Antioxidant potential of mint (*Mentha spicata* L.) in radiation-processed lamb meat. Food Chem 100:451–458. <https://doi.org/10.1016/j.foodchem.2005.09.066>
- Kapp K (2015) Polyphenolic and essential oil composition of *Mentha* and their antimicrobial effect. PhD Thesis, University of Helsinki, Helsinki, Finland. Full text: Polyphenolic and essential oil composition of *Mentha* and their antimicrobial effect (helsinki.fi) Accession: 19 April 2024
- Karousou R, Grammatikopoulos G, Lanaras T, Manetas Y, Kokkini S (1998) Effects of enhanced UV-B radiation on *Mentha spicata* essential oils. Phytochemistry 49:2273–2277
- Karousou R, Balta M, Hanlidou E, Kokkini S (2007) “Mints”, smells and traditional uses in Thessaloniki (Greece) and other Mediterranean countries. J Ethnopharmacol 109:248–257. <https://doi.org/10.1016/j.jep.2006.07.022>
- Kedia A, Prakash B, Mishra PK, Chantotiya CS, Kishore Dubey N (2014) Antifungal, antiaflatoxigenic, and insecticidal efficacy of spearmint (*Mentha spicata* L.) essential oil. Int Biodeterior Biodegrad 89:29–36. <https://doi.org/10.1016/j.ibiod.2013.10.027>
- Kehili S, Boukhatef MA, Belkadi A, Boulaghmen F, Ferhat MA, Setzer WN (2020) Spearmint (*Mentha spicata* L.) essential oil from Tipaza (Algeria): In vivo anti-inflammatory and analgesic activities in experimental animal models. Acta Pharm Hung. 90:15–26. <https://doi.org/10.3389/aph.2020.90.15-26>
- Khoury M, Stien D, Eparvier V et al (2016) Report on the medicinal use of eleven *Lamiaceae* species in Lebanon and rationalization of their antimicrobial potential by examination of the chemical composition and antimicrobial activity of their essential oils. Evid-Based Complement Altern Med ECAM 2016:2547169. <https://doi.org/10.1155/2016/2547169>
- Kivilompolo M, Hyötyläinen T (2007) Comprehensive two-dimensional liquid chromatography in analysis of *Lamiaceae* herbs: characterisation and quantification of antioxidant phenolic acids. J Chromatogr A. 1145:155–164. <https://doi.org/10.1016/j.chroma.2007.01.090>
- Kizil O, Tonçer S (2006) Influence of different harvest times on the yield and oil composition of spearmint (*Mentha spicata* L. var. *spicata*). J Food Agric Environ. 4:135–137
- Kofidis G, Bosabalidis A, Kokkini S (2004) Seasonal variation of essential oils in a linalool-rich chemotype of *Mentha spicata* grown wild in Greece. J Essent Oil Res 16:469–472. <https://doi.org/10.1080/10412905.2004.9698773>
- Kokkini S, Vokou D (1989) *Mentha spicata* L. (*Lamiaceae*) chemotypes growing wild in Greece. Econ Bot 43:192–202. <https://doi.org/10.1007/BF02859860>
- Kokkini S, Karousou R, Lanaras T (1997) Essential oils with 1,2-Epoxy-p-menthane derivatives from *Mentha spicata* plants growing across the island of Crete. Botanica Acta 110:184–189. <https://doi.org/10.1111/j.1438-8677.1997.tb00627.x>
- Koksai E, Bursal E, Dikici E, Tozoğlu F, Gülçin I (2011) Antioxidant activity of Melissa officinalis leaves. J Med Plants Res 5:217–222
- Koliopoulos G, Pitarokili D, Kioulos E, Michaelakis A, Tzakou O (2010) Chemical composition and larvicidal evaluation of *Mentha*, *Salvia*, and *Melissa* essential oils against the West Nile virus mosquito *Culex pipiens*. Parasitol Res 107:327–335. <https://doi.org/10.1007/s00436-010-1865-3>
- Kowalczyk A, Piątkowska E, Kuś P, Jerković I, Marijanović Z, Tuberoso CIG, Fecka I (2021) Volatile compounds and antibacterial effect of commercial mint cultivars—chemotypes and safety. Ind Crops Prod 166:113430. <https://doi.org/10.1016/j.indcrop.2021.113430>
- Kumar A, Chattopadhyay S (2007) DNA damage protecting activity and antioxidant potential of pudina extract. Food Chem 100:1377–1384. <https://doi.org/10.1016/j.foodchem.2005.12.015>
- Kumar V, Kural MR, Pereira BM, Roy P (2008) Spearmint induced hypothalamic oxidative stress and testicular anti-androgenicity in male rats—altered levels of gene expression, enzymes and hormones. Food Chem Toxicol. 46:3563e3570. <https://doi.org/10.1016/j.fct.2008.08.027>
- Kumar P, Mishra S, Malik A, Satya S (2011) Insecticidal properties of *Mentha* species: a review. Ind Crops Prod 34:802–817. <https://doi.org/10.1016/j.indcrop.2011.02.019>
- Kwiatkowski P, Pruss A, Wojciuk B, Dołęgowska B, Wajs-Bonikowska A, Sienkiewicz M, Mężyńska M, Łopusiewicz Ł (2019) The influence of essential oil compounds on antibacterial activity of mupirocin-susceptible and induced low-level mupirocin-resistant MRSA strains. Molecules 24:3105. <https://doi.org/10.3390/molecules24173105>
- Lagoune S, Öztürk M, Erol E, Duru ME, Abaza I, Kabouche A, Kabouche Z (2016) Chemical composition, antioxidant and antibacterial activities of the essential oil of *Mentha spicata* L. from Algeria. J Mater Environ Sci 7:4205–4213

- Lahlou S, Carneiro-Leão RFL, Leal-Cardoso JH, Toscano CF (2001) Cardiovascular effects of the essential oil of *Mentha × villosa* and its main constituent, piperitenone oxide, in normotensive anaesthetised rats: role of the autonomic nervous system. *Planta Med* 67:638–643. <https://doi.org/10.1055/s-2001-17352>
- Lasrado JA, Trinker D, Ceddia MA, Herrlinger KA (2015) The safety of a dry spearmint extract *in vitro* and *in vivo*. *Regul Toxicol Pharmacol* 71:213–224. <https://doi.org/10.1016/j.yrtph.2014.12.007>
- Lasrado JA, Nieman KM, Fonseca BA, Sanoshy KD, Schild AL, Herrlinger KA (2017) Safety and tolerability of a dried aqueous spearmint extract. *Regul Toxicol Pharmacol* 86:167–176. <https://doi.org/10.1016/j.yrtph.2017.03.005>
- Lawrence BM (ed) (2007b) *Mint: the genus Mentha*. CRC Press, Boca Raton
- Lawrence BM (2007) Oil composition of other *Mentha* species and hybrids. In: *Mint: The Genus Mentha*. pp 325–346
- Lima TC, da Silva TK, Silva FL, Barbosa-Filho JM, Marques MO, Santos RL, Cavalcanti SC, de Sousa DP (2014) Larvicidal activity of *Mentha × villosa* Hudson essential oil, rotundifolia-ne and derivatives. *Chemosphere* 104:37–43. <https://doi.org/10.1016/j.chemosphere.2013.10.035>
- Lin D, Xiao M, Zhao J, Li Z, Xing B, Li X, Kong M, Li L, Zhang Q, Liu Y, Chen H, Qin W, Wu H, Chen S (2016) An overview of plant phenolic compounds and their importance in human nutrition and management of Type 2 diabetes. *Molecules* 21:1374. <https://doi.org/10.3390/molecules21101374>
- Llorens-Molina JA, Rivera Seclén CF, Vacas Gonzalez S, Boira Tortajada H (2017) *Mentha suaveolens* Ehrh chemotypes in Eastern Iberian Peninsula: essential oil variation and relation with ecological factors. *Chem Biodivers* 14:00320. <https://doi.org/10.1002/cbdv.201700320>
- Loayza F, Graham JP, Trueba G (2020) Factors obscuring the role of *E. coli* from domestic animals in the global antimicrobial resistance crisis: an evidence-based review. *Int J Environ Res Public Health* 17:3061. <https://doi.org/10.3390/ijerph17093061>
- Ludwiczuk A, Kiełtyka-Dadasiewicz A, Sawicki R, Golus J, Ginalska G (2016) Essential oils of some *Mentha* species and cultivars, their chemistry and bacteriostatic activity. *Nat Prod Commun* 11:1015–1018
- Maffei M, Berteau CM, Mucciarelli M (2007) Anatomy, physiology, biosynthesis, molecular biology, tissue culture, and biotechnology of mint essential oil production. In: *Mint: The Genus Mentha*. pp 41–87
- Mahendran G, Verma SK, Rahman L-U (2021) The traditional uses, phytochemistry and pharmacology of spearmint (*Mentha spicata* L.): a review. *J Ethnopharmacol* 278:114266. <https://doi.org/10.1016/j.jep.2021.114266>
- Mahendran G, Verma SK, Rahman L-U (2021) The traditional uses, phytochemistry and pharmacology of spearmint (*Mentha spicata* L.): a review. *J Ethnopharmacol* 278:114266. <https://doi.org/10.1016/j.jep.2021.114266>
- Mamadaliyeva NZ, Hussain H, Xiao J (2020) Recent advances in genus *Mentha*: Phytochemistry, antimicrobial effects, and food applications. *Food Front* 1:435–458. <https://doi.org/10.1002/fft2.53>
- Mekkaoui M, Boudida EH, Naceiri Mrabti H, Ouamr A, Lee L-H, Bouyahya A, Cherrah Y, Alaoui K (2022) Investigation of chemical compounds and evaluation of toxicity, antibacterial, and anti-inflammatory activities of three selected essential oils and their mixtures with Moroccan thyme honey. *Foods* 11:3141. <https://doi.org/10.3390/foods11193141>
- Mimica-Dukić N, Bozin B (2008) *Mentha* L. species (*Lamiaceae*) as promising sources of bioactive secondary metabolites. *Curr Pharm des* 14:3141–3150. <https://doi.org/10.2174/138161208786404245>
- Mimica-Dukić N, Jakovljević V, Popović M, Gašić O, Szabo A (1999) Pharmacological study of *Mentha longifolia* phenolic extracts II. Hepatoprotective Activity *Pharm Biol* 37:221–224. <https://doi.org/10.1076/phbi.37.3.221.6306>
- Mimica-Dukić N, Husain SZ, Jančić R, Gašić O, Loukis A, Khan MR (1991) Composition and variation of essential oil constituents in three *Mentha* L. (*Labiatae*) species in Yugoslavia. *Pak. J. Bot.* 23(2): 243–248. Full text: <http://142.54.178.187:9060/xmlui/handle/123456789/16725>
- Accession: 19 April 2024
- Moetamedipoor SA, Saharkhiz MJ, Khosravi AR, Jowkar A (2021) Essential oil chemical diversity of Iranian mints. *Ind Crops Prod* 172:114039. <https://doi.org/10.1016/j.indcrop.2021.114039>
- Moldovan RI, Oprean R, Benedec D, Hanganu D, Duma M, Oniga I, Vlase L (2014) LC-MS analysis, antioxidant and antimicrobial activities for five species of *Mentha* cultivated in Romania. *Dig. J. Nanomater. Biostructures* 9:559–566. DOI: NA. **Full text:** (18) (PDF) LC-MS analysis, antioxidant and antimicrobial activities for five species of *Mentha* cultivated in Romania (researchgate.net)
- Accession: 19 April 2024
- Morris-Schaffer K, McCoy MJ (2021) A review of the LD50 and its current role in hazard communication. *ACS Chem Health Saf* 28:25–33. <https://doi.org/10.1021/acs.chas.0c00096>
- Mugisha MK, Ndukui JG, Namutembi A, Waako P, Karlson AKB, Vudriko P (2014) Acute and sub-acute toxicity of ethanolic leaf extracts of *Rumex abyssinica* Jacq. (*Polygonaceae*) and *Mentha spicata* L. (*Lamiaceae*). *Pharmacol Pharm* 5(3):309–318. <https://doi.org/10.4236/pp.2014.53038>
- Musa AH, Hagos AD, Dimsu GG, Eshetu EM, Tola MA, Admas A, Gelagle AA, Tullu BL (2022) Subchronic toxicity study of herbal tea of *Moringa stenopetala* (Baker f.) Cudof. and *Mentha spicata* L. leaves formulation in Wistar albino rats. *Toxicol Rep* 9:797–805. <https://doi.org/10.1016/j.toxrep.2022.03.043>
- Nagell VA, Hefendehl FW (1974) Composition of the essential oil of *Mentha rotundifolia*. *Planta Med* 26:1–8
- Naidu JR, Ismail R, Sasidharan S (2014) Acute oral toxicity and brine shrimp lethality of methanol extract of *Mentha spicata* L. (*Lamiaceae*). *Trop J Pharmacut Res* 13:101–107. <https://doi.org/10.4314/tjpr.v13i1.15>
- Narasimhamoorthy B, Zhao LQ, Liu X, Yang W, Greaves JA (2015) Differences in the chemotype of two native spearmint clonal lines selected for rosmarinic acid accumulation in comparison to commercially grown native spearmint. *Ind Crop Prod* 63:87–91. <https://doi.org/10.1016/j.indcrop.2014.10.044>
- Németh-Zámboiné É (2016) Natural variability of essential oil components. In Başer KHC, Buchbauer G: *Handbook of*

- essential oils, 2nd edn. CRC Press, Taylor and Francis Group LLC.
- Nieman K, Herrlinger K, Sanoshy K, Schild A, Kelley K, Maki K, Ceddia M (2014) Tolerance and cognitive function effects of a proprietary spearmint extract in men and women with self-reported memory impairment—a pilot study (LB402). *Faseb J*. 28:402. https://doi.org/10.1096/fasebj.28.1_supplement.lb402
- Nieto G (2020) A review on applications and uses of *Thymus* in the food industry. *Plants* 9:961. <https://doi.org/10.3390/plants908096>
- Nozhat F, Alaei S, Behzadi K, Chegini NA (2014) Evaluation of possible toxic effects of spearmint (*Mentha spicata*) on the reproductive system, fertility and number of offspring in adult male rats. *Avicenna J Phytomed* 4(6):420–429
- Olugbami J, Gbadegesin M, Odunola O (2014) In vitro evaluation of the antioxidant potential, phenolic and flavonoid contents of the stem bark ethanol extract of *Anogeissus leiocarpus*. *Afr J Med Med Sci* 43:101–109
- Omar AN, El-Sayed IAZ, Romeh AA (2009) Chemical constituents and biocidal activity of the essential oil of *Mentha spicata* L. grown in Zagazig region. *Egypt Res J Agric Biol Sci (RJABS)* 5:1089–1097
- Oumzil H, Ghouli S, Rhajaoui M, Iidirissi A, Fkih-Tetouani S, Faid M, Benjouad A (2002) Antibacterial and antifungal activity of essential oils of *Mentha suaveolens*. *Phytother Res* 16:727–731. <https://doi.org/10.1002/ptr.1045>
- Özer Z (2018) Investigation of phenolic compounds and antioxidant activity of *Mentha spicata* L. subsp. *spicata* and *M. longifolia* (L.) L. subsp. *typhoides* (Briq.) Harley decoction and infusion. *J Turk Chem Soc Sect Chem* 5:445–456. <https://doi.org/10.18596/jotcsa.350089>
- Papageorgiou V, Mallouchos A, Komaitis M (2008) Investigation of the antioxidant behavior of air- and freeze-dried aromatic plant materials in relation to their phenolic content and vegetative cycle. *J Agric Food Chem* 56:5743–5752. <https://doi.org/10.1021/jf8009393>
- Pappas PG, Kauffman CA, Andes DR, Clancy CJ, Marr KA, Ostrosky-Zeichner L, Reboli AC, Schuster MG, Vazquez JA, Walsh TJ, Zaoutis TE, Sobel JD (2016) Clinical practice guideline for the management of candidiasis: 2016 update by the infectious diseases society of America. *Clin Infect Dis* 62:e1–e50. <https://doi.org/10.1093/cid/civ933>
- Park YJ, Baek SA, Choi Y, Kim JK, Park SU (2019) Metabolic profiling of nine *Mentha* species and prediction of their antioxidant properties using chemometrics. *Molecules* 24:258. <https://doi.org/10.3390/molecules24020258>
- Patonay K, Németh-Zámboriné É (2021) Horsemint as a potential raw material for the food industry: survey on the chemistry of a less studied mint species. *Phytochem Rev* 20:631–652. <https://doi.org/10.1007/s11101-020-09718-0>
- Patonay K, Szalontai H, Csugány J, Szabó-Hudák O, Helga Péntesné Kónya E, Zámboriné Németh É (2019) Comparison of extraction methods for the assessment of total polyphenol content and in vitro antioxidant capacity of horsemint (*Mentha longifolia* (L.) L.). *J Appl Res Med Aromat Plants* 15:100220. <https://doi.org/10.1016/j.jarmap.2019.100220>
- Patonay K, Szabó-Hudák O, Szalontai H, Jánószky M, Kónya E, Németh É (2020) Extraction and identification of major polyphenol constituents of Northern Hungarian horsemint (*Mentha longifolia* L. (L.)). *Acta Biol Plant Agriensis*. 8:53–68. <https://doi.org/10.21406/abpa.2020.8.1.53>
- Pavela R, Kaffková K, Kumšta M (2014) Chemical composition and larvicidal activity of essential oils from different *Mentha* L. and *Pulegium* species against *Culex quinquefasciatus* Say (Diptera: Culicidae). *Plant Protect Sci* 50:36–42
- Pérez Raya MD, Utrilla MP, Navarro MC, Jiménez J (1990) CNS activity of *Mentha rotundifolia* and *Mentha longifolia* essential oil in mice and rats. *Phytother Res* 4(6):232–234. <https://doi.org/10.1002/ptr.2650040606>
- Petretto GL, Fancello F, Zara S, Foddai M, Mangia NP, Sanna ML, Omer EA, Menghini L CM, Pintore G (2014) Antimicrobial activity against beneficial microorganisms and chemical composition of essential oil of *Mentha suaveolens* ssp. *insularis* grown in Sardinia. *J. Food Sci.* 79:M369–M377. <https://doi.org/10.1111/1750-3841.12343>
- Pietrella D, Angiolella L, Vavala E, Rachini A, Mondello F, Ragno R, Bistoni F, Vecchiarelli A (2011) Beneficial effect of *Mentha suaveolens* essential oil in the treatment of vaginal candidiasis assessed by real-time monitoring of infection. *BMC Complement Altern Med*. 11:18. <https://doi.org/10.1186/1472-6882-11-18>
- Piras A, Porcedda S, Falconieri D, Maxia A, Gonçalves M, Cavaleiro C, Salgueiro L (2021) Antifungal activity of essential oil from *Mentha spicata* L. and *Mentha pulegium* L. growing wild in Sardinia island (Italy). *Nat Prod Res* 35:993–999. <https://doi.org/10.1080/14786419.2019.1610755>
- Poli J-P, Guinoiseau E, De Rocca Serra D, Soutour S, Paoli M, Tomi F, Quilichini Y, Berti L, Lorenzi V (2018) Antiquorum sensing activity of 12 essential oils on *Chromobacterium violaceum* and specific action of *cis-cis*-p-menthenolide from Corsican *Mentha suaveolens* ssp. *insularis*. *Molecules* 23:2125. <https://doi.org/10.3390/molecules23092125>
- Powers CN, Osier JL, McFeeters RL, Brazell CB, Olsen EL, Moriarity DM, Satyal P, Setzer WN (2018) Antifungal and cytotoxic activities of sixty commercially-available essential oils. *Molecules* 23:1549. <https://doi.org/10.3390/molecules23071549>
- PubChem [Internet]. (2004) Bethesda (MD): National Library of Medicine (US), National Center for Biotechnology Information. PubChem Compound Summary for CID 442497, Piperitenone oxide; [cited 2024 Mar. 26]. Available: <https://pubchem.ncbi.nlm.nih.gov/compound/Piperitenone-oxide>
- Puig CG, Álvarez-Iglesias L, Pardo-Muras M, Andrade PB, Pedrol N (2023) *Mentha suaveolens* as Allelopathic Biomass for Weed Control: Phenolics Organic Acids and Volatile Organic Compounds Profiles. *Agronomy* 13(11):2793. <https://doi.org/10.3390/agronomy13112793>
- EMA/HMPC/138386/2005 Rev.1. (2005) Public statement on the use of herbal medicinal products containing pulegone and menthofuran. In: Eur. Med. Agency. https://www.ema.europa.eu/en/documents/scientific-guideline/public-statement-use-herbal-medicinal-products-containing-pulegone-and-menthofuran-revision-1_en.pdf Accessed 22 Jan 2025

- Pyrzyska K (2022) Hesperidin: a review on extraction methods, stability and biological activities. *Nutrients* 14:2387. <https://doi.org/10.3390/nu14122387>
- Raeisi M, Bidkorpheh FG, Hashemi M, Tepe B, Moghaddem Z, Mohammadi MA, Noori Ali SM (2019) Chemical composition and antibacterial and antioxidant properties of essential oils of *Zataria multiflora*, *Artemisia dracunculus* and *Mentha piperita*. *Med Lab J*. 13:1–7. <https://doi.org/10.29252/mlj.13.2.1>
- Ranjbar M, Kiani M, Gholami F (2023) Phytochemical profiling and biocidal activity of four Iranian *Mentha* (Lamiaceae) species. *South Afr J Bot* 155:110–117. <https://doi.org/10.1016/j.sajb.2023.01.048>
- Rasooli I, Gachkar L, Yadegarinia D, Bagher Rezaei M, Alipoor Astaneh S (2008) Antibacterial and antioxidative characterisation of essential oils from *Mentha piperita* and *Mentha spicata* grown in Iran. *Acta Aliment* 37:41–52. <https://doi.org/10.1556/aalim.2007.0019>
- Rita I, Pereira C, Barros L, Santos-Buelga C (2016) *Mentha spicata* L. infusions as sources of antioxidant phenolic compounds: emerging reserve lots with special harvest requirements. *Food Funct* 10:4188–4192. <https://doi.org/10.1039/C6FO00841K>
- Salehi B, Stojanović-Radić Z, Matejić J, Sharopov F, Antolak H, Kregiel D, Sen S, Sharifi-Rad M, Acharya K, Sharifi-Rad R, Martorell M, Sureda A, Martins N, Sharifi-Rad J (2018) Plants of genus *Mentha*: from farm to food factory. *Plants* 7:70. <https://doi.org/10.3390/plants7030070>
- Sartoratto A, Machado ALM, Delarmelina C, Figueira GM, Duarte MCT, Rehder VLG (2004) Composition and antimicrobial activity of essential oils from aromatic plants used in Brazil. *Braz J Microbiol* 35:275–280. <https://doi.org/10.1590/S1517-83822004000300001>
- Sato A, Tamura H (2015) High antiallergic activity of 5,6,4'-trihydroxy-7,8,3'-trimethoxyflavone and 5,6-dihydroxy-7,8,3',4'-tetramethoxyflavone from eau de cologne mint (*Mentha × piperita citrata*). *Fitoterapia* 102:74–83. <https://doi.org/10.1016/j.fitote.2015.02.003>
- Scazzocchio F, Garzoli S, Conti C, Leone C, Renaioli C, Pepi F, Angiolella L (2016) Properties and limits of some essential oils: chemical characterisation, antimicrobial activity, interaction with antibiotics and cytotoxicity. *Nat Prod Res* 30:1909–1918. <https://doi.org/10.1080/14786419.2015.1086346>
- Sertkaya E, Kaya K, Soylu S (2010) Acaricidal activities of the essential oils from several medicinal plants against the carmine spider mite (*Tetranychus cinnabarinus* Boisd) (*Acarina: Tetranychidae*). *Ind. Crops Prod*. 31:107–112. <https://doi.org/10.1016/j.indcrop.2009.09.009>
- Sevindik M (2018) Pharmacological properties of *Mentha* species. *J Tradit Med Clin Naturop*. <https://doi.org/10.4172/2573-4555.1000259>
- Shahbazi Y (2015) Chemical composition and in vitro antibacterial activity of *Mentha spicata* essential oil against common foodborne pathogenic bacteria. *J Pathog*. <https://doi.org/10.1155/2015/916305>
- Shahbazi Y, Shavisi N (2016) Interactions of *Ziziphora clinopodioides* and *Mentha spicata* essential oils with chitosan and ciprofloxacin against common food-related pathogens. *LWT Food Sci Technol* 71:364–369. <https://doi.org/10.1016/j.lwt.2016.04.011>
- Shahidi F, Ambigaipalan P (2015) Phenolics and polyphenolics in foods, beverages and spices: antioxidant activity and health effects—a review. *J Funct Foods* 18B:820–897. <https://doi.org/10.1016/j.jff.2015.06.018>
- Shen D, Pan MH, Wu QL, Park CH, Juliani HR, Ho CT, Simon JE (2011) A rapid LC/MS/MS Method for the analysis of nonvolatile antiinflammatory agents from *Mentha* spp. *J Food Sci*. <https://doi.org/10.1111/j.1750-3841.2011.02281.x>
- Sitzmann J, Habegger R, Schnitzler WH, Grassmann J (2014) Comparative analysis of antioxidant activities of fourteen *Mentha* essential oils and their components. *Chem Biodivers* 11:1978–1989. <https://doi.org/10.1002/cbdv.201400100>
- Sivropoulou A, Kokkini S, Lanaras T, Arsenakis M (1995) Antimicrobial activity of mint essential oils. *J Agric Food Chem* 43:2384–2388. <https://doi.org/10.1021/jf00057a013>
- Snoussi M, Noumi E, Trabelsi N, Flamini G, Papetti A, De Feo V (2014) *Mentha spicata* essential oil: chemical composition, antioxidant and antibacterial activities against planktonic and biofilm cultures of *Vibrio* spp. strains. *Molecules* 20:14402–14424. <https://doi.org/10.3390/molecules200814402>
- Soković MD, Vukojević J, Marin PD, Brkić DD, Vajs V, van Griensven LJ (2009) Chemical composition of essential oils of *Thymus* and *Mentha* species and their antifungal activities. *Molecules* 14:238–249. <https://doi.org/10.3390/molecules14010238>
- Sousa PJ da C (1999) Estudos farmacológicos do óleo essencial de *Mentha × villosa* e seu principal constituinte, óxido de piperitenona, em músculos lisos gastrointestinais de cobaia e pressão arterial de rato. 204 f. Tese (Doutorado em Farmacologia) - Faculdade de Medicina, Universidade Federal do Ceará, Fortaleza, state Ceará, Brazil. Written in Portuguese (Brazil). Full text: <http://www.repositorio.ufc.br/handle/riufc/65397> Accession: 19 April 2024
- Spagnoletti A, Guerrinia A, Tacchini M, Vinciguerra V, Leone C, Maresca I, Simonetti G, Sacchetti G, Angiolella L (2016) Chemical composition and bio-efficacy of essential oils from Italian aromatic plants: *Mentha suaveolens*, *Coridothymus capitatus*, *Origanum hirtum* and *Rosmarinus officinalis*. *Nat Prod Commun* 11:1934578X1601101023. <https://doi.org/10.1177/1934578X1601101023>
- Stoeva T, Iliev L (1997) Influence of some phenylurea cytokinins on spearmint essential oil composition. *Bulg J Plant Physiol* 23(3–4):66–71
- Straumite E, Kruma Z, Galoburda R (2015) Pigments in mint leaves and stems. *Agron Res* 13:1104–1111
- Stringaro A, Vavala E, Colone M, Pepi F, Mignogna G, Garzoli S, Cecchetti S, Ragno R (2014) Effects of *Mentha suaveolens* essential oil alone or in combination with other drugs in *Candida albicans*. *Evid-Based Complement Altern Med ECAM* 2014:125904. <https://doi.org/10.1155/2014/125904>
- Sutour S, Bradesi P, Casanova J, Tomi F (2010) Composition and chemical variability of *Mentha suaveolens* ssp. *suaveolens* and *M. suaveolens* ssp. *insularis* from Corsica. *Chem Biodivers* 7:1002–1008. <https://doi.org/10.1002/cbdv.200900365>

- United Nations Economic Commission for Europe (2023) Globally Harmonized System of Classification and Labelling of Chemicals (GHS). Tenth revised edition. <http://unece.org/transport/dangerous-goods/ghs-rev10-2023> (fulltext). Accession date: 26 February 2025.
- Tafrihi M, Imran M, Tufail T, Gondal TA, Caruso G, Sharma S, Sharma R, Atanassova M, Atanassov L, Valere Tsouh Fokou P, Pezzani R (2021) The wonderful activities of the genus *Mentha*: not only antioxidant properties. *Molecules* 26:1118. <https://doi.org/10.3390/molecules26041118>
- Tayarani-Najaran Z, Talasaz-Firoozi E, Nasiri R, Jalali N, Hassanzadeh MK (2013) Antiemetic activity of volatile oil from *Mentha spicata* and *Mentha piperita* in chemotherapy-induced nausea and vomiting. *Ecantermalscience* 7(1, article 290):290. <https://doi.org/10.3332/ecancer.2013.290>
- Teixeira ML, Cardoso MG, Figueiredo ACS, Moraes JC, Assis FA, Andrade J, Nelson DL, Gomes MS, Souza JA, Albuquerque LRM (2014) Essential oils from *Lippia origanoides* kunth. and *Mentha spicata* L.: chemical composition, insecticidal and antioxidant activities. *Am J Plant Sci* 5:3551–3557. <https://doi.org/10.4236/ajps.2014.59131>
- Telci I, Demirtas I, Bayram E, Arabaci O, Kacar O (2010) Environmental variation on aroma components of pulegone/piperitone rich spearmint (*Mentha spicata* L.). *Ind Crops Prod* 32:588–592. <https://doi.org/10.1016/j.indcrop.2010.07.009>
- Teles S, Pereira JA, Santos CH, Menezes RV, Malheiro R, Lucchese AM, Silva F (2013) Effect of geographical origin on the essential oil content and composition of fresh and dried *Mentha* × *villosa* Hudson leaves. *Ind Crops Prod* 46:1–7. <https://doi.org/10.1016/j.indcrop.2012.12.009>
- Thesis (MSc), in Portuguese (Brazil). Not available. **Full text:** [Repositório Institucional da UnB: Principais componentes do óleo essencial de acessos de Mentha spp em Brasília e estudo da propagação vegetativa](#) Accession 19 April 2024
- Tomás-Barberán FA, Husain SZ, Gil MI (1988) The distribution of methylated flavonoids in the *Lamiaceae*. *Biochem Syst Ecol* 16:43–46. [https://doi.org/10.1016/0305-1978\(88\)90115-9](https://doi.org/10.1016/0305-1978(88)90115-9)
- Tucker AO, Naczi RFC (2007) *Mentha*: an overview of its classification and relationships. In: *Mint: The Genus Mentha*. pp 1–39
- Ulubelen A, Topcu U, Kolak U (2005) *Labiatae* flavonoids and their bioactivity. *Stud Nat Prod Chem* 30:233–302. [https://doi.org/10.1016/S1572-5995\(05\)80035-3](https://doi.org/10.1016/S1572-5995(05)80035-3)
- Verma RS, Pandey V, Padalia RC, Saikia D, Krishna B (2011) Chemical composition and antimicrobial potential of aqueous distillate volatiles of Indian peppermint (*Mentha piperita*) and spearmint (*Mentha spicata*). *J Herbs Spices Med Plants* 17:258–267. <https://doi.org/10.1080/10496475.2011.591519>
- Vian MA, Fernandez X, Visinoni F, Chemat F (2008) Microwave hydrodiffusion and gravity, a new technique for extraction of essential oils. *J Chrom A* 1190(1–2):14–17. <https://doi.org/10.1016/j.chroma.2008.02.086>
- Vining KJ, Pandelova I, Hummer K, Bassil N, Contreras R, Neill K, Chen H, Parrish AN, Lange BM (2019) Genetic diversity survey of *Mentha aquatica* L. and *Mentha suaveolens* Ehrh., mint crop ancestors. *Genet. Resour. Crop Evol.* 66:825–845. <https://doi.org/10.1007/s10722-019-00750-4>
- Voirin B, Bayet C, Faure O, Jullien F (1999) Free flavonoid aglycones as markers of parentage in *Mentha aquatica*, *M. citrata*, *M. spicata* and *M. × piperita*. *Phytochemistry* 50:1189–1193. [https://doi.org/10.1016/s0031-9422\(98\)00672-4](https://doi.org/10.1016/s0031-9422(98)00672-4)
- Wafa N, Djamila M, Rima A, Merghem M (2025) Acute toxicity study of *Mentha suaveolens* Ehrh aqueous extract in Swiss Albino mice. *Afr J Biol Sci.* 7(1):398–409. <https://doi.org/10.48047/AFJBS.7.1.2025.398-409>
- Wang H, Provan GJ, Helliwell K (2004) Determination of rosmarinic acid and caffeic acid in aromatic herbs by HPLC. *Food Chem* 87(2):307–311. <https://doi.org/10.1016/j.foodchem.2003.12.029>
- Wilson L (2016) Spices and Flavoring Crops: Leaf and Floral Structures. In: Caballero B, Finglas PM, Toldrá F (eds) *Encyclopedia of Food and Health*. Academic Press, Oxford, pp 84–92
- Winkel-Shirley B (2001) Flavonoid biosynthesis. A colorful model for genetics, biochemistry, cell biology, and biotechnology. *Plant Physiol* 126:485–493. <https://doi.org/10.1104/pp.126.2.485>
- Yamamura S, Ozawa K, Ohtani K, Kasai R, Yamasaki K (1998) Antihistaminic flavones and aliphatic glycosides from *Mentha spicata*. *Phytochemistry* 48(1):131–136. [https://doi.org/10.1016/s0031-9422\(97\)01112-6](https://doi.org/10.1016/s0031-9422(97)01112-6)
- Yao L, Liu W, Bashir M, Nishar MF, Wan C (2022) Eriocitrin: a review of pharmacological effects. *Biomed Pharmacother.* <https://doi.org/10.1016/j.biopha.2022.113563>
- Yousuf PH, Noba NY, Shohel M, Bhattacharjee R, Das BK (2013) Analgesic, anti-inflammatory and antipyretic effect of *Mentha spicata* (spearmint). *Br J Pharm Res* 3(4):854–864. <https://doi.org/10.9734/BJPR/2013/4640>
- Yousuf T, Akter R, Ahmed J, Mazumdar S, Talukder D, Nandi NC, Nurulamin M (2021) Evaluation of acute oral toxicity, cytotoxicity, antidepressant and antioxidant activities of Japanese mint (*Mentha arvensis* L.) oil. *Phytomedicine Plus* 1(4):100140. <https://doi.org/10.1016/j.phyplu.2021.100140>
- Zaidi F, Voirin B, Jay M, Viricel MR (1998) Free flavonoid aglycones from leaves of *Mentha pulegium* and *Mentha suaveolens* (Labiatae). *Phytochemistry*. 48(6):991–994. [https://doi.org/10.1016/S0031-9422\(97\)01042-X](https://doi.org/10.1016/S0031-9422(97)01042-X)
- Zehiroglu C, Ozturk Sarikaya SB (2019) The importance of antioxidants and place in today's scientific and technological studies. *J Food Sci Technol* 56:4757–4774. <https://doi.org/10.1007/s13197-019-03952-x>
- Zeinali H, Arzani A, Razmjoo K, Rezaee MB (2005) Evaluation of oil compositions of Iranian mints (*Mentha* spp.). *J Essent Oil Res* 17:156–159. <https://doi.org/10.1080/10412905.2005.9698863>
- Zekri N, Sabri H, Khannouchi S, El Belghiti MA, Zair T (2014) Phytochemical study and fumigant toxicity of *Mentha suaveolens* Ehrh essential oil from Morocco against adults of *S. oryzae* (L.). *Aust J Basic Appl Sci* 7:599–606
- Zekri N, Elazzouzi H, Ailli A, Gouruch AA, Radi FZ, El Belghiti MA, Zair T, Nieto G, Centeno JA, Lorenzo JM (2023) Physicochemical characterization and antioxidant properties of essential oils of *M. pulegium* (L.), *M. suaveolens*

(Ehrh.) and *M. spicata* (L.) from Moroccan Middle-Atlas. Foods 12:760. <https://doi.org/10.3390/foods12040760>

Znini M, Bouklah M, Majidi L, Kharchouf S, Aouniti A, Bouyanzer A, Hammouti B, Costa J, Al-Dyab SS (2011) Chemical composition and inhibitory effect of *Mentha spicata* essential oil on the corrosion of steel in molar

hydrochloric acid. Int J Electrochem Sci 6:691–704. [https://doi.org/10.1016/S1452-3981\(23\)15027-9](https://doi.org/10.1016/S1452-3981(23)15027-9)

Publisher's Note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.