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Research Article

Phytochemical Analysis and Antioxidant Activity of *Mentha piperita* L. (Peppermint) from Iraq

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Abstract

Background: *Mentha piperita* L. (Lamiaceae) owes its pharmacological reputation to two chemically distinct fractions, a non-volatile phenolic pool and a volatile essential oil. These are seldom characterized within the same study, and no phytochemical data appear to exist for material of Iraqi origin. ***Methods***: Dried aerial parts of Iraqi origin, obtained from a laboratory plant collection, were macerated in parallel in ethanol and ethyl acetate (50.5 g/500 mL, 72 h, 25±2°C). Seven phenolic compounds were quantified by RP-HPLC (C18-ODS column, UV 220 nm) against certified reference standards. Essential oil recovered by Clevenger hydrodistillation (3 h) was profiled by GC-FID (ZB-1 column, 30 m). Antioxidant capacity was assessed by DPPH radical scavenging (30–500 ppm) against ascorbic acid, with IC50 derived by log-linear regression (n=3). ***Results***: Gallic acid was the most abundant phenolic (74.90 µg/mL in ethanol; 70.22 in ethyl acetate), followed by quercetin (62.55; 55.99), rutin (40.12; 51.44), caffeic acid (34.55; 44.14), ferulic acid (20.33; 32.69), apigenin (14.15; 27.74) and kaempferol (9.15; 19.88 µg/mL). Menthol (47.22%) and menthone (15.14%) dominated the oil, with six identified constituents accounting for 74.49% of total peak area. Both extracts surpassed ascorbic acid in radical scavenging: IC50 74.48 ppm for the ethanolic extract (1.61-fold, p=0.0041) and 86.68 ppm for the ethyl acetate extract (1.38-fold, p=0.0157). ***Conclusions***: Antioxidant activity tracked the identity of individual phenolics, chiefly gallic acid and quercetin, rather than total phenolic content. The values reported are analytical replicates from a single batch and require confirmation across independent batches.

Keywords: DPPH; GC-FID; *Mentha piperita* L.; Phenolic quantification; Phytochemistry; RP-HPLC.

التحليل الكيميائي النباتي والنشاط المضاد للأكسدة لزهرة المنثا بيبريتا (النعناع) من العراق

الخلاصة

الخلفية: تدين شجرة المنثا بيبريتا L. (اللامياسية) بسمعتها الدوائية لجزئين كيميائيين مختلفين، أحدهما تجمع فينولي غير متطاير وزيت عطري متطاير. نادرا ما يتم توصيف هذه المواد ضمن نفس الدراسة، ولا توجد بيانات كيميائية نباتية عن مواد ذات أصل عراقي. **الطرائق**: تم نقع أجزاء هوائية مجففة من أصل عراقي، تم الحصول عليها من مجموعة مصادر مختبرية، بالتوازي في الإيثانول وأسيتات الإيثيل (50.5 جم/500 مل، 72 ساعة، 25±2°م). تم قياس سبعة مركبات فينولية بواسطة RP-HPLC (عمود C18-ODS، UV 220 نانومتر) وفقا لمعايير مرجعية معتمدة. تم تحليل الزيت العطري المستخرج من التقطير الهيدروستيلاندي بتقنية كليفينجر (3 ساعات) بواسطة GC-FID (عمود ZB-1، 30 متر). تم تقييم قدرة مضادات الأكسدة من خلال إزالة جذور DPPH– (30 500 جزء في المليون) ضد حمض الأسكوربيك، حيث تم اشتقاق IC50 عن طريق الانحدار اللوغاريتمي الخطي (n=3). ***النتائج***: كان حمض غاليك هو الأكثر وفرة في الفينول (74.90 ميكروغرام/مل في الإيثانول؛ 70.22 في أسيتات الإيثيلي)، يليه الكيرسيتين (62.55؛ 55.99)، الروتين (40.12؛ 51.44)، حمض الكافيك (34.55؛ 44.14)، حمض الفيروليك (20.33؛ 32.69)، الأبيجينين (14.15؛ 27.74) والكيمبفيرول (9.15؛ 19.88 ميكروغرام/مل). هيمن المنثول (47.22٪) والمنثون (15.14٪) على النفط، حيث شكلت ستة مكونات محددة 74.49٪ من إجمالي مساحة الذروة. تجاوزت كلتا المستخلصتين حمض الأسكوربيك في إزالة الجذور الراديكالية: IC50 74.48 جزء في المليون لمستخلص الإيثانولي (1.61 ضعف، p=0.0041) و86.68 جزء في المليون لمستخلص أسيتات الإيثيل (1.38 مرة، p=0.0157). **الاستنتاجات**: تتبع النشاط المضاد للأكسدة هوية الظاهرات الفردية، وخاصة حمض الغاليك والكويرسيتين، وليس المحتوى الفينولي الكلي. القيم المبلغ عنها هي نسخ تحليلية من دفعة واحدة وتتطلب تأكيدا عبر دفعات مستقلة.

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INTRODUCTION

For a lot of the world's population, medicinal plants aren't a supplement to modern medicine—they're the main event. This is especially true in areas where formal healthcare is either too expensive or unavailable. The WHO's own traditional medicine strategy says this outright and pushes for scientific follow-up on the plants people are already using anyway [1]. Pharmacognosy is the field that tries to answer that: authenticate the crude drug, work out what's in it, and verify whether the pharmacology holds up before anyone repeats a therapeutic claim as fact [2]. And that matters more now than it did a decade ago. Antimicrobial resistance kills more people every year; new antibiotics aren't arriving fast enough. Plant-derived antimicrobials and antioxidants are getting a second look partly because of that gap [3]. Lemnaceae, the peppermint family belongs to, tends to pack both non-volatile phenolics and essential oils into tiny glandular trichomes on the leaf surface—that's true across most of the family, not just this species. *M. piperita* specifically is a sterile F1 hybrid (M. aquatica × M. spicata), propagated by cuttings, never seed, and it's grown on every inhabited continent now for food, flavoring, and pharmaceutical use. The official

monograph status of peppermint is recognized in the EU, US, and Japanese pharmacopoeias. Menthol alone, its signature constituent, is thought to represent tens of thousands of tons of demand a year across confectionery, oral care, and topical analgesics [4]. Traditional Arabic and Iraqi medicine have its own thread here too: peppermint infusions or decoctions for gastrointestinal spasms, fever, and upper respiratory congestion—which tracks reasonably well with how the ethnopharmacological literature describes peppermint tea more broadly [5,6]. Two groups are credited with most of the bioactivity. Non-volatile phenolics first—rosmarinic acid, luteolin, a scatter of related flavonoids, and hydroxycinnamic acids. Reviews tie these to antioxidant and anti-inflammatory effects, some of it direct radical scavenging, some of it chelating the transition metals that would otherwise drive oxidative damage [7,8,9]. Then the essential oil: oxygenated monoterpenes, menthol and menthone mainly, and the literature credits it with analgesic, antispasmodic, and antibacterial effects against various food-borne and clinically relevant organisms [10,11]. Here's the catch, though—these two fractions almost never are studied in the same paper. Essential-oil papers, comparative work across several Mentha species included, will report volatile composition, sometimes the oil's own antimicrobial or antioxidant activity, and then just not bother quantifying the phenolic fraction sitting right next to it [12,13]. Phenolic papers do the mirror-image thing: aqueous or hydro-alcoholic extracts, antioxidant capacity, total phenolic content, and essential oil are nowhere in sight [9]. A dataset running both fractions through the same testing, on one plant batch, turned out harder to find than we expected. There's a geographic gap layered on top of the fractional one. Most RP-HPLC and GC work on *M. piperita* comes out of temperate Europe, the Balkans, and South Asia [12,13,7-9,14]— nothing like Iraq's growing conditions. Peppermint from Iraq doesn't show up in the indexed literature at all, not that we could find. We searched Scopus, PubMed, and Web of Science directly (1990–2024; '*Mentha piperita*' AND ['Iraq' OR 'Baghdad'] AND ['HPLC' OR 'phenolic' OR 'GC' OR 'volatile']), and nothing came back — no phenolic profiling, no volatile characterization, no antioxidant testing, single-batch or otherwise, for peppermint from that country. So, one voucher-referenced batch of *M. piperita* from Iraq, characterized through RP-HPLC phenolic quantification, GC-FID volatile profiling, and DPPH antioxidant testing, all inside a single experimental framework.

METHODS

Study design and setting

Experimental procedures including plant collection, authentication, extraction, RP-HPLC, GC-FID, DPPH are conducted at the Pharmacognosy and Medicinal Plants Laboratory, Department of Pharmacy, Al-Rasheed University College, Baghdad.

Plant material and authentication

The plant sample is *M. piperita* L. cultivated in Iraq. We got it whole and already dried, pulled from the plant collection at the lab; so, no harvest date, no plant age, no precise growing location within Iraq to report. A certified pharmacognosist authenticated the taxonomic identity; we deposited a voucher specimen (No. ARUC-2024-MP-01). Ground the dried aerial parts with an electric grinder (IKA A11 basic) and pass the powder through a 500 µm sieve before touching any extraction or distillation step. Every number in this paper is analytical triplicate (n= 3) on this one batch. No replication across separate batches, no different collection dates.

Preparation of the extracts

Two 50.5 g samples, from the same dried powder batch, are macerated in parallel for 72 hours at 25 ± 2°C—dark, agitated by hand for 10 minutes every 12 hours (150 rpm). One went into 500 mL absolute ethanol, the other into 500 mL ethyl acetate (both ≥99.5%, Merck). Filtered through Whatman No. 1, then concentrated under reduced pressure on a rotary evaporator (40°C, 150 mbar). Dry residues were redissolved to 10.0 mg/mL in their own solvent and stored at −4°C.

Essential oil isolation

20.0 g of the dried, ground aerial parts, straight into a Clevenger apparatus, 3 hours of hydrodistillation, per the European Pharmacopoeia 11th edition [15]. Dried the recovered oil over anhydrous Na_2SO_4, filtered, and stored at −4°C. Yield: % v/w against the dried plant material.

RP-HPLC phenolic profiling

Sykam S600 system, UV detection at 220 nm, Phenomenex Luna C18-ODS column (250 × 4.6 mm, 5 µm), held at 25.0 ± 0.1°C. Mobile phase: acetonitrile (A), 5% aqueous acetic acid (B). 30% A for the first 5 minutes; gradient up to 50% A over the next 10; hold at 50% A for 5; re-equilibrate for 5 more. Flow 1.00 mL/min, injection 0.1 mL, every sample filtered through a 0.45 µm PVDF membrane first. Seven certified reference standards ran alongside the samples — Sigma-Aldrich, ≥98%: apigenin, rutin, gallic acid, quercetin, ferulic acid, caffeic acid, kaempferol — and identification plus quantification came from external calibration against those. Rosmarinic acid we left out deliberately; this study targeted flavonoids and simple phenolic acids, not the full phenolic spectrum.

GC-FID analysis of essential oil

Shimadzu GC-2010, flame ionization detector, ZB-1 capillary column (30 m × 0.25 mm, 0.25 µm film). Injector at 295°C, detector at 330°C. Oven ramped 100–250°C at 8°C/min, nitrogen carrier at 100 kPa, 1:20 split, 1 µL of neat oil per injection. Peaks matched against the Adams (2007) retention-index database [16], confirmed by co-injecting authentic standards—accepted when ΔRI landed within 2 units. Quantification: normalized FID peak-area percentages, nothing more elaborate.

DPPH radical scavenging assay

Molyneux's method [17] followed as written. 1,000 ppm stock solutions, each in its own natural solvent — ethanolic extract and ascorbic acid standard in ethanol (≥99.8%, Merck), ethyl acetate extract in ethyl acetate (≥99.8%, Merck) — then diluted to five working concentrations (30, 60, 120, 250, 500 ppm). Fresh DPPH solution, 0.1 mM in ethanol, absorbance standardized to 1.000 ± 0.050 at 517 nm, mixed 1:1 (v/v) with each sample. Dark, 25 ± 1°C, 30 minutes, then read at 517 nm on a Shimadzu UV-1900. Percentage inhibition: $[(A_0 - A_s)/A_0] \times 100$. IC50 from triplicate measurements, log-linear regression.

Statistical analysis

Means, standard deviations, n = 3 throughout. Group comparisons by one-way ANOVA with Tukey's HSD post-hoc (α = 0.05). Python 3.12 (SciPy v1.11) did the heavy lifting; Excel 2019 cross-checked.

RESULTS AND DISCUSSION

50.5 g of plant material went in; 4.8 ± 0.12 g (9.5% w/w) of ethanolic extract came out, 2.6 ± 0.08 g (5.1% w/w) of ethyl acetate extract (Table 1).

Table 1: Extraction yields from *Mentha piperita* L. aerial parts (n=3)

Preparation	Method	Colour	Yield
Ethanolic extract	Cold maceration; ethanol ≥99.5%; 72 h	Dark green	4.8±0.12 g (9.5% w/w)
Ethyl acetate extract	Cold maceration; ethyl acetate ≥99.5%; 72 h	Pale green	2.6 ± 0.08 g (5.1% w/w)
Essential oil	Clevenger hydrodistillation; 3 h	Pale yellow	0.25 ± 0.02 mL (1.25% v/w)

Values are presented as mean±SD. Yields relative to dried plant mass for both the solvent extracts and the essential oil.

Essential oil: 1.25 ± 0.02% v/w — more than the European Pharmacopoeia minimum [15], and it sits within the 0.5–1.8% range reported elsewhere for *M. piperita* [18]. Seven phenolic compounds, identified and quantified in both extracts (Table 2), each one confirmed by retention-time concordance against the reference standards and by UV profile at 220 nm. Ethanolic extract: gallic acid on top, RT 6.07 min, 74.90 ± 1.12 µg/mL.

Table 2: RP-HPLC identification and quantification of phenolic constituents in *Mentha piperita* L. ethanolic and ethyl acetate extracts

Compound	Structural Class	RT (min)	EtOH ± SD (µg/mL)	EtOAc ± SD (µg/mL)	Solvent Preference
Gallic acid	Phenolic acid	6.07	74.90 ± 1.12	70.22 ± 0.98	EtOH
Quercetin	Flavonol	10.09	62.55 ± 0.87	55.99 ± 1.03	EtOH
Rutin	Flavonoid glycoside	7.99	40.12 ± 0.94	51.44 ± 1.21	EtOAc
Caffeic acid	Hydroxycinnamic acid	8.84	34.55 ± 0.76	44.14 ± 0.88	EtOAc
Ferulic acid	Hydroxycinnamic acid	11.91	20.33 ± 0.63	32.69 ± 0.71	EtOAc
Apigenin	Flavone	3.98	14.15 ± 0.55	27.74 ± 0.69	EtOAc
Kaempferol	Flavonol	13.14	9.15 ± 0.48	19.88 ± 0.52	EtOAc

RT: retention time. Values: mean±SD, n= 3. Solvent Preference denotes the extract yielding the higher concentration. EtOH: ethanolic extract; EtOAc: ethyl acetate extract.

Quercetin next (10.09 min; 62.55 ± 0.87), then rutin (7.99 min; 40.12 ± 0.94), caffeic acid (8.84 min; 34.55 ± 0.76), ferulic acid (11.91 min; 20.33 ± 0.63), apigenin (3.98 min; 14.15 ± 0.55), kaempferol (13.14 min; 9.15 ± 0.48). Apigenin eluted earlier than its lipophilicity (log P = 1.49) suggests it should—most likely be a strong UV response during the initial 30% acetonitrile isocratic phase; there's nothing unusual about the retention itself. Ethyl acetate extract: retention times within 0.11 min of the ethanolic run, so cross-solvent reproducibility holds up fine. Concentrations ran from 70.22 ± 0.98 µg/mL (gallic acid) down to 19.88 ± 0.52 µg/mL (kaempferol), with rutin, caffeic acid, ferulic acid, apigenin, and kaempferol all coming in higher than in ethanol (Table 2) — consistent with their greater lipophilicity relative to the more polar solvent [19]. As an antioxidant, gallic acid (MW 170.12 g/mol) — the dominant compound by a wide margin — works through hydrogen-atom donation, Fe(III)/Cu(II) chelation, Nrf2 activation [20]. Quercetin's mechanism runs through its catechol B-ring [21]. The other five contribute antioxidant and anti-inflammatory activity too, each through its own structural quirks [22,23,24,25,26]. Here's the odd part: 74.90 µg/mL of gallic acid isn't really what the literature would predict for *M. piperita*. Temperate populations usually run dominated by rosmarinic acid instead [9]. We didn't chase that difference down mechanistically—no enzyme assays, no direct measurement of rosmarinic acid content. Polarity explains the split: ethanol (ε = 24.5) pulled gallic acid and quercetin preferentially, and ethyl acetate (ε = 6.0) took more of the other five. Summing all seven, the total phenolic content actually favors ethyl acetate—302.10 µg/mL against 255.75 in ethanol, roughly 15% lower. Yet the ethanolic extract scavenged

DPPH more strongly (74.48 vs 86.68 ppm IC50). Which is the whole point, really: scavenging capacity here tracks which specific phenolics are present—gallic acid, quercetin—not the raw total. Kaempferol swung hardest toward ethyl acetate (+117%; log P = 1.90, consistent with lipophilicity-driven partitioning [19]), while gallic acid, the most hydrophilic of the seven (log P = 0.70), barely moved toward ethanol at all (+6.7%). Table 3 lines these numbers up against three published studies and three regions.

Table 3: Comparative literature analysis: phenolic profiles and DPPH antioxidant potency of *Mentha piperita* L. across geographic origins

Study [Ref]	Origin	Method	Dominant Phenolic Reported	Gallic Acid (µg/mL)	DPPH IC_{50} (ppm)	Methodological Note
This study	Iraq	RP-HPLC (UV 220 nm) + GC-FID + DPPH	Gallic acid (74.90 µg/mL)	74.90±1.12	74.48±1.23	Ethanol maceration; 7 phenolics quantified
Mimica-Dukic *et al*. [12]	Serbia	GC-MS + DPPH (essential oil only)	Menthol (volatile; 43.7%)	Not measured†	82–156 (essential oil)	Phenolic HPLC not performed; DPPH on essential oil fraction only
Hussain *et al*. [13]	Pakistan	GC-MS + DPPH (4 seasons)	Menthol (volatile; dominant)	Not measured†	91–143 (seasonal range)	Essential oil focus; no RP-HPLC phenolic quantification reported
Dorman *et al*. [9]	Finland	Folin–Ciocalteu + DPPH (aqueous extract)	Total phenolics by Folin–Ciocalteu; individual compounds not quantified by HPLC	Not measured†	Not reported‡	TPC by Folin only; individual HPLC quantification not performed

† Gallic acid was not an analyzed target in these investigations; its omission from the reported data does not preclude its presence in the plant material. ‡ IC_{50} not presented in equivalent units (ppm, ethanol extract); values are not directly comparable. Bold row (This study) denotes the present dataset. All IC_{50} values are given in ppm unless otherwise specified.

Two things worth flagging. None of them quantified gallic acid by RP-HPLC in µg/mL [12,13,9] — nothing directly comparable there. And the DPPH ranges Mimica-Dukic et al. [12] (82–156 ppm) and Hussain *et al*. [13] (91–143 ppm) report come from essential oil, not the polar ethanolic extract used here, so a direct comparison wouldn't tell us much anyway. 1.25% v/v essential oil out of the hydrodistillation, and GC-FID resolved six major components (Table 4, Figure 1)—74.49% of the total peak area between them.

Table 4: Volatile composition of *Mentha piperita* L. essential oil as determined by GC-FID

Compound	Chemical Class	RI (this study)	Area (%)
Menthol	Oxygenated monoterpene	1172	47.22
Menthone	Monoterpene ketone	1152	15.14
1,8-Cineole	Oxygenated monoterpene	1030	5.12
Limonene	Monoterpene hydrocarbon	1028	2.55
Linalool	Oxygenated monoterpene	1095	2.45
Geraniol	Monoterpene alcohol	1255	2.01
Unidentified minor components	—	—	25.51
Total identified			74.49

RI: linear retention index relative to the C8–C25 n-alkane reference series; Adams (2007) [22] comparators: menthol 1173, menthone 1152, 1,8-cineole 1031, limonene 1029, linalool 1096, geraniol 1256. Area percentage denotes normalized FID peak area.

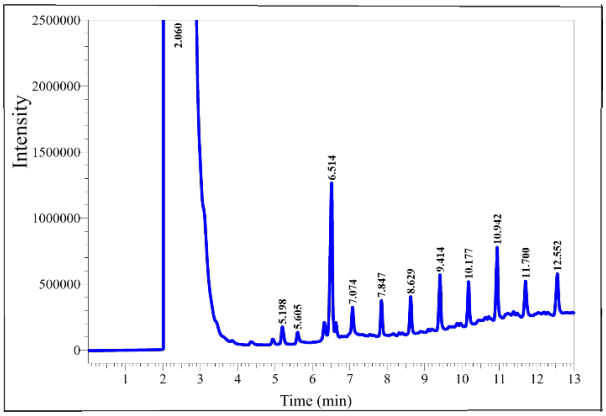

Figure 1: GC-FID chromatogram of *Mentha piperita* L. essential oil obtained during Clevenger hydrodistillation for three hours. Analysis parameters: ZB-1 capillary column (30 m); injector temperature 295 °C; detector temperature 330 °C; oven temperature range 100–250 °C at 8 °C/min; nitrogen carrier gas at 100 kPa; 1 µL of neat oil. The prominent peak at RT 2.060 min corresponds to menthol, comprising 47.22% of total area. Peak identity assignments appear in Table 4.

Menthol out-forest at 47.22% (RI 1172, reference 1173), above the 35–45% range reported for essential oil from European temperate populations [27]. We put this sample in the high-menthol chemotype of *M. piperita* var. piperita. Menthone (15.14%) is reported elsewhere to sharpen menthol's antibacterial action through additional membrane disruption [28,10]—not something we tested ourselves, worth saying plainly. The rest, each with its own documented activity: 1,8-cineole (5.12%, anti-inflammatory [11]), limonene (2.55%, chemopreventive [29]), linalool (2.45%, anxiolytic [30]), geraniol (2.01%, antifungal [31]). Concentration-dependent scavenging which are both more concentrated in ethanol (74.90 vs. 70.22 µg/mL and 62.55 vs. 55.99 µg/mL), are extracts, across 30–500 ppm (Table 5; $R^2 \geq 0.998$ for all three samples).

Table 5: DPPH radical scavenging activity (% inhibition) of *Mentha piperita* L. extracts and ascorbic acid positive control

Sample	30 ppm	60 ppm	120 ppm	250 ppm	500 ppm	IC_{50} (ppm)
Ethanolic extract	31.41	45.58	59.75	74.75	88.92	74.48±1.23*
Ethyl acetate extract	27.27	42.12	56.97	72.69	87.54	86.68±1.89*
Ascorbic acid (positive control)	18.77	34.39	50.01	66.55	82.17	119.95±2.41

Values: mean % DPPH inhibition (n = 3). IC_{50} by log-linear regression ($R^2 \geq 0.998$). * $p < 0.05$ *vs*. ascorbic acid (one-way ANOVA + Tukey's HSD). Lower IC_{50} = greater potency.

Ethanolic extract is the most potent (IC50 = 74.48 ppm), then ethyl acetate (86.68 ppm), then ascorbic acid trailing at 119.95 ppm. One-way ANOVA: significant overall effect ($p < 0.001$). Tukey's HSD separated each extract from ascorbic acid ($p = 0.0041$ and 0.0157) and the two extracts from each other ($p < 0.05$). Worth repeating, because it matters: these numbers come from analytical triplicates on a single batch. The significance tells us how precise the measurements were within that batch. It does not tell us how the wider population would behave. HPLC data backs this ranking up. Gallic acid and quercetin, both more concentrated in ethanol (74.90 *vs*. 70.22 and 62.55 *vs*. 55.99 µg/mL), are both well-established reactive antioxidants [21,20]. The five compounds richer in ethyl acetate didn't make up for the shortfall in these two. 74.48 ppm sits numerically below the essential-oil-based ranges from Mimica-Dukic *et al*. [12] (82–156 ppm) and Hussain *et al*. [13] (91–143 ppm) — though a polar extract and an essential oil aren't really the same kind of comparison. TPC (Folin–Ciocalteu) and TFC ($AlCl_3$): neither was measured here. Would've let us compare directly against [12,13,9], and, more to the point, would've let us actually test—not just infer—whether gallic acid and quercetin content specifically, rather than total phenolic content, is what drives the antioxidant activity. Three datasets, put together, sketch out a composite picture. Both extracts beat ascorbic acid in DPPH; the HPLC data ties that back to gallic acid and quercetin working through hydrogen transfer, metal chelation, and Nrf2 activation [21,20,32]. The essential-oil side adds another layer, documented in the literature though not independently verified here — antibacterial for menthol and menthone, anti-inflammatory for 1,8-cineole, chemopreventive for limonene, anxiolytic for linalool, antifungal for geraniol [28–31]. None of that overlaps mechanistically with radical scavenging. Reasonable hint, then, that the two fractions complement each other rather than duplicate each other. Table 6 lays out the full profile.

Table 6: Consolidated phytochemical and bioactivity profile of identified *Mentha piperita* L. constituents

Compound	Fraction	Principal Documented Biological Activities	Refs.
Gallic acid	Phenolic	Antioxidant and antimicrobial	[20]
Quercetin	Phenolic	Antioxidant and antiviral	[21]
Rutin	Phenolic	Antioxidant; $Fe^{2+/3+}$ chelation; anti-thrombotic; capillary protective	[25]
Caffeic acid	Phenolic	Anti-inflammatory and antioxidant	[23]
Ferulic acid	Phenolic	Antifibrotic and neuroprotective	[22]
Apigenin	Phenolic	Anticancer and antioxidant	[24]
Kaempferol	Phenolic	Anti-inflammatory and antioxidant	[26]
Menthol	Essential oil	Analgesic and antibacterial	[28,10]
Menthone	Essential oil	Antibacterial	[28,10]
1,8-Cineole	Essential oil	Mucolytic	[11]
Limonene	Essential oil	Chemopreventive; hepatic GST/UGT phase II enzyme induction	[29]
Linalool	Essential oil	Sedative	[30]
Geraniol	Essential oil	Antifungal	[31]

Conclusions

RP-HPLC, GC-FID, and DPPH—all three, on one dried batch of *M. piperita* from Iraq. A combination we couldn't track down anywhere else in the published literature for this geographic origin. Seven phenolics quantified; gallic acid (74.90 µg/mL) and quercetin (62.55 µg/mL) dominant in the ethanolic extract, which hit an IC50 of 74.48 ppm — 1.61-fold more potent than ascorbic acid, within this batch ($p = 0.0041$). GC-FID found a menthol-dominant oil (47.22%), above typical European levels. Ethanol maceration pulled out more of the two main antioxidant phenolics than ethyl acetate managed, at least in this batch. These results describe one batch—a starting baseline, not a validated population trend. Every value here is analytical, not biological; replication and compound identification relied on retention time and retention-index matching rather than LC-MS/MS or GC-MS confirmation. Extending this work to independent, field-documented batches, spectral verification, TPC/TFC determination, and direct antimicrobial testing would turn this baseline into a fuller picture of M. piperita from Iraq and into a stronger case for its potential as a pharmaceutical raw material.

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Conflict of interests

The authors declared no conflict of interest.

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Data sharing statement

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

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