



RESEARCH ARTICLE

Phytochemical profile, mineral composition and antioxidant potential of *Daucus carota* aqueous extracts: A correlation study

Soukaina Lamrak, Fatima Lamchouri*, Hafida Bouhazama & Hamid Toufik

MPCAE Laboratory - Materials, Natural Substances, Environment and Modeling Team (MSNEM), Polydisciplinary Faculty of Taza (FPT), Sidi Mohamed Ben Abdellah University (USMBA) of Fez, Taza-Gare 1223, Taza, Morocco

*Email: fatima.lamchouri@usmba.ac.ma



ARTICLE HISTORY

Received: 10 November 2025
Accepted: 20 February 2026

Available online
Version 1.0 : 02 July 2026

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonpublishing.com/journals/index.php/TCB/open_access_policy

Publisher's Note: The article processing was done by atom e-Publishing, Thiruvananthapuram, India. Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Copyright: © The Author(s). This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution and reproduction in any medium, provided the original author and source are credited (<https://creativecommons.org/licenses/by/4.0/>)

CITE THIS ARTICLE

Lamrak S, Lamchouri F, Hafida B, Toufik H. Phytochemical profile, mineral composition and antioxidant potential of *Daucus carota* aqueous extracts: A correlation study. Trends in Current Biology. 2026; 4(3): 21-30. <https://doi.org/10.14719/tcb.9459>

Abstract

Daucus carota (Apiaceae), commonly known as “Sannariya” and is widely distributed in temperate and Mediterranean regions, particularly in Morocco. The aim of this study is to conduct mineralogical analysis, phytochemical investigations through aqueous extractions, essential oil extraction, phytochemical screening, quantification of phenolic compounds and evaluation of antioxidant activity using both H₂O₂ and ferric reducing antioxidant power (FRAP) assays. Principal component analysis (PCA) was used to examine the correlation between antioxidant activity and the plant's chemical composition. The results showed that the plant is very rich in minerals, particularly potassium (K) (117210), calcium (Ca) (13596.6), magnesium (Mg) (11525.1), sodium (Na) (6048.6), phosphorus (P) (5329.5) and iron (Fe) (2738.16) mg/kg of dry matter. The decocted exhibited the highest extraction yield (18.36 ± 0.14 %). Essential oil extraction limited to trace amounts. Phytochemical screening indicated that the plant is rich in flavonoids, catechic tannins, saponins, free quinones, sterols, anthraquinones and anthracenosides, while alkaloids and gallic tannins were absent. Quantification analysis showed that the decocted *D. carota* contained the highest levels of total polyphenols and catechic tannins, with 19.92 ± 0.08 µg GAE/mg E and 1.42 ± 0.10 µg CE/mg E, respectively, while the infused displayed the highest flavonoid content at 132.64 ± 0.57 µg QE/mg E. Similarly, the infused exhibited the strongest antioxidant potential in both H₂O₂ and FRAP tests, with 10.22 ± 0.41 % and 64.24 ± 0.14 µg TE/mg E, respectively. Principal component analysis revealed a strong correlation between polyphenol, flavonoid contents and antioxidant activity. The findings demonstrate that *D. carota* is a rich source of bioactive compounds with potential for the development of pharmacologically relevant products.

Keywords

antioxidant activity; *Daucus carota*; mineral composition; phytochemical screening; principal component analysis; quantitative analysis

Introduction

Aromatic and medicinal herbs represent one of the fundamental aspects of biodiversity's contribution to society (1). Researchers worldwide are increasingly interested in medicinal and aromatic plants as essential sources of raw materials for the pharmaceutical, cosmetic, aromatic and perfumery industries. Although significant progress has been made in synthetic drug research, a large proportion of currently used medicines still originate from plants, thanks to the integration of contemporary technologies into traditional methods (2).

The Apiaceae family, commonly known as the celery, carrot or parsley family, also referred to as the Umbelliferae, belongs to the order *Apiales*. Considered one of the most important groups of flowering plants, it comprises approximately 434 genera and nearly 3700 species, mainly distributed in temperate and tropical regions (3, 4). Among the economically significant species of the Apiaceae family are celery (*Apium graveolens*), carrot (*Daucus carota*), gotu kola (*Centella asiatica* L. Urb), parsley (*Petroselinum crispum*), parsnip (*Pastinaca sativa*), angelica (*Angelica archangelica*), coriander (*Coriandrum sativum*), caraway (*Cuminum cyminum*), fennel (*Foeniculum vulgare*), anise (*Pimpinella anisum*), dill (*Anethum graveolens*) and cumin (*Carum carvi*) (5, 6).

Beyond their economic importance, Apiaceae are also considered a promising source for bioprospecting. They contain a wide diversity of specialized metabolites, volatile phenylpropanoids, furanocoumarins, sesquiterpene coumarins, polyacetylenes and phthalides, some of which are rare phytochemicals found exclusively within this family (2, 6). Moreover, the Apiaceae family is known for its numerous medicinal properties, including antimicrobial and anti-inflammatory activities, as well as demonstrated effects in diabetes regulation and hepatoprotection (6).

Daucus carota is among the most important species of the Apiaceae family (6). Several studies on the chemical composition of its various subspecies have revealed its richness in terpenes, phenolic compounds and flavonoids, which confer antimicrobial, antioxidant and anti-inflammatory properties (7).

The research gap lies in the lack of studies focusing on the phytochemical composition and antioxidant potential of *D. carota* growing in the Taza region, despite its wide distribution and significant phytomass in this area. This study addresses this gap by providing the first comprehensive characterization of extracts from locally harvested *D. carota*, thereby contributing to the valorization of the regional flora and offering scientific data that support its potential biological value.

This study focuses on *D. carota* from the Taza region of Morocco, an area where this species is abundant and represents a significant phytomass but remains poorly documented in terms of its phytochemical composition and antioxidant potential. By analyzing locally harvested plant material, this work provides original data that contribute to the scientific valorization of the regional flora and enhance understanding of the biological potential of *D. carota* from this specific ecosystem. In this context, different extraction methods were carried out, including aqueous extractions (hot and cold) and essential oil extraction, to characterize the diversity of metabolites present. Phytochemical screening, complemented by the quantification of phenolic compounds, was performed to provide precise data on the chemical richness of the species. In parallel, antioxidant activity was assessed using two complementary assays: the hydrogen peroxide (H_2O_2) and ferric reducing antioxidant power (FRAP) tests, to highlight the reducing and protective potential of the extracts. These analyses set the stage for the objectives of the study, which aim to characterize the chemical composition of Moroccan *D. carota*, evaluate its antioxidant properties and explore the relationships between its

secondary metabolites and biological activity. Finally, principal component analysis (PCA) was applied to establish possible correlations between the observed biological activity and the chemical composition, thereby contributing to a better understanding of the relationship between secondary metabolites and biological properties.

Materials and Methods

Plant material

The plant material used in this study consisted of the aerial parts of *D. carota*, collected in June 2024 from Douar Ahl Karia, Taifa rural commune, located 25 km from Taza, Morocco (GPS coordinates: 34°21'47.2" N, 4°02'07.3" W) (Fig. 1).

The botanical identification of the species was confirmed in consultation with Prof. Mohamed Boulfia from the Higher Institute of Nursing and Health Techniques, Tetouan, Morocco. A reference specimen (DC 2024/06) was deposited in the laboratory herbarium.

Mineral content

For the determination of mineral contents, the protocol described by (8) was followed. The steps for preparing the analytical solution were performed according to previously established procedures in our laboratory (9–13). Specifically, 0.5 g of powdered aerial parts of *D. carota* were digested in 5 mL of an acid mixture composed of 25 % nitric acid (HNO_3) and 75 % hydrochloric acid (HCl), until complete evaporation of the acids. The resulting residue was then dissolved in 10 mL of 5 % HCl. After filtration, the final volume was adjusted to 25 mL with distilled water. The resulting solution was analyzed for the mineral composition including calcium (Ca), zinc (Zn), phosphorus (P), sodium (Na), selenium (Se), strontium (Sr), potassium (K), copper (Cu), iron (Fe) and magnesium (Mg), using inductively coupled plasma atomic emission spectroscopy (ICP-AES).

Aqueous extraction

Three aqueous extracts: decocted, infused and macerated, were prepared using distilled water as the extraction solvent. The extraction procedures were carried out following the methods detailed in previous studies (9–15). For the decoction, 20 g of powdered plant material were added to 200 mL of distilled water, boiled for 20 min, cooled and then filtered. For the infusion, 200 mL of boiling distilled water were poured over 20 g of plant powder and



Fig. 1. *Daucus carota* (Photos taken at the harvest site, Douar Ahl Karia, rural commune of Taifa, 25 km from Taza, GPS coordinates GPS 34° 21'47.2" N 4°02'07.3" W).

the mixture was left to stand for 30 min before filtration. For the maceration, 20 g of plant powder were immersed in 200 mL of distilled water at room temperature ($25 \pm 2^\circ\text{C}$) for 24 hr, followed by filtration using Whatman filter paper. All extractions were performed in triplicate. The obtained extracts were frozen and lyophilized to constant weight to obtain dry powders, which were stored at 4°C until further analysis. The extraction yields were calculated using the following formula:

$$\text{Yield (\%)} = (\text{dry extract mass} / \text{initial plant mass}) \times 100 \quad (\text{Eqn. 1})$$

Extraction of essential oils

Essential oils from the aerial parts of *D. carota* were obtained by hydrodistillation using a Clevenger apparatus. In accordance with the protocol described by Boulfia and his collaborators, 100 g of dried plant material was immersed in a flask containing 1 L of distilled water and then heated to boiling point (9).

Qualitative phytochemical analysis

Qualitative analysis of secondary metabolites was conducted on the dried powder of the aerial parts of *D. carota*, as well as on the 3 aqueous extracts prepared from this plant. Following the protocols rigorously described in previous studies from our laboratory (9, 10, 13–16). The compounds researched included alkaloids, tannins, saponins, anthracenosides, anthraquinones, quinones, flavonoids and sterols are detected by precipitation reactions or color changes specific to each family.

Quantitative phytochemical analysis

Total polyphenol contents

The quantification of total polyphenols in aqueous extracts of the aerial parts of *D. carota* was performed using the Folin-Ciocalteu reagent method (17), which has been described previously in our earlier publications (9, 15, 16). The results obtained were expressed in micrograms of gallic acid equivalent per milligram of extract ($\mu\text{g GAE/mg E}$).

Total flavonoid contents

The flavonoid content in our extracts was determined using the aluminium trichloride method (18). The protocol followed has been described in detail in our previous work (9, 10, 13, 15). The standard curve for quercetin was used to calculate flavonoid content, in order to express flavonoid content in micrograms of quercetin equivalent per milligram of extract ($\mu\text{g QE/mg E}$).

Catechic tannin contents

Catechic tannin concentrations were quantified using the vanillin method (19), following the protocol described in our previous research (9, 10, 15, 16). Catechic tannin contents were determined from a standard curve and expressed as micrograms of catechic equivalent per milligram of extract ($\mu\text{g CE/mg E}$).

Antioxidant activity

The antioxidant activity of aqueous extracts from the aerial parts of *D. carota* was evaluated using two tests: H_2O_2 and FRAP. The procedure followed to carry out this activity is described in previous work from our laboratory (9–12).

H_2O_2 test

The method developed by Ruch and his collaborators (20) was used to evaluate the ability to reduce H_2O_2 . This test is based on determining the concentration of H_2O_2 by spectrophotometry at 230 nm after a 10 min reaction at room temperature of 1 mL of extract or ascorbic acid with 0.6 mL of H_2O_2 solution. The percentage of hydrogen peroxide scavenging was determined using the following equation:

$$\% = [(AC - AE) / AC] \times 100 \quad (\text{Eqn. 2})$$

Where: AC: absorbance of the control; AE: absorbance of the sample

Ferric reducing antioxidant power test

The FRAP test was performed according to the protocol described by (21). The FRAP solution was prepared by mixing 25 mL of sodium acetate buffer solution, 2.5 mL of FeCl_3 solution and 2.5 mL of TPTZ solution. 3 mL of this solution was added to 100 μL of the extract. After incubation for 30 min, the absorbance was measured at 593 nm (16).

Statistical analyses and principal component analysis

Statistical analysis was performed using GraphPad Prism 8.0.2 software. The results of each experiment were performed in triplicate and are presented as mean $\pm$ SEM. Values of $p < 0.05$ were considered statistically significant.

Principal component analysis was evaluated to highlight the relationships between the chemical composition of the aqueous extracts of *D. carota* and their *in vitro* antioxidant activity.

Results

Mineral content

Analysis of the mineralogical composition of the aerial parts of *D. carota* via ICP–AES revealed the presence of Ca, K, Mg, P, Na, Cu, Fe, Sr, Se and Zn (Table 1).

The aerial part of *D. carota* is characterized by its high mineral content, with high levels of K, Ca, Mg, Na, P and Fe, with values of 117210, 13596.6, 11525.1, 6048.6, 5329.5 and 2738.16 mg/kg dry matter respectively; moderate levels of Sr and Zn, with values of 382.5 and 117.81 mg/kg dry matter respectively and low Cu and Se levels, with values of 43.8 and < 3 mg/kg dry matter, respectively (Table 1).

Extraction aqueous yield

The results of the aqueous extraction of bioactive compounds from the aerial parts of *D. carota* are shown in Table 2.

The values shown in Table 2 represent the means of 3 replicates $\pm$ the mean standard error. Differences were considered statistically significant at $p < 0.05$.

The yields of aqueous extracts from the aerial parts of *D. carota* vary depending on the extraction method used. The decoction yields the best results ($18.36 \pm 0.14\%$), followed by infusion ($15 \pm 0.20\%$) and maceration ($11.30 \pm 0.10\%$). Statistical analysis revealed that the three extracts were significantly related to each other (Table 2).

Table 1. Mineralogical composition of the aerial part of *D. carota*

Mineral elements	Ca	Cu	Fe	K	Mg	Na	P	Se	Sr	Zn
Content in mg/kg of dry matter	13596.6	43.8	2738.16	117210	11525.1	6048.6	5329.5	< 3	382.5	117.81

Fe: iron; K: potassium; Mg: magnesium; P: phosphorus; Na: sodium; Cu: copper; Ca: calcium; Sr: strontium; Se: selenium; Zn: zinc.

Table 2. Yields of aqueous extracts from the aerial parts of *D. carota*

Extracts	Yield (%)
Decocted	18.36 ± 0.14 ^a
Infused	15 ± 0.20 ^b
Macerated	11.30 ± 0.10 ^c

Extraction of essential oils

The extraction of essential oils from the aerial parts of *D. carota* produced a low yield in the form of traces, which were deposited on the upper surface of the Clevenger apparatus.

Qualitative analysis

Phytochemical screening was carried out to determine the various categories of secondary metabolites present in the powder and aqueous extracts of the aerial parts of *D. carota*. It is based on various qualitative characterization reactions, which rely on precipitation or coloration phenomena in the presence of specific reagents. (Table 3) contains a record of the results obtained.

The phytochemical screening results presented in the table revealed that *D. carota* powder, as well as its three aqueous extracts prepared by different extraction methods (hot and cold), are rich in flavonoids, catechic tannins and saponins. Thus, we noted an average abundance of sterols and anthracenosides, a low abundance of anthraquinones and the strict absence of gallic tannins and alkaloids (Table 3).

Quantitative analysis

The quantitative analysis of three secondary metabolites, total polyphenols, total flavonoids and catechic tannins, was performed on the basis of the phytochemical diversity of the aqueous extracts of *D. carota*. (Table 4) shows the results obtained.

The results revealed that the decocted fermentation mixture had the highest total polyphenol content (19.92 ± 0.08 µg GAE/mg E), followed by the infusion (19.08 ± 0.09 µg GAE/mg E), with a slightly significant difference. On the other hand, the lowest content was found in the macerated samples, with a content of 13.66 ± 0.02 µg GAE/mg E.

Table 3. Phytochemical screening of the aerial parts of *D. carota*

Secondary metabolites	Plant material	Extracts		
		Decocted	Infused	Macerated
Flavonoids	+++	+++	+++	+++
Catechic tannins	+++	+++	+++	++
Gallic tannins	-	-	-	-
Saponins	+++	+++	+++	+++
Sterols	++	++	++	++
Alkaloids	-	-	-	-
Anthraquinones	+	+	+	+
Anthracenosides	++	++	++	++
Quinones	+++	+++	+++	+++

(+++): strong presence; (++): moderate presence; (+): weak presence; (-): absence.

Table 4. Total polyphenol, total flavonoid and catechic tannin contents of aqueous extracts from the aerial parts of *D. carota* using different extraction methods

Extracts	Polyphenols (µg GAE/mg E)	Flavonoids (µg QE/mg E)	Catechic tannins (µg EC/mg E)
Decocted	19.92 ± 0.08 ^a	130.76 ± 0.45 ^a	1.42 ± 0.10 ^a
Infused	19.08 ± 0.09 ^b	132.64 ± 0.57 ^a	0.62 ± 0.05 ^b
Macerated	13.66 ± 0.02 ^c	59.15 ± 0.51 ^b	1.25 ± 0.08 ^a

The average of three individual replicates (n = 3 ± SEM) was used for all the results. Differences were considered statistically significant at p < 0.05 between extraction methods.

The richness of the extracts in terms of flavonoids was confirmed by the assay, which revealed high levels, the best being those of the hot-prepared extracts, with values of 132.64 ± 0.57 µg QE/mg E for the infused extract and 130.76 ± 0.45 µg QE/mg E for the decocted extract. In contrast, a low concentration was observed in the macerated samples, at 59.15 ± 0.51 µg QE/mg E.

Compared with those of the other metabolites, the catechic tannin content was minimal. The highest levels were recorded in the decocted and macerated samples, with a nonsignificant difference: 1.42 ± 0.10 µg CE/mg E and 1.25 ± 0.08 µg CE/mg E, respectively. In contrast, the infusion resulted in a low concentration of 0.62 ± 0.05 µg CE/mg E (Table 4).

Antioxidant activity

The antioxidant activity of aqueous extracts from the aerial parts of *D. carota* was determined on the basis of the percentage of free radical scavenging via the H₂O₂ test and the iron reduction capacity via the FRAP test. The results obtained are shown in Table 5.

The determination of the antioxidant power via free radical inhibition revealed that the infused had the best antioxidant capacity (10.22 ± 0.41 %), followed by the decocted (10.10 ± 0.22 %) and then the macerated (9.85 ± 0.54 %). There was no statistically significant difference among the three aqueous extracts. Moreover, the evaluation of the ability of the extracts to reduce iron revealed that the infused extract has the most powerful effect (64.24 ± 0.14 µg TE/mg E), followed by the decocted extract (58.96 ± 0.17 µg TE/mg E) and finally the macerated extract (30.26 ± 0.43 µg TE/mg E); these three extracts are significantly different from each other (Table 5).

Principal component analysis

Correlation matrix

Principal component analysis was performed to examine the correlations between the aqueous extracts of *D. carota* and the results of the quantitative analysis, antioxidant activity and yield of the aqueous extracts, which were considered variables.

Table 5. Results of the *in vitro* antioxidant activity of aqueous extracts from the aerial parts of *D. carota* via H₂O₂ and FRAP tests

Extracts and reference drugs		H ₂ O ₂ (% inhibition)	FRAP test (μg TE/mg E)
Aqueous extracts	Decocted	10.10 ± 0.22 ^a	58.96 ± 0.17 ^a
	Infused	10.22 ± 0.41^a	64.24 ± 0.14^b
	Macerated	9.85 ± 0.54 ^a	30.26 ± 0.43 ^c
Standard	Ascorbic acid	37.54 ± 0.27 ^b	-

The values shown in Table 5 represent the means of three replicates ± the mean standard error. Differences were considered statistically significant at $p < 0.05$.

The correlation analysis presented in Table 6 reveals that the total polyphenol content is strongly correlated with both flavonoids ($r = 0.989$), extraction yields ($r = 0.932$) and antioxidant activities, as assessed by FRAP ($r = 0.964$) and H₂O₂ ($r = 0.902$) tests. Flavonoids also strongly correlated with FRAP ($r = 0.993$) and H₂O₂ ($r = 0.955$). Moreover, the extraction yields were strongly correlated with the FRAP test results ($r = 0.802$) and moderately correlated with the H₂O₂ test results ($r = 0.683$), reflecting a partial relationship between the amount of material extracted and the antioxidant efficacy. In addition, the results indicate a marked correlation between the two antioxidant assessment methods, H₂O₂ and FRAP. Conversely, catechic tannins were not significantly correlated with total polyphenols, flavonoids, or antioxidant activity and were only weakly correlated with yield ($r = 0.174$), suggesting a limited role in the overall activity observed (Table 6).

Graphical representation

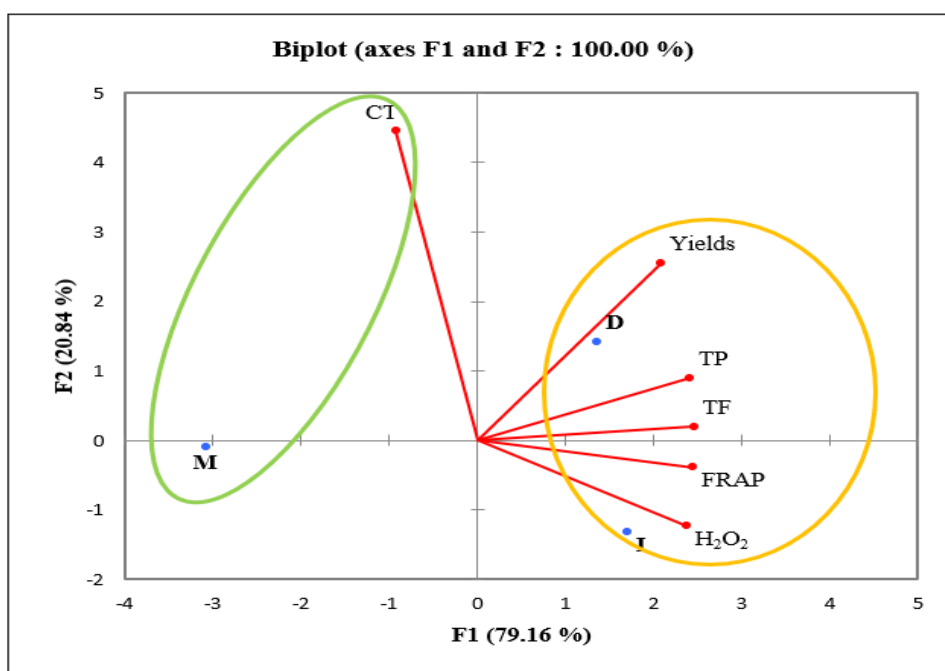
As shown in (Fig. 2), the factor axes F1 and F2 of the PCA cumulatively represent 100 % of the data in percentage terms. The first principal component (F1) accounts for 79.16 % of the total data, whereas the second (F2) accounts for 20.84 %. On the basis of the graphical analysis of the correlations, we identified 2 groups.

The PCA biplot explains 100 % of the total variance, with F1 and F2 accounting for 79.16 % and 20.84 %, respectively. The samples are clearly separated into two main groups along the F1 axis. Group G1, located on the positive side of F1, is strongly associated with yield, total polyphenols (PT), total flavonoids (TF), FRAP and H₂O₂, indicating higher extraction efficiency and antioxidant potential. In contrast, Group G2, positioned on the negative side of F1, is weakly correlated with these variables, suggesting lower phytochemical content and antioxidant capacity.

Table 6. Correlation coefficients between the chemical composition, antioxidant activity and yield of aqueous extracts of *D. carota*

Variables	PT	TF	CT	Yields	H ₂ O ₂	FRAP
PT	1	0.989	-0.195	0.932	0.902	0.964
TF		1	-0.336	0.869	0.955	0.993
CT			1	0.174	-0.600	-0.449
Yields				1	0.683	0.802
H ₂ O ₂					1	0.984
FRAP						1

PT: total polyphenols; TF: total flavonoids; CT: catechic tannins.

**Fig. 2.** Graphical representation of the (PCA) of the correlations among the chemical composition, antioxidant activity and yield of aqueous extracts of *D. carota*.

D: decocted; I: infused; M: macerated. PT: total polyphenols; TF: total flavonoids; CT: catechic tannins; G1: group 1; G2: group 2. Group 1: included the following groups: decocted, infused, extraction yields, total polyphenols, flavonoids, FRAP and H₂O₂ tests. Group 2: was composed of macerated and catechic tannins.

The separation along the F2 axis further discriminates extraction methods within each group, with decoction and infusion showing positive correlations with antioxidant-related variables, whereas maceration is positioned farther from these variables. Overall, the PCA highlights the strong relationship between extraction method, chemical composition, antioxidant activity and extract yield.

Discussion

Mineral content

Analysis of the mineral composition of the aerial parts of *D. carota* revealed that it is rich in minerals, mainly K, Ca, Mg, Na, P and Fe. The abundance of these minerals attests to the nutritional value and pharmacological interest of this plant, given that these components play important roles in metabolism and maintaining physiological balance. Potassium is the major mineral in the aerial parts of *D. carota*, suggesting that this plant plays an essential role in regulating blood pressure and cardiovascular disease (22). The high calcium content of these plants is consistent with previous data indicating the need for calcium in bone development and the maintenance of bone health (23). Magnesium ensures neuromuscular function by acting as a calcium antagonist necessary for muscle contraction (24). Sodium is an essential element for maintaining water and mineral homeostasis (25). Phosphorus is also important in plants, as this mineral is essential for the structure of nucleic acids and the production of ATP, which demonstrates its role in cell division and energy metabolism (26). Iron is also an important element in the body and is involved in oxygen transport via hemoglobin and ensures electron transfer as a cofactor of key enzymes in the respiratory chain (27). The results of a study conducted on the same species in Nigeria revealed that the plant is rich in minerals, with relatively high levels of Ca, P, Mg, Na, Fe, K, Zn, manganese (Mn) and Se, with levels of 49.30 ± 0.87 , 40.10 ± 0.15 , 29.90 ± 0.07 , 23.50 ± 0.22 , 16.25 ± 0.65 , 9.72 ± 0.34 , 7.80 ± 0.27 , 0.60 ± 0.16 and 0.20 ± 0.65 mg/100 g of protein concentrated from dried *D. carota* leaves, respectively (28). While that study primarily emphasized the nutritional value of *D. carota* for dietary applications, the present work focuses on its pharmacological relevance by providing a detailed mineral profiling of the aerial parts. The observed differences in mineral levels and distribution are related to variations in plant parts, analytical expression and geographic origin and they underline the potential of the Moroccan *D. carota* population as a promising source of bioactive minerals with physiological and pharmacological importance.

A study conducted in the same laboratory revealed that *Leopoldia comosa* bulbs are rich in minerals, mainly Fe, K, P, Na, Cu, Mg and Ca, with contents of 33552, 1843.14, 756.36, 439.65, 303.9, 272.37 and 20.55 mg/kg dry matter, respectively (9). Research carried out on the *Chamaerops humilis* plant revealed high levels of minerals present in the leaves of this plant, particularly Fe, K, P, Mg, Na, Cu, Ca and Zn, with values of 82395, 9354.90, 1828.62, 1312.47, 627.03, 542.64, 92.19 and 66.15 mg/kg dry matter, respectively (11). Another study on *Morchella esculenta* revealed that this mushroom has moderately high levels of K, Fe, P and Mg, with values of 3578.4, 2969.16, 1818.66 and 183.657 mg/kg dry matter, respectively (13).

Extract yield

Decoction is the extraction method that yields the highest results.

Distilled water is a polar solvent capable of extracting a wide variety of molecules from medicinal plants. The variation in extraction yields depending on the method can be explained by several factors, including temperature, exposure time, the types of molecules in the plant studied, the part of the plant used and the phenological stage of the plant at harvest (29).

A study on the same species harvested in Gujwa-eup, Jeju Island, South Korea, revealed that decoction extraction of the leaves of this plant yielded 29.48 %, whereas extraction with 70 % ethanol yielded 25.80 % (30). Another study revealed that ethanol extraction of *D. carota* leaves yielded 10.3 ± 0.1 % (31). A study on a species of the same family (*Pimpinella anisum*) revealed that a decoction of this plant yielded 20.99 % (32).

A series of studies conducted under the same experimental conditions revealed that decoction yields the highest yield. Indeed, *Atractylis gummifera* roots have a yield of 35 % (14), *Leopoldia comosa* bulbs have a yield of 8 % (9), *Peganum harmala* seeds have a yield of 12.02 % (12), *Chamaerops humilis* leaves have a yield of 10 % (11), *Morchella esculenta* mushrooms have a yield of 27.66 % (13) and *Rhamnus alaternus* leaves have a yield of 37.5 % (15).

Yield of essential oils

The extraction of essential oils from the aerial parts produced only trace amounts, because *D. carota* from the Taza region is not a highly aromatic chemotype and its bioactive compounds are mainly polar and water-soluble rather than volatile. This low essential oil yield indicates that the plant's potential is better expressed through its aqueous extracts, which still showed significant phytochemical richness and biological activity, supporting its valorization despite the limited essential oil content. However, analyses confirmed the presence of essential oil in the seeds of *D. carota* of Turkish origin. This oil is characterized mainly by the presence of carotol, daucene, farnesene, germacrene D (2.34 %), trans- α -bergamotene and selinene. In contrast, the essential oils extracted from edible carrot seeds contained carotol (30.55 %), daucol (12.60 %) and copaenol (0.62 %) as the major constituents (33). In addition, studies have been conducted on species of the same family as our plant that have recorded significant yields in terms of essential oils (34). Indeed, Samadi and his collaborators have shown that the yield and quality of essential oil depend on the extraction method used (35). Furthermore, according to Moghaddam and Mehdizadeh, the composition of essential oils can be affected by various factors, such as growing conditions, climate, altitude, soil type, agricultural techniques and practices, stage of development, part of the plant extracted and harvest season (36).

Similar results were noted by Lachkar and his collaborators for the extraction of essential oils from fresh *Chamaerops humilis* leaves, which were carried out under identical experimental conditions (11).

Qualitative analysis

The results revealed that various aqueous extraction methods (hot and cold) are effective for extracting several families of metabolites, particularly flavonoids, catechic tannins, saponins, sterols and anthracenosides, from the aerial parts of *D. carota*. In addition, we noted that the extraction method did not influence the qualitative presence of these compounds. However, we did not detect the presence of gallic tannins or alkaloids.

In the present study, the use of aqueous extraction and the specific phytochemical profile of the analysed aerial parts may have favoured the extraction of other classes of secondary metabolites,

while alkaloids and gallic tannins, which are often solvent and tissue-specific, remained undetectable under the applied experimental conditions. These findings suggest that our extracts could have powerful pharmacological potential with a reduced risk of toxicity. Indeed, secondary metabolites are widely recognized for their pharmacological properties (37), confirming their presence in our extracts and making the studied species an original source for investigating active ingredients. Preliminary phytochemical screening revealed the presence of steroids/triterpenes, flavonoids, tannins and saponins in the crude ethyl acetate and methanol extracts (38). According to the literature, the Apiaceae family is characterized by a phytochemical richness dominated by phenolic compounds, flavonoids, terpenes and volatile compounds (6) and *D. carota* reflects this family pattern through its own chemical composition, which underlies its reported bioactive potential.

By comparing our data with studies conducted on species from the same harvest origin and under the same operating conditions, we can say that the phytochemical composition of the plant depends on the geographical origin of the harvest, the type of solvent used and the extraction method chosen. Indeed, the absence of alkaloids and gallic tannins has also been revealed in *Atractylis gummifera* (14), *Anabasis aretioides* (16), *Chamaerops humilis* (10) and *Rhamnus alaternus* (15).

Quantitative analysis

The results revealed that the aerial parts of *D. carota* are important sources of secondary metabolites, particularly phenolic compounds. These compounds play essential roles in the plant's defense against biotic and abiotic stress and contribute to its pharmacological properties.

D. carota exhibits a wide range of pharmacological applications that are closely linked to its mineral composition and richness in secondary metabolites. Its appreciable levels of essential minerals contribute to nutritional support and may help in maintaining physiological balance, while also enhancing the bioavailability and synergistic effects of bioactive compounds. In parallel, the presence of phenolic compounds, flavonoids and other secondary metabolites underpins its reported antioxidant, anti-inflammatory and protective activities (39). Together, these constituents suggest that *D. carota* has potential applications as a natural source of health-promoting agents, supporting its traditional uses and its possible development in nutraceutical and phytotherapeutic formulations.

Several studies have shown that carrot leaves and stems contain high levels of polyphenols, particularly phenolic acids (caffeic acid, chlorogenic acid and ferulic acid) and flavonoids (luteolin, apigenin and quercetin) (40). These compounds are particularly known for their ability to trap free radicals and reduce oxidative stress, which partly explains the traditional use of leaf extracts in herbal medicine (41). In addition, phenolic richness varies depending on the growing conditions, stage of development and extraction methods (42).

A comparative analysis with a study conducted in Azerbaijan on *D. carota* revealed disparities associated with the nature of the extracts and the geographical origin of the plant. While our research in Morocco focused on aqueous extracts rich in polyphenols, flavonoids and tannins, Dehghani and his collaborators focused on essential oils, dominated by carotol and oxygenated sesquiterpenes. This difference in extraction method explains the variation in the

phytochemical profiles observed. However, both studies agree on the high variability of secondary metabolites, which are influenced by both environmental conditions and extraction techniques, confirming the significant bioactive potential of this species in various ecological contexts (34).

Bouhazama and his collaborators conducted their work under the same experimental conditions on aqueous extracts from the aerial parts of *Rhamnus alaternus*. Their results revealed that the hot-prepared decoction extract had the highest total polyphenol, total flavonoid and catechic tannin contents, with values of $21.67 \pm 0.10 \mu\text{g GAE/mg E}$, $58.40 \pm 0.33 \mu\text{g QE/mg E}$ and $5.43 \pm 0.01 \mu\text{g CE/mg E}$, respectively (15).

Antioxidant activity

The phytochemical screening revealed that the extracts are rich in polyphenols, flavonoids and catechin tannins, which are well known for their strong antioxidant properties due to their ability to donate hydrogen atoms or electrons and to scavenge free radicals. In addition, the presence of other secondary metabolites such as saponins, sterols and quinones may contribute synergistically to the observed antioxidant activity, either by enhancing radical scavenging capacity or by stabilizing reactive species. These findings support the antioxidant activity results and explain the variations observed among extracts based on their phytochemical profiles.

The evaluation of the antioxidant activity of aqueous extracts from the aerial parts of *D. carota* revealed that the infused extract had the best antioxidant power in both the H_2O_2 and FRAP tests. The FRAP test is based on estimating the ability of aqueous extracts to reduce the TPRZ-Fe(III) complex to TPTZ-Fe(II). Indeed, the results of the quantification of phenolic compounds revealed that the infused extract has the highest flavonoid content, which led us to believe that the strong antioxidant activity of this extract is linked to the capacity of these compounds to act as antioxidants. The macerated extract exhibited the lowest antioxidant activity compared to the decocted and infused extracts because it contained significantly lower amounts of polyphenols ($13.66 \mu\text{g GAE/mg E}$) and flavonoids ($59.15 \mu\text{g QE/mg E}$), which are the main contributors to antioxidant capacity. Although catechic tannins were present at similar levels to the decocted extract, the lower overall content of other key antioxidant compounds (polyphenols and flavonoids) limited its activity. Heat-assisted methods, such as decoction and infusion, enhance the extraction efficiency of these secondary metabolites by increasing solubility and diffusion from the plant matrix, explaining the higher antioxidant potential observed in those extracts. These results are confirmed by other studies (43). A study conducted on the oily extract of *D. carota* subsp. *Carota* has a ferric reducing antioxidant capacity of $164 \pm 5.5 \mu\text{mol FeSO}_4/\text{g}$ (44). A previous study (45), which aimed to determine the appropriate drying method for achieving better antioxidant activity, revealed that freeze-drying could be the most effective method for preserving the maximum amount of antioxidant properties in plant leaves.

The antioxidant activity of the plant *D. carota*, as demonstrated by the H_2O_2 test, shows the ability of extracts from this plant to neutralize radicals, reflecting their richness in phenolic compounds and flavonoids known for their potential against oxidative stress (46). A study on a species from the same family (*Coriandrum sativum*) revealed that the methanolic extract from the leaves of this plant shows a higher percentage of H_2O_2 trapping than seeds, with percentages of 70.61 % and 60.2 %, respectively, at a

concentration of 400 µg/mL (47). Another study on the species *Anethum graveolens* of the Apiaceae family revealed that the aqueous extract of the leaves of this plant has hydrogen peroxide trapping capacities of 44.13 ± 0.81 and 60.96 ± 2.78 % at concentrations of 250 and 400 µg/mL, respectively (48).

A previous study under the same experimental conditions revealed hydrogen peroxide scavenging capacities of 62.12 ± 0.2 , 61.89 ± 0.3 and 61.72 ± 0.1 % for the decocted, the infused and the macerated *Leopoldia comosa* bulbs, respectively, whereas the most powerful antioxidant activity via the FRAP test was recorded for the macerated bulbs, with 15.27 ± 0.1 µg TE/mg E (9). The leaves of *Chamaerops humilis* presented higher H₂O₂ trapping capacities of 45.77 ± 0.15 , 29.65 ± 0.31 and 29.24 ± 0.62 % for the decocted, infused and macerated plants, respectively. The activity of these extracts exceeds that of ascorbic acid (14.35 ± 0.002 %) (11). In line with several studies conducted under comparable experimental conditions, organic solvent extracts generally exhibit higher antioxidant activity than aqueous extracts, as organic solvents are more effective at solubilizing phenolic compounds with moderate to low polarity. Nevertheless, the present study focused on aqueous extraction to reflect traditional usage and to evaluate the antioxidant potential of water-extractable compounds. Future work could therefore explore organic or mixed-solvent extraction methods to further enhance antioxidant yields and activity (9–13).

Principal component analysis

The PCA revealed that the first two principal components (F1 and F2) explain 100 % of the total variance, with F1 accounting for 79.16 % and F2 for 20.84 %, indicating that the selected variables fully describe the variability among the aqueous extracts. The strong contribution of F1 reflects a common underlying factor associated with antioxidant potential and extraction efficiency. The PCA correlation plot clearly discriminated two distinct groups. Group 1 included the decocted and infused extracts, extraction yields, total polyphenols, total flavonoids and antioxidant activity parameters (FRAP and H₂O₂). This grouping is consistent with the strong positive correlations observed between polyphenols and flavonoids with FRAP ($r = 0.964$ and $r = 0.993$, respectively) and H₂O₂ scavenging activity ($r = 0.902$ and $r = 0.955$), demonstrating that these compounds are the main contributors to the antioxidant activity of the extracts. In contrast, Group 2 was characterized by macerated extracts and catechic tannins, which were weakly correlated with both antioxidant assays and extraction yields. This separation highlights the limited contribution of catechic tannins to the overall antioxidant activity compared to polyphenols and flavonoids. Overall, the PCA confirms and strengthens the correlation analysis by providing a global and integrative visualization of the relationships between phytochemical composition, extraction yield and antioxidant activity, thereby supporting the conclusion that polyphenols and flavonoids are the key determinants of the antioxidant potential of the aqueous extracts of *D. carota*.

The presence of two distinct groups among the aqueous extracts of *D. carota*: the first group, which includes hot-prepared extracts, was strongly correlated with overall extraction efficiency, antioxidant activity measured by FRAP and high concentrations of polyphenols and flavonoids, whereas the second group, which includes macerated extracts, was exclusively linked to the concentration of catechic tannins. These results show that catechic tannins are weakly associated with antioxidant activity, indicating a limited contribution to the antioxidant potential of the extracts.

Conversely, total polyphenols and flavonoids are closely correlated with antioxidant activity and are positioned near antioxidant variables in the PCA, suggesting that these compounds play a predominant role in the observed antioxidant effects.

The present findings highlight the crucial impact of temperature and/or the extraction process on the chemical profile and antioxidant characteristics of the extracts.

Similarly, a study conducted by Qi and his collaborators reported that moderate heat treatment improved the solubilization and diffusion of polyphenols and flavonoids, resulting in increased FRAP and H₂O₂ scavenging values (49).

Conversely, cold-prepared macerated have a more limited composition and are dominated by catechic tannins. This observation suggests that cold extraction favors the recovery of molecules that are stable at low temperatures but does not allow for the complete release of polyphenols bound to the plant matrix (50). Thus, the correlations observed confirm that temperature affects both the yield of the extracts and their biological activity. This has been confirmed by the work carried out by Mahtal and his collaborators on *Morchella esculenta* (L.) Pers. from the province of Taza (13).

The reproducibility and applicability of the present findings may be influenced by certain methodological constraints. The exclusive use of aqueous extraction methods (decoction, infusion and maceration, conducted under hot and cold conditions) may limit the recovery of less polar antioxidant compounds, potentially underestimating the full antioxidant potential of *D. carota*. In addition, antioxidant activity was assessed solely using FRAP and H₂O₂ scavenging assays, which target specific redox mechanisms and therefore do not encompass all antioxidant pathways. Furthermore, phytochemical screening was qualitative, focusing on the presence or absence of eight classes of secondary metabolites rather than their quantitative contribution. Variations in extraction parameters and plant material composition may also affect reproducibility. Nevertheless, these methods remain appropriate for comparative assessment of traditionally prepared aqueous extracts. Future investigations integrating quantitative analyses and complementary antioxidant assays would strengthen the robustness and applicability of these findings.

Conclusion

In this study, we analyzed the mineralogical composition of the plant, the yields of aqueous extracts, phytochemical screening, phenolic compound quantification and the antioxidant activity of the aerial parts of *Daucus carota*.

The results obtained highlight the richness of the aerial parts of this plant in minerals, mainly potassium (P), calcium (Ca), magnesium (Mg), sodium (Na), phosphorus (P) and iron (Fe). The extraction results revealed that decoction is the method that allows the greatest number of bioactive compounds to be extracted. The extraction of essential oils revealed a very low yield. Qualitative analysis indicated that the plant is rich in secondary metabolites such as flavonoids, catechic tannins, sterols, saponins and quinones. Quantitative analysis revealed that the decocted and infused samples presented the highest levels of phenolic compounds, in addition to significant antioxidant activity in the infused samples, as measured by both the H₂O₂ and ferric reducing antioxidant power (FRAP) tests. According to the results of the principal component

analysis (PCA), the antioxidant power of this plant is related to its total polyphenol and total flavonoid contents.

These data suggest that *D. carota* could be a promising source of minerals and secondary compounds that could find applications in the pharmaceutical and food industries. Further research is needed to explore and exploit these results.

Acknowledgements

We would like to thank Prof. Mohamed Boulfia from the Higher Institute of Nursing and Health Techniques, Tetouan, Morocco, for his help in the botanical identification of the plant.

Authors' contributions

SL carried out the experimental work and drafted the manuscript. FL planned the experiments, provided regular scientific support, analyzed the results, drafted and revised the manuscript, finalized the final version and submitted it for publication. HB performed the experimental work and wrote the manuscript. HT designed the experiments, provided ongoing methodological advice and participated in the revision of the manuscript. All authors read and approved the final version of the manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no competing interests.

Ethical issues: None

References

- Kumar P. Valuation of medicinal plants for pharmaceutical uses. *Curr Sci.* 2004;86(7):930-7.
- Sayed-Ahmad B, Talou T, Saad Z, Hijazi A, Merah O. The *Apiaceae*: ethnomedicinal family as source for industrial uses. *Ind Crops Prod.* 2017;109:661-71. <https://doi.org/10.1016/j.indcrop.2017.09.027>
- Plunkett GM, Lowry PP II, Pinney SM, Sprengle TA, Chandler GT. Recent advances in understanding *Apiales* and a revised classification. *S Afr J Bot.* 2004;70(3):371-81. [https://doi.org/10.1016/S0254-6299\(15\)30220-9](https://doi.org/10.1016/S0254-6299(15)30220-9)
- Xu Z, Chang L. *Apiaceae* or *Umbelliferae*. In: Chen X, editor. *Flora of China Illustrated*. Singapore: Springer; 2017. https://doi.org/10.1007/978-981-10-5403-7_1
- Tamokou JDD, Mbaveng AT, Kuete V. Antimicrobial activities of African medicinal spices and vegetables. In: Kuete V, editor. *Medicinal Spices and Vegetables from Africa*. Amsterdam: Elsevier; 2017. p. 207-37. <https://doi.org/10.1016/B978-0-12-809286-6.00008-X>
- Kozhanova K, Alimanova A, Datkhayev U, Serikbayeva E, Kayupova F, Zhumalina K, et al. Unlocking the potential: exploring pharmacological properties from *Apiaceae* family. *Pharmacia.* 2025;72:1-14. <https://doi.org/10.3897/pharmacia.72.e145193>
- Ismail J, Shebaby WN, Daher J, Boulous JC, Taleb R, Daher CF, et al. The wild carrot (*Daucus carota*): a phytochemical and pharmacological review. *Plants (Basel).* 2024;13(1):93. <https://doi.org/10.3390/plants13010093>
- Arora M, Kiran B, Rani S, Rani A, Kaur B, Mittal N. Heavy metal accumulation in vegetables irrigated with water from different sources. *Food Chem.* 2008;111(4):811-5. <https://doi.org/10.1016/j.foodchem.2008.04.049>
- Boulfia M, Lamchouri F, Senhaji S, Lachkar N, Bouabid K, Toufik H. Mineral content, chemical analysis, *in vitro* antidiabetic and antioxidant activities and antibacterial power of aqueous and organic extracts of Moroccan *Leopoldia comosa* (L.) Parl. bulbs. *Evid Based Complement Alternat Med.* 2021;2021:9932291. <https://doi.org/10.1155/2021/9932291>
- Lachkar N, Lamchouri F, Bouabid K, Boulfia M, Senhaji S, Stitou M, et al. Mineral composition, phenolic content and *in vitro* antidiabetic and antioxidant properties of aqueous and organic extracts of *Haloxylon scoparium* aerial parts. *Evid Based Complement Alternat Med.* 2021;2021:9011168. <https://doi.org/10.1155/2021/9011168>
- Lachkar N, Lamchouri F, Toufik H. Ethnopharmacological survey, mineral and chemical content, *in vitro* antioxidant and antibacterial activities of aqueous and organic extracts of *Chamaerops humilis* L. var. *argentea* André leaves. *Biomed Res Int.* 2022;2022:1091247. <https://doi.org/10.1155/2022/1091247>
- Senhaji S, Lamchouri F, Boulfia M, Lachkar N, Bouabid K, Toufik H. Mineral composition, content of phenolic compounds and *in vitro* antioxidant and antibacterial activities of aqueous and organic extracts of the seeds of *Peganum harmala* L. *S Afr J Bot.* 2022;147:697-712. <https://doi.org/10.1016/j.sajb.2022.03.005>
- Mahtal A, Lamchouri F, Toufik H. Mineral composition, phenolic content and antibacterial activity of aqueous and organic extracts of wild *Morchella esculenta* (L.) Pers. from the province of Taza, Morocco. *Biochem Res Int.* 2024;2024:6769243. <https://doi.org/10.1155/bri/6769243>
- Bouabid K, Lamchouri F, Toufik H, Sayah K, Cherrah Y, My El Abbes F. Phytochemical screening and *in vitro* evaluation of alpha amylase, alpha glucosidase and beta galactosidase inhibition by aqueous and organic *Atractylis gummifera* L. extracts. *Plant Sci Today.* 2018;5(3):103-10. <https://doi.org/10.14719/pst.2018.5.3.393>
- Bouhazama H, Lamchouri F, Toufik H. Phytochemical investigation and quantification of bioactive compounds of *Rhamnus alaternus* (L.). *Trop J Drug Res.* 2024;1(1):19-28. <https://doi.org/10.26538/tjdr/v1i1.3>
- Senhaji S, Lamchouri F, Toufik H. Phytochemical content, antibacterial and antioxidant potential of endemic plant *Anabasis aetarioides* Coss. & Moq. (Chenopodiaceae). *Biomed Res Int.* 2020;2020:6152932. <https://doi.org/10.1155/2020/6152932>
- Singleton VL, Orthofer R, Lamuela-Raventós RM. Analysis of total phenols and other oxidation substrates and antioxidants by means of Folin-Ciocalteu reagent. In: Packer L, editor. *Methods Enzymol.* Vol. 299. San Diego: Academic Press; 1999. p. 152-78. [https://doi.org/10.1016/S0076-6879\(99\)99017-1](https://doi.org/10.1016/S0076-6879(99)99017-1)
- Dewanto V, Wu X, Adom KK, Liu RH. Thermal processing enhances the nutritional value of tomatoes by increasing total antioxidant activity. *J Agric Food Chem.* 2002;50(10):3010-4. <https://doi.org/10.1021/jf0115589>
- Julkunen-Tiitto R. Phenolic constituents in the leaves of northern willows: methods for the analysis of certain phenolics. *J Agric Food Chem.* 1985;33(2):213-7. <https://doi.org/10.1021/jf00062a013>
- Ruch RJ, Cheng SJ, Klaunig JE. Prevention of cytotoxicity and inhibition of intercellular communication by antioxidant catechins isolated from Chinese green tea. *Carcinogenesis.* 1989;10(6):1003-8. <https://doi.org/10.1093/carcin/10.6.1003>
- Benzie IF, Strain JJ. The ferric reducing ability of plasma (FRAP) as a measure of "antioxidant power": the FRAP assay. *Anal Biochem.* 1996;239(1):70-6. <https://doi.org/10.1006/abio.1996.0292>
- Houston MC, Harper KJ. Potassium, magnesium, and calcium: their role in both the cause and treatment of hypertension. *J Clin Hypertens (Greenwich).* 2008;10(7 Suppl 2):3-11. <https://doi.org/10.1111/j.1751-7176.2008.08575.x>
- Flynn A. The role of dietary calcium in bone health. *Proc Nutr Soc.* 2003;62(4):851-8. <https://doi.org/10.1079/PNS2003301>

24. Okamoto T. Effects of magnesium and calcium on muscle contractility and neuromuscular blockade produced by muscle relaxants and aminoglycoside. *Masui*. 1992;41(12):1910-22.
25. Bernal A, Zafra MA, Simón MJ, Mahía J. Sodium homeostasis, a balance necessary for life. *Nutrients*. 2023;15(2):395. <https://doi.org/10.3390/nu15020395>
26. Serna J, Bergwitz C. Importance of dietary phosphorus for bone metabolism and healthy aging. *Nutrients*. 2020;12(10):3001. <https://doi.org/10.3390/nu12103001>
27. McDermid JM, Lönnerdal B. Iron. *Adv Nutr*. 2012;3(4):532-3. <https://doi.org/10.3945/an.112.002261>
28. Sodamade A, Raimi SM, Owonikoko AD, Adebimpe AT. Nutritive evaluation, mineral composition and phytochemical analysis of leaf protein concentrates of *Daucus carota*. *Int J Trend Sci Res Dev*. 2019;3(5):767-72.
29. Hazrati S, Mousavi Z, Nicola S. Harvest time optimization for medicinal and aromatic plant secondary metabolites. *Plant Physiol Biochem*. 2024;212:108735. <https://doi.org/10.1016/j.plaphy.2024.108735>
30. Kim JS, Lim JH, Cho SK. Effect of antioxidant and anti-inflammatory on bioactive components of carrot (*Daucus carota* L.) leaves from Jeju Island. *Appl Biol Chem*. 2023;66(1):34. <https://doi.org/10.1186/s13765-023-00786-2>
31. Akune NAS, Rahmawati I, Sulaiman S. Antibacterial activity test of ethanol extract and fraction of carrot leaf (*Daucus carota* L.) against *Staphylococcus aureus*. *J Multidisiplin Madani*. 2024;4(3):458-63. <https://doi.org/10.55927/mudima.v4i3.8604>
32. Bekara A, Ait Hamadouche N, Kahloulou K, Sadi N, Aoues A. Phytochemical study and antioxidant activity of the aqueous extract of *Pimpinella anisum* L. *Alger J Nat Prod*. 2016;4(3):299-307.
33. Özcan MM, Chalchat JC. Chemical composition of carrot seeds (*Daucus carota* L.) cultivated in Turkey: characterization of the seed oil and essential oil. *Grasas Aceites*. 2007;58(4):359-65. <https://doi.org/10.3989/gya.2007.v58.i4.447>
34. Dehghani L, Fattahi M, Ashrafi-Saeidlou S. Morpho-phytochemical screening and biological assessments of aerial parts of Iranian populations of wild carrot (*Daucus carota* L. subsp. *carota*). *Sci Rep*. 2025;15(1):12619. <https://doi.org/10.1038/s41598-025-96965-w>
35. Samadi M, Zainal Abidin Z, Yoshida H, Yunus R, Awang Biak DR. Toward higher oil yield and quality of essential oil extracted from *Aquilaria malaccensis* wood via the subcritical technique. *Molecules*. 2020;25(17):3872. <https://doi.org/10.3390/molecules25173872>
36. Moghaddam M, Mehdizadeh L. Chemistry of essential oils and factors influencing their constituents. In: Grumezescu AM, Holban AM, editors. *Soft Chemistry and Food Fermentation*. Amsterdam: Academic Press; 2017. p. 379-419. <https://doi.org/10.1016/B978-0-12-811412-4.00013-8>
37. Bhatti MZ, Ismail H, Kayani WK. Plant secondary metabolites: therapeutic potential and pharmacological properties. In: *Secondary Metabolites-Trends and Reviews*. London: IntechOpen; 2022.
38. Ayeni E, Ahmed A, Ibrahim G, Atinga V, Muhammad Z. Phytochemical, nutraceutical and antioxidant studies of the aerial parts of *Daucus carota* L. (*Apiaceae*). *J HerbMed Pharmacol*. 2018;7(1):68-73. <https://doi.org/10.15171/jhp.2018.12>
39. Choi SS, Lee JE, Lee HJ, Lee KA. Comparative evaluation of the antioxidant and immunomodulatory activities of carrot (*Daucus carota* L.) aerial parts and roots using different extraction methods. *Foods*. 2025;14(23):3993. <https://doi.org/10.3390/foods14233993>
40. Kalt W, Ryan DAJ, Duy JC, Prior RL, Ehlenfeldt MK, Kloet SP. Interspecific variation in anthocyanins, phenolics and antioxidant capacity among genotypes of highbush and lowbush blueberries (*Vaccinium* section *Cyanococcus* spp.). *J Agric Food Chem*. 2001;49(10):4761-7. <https://doi.org/10.1021/jf010653e>
41. Chandran R, Abrahamse H. Identifying plant-based natural medicine against oxidative stress and neurodegenerative disorders. *Oxid Med Cell Longev*. 2020;2020:8648742. <https://doi.org/10.1155/2020/8648742>
42. Alasalvar C, Grigor JM, Zhang D, Quantick PC, Shahidi F. Comparison of volatiles, phenolics, sugars, antioxidant vitamins and sensory quality of different colored carrot varieties. *J Agric Food Chem*. 2001;49(3):1410-6. <https://doi.org/10.1021/jf000595h>
43. Addi M, Elbouzidi A, Abid M, Tungmunthum D, Elamrani A, Hano C. An overview of bioactive flavonoids from citrus fruits. *Appl Sci (Basel)*. 2022;12(1):29. <https://doi.org/10.3390/app12010029>
44. Shebaby WN, El-Sibai M, Smith KB, Karam MC, Mroueh M, Daher CF. The antioxidant and anticancer effects of wild carrot oil extract. *Phytother Res*. 2013;27(5):737-44. <https://doi.org/10.1002/ptr.4776>
45. Rahim MA, Baharudin NA, Nazri IA, Mohamad S, Muazzam KAAR. Effect of different drying methods on the antioxidant properties of leaves of *Centella asiatica*. *IOP Conf Ser Earth Environ Sci*. 2021;756(1):012054. <https://doi.org/10.1088/1755-1315/756/1/012054>
46. Afsar T, Razak S, Khan MR, Mawash S, Almajwal A, Shabir M, et al. Evaluation of antioxidant, anti-hemolytic and anticancer activity of various solvent extracts of *Acacia hydasypica* R. Parker aerial parts. *BMC Complement Altern Med*. 2016;16(1):258. <https://doi.org/10.1186/s12906-016-1240-8>
47. Yadav M, Kumari S, Nagraj N, Sharma N, Bharati SL, Singh S, et al. Hydrogen peroxide scavenging by methanolic extracts of coriander: an *in vitro* antioxidant study. *Pharm Drug Regul Aff J*. 2025;8(1):162. <https://doi.org/10.23880/pdraj-16000162>
48. Isbilir SS, Sagioglu A. Antioxidant potential of different dill (*Anethum graveolens* L.) leaf extracts. *Int J Food Prop*. 2011;14(4):894-902. <https://doi.org/10.1080/10942910903474401>
49. Qi K, Xia G, Huang G, Huang H. Extraction, chemical modification and antioxidant activities of *Daucus carota* polysaccharide. *Chem Biol Drug Des*. 2021;98(6):1098-103. <https://doi.org/10.1111/cbdd.13968>
50. Chemat F, Fabiano-Tixier AS, Abert Vian M, Allaf T, Vorobiev E. Solvent-free extraction. In: Ibáñez E, Cifuentes A, editors. *Compr Anal Chem*. Vol. 76. Amsterdam: Elsevier; 2017. p. 225-54.