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Nutritional and Bioactive Properties of *Arbutus unedo, Myrtus communis, and Lavandula stoechas*: Implications for Functional Foods

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ABSTRACT

In response to the growing demand for natural and alternatives to synthetic food preservatives, this study evaluates the physicochemical characteristics and bioactive potential of *Arbutus unedo, Myrtus communis*, and *Lavandula stoechas*. These Mediterranean herbs, traditionally valued for their medicinal properties, offer promising applications in functional food design due to their rich bioactive profiles. Although these plants have been used for centuries, their antioxidant properties remain underexplored in the context of food preservation. This research investigates key attributes such as fiber content, protein levels, pH, and bioactive compounds. Among the plants studied, *Arbutus unedo* exhibited the highest fiber content (55.83% neutral detergent fiber) and potent antioxidant activity, making it suitable for functional diets aimed at promoting health. *Myrtus communis* demonstrated the highest flavonol content (6.21 mg quercetin equivalents per gram) and protein levels (9.45%), highlighting its potential for health-conscious food products. Utilizing hexane extraction, *Lavandula stoechas* revealed the highest lipid content (11.87%) and a distinctive profile for flavoring and cosmetics applications. These findings emphasize the potential of these plants as natural additives, providing environmentally friendly and health-promoting solutions for food preservation. By exploring the characteristics of these species, this study contributes valuable insights into the development of innovative functional food design strategies.

Keywords: *Arbutus unedo, Myrtus communis, Lavandula stoechas*, Bioactive compounds, Antioxidant activity, *Functional* foods.

Introduction

Plants have historically served as indispensable resources for human societies, fulfilling critical roles as primary food sources, medicinal practices, and ecological sustainability.[1] Recent scientific attention has shifted towards understanding the complex physicochemical properties of plants, which have the potential to enhance food quality and promote health. Over time, the study of plant properties has evolved, with modern research focusing on their physicochemical characteristics and the potential to address pressing global issues. Among these challenges is the growing concern over synthetic food additives, which despite their functionality, have been linked to adverse health effects and environmental issues. This has spurred an urgent need for natural alternatives that align with health-conscious and sustainable practices.[2,3]

Recently, there has been an increasing interest in studying the physicochemical properties of plants for their potential to enhance food quality, promote better health, and support sustainable practices.[4] These properties are increasingly relevant in the global shift towards vegetarian and plant-based diets, driven by environmental concerns, ethical considerations, and rising health awareness.[5]

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Comprehending the physicochemical characteristics of plants enables their practical use in food recipes, functional foods, and nutraceuticals, providing options for artificial additives and preservatives that could harm health.[6,7] Moreover, investigating the structural and chemical composition of plants opens new avenues for applications in bioplastics, biofuels, and eco-friendly packaging materials, positioning plants as critical players in addressing modern challenges such as climate change and resource depletion.[2,5]

The study of plant-based antioxidants has also gained prominence because of their role in combating oxidative stress, a key factor in developing chronic diseases such as cancer, cardiovascular diseases, and neurodegenerative disorders.[8,9] Antioxidants neutralize free radicals and reactive oxygen species (ROS), protecting cellular structures and promoting overall health.[10,11] Plants rich in antioxidants are being increasingly explored for their ability to prevent or manage these diseases and offer a natural alternative to synthetic drugs, which are often associated with undesirable side effects. Concurrently, growing resistance to conventional antibiotics has led to the search for novel medicinal compounds, with plant-derived bioactive compounds emerging as promising candidates owing to their chemical diversity and multifunctional properties.[12,13]

In this context, *Arbutus unedo* (strawberry tree), *Myrtus communis* (myrtle), and *Lavandula stoechas* (French lavender) stand out as significant species warranting detailed investigation.

Arbutus unedo (*A. unedo*), a strawberry tree, is native to the Mediterranean and parts of Western Europe. It produces small red fruits are rich in antioxidants, such as polyphenols, flavonoids, and vitamin C, contributing to its antimicrobial and anti-inflammatory properties. The tree is adaptable, drought-tolerant, and valued in traditional medicine, with its fruits and leaves used in food products and for health benefits.[14–16]

Myrtus communis (*M. communis*), native to the Mediterranean, is an aromatic evergreen shrub known for its essential oils used in perfumery

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and traditional medicine. It is rich in phenolic acids, flavonoids, and tannins and has potent antioxidant, anti-inflammatory, and antimicrobial effects. Plant berries are also used in Mediterranean cuisine to flavor meat and beverages.[17,18]

Lavandula stoechas (*L. stoechas)*, also native to the Mediterranean, is distinguished by its deep purple flowers and aromatic oils. Its essential oils contain camphor and cineole, known for their antimicrobial and anti-inflammatory properties. Traditionally used for respiratory and skin conditions, *L. stoechas* is widely used in cosmetics and aromatherapy because of its therapeutic and fragrant qualities.[7,19]

This study aimed to comprehensively evaluate the bioactive and nutritional profiles of *A. unedo*, *M. communis*, and *L. stoechas* and highlight their potential as natural food additives and sustainable resources. Detailed analyses were conducted to determine fiber, lipid, and protein content and pH and bioactive compounds such as saponins, tannins, condensed tannins, flavonols, and carotenoids. Elemental compositions were quantified using advanced techniques to assess essential minerals and trace elements, including Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) and Wavelength Dispersive X-ray Fluorescence (WD-XRF). These results highlight the potential of these plants as future alternatives for artificial food additives, supporting international initiatives to encourage ecologically responsible and health-conscious behavior.

Materials and Methods

Chemical and reagent

The reagents used in this study were as follows: Neutral Detergent Solution, Thermostable Alpha-Amylase, Acid Detergent Solution, Methanol (80%, 70%), Sulfuric acid (95-97%), and Sulfuric acid (72%), Sodium hydroxide (NaOH), Boric acid, Hydrochloric acid (HCl) (0.1N), Nitric acid (HNO), Folin-Ciocalteu reagent, Sodium carbonate solution, vanillin (1% in methanol), 2% Aluminum chloride ($AlCl_3$), acetone, *β*-Carotene, HCl and HNO_3 mixture (for elemental analysis), Tannic acid, Quercetin standard, Catechin standard. All the reagents were purchased from Sigma-Aldrich (USA).

Plants material

Plant samples of *Arbutus unedo*, *Myrtus communis*, and *Lavandula stoechas* were collected in September 2022 from northern Morocco (35°46′48″ N, 5°54′36″ W). Mohamed El Kadiri, botanist at the Faculty of sciences Tetouan, Morocco, identified the plants. Voucher specimens were deposited with the identification numbers LAMSE-AU-22-005, LAMSE-MC-22-006, and LAMSE-LS-22-007. After collection, leaves were carefully separated from the rest of the plant material. The leaves were then dried in the shade at an ambient temperature of approximately 25°C until they reached constant weight. After drying, the plant material was crushed using a blender (Retsch SM100, Paris, France) and passed through a 1 mm sieve (Gylson Company, Inc., Lewis Center, OH, USA) to obtain a uniform powder for further analysis.

Fiber content

The fiber content of plant materials was determined using the methods of Goering and Van Soest for Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF), and Acid Detergent Lignin (ADL).[20–22]

Neutral Detergent Fiber (NDF):

To measure Neutral Detergent Fiber (NDF), plant powder samples (0.5 g) were placed in pre-labeled F57 bags from ANKOM and weighed. The bags were treated with 1900–2000 mL neutral detergent solution and 4 mL thermostable alpha-amylase at 90°C for 90 min using a Fiber Analyzer ANKOM 200 (ANKOM Technology, Macedon, NY, USA), followed by rinsing with distilled water. The bags were treated with acetone, air-dried, and oven-dried at 102°C for 4 h. The NDF content was calculated as the percentage of dry matter.

Acid Detergent Fiber (ADF)

To measure the Acid Detergent Fiber (ADF), a 1 g sample was weighed into pre-labeled F57 bags, sealed, and treated with 1900–2000 mL of acid detergent solution at 90°C for 75 min. After rinsing with distilled water at 70–90°C for 5 min, the bags were immersed in acetone for 3–5 min, air-dried and oven-dried at 102°C for 4 h. ADF content was expressed as a percentage of dry matter.

Acid Detergent Lignin (ADL)

For Acid Detergent Lignin (ADL), following the ADF analysis, the same bags were treated with 72% sulfuric acid in a 250 mL beaker for 3 h, ensuring complete immersion by gently tapping the bags every 30 min. The bags were rinsed three times with boiling distilled water for 5 min each, followed by acetone immersion for 3–5 min, air drying, and oven drying at 102°C for 4 h. The ADL content was calculated as the percentage of dry matter.

Total protein content

The total protein content was determined using the Kjeldahl method.[23] Involving mineralization, distillation, and titration. A 1 g sample of ground material was weighed into a 250 mL mineralization tube, and then 1 g of Kjeldahl catalyst and 15 mL of concentrated sulfuric acid (95-97%) were added. The tube was heated at 120°C for 60 min and then at 420°C for 120 min until a clear solution was formed. After cooling, the sample was distilled in a UDK 129 Kjeldahl distillation unit (VELP Scientifica, Italy), adding 100 mL of distilled water and 80 mL of sodium hydroxide were added to collect approximately 150 mL of distillate. The distillate, mixed with 20 mL of boric acid and a color indicator, turned green. Titration was performed with 0.1 N hydrochloric acid.

The nitrogen content was calculated using the equation:

$$\%Total\ nitrogen = (\frac{(V1 - V2) \times N \times 14)}{m}) \times 100$$

Where V1 is the volume of acid used to titrate the sample (mL), V2 is the volume of acid used for titrating the blank (mL), N is the normality of the acid (equivalents/L), 14.01 is the molar mass of nitrogen (mg/mmol), and m is the mass of the sample (g).

To estimate crude protein content, the following conversion is applied:

$$\%\ Protein = \%\ total\ nitrogen\ \times 6.25$$

pH analysis

The pH of the plant materials was determined by dissolving 1 g of plant powder leaf in 10 mL of distilled water in a clean container to create a slurry. This mixture was stirred thoroughly and allowed to settle for a few minutes to obtain a solution. pH was measured using a pH meter (HI83141, Hanna Instruments, Maroc).

Total lipid content

The total lipid content of the dried plant materials was determined using the Soxhlet extraction method.[24] A sample of 5 g of plant powder leaf material was placed in a cellulose thimble and subjected to continuous extraction with hexane, methanol, and chloroform as solvents for 6 h in a Soxhlet apparatus. The solvent was evaporated using a rotary evaporator, leaving behind the extracted lipids. The lipid residue was then weighed, and the total lipid content was calculated as the percentage of the dry weight of the sample. This method effectively quantifies various lipid types and provides insights into the fatty acid profile of plants, which is crucial for understanding their nutritional value and potential applications in food and pharmaceuticals.

Saponins content

The quantification of saponins in the plant extracts was performed through a spectrophotometric method using a colorimetric assay with vanillin and sulfuric acid. In this process, saponins were extracted from dried and powdered plant material (5 g of sample) using 50 mL of 80% methanol. The mixture was shaken and stirred for 4 h to ensure maximal extraction. After filtering the mixture, an aliquot of the concentrated extract (0.1 mL) was mixed with 1 mL of the vanillin reagent and 1 mL

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of concentrated sulfuric acid. The absorbance of the resulting solution was measured at 430 nm using a UV-Vis spectrophotometer (Jenway 6305, Cole-Parmer Ltd., United Kingdom). A calibration curve, constructed using different concentrations of standard saponins, was used for quantification.[25,26] The results are presented as milligrams of saponins per gram of dry plant material (mg/g).

Tannins content in plant extract

Tannins were quantified in plant extracts using the colorimetric method through the Folin-Ciocalteu assay.[27] 5 g of dried plant leaf was subjected to extraction using 80% methanol. The extraction process involved soaking the plant powder for 6 h to ensure total extraction, followed by centrifugation to separate the liquid extract from the solid residue. Then, 0.5 mL was mixed with Folin–Ciocalteu reagent (2.5 mL) and allowed to react, after which 2 mL of sodium carbonate solution was added to develop the color. The absorbance of the resulting solution was measured at a wavelength of approximately 765 nm using a UV-Vis spectrophotometer. The tannin concentration was then determined by comparing the absorbance with a calibration curve of tannic acid at different concentrations. The results are expressed as milligrams of tannic acid equivalents per gram of dry plant material (mg/g).

Condensed tannin content (proanthocyanidins)

The vanillin-HCl technique was used to quantify the condensed tannins.[28] Five grams of dried, powdered plant material was extracted in 50 mL of 70% methanol with 1% HCl for two hours, then filtered. One milliliter of the extract was mixed with 5 mL 1% vanillin in methanol and 1 mL concentrated HCl, followed by incubation for 20 min at room temperature in the dark. The absorbance was measured at 500 nm using a UV-Vis spectrophotometer, with methanol as the blank. Results are expressed as mg catechin equivalents per gram of dry material (mg CE/g), with a catechin-based standard curve, and reported as the mean ± standard deviation for triplicate analyses.

Flavonol Content Analysis

A colorimetric method using aluminum chloride was used to quantify flavonols.[29] Dried plant powder (5 g) was extracted in 50 mL of 80% ethanol, agitated for two hours, and then filtered. After combining 1 mL of the extract with 2 mL of a 2% $AlCl_3$ solution, the mixture was left to incubate for 30 minutes in the dark. Absorbance was measured at 415 nm using ethanol as a blank. The flavonol concentration was expressed as milligrams of quercetin equivalents per gram of dried plant (mg QE/g), and a calibration curve was developed using quercetin standards.

Carotenoids content

5 g of plant powder was dissolved in 50 ml of acetone for two hours to extract carotenoids, which were then filtered out.[30] Measurements of the extract were measured at 470, 645, and 662 nm. The results were determined and presented as milligram *β*-carotene equivalents per gram of dry plant (mg *β*CE/g), with *β*-carotene as a reference. Three replicates of each assay were performed, and the results were reported as mean values with standard deviations.

Elemental Characterization Using Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES)

To quantify the concentrations of different elements in the plants, 0.1 g of sample (leaf powder) was mixed with 3 ml of hydrochloric acid and 1 ml of nitric acid.[31] The mixture was left to stand for 24 h to ensure the digestion of the organic material and ensure complete dissolution of the sample. Following this period, the mixture was heated at 95°C for 2 h to promote the breakdown of the sample matrix. After heating, the solution was diluted to a final volume of 25 ml using ultrapure water. To eliminate any remaining particulates and ensure the clarity of the solution, the mixture was filtered through a 45 µm sieve. The resulting solution was prepared for analysis using an ICP ULTIMA EXPERT apparatus (HORIBA, Palaiseau, France). Elemental concentrations were determined by measuring the intensity of the emitted light at specific wavelengths corresponding to each element calibrated against standard solutions of known concentrations.

WD-XRF Analysis

This method is particularly useful for identifying and quantifying elements in various materials, including solids, liquids, and powders.[32] In this study, a Wavelength Dispersive X-ray Fluorescence (WDXRF) spectrometer was utilized, precisely the Axios 2005 model from PANalytical (Malvern, UK). This advanced instrument allows precise elemental analysis and operates with a rhodium anode, providing a maximum power of 4 kW and a current of 160 mA. The WDXRF spectrometer recorded the characteristic radiation from major, minor, and trace elements through ten distinct scans, ensuring comprehensive identification of all sample elements.

Statistical analysis

All analyses were performed in quadruplicates. The results were statistically analyzed using the Minitab® 17 software (Minitab, Inc., State College, PA, USA; release year: 2014). Analysis of variance (ANOVA) was conducted, followed by Tukey's multiple comparison test, to identify significant differences among the samples ($p < 0.05$). Results are expressed as mean ± standard deviation. Different superscript letters indicate significant differences.

Results and Discussion

Fiber content

Table 1 presents the concentrations of Neutral Detergent Fiber (NDF), Acid Detergent Fiber (ADF), and Acid Detergent Lignin (ADL) in *Arbutus unedo*, *Myrtus communis*, and *Lavandula stoechas*. Significant differences in fiber content were observed across these species, with implications for their potential functional applications in food and nutraceutical formulations. Statistically, the differences in NDF, ADF, and ADL content were significant ($p < 0.05$), supporting the hypothesis that these plants vary considerably in their structural components.

Arbutus unedo exhibited the highest fiber content across all measurements, with NDF at 55.83%, ADF at 36.24%, and ADL at 13.74%. These values are notably higher than those reported in previous studies, where *A. unedo* had an NDF content of approximately 34.8%. This can be attributed to differences in environmental factors, such as soil composition and climatic conditions, which influence fiber composition.[33] The high results suggest that *A. unedo* possesses a robust cell wall structure composed of cellulose, hemicellulose, and lignin. Furthermore, the elevated ADL content indicates that this species has a relatively high lignin content, contributing to its rigidity. The increased lignin concentration may enhance its antioxidant potential, as lignin's phenolic structure can scavenge free radicals.[34] This characterizes *A. unedo* as a suitable species for formulations requiring high fiber rigidity and antioxidant properties, especially in the food and nutraceutical industries.[35,36]

Table 1: Fiber content in the three plants leaves powder

Plants samples	NDF (%)	ADF (%)	ADL (%)
A.unedo	55.83±0.16^a	36.24±0.28^a	13.74±0.11^a
M.communis	42.05±0.35^b	27.09±0.65^b	12.76±0.75^b
L. stoechas	39.56±0.41^c	23.78±0.98^c	10.34±0.30^c

NDF: Neutral Detergent Fiber, ADF: Acid Detergent Fiber, ADL: Acid Detergent Lignin. The results are presented as mean ± standard deviation. a–c Letters in the same column indicate significant differences ($p < 0.05$).

In contrast, *Myrtus communis* and *Lavandula stoechas* had lower fiber contents. *M. communis* had an NDF of 42.05%, ADF of 27.09%, and ADL of 12.76%, significantly lower than *A. unedo* ($p < 0.05$). This suggests that *M. communis* has less cellulose and hemicellulose but comparable lignin content, indicating that it might be structurally less rigid but still retains some of the mechanical properties beneficial for

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dietary fiber applications. This could make it more suitable for formulations that require a balance between digestibility and rigidity.[37,38]

Lavandula stoechas had the lowest fiber content, with an NDF of 39.56%, ADF of 23.78%, and ADL of 10.34%. These values were significantly lower than those of both *A. unedo* and *M. communis* ($p < 0.05$), reflecting a less rigid structure, potentially making them more digestible. The lower lignin content suggests that *L. stoechas* may be better suited for applications where softer textures and higher digestibility are desired, such as in animal feed or food products, where fiber inclusion must not negatively affect texture or palatability.

The fiber profiles of these plants suggest that they have distinct applications depending on the desired fiber characteristics. *A. unedo* could be more suitable for applications requiring high rigidity and potential antioxidant benefits, whereas *M. communis* and *L. stoechas* offer lower fiber content options that may be easier to digest or process.[39,40]

In a previous study, *A. unedo* displayed an NDF content of approximately 34.8%, which with the current results, although the NDF values were higher at 55.83%.[41] This variation might be due to the season or specific growing conditions, as environmental factors significantly influence fiber composition. *M. communis* typically shows high ADF values owing to its structural components, with recorded NDF levels ranging from 38% to 45%, depending on the season.

Total protein content

The protein contents of the three plant species were determined using the Kjeldahl method (figure 1). *Myrtus communis* has the highest protein content (9.45%), making it a possible source of protein-rich foods or supplements. *Arbutus unedo* has a moderate protein concentration of 7.58%, which makes it appropriate for balanced health products that incorporate both proteins and have high fiber content. However, because *Lavandula stoechas* has the lowest protein concentration (4.82%), it is more suitable for use as a flavoring ingredient or in functional health products than applications that are primarily focused on proteins. These plants have distinct applications in the food industry, as natural protein sources or as functional ingredients in health-focused products.

In the food industry, the protein content is critical for assessing the nutritional value of plant materials used in food formulations. For example, *Myrtus communis* has been investigated for its potential as an antioxidant-rich food product, and its protein content can add further nutritional appeal.[42]

Similarly, *Arbutus unedo* and *Lavandula* species are being explored for their functional food applications owing to their bioactive compounds, and the protein content can play a role in developing plant-based supplements or additives.[43]

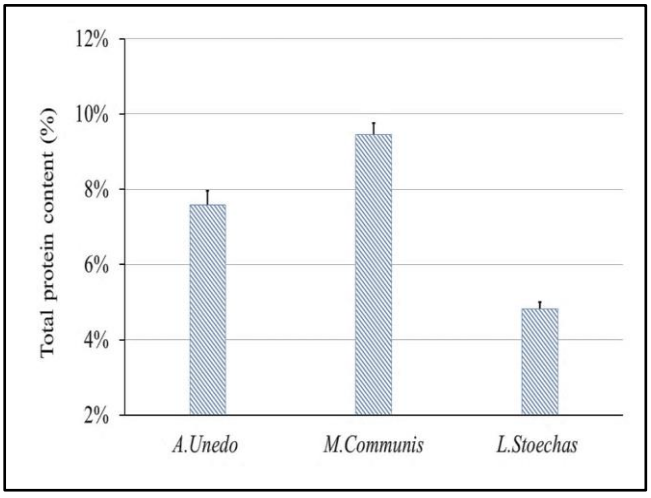

Figure 1: Total protein content (%) in the three plants leaf powder.

pH measurement

The pH values obtained for *Arbutus unedo* (4.9), *Myrtus communis* (5.8), and *Lavandula stoechas* (6.0) highlight their slightly acidic to neutral characteristics, which have significant implications for their potential use in food products. *Arbutus unedo*'s moderately acidic pH of *Arbutus unedo* (4.9) is a candidate for natural preservation. Acidity plays a crucial role in inhibiting microbial growth, which can extend the shelf life of food products.[44] This makes *A. unedo* suitable for use in fruit-based products, beverages, and natural preservatives, where its acidic properties enhance flavor and provide stability to antioxidants, which tend to be more stable at lower pH levels.[45,46]

In contrast, *Myrtus communis* has a near-neutral pH of 5.8, making it versatile for various food applications. Although it is less acidic, its pH still supports mild preservation properties; however, its primary value may lie in flavor enhancement, especially in traditional Mediterranean foods, where it is commonly used. Additionally, this balanced pH makes *M. communis* ideal for inclusion in functional food products, where its bioactive compounds can be effectively preserved, enhancing the product's nutritional profile without significantly altering the taste or texture of the food.[47,48]

Lastly, *Lavandula stoechas* exhibits a pH of 6.0, close to neutral, indicating its primary role as a flavoring and functional ingredient rather than a preservative. This neutral pH makes it suitable for products where maintaining a balanced pH is essential, such as herbal teas, flavored water, or foods with delicate flavors.[19]

Total lipid content

Soxhlet extraction of total lipids from *Arbutus unedo*, *Myrtus communis*, and *Lavandula stoechas* using different solvents (hexane, methanol, and chloroform) revealed significant variations in lipid content within the same species (table 2). For *Arbutus unedo*, hexane yielded the highest lipid content (9.91%), which was significantly higher than that of methanol (6.23%) and chloroform (7.14%) ($p < 0.05$). Similarly, *Myrtus communis* had the highest lipid content when extracted with hexane (5.67%), which was significantly higher than that extracted with methanol (4.25%) or chloroform (4.89%) ($p < 0.05$).

Lavandula stoechas exhibited the highest lipid yield when extracted with hexane (11.87%), which was significantly higher than the yields from methanol (9.47%) and chloroform (9.93%) ($p < 0.05$). These results underscore the impact of the solvent on lipid extraction efficiency, with hexane consistently outperforming both methanol and chloroform across all species, indicating its superior extraction power for lipophilic compounds.

These findings are in line with previous studies showing that non-polar solvents, such as hexane, are generally more effective in extracting lipids from plant materials than polar solvents, such as methanol and chloroform, owing to the greater affinity between non-polar solvents and lipid molecules.[49]

The lipid profiles of plants can significantly influence their functional properties for food applications. Lipids are crucial in determining flavor, texture, and nutritional value. They are essential for the absorption of fat-soluble vitamins (A, D, E, and K) and can enhance the bioavailability of antioxidants.[50]

Table 2: Total lipid content (%) of the three plants in three different solvent

Plants samples	Hexane (%)	MeOH (%)	Chloroform (%)
A.unedo	9.91 ± 0.32^{b}	4.24 ± 0.45^{c}	8.53 ± 0.09^{b}
M.communis	5.67 ± 0.09^{b}	3.05 ± 0.15^{c}	6.89 ± 0.35^{a}
L. stoechas	11.87 ± 0.19^{a}	4.97 ± 0.08^{c}	10.35 ± 0.28^{b}

MeOH: Methanol. The results are presented as mean ± standard deviation. a–c Letters in the same row indicate significant differences ($p < 0.05$).

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Saponins content

The results of saponin extraction (figure 2) from *Arbutus unedo, Myrtus communis*, and *Lavandula stoechas* revealed significant variations in saponin content depending on the solvent used (hexane, methanol, or chloroform). These differences can be primarily attributed to the polarity of the solvents and the chemical nature of saponins, which exhibit both hydrophilic and hydrophobic properties.

Methanol consistently produced the highest extraction yields for *Arbutus unedo* and *Myrtus communis*, with values of 58.46 mg/g and 31.72 mg/g, respectively. The amphipathic property of methanol, a polar solvent, allows it to interact with both polar and nonpolar substances, making it an extremely powerful saponin extractor.[51.] The fact that saponins are highly soluble in methanol indicates that they are primarily hydrophilic, which is consistent with the fact that saponins are more soluble in polar solvents because of their sugar molecules.[52]

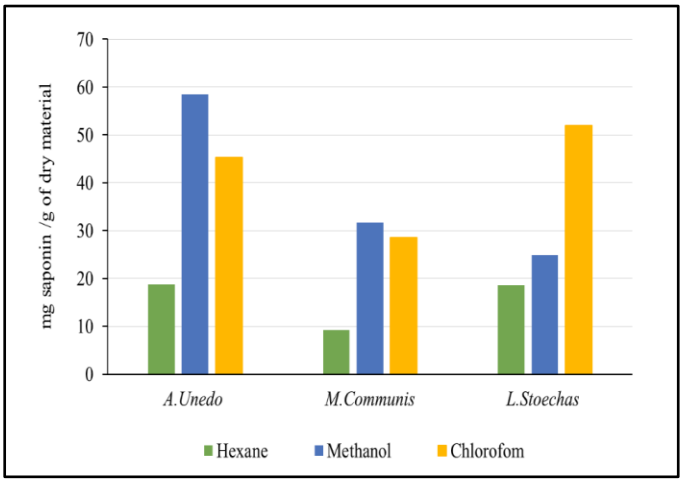

Figure 2: Saponin extraction yield (mg saponin/g dry material) from *Arbutus unedo, Myrtus communis*, and *Lavandula stoechas* using hexane, methanol, and chloroform.

Chloroform, which is less polar than methanol but more polar than hexane, produced the second-highest extraction efficiencies for *A. unedo* (45.32 mg/g) and *M. communis* (28.55 mg/g). Although it might not be as efficient as methanol because saponins are mostly polar, this solvent is an excellent alternative to saponin extraction because it can dissolve both polar and non-polar substances. *L. Stoechas* produced the highest saponin concentration (51.89 mg/g) when extracted with chloroform, indicating that saponins in this species may have a more hydrophobic profile.

Among the three plants, hexane, a nonpolar solvent, consistently produced the lowest saponin yields; *M. communis* produced just 9.23 mg/g. This is expected because hexane is not the best solvent for extracting polar substances, such as saponins. Hexane is less effective at extracting saponins because of its polar sugar chains, which make it more soluble in polar solvents.

These results are in line with the available research, which frequently reports that the best solvents for extracting saponins are polar solvents, such as methanol and ethanol. For example, methanol has been shown to be more effective than nonpolar solvents, such as petroleum ether, in the extraction of saponins from *Quillaja saponaria*.[51] Polar solvents are always better than nonpolar solvents for extracting saponins and other secondary metabolites, according to research on *Myrtus communis* and other Mediterranean plants.[53,54]

Tannins content

Table 3 presents the tannin extraction results for *Arbutus unedo, Myrtus communis*, and *Lavandula stoechas* using three different solvents. Significant variations in tannin content were observed among the species and solvents, with methanol being the most efficient solvent.

Myrtus communis exhibited the highest tannin concentration of 89.36 mg TAE/g dry weight when extracted with methanol, significantly higher than that of other solvents and species ($p < 0.05$). This finding is consistent with previous studies, which have highlighted the superior ability of methanol to extract polyphenolic compounds, such as tannins, due to its polarity, facilitating the dissolution of such compounds. This significant difference suggests that methanol is the preferred solvent for extracting tannins from *M. communis*.[55]

In contrast, *Lavandula stoechas* showed the lowest tannin concentration, particularly when extracted with hexane. The hexane extract yielded only 6.28 mg TAE/g dry weight, significantly lower than that of the other solvent extracts ($P < 0.05$). This result is expected because hexane, a non-polar solvent, is less effective in extracting polar compounds such as tannins. Moreover, *Arbutus unedo* exhibited an intermediate tannin concentration (49.52 mg TAE/g dry weight) in chloroform extracts, which was significantly higher than the hexane extract but lower than the methanol extract ($P < 0.05$).

Table 3: Tannins content of the three plants extracted with three different solvents

	Tanins content (mg TAE / g DW)		
Plants samples	**Hexane**	**MeOH**	**Chloroform**
A.unedo	16.67 ± 1.31^{c}	77.98 ± 2.45^{a}	49.52 ± 0.90^{b}
M.communis	12.42 ± 1.91^{c}	89.36 ± 0.98^{a}	43.71 ± 1.35^{b}
L. stoechas	6.28 ± 1.23^{c}	23.68 ± 0.82^{a}	9.46 ± 2.28^{b}

TAE: Tannic acid equivalent. The results are presented as mean ± standard deviation. a–c Letters in the same row indicate significant differences ($p < 0.05$).

Condensed tannin content (proanthocyanidins)

Figure 3 presents the condensed tannin content, also known as proanthocyanidins, in the three plants.

The measurement of condensed tannins (proanthocyanidins) in the studied plants yielded significant results. *Lavandula stoechas* had the lowest concentration at 1.88±0.07 mg CE/g, *Myrtus communis* had the highest at 7.21±0.42 mg CE/g, and *Arbutus unedo* had the highest at 3.67±0.19 mg CE/g. These results support those of earlier studies on the tannin content of these species.

Condensed tannins are known to play important roles in plant defense systems, offering defense against pathogens and herbivory attacks and enhancing the general antioxidant qualities of plants. For example, the complex phytochemical profile of *M. communis* is well established. Its high flavonoid and tannin contents have been linked to several health benefits, such as anti-inflammatory and anti-cancer effects. This study further highlights *M. communis* as a source of advantageous phytochemicals.[30]

The lower tannin concentration in *L. stoechas* is consistent with the literature, showing that although Lavandula species are frequently used for their aromatic properties, their tannin levels are generally lower than those of other Mediterranean plants. In contrast, the tannin content in *A. unedo* is in line with the findings of Tsakni et al.[56], who reported similar values and highlighted the relevance of the species in traditional medicine and functional foods.

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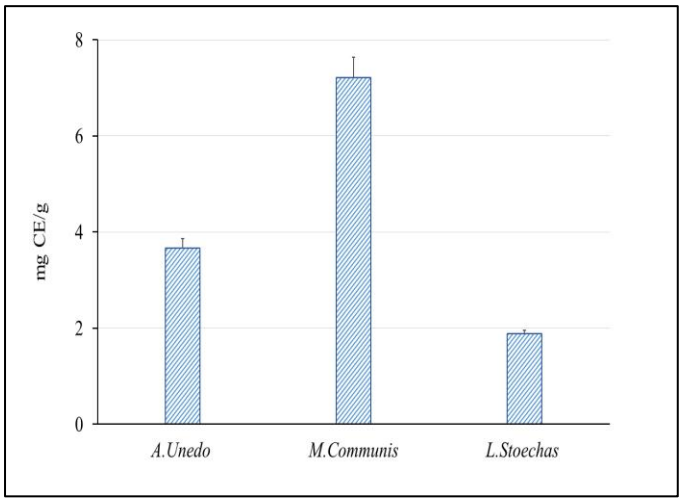

Figure 3: The condensed tannin content in the three plants. CE: Catechin equivalents.

Flavonols and carotenoids contents

The results presented in table 4 indicate that *Myrtus communis* has a significantly higher flavonol content (6.21 ± 1.18 mg QE/g) compared to *Arbutus unedo* (1.67 ± 0.98 mg QE/g) and *Lavandula stoechas* (0.45 ± 1.11 mg QE/g). It is generally known that flavonols, especially quercetin, have antioxidant qualities that can help fight oxidative stress and lower inflammation. According to earlier research, the high flavonoid concentration in *M. communis* has been linked to its traditional use in folk medicine to treat various illnesses, including inflammation and respiratory conditions.

In contrast, *L. stoechas* may be used primarily as an aromatic plant rather than as a source of health-promoting components, as evidenced by its lower amounts of flavonols. Nevertheless, *Arbutus unedo*'s flavonoid content still points to possible health advantages because even low levels of flavonoids have been associated with better cardiovascular health and a lower risk of cancer. As for carotenoids, *Myrtus communis* once more exhibits the highest concentration (2.06 ± 0.71 mg *β*CE/g), followed by *Arbutus unedo* (0.76 ± 0.10 mg *β*CE/g) and *Lavandula stoechas* (0.59 ± 0.89 mg *β*CE/g).

Carotenoids are crucial for human health because they act as precursors of vitamin A and have significant antioxidant properties, which help protect against chronic diseases such as cancer and heart disease.[7,57,58]

Table 4: Flavonols and carotenoids content in *A. undo*, *M. communis*, and *L. stoechas*

	A. unedo	*M. communis*	*L. stoechas*
Flavonols content (mg QE/g)	1.67 ± 0.98^{b}	6.21 ± 1.18^{a}	0.45 ± 1.11^{c}
Carotenoids content (mg *β*CE/g)	0.76 ± 0.10^{b}	2.06 ± 0.71^{a}	0.59 ± 0.89^{c}

QE: Quercetin equivalent, *β*CE: Beta-carotene equivalent, TAE: Tannic acid equivalent.
The results are presented as mean ± standard deviation. a–c Letters in the same row indicate significant differences ($p < 0.05$).

Mineralogical analysis

To determine the three plants' mineralogical profiles, ICP-AES was used for elemental quantification, and XRF was used for oxide content detection (tables 5 and 6).

According to the ICP results (table 5), *Arbutus unedo* had the highest concentrations of calcium 3723.94 mg/kg and potassium 5869.68 mg/kg. This suggests that it can absorb and store nutrients better than *Myrtus communis*, which has 2589.76 mg/kg of calcium and 4638.10 mg/kg of potassium. *Arbutus unedo* has a significantly higher magnesium (Mg) content (278.47 mg/kg) than *Myrtus communis* (156.89 mg/kg) and Lavandula stoechas (99.51 mg/kg), suggesting that these minerals may be essential for supporting physiological processes like photosynthesis and enzymatic activities.

Table 5: Elemental content of *A. unedo, M. communis,* and *L. stoechas* by ICP-AES

Elements	Mn	Fe	Mg	Ca	Cu	Al	K	Cr	Zn
A.unedo (mg/kg)	20.68	89.24	278.47	3723.94	-	121.54	5869.68	-	29.48
M. communis (mg/kg)	19.15	55.61	156.89	2589.76	-	110.5	4638.10	-	17.57
L. stoechas (mg/kg)	5.77	25.11	99.51	1162.7	-	54.91	2569.50	-	6.89

Compared to *Myrtus communis* (55.61 mg/kg) and *Lavandula stoechas* (25.11 mg/kg), *Arbutus unedo* has much higher iron (Fe) levels (89.24 mg/kg). This suggests that *Arbutus unedo* may have improved metabolic capabilities, especially chlorophyll synthesis and plant vigor. This may be related to the possible health advantages of consuming this plant, which has a higher elemental content and may contain more bioactive substances.

The elemental analysis results were further supported by XRF analysis (table 6). The highest calcium oxide (CaO) concentrations were found in *Myrtus communis* (1.851%), *Arbutus unedo* (1.510%), and *Lavandula stoechas* (0.750%). *Myrtus communis* had the highest concentration of phosphates (P_2O_3) at 0.238%, which may increase its potency as a nutrient source. Their presence was interesting.

The sulfates (SO_3) content is relatively low across all three species, but *Myrtus communis* again leads with 0.129%. Sulfates are essential for protein synthesis and contribute to plant growth, which further underscores this species' potential nutritional benefits. The relatively low mineral concentrations in *Lavandula stoechas* suggest that while it may not be as rich in these minerals, it might still provide unique health benefits owing to its phytochemical profile.

To determine the mineralogical profile of the three plants, ICP-AES was used for elemental quantification and XRF was used for oxide content detection (tables 5 and 6).

According to the ICP results (table 5), *Arbutus unedo* had the highest concentrations of calcium () 3723.94 mg/kg and potassium () 5869.68 mg/kg. This suggests that it has a better ability to absorb and store nutrients than *Myrtus communis*, which has 2589.76 mg/kg of calcium and 4638.10 mg/kg of potassium. *Arbutus unedo* has a significantly higher magnesium (Mg) content (278.47 mg/kg) than *Myrtus communis* (156.89 mg/kg) and *Lavandula stoechas* (99.51 mg/kg), suggesting that these minerals may be important for supporting physiological processes like photosynthesis and enzymatic activities.

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Lavandula stoechas (0.750%). *Myrtus communis* had the highest concentration of phosphates (P_2O_3) at 0.238%, which may increase its potency as a nutrient source. Their presence was particularly interesting. When considering the plant bioactive compound content, these mineral and oxide profiles suggest that *Arbutus unedo* may be particularly promising for applications requiring high nutrient levels and antioxidant potential. *Myrtus communis* appears to be a valuable candidate for nutrient-enriched food products, whereas *Lavandula stoechas* might be more suited to flavoring and functional health products, where its phytochemicals can offer complementary benefits. Thus, plant choice depends largely on its intended use, which balances both nutritional and bioactive properties.

Table 6: Oxide content of the three plants using WD-XRF

Elements	MnO	Fe_2O_3	MgO	CaO	P_2O_5	Na_2O	K_2O	SO_3	ZnO
A.unedo (%)	0.014	0.123	0.350	1.510	0.108	0.031	2.821	0.119	0.008
M. communis (%)	0.009	0.286	0.048	1.851	0.238	0.029	3.110	0.129	0.015
L. stoechas (%)	0.002	0.041	0.151	0.750	0.051	0.005	2.459	0.031	0.002

Conclusion

A comprehensive evaluation of *Arbutus unedo*, *Myrtus communis*, and *Lavandula stoechas* demonstrated their potential as natural alternatives to synthetic additives in various industrial and health applications. Each plant displayed distinct physicochemical and bioactive qualities: *Myrtus communis* showed high levels of protein and flavonoids, which supports its use as a dietary supplement; *Arbutus unedo* showed remarkable mineral and fiber content, which made it ideal for functional foods with increased health benefits; and *Lavandula stoechas*, with its high lipid content, showed promise as a flavoring and cosmetic ingredient. These findings also emphasize the pivotal role of solvent selection in optimizing bioactive compound extraction, with methanol yielding the highest levels of tannins and saponins. This insight provides valuable guidance for advancing food technology and nutraceutical innovations.
In the future, more investigation is necessary to determine whether these applications can be scaled up in industrial processes and to evaluate their long-term durability and effectiveness in various food matrices.

Conflicts of Interest

The authors declare no conflict of interest.

Authors' Declaration

The authors hereby declare that the work presented in this article is original and that any liability for claims related to the content of this article will be borne by them.

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