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Chemical and Elemental Composition of *Ammi visnaga* L. and *Calendula officinalis* L. from Meknes, Morocco

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ABSTRACT

The powders of *Ammi visnaga* L. and *Calendula officinalis* L. plants collected from Meknes region were subjected to three types of analysis, including Fourier transforms infrared spectroscopy (FTIR) analysis, CHNS/O analysis, and ICP-AES analysis with the aim of comparing and giving an insight into the nutritional value, medicinal properties, and potential applications in different fields. The results of the FTIR analysis showed absorbance bands in the same wavelengths, but with different peaks, indicating the presence of long-chain linear aliphatic compounds, lipids, amides, aromatic compounds, and other functional groups in both plants. The CHNS/O analysis revealed high levels of carbon and oxygen, followed by hydrogen, nitrogen, and sulfur for both plants, with no significant differences in the values. The ICP analysis detected 16 minerals, including calcium, potassium, phosphorus, and magnesium in *Ammi visnaga*, and low levels of sodium in comparison to *Calendula officinalis*. *Calendula officinalis* accumulated more aluminum and lead than *Ammi visnaga*, indicating higher tolerance to contaminations. Zinc, iron, manganese, and copper were important micronutrients present in both plants. The findings of this study suggest that both plants have significant amounts of phytochemical compounds and minerals, which could be beneficial for their potential use in the pharmaceutical, nutraceutical, and cosmetic industries.

Keywords: *Ammi visnaga* L., *Calendula officinalis* L., CHNS/O, FTIR, ICP-AES.

INTRODUCTION

Plants in general are multicellular organisms that belong to the *Plantae* kingdom. They are essential to life on Earth because they produce oxygen and are the basis of many food chains (Evans, 2023). They have a chemical composition that refers to the various organic and inorganic compounds that are present in different plant parts such as leaves, stems, roots, flowers, and fruits. These compounds play an important role in plant physiology, including their growth, development, and reproduction. Additionally, they also have a significant impact on the plant's interactions with other organisms and the environment (Zhan et al., 2022). Plants produce a diverse array of chemical compounds, such as alkaloids, flavonoids, terpenes, and phenolic compounds. These compounds have various functions, including defense against herbivores and pathogens, attraction of pollinators and seed dispersers, and regulation of growth and development. Therefore, studying the chemical composition of plants is essential for understanding their defense mechanisms against biotic stresses such as herbivory, predation, and disease, as well as abiotic stresses such as drought, salinity, and extreme temperatures. Chemical compounds produced by plants can act as natural pesticides or fungicides, and some compounds even have antibacterial and antiviral properties (Khare et al., 2020). Moreover, the chemical composition of plants also has important implications for human health and nutrition and can provide insight into their mineral content. This is because minerals are a type of chemical element that plays a vital role in maintaining optimal health and well-being for both humans and plants. They are essential for the growth, metabolism, and antimicrobial defense of plants. Moreover, the antimicrobial properties of minerals in plants have significant implications for human health. Minerals are involved in the formation of bones and teeth, maintenance of healthy muscle and nerve function, and regulation of various metabolic processes (Rahmatollah & Mahbobeh, 2010). Additionally, plants are a major source of nutrients for humans and animals, and understanding the chemical composition and the mineral content of different plant species can help identify those that are most beneficial for human health and nutrition (El Sharabasy et al., 2019).

Ammi visnaga L. (AV) and *Calendula officinalis* L. (CO) are two plant species with various uses and properties and which have been widely studied for their potential use in modern medicine. *Ammi visnaga*, also known as Ammi daucoides and Daucus visnaga, is a hardy annual or biennial herb belonging to the Umbelliferae family (*Apiaceae*) (Bhagavathula et al., 2015; Keddad et al., 2016). While it is native to North Africa, it has been widely cultivated and distributed across the globe using advanced farming techniques (Hashim et al., 2014). Reaching a height of up to 130 cm, the plant is referred to as "khella" in the Arab world and "toothpeak weed" in English-speaking countries (Kamal et al., 2022). It is commonly used to treat respiratory ailments such as bronchitis and asthma, colic and gastric problems, facilitate the passage of kidney stones, and cardiac disorders like arrhythmia and hypertension. Additionally, it has shown promising results in treating vitiligo, psoriasis, angina inflammation, and menstrual pain. Ammi visnaga has also been found to be effective in managing hypercholesterolemia and hypoglycemia (Hashim et al., 2014; Kamal et al., 2022; Keddad et al., 2016). Numerous conventional drugs have been already developed from *Ammi visnaga* (Bhagavathula et al., 2015).

Calendula officinalis L., commonly known as marigold or pot marigold, is a species of herbaceous plant in the daisy family (*Asteraceae*). It is native to the Mediterranean region, but is widely cultivated and naturalized in other parts of the world, including North America and Australia. The plant has bright orange or yellow flowers that bloom from early summer to fall. It grows to a height of 30–60 cm and has hairy stems and leaves (Nagaraj et al., 2022; Sahingil, 2019). It has been used for centuries for its medicinal properties, and it is still commonly used in traditional medicine today. It is rich in antioxidants and has anti-inflammatory, antibacterial, and antifungal properties (Patil et al., 2022). Calendula extracts are used in various products, including creams, lotions, and ointments, to treat skin irritations, wounds, and other skin conditions (Hasan & Alnaqqash, 2020). In addition to its medicinal uses, calendula is also used as a culinary herb and as a dye for fabrics and cosmetics. Its flowers can be used fresh or dried to make teas, tinctures, and infusions (Nagaraj et al., 2022).

In this study, the powder of two plants belonging to different families (*Ammi visnaga* and *Calendula officinalis*) was analyzed using three different analytical techniques: Fourier transforms infrared spectroscopy (FTIR) analysis, CHNS/O elemental analysis, and Inductively Coupled Plasma-Atomic Emission Spectrometry (ICP-AES). By investigating their chemical and elemental composition, the aim of this study is to compare, and give an insight into the nutritional value, medicinal properties, and potential applications in agriculture, food supplements, pharmaceuticals, cosmetics, and other industries.

MATERIEL AND METHODS

Biological materiel preparation

The aerial components were manually collected in an area close to Meknes, Morocco during June's midday weather, which had temperatures peaking at 25 °C. The gathered material was then promptly moved to a well-ventilated spot with moderate lighting and no direct sunlight. This location was situated at the Plant Protection and Environment Laboratory of the National School of Agriculture in Meknes.

The electric grinder equipped with a stainless steel tank facilitated the production of a uniform powder through the grinding process. To preserve the quality of the powder, it was stored in an airtight glass jar and kept in a dry location, shielded from light and moisture.

FTIR analysis

The Fourier transform infrared spectrophotometer (FTIR) is one of the strongest methods to detect the types of functional groups in compounds. This is an assay that can be used to describe samples in the form of liquids, solutions, pastes, powders, films, fibres and gases (Nandiyanto et al., 2019). This study focuses mainly on dry samples (powders) which are the bases of all extracts. A very small amount of each powdered sample was analyzed in the 450 cm^{-1} and 4000 cm^{-1} infrared radiation region (mid IR region) by the "Perkin-Elmer LS 55" spectrophotometer which is coupled to "PerkinElmer SpectrumTM 10" software that allows presenting the results as spectra. Each analysis was repeated three times for spectrum confirmation.

CHNS/O elemental analysis

A Flash Smart CHNS/O Thermo Fisher scientific organic elemental analyzer was used to investigate the organic elemental analysis. The CHNS analysis was conducted by combusting the sample with 240 ml/min oxygen flow at a furnace temperature of 950 °C. The produced gases (CO_2, H_2O, SO_2, and N_2) were separated by gas chromatography, using a constant flow of carrier gas (helium) of 100 ml/min and an oven temperature of 65 °C. For oxygen determination, a pyrolysis furnace temperature of 1050 °C and the same helium flow (100 ml/min) were used.

Digestion protocol and ICP-AES conditions for sample analysis

To prepare the sample for ICP/AES analysis, a conventional digestion method was utilized. Roughly 0.1 gram of the sample was combined with a mixture of HNO_3 and HCl in a 4:1 ratio within a digestion vessel. The container was left uncovered overnight to prevent the occurrence of foam and gas that might result from the high organic content of the sample, which could lead to sample loss due to excessive pressure within the container during digestion (Kashulina et al., 2003; Lv et al., 2019).The digestion container was subjected to heating in a sand bath at 120 °C for a period of 6 hours. Following filtration, the acid mixture was incorporated into the resulting extract to attain a volume of 10 ml, and subsequently, the solution was diluted with distilled water (Kettunen, 2022; Rahmatollah & Mahbobeh, 2010). The resulting was transported for the ICP-AES analysis performed with the equipment named HORIBA Jobin Yvon-ACTIVA-S with specific working conditions. The gas used for the analysis is Argon, and the detection limit ranges from 0.01 to 1000 ppm. The equipment requires 1 kW of power to function properly. The gas flow rate of the plasmagen used in the analysis is 12 L/min, while the auxiliary gas flow rate is set at zero.

RESULT AND DISCUSSION

FTIR analysis

We notice in the Figures 1 and 2 that the plant powders studied showed characteristic absorbance bands in about the same wavelength regions. The mid-IR region is divided into 4 areas:

The single bond area (2500–4000 cm^{-1}): Each sample shows significant peaks, the first with the broadest absorption band between 3658 cm^{-1} and 3017 cm^{-1} for CO and between 3021 cm^{-1} and 3650 cm^{-1} for AV indicate the existence of hydroxyl (-OH), or ammonium or amino (amino acids). The narrow band at 2922 cm^{-1} for AV and 2921 cm^{-1} for CO reveal long chain linear

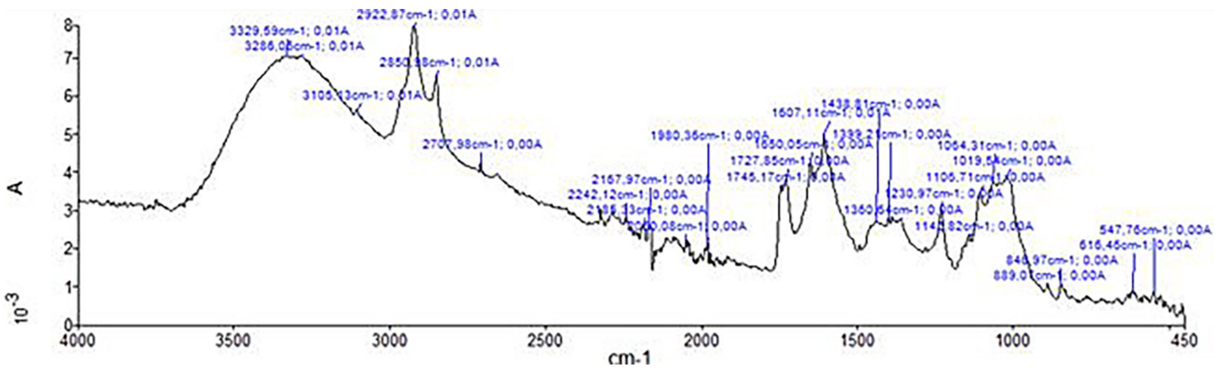

Figure 1. FTIR spectrum of *Ammi visnaga* L.

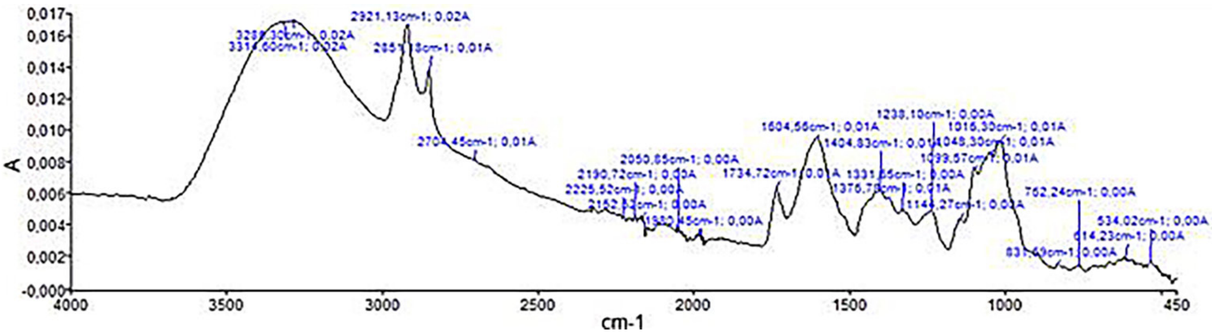

Figure 2. FTIR spectrum of *Calendula officinalis* L.

aliphatic compounds and the peaks at 2852 cm^{-1} (CO) and 2850 cm^{-1} (AV) reveal C-H stretch those last peaks are characteristics for Lipid contents (Movasaghi et al., 2008).

The broad bands of low intensity in the range of 2500–2700 cm^{-1}, observed in both spectra, are attributed to the intramolecular hydrogen bonding between the phenolic groups -OH and azomethine -CH=N- and confirm oxygen and nitrogen atoms coupling to metal ions (Beyazit et al., 2017).

The triple bond area (2000–2500 cm^{-1}): The weak absorption intensity with several peaks show the presence of Acetylenes and alkynes substituent, the extremely weak absorption reveal a medial acetylenic function and the moderate absorption intensities are a sign of a terminal alkyne group (C≡C). Cyanides (nitriles) compounds present absorptions that range from weak to moderate or strong, depending on the nature of the other substituents of the molecule. The conjugation, including substitution on an aromatic ring, changes the intensity of this absorption. The weak intensities above 2400 cm^{-1} are the result of hydride vibrations such as silanes (Si-H), thiols and sulfides (S-H), etc.

The double bond area (1500–2000 cm^{-1}): The peaks 1735 cm^{-1} (CO) and 1728 cm^{-1} (AV) describe a simple carbonyl compounds such as ketones, aldehydes, esters, or carboxyl. The peaks at 1605 cm^{-1} (CO) and 1606 cm^{-1} (AV) reply to amides or carboxylates functional group and inform about the presence of aromatic compounds (aromatic ring). 1650 cm^{-1} (AV) is precisely for double bond carbon or olefinic compounds (C=C). The band at 1981 cm^{-1} with week intensity plus others reveal simple aromatic compounds. Those several bands support the aromatic ring absorption band called C-H bending vibration (Coates, 2006).

The fingerprint area (600–1500 cm^{-1}): gives various identifications cited in Table 1. The observed frequencies are supportive of the presence of functional groups such as -OH, C-O, -C≡C, and C─H, commonly found in compounds such as phenols, alcohols, fatty acids, glycosides, acylglycerols, collagen, vitamins, saturated fatty acids, reducing sugars, carboxylic acids, amides, and alkaloids. These molecular constituents are present in plant material and contribute to the diversity of therapeutic properties associated with their pharmacological activities (Khan et al., 2022).

To the best of our knowledge, there are no studies concerning the FTIR analysis of *Ammi visnaga* L. powder. However, studies have focused on two molecules of this plant, namely khellin and visnagin, due to their therapeutic and pharmaceutical importance, etc (Abousamra et al., 2016; Ruiz et al., 2012). Ruiz et al. (2012) studied the infrared spectrum and identified the bonds related to the structure of the khellinone and visnaginone molecule which are the product of the hydrolysis of khellin and visnagin, these bonds fit tightly with those present in this study demonstrating the existence of these compounds in our sample. On the other hand, several functional chemical groups were detected in *Calendula officinalis* L. by Al-mussawi & Al-hussani, (2019) from Iraq using FTIR analysis: alkyl halides, aliphatic amine, alkanes, carboxylic acids, alcohols and phenols (O-H Alkanes , H- bonded) which possess antimicrobial and antioxidant properties. Safdar et al., (2010) found that *Calendula officinalis* contains principally OH, CH, C=O, C=C and COOH as functional groups. These two studies revealed results in agreement with the present one even though they performed FTIR analysis on methanolic extracts. Therefore we can summarize that carrying out this type of analysis (FTIR) on the powder is more efficient to obtain the most functional groups and bonds contained in the plant.

Table 1. Major FTIR peaks of *Calendula officinalis* L. and *Ammi visnaga* L.

AV peaks (cm^{-1})	CO peaks (cm^{-1})	Group frequancy wavenumber (cm^{-1}) from literature (Coates, 2006)	Assignments
548	534	680–610	Alkyne C-H bend
617	614	1300–700	Skeletal C-C vibrations (methyne (>CH-))
846	763	770–730	C-H monosubstitution (phenyl) (aromatic ring “aryl”)
889	832	770–735	C-H 1,2 disustitution (ortho) (aromatic ring “aryl”)
1018	1016	810–750+900–860	C-H 1,3 disbstitution (meta) (aromatic ring “aryl”)
1065	1048	860–800	C-H 1,4 disubstitutio (para)(aromatic ring “aryl”)
		900–670 (several)	Aromatic C-H out of plane bend (aromatic ring “aryl”)
		800–700	Aliphatic chloro compounds, C-Cl stretch
		700–600	Aliphatic bromo compounds, C-Br stretch
		600–500	Aliphatic iodo compounds C-I stretch
		720–590	Alcohol, OH out of plane bend
		890–800	Epoxy and oxirane rings (ether and oxy compounds)
		890–820	Peroxide, C-O-O stretch (ether and oxy compounds)
		705–570	Disulfides(C-S stretch) (thiols and thio-sustituted)
		895–885	Vinylidene C-H out of plane bend
		1055–1000	Cyclo hexane ring vibration
		1050–990	Aliphatic phosphate
		1100–1000	Phosphate ion
		1100–900	Silicate ion
		1090–1020	Primary amine, CN stretch(primary amino)
1107	1100	1150–1000	Aliphatic fluoro coumpounds C-F stretch
1143	1144	1225–950 (several)	Aromatic C-H in plane bend
		≈ 1050	Primary alcohol C-O stretch
		≈1100	Secondary alcohol C-O stretch
		1150–1050	Alkyl substituted ether, C-O stretch
		1140–1070	Cyclic ethers+large ring-C-O stretch
		1200–1100	Sulfonate
		1110–1080	Organic siloxane –Si-O-C
		1130–1080	Sulfate ion
1231	1237	1270–1230	Aromatic ethers, Aryl –O stretch
		1240–1190	Aromatic phosphate P-O-C stretch
1360	1330	1350–1250	Organic phosphate P-O stretch
		1350–1330	Methyl C-H bend
		1350–1260	Primary or secondary OH in plane bend
		1340–1250	Aromatic primary amine, CN stretch (aromatic amino)
		1350–1280	Aromatic secondary amine, CN stretch (aromatic amino)
		1360–1310	Aromatic tertiary amine, CN stretch (aromatic amino)
1399	1377	1410–1310	Phenol or tertiary alcohol OH bend
		1420–1300	Carboxylate
1438	1405	1420–1370	Organic sulfate
		1430–1390	Ammonium ion
1606	1605	1615–1580	C=C-C aromatic ring stretch
		1610–1550	carboxylate
1650		1650–1600 (lower band)	Quinine or conjugated ketone
		1650–1590	Primary amine N-H bend
		1650–1550	Secondary amine > N-H bend
		1680–1630	Amide
		1680–1620	Alkenyl C=C stretch
	1735	1735	Six membered ring lactone
1728		1760–1740	Alkyle carbonate
1745		1740–1725	Aldehyde
		1750–1725	Ester
1981	1981	2000–1660 (several)	Aromatic combinations bands
2050	2050	2140–2100	C≡C terminal alkyne (acetylenic)
2167	2162	2260–2190	C≡C medial alkyne(acetylenic)
2185	2190	2200–2000	Cyanide ion, thiocyanate ion and related ions
2240	2224	2240–2220	Aromatic cyanides
	2705	2880–2860	Methyl C-H asym./sym. Stretch (Methyl -CH_3)
2708	2852	2865–2845	Methylene C-H asym./sym. Stretch (Methylene >CH_2)
2850		2850–2815	Methoxy, methyl ether O-CH3, C-H stretch (special methyl –CH_3 frequencies)
2922	2921	2935–2915	Methylene C-H asym./sym. Stretch (Methylene >CH_2)
3105	3285	3570–3200 (broad)	Hydroxyl group H-bonded OH stretch
3285	3315	3320–3310	Alkyle C-H stretch
3328		3345–3325	Aliphatic primary amine N-H stretch (primary amino)
		3360–3310	Aliphatic secondary amine, >N-H stretch(secondary amino)
		3300–3030	Ammonium ion

CHNS/O Elemental analysis

Carbon (C), nitrogen (N), hydrogen (H), sulfur (S), and oxygen (O) are five of the six most abundant elements found in living organisms, including plants. Each of these elements plays a unique and critical role in plant growth and development (Pandy, 2018).

In this study, the values of carbon, hydrogen, nitrogen, sulfur, and oxygen, represented in Figure 3, are respectively 58%, 6.22%, 2.18%, 0%, and 36.53% for *Calendula*. For *Ammi visnaga*, the values are 58.07%, 6.01%, 1.73%, 0%, and 35.14%.

In plants, these elements are not independent of each other but rather are closely related and interact in a variety of ways.

Carbon is the most abundant macro element for both samples. It makes with the hydrogen a fundamental building block of all organic compounds found in plants, including, hydrocarbons carbohydrates, lipids, proteins, and nucleic acids (Benabderrahmane et al., 2023; Mandal et al., 2017). It is obtained from the carbon dioxide in the air through the process of photosynthesis. Carbon and hydrogen provide the basic structure for all plant tissues and helps to maintain their shape (Duan et al., 2023). A decrease in the hydrogen to carbon (H/C) ratio suggests greater aromaticity. Plants with higher aromaticity tend to be more resistant to decomposition, making them recalcitrant and valuable for sequestering carbon in soil (Sahu et al., 2020).

Nitrogen is an essential element required for the synthesis of proteins and nucleic acids. Plants obtain nitrogen from the soil in the form of nitrate or ammonium ions. Nitrogen is a component of chlorophyll, which is required for the assimilation of carbon during photosynthesis, and it plays a critical role in the growth and development of leaves, stems, and roots (Duan et al., 2023). As nitrogen is an unreactive and non-flammable gas, a lower nitrogen content is indicative of higher quality (Nair et al., 2017). Organic materials with a higher carbon to nitrogen ratio tend to be richer in carbon-based compounds such as carbohydrates and proteins, which can enhance the structural integrity of the cell wall (Mandal et al., 2017).

Oxygen, the second most abundant element after carbon, is a critical element in the process of respiration, which releases energy from organic compounds. It is obtained through photosynthesis and is also present in water molecules. Oxygen is essential for maintaining plant metabolism and helps to drive the production of ATP, the energy currency of the cell. It is synthesized as a product of basic metabolic processes occurring in various subcellular locations (Mhamdi & Breusegem, 2018). Oxygen with hydrocarbons can undergo chemical reactions to form compounds with functional groups (Benabderrahmane et al., 2023).

Other studies have analyzed plant samples for macroelement content. Mandal et al. (2017) reported that *Hydrocotyle javanica* Thunb contains 38.18% C, 5.67% H, and 2.23% of N. Nair et al. (2017) presented values of C, H, N, and O for some medicinal plants that range between 37–42%, 4–9.4%, 3.3–7.4%, and 38–51% respectively. Maiti et al. (2015) revealed C levels between 51.66% and 47.77% in some trees. Abdurabu, (2022) gave values of C, H, N and

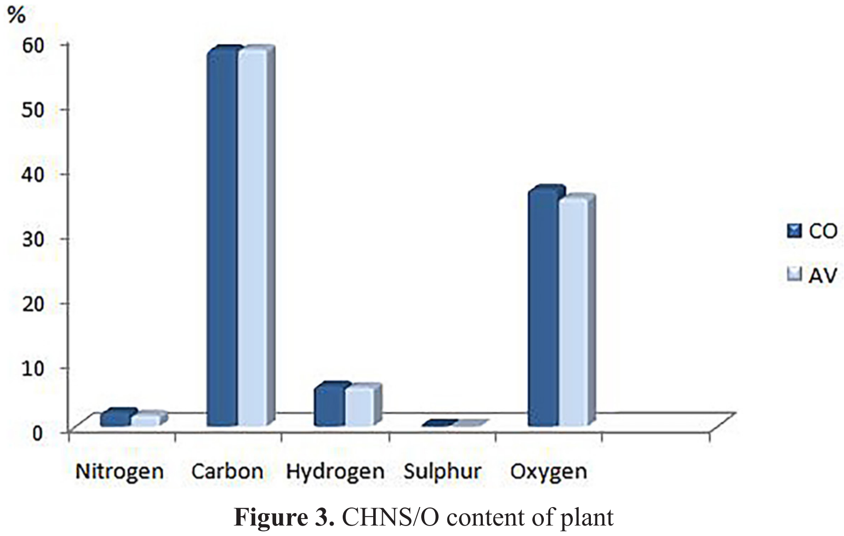

Figure 3. CHNS/O content of plant

O for floral waste of *Calendula* which are 50%, 15.30%, 31.25%, and 3.60% respectively. Anjum et al. (2019) made a comparison between plants belonging to protected and unprotected sites and cited values between 46.06–34.93% for C, between 6.19–4.78% for H, and between 4.93–1.32% for N.

Sulfur is a component of several essential plant compounds, including amino acids, proteins, and some vitamins. It is obtained from the soil in the form of sulfate ions (Zenda et al., 2021). Compared to other studies, it is uncommon for a plant to have a 0% concentration of sulfur, as sulfur is an essential element for plant growth and development (Mandal et al., 2017; Nair et al., 2017), but in the study of Anjum et al. (2019) a very low value (0.01%) was reported in unprotected sites. However, it is possible that the analysis method used to determine the sulfur concentration was not sensitive enough to detect low levels of sulfur in the plant material. Alternatively, the plant species in question may have a naturally low sulfur requirement or may have been grown in a sulfur-deficient environment, resulting in a low sulfur concentration in the plant tissues. Further investigation is required to determine the cause of the low sulfur concentration and its potential impact on plant growth and development.

ICP-AES

This analysis was conducted to investigate the presence of 34 different elements. Table 2 displays the 16 most significant elements that were identified. The plant samples contained Ca, K, P, Mg, and Na as the most prevalent nutrients. *Ammi visnaga* had higher levels of Ca (31492.4 mg/kg), K (21247.6 mg/kg), P (11184.4 mg/kg), and Mg (9330.8 mg/kg) but lower levels of Na (7010.4 mg/kg) compared to *Calendula officinalis* (Ca: 24062 mg/kg, K:18952.8 mg/kg, P: 5670.4 mg/kg, Mg: 5178 mg/kg, and Na: 11196.8 mg/kg). Calcium and potassium are essential nutrients for plant growth and development. Calcium helps to strengthen cell walls, regulate water movement, and activate enzymes, leading to improved plant growth, fruit quality, and disease and pest resistance (Edel et al., 2017). Potassium helps to regulate water balance, activate enzymes, and enhance photosynthesis, which also optimizes growth and resistance to stress, disease and pests. Potassium also enhances the plant's ability to take up other essential nutrients, such as nitrogen and phosphorus. It's important to maintain the appropriate balance of these nutrients to ensure optimal plant health and productivity (Wang et al., 2013). Phosphorus, magnesium, and sodium are important nutrients for plant growth and development. Phosphorus plays a crucial role in energy transfer, membrane function, and nucleic acid synthesis, which are essential for plant growth and productivity. However, phosphorus is often limited in soil, and sustainable management practices are needed to ensure adequate phosphorus availability for crops (Billah et al., 2019).

Magnesium is also critical for plant growth, as it is involved in photosynthesis, protein synthesis, and stress response. Adequate magnesium uptake is essential for optimizing crop yields, and magnesium supplementation can help improve plant tolerance to abiotic stresses such as drought and salinity (Dassou et al., 2022).

Sodium, although not considered an essential nutrient, can have beneficial effects on plant growth and stress tolerance when taken up in small amounts. However, excessive sodium uptake can be toxic to plants and lead to reduced growth and productivity. Therefore, sodium management is important for optimizing crop growth and productivity in saline environments (Hanana et al., 2011). A high level of Na in CO, compared to AV, may indicate that the first plant is more adapted to grow in saline soils or environments. Some plants have evolved mechanisms to cope with high levels of salt, including the ability to exclude or compartmentalize sodium ions within their tissues. This adaptation allows them to thrive in saline soils where other plants cannot grow (Hussain, 2011).

Table 2. Mineral content of plants

Minerals (mg/kg)	Al	B	Ba	Ca	Cu	Fe	K	Mg
AV	876.28	ND	19.36	31492.4	15.92	134.88	21247.6	9330.8
CO	1162.32	38.04	15.36	24062	14.76	313.56	18952.8	5178
Minerals (mg/kg)	Mn	Na	P	Pb	Si	Sn	Sr	Zn
AV	42.96	7010.4	11184.4	55.12	171.2	10.08	133.56	173.52
CO	31.88	11196.8	5670.4	56.4	129.92	10.08	48.08	221.92

According to the order of prevalence, aluminum (Al) is not a necessary element for plant growth, but its presence in the soil can have an impact on productivity and plant growth, especially in acidic soils. Nevertheless, certain plant species have developed adaptive strategies to withstand elevated levels of aluminium. According to the findings of this study, *Calendula* demonstrates greater tolerance to aluminium than *Ammi visnaga* (Ma, 2000; Mossor-Pietraszewska, 2001).

Zinc (Zn), Iron (Fe), Manganese (Mn), and Copper (Cu) are crucial micronutrients required for optimal plant growth. Zinc is specifically essential for chlorophyll formation, protein synthesis, and enzyme function in carbohydrate metabolism and other metabolic processes (Alloway, 2008). Iron is required for both chlorophyll formation and enzyme function in respiration and nitrogen fixation (Briat et al., 2010). Manganese is necessary for the functioning of enzymes involved in photosynthesis and respiration, as well as for chlorophyll formation (Alejandro et al., 2020). Copper, on the other hand, is necessary for lignin synthesis, respiration, and chlorophyll formation (Yruela, 2009). Additionally, Silicon (Si) is a beneficial element for many plant species as it improves growth, strength, and resistance to environmental stresses (Ma & Yamaji, 2006). Boron (B) is also a micronutrient that benefits many plants, serving a crucial role in the formation of cell walls and the regulation of plant hormones (Camacho-Crist et al., 2008).

Strontium (Sr), Lead (Pb), Barium (Ba), and Tin (Sn) are not essential elements for plant growth. These elements can be found in plants due to various reasons such as soil contamination, natural occurrence, or atmospheric deposition. Although Strontium is a naturally occurring element that may have some benefits for plant growth, excessive uptake can cause toxicity. Some studies suggest that the uptake of Sr by plants is affected by soil pH and other factors (Burger & Lichtscheidl, 2019). On the other hand, Lead is a toxic heavy metal, and its presence in plants can result in reduced growth, photosynthesis, and nutrient uptake. However, some plant species like sunflowers can accumulate high levels of Pb and are useful for phytoremediation (Alaboudi et al., 2018). Additionally, Barium toxicity can cause symptoms such as reduced growth and chlorosis. The uptake of Ba by plants can be influenced by factors like soil pH, cation exchange capacity, and others (Alloway, 2013; Suwa et al., 2008).

Tin (Sn) is a relatively rare element in the earth's crust and is not commonly found in plants. However, certain plant species, such as ferns and lichens, have been found to accumulate Sn in their tissues (Agus et al., 2017; Alloway, 2013; Müller et al., 2015; Ondeko et al., 2020).

Jurca et al. (2017) conducted an analysis of *Calendula officinalis* plant material, revealing significant quantities of aluminum, iron, barium, manganese, and strontium. Additionally, trace amounts of copper, lithium, nickel, and zinc were detected.

In a study conducted by Ahmed et al. (2003), it was found that *Calendula officinalis* and its constituent parts possess abundant quantities of essential minerals such as calcium, sodium, potassium, and magnesium. These minerals play a crucial role in maintaining the body's hemostatic balance, as evidenced by their presence in both aqueous and ethanolic extracts.

In the study by Angelova & Ichtjarova in 2018, various plant species were investigated for their potential in phytoremediation of contaminated soils using ICP analysis. Results showed that *Calendula officinalis* had high accumulation of Pb, Cd, and Zn, suggesting its potential as a phytoremediation tool. These findings emphasize the importance of using advanced techniques like ICP to understand the potential of different plant species in this field.

Ebrahim et al. conducted two studies on *Ammi visnaga*, which revealed the presence of various elements in the plant. The first study, conducted in 2012, reported the presence of magnesium (Mg), iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), and chromium (Cr), as well as trace amounts of selenium (Se), lead (Pb), and tin (Sn). The second study, conducted in 2014, identified the additional elements of calcium (Ca), potassium (K), strontium (Sr), and nickel (Ni) in the plant.

CONCLUSIONS

It is essential to note that the results of plant nutrient analysis can vary based on the analytical technique used, accuracy of the sampling method, and the quality of the plant material analyzed. The findings of this study indicate that both plants are rich in essential minerals like calcium, potassium, phosphorus, sodium, and magnesium. Precise determination of mineral concentrations can provide valuable insight into the nutritional value and potential health benefits of the plants. The FTIR spectra of both plants showed differences in their peaks, indicating the presence of functional groups and aromatic compounds for both. CHNS/O analysis revealed that the two plants' most abundant elements were carbon and oxygen, followed by hydrogen and nitrogen, respectively, which confirms the abundance of organic compounds and the high aromaticity of both plants. The results suggest that both plants possess valuable nutritional and medicinal properties that could have significant implications for human health and agriculture.

Furthermore, this study highlights the importance of using a multidisciplinary approach to analyze plant properties. Such investigations can aid in the discovery of new compounds with potential medicinal or nutritional properties and enhance crop selection and cultivation practices. Based on our findings, we recommend that researchers consider employing a combination of analytical techniques and collaborate from different disciplines, such as botany, chemistry, agriculture, and medicine, to ensure a comprehensive understanding of plant chemical composition and their potential applications. Further studies should be conducted on a wider variety of plant species to identify additional sources of essential nutrients and bioactive compounds, which could contribute to the development of novel products or therapies.

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