Chapter 14

Medicinal And Aromatic Plants Used As Functıonal Feed Additives

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Abstract

Medicinal and aromatic plants are increasingly recognised as valuable functional feed additives in modern animal production. Owing to their high content of phytochemical compounds, these plants have long been utilised in food and medicine, and are now considered promising alternatives to synthetic feed additives and antibiotic growth promoters. Plant metabolism is generally classified into primary and secondary pathways; while primary metabolites are indispensable for vital plant functions, secondary metabolites—referred to as phytochemicals—are responsible for a wide range of bioactivities. Major groups of phytochemicals include phenolic compounds, terpenes, nitrogenous compounds, and sulphurcontaining metabolites, all of which exhibit antimicrobial, antioxidant, anti-inflammatory, and immunomodulatory effects. When incorporated into animal diets, these bioactive compounds can enhance feed efficiency, support growth, strengthen the immune system, and improve overall health and product quality. Furthermore, their use contributes to more sustainable and environmentally friendly livestock systems by reducing reliance on synthetic additives. However, the beneficial effects of phytochemicals are dose-dependent, and excessive levels may cause

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adverse outcomes. A deeper understanding of their mechanisms of action and optimal inclusion levels is therefore essential to fully exploit the potential of medicinal and aromatic plants as functional feed additives.

1. Introduction

Throughout human history, plants have constituted the foundation of traditional medicine and nutrition, serving not only as sources of essential food but also as therapeutic agents. Their use has taken multiple forms, including the direct consumption of fresh leaves, extraction of essential oils, and preparation of plant-based remedies. Medicinal and aromatic plants are particularly valued for their multifunctional properties: they are widely employed as spices due to their aromatic compounds, utilised as natural pigments and colourants, and applied in the preservation of foodstuffs. Moreover, their bioactive constituents provide the basis for the development of pharmaceutical products. In recent decades, interest in these plants has expanded beyond the field of medicine into diverse industrial sectors in Europe, America, the Middle East, and Asia, where they are increasingly integrated for enhancing product quality, safety, and sustainability (Fakim, 2006; Gurgu et al., 2025; Güldiken et al., 2018; Bharadvaja, 2023).

Plants naturally synthesise a wide spectrum of organic compounds during their life cycle, which are generally classified into primary and secondary metabolites. Primary metabolites—including nucleic acids, amino acids, carbohydrates, lipids, and proteins—are indispensable for fundamental physiological processes such as photosynthesis, glycolysis, electron transport, and energy regulation. Secondary metabolites, on the other hand, are biosynthetically derived from primary metabolites. Although not essential for the survival of plants, they play crucial roles in ecological adaptation, including defence against pathogens, tolerance to abiotic stress, and allelopathic interactions with competing vegetation (Tiring et al., 2020; Fakim, 2006; Bakır, 2020).

Secondary metabolites are commonly categorised into phenolic compounds, terpenes, nitrogenous compounds (alkaloids), and sulphur-containing compounds. These phytochemicals have been widely studied for their biological activities, which include antimicrobial, antioxidant, anti-inflammatory, anti-diabetic, and anti-carcinogenic effects. Their applications extend across pharmaceutical and agricultural sectors, where they are utilised in the development of drugs, natural herbicides, and insecticides. In addition, they play a significant role in the food and cosmetic industries by contributing to flavour, aroma, and colour. However, the health-promoting effects of phytochemicals are strongly dose-dependent, as excessive intake may lead to toxic effects, including neurotoxicity, genotoxicity, and gastrointestinal disturbances (Özay and Pehlivan, 2024; Bakır, 2020; Ülger and Ayhan, 2020; Güldiken et al., 2018).

In the context of animal nutrition, medicinal and aromatic plants have gained growing attention as functional feed additives. Their incorporation into diets has been associated with enhanced nutrient utilisation, improved feed efficiency, stimulation of digestive enzyme secretion, modulation of gut microbiota, and reinforcement of immune responses. Additionally, their antioxidant and anti-inflammatory properties contribute to reducing oxidative stress and improving overall animal health and welfare. Importantly, the use of phytogenic feed additives provides an effective alternative to synthetic additives and antibiotic growth promoters, thus addressing consumer demand for sustainable, residue-free, and environmentally friendly livestock production. Nevertheless, their efficacy and safety are contingent upon plant species, bioactive composition, dosage, and administration method, highlighting the necessity of continued research to optimise their utilisation in modern production systems.

1.1. Medicinal And Aromatic Plants Used As Functional Feed Additives

Medicinal and aromatic plants contain valuable bioactive compounds that occur naturally and have numerous health effects in humans and animals. These substances are employed extensively in traditional medicine, the pharmaceutical industry, and the food and feed industries. In the contemporary context, distrust of artificial additives and a growing demand for natural products have led to an increased focus on aromatic plants. This phenomenon can be better elucidated by data from the World Health Organisation (WHO) which indicates that approximately 80% of the global population uses herbal medicines. In the field of animal husbandry, the utilisation of extracts and essential oils derived from aromatic plants, through various extraction methodologies, has emerged as a preferred feed additive. This preference is attributed to the numerous benefits these substances offer, including their role as a natural substitute for antibiotics, as well as their use as a replacement for artificial additives. This practice is in alignment with the European Union's decision, which has effectively prohibited the use of artificial additives as feed additives. The utilisation of feed additives has been demonstrated to enhance productivity in animals, thereby facilitating the production of high-quality and reliable animal products. This has led to an increased emphasis on the incorporation of aromatic plants within the domain of animal husbandry (Hasan et al., 2024; Christaki et al., 2012; Adawy et al., 2020).

1.1.1. Thyme (*Thymus vulgaris*)

Thymus vulgaris is a perennial herbaceous, semi-shrubby aromatic plant belonging to the *Lamiaceae* (mint) family. Despite its Mediterranean provenance, where it is found in approximately 400 different species, it is a plant that has been widely used across the world, particularly in traditional medicine and nutrition, due to its aromatic properties and chemical composition. The species under consideration is able to thrive in conditions characterised by elevated temperatures, aridity, and abundant sunlight. The plant possesses a stem that is both woody and hairy, with a variability in height ranging from approximately 10 to 40 centimetres. The leaves constitute the edible portion of the plant and are arranged circumferentially around the stem. The specimens are green and greyish in colour, ranging in length from 2 to 6.5 mm, and exhibit diverse morphologies, predominantly linear, oval, spear-shaped, with pointed tips and curved edges. An aromatic scent is also present. The flowers are predominantly purple or white in colour and possess a hairy, tubular, and bilabiate structure, located in the leaf axils (see Figure 1). Thyme has been observed to demonstrate a high level of resistance to various stress factors, including drought, salty soil, and frost. Propagation can be achieved through cuttings, seeds, or layering (Pirbalouti et al., 2013; Silva et al., 2021; Halat et al., 2022; Jain and Choudhary,2022).

Figure 1 Thymus vulgaris above-ground parts (Cianfaglione et al., 2022)

The above-ground parts of the thyme plant are particularly significant due to their high content of flavonoids and phenolic antioxidants, making them a valuable component in herbal teas, spices, and medicinal products. The plant's leaves are characterised by a high concentration of valuable minerals, including potassium, iron, calcium, magnesium, manganese and selenium, in addition to vitamins B, C, A, E and K. Analysis of its volatile components reveals their classification into multiple categories, namely monoterpenes, phenols, ketones, aldehydes, ethers and esters. The essential oil is comprised of a number of volatile components, including two phenolic compounds of particular value: thymol and carvacrol. These compounds belong to the monoterpene group, which is responsible for the antioxidant activity of the oil. These components possess a range of biological activities, including antimicrobial, antioxidant, anti-inflammatory, and antifungal properties. Consequently, they have a wide range of applications, including in the treatment of respiratory tract infections, parasitic diseases, sprains, coughs, expectorants, disinfectants, and food preservation. However, studies have indicated that the essential oil may also exert cytotoxic effects due to its increasing concentration, damage intestinal cells, irritate the skin, and cause rare allergic reactions (Dauqan and Abdullah, 2017; Nikolic et al., 2014; Kowalczyk et al., 2020).

1.1.2. Rosemary (*Rosmarinus officinalis* L.)

Rosmarinus officinalis L., a member of the *Laminaceae* family, is an aromatic plant species that contains a plethora of valuable bioactive compounds. Its utilisation in culinary practices and as a medicinal agent dates back to antiquity, with contemporary applications extending to various domains such as cosmetics, aromatherapy, pharmacy, and food preservation. Despite its Mediterranean provenance, it has been observed to thrive in a variety of environments, including rocky, sandy, and coastal regions across Europe, Africa, and Asia. The classification system under consideration comprises approximately 236 genera and 6,900 to 7,200 species. Rosemary (Rosmarinus officinalis) is a shrubby plant that can grow up to 1 metre in height. The plant's inflorescences exhibit a colour spectrum ranging from blue to white, with a stemless structure that is characterised by a curved, linear or lanceolate morphology. The leaves are distinguished by a medium vein configuration, as illustrated in Figure 2 The presence of an aromatic scent is attributable to the accumulation of essential oils in the trichomes present on the leaves and flowers of the plant (Malayoğlu, 2010; Moore et al., 2016; Santos et al., 2015; Hassani et al., 2016; Andrade et al., 2018).

Figure 2 The morphological appearance of the rosemary plant (Diass et al., 2021)

The bioactive components of rosemary are primarily classified as phenolic and volatile compounds. In particular, the following substances were identified: diterpenes, triterpenes, ursolic acid, betulinic acid, phenolic acids such as carnosic acid and rosmarinic acid, and volatile compounds, namely the essential oil's main components, including camphor, eucalyptus, 1,8-cineole, α-pinene and β-pinene, borneol, limonene, and camphene. Rosmarinus officinalis is employed in various forms, including fresh, dried, extracted, or essential oil, derived from various plant parts such as flowers, buds, leaves, stems, and bark. Of particular interest are rosmarinic acid and carnosic acid, which are phenolic compounds, and which have been used in traditional medicine due to their antioxidant, antiviral, anti-inflammatory, and antibacterial properties (Malayoğlu, 2010; Moore et al., 2016; Santos et al., 2015; Hassani et al., 2016; Andrade et al., 2018).

1.1.3. Laurel (*Laurus nobilis*)

Laurus nobilis L., the plant under discussion is a green, aromatic shrub belonging to the *Lauraceae* family, which comprises between 2,500 and 3,500 different species. The natural habitats of this species are countries such as Turkey, Spain, Greece, Portugal, Mexico and Morocco, which account for 97% of production. These countries are endemic to regions with temperate and warm climates, such as southern Europe and the Mediterranean. In the context of domestic gardens, the maximum recorded height of Laurel is 2 to 6 metres, whereas in its natural habitat, it has been observed to reach heights of up to 20 metres. The bark is characterised by a smooth texture, with a colour spectrum ranging from olive green to reddish tones. The leaves of the plant under scrutiny are characterised by their pointed and spear-like morphology, their absence of hair, and their notable glossiness. The colouration of these leaves ranges from olive green to brown, with the presence of veins on the underside and an alternate arrangement of veins and veins. The leaves are also characterised by a bitter taste and an aromatic scent. The flowers, which bloom in spring, are characterised by a yellowish-white hue and a pleasant scent. The fruits, which bear a resemblance to olives, are characterised by a black and purplish pigmentation. Volatile oils have been identified within these fruits (Figure 3). Propagation can be achieved through seeds, cuttings, or in vitro culture. The species exhibits a high degree of adaptability to a wide range of climatic conditions, but it has been observed to thrive in moist, well-drained soils with a pH range of 4.5 to 8.2 and in humid regions with a maritime climate (Awada et al., 2023; Caputo et al., 2017; Kaurinovic et al., 2010; Paparella et al., 2022; Sırıken et al., 2018; Khodja et al., 2023).

Figure 3 Bay leaf and fruit (Awada et al., 2023)

L. nobilis the extract is characterised by the presence of flavonoids, phenolic acids, and tannin-class compounds. The essential oil components obtained from the plant's flowers, seeds, and stem contain a high proportion of monoterpene group compounds, with 1,8-cineole being the predominant component present in the highest proportion, followed by sabinene, α-terpinyl acetate, linalool, limonene, α-pinene, β-pinene, camphene, cadinene, caryophyllene, and terpinol. In addition to these prominent components, the plant possesses various bioactive compounds with antimicrobial, antioxidant, anticarcinogenic, digestive and immune-supporting properties. In addition, it is the components eugenol, methyl eugenol and elemicin that are responsible for the quality and aroma of the spice. These valuable components have been utilised in various sectors throughout history, including the pharmaceutical industry due to its antibacterial, antifungal, and antioxidant properties, the food industry as a preservative and spice, and the cosmetics sector in creams and soaps due to its pleasant aroma (Caputo et al., 2017; Kaurinovic et al., 2010; Paparella et al., 2022; Siriken et al., 2018; Khodja et al., 2023).

1.1.4. Fennel (*Foeniculum vulgare*)

Foeniculum vulgare Mill. is an aromatic, herbaceous plant belonging to the *Apiaceae (Umbelliferaceae)* family, which grows as an annual, biennial or perennial. Despite its provenance in temperate and tropical regions, such as the southern Mediterranean, it has also been identified in various other parts of the world, including Asia, North America and Central Europe, particularly in areas with high levels of coastal erosion and in arid soils. Fennel (Foeniculum vulgare) can reach a height of 2-2.5 m and possesses upright, stiff branches and bright green, hairy, thread-like leaves that resemble those of dill (Anethum graveolens). The plant is distinguished by its yellow flowers, which bloom during the summer months. The fruits of the plant are characterised by their thick skins, elongated and rectangular-oval in shape, and reach maturity in October. The propagation of this species may be achieved through the utilisation of seeds, roots, or crowns (see Figure 4) (Rather et al., 2016; Badgujar et al., 2014; Diao et al., 2014; Noreen et al., 2023; Rafieian et al., 2023).

Figure 4 Foeniculum vulgare (a) stem (b) bulb (c) leaves and flowers (d) F. vulgare population (Noreen et al., 2023)

Fennel seeds have been found to contain varying amounts of carbohydrates, fats, proteins and fibre. In addition, the leaves are rich in minerals and vitamins, including calcium, potassium, sodium, phosphorus, iron, riboflavin, niacin and vitamin C. Furthermore, the fruits/seeds contain oil components such as oleic acid, linoleic acid, palmitic acid, and petrosilicic acid in varying proportions, as well as phenolic compounds including rosmarinic acid, chlorogenic acid, and flavonoids such as quercetin and apigenin. Furthermore, the presence of volatile compounds in Fennel has been identified as the source of its distinctive aniseed aroma, a quality that has garnered significant attention in the culinary realm, where it is frequently employed as a flavouring agent in various food products. These include trans-anethol, the main component known for its medicinal effects, as well as etragol, limonene, fenchone, and α-phellandrene. The primary medicinal effects of these compounds encompass antibacterial, antifungal, antiviral, anti-inflammatory, antimutagenic, and memory-enhancing properties (Rather et al., 2016; Badgujar et al., 2014; Diao et al., 2014; Noreen et al., 2023; Rafieian.et al., 2023).

1.1.5. Ginger (*Zingiber officinale Roscoe*)

Zingiber officinale Roscoe is a species belonging to the genus Zingiber of the *Zingiberaceae* family, which comprises 1,300 different species worldwide. It is a herbaceous perennial plant with aromatic rhizomes. Despite its provenance in India and the Pacific Islands, it is now cultivated across the tropical and subtropical regions of the world. The leading producers are India, China, and Nigeria. Ginger (Zingiber officinale) is a perennial plant that grows to a height of approximately 1 m. It has fibrous roots, green, usually lanceolate, hairless leaves, and yellow-green flowers (see Figure 5). Its rhizomes, which possess medicinal properties, are yellowish-brown in colour and have a thick, aromatic scent. The optimal climatic conditions for its growth include warm and humid weather conditions and loamy soils, with altitudes of up to 1,500 metres above sea level being particularly conducive. The period from planting to harvest is of particular significance. The optimal planting period is typically in April or May, with harvesting concluding in winter (Bauza et al., 2019; Semwal et al., 2015; Zhang et al., 2021; Ali et al., 2008; Mao et al., 2019).

Figure 5 Parts of the ginger plant (Begum A., 2024)

The distinctive aroma of ginger is attributable to the presence of phenolic and terpene group compounds within its chemical structure. The phenolic compounds have been identified as the principal components responsible for its bioactivity, particularly its pungent taste when used as a spice or flavouring. The main phenolic compounds responsible for ginger's pungent taste are gingerol, shogaol, zingerone and paradol. While gingerols are recognised as the primary component responsible for the pungent taste, they undergo a transformation into shogaols at elevated temperatures due to alterations in their stable structure, thereby acquiring a spicy character. Conversely, sesquiterpenoids, diterpenoids and monoterpenoids belonging to the terpene group constitute the primary components of essential oil. The most prevalent components include β-bisabolene, α-curcumin, zingiberene, α-farnesene, β-sesquiphellandrene, camphene, cineole, eugenol, curcumen, citral, geraniol and terpinenol. It has been determined that these components, which form part of its structure, have been utilised for medicinal and culinary purposes, with a view to alleviating symptoms such as headaches, colds and nausea, a practice that has been in evidence since time immemorial (Bauza et al., 2019; Semwal et al., 2015; Zhang et al., 2020; Ali et al., 2008; Mao et al., 2019).

1.1.6. Turmeric (*Curcuma longa*)

Curcuma longa, which belongs to the *Zingiberaceae* family, is a herbaceous and perennial plant that is widely cultivated in tropical countries, primarily in Asia, particularly in India, where it accounts for 78% of production and consumption. It is also cultivated in China. The turmeric plant (*Curcuma longa*), from which the rhizomes are harvested for use in both spice and medicine production, possesses a pleasant aroma and a bitter taste. It possesses spear-shaped, green shoots that can reach lengths of approximately 1 m and up to 12 leaves (see Figure 6). The plant in question produces yellow flowers, which are surrounded by purplish bracts. Turmeric (*Curcuma longa*) is a plant that is native to tropical and subtropical regions, but it is able to thrive in a wider range of conditions. It is able to grow in humid, sandy, nutrient-rich soils with sufficient annual rainfall, and it grows best at temperatures between 20°C and 30°C. The maturation process takes 7 to 9 months, and turmeric is harvested between January and April (Jyotirmayee and Mahalik, 2022; Fuloria et al., 2022; Iweala et al., 2023).

Figure 6 Certain parts of the turmeric plant b) rhizome c) dried powder form (Fuloria et al., 2022)

The colour of the substance ranges from yellow to brown, and it is this colouration that is responsible for the majority of its medicinal benefits. These benefits are derived from curcumin, which is the main component of the phenolic compound group in its structure. Furthermore, it has been determined that the substance contains over 300 active components, which are classified into the following groups: polyphenols, terpenes, sterols and alkaloids. Research has determined that these bioactive compounds in its structure have antioxidant, hepatoprotective, anti-osteoarthritic, anti-inflammatory, anti-cancer, anti-arthritic, neuroprotective, anti-diabetic, anti-depressant, wound healing, memory enhancing and anti-ageing properties (Jyotirmayee and Mahalik, 2022; Fuloria et al., 2022; Iweala et al., 2023).

1.1.7. Sage (*Salvia officinalis* L.)

Salvia officinalis is the largest genus in the *Lamiaceae* family, with approximately 900 to 1,000 known species worldwide. It is a perennial aromatic shrub. Despite its global distribution, spanning Asia, Africa, America and Europe, the provenance of sage is firmly rooted in the Mediterranean region. The sage plant is characterised by a woody stem, long, serrated, lanceolate leaves that are greyish green in colour, and purple to bluish flowers (see Figure 7). Sage is a hardy plant that typically flourishes between the spring and summer months. It is capable of thriving in a range of environmental conditions, including high altitudes, low temperatures, and across a broad pH spectrum (Ghorbani and Esmaeilizadeh, 2017; Jakovljević et al., 2019; Akacha et al., 2024; Assaggaf et al., 2022).

Figure 7 The sage plant (Ertaş et al., 2023)

Sage is notable for its high content of phenolic compounds and terpenes, which endow it with significant medicinal and aromatic properties. A range of studies have identified the following main volatile compounds: borneol, caryophyllene, elemene, humulene, α-thujone, camphor, 1,8-cineole, limonene and β-thujone. Furthermore, phenols such as caffeic acid, carnosic acid, carnosol, and rosmarinic acid, as well as flavonoids such as apigenin, luteolin, and quercetin, have been reported as prominent components in sage extract (Ghorbani and Esmaeilizadeh, 2017; Jakovljević et al., 2019; Akacha et al., 2024; Assaggaf et al., 2022).

1.1.8. Garlic (*Allium sativum* L.)

Allium sativum L. is a bulbous, perennial, herbaceous species belonging to the *Amaryllidaceae* family, which is known to comprise 750 genera and approximately 600 species. Its provenance is believed to be Central Asia, and contemporary countries with the highest production worldwide include China, India, the United States, Turkey, Korea, Egypt, and Spain. A study of the morphology of garlic reveals that the part consumed, responsible for the pungent aroma and flavour, is the bulb. This is encased in a white skin or membrane and contains 10 to 20 cloves (see Figure 8). The aboveground part of the plant is characterised by sparse stems and leaves that measure 2 to 3 centimetres in width. The utilisation of these bulbs as propagation material is a key aspect of the study. Garlic cultivation is a straightforward process, and in temperate climates, it can be planted throughout the year. The bulbs are harvested after they have reached full maturity (Ammarellou et al., 2022; Okoro et al., 2023; Shang et al., 2019; Batiha et al., 2020; Jikah et al., 2024).

Figure 8 Allium sativum underground onions (Magrys et al., 2021)

Garlic's flavour and aroma are derived from its aromatic properties, specifically from the phenolic compounds, organic sulphides, saponins, and polysaccharide group bioactive compounds that are present in its structure. These include, in particular, allicin—a sulphur-containing compound known as garlic's primary component—followed by diallyl sulphide, diallyl disulphide, diallyl trisulphide, ajoene, S-allylcysteine, and vinyl dithione. The primary phenolic compound present is identified as β-resorcylic acid (Ammarellou et al., 2022; Okoro et al., 2023; Shang et al., 2019; Batiha et al., 2020; Jikah et al., 2024).

1.1.9. Mint (*Mentha piperita* L.)

Mentha piperita L. is a perennial medicinal and aromatic plant belonging to the *Lamiaceae* family, which comprises approximately 7,000 species and 260 genera. Originating in Europe, this species is now cultivated extensively in temperate climate regions worldwide, particularly in America and Africa. In terms of morphology, the stem of a mint plant is typically square in form and branched, with a range of heights between 30 and 90 centimetres. The leaves are oblong-ovate in shape with serrated edges. The plant is distinguished by its flowers, which exhibit a colouration that can be described as purple or pinkish. As illustrated in Figure 9, the propagation of plants can be facilitated by the development of underground shoots. While mint can grow in a wide range of pH levels, it has been observed to thrive optimally in well-drained, humus-rich soils with a pH range between 6 and 7.5 (Singh et al., 2015; Mahendran and Rahman, 2020; Hudz et al., 2023; Gholamipourfard et al., 2021).

Figur 9 General appearance of M. piperita (Mahendran and Rahman, 2020)

The essential oils present in the leaves are the primary contributors to its medicinal properties. The predominant volatile components, namely menthol, menthone, menthofuran and menthyl acetate, account for approximately 90% of the total oil composition. Furthermore, a range of terpenoids, including α-pinene, β-pinene, carvone and 1,8-cineole, have also been identified as components. Peppermint extract is characterised by a high flavonoid content, including rutin, quercetin, and naringenin, as well as phenolic acids such as caffeic and rosmarinic acid. Notably, peppermint extract is a rich source of ursolic acid, which belongs to the triterpenoid group (Singh et al., 2015; Mahendran and Rahman, 2020; Hudz et al., 2023; Gholamipourfard et al., 2021).

1.1.10. Cumin (*Cuminum cyminum*)

Cumin (*Cuminum cyminum*) is a plant species that belongs to the *Apiaceae* family. It is generally considered to be an annual species and is characterised by its aromatic properties. The provenance of this plant is the Eastern Mediterranean and Middle East regions, from which it has now been cultivated in many temperate climate regions, primarily in India, Iran, Turkey, and Mediterranean countries (Khan et al., 2016; Patel and Singh, 2019). The plant is typically 30-50 cm in height and possesses a slender, branched stem. The leaves of the plant are thin, lobed and devoid of hair. The flowers are diminutive in size, with a white or pink hue, and are arranged in umbrella-shaped clusters (see Figure 10). Cumin is predominantly propagated through seed, and optimal growth conditions include well-drained, slightly clayey, organic-rich soils with a pH range of 6-8 (Ali and Kumar, 2018).

Figure 10 Cumin herb and seed (Johri, 2011)

The most significant medicinal constituent of cumin is the volatile oil content found in its seeds. The chemical composition of the essential oil is dominated by cuminaldehyde, thymol, carvacrol, γ-terpinene and β-pinene, with the total volatile oil content ranging between 70-80%. Furthermore, the seeds have been found to contain significant concentrations of flavonoids, phenolic acids, and other biologically active substances (Zhao et al., 2020; Riaz and Khan, 2022). Cumin's antioxidant, antimicrobial, and digestive-facilitating properties are attributable to the chemical compounds it contains (Gupta and Verma, 2017).

1.1.11. Partridge (*Satureja hortensis*)

The common name for *Satureja hortensis* is summer savory. This is an annual, herbaceous, aromatic plant belonging to the *Lamiaceae* family. It is also referred to as savory, savory herb, and savory plant. The Satureja genus, which is native to southern Europe and the Mediterranean region, comprises approximately 50 different species worldwide, 16 of which are endemic to Turkey. The plant under discussion is capable of reaching a height of between 30 and 60 centimetres. It produces flowers that are purplish in colour and bloom during the summer months. The leaves of the plant are lanceolate to linear in shape, sessile, green to bronze in colour and hairy. These leaves are used as a spice. As illustrated in Figure 11, summer savory, which typically thrives in rocky environments, can be propagated through the use of seeds (Fierascu et al., 2018; Ejaz et al., 2023; Borojo et al., 2018; Körük and Gedik, 2024; Mašković et al., 2024).

Figure 11 The above-ground branched stem portion of Satureja hortensis L. (Hassanzadeh et al., 2016)

The plant is notable for its high concentration of biologically active components, particularly in its leaves. These are rich in minerals such as potassium, phosphorus, iron, and calcium, as well as vitamins A, C, and riboflavin. Furthermore, its extracts and essential oils have been found to contain phenolic compounds, tannins, flavonoids, steroids, rosmarinic acid, caffeic acid, mucilage, and volatile components. The bioactive components of the essential oil are carvacrol, γ-terpinene, thymol, and p-cymene. The bioactive components of the plant have been shown to possess medicinal properties, including antioxidant, anti-inflammatory, antimicrobial, and antispasmodic effects. The essential oil is employed in a variety of domains, including but not limited to the pharmaceutical industry, the cosmetics industry, and the food industry (Fierascu et al., 2018; Ejaz et al., 2023; Borojo et al., 2018; Körük and Gedik, 2024; Mašković et al., 2024).

1.1.12. Carnation (*Syzygium aromaticum*)

Syzygium aromaticum L. is a perennial medicinal and aromatic plant that belongs to the *Myrtaceae* family. The species is believed to have originated in Indonesia, and is now widespread in tropical regions such as Madagascar, Sri Lanka, India and Tanzania. Carnation is a plant that can grow to a height of 10 to 20 metres and is categorised as an evergreen tree. The leaves exhibit a dark green hue, a lustrous appearance, and an oval or elliptical morphology. The plant is notable for its red and pink flowers, and its buds are hand-picked before harvest and used in spice production (Figure 12). Carnation (Syzygium aromaticum) is a plant that thrives in conditions of high humidity and temperature, as well as in well-drained, humus-rich, slightly acidic soils (Xue et al., 2022; Cetin, 2014).

Figure 12 The carnation plant and its buds

The essential oil extracted from the flower buds is the primary component that is utilised for its medicinal properties. The essential oil under scrutiny is predominantly composed of eugenol, a constituent that has been identified as the primary active ingredient responsible for the characteristic scent and medicinal benefits of cloves. However, components from the terpenoid group, such as eugenyl acetate, β-caryophyllene, α-humulene, and methyl salicylate, are also found in clove essential oil. Non-volatile components include tannins, flavonoids, sterols, and triterpenes. The phenolic compounds it contains have been shown to possess antibacterial, antifungal, antioxidant, and insecticidal properties. The essential oil is utilised in a variety of industries, most notably in the pharmaceuticals, food, and cosmetics sectors (Teixeira et al., 2013; Szente and Szejtli, 2004; Gonzalez et al., 2021).

1.1.13. Cinnamon (*Cinnamomum zeylanicum*)

Cinnamomum zeylanicum, belonging to the genus *Cinnamomum* of the *Laureaceae* family, which has approximately 250 species, and commonly known as true cinnamon or Ceylon cinnamon, originates from India, Sri Lanka and the tropical regions of Asia. Zeylanicum is a tree-like, evergreen species that can reach a height of approximately 12 metres. It can be distinguished from other species by its acute-shaped leaves, which turn from red to dark green, and its greenish flowers. (Figure 13) Although it can grow at elevations of 500 metres, it is generally more common at lower elevations. Its fruits ripen between May and August (Ranasinghe et al., 2013; Jayaprakasha and Rao, 2011; Behbahani et al., 2020; Unlu et al., 2010; Weerasekera et al., 2021).

(a) **(b)**

Figure 13 Cinnamon a) green stem b) bark (Husain et al., 2018)

All parts of the plant, including the bark, leaves, fruit and roots, contain bioactive compounds, and are used both medicinally and as food or spice. The essential oils analysed in this study were cinnamaldehyde, eugenol, linalool, beta-caryophyllene, eucalyptus and benzaldehyde. It has been determined through rigorous analysis and experimentation that cinnamaldehyde and eugenol are the primary active components of cinnamon extract. Furthermore, cinnamaldehyde has been identified as the main component of the essential oil, which possesses antioxidant effects (Ranasinghe et al., 2013; Jayaprakasha and Rao, 2011; Behbahani et al., 2020; Unlu et al., 2010; Weerasekera et al., 2021).

1.1.14. Maral Root (*Rhaponticum carthamoides*)

Rhaponticum carthamoides is a perennial plant that belongs to the *Asteraceae* family. It is commonly known by names such as maral root and Russian leuzea. The plant's provenance is the Altai and Sayan Mountains in southern Siberia, where it is endemic, growing at elevations ranging from 1,200 to 2,300 metres. The maral root is capable of attaining a length of approximately 150 centimetres. It possesses black, branched, vertical rhizomes and a smooth root structure with an elastic texture, which are the primary components employed in its extract (Figure 14) (Todorova et al., 2022; Kokoska and Janovska, 2009 Głazowska et al., 2018; Todorova et al., 2023).

Figure 14 The maral root with its flowers in bloom (Kokoska and Janovska, 2009)

The Maral root plant is characterised by a high concentration of phytoecdysteroids, which are its primary bioactive compounds and have been demonstrated to be beneficial to health. These compounds have been found to be present in both the generative and vegetative parts of the plant but are particularly abundant in the root section. The primary active compound is succeeded by phenolic and steroid groups. Research has indicated the presence of various constituents within the plant, including flavonoids, sesquiterpenes, monoterpenes, and glycosides. The essential oil, isolated from the root parts of the plant, contains bioactive components that are comprised of terpenoid group compounds. These active components are used in medical treatments for a variety of purposes, including the treatment of kidney and cardiovascular diseases, the alleviation of physical fatigue, the promotion of muscle development, the stimulation of protein synthesis, and the prevention of bacterial, antioxidant, and anticarcinogenic processes (Kokoska and Janovska, 2009; Głazowska et al., 2018; Todorova et al., 2023; Todorova et al., 2022).

1.1.15. Chicory (*Cichorium İntybus L.*)

Cichorium intybus, a species within the *Asteraceae* family, is found in Europe, Asia and Africa in its wild state. However, it is originally a plant that thrives in a Mediterranean climate, and is a perennial medicinal plant commonly found throughout Europe and Asia. The plant known as chicory can reach heights of between 20 and 150 centimetres. It possesses a green stem of considerable strength, green leaves, and flowers that are predominantly blue, but which can also be whitish in colour. These flowers open in conditions of bright sunlight and are rich in nectar and pollen. The leaves exhibit a green hue and can be classified into various shapes, including oval, lanceolate, or oblong, with a hairy texture (see Figure 15) (Janda et al., 2021; Mulabagal et al. 2009; Birsa and Sarbu, 2023; Abbas et al., 2015).

Figure 15 The open flowers and green stems of the chicory plant (Khan et al., 2020)

Notwithstanding the fact that the edible components are the flowers and buds, it is notable that all parts of chicory are abundant in bioactive compounds. The roots contain a number of chemical compounds, including sesquiterpenes, lactones, phenolic acids such as caffeic and cichoric acids, triterpenes, intybin glycoside, and inulin. The leaves contain vitamins A, B and C, minerals such as calcium, potassium, phosphorus, iron and zinc, and phenolic compounds that are medically significant. In addition to the numerous health benefits of its components, the anti-inflammatory properties of its anthocyanin content are well-documented, and inulin has a variety of industrial applications, including in coffee and animal feed (Janda et al., 2021; Duda et al., 2024; Mulabagal et al. 2009; Birsa and Sarbu, 2023; Abbas et al., 2015)

1.1.16. Echinacea (*Echinacea purpurea* L.)

The *Asteraceae* family and *Echinacea purpurea* L., belonging to the Echinacea genus, which is known to comprise 9 to 13 species, is the most commonly used species for medicinal purposes. Despite its provenance in North America, the plant is classified as a flowering, herbaceous, perennial, and medicinal species. It is predominantly distributed across the central and south-eastern regions of the continent, extending to Europe. The plant's growth potential is evident in its ability to reach a height of approximately 60 to 150 centimetres, accompanied by a robust and well-developed root and stem structure. The leaves of the plant under scrutiny are of a linear-lanceolate configuration and display a green pigmentation. They are also characterised by the presence of stiff hairs. The flowers of this species bloom during the summer months and display a pinkish hue (see Figure 16) (Manayi et al., 2015; Nagy et al., 2022; Dosoky et al., 2023; Mohamed et al., 2023).

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Figure 16 The spear-shaped upper leaves and flowers of echinacea (Lim, 2014)

1.1.17. *Hypericum perforatum*

Hypericum perforatum L., a perennial plant in the *Hypericaceae* family, is highly prized for its medicinal properties. The Hypericum genus is comprised of approximately 400 species on a global scale, with around 70 species being present in Turkey. This species, which originated in Europe, is now widespread in temperate and tropical climate zones. Hypericum is herbaceous in form, with yellow flowers and hairy leaves (see Figure 17) (Ekren et al., 2010; Cakmak and Bayram, 2003).

The medicinal value of the plant is attributed to the flowers, which contain bioactive compounds. In addition to flavonoids and tannins, the main bioactive components are understood to be hypericin, sitosterol, essential oils, pseudohypericin, hyperforin, choline, and pectin. The bioactive components present in it have been shown to possess antidepressant, wound healing, antiseptic, antiviral, and sedative properties (Cakmak and Bayram, 2003; Burunkaya et al., 2021; Ekren et al., 2010).

Figure 17 Hypericum perforatum L. (Gritsenko, 2021)

1.1.18. Hot Pepper (*Capsicum annuum* L.)

Capsicum annuum L. is a member of the *Solanaceae* family and is a perennial, shrub-like plant that is native to North and South America and is extensively cultivated in Asia, Africa and the Mediterranean. The plant is referred to by a number of common names, including hot pepper, red pepper, bell pepper and jalapeño. Morphologically, Capsicum has been observed to attain a maximum length of approximately 1 m. The morphology of its leaves exhibits significant variation in shape, yet they are predominantly classified as oval-lanceolate or oblong-oval in form. The flowers of this plant range from purple to white in colour, and the fruits it produces can be red, green, yellow or orange. As illustrated in Figure 18, the optimal temperature range for seed germination is 25 to 30°C, while 18 to 30°C is required for fruit development. The optimal climatic conditions for the plant's growth are those that are humid and warm, with loamy soils that are well-drained, characterised by high water retention capacity and abundant organic matter content (Silva et al., 2013; Zhigila et al., 2014; Olatunji and Afolayan, 2018).

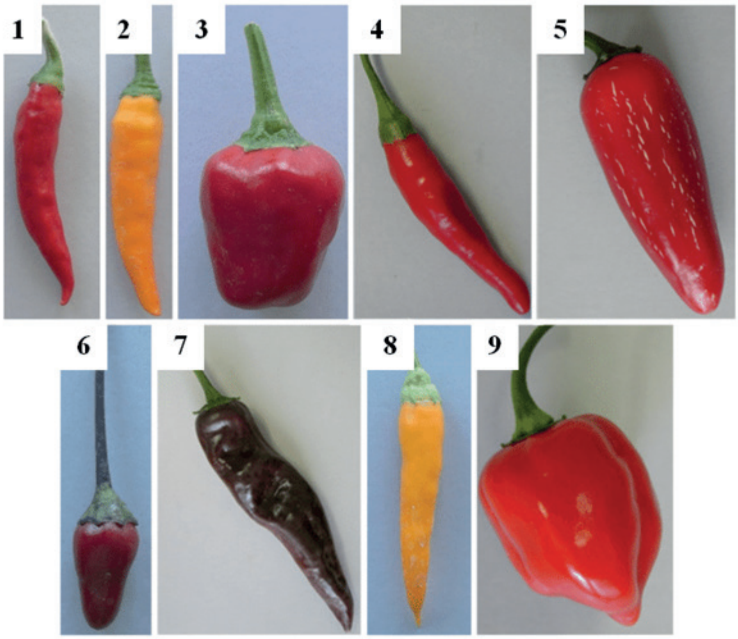

Figure 18 Capsicum annuum varieties 1) Black Cobra Pepper 2) Kilian Pepper 3) Greek Pepperoncini Pepper 4) Tabasco Pepper 5) Jalapeño Pepper 6) Black Prince Pepper 7) Chocho Pepper 8) Medusa Pepper 9) Red Habanero Pepper (Mňahončáková et al., 2021)

The capsicum genus of plants is characterised by a high nutritional content, including vitamins A, C and E, which have been demonstrated to play a significant role in human health . In addition to these vitamins, the genus contains minerals such as calcium, phosphorus and potassium, as well as carotenoids, which are known to be beneficial to human health .Furthermore, these fruits contain a plethora of bioactive compounds, including capsaicinoids, phenolic compounds, flavonoids, volatile oils and alkaloids. The medicinal effects of chilli are attributed to the active ingredient capsaicin, while its pungency is attributed to active ingredients in the alkaloid group. In a study, the main active component of two different capsicum varieties was determined to be betulin and the main volatile component was methyl benzoate (Silva et al., 2013). The bioactive compounds present in peppers have been shown to possess antioxidant, anti-inflammatory, and anticancer properties, among other health-promoting effects. These valuable compounds have led to the utilisation of peppers as a food, spice, and colouring agent. In addition, peppers have been employed in the treatment of various diseases, including cancer, stomach disorders, eye disorders, and cholesterol (Silva et al., 2013; Zhigila et al., 2014; Olatunji and Afolayan, 2018; Sanati et al., 2018).

2. Conclusion

Medicinal and aromatic plants represent a promising group of natural resources that can be effectively utilised as functional feed additives in animal nutrition. Their rich phytochemical composition, including phenolic compounds, terpenes, alkaloids, and sulphur-containing metabolites, provides a wide spectrum of biological activities such as antimicrobial, antioxidant, and immunomodulatory effects. When incorporated into animal diets, these plants not only enhance feed efficiency and growth performance but also strengthen the immune system, improve animal welfare, and contribute to the production of high-quality, residue-free animal products. Furthermore, their use offers sustainable alternatives to synthetic additives and antibiotic growth promoters, aligning with the increasing demand for environmentally friendly and safe livestock production systems.

Despite these advantages, the utilisation of medicinal and aromatic plants as feed additives faces certain challenges. The variability in phytochemical composition among plant species, as well as differences in cultivation conditions, extraction methods, and processing, may significantly affect their efficacy. Moreover, the beneficial effects of phytochemicals are dose-dependent, and inappropriate inclusion levels may lead to adverse health consequences. Therefore, standardisation of plant-based feed additives, along with comprehensive evaluations of their safety and effectiveness, remains an essential research priority.

Future studies should focus on elucidating the precise mechanisms of action of plant-derived bioactive compounds, optimising dosage levels for different animal species, and developing innovative delivery systems to maximise their stability and bioavailability. Additionally, integrating medicinal and aromatic plants into precision feeding strategies, in combination with modern biotechnological tools such as metabolomics and microbiome analysis, may offer new opportunities to enhance their functional potential. Ultimately, a deeper understanding of these natural resources will facilitate their wider adoption as safe, effective, and sustainable functional feed additives in modern animal production systems.

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