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Review Paper

Phytochemical, Macroscopic, And Pharmacological Insights into *Medicago Sativa*: A Comprehensive Review

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ABSTRACT

Medicago sativa (alfalfa) is a cultivated legume plant known for its nutritional value, agricultural importance, and wide pharmacological potential. The present review article exhaustively discusses the phytochemical composition of *M. sativa*, such as flavonoids, saponins, alkaloids, and phytoestrogens, responsible for its antioxidant, anti-inflammatory, antimicrobial, and anticancer activities. The plant pharmacological activities are studied in both traditional and contemporary medicinal applications, listing its potential for cardiovascular wellness, hormone regulation, and immune modulation. In agriculture, *M. sativa* is an important forage crop that provides soil nutrient enhancement through nitrogen fixation and promotes sustainable animal nutrition. The article also focuses on the environmental contribution of alfalfa cultivation, specifically the enhancement of soil structure, erosion prevention, and greenhouse gas emission reduction. By an integrative strategy, this review confirms *M. sativa*'s diverse function in health, agriculture, and environmental sustainability, and proposes avenues for future research and biotechnological applications.

INTRODUCTION

As an herbaceous legume plant *Medicago sativa* functions within two botanical names: alfalfa and lucerne (Fabaceae). A main utilization purpose for this plant as forage is due to its outstanding nutritional properties. The use of alfalfa agricultural cultivation expanded to more than a thousand years after its discovery in South-Central

Asia. Alfalfa serves agriculture as well as pharmaceutical industries through its extensive employment since the thousandth century. across the globe^[1]

- **General Overview of *Medicago sativa* (Alfalfa)**
- **Historical and Cultural Significance**

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Records shows that alfalfa producers cultivated this plant thousands of years ago dating from more than 2,000 years in countries like Iran, Greece, and Rome. The plant's source of naming comes from Arabic roots Al-fisfisa in Arabic serves as the term for this product due to its importance as animal fodder ^[2]. The crop was Spanish colonizers conducted the first importation of this plant to the Americas during the 16th century and it developed into a worldwide prominent forage crop ^[3].

➤ **Common Uses**

The agricultural cultivation of alfalfa primarily focuses on animal feed production because the vegetation contains nutritious proteins alongside excellent digestibility properties that also restore the quality of the soil. enrichment properties through nitrogen fixation. Alfalfa has other applications outside agriculture, such as in human nutrition and herbal medicine. Consumers take alfalfa as plant sprouts for tea preparations along with supplementation in diets. Dietary supplements commonly praise the vitamin and mineral content (A, C, E, K) and calcium and magnesium and iron components of alfalfa ^[4].

➤ **Relevance in Modern Herbal Medicine and Agriculture**

Traditional herbal practitioners recognize alfalfa because it offers possible health benefits through the treatment of digestion issues and cardiovascular health and hormonal regulation. The herb helps digestion and maintains heart health and regulates hormones..Alfalfa has received medical use in traditional practices for arthritis management while enhancing cholesterol levels and offering benefits to general wellness according to research^[4].

• **Importance of the Review**

Research and medical professionals along with environmental scientists require an extensive report about *Medicago sativa* (alfalfa) to further extend their work. *Medicago sativa* continues to gain importance among research groups together with healthcare workers and environmental defenders because of its massive applications in medical fields and agricultural sectors and conservation efforts. Researchers need to study *Medicago sativa* (alfalfa) through analysis of its phytochemical properties as well as its macroscopic features and pharmacological attributes. The analysis of *Medicago sativa* (alfalfa) enables researchers to uncover potential advantages and challenges as well as future development pathways ^[5].

➤ **Scientific and Medical Research**

a. **Phytochemical Composition and Possible Drug Development**

The bioactive components in *Medicago sativa* reference flavonoids as well as saponins along with alkaloids and phenolics and phytoestrogens. The medicinal worth of *Medicago sativa* comes from its phytoestrogens as well as flavonoids and saponins and alkaloids and phenolics and all these compounds play significant roles ^[6]. The profile information about phytochemicals in *Medicago sativa* offers valuable potential for identifying new pharmaceutical compounds. Natural treatments for chronic cardiovascular conditions together with diabetes and osteoporosis should be developed through research. The investigation of secondary metabolites in *Medicago sativa* can create therapeutic applications for modern medicine and pharmaceuticals medicine and pharmaceuticals ^[7].

b. **Pharmacological and Therapeutic Significance**

Traditional users employ alfalfa because it exhibits antiinflammatory as well as antioxidant effects and



helps manage high lipid levels in the blood and strengthens immunity, anti-diabetic, and immune-enhancing effects. This paper reviews the pharmacological activities of alfalfa. The author uses scientific studies to validate these benefits [6]. Alfalfa has gained recognition for its ability to balance hormones and contain phytoestrogenic properties because of this it demonstrates potential as a therapeutic agent natural therapy for menopausal syndrome and hormone disorders. New discoveries about the gastroprotective functions and hepatoprotective along with neuroprotective properties of this plant may lead to essential medical findings could unveil new avenues for its incorporation into integrative medicine [7]. Scientific studies are needed to assess the drug interaction properties of phytoestrogens as part of their development toward safer and more beneficial use to the patients with chronic diseases.

c. Evidence-Based Herbal Medicine and Nutritional Applications

Elaborate analysis of its nutritional content, such as proteins, vitamins (A, C, E, K), minerals (calcium, magnesium, iron), and fiber, can make it more useful as a dietary supplement. Knowledge of its bioavailability and absorption in humans can make it a more useful functional food ingredient [8]. With growing popularity for plant-based food, alfalfa may be developed as a green source of plant proteins and essential micronutrients [9].

➤ Agricultural and Environmental Significance

a. Contribution to Sustainable Farming and Soil Health

Alfalfa is a nitrogen-fixing legume crop, making it valuable in improving soil health and reducing reliance on inorganic fertilizers [10]

It protects soil from erosion, enhances soil physical structure, and enhances farming system biodiversity^[11].

As a cover crop, it facilitates suppression of weeds and retention of water, qualifying it as a natural choice for organic farming^[12].

b. Increasing Livestock Nutrition and Dairy Sector

Alfalfa is a protein-rich forage crop and hence becomes crucial for the dairy and livestock sectors [13].

Analysis of its digestibility, absorption of nutrients, and influence on animal health will make it suitable to be utilized in formulations for livestock feed to maximum extent [14].

It contributes to milk yield and quality in dairy animals because of its high amino acid content^[15].

c. Climate Adaptability and Resilience

Alfalfa is adaptable and tolerates varied climatic conditions and drought, and so it is an essential crop in arid and semi-arid climates [16]. A review can assist in framing climate-smart agriculture practices that can enhance its yield under varied conditions [17].

2. Taxonomic Classification of *Medicago sativa*

• Family and Genus of *Medicago sativa*

I. Taxonomic Classification

- Kingdom: Plantae
- Phylum: Angiosperms (Flowering plants)
- Class: Eudicots
- Order: Fabales
- Family: Fabaceae (Legume family)
- Genus: *Medicago*
- Species: *Medicago sativa* [18],[19]

II. Family: Fabaceae (Legume Family)

Medicago sativa belongs to the Fabaceae family, commonly known as the legume, pea, or bean family. This is one of the largest and most economically significant plant families, comprising over 19,500 species spread across approximately 765 genera^[20].

III. Genus: *Medicago*

The genus *Medicago* contains 83 species which naturally inhabit the temperate and subtropical environmental areas. These plants exist as both deep-rooting perennial and annual herbaceous life forms. People cultivate *Medicago* plants because they serve both as grazing forage and as agents for soil improvement^[21].

Notable Species in the *Medicago* Genus:

- *Medicago sativa* (*Alfalfa*): The most widely cultivated species, valued as a forage crop and medicinal herb.
- *Medicago lupulina* (*Black Medick*): A smaller species commonly found in pastures and roadsides.
- *Medicago truncatula*: A model organism used in genetic and agricultural research.
- *Medicago polymorpha* (*Bur Clover*): Known for its ability to thrive in various climates and improve soil nitrogen levels.

IV. Species: *Medicago sativa*

The plant species *Medicago sativa* stands as the primary valuable member of its genus. As a deep-rooted perennial legume *Medicago sativa* stands out because of its high protein content as well as its nitrogen-fixing ability and climate resistance properties in diverse climates. People grow this plant globally both as pastureland for animals and as temporary soil covering to add nutrients to the earth, soil enrichment, and a medicinal plant with numerous health benefits^[22].

• Botanical Features of *Medicago sativa*

I. Biological Classifications^[23]

Kingdom: Plantae (Plants)

Phylum: Angiosperms (Flowering plants)

Class: Eudicots (True dicotyledons)

Order: Fabales

Family: Fabaceae (Legume or Pea family)

Genus: *Medicago*

Species: *Medicago sativa* (Alfalfa)

II. Morphological Features

a. Growth Habit

Medicago sativa develops into a perennial herbaceous plant that regulates its root structure through its wide deep root system. This herbaceous plant continues to exist beneficial environmental conditions during multiple years. The plant grows to heights between 0.6 to 1 meter (2 to 3 feet) unless conditions or management practices cause variation^[24].

b. Root System

The plant has a deep taproot which penetrates the soil layer up to 6 meters (20 feet) depth. The plant system operates with deep underwater resources and maintains health during dry conditions. The root system applies nitrogen fixation capabilities which offer advantages for plant health and neighbouring crops^[25].

c. Leaves

The plant exhibits trifoliate leaves that appear similar to clover leaves. Each leaflet appears in the shape of an oval or grows as an oblong format and bears firm serrations toward its terminal section. The leaf content includes high chlorophyll along with vitamins and minerals that provide significant value to livestock feed as well as food for humans and human nutrition^[24].



d. Flowers

Each raceme of *M. sativa* flowers exhibits dense arrangement of purple to bluish-violet flowers. Each flower is papilionaceous (pea-like structure), consisting of a banner (standard petal), wings, and a keel. Alfalfa is insect-pollinated (entomophilous), mainly bees, which are important for seed set^[24].

e. Fruits and Seeds

The fruit is a small, coiled legume pod, bearing several kidney-shaped seeds. Seeds are very small, yellowish-brown, and highly viable, enabling easy germination and growth^[24].

III. Natural Habitat and Distribution^[26]

a. Native Range

Medicago sativa is thought to have originated in South-Central Asia and the Middle East, with early cultivation dating thousands of years. It was disseminated along ancient trade routes and came to be widely grown in Europe, North Africa, and the Americas.

b. Global Distribution

Currently grown globally, especially in temperate and subtropical areas, such as North America, Europe, Australia, China, and South America. It grows well in areas with moderate rainfall (400–600 mm per year), full sun, and well-drained soils.

c. Soil and Climate Preferences

Soil: Loamy, well-drained soils with a neutral to slightly alkaline pH (6.5–7.5).

Climate: Drought-tolerant and resistant to extreme temperatures but does best in temperate climates with warm summers and cool winters.

Altitude: Will grow at different altitudes but prefers lowland to mid-elevation areas.

• Subspecies and Varieties of *Medicago sativa*

Medicago sativa (alfalfa) contains a number of subspecies and varieties grown under cultivation, differing in growth habit, climatic tolerance, chemical content, and pharmacological activity. These have been bred by natural selection and breeding schemes to enhance resistance to pests, pathogens, drought, and climatic stresses and maximize yield and nutritional quality.

I. Major Subspecies^[27]

a. *Medicago sativa* subsp. *sativa* (Common Alfalfa)

The most cultivated form, produced on a large scale for animal feed and soil improvement. Tall in growth, high in biomass yield, and deep-rooting habit. Rich in protein, flavonoids, saponins, and phytoestrogens, thus of great importance in herbal medicine and animal nutrition.

b. *Medicago sativa* subsp. *falcata* (Yellow-flowered Alfalfa)

Native to cold and dry areas, especially in Eurasia and Siberia. Yellow flowers, prostrate habit, and more fibrous in structure than common alfalfa. resistant to drought and cold, making it more suitable for severe climates. Lower in saponin content, which can decrease bitterness and enhance digestibility in forage uses.

c. *Medicago sativa* subsp. *caerulea* (Blue Alfalfa)

Regarded as an ancient version of current alfalfa varieties. Has bluish-purple flowers and a wild-type growth habit. Less widely grown but is of genetic interest for breeding disease-resistant and stress-tolerant types.

d. *Medicago sativa* subsp. *x varia* (Hybrid Alfalfa)



A hybrid between *M. sativa* subsp. *sativa* and *M. sativa* subsp. *falcata* that occurs naturally.

Has variable flower color (yellow to purple) and intermediate growth habit. Very versatile in both temperate and dry areas, providing an intermediate between biomass yield and persistence.

II. Selected Cultivars and Variations^{[28],[29]}

There have been hundreds of alfalfa cultivars developed through breeding programs, each adapted to a particular environment and purpose. Some significant commercial cultivars are:

'Vernal' – Cold-hardy, widely cultivated in North America, and having the character of winter dormancy.

'WL 525HQ' – High-yielding, disease-resistant, and high in protein.

'CUF 101' – A non-dormant type suitable for warm climates, especially in California.

'Agate' – Possesses high salt tolerance, hence being ideal for use in saline soils.

'Alfagraze' – A grazing-tolerant type designed for repeated pasture utilization.

III. Differences in Chemical and Pharmacological Properties

Saponin Content: Certain types (e.g., subsp. *sativa*) contain more saponins, which are responsible for cholesterol-lowering activity but may lead to bitterness in feed^[30].

Phytoestrogen Levels: *M. sativa* is rich in isoflavones and coumestrol, which affect hormonal activity; some cultivars have been developed with reduced phytoestrogen content to minimize reproductive hazards in livestock^[31].

Drought and Salt Tolerance: Subsp. *falcata* and hybrid varieties have developed increased stress tolerance, which is usually linked with modifications in root exudates and antioxidant metabolites.

Disease Resistance: Certain cultivars have been developed to be resistant to fungal infection, nematodes, and bacterial wilt, which will provide greater forage yield and quality^[31].

3. Macroscopic Characteristics

• Morphology of *Medicago sativa*

Medicago sativa or alfalfa is a perennial herbaceous legume with characteristic morphological traits that enable it to grow in various environments. Here is a close description of its physical attributes, such as leaves, flowers, roots, and general growth habit.

1. Leaves^[32]

Shape & Structure: Leaves are trifoliate, i.e., they consist of three elliptic to oblong leaflets per leaf.

Size: Each leaflet is around 0.5 to 2.5 cm long.

Edges: Leaflet edges are finely toothed towards the tip, aiding in differentiation from clover (*Trifolium* spp.), which has a smooth-edged leaf.

Color: Leaves range from bright green to dark green, depending on conditions of growth.

Attachment: Leaves are alternately attached along the stem with a short petiole (leaf stalk).

Surface Texture: Leaves can have a slightly hairy (pubescent) or smooth (glabrous) surface, variety dependent.

2. Flowers^[33]

Flower Shape: Papilionaceous, typical of the family Fabaceae, with a banner (standard petal), wings, and keel.

Color: Violet to purple, but flowers in some wild forms can be blue, pink, or yellow (*M. sativa* subsp. *falcata*).



Arrangement: Flowers in dense, spike-like racemes, each consisting of 10–30-minute flowers.

Size: 5–10 mm long per flower.

Blooms primarily during late spring to summer (April to September) in warm temperate climates. Flowering is indeterminate, as the plant continues to bloom as long as the environment supports it.

Pollination: Bee and other insect-pollinated, as flower structure necessitates mechanical action for pollen release.

3. Stems and Growth Habit ^[34]

Stem Type: Erect to semi-erect, branched, and slender, with several varieties having a more sprawling or prostrate growth habit.

Stem Height: Generally, grows 0.5 to 1 meter (1.5 to 3 feet) high, but can grow more under favorable conditions.

Stem Surface: Finely hairy in some species, or smooth.

4. Roots and Adaptations ^[35]

Root System:

Medicago sativa possesses a deep taproot that can extend up to 6 meters (20 feet) into the ground, making it very drought-resistant. The root system also comprises lateral fibrous roots, which serve to anchor the plant and enhance soil texture.

Nitrogen Fixation:

Establishes symbiotic associations with *Rhizobium* bacteria, which convert atmospheric nitrogen into the soil, enhancing fertility.

Drought Adaptations:

Deep roots enable the plant to tap subsoil moisture, guaranteeing survival in semi-arid and arid conditions. Leaves are able to partially close under drought stress to minimize water loss via transpiration.

• Identification of *Medicago sativa*

1. How to Identify *Medicago sativa* in the Wild or During Harvest

Recognizing *Medicago sativa* involves examining a combination of its leaves, flowers, growth habit, and root system.

a. Key Identification Features ^[36]

Feature	Description
Leaves	Trifoliate (three leaflets), oblong with serrated tips, green color.
Flowers	Small, violet to purple, arranged in dense clusters (racemes).
Stems	Erect to semi-erect, branched, slightly hairy.
Roots	Deep taproot system, nitrogen-fixing nodules present

3. Distinguishing *Medicago sativa* from Related Species:

***Medicago falcata* (Yellow Alfalfa):**

Flower Color: Yellow.

Seed Pod Shape: Falcate-curved or occasionally straight or partially coiled.

Leaflet Serration: Not mentioned.

***Melilotus officinalis* (Yellow Sweet Clover):**

Flower Color: Yellow.

Seed Pod Shape: Linear and not coiled.

Leaflet Serration: Fully serrated margins.



Proper identification of *Medicago sativa* brings value to forage quality and ecological research. Observing the unique morphological features described here will lead to proper identification of *Medicago sativa*. Those characteristics serve as identification markers to separate *Medicago sativa* from other species in the group.

4. Phytochemical Constituents of *Medicago sativa*

- **Primary Bioactive Compounds:**

Medicago sativa, or alfalfa, is found to be rich in a number of bioactive compounds that make it valuable from a medicinal and nutritional point of view. The major bioactive constituents are:

1. Phenolic Compounds ^[37]:

Alfalfa contains phenolic compounds that include several flavonoids such as apigenin and luteolin together with their glycosides. The compounds exhibit strong antioxidant properties that are commonly recognized by scientists.

2. Isoflavonoids ^[37]:

The isoflavonoid compounds genistin, daidzein together with glycitein and genistein exist in alfalfa. These Phytoestrogenic activity exists in these substances thus affecting hormone balance potentially hormonal balance and well-being.

3. Saponins ^[38]:

Authentic research suggests that triterpene saponins discovered in alfalfa deliver multiple health benefits to users such as cholesterol-reducing activities and immune modulation.

4. Alkaloids ^[38]:

The alkaloids found in alfalfa constitute a part of its therapeutic value through the creation of various pharmacological actions.

5. Carotenoids ^[38]:

Carotenoids like lutein and beta-carotene in alfalfa account for its antioxidant activity and possible advantage to eye health.

6. Phytoestrogens ^[38]:

Almost 100 years ago scientists discovered that alfalfa contained coumestrol which displays estrogenic behavior especially since this substance manifests potential effects regarding reproductive wellness and endocrine system disease risks, reproductive health and endocrine-related disorders.

7. Sterols ^[38]:

The sterols from alfalfa are responsible for its therapeutic qualities that act as anti-inflammatory agents and reduce cholesterol levels. All bioactive phytochemicals in *Medicago sativa* contribute to its antioxidant and anti-inflammatory properties, antimicrobial and other beneficial properties of *Medicago sativa*. The phytochemical variety in alfalfa positions it as both a valuable functional food item and a medicinal substance.

- **Nutrient content**

The plant *Medicago sativa* commonly known as alfalfa maintains high importance because it contains many essential nutrients. ingredient in animal feed as well as human nutrition. These are the predominant nutrients present in alfalfa:

1. Proteins:

Alfalfa possesses substantial crude proteins reaching between 17.2% to 24.1%. The protein content of alfalfa depends on its development stage as well as environmental conditions.

2. Vitamins:



Alfalfa contains a high concentration of vitamins which include A, D, E, K, C and all B vitamins B1, B2, B6 among others. A general wellbeing exists from vitamins while they support various metabolic processes.

3. Minerals:

Alfalfa has various minerals which exist as important elements including calcium. The nutritional value stems from the mixture of phosphorus with magnesium as well as potassium and trace elements.

4. Fiber:

Alfalfa contains high amounts of crude fiber that benefits gut health. The digestion rate of both poultry animals and other livestock depends on this parameter.

5. Metabolizable Energy:

Alfalfa contains 3,000 kcal/kg of metabolizable energy together with serving as a beneficial nourishing source. The nutritional values within alfalfa show diverse ranges due to factors such as plant variety type together with environmental elements and the point of harvest. Sheep and other farm animals require particular environmental factors and specific harvest stages amidst varying environmental conditions. For example, research has demonstrated. The study reveals that different alfalfa accessions show varying results regarding their yield production levels and nutrient content thus emphasizing the importance of right variety selection and choice of varieties for cultivation. *Medicago sativa* stands as a protein-abundant forage plant which possesses vitamins and minerals and fibrous and energy-filled compounds. Food producers can use alfalfa components as valuable nutritional additions to diets for both human consumption and animal feed consumption.

5. Pharmacological Properties

The therapeutic properties in *Medicago sativa* commonly known as alfalfa create numerous pharmacological activities because of its elevated phytochemical content. The following remarkable therapeutic benefits are among them:

1. The antioxidant property of alfalfa stands out as strong because phenolic compounds along with flavanoids compose its antioxidant compounds. The antioxidants within the plant function as the essential agents to deactivate free radicals. Free radicals undergo neutralization in cells due to the protective mechanism of alfalfa thus eliminating oxidative stress^[39].

2. Anti-inflammatory Constituents at a low level exist within the plant while blocking the formation of nitric oxide in macrophages invitro. It is speculated to be helpful for controlling inflammation^[40].

3. Hypocholesterolemic Property^[41] Experiment results indicate that Alfalfa contains hypocholesterolemic properties which help protect cardiac health. Saponin in alfalfa allows this action due to its structure which blocks cholesterol absorption.

4. Neuroprotective Potential^[42] Scientific research indicates the plant possesses protective properties for the nervous system. Researchers explore the potential use of Alfalfa as a therapeutic agent for neurodegenerative conditions along with mood disorders and tissue cells under stressful oxidative conditions in the central nervous system.

5. Antidiabetic Activity^[43]: Alfalfa reveals antidiabetic properties which aid in diabetes control function.

6. Antimicrobial Action^[44]: Bioactive compounds in the plant demonstrate antimicrobial properties could act against many pathogens.



7. Estrogenic Effects ^[45]: Alfalfa has phytoestrogens, e.g., coumestrol, that are estrogenic in activity. This has possible implications for treating hormone-related diseases.

8. Antiulcer Activity ^[46]: Alfalfa has been shown to be antiulcer in action and could possibly help prevent and treat gastric ulcers.

9. Anticancer Potential ^[47]: Early findings indicate alfalfa might have anticancer effects, thanks to its dense content of phytochemicals

10. Hepatoprotective Actions ^[48]: Alfalfa has been said to provide protective action against hepatotoxicity, which indicates its usefulness in maintaining liver health.

11. Cardioprotective Activity ^[49]: The plant compounds may help cardiovascular well-being by reducing oxidative stress and inflammation, thus providing protection against myocardial infarction.

12. Wound Healing Potential ^[50]: Alfalfa is used traditionally for the healing of burn wounds, suggesting its value in tissue regeneration and repair.

6. Safety and Toxicity Considerations

Medicago sativa, or alfalfa, is extensively used for its nutritional value. A number of safety and toxicity factors must be kept in mind, though:

1. Photosensitivity ^[51]: Alfalfa intake can enhance sun sensitivity in the skin, which increases the risk of sunburn, blistering, or rashes when exposed to sunlight.

2. Blood Cell Effects ^[52]: The ingestion of huge amounts of alfalfa seeds has been linked with pancytopenia, a disorder involving the reduction in red and white blood cells and platelets.

3. Gastrointestinal Symptoms ^[53]: As a result of its high fiber level, eating raw alfalfa leads to gastrointestinal symptoms, such as gas, stomach upset, and diarrhea.

4. Hormone-Sensitive Disorders ^[53]: Alfalfa has phytoestrogens that can act similarly to estrogen in the body. Patients with hormone-sensitive disorders like breast, prostate, cervical, or uterine cancer must avoid alfalfa as it might have negative consequences.

5. Interference with Immunosuppressive Therapy ^[54]: Alfalfa has the potential to interfere with immunosuppressive drugs, weakening their action. Patients on such therapies must take care while opting for alfalfa intake.

6. Bacterial Contamination ^[55]: Alfalfa sprouts are prone to contamination by bacterial pathogens like *Salmonella* and *Escherichia coli*. Ingestion of contaminated sprouts can cause foodborne illness, which is of serious concern, particularly to susceptible groups.

7. Vitamin K Content ^[56]: *Medicago sativa* is high in vitamin K, which is necessary for blood clotting. The person taking anticoagulant drugs, for example, warfarin, should be very careful because an excessive intake of vitamin K interferes with these medications.

Finally, while *Medicago sativa* has diverse nutritional advantages, one must remember these safety and toxicity factors for proper and secure use.

7. Sustainable Cultivation and Environmental Impact

Medicago sativa, commonly known as alfalfa, is a perennial legume widely cultivated for its high nutritional value as forage. Its sustainable cultivation practices and environmental impacts have been the subject of extensive research.



• Sustainable Cultivation Practices

Intercropping alfalfa with other plants has been recognized as a sustainable agricultural system. Intercropping not only increases forage yield and quality but also decreases the use of synthetic fertilizers, thus alleviating environmental degradation. It was shown through a study that alfalfa intercropping is able to meet food security and forage requirements while maintaining the ecological environment, hence a potential model under environmental limitations ^[57]. Breeding programs have emphasized the creation of alfalfa varieties suited for particular climatic conditions, including subtropical and tropical climates. The goal is to enhance biomass yield and persistence, which will help in sustainable forage production in multiple agroecosystems ^[58].

• Environmental Impacts

The environmental impact of alfalfa production differs in relation to management practice. Alfalfa monoculture with continuous cropping has been found to increase soil carbon content and enhance biological soil health by developing microbial biomass. The approach improves soil health and sustainability ^[59]. Several agricultural methods cause detrimental effects to Earth's environment. For example, the application of herbicides on alfalfa pastures leads to larger greenhouse gas emissions as demonstrated by research, notably on methane uptake and gas fluxes from soil. The management of chemical demands special attention because of environmental reasons. The usage of chemicals requires careful monitoring as a way to protect environmental quality ^[60]. The determination of suitable land areas employs agro-ecological zoning methods. The soil characteristics and climate determine which areas of land will serve best for planting alfalfa. The procedure successfully determines suitable locations for alfalfa cultivation. Land can support

alfalfa without damaging the environment because it grows naturally there and land management remains sustainable. ^[61]. Sustainable production of *Medicago sativa* includes methods like intercropping and climate-adapted variety development, which increase productivity and minimize environmental effects. On the other hand, herbicide use needs to be considered cautiously because of possible greenhouse gas emissions increases. The application of agro-ecological zoning can also maximize land suitability for alfalfa production to ensure environmental sustainability.

CONCLUSION

Medicago sativa, or alfalfa, appears as a plant of great therapeutic and nutritional value due to its rich diversity of phytochemicals and wide range of pharmacological activities. Its macroscopic features not only facilitate its identification and cultivation but also indicate its adaptability in different agro-climatic regions. Its availability of bioactive compounds like flavonoids, saponins, phenolic acids, and phytoestrogens provides the basis for its antioxidant, anti-inflammatory, hypolipidemic, antimicrobial, and estrogenic properties, some of which have been confirmed in in vitro and in vivo tests. In addition, its traditional medicine-established application is consistent with existing scientific reports, supporting its application in contemporary phytotherapy. In spite of these encouraging characteristics, a number of gaps continue to exist in fully realizing its pharmacological potential for clinical use. Standardization of extracts, extensive toxicological studies, and rigorous clinical trials are necessary to ascertain efficacy and safety. Nonetheless, *Medicago sativa* has considerable potential as a multi-purpose botanical resource that merits further study to realize its full potential for human and animal health.



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CONFLICT OF INTEREST

The authors claim no conflict of interest

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