frontiers | Frontiers in Sustainable Food Systems

TYPE Review
PUBLISHED 06 March 2023
DOI 10.3389/fsufs.2023.1126151

OPEN ACCESS

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SPECIALTY SECTION
This article was submitted to Nutrition and Sustainable Diets, a section of the journal Frontiers in Sustainable Food Systems

RECEIVED 17 December 2022
ACCEPTED 09 February 2023
PUBLISHED 06 March 2023

CITATION
Latif A, Sun Y and Noman A (2023) Herbaceous Alfalfa plant as a multipurpose crop and predominant forage specie in Pakistan. *Front. Sustain. Food Syst.* 7:1126151. doi: 10.3389/fsufs.2023.1126151

Herbaceous Alfalfa plant as a multipurpose crop and predominant forage specie in Pakistan

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Fodder crops play an important role in agriculture as they deliver food for animals, which is eventually converted to food for humans. All over the world, Alfalfa has had utmost importance for a few decades, not only as a fodder crop due to having high nutritional value for dairy farming but also being positively involved in many health-related and environmental affairs. Medicinally, it helps in controlling diseases such as arthritis, cholesterol, anemia, and cardio-related illnesses. Furthermore, like other cereal crops (wheat, rice, corn, etc.), it could also be a great source of several healthy nutrients for humans when the proper quantity is added to daily meals. However, unlike other nations of the world such as America, China, and India, Pakistan does not utilize it directly in human meals. This crop also has eco-friendly behavior since it controls soil erosion by binding the soil particles together and makes atmospheric nitrogen available to the plants by fixing it in the soil. Other uses include its role in water purification, improved pollination, and most importantly, its tolerance against water, salt, and temperature stress, making its position even stronger in arid and semi-arid areas. This review will draw researchers' attention to its multiple uses other than fodder crop and most importantly, its nutritional availability at a very low cost, which could prove nothing short of a miracle for the economy if properly mediated.

KEYWORDS

***Medicago sativa L.*, multipurpose crop, human diet, nutritive value, medicinal value**

1. Introduction

Alfalfa (*Medicago sativa)* belongs to the family of Leguminosae, which is a perennial crop that could live years and years depending on the suitable climatic conditions, even in dry conditions can live for up to 10 years (Fernandez et al., 2019a). It has a high yield outcome and capacity for tolerance toward extreme environmental fluctuations (Li et al., 2007). It is a most abundantly harvested legume, mainly as hay and silage but also consumed fresh and desiccated for grazing and meals, respectively (Larson et al., 1997). Alfalfa is an important source of protein (estimated 15–22% crude protein), carbohydrates and crude fiber as well as several other important vitamins (A, B, C, E, and K) and minerals such as calcium, phosphorus, copper, and potassium, which are directly or indirectly vital for most of the livestock and dairy industries (Summers and Putnam, 2008). Its sprout can be consumed directly as salads, soups, and casseroles (Mandle and Chaudhari, 2020). It is predicted that by the year 2050, the growing world population will reach 9 billion (Nations, 2015) and the poverty level will also increase with this growing population. Because of its high nutritional value and availability at a cheap cost, it could impart important vital nutrients to the economy, specifically in developing and underdeveloped countries like Pakistan, India, Bangladesh, Vietnam, and Laos etc.

This crop's worldwide cultivation area is about 30 million hectares, with a total production of about 450 million tons. Major alfalfa producers are North and South America, Europe and Asia, with a total production of around 41, 23, 25, and 8%, respectively (Firdaous et al., 2010). In Pakistan, the reported forage production of 4 main fodder crops: Berseem (*Trifolium alexandrinum*), Lucerne (*Medicago sativa*), Oat (*Avena sativa*) and Ryegrass (*Lolium sp.*) during 2016–17 was 29,653 kg per hectare and Alfalfa ranked second among all these forage crops. Alfalfa accounts for 7% of Pakistan's total forage cultivation area, which is very little. Under ideal environmental conditions, it could produce 120-200 kg of seed per acre. Pakistan has four seasons per year (Zia et al., 2017; Iqbal and Athar, 2018) where temperature in winters go up to −24°C and in summers up to 53°C and the average temperature of the country during winters range from 12 to 20°C and 19–35°C during summers (Haider and Adnan, 2014; Zhongming et al., 2019). The specificity of this crop to survive in extreme environments of hot summers and cold winters makes it a more tolerable and profitable crop all over the country. Because of its high organic matter digestibility (55–77%), it is considered as the most valuable crop all over the world, but its total production in Pakistan compared to other countries of the world is very low and needs special attention (Shakil, 2018).

The goal of this study was to demonstrate the value of alfalfa as a versatile crop. The secondary objective was to raise awareness of its importance as a low-cost source of nutrition for both humans and animals, which can serve as both a nutritious food source and a preventive measure against various diseases. Furthermore, this review will compile a number of applications of Alfalfa in an article.

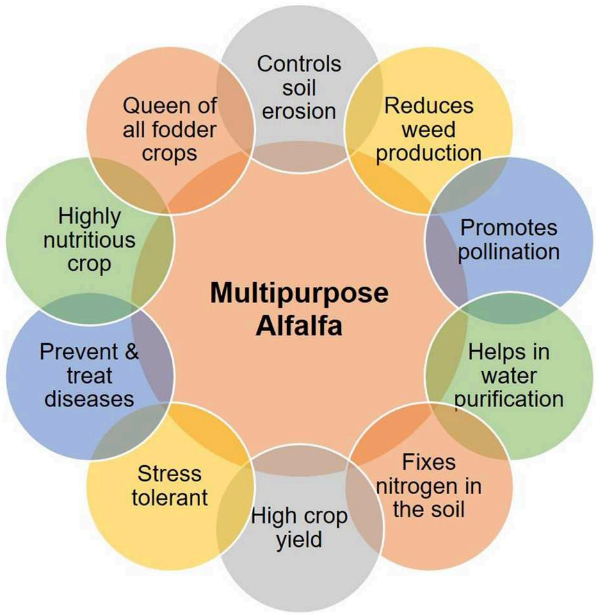

FIGURE 1
Uses of Alfalfa as a multipurpose crop.

2. Uses of Alfalfa

Alfalfa is a rich source of healthy nutrients and has countless benefits for livestock and humans. Figure 1 illustrates the uses of alfalfa as a multipurpose crop.

2.1. Role of Alfalfa as a fodder crop

Crops used as fodder are crucial in providing nourishment for cattle. Around the world more than 60 different varieties of legume crops have been produced for use as animal feed however, the most popular and widely used legume crop is alfalfa. Alfalfa has long been used as forage crop and also called as "queen of forages" because of its name which is derived from the Arabic word "Al-Fasfasa" which means "father of all plants". It is one of the top feed fodders in the world because of its outstanding nutritional profile, which includes high amounts of crude protein, secondary metabolites, as well as macro and micro minerals (Kim et al., 2022; Saifuzzaman et al., 2022; Suwignyo et al., 2022; Jiang et al., 2023). In comparison to other emerging nations, Pakistan has poor alfalfa seed and fodder output and reduced yields are the result of a number of issues including inadequate field management, an unjustified final cutting, weather changes, and ineffective treatment of diseases, pests, and insects. Numerous insect pests also affect the alfalfa crop by drastically lowering the output and product quality (Godfrey et al., 2013; Karar et al., 2021).

According to Global Lucerne (Alfalfa) seed market, America, Australia and Spain were the top exporters of Alfalfa seeds followed by Canada, Italy, France, Netherlands, Romania, Germany and South Africa in 2021. The positive and negative growth relationships of the top 10 exporters for the years 2018–2021 (Figure 2) suggest that these countries are working on developing the new technologies for improved alfalfa production. Several countries grow alfalfa in large quantities but their export value is quite low due to larger domestic consumption, notably China and Russia, which have 0.08 and 0.06% export values, respectively (Jiang et al., 2021). Pakistan ranked 42nd in Alfalfa exporters with only 0.02% export value, despite the fact that the consumption is confined to fodder crops only. A comparison between two main fodder crops of Pakistan has been done to analyze their characteristic features in Table 1.

2.2. Alfalfa as a source of essential nutrients for humans

Alfalfa is high in nutrients that aid in bodily growth and development. Its leaves have around 439 kcal/100 g of energy which is mostly made up of proteins, carbohydrates, lipids, and other nutrients (Achilonu et al., 2018). Proteins are usually considered as high-quality meals for health reasons and many nutritionists believe that alfalfa proteins can help a man's health since they contain more protein than any other proteinaceous foods like beef, chicken, egg, and milk (Table 2). Furthermore, it contains a number of key amino acids, eight of which are essential and

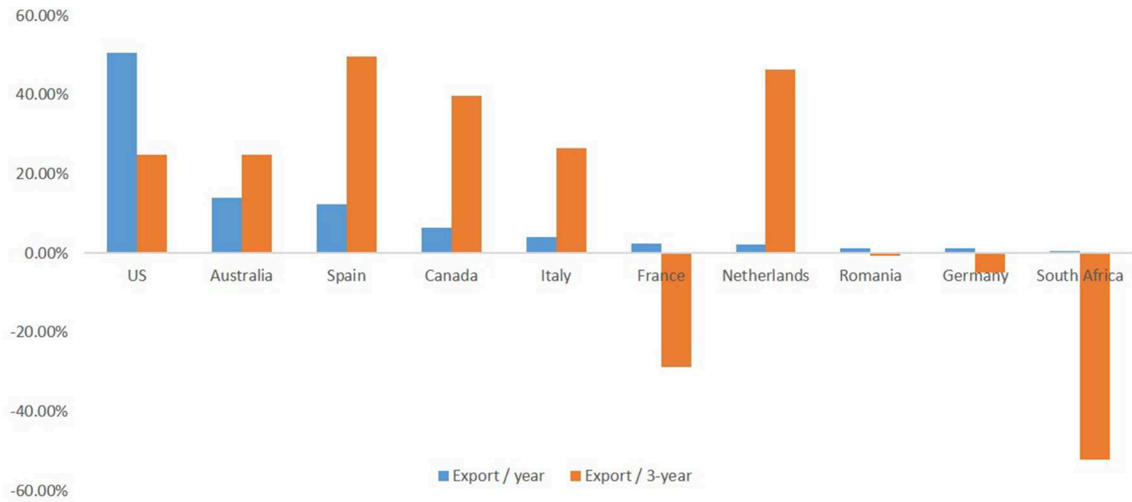

FIGURE 2
Top exporting countries of Alfalfa seeds (Source: tridge.com/intelligences/lucerne-seed). The blue bar represents the rank-wise exports of alfalfa seeds in 2021. The majority of the top exporters have a positive tendency in their annual export whereas the red line represents the variations in export per three years. The rate of increase in export growth is proportional to decreased self-usage or a broad adoption of new technologies. Due to high domestic consumption of seeds, China ranked 29th in the world with an export value of 0.08%. Pakistan is not even among the top 40 exporters with only (0.02%) export value.

it meets the amino acid requirements of adults as suggested by the United Nations FAO (Kerfai et al., 2011), some of them are mentioned in Table 3 (World Health Organization, and United Nations University, 2007). It also includes vital vitamins including vitamin A and C as well as a variety of minerals like zinc, iron, manganese, calcium, and molybdenum as mentioned in Table 2 (Kerfai et al., 2011; Zhang et al., 2017). Overall, it contains a vast quantity of energy that may meet a body's energy requirements to greater extent and it has the potential to play key part in socioeconomic civilizations due to its low cost, also including minor crops such as alfalfa in modern cropping systems is one possible way to diversify food supplies, increase nutritional security and lessen the impact of unfavorable weather patterns (Joshi et al., 2019). According to the USDA National Nutrient Database, 100 grams of alfalfa contain the following nutrients (Figure 3) however, because alfalfa sprouts have some link to the food poisoning, there is still controversy regarding the daily consumption that is safe for human health due to lack of quantitatively recorded studies on humans (Michalczyk et al., 2019; Mohammad et al., 2019).

Edible Alfalfa Leaf Protein (EALP) was administered to people for the first time in 1962 and the results showed that its biological value was comparable to milk. It also contains a number of amino acids that are similar to those found in chicken and animal proteins. Not only did children's height and weight increase as a result of taking it, but their blood quality also improved significantly, assisting anemic patients in overcoming low hemoglobin levels (Diedrich and Macholz, 1989). Another study found that EALP is easy to digest and can promote development if it is included in sufficient quantities in regular meals (Firdaous et al., 2010). EALP contains 1667.4 kilojoules of heat, 60 grams of protein, 50 milligrams of iron, 0.8 milligrams of calcium, and 1.4 micrograms of carotene per 100 grams (Aletor et al., 2002). Another study found that EALP is easy to digest and can promote development if it is included in sufficient quantities in regular meals (Firdaous et al., 2010). To benefit from this nutrient rich plant, humans can also take its sprouts, directly in salads, soups, and casseroles as well as its seeds, dried leaves as tea, concentrates as powder, pills, capsules, or liquid extracts as drinks (Mandle and Chaudhari, 2020). As a result, this might be the most cost-effective energy source available to socioeconomic societies like Pakistan, Bangladesh, and Laos. etc.

2.3. Role of Alfalfa in diet therapy

Alfalfa is a plant that may be used to treat a variety of health issues. It has long been utilized in homeopathic and ayurveda remedies to treat digestive and nervous system diseases (Bora and Sharma, 2011). It is good for cholesterol control which is a leading problem these days and makes the body susceptible to various disorders. The recommended treatment for this problem is to eat cooked alfalfa seeds three times a day, each dosage being 40 grams (Marles and Farnsworth, 1995). CholestaidTM, an American medication that comprises *M. sativa* extract and citric acid in concentrations of (900 + 100 mg), acts well against excessive cholesterol by neutralizing cholesterol in the stomach before reaching the liver. In addition, it is also said that it has no negative or poisonous effects on the body.

Leaf protein extracts have anti-cancer properties due to the presence of carotene as well as function in slowing down the aging process and other bone-related disorders such as rheumatoid

TABLE 1 A comparison of Pakistan's top two leguminous fodder crops (Alfalfa and Berseem).

Plant characteristics	Alfalfa	Berseem
Common name	Lucerne, Alfalfa	Berseem, Egyptian clover, Clover
Scientific name	*Medicago sativa L.*	*Trifolium alexandrinum L.*
Family	Fabaceae	Fabaceae
Origin	Iran	Syria
Leading producers	USA, Australia, Spain, Canada	Egypt, Syria, Pakistan, India
Type of crop	C_3 plants	C_4 plants
Life cycle	Perennial	Annual
Ideal soil	Light textured	Heavy textured
Crude protein content	16–25%	12.8%
Crude fiber content	20–30%	26.7%
Type of Roots	Deep root system (16–20 feet)	Shallow taproot system
Crop practice	Green fodder, Hay, silage, sprouts	Green fodder, silage
Green fodder production year^{-1}	80–100 Mg ha^{-1}	1.0–1.2 Mt ha^{-1}
Grain yield (Mg ha$^{-1)}$	300–2,000 kg ha^{-1}	340 kg ha^{-1}
Forage cuts season^{-1}	7–8 cuts	4–6 cuts
Water requirements season^{-1}	7,500 m^3 ha^{-1}	4,500 m^3 ha^{-1}
Fertilizer demand year^{-1}	20 kg N ha^{-1}, 60–75 kg P_2O_5 ha^{-1}, 40 kg K_2O ha^{-1}	10 kg N ha^{-1}, 60–75 kg P_2O_5 ha^{-1}, 30–40 kg K_2O ha^{-1}
Salinity stress	Moderately sensitive-resistant	Sensitive
Drought stress	Highly resistant-tolerant	Less resistant
Waterlogging stress	Sensitive	Tolerant

Hedayetullah and Zaman, 2022.

arthritis and osteoarthritis. After going through a deodorization procedure, the supernatant obtained during the protein extraction process might be a good source of nutritious beverages with high nutritional value for elderly folks (Ibarra-Herrera et al., 2011). It can also help those with renal problems to maintain a steady flow of pee. It also helps with emphysema, cardiovascular and senile cataracts, asthma, stomachaches and bleeding problems (W. Zhang et al., 2017). Other uses include its role in hormonal misbalances, menopause related symptoms and infertility related issues in females. Most importantly it can also reduce blood sugar level in diabetic patients which is a genetically transferred chronic disease and is not curable yet. Hence, Alfalfa is also getting attention as an emerging nutraceutical crop which has multiple health benefits like buckwheat (Joshi et al., 2020) and amaranth (Joshi et al., 2018). Table 4 lists some of the medical uses for alfalfa as well as its functional activity.

2.4. Role of Alfalfa in nitrogen fixation

Alfalfa roots develop well in the second to third year of growth, yielding 80–120 quintals of root biomass per hectare, returning nitrogen, potassium, phosphorus, and other associated components in the form of manure and replacing 40–60 t of manure application in the soil (Ivanov, 1988; FAO, 2017). In comparison to soybean and corn, alfalfa roots can reach up to a depth of 16–20 feet in the soil (Figure 4, Fernandez et al., 2019b), but corn and soybean roots can only reach a depth (Saifuzzaman et al., 2022) of 6 feet and are primarily concentrated in the top layer of the soil (Yang et al., 2014). It not only fixes nitrogen in the soil, but also makes N_2 accessible to the plants planted after alfalfa in a crop rotation system like corn, as illustrated in Figure 5 (Fernandez et al., 2019b). The association between Alfalfa and *Sinorhizobium meliloti* is thought to be the most effective association for nitrogen fixation in the soil (Oliveira et al., 2004). Its deep and powerful root structure aids nitrogen fixation more than any other leguminous crop such as soybean (Yang et al., 2010; Collino et al., 2015). The ability of soybean to fix nitrogen is well known, however the total nitrogen fixed in Australia was between 75 and 109 kg/hectare/year which is much lower than that of alfalfa (Hughes and Herridge, 1989).

In one study, it was found that alfalfa may fix up to 4–650 kg of nitrogen per hectare each year (Peoples and Baldock, 2001). The reported BNF (biological nitrogen fixation) ranged from 70 to 250 kg N in North America (McCaughey and Chen, 1999) 152 kg N for the Mississippi River Basin (Russelle and Birr, 2004), 93–258 kg N for eastern Canada (Burity et al., 1989), 174–466 kg N for western Canada (Kelner et al., 1997), 120–250 kg N for Minnesota (Zhu Y. et al., 1996; Zhu Y. P. et al., 1996), and 200–650 kg N in Argentina (Racca et al., 1998). This suggests that the stated nitrogen fixation rates in each of the other parts were highly different.

However, its capacity to use nitrogen for its own growth is limited, making it reliant on foreign nitrogen fertilizer for growth (Tufenkci et al., 2006). Over 800 million hectares of land is impacted by salt as sodic or saline or both, globally, accounting for 6% of the world's total land area (FAO, 2010). So, for maximum symbiotic advantages in salty soils, roughly 120 kg N per hectare or 30 mg N per kilogram is the optimal amount. More than 30 mg N per kilogram is thought to have a deleterious impact on nodulation and biological N_2 fixation (Issah et al., 2020). As a result, exogenous nitrogen fertilizer use should be carefully monitored.

2.5. Alfalfa in soil erosion controls

Soil erosion is a displacement of the uppermost layer of the soil. It increases the risk of vital nutrients to runoff and decreases the water quality and agricultural productivity that ultimately results in ecological and economic losses in semi-arid regions that is a vivacious element of terrestrial eco-systems (Zhang et al., 2016). For sustainable agriculture, especially in hilly areas, soil conservation management is a crucial factor and cover crops are best solutions for soil preservation (Hunt et al., 2019). Cultivation of cover crops, precisely alfalfa in comparison to bare land can reduce soil erosion by up to 98%. It also helps in providing organic matter to the soil by triggering soil microorganism's activity (Bak and Lee, 2021).

TABLE 2 Nutritional comparison of alfalfa with well-known daily diets mg/100g.

Food item	Raw protein	Ca	Fe	Mn	Zn	Mo	Vitamin A	Vitamin C	Folic acid
Alfalfa Leaf	5.1×10^4	3,140	80.0	118	1.26	0.78	55	30.0	0.30
Egg	1.4×10^4	55	2.8	11	1.0	0.16	0.3	1.0	–
Chicken	2.1×10^4	14	1.0	19	–	0.35	–	–	–
Beef	1.7×10^4	10	3.0	20	1.5	0.05	0.02	0.3	0.02
Milk	3.5×10^3	130	0.1	11	0.75	0.07	0.03	0.1	–

The information is gathered from Volenec et al. (2002).

TABLE 3 Amino acid comparison of Alfalfa with other foods.

Protein source	Lys	Phe	Met	Thr	Iso	Val	Tyr
Alfalfa leaf	6.3	6.0	2.1	5.2	9.8	6.3	1.6
Meat (fish and poultry)	8.1	4.9	3.3	4.6	7.7	5.8	1.3
Hen's egg	7.2	6.3	4.1	4.3	4.1	4.0	1.5
Wheat gluten	0.8	6.4	1.5	4.1	3.7	4.2	0.7
Soybean	6.4	4.8	0.6	3.7	3.5	5.0	1.2

Lys, Lysine; Phe, Phenylalanine; Met, Methionine; Thr, Threonine; Iso, Isoleucine; Val, Valine; Tyr, Tyrosine.
The information is gathered from World Health Organization, and United Nations University (2007).

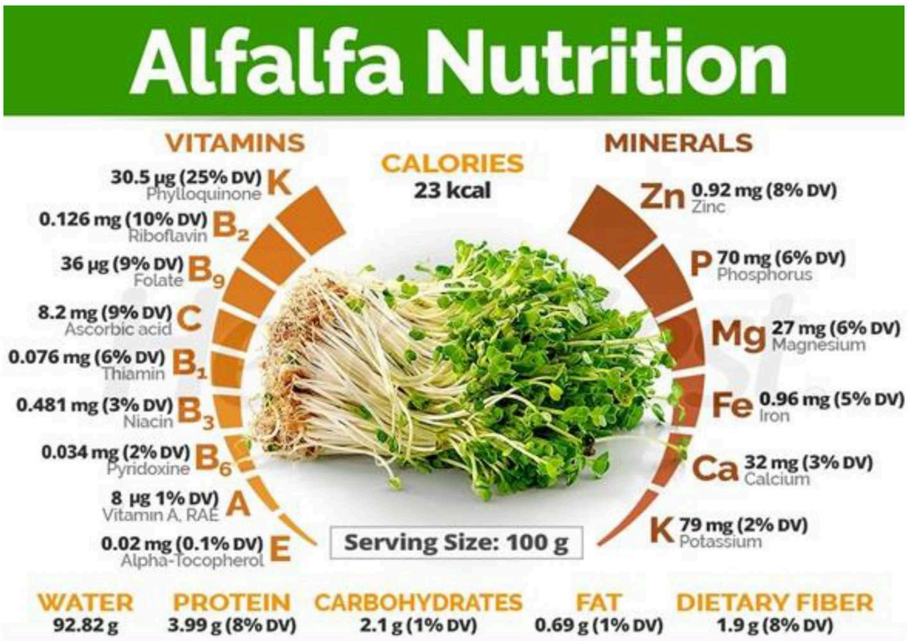

FIGURE 3
Nutritional value of alfalfa per 100 grams of serving. %DV stands for: percentage daily value (Source: USDA National Nutrient Database).

A study reveals that alfalfa can control soil erosion to a higher extent when planted along with potato and maize as an intercrop in the same environmental conditions (Sun et al., 2014; Afshar et al., 2018) due to its highly penetrating and wide-ranging root system (Li et al., 2017) that holds soil particles together. Another study explains that continuous production of corn when planted alone gives around 7.4 tons/acre of soil loss, while crop rotation of corn along with oat and alfalfa, lessens this loss to approximately 2tons/acre (Figure 6, Larson et al., 1997). It also contributes to better soil health by boosting soil fertility and preserving soil structure (Ehsas et al., 2018). Hence it is clearly seen that alfalfa significantly controls soil erosion in a crop rotation practice.

It is also reported that continuous cultivation of alfalfa in the same place can cause extreme water losses. Alfalfa gives maximum production in 8th to 9th year and afterward started to decline due to

TABLE 4 Medicinal properties of alfalfa.

Part of plant used	Functional activity/role	Medicinal applications	
Alfalfa sec. metabolites: saponins & phytoestrogens	Phytoestrogens, typically coumestrol, quercetin & apigenin exhibit strong estrogenic activity	Can be used in treatment of hormone related cancers	Huyghe et al., 2007; Wei et al., 2007
Seed & Bud extract in beverages	Relieve indigestion by clearing arteries to become narrow	Prevent atherosclerosis or arteriosclerosis, aging & osteoporosis	Wei et al., 2007; Bora and Sharma, 2011
Seeds & Roots	Controls cholesterol by dropping the lipid conc. in blood	Improves liver functioning & treated calculus	Basch et al., 2003; Bora and Sharma, 2011
Mostly Leaf extracts	Avoid menopausal symptoms in old females by balancing the effect of hypoestrogenism	Treated hot flushes, night sweating, mood swings and palpitations	Frank et al., 1998; Kargozar et al., 2017
As infusion (1 g/400 mL) As diet (6.25% by weight)	The manganese content of *M. sativa* (45.5 mg/kg) Reduce sugar level in diabetic patients	Reduces the level of hyperglycemia in streptozotocin induced diabetes	Swanston-Flatt et al., 1990
Aerial parts	Relieve endometriosis symptoms in young females	Regularizes menstruation, reduces heavy bleeding, clotting and inflammation	Mandle and Chaudhari, 2020
Alfalfa sprouts as source of calcium, vitamin K, D2, D3, & genistein	Helps in bone formation, hinder bone resorption & prevent bone loss	Treated osteoporosis	Mandle and Chaudhari, 2020
Direct intake of leaves before giving birth to child	Can be used as alternative of iron & folic acid	Avoid hemorrhage at birth time & treated anemia	Mills, 1994
Sprouts	Fulfills the need of vitamin c	Treated dysuria, scurvy & herpes simplex	Castleman, 1995; Duke, 2002
Sprouts & powder extract	Induces prolactin production, also used as Galactagogue	increases breast milk in nursing mothers	Reilly, 1989; Goksugur and Karatas, 2014; Rajagopal et al., 2016; Javan et al., 2017
Sprouts	Balances hormone, by increasing LH & estradiol conc., also enhances ovulation & folliculogenesis	Cures infertility in females	Adaay et al., 2013; Contero et al., 2015
Extracts	Maintains kidney health	Treat urinary and bowel problems, remove kidney stones	Lust, 2014

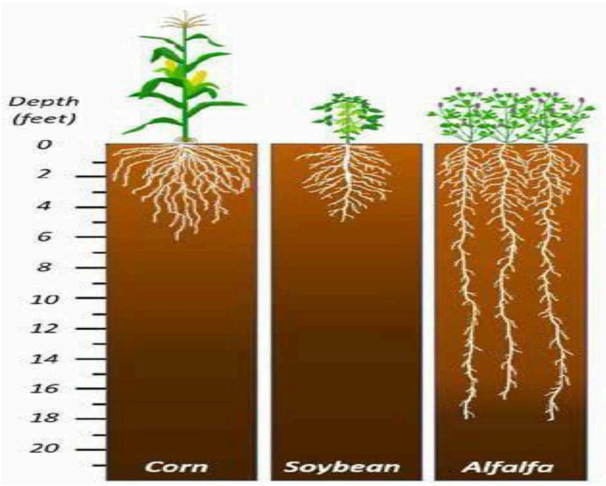

FIGURE 4
Root length of corn, soybean and alfalfa in 2nd to 3rd year of growth (Fernandez et al., 2019b).

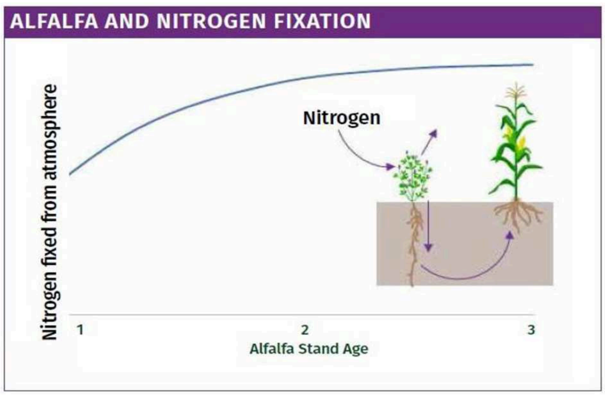

FIGURE 5
Alfalfa's nitrogen fixation from atmosphere to the soil in the 2nd to 3rd year of stand. (Fernandez et al., 2019b). Part of this nitrogen is lost during hay harvest, but the majority of it is absorbed into the soil, providing a positive nitrogen balance after alfalfa harvest that may be utilized by subsequent crops.

soil water depletion in the western Loess Plateau (Luo et al., 2015). Considering a precipitation rate of about 600 mm in certain area, alfalfa should not grow in a same place for more than 8 consecutive years to withstand soil water content (Ren et al., 2011).

2.6. Use of Alfalfa in water purification

The residues of wastewater after removing settled solids from it is called sludge. This can be achieved by chemical precipitation or a simple sedimentation process. A study revealed that this grass can also grow well in sandy loam soil up to a concentration of

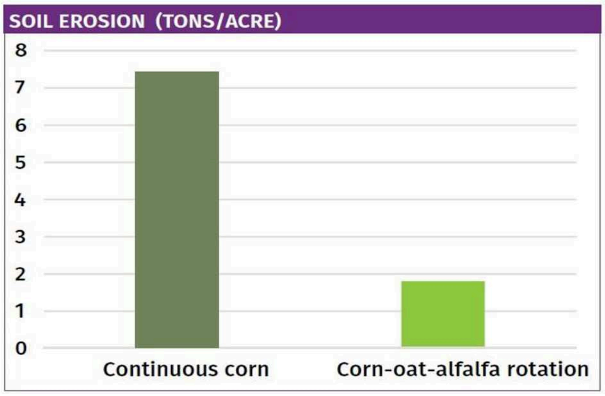

FIGURE 6
Rate of soil erosion in continuous and intermittent corn production fields by oat and alfalfa (Larson et al., 1997).

75% sludge water without being negatively affected. Although, Pure sludge water could be dangerous for plants and animals both (Dube et al., 2018). This clearly exhibits that it can grow equally well in pure water and sludge water. This quality can lessen the clean water needs for the irrigation system which is highly in demand in this water shortage time period.

Many societies in the agricultural areas are dependent on well water and face the problem of excessive nitrate (the soluble form of nitrogen which is normally used as fertilizer) in their drinking water supplies. The presence of excessive nitrate in drinking water can cause "blue baby" syndrome (reduced blood oxygenation) and related health issues. Societies whose groundwater is polluted with nitrate may have to pay lots of money for filtration equipment to purify their drinking water, this money could be saved if nearby farmers reduce nitrogen loss by growing alfalfa in their fields. It is because, alfalfa delivers valuable provision in maintaining groundwater nitrate levels since it upholds living roots all over the year by fixing nitrogen. It not only minimizes the need of nitrogen fertilizer but also take-up surplus soil nitrate from the ground, predominantly in the late fall and early spring. In a case study in California, mobile soil nitrate level observed was 55–60% lower in alfalfa growing fields than corn growing field specially when noticed in late fall (Fernandez et al., 2019a). So, growing of Alfalfa near excessive nitrogen mixed water bodies could save lives of many people who are at a risk to get disease like blue baby syndrome.

2.7. Alfalfa flower attracts so many pollinating insects

Globally, Animal pollination supports nearly 87% of flowering plants (Ollerton et al., 2011) and about 35% of crops consumed by humans also get pollinated by animals (Klein et al., 2007). Alfalfa is a cross-pollinated crop and its optimal seed production depends on pollinator's activity. Alfalfa flowers also get pollinated by different kind of visiting bees for sexual contact (Cane, 2002). The most common pollinators of alfalfa are honey bees (*Apis mellifera L.)*, leaf cutter bees (*Megachile rotundata*), bumble bees (*Bombus terrestris L.*) and specie of alkali bees (*Nomia melanderi*) and (*Rhophitoides canus)*. The alfalfa leaf cutter bee, which is intensively encouraged in and around the alfalfa fields in USA and is traded commercially for about 800 million insects annually, is the most important pollinator of alfalfa seeds in North America (Peterson, 1992; Reisen et al., 2009; Osterman et al., 2021). In China, the primary and most widely used pollinators of alfalfa are honey bees. However, according to Zhang et al. (2022) the bumble bees are the more efficient ones than honey bees in pollen dispersal of alfalfa for wind pollination. Alfalfa is also a home for most of the beneficial insects to live on, hence called as "insectary" (Summers and Putnam, 2008). Alfalfa fields alone give one third of the overall honey achieved from United States (Fernandez et al., 2019a). Hence, it promotes pollination.

Although most of the insects are beneficial for many other plants as well as alfalfa but still it helps some pests to grow which is not healthy for those crops which are directly consumed by livestock. The current threat to alfalfa is a stink bug pest that is recently being noticed in Pakistan and the only solution to control it right now is: the use of pesticide (Karar et al., 2021). However, use of pesticides is not always considered as a decent option for the crops which are directly consumed. So, it is necessary to find a more suitable way to get rid of these pests and overall economic losses in alfalfa.

2.8. Reduces weed production

Some alfalfa varieties positively control growing weeds in the paddy fields. In a study, two species of alfalfa (*Yuba* & *Rasen*) were used along with bran and hull (by products of rice) in a paddy field for weed control. Both the varieties showed incredibly higher results 95.2 and 90.5%, respectively. On the other hand, hull and bran could control only 51.7 and 25.1%, respectively. *Rasen* not only controls the weed production within the field, also it increases the paddy yield up to 80.6% which was 9.6% higher than the herbicide treatment (Xuan et al., 2003). Planting alfalfa with oat (*Avena sativa*) as an intercrop can significantly controls weed production in the field (Figure 7) shows that seed predation rate was maximum in alfalfa fields because of maximum activity of birds in the field (Westerman, 2005). More visitors, more chances of seeds to be lost and this seed loss activity by predators control the weed production in the alfalfa fields more than soybean, corn and small grains (Nichols et al., 2015).

2.9. Can be planted as stress tolerant specie in stress prone areas

Worldwide, salinity affects approximately 800 m ha of irrigated land and a major limiting factor in agricultural productivity (Roy et al., 2014). Higher salt levels cause ion toxicity primarily $Na+$, hyperosmotic stress and some derived stresses as oxidative damage (Zhu, 2002). Unlike most high value crops (rice) Alfalfa is reasonably a salt-tolerant crop with high commercial value and relatively more fit for yield purposes with low quality water (Li et al., 2020). In a study, a salinity tolerant cultivar (Halo) shows less sodium concentration in shoots as compared to roots which

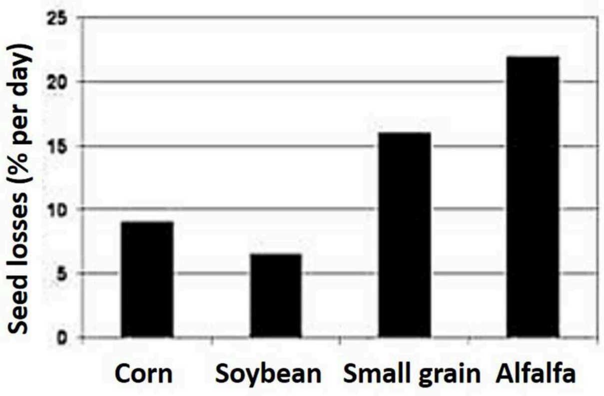

FIGURE 7
Seed loss rate in corn, soybean, small grain and alfalfa fields (Westerman et al., 2005).

indicates that this plant restricts the sodium translocation from roots to shoots by controlling salinity affects (Cornacchione and Suarez, 2017).

Ecologically, alfalfa can live in arid and semi-arid regions with equitable tolerance to water deficit (Hamidi and Safarnejad, 2010). Alfalfa breeding species are considered as drought and salinity tolerant because they consume less water when compared to other leguminous crops like clover, peas and soybean etc. Alfalfa grows up to 3 feet in height and its extensively strong root system spread widely to several meters by accessing water at longer distances (Shi et al., 2017). Its root length commonly extends up to 16 feet (Fernandez et al., 2019a). It also has a high range of adaptability toward extreme temperature fluctuations from extreme cold plains to high mountainous valleys, from temperate agricultural land to intense hot deserts (Bora and Sharma, 2011; Suwignyo et al., 2022). Under drought, many of alfalfa sp. shows some anatomical adaptations (increased leaf and ground tissue thickness and particularly leaf sclerenchyma thickness which is mainly responsible for moisture lock) and physiological modifications (increased carotenoids and soluble sugars content) making it resistant toward water shortages (Mickky et al., 2018). All these characteristics confirmed its place in the group of drought tolerant plants.

2.10. Early maturation and high yield by osmopriming

Seed osmopriming is a process in which seeds are treated with chemical agents such as Polyethylene glycol (PEG), hydrogen peroxide, sodium hydrosulphide, melatonin or sodium nitroxide before soaking. Osmopriming reduces the germination time in the areas where abiotic stress is expected due to semi-arid environmental conditions. This not only help plants to mature early but also improve germination percentage for high yield outcomes. This will lessen the threat of global food security in stress prone areas like Punjab Pakistan (Savvides et al., 2016). A study in Morocco revealed that treated seeds with osmopriming agent (PEG-6000) at 25°C for 24 h showed remarkable difference in physiological (low MDA content, ROS reduction, better membrane stability) and phenotypical parameters (quick seed germination, improved plumule & radicle length) of Moroccan Alfalfa (Mouradi et al., 2016). This shows that osmopriming could play an important role in higher production of alfalfa.

Seed priming with water and mannitol 4% at 25°C for 12 h significantly improved the germination percentage, also root and shoot length of alfalfa cultivars improved greatly by enhancing the activities of peroxidase (POD), proline content, catalase (CAT) and superoxide dismutase (SOD). In addition, reduced Malondialdehyde (MDA) content and electrolyte leakage further confirmed its resistance toward salt stress at seedling stage (Amooaghaie, 2011). In saline areas, the use of seed priming can be a great contribution in enhancing the crop yield.

3. Major constraints of Alfalfa production

Alfalfa production is primarily influenced by environmental and botanical factors as well as environmental stresses (Zahran, 2017). These adverse environmental conditions pose a substantial threat to alfalfa growth, development, survival and yield with significant consequences at the biochemical, morphological, physiological and molecular levels (Lei et al., 2018). Abiotic factors such as salt, drought, heavy metals stress and climate change) are expected to reduce alfalfa yield endangering world feed and food security (Worknesh and Getachew, 2018). Biotic stress factors including pest insects and pathogens specially nematodes and aphids, reduce the yield of alfalfa plants which are considered as major limiting factors. For example, the Stink Bug, Alfalfa Weevil and Potato Leafhopper (PLH) are the main threats to alfalfa production as described below (Hutchins et al., 1990; Sulc et al., 2004).

a) **Stink bug**

The seed production of the alfalfa crop is seriously impacted by a number of biotic factors but the highest reduction in seed yield losses are because of stink bug infestation (Rice et al., 2014). Stink bugs are an invasive species from Asia that first arrived in Pennsylvania in 1996 and can now be found in much of the continental United States (Rice et al., 2014; Leskey and Nielsen, 2018; Schuler et al., 2021). It is a renowned pest of alfalfa pods and also has more than 60 host plants (Bernon et al., 2005). Global yearly agricultural losses attributed to stink bugs alone are estimated to be larger than those attributed to other insects. According to Wheeler (2001) sucking by the alfalfa bug, *A. lineolatus*, can reduce seed production by 50%. According to a research, 10 different types of insecticides were reportedly employed to manage stink bugs between 2016 and 2017 from which the Acetamiprid and Acephate were shown to be the most efficient killers of stink bugs at the rates of 81.14 and 80.65%, respectively. Insecticide application not only killed the stink bugs but also increased seed output from 28.05 to 116 kg/acre in following 4 years without chemical control. In order to increase the alfalfa seed output, it is advised that acetamiprid and acephate can be used in an integrated management program (Karar et al., 2021).

b) **Alfalfa weevil**

The alfalfa weevil, (Hypera posticais) is also current main pest in alfalfa crops across the world and causes a lot of damage in Spain during its first cut (Levi-Mourao and Pons, 2021). It was discovered in Utah (United States) in 1904 and its origin can be traced back to Europe, South Central Asia, Northern Africa and in the United States. In the early season, this aggressive insect causes defoliation and poorer hay yield and quality. Although both adults and larvae eat alfalfa but the larvae causes the most harm to terminals, leaves and new crown shoots (Kingsley et al., 1993). Cultural, chemical and biological control methods are all viable options to include in an alfalfa weevil integrated management plan but complete control needs further research (Pellissier et al., 2017).

c) **Potato Leafhopper**

In most of the years, the potato leafhopper (PLH) was the most devastating alfalfa pest in North Central and Northeast United States (Chasen, 2014). Yellowing of the leaf tips is one of its indications. Due to the timing of spring migration, early cuttings often escape potato leafhopper damage; however, mid- and late-season cuttings are vulnerable to intense potato leafhopper pressure and damage. Alfalfa damage is most severe in young plants either during the seeding year or shortly after harvest during first regrowth. Potato leafhopper feeding reduces production by reducing internodal length and stem heights (Lamp et al., 1985; Lefko et al., 2000). This pest also significantly reduces the crude protein content of alfalfa (Hower and Flinn, 1986; Sulc et al., 2004) which is an important nutritious component provided by alfalfa. It was also discovered that this trend was mediated by the influence of Potato leafhoppers on alfalfa where infested alfalfa matures around 30% slower than uninfested alfalfa, resulting in decreased daily accumulation of dry matter and nutrients (Hutchins et al., 1990).

4. Conclusion and future perspective

Alfalfa is a valuable food and feed crop for both humans and animals. In many countries throughout the world, it is directly consumed by people due to its extensive nutraceutical (nutrition+ pharmaceutics) applications, however in Pakistan it is still considered as fodder. The rising desire for nutritious diets as well as improved public awareness has fueled the creation of new crops in the enormous nutraceutical industry. However, when compared to main crops, breeding projects for nutraceutical production of alfalfa is lacking. Alfalfa thrive excellent results in the field of medicine and food and apart from nutraceutical applications the strong root system of cultivated plants may flourish well under abiotic pressures. Besides, due to its broad adaptability, alfalfa is an excellent choice for diversifying current agroecosystems and mitigating adverse weather extremes. However, large-scale genetic resource development is required for the creation of nutraceutical traits and nutrient-rich alfalfa commercial cultivars with respect to environmental fluctuations. Also, the comparative histological approaches of alfalfa can be a useful signal for good understanding of the growth settings, particularly stressed ones. Therefore, detailed anatomical research on the production of alfalfa in different conditions is required. There are numerous unanswered questions about alfalfa practices in terms of various alfalfa applications notably for human nutrition, for that reason the current state of alfalfa research requires further exploration. In addition, the components obtained from alfalfa are required for research under development of horticultural and agricultural crops. As a result, extensive biochemical and human-based clinical research is required to promote it as a viable dietary intervention for human consumption. In a word, increasing the nutraceutical potential of alfalfa can help to shape modern cropping systems to meet future consumer demands in developing countries like Pakistan, India, Bangladesh, Vietnam, and Laos.

Author contributions

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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