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REVIEW ARTICLE

Nutritional, ecological and livelihood significance of *Moringa oleifera*: A review

Kishor Atreya[1,2,*], Kanchan Kattel[3], Krishna Raj Tiwari[1,2], Sony Baral[1,3,4], Rabindra Adhikari[2], and Om Prakash Kalwar[5]

[1]School of Forestry and Natural Resources Management, Institute of Forestry, Tribhuvan University, Kathmandu, NEPAL
[2]Department of Watershed Management and Environmental Science, Institute of Forestry (Pokhara Campus), Tribhuvan University, Pokhara, NEPAL
[3]Institute of Forestry, Office of the Dean, Tribhuvan University, Kathmandu, NEPAL
[4]Department of Social Science and Forestry, Institute of Forestry (Pokhara Campus), Tribhuvan University, Pokhara, NEPAL
[5]Department of Watershed Management and Environmental Science, Institute of Forestry (Hetauda Campus), Tribhuvan University, Hetauda, NEPAL
[*]Corresponding author's E-mail: k.atreya@gmail.com

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ABSTRACT

The potential ecological and livelihood benefits of Moringa plants are often overlooked. There is a need to raise awareness and encourage farmers and decision makers to adopt Moringa on marginal and degraded lands with changing climate risks. Previous studies have focused mainly on the pharmacological uses and oil content from a commercial point of view and failed to explore its ecological benefits and economic potential to address the growing problems of global food insecurity, malnutrition, and climate risks. Planting Moringa on unused and marginal land can improve soil fertility, food production, and resilience to climate change, offering a significant opportunity for diversification of livelihoods and economic development in the changing climate. Henceforth, this study compiles scientific evidence through a systematic literature search to highlight the ecological benefits and livelihood opportunities associated with the use of Moringa. Initially, we retrieved 206 pieces of global literature and, through the application of inclusion and exclusion criteria, extracted information from 22 articles. Various studies have consistently shown that Moringa leaves are highly nutritious and that their consumption can combat food and nutrition insecurity in low-income countries. Its seeds offer the potential for the commercial production of oils with heart-healthy properties. The oil is stable and suitable for cooking and its quality varies depending on location and environmental factors. When included in the diet, Moringa leaves improve the quality and quantity of goat milk and support the growth of fish in aquaculture. The extract of Moringa provides versatile uses in water purification, offering sustainable solutions to water pollution. We thus conclude that Moringa's diverse applications can contribute to the livelihood enhancement and economic well-being of poor and marginalized farmers in low-income countries. Planting Moringa trees in abandoned croplands and other degraded areas can have positive ecological and socioeconomic outcomes for rural communities. However, to support smallholders in low-income countries, favorable policies, field-based research evidences, and products development are crucial.

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INTRODUCTION

The Moringa (*Moringa oleifera* Lam.) tree is becoming popular for its many uses, such as medicine, industry, nutrition, and environmental benefits (Islam *et al.*, 2021; Horn *et al.*, 2022; Pareek

et al., 2023). It also provides opportunities for livelihoods (Amaglo *et al.*, 2017). Since 1998, the World Health Organization has promoted Moringa as an alternative to imported food supplies to treat malnutrition (Sreelatha and Padma, 2009). It is a fast-growing, drought-tolerant, and a multi-purpose tree due to its medicinal and nutritional properties (Yisehak *et al.*, 2011). Scholars have reputedly known it as the "cabbage tree," the "drumstick tree," the "horseradish tree," the "benzoil tree," the "miracle tree" and the "mother's best friend tree" (Daba 2016; Devkota and Bhusal 2020; Kashyap *et al.*, 2022). Moringa cultivation has significant commercial, industrial, nutritional, and medical uses (Horn *et al.*, 2022; Pareek *et al.*, 2023). Commercial cultivation of Moringa has the potential to bring numerous advantages to farmers, specifically small-scale farmers. Moringa can help ensure food security and create more sustainable landscapes. Studies have highlighted the positive impact that Moringa farming can have on livelihoods (Amaglo *et al.*, 2017; Devkota and Bhusal 2020). Inclusion of Moringa in agricultural systems along with other crops is more profitable than monocropping methods (Devkota and Bhusal 2020; Shode and Amanuel 2016). Moringa cultivation is also a profitable. For example, a recent Ghanian study (Kudzinawo *et al.*, 2022) revealed that investment in Moringa farming is a profitable for smallholders, with a rapid payback period of only 22 months. For a hectare of leased land, the estimated net present value was $833 spread over 10 years, and the benefit-cost ratio was 1.65.

Moringa trees can be the most suitable species for adapting to climate change and ensuring nutritional security for particularly poor households in the rural community (Daba 2016; Amaglo *et al.*, 2017; Yadav and Ghimire 2019; Devkota and Bhusal 2020). Despite the widespread distribution and its numerous benefits, many smallholders are unaware of its potential benefits. Small-land farmers often overlook the Moringa crop due to their limited acreage (Animashaun *et al.*, 2016), and a lack of awareness of its numerous benefits, and as a result, the full potential of this crop remains untapped (Devkota and Bhusal 2020). Previous works on Moringa have focused mainly on its extract analysis for medicinal and pharmacological uses (Anwar *et al.*, 2006; Kasolo *et al.*, 2010; Gopalakrishnan *et al.*, 2016), as well as its oil content (Anwar and Bhanger 2003; Abdulkarim *et al.*, 2007; Anwar and Rashid, 2007; Manzoor *et al.*, 2007). There are limited studies on the effect of Moringa farming on smallholder livelihoods in developing countries in the changing climate. Therefore, our review aims to understand the ecological benefits and economic potential of Moringa for these communities to address issues such as food insecurity, malnutrition, increased vulnerability to climate risk, and reduced livelihood quality in rural areas of developing countries, including the Chure landscape of Nepal. This study gathers scientific evidence on ecological benefits and livelihood opportunities to promote the use of Moringa. Planting Moringa on unused or degraded land can increase soil fertility, food production, fuel and livestock resources, and decrease vulnerability to climate change and other hazards.

METHODOLOGY

We retrieved literature from the Elsevier-produced Scopus bibliographic database, which now contains more than 90 million records and nearly 35,000 peer-reviewed journals (https://blog.scopus.com/posts/scopus-now-includes-90-million-content-records). Scopus provides comparatively better scholarly information on a global scale (Baas *et al.*, 2020). We also retrieved articles from Nepal Journals Online (NepJOL), which contain more than 160 scholarly journals on various topics. Since its inception in 2007, NepJOL has helped promote Nepalese scholarship and research to a global audience. We searched the literature with 'Moringa' in the title published between 2000 and 2022. We found 200 articles in Scopus, but only six in NepJol. We developed some exclusion and inclusion criteria to select these articles for review. Excluded are review articles (23), conference articles (01) and chemistry of phytochemicals (160). We did not review studies whose main objective was to analyze the medicinal properties of Moringa extracts. We included only 22 articles in our study that evaluated the nutritional, ecological, or livelihood benefits of the Moringa plant. We extracted information from the 22 articles in a well-developed review protocol. Figure 1 detailed search criteria and other processes we adopted on this review.

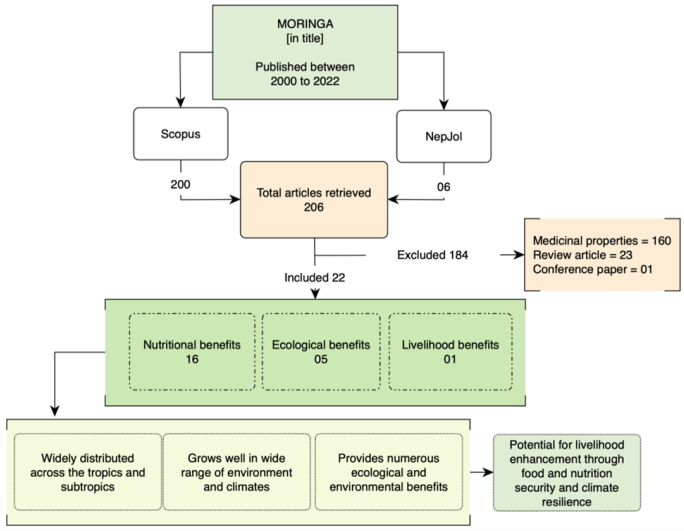

Figure 1. *Methods adopted during literature search and information extraction.*

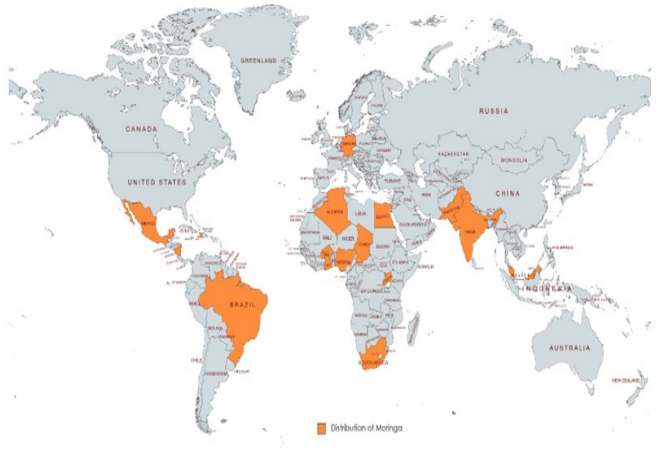

Figure 2. Country-wise distribution of moringa studies.

RESULTS

Distribution of moringa

The 22 selected articles were further classified according to their broad thematic areas, 16 focused on nutrition, 5 on ecology, and 1 on livelihood. Three of the articles delved into the potential pharmacological applications of Moringa-derived products, while two highlighted the traditional ethnobotanical uses of the plant. Almost all articles (21) were based on laboratory or field experiments and other had collected data from household surveys. The articles chosen are from various locations around the world, such as southwestern Algeria, South Africa, Brazil, Burkina Faso, Chad, Egypt, Germany (Lab work), Ghana, Haiti, India, Malaysia, Mexico, Nicaragua, Nigeria, Pakistan, and Uganda (Figure 2). We have summarized some main findings of these 22 articles, which are provided in Table 1.

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Nutritional benefits

Moringa holds great promise for improving livelihoods, improving food security, and improving climate resilience. Moringa leaves are used in tea, soup, and powder forms. A study in Uganda (Popoola and Obembe 2013) found that different ethnic groups use Moringa leaves to make soup and tea and eat crushed roasted seeds such as groundnuts. Moringa leaves contain a variety of useful phenolic compounds, such as apigenin-7-C-glucoside, apigenin-8-C-glucoside, and 3-p-coumaroylquinicacid, as well as most flavonoids, while the concentration of flavonoids (total and individual) was highly associated with the type of cultivar (Nouman *et al.*, 2016). The leaves of the cultivar 'Pakistan Black' had a higher percentage of crude proteins (31.4% higher than other cultivars), while 'Pakistan White', 'Sunyaw', 'Kumasi' and 'Techiman' had lower percentages, and cultivar 'China' had the lowest crude proteins. This research found that Moringa leaves are rich in dietary protein and minerals, specifically calcium, phosphorus, magnesium, and potassium (with higher levels in Pakistan Black). These leaves are a valuable source of nutrition for humans and livestock, despite slight variations in nutritional content between different types of Moringa. Nouman *et al.* (2016) also observed that 'Pakistan Black' and 'Techiman' are more nutritious than others. Similarly, Oduro *et al.* (2008) found that *Moringa oleifera* leaves are more nutritious than other vegetables such as cassava leaves, amaranth, mushrooms, taro leaves, and pumpkin leaves, and established that Moringa leaves contain higher calcium, iron, dietary fibers, and proteins, so they are superior in dietary nutrients.

Compared between different parts of the plant, a high content of crude protein was present in Moringa leaves, a moderate content of crude fat, a high fiber content (especially in the insoluble fraction), sugar content varied between samples, a high mineral content in the diet (calcium, iron, sodium, copper, magnesium and zinc content), high phytates and β-carotene 2 (Leone *et al.*, 2015). They observed the highest content of fiber, glucose and fructose in Haitian leaves, and the sucrose content in Algerian samples. The dried Moringa leaves have a remarkable nutritional profile, containing a whopping 30.3% crude protein and 19 different amino acids (Moyo *et al.*, 2011). Furthermore, they are a rich source of crucial macronutrients, with a content of 3.65% calcium, 1.5% potassium, and 0.30% phosphorus (Moyo *et al.*, 2011). In addition, they are rich in microminerals such as 490 mg/kg of iron, 31.03 mg/kg of zinc, 3.63 mg/kg of selenium, and 8.25 mg/kg of copper (Moyo *et al.*, 2011). In addition to that, they contain 17 different fatty acids and are packed with vitamin E (77 mg/100g) and beta-carotene (18.5 mg/100g) (Moyo *et al.*, 2011). Their impressive fiber content further increases their potential as a nutritional powerhouse plant, particularly for nutritionally challenged regions around the world. This makes Moringa an excellent candidate to improve the health and well-being of people in need. Drying and dehydrating Moringa leaves can reduce their nutrient content compared to fresh leaves. For the best drying results at home, it is recommended to use the cabinet tray or oven drying instead of the sun. These methods help to preserve nutrients in the leaves. Yameogo *et al.* (2011) found that Moringa leaves have less protein and fat compared to the seeds of the plant. However, according to the Food and Agriculture Organization, Moringa leaves have more iron (17.2 mg/100g) than other vegetables that are known to contain large amounts of iron. Amaglo *et al.* (2010) conducted research on flavonoid and crude fat content in various parts of a plant. Their study found that leaves contained the highest and most complex flavonoid content, which was completely absent from roots and seeds. Although seeds had the highest crude fat content, leaves, flowers, and pods also contained a significant amount. This provides crucial information on the nutritional value of different plant parts and can guide individuals in selecting the parts they consume. Leaves were also rich in fatty acids such as palmitic (16:0) and linolenic (18: 3), the seeds were predominated by oleic acid (18: 1), roots rich in palmitic and oleic acid, and stems and twigs contained mainly palmitic acid (Amaglo *et al.*, 2010). Another study (Sánchez-Machado *et al.*, 2010) discovered that immature pods have the highest dietary fiber levels, which is nearly two times higher than leaves and flowers. Furthermore, leaf samples have the highest levels of protein and lipids. The percentage of non-structural carbohydrates ranged from 24.98% in immature pods to 36.04% in flowers. The three parts of *Moringa oleifera*, in total, comprise 14 different fatty acids. The leaves contained the highest amount of amino acids, that is, almost twice as much as the flowers. Different parts of the moringa plant contain all amino acids except methionine, which is absent in most green leaves (Sánchez-Machado *et al.*, 2010).

Moringa seeds contain mainly two types of proteins, globulins that comprise approximately 53% of total proteins in the seed, and albumins that comprise approximately 44% of total proteins in the seed (Baptista *et al.*, 2017). Moringa seeds are also considered potential commercial oilseeds. Moringa oil has the highest amount of oleic acid (74.5%) of all other oils (compared to canola, soybean and palm) with low levels of palmitic acids (6.1%) and linoleic acids (0.7%), and a high content of oleic acid associated with a lower risk of coronary heart disease. Its oil was also found to be less susceptible to oxidation or to have a high oxidative

Table 1. Summary of findings.

S.N.	Article	Country	Thematic focus	Major findings
1	Abdulkarim *et al.* (2007)	Malaysia	Nutrition	Moringa seed oil is more stable in high-temperature frying and less subjected to deterioration compared to canola, soybean, or palm oil due to the high oleic acid content; the high oleic acid in moringa oil is beneficial in reducing the risk of cardiovascular disease and cholesterol.
2	Abdullahi *et al.* (2014)	Nigeria	Ecological	No significant effect of Moringa use was found on sweet potato yield or growth in the investigation, but Moringa is suggested for alley planting together with other legumes.
3	Amaglo *et al.* (2010)	Ghana	Nutrition	Flavonoids, proteins, and minerals were detected in different parts of *Moringa oleifera*, making it important for the health and nutrition of both humans and livestock; The moringa seed contains high oleic acid similar to that of olive oil, perhaps with health benefits.
4	Anwar and Bhanger (2003)	India and Pakistan	Nutrition	The Moringa seed produces high oleic oil, has potential for international trade through large-scale cultivation and oil production; Regular and adequate water availability for the Moringa plant improves the oil content in the seeds.
5	Anwar and Rashid (2007)	Pakistan	Nutrition	*Moringa oleifera* is valuable for the production of health-friendly cooking oil with high oleic content that could be used in households and commercial purposes.
6	Baptista *et al.* (2017)	Brazil	Ecological	The protein fractions (globulin and albumin) of the Moringa seeds are effective in water treatment; fractionation reduces the addition of the organic load of the Moringa seeds in water during purification.
7	Camacho *et al.* (2017)	Brazil	Ecological	Moringa is an effective coagulant to remove cyanobacteria and turbidity from surface waters; lowest concentration of moringa (50 mg/L) provided the highest removal of turbidity.
8	Abd El-Mageed *et al.* (2017)	Egypt	Ecological	Moringa leaf extract is an economic and nutritive biostimulant for plant growth in drought and salt stress
9	Kasolo *et al.* (2010)	Uganda	Nutrition	*Moringa oleifera* has a high preventive and curative property for diseases, as suggested by the phytochemicals present in the leaves extracts as well as traditional uses; leaves are used for the treatment of HIV, diabetes, malaria, and other human and livestock diseases.
10	Kholif *et al.* (2015)	Behera Governorate (Egypt)	Nutrition	Moringa leaf meal can substitute/supplement livestock feed as a protein source diet for lactating goats and possibly other livestock, too.
11	Leone *et al.* (2015)	Haiti, Chad and South-West Algeria	Nutrition	The nutritional composition and phenolic content of Moringa leaves are influenced by environmental conditions such as water stress, genetic factors, cultivation, and drying techniques; Moringa leaves contain flavonoids and phenolic acids such as salicylic and ferulic acids that are important as nutritional, nutraceutical, and functional ingredients.
12	Manzoor *et al.* (2007)	Pakistan	Nutrition	Compared to other Moringa species and vegetable oils, *Moringa concanensis* is found to be a better oil seed substitute; the geology and soil characteristics influence the oil content of *Moringa concanensis*.
13	Moyo *et al.* (2011)	South Africa	Nutrition	The high nutritional content in dried Moringa leaves suggests that it has a good potential for use as food and feed, it argues that drying the leaves assists to concentrate nutrients, facilitate conservation, and consumption.
14	Nouman *et al.* (2016)	Pakistan	Nutrition	Cultivar-wise, the nutrient composition should be considered during Moringa plant selection for nutrition; 'Pakistan Black' leaves had the highest total flavonoids and individual phenolic compounds.
15	Oduro *et al.* (2008)	Ghana	Nutrition	Moringa leaves are more palatable and nutritious than sweet potato leaves and have good potential to support daily nutrient needs.
16	Popoola and Obembe (2013)	Nigeria	Livelihood	Knowledge on the value of Moringa use can differ depending on ethnicity, age, and gender; *Moringa oleifera* has a high value of use for medicinal and nutritional (food) purposes, but more scientific explorations are needed.
17	Richter *et al.* (2003)	Germany	Nutrition	Moringa leaf can be used as a fish meal supplement, but the level of inclusion of moringa is still subject to further research, as higher use results in lower performance.
18	Saini *et al.* (2014)	India	Nutrition	The drying of Moringa leaves reduces the nutrient content and the cabinet tray method is the most recommended method of drying; For household purposes, the oven drying is better than the sun drying.
19	Sánchez *et al.* (2006)	Nicaragua	Nutrition	The use of Moringa in livestock feed is a protein-rich feed option that significantly improves dry matter intake, nutrient digestibility, and milk yields.
20	Sánchez-Machado *et al.* (2010)	Mexico	Nutrition	Moringa leaves and flowers are a good protein source; Immature pods have high dietary fiber and low lipid content; All parts of Moringa contain 14 different fatty acids; Variations in the amino acid composition of leaves are influenced by the quality of the protein and whether the plant is cultivated or wild.
21	Yameogo *et al.* (2011)	Burkina Faso	Nutrition	Moringa leaves have a high concentration of proteins, Ca, K, Mg, P, Fe, and Zn; Variability in the composition of nutrients was observed for *Moringa oleifera* leaves from three different sectors of the same city that have the same climate.
22	Zubair *et al.* (2021)	Pakistan	Ecological	Amendment of the Cd-polluted soil increased the dietary parameters in Moringa and prevented the possibility of human health risk through the diet.

stability during cooking (Abdulkarim *et al.*, 2007). The oleic acid content can differ between varieties, locations, and types of cultivation (wild or cultivated). A study reported that a high content of oleic acid is found in wild-derived Moringa oil in Pakistan, as in other Moringa oils (Anwar and Rashid, 2007). *Moringa oleifera* is the most studied Moringa species for oil content, but a significantly higher oil content was also found in Nagarpakar *Moringa cocanensis* seeds, which is attributed to geological characteristics and soil texture (slopes of low rocky hills) in the study area (Manzoor *et al.*, 2007). The same study also found that the residues of *Moringa concanensis* oilseeds contained a high protein content (30.07% of the seeds), a low fiber content (6%) and a ash content (9%), showed high resistance to hydrolysis and oxidation and a high level of oleic acid. Its oleic acid content represented 68% of total fatty acids followed by others, namely palmitic, stearic, behenic, and arachidic acids, and the ratio of monosaturated to saturated fatty acids is higher (Manzoor *et al.*, 2007). Another study (Anwar and Bhanger, 2003) discovered that seeds gathered from healthy cultivated plants in the Indus River belt (Pakistan) contain high levels of oil. This study found that Moringa plants with an adequate and consistent water supply produced superior oil. The findings of this study are comparable to those of other similar studies and present that Moringa seed oil has a high oleic acid content and excellent oxidative stability and is a potential plant for useful oil production. Zubair *et al.* (2021) discovered that providing consistent access to water and providing proper care to Moringa, while also using soil pollution control measures to limit the presence of heavy metals in the soil, is an effective way to improve food safety and nutrient levels in both leaves and roots of Moringa.

For livestock feed purposes, diets containing Moringa leaf meal were found to be more palatable, digestible, and beneficial for a significant increase in milk yield, milk energy production, and milk nutrient constituents (fat, protein and lactose) (Kholif *et al.*, 2015). A study observed an increase in milk production in lactating goats by 15% when fed Moringa leaf meal, and the increase was attributed to improved feed intake, digestibility, and ruminant fermentation (Kholif *et al.*, 2015). Moringa-based feed also improved milk composition by decreasing saturated fatty acids, increasing unsaturated fatty acids, and increasing conjugated linoleic acid content (Kholif *et al.*, 2015). When the cows were fed Moringa-supplied feed (2 kg or 3 kg of dry matter per day) during milking experiments, a notable increase in milk production was observed and no significant differences in milk composition were observed (Kholif *et al.*, 2015) . Furthermore, the milk produced had slightly higher fat and protein content, as well as higher fat-corrected milk production (Kholif *et al.*, 2015). These results suggest that incorporating Moringa into the livestock diet could be a beneficial way to increase milk production and improve milk quality. This resulted from an improved feed intake and digestibility with the incorporation of Moringa into *Brachiaria brizantha* hay due to the low concentration of neutral detergent fiber (NDF) present in Moringa (Sánchez *et al.*, 2006). Richter *et al.* (2003) also observed growth of fish fed a Moringa-based diet, showing inferior growth performance with higher percentages of incorporation of Moringa leaf meal (20% and 30% Moringa leaf meal), but suggesting that Moringa leaf meal could substitute up to 10% of protein feed for fish species (*Nile tilapia*).

Ecological benefits

Moringa seed powder has been found to be an efficient coagulant that effectively removes cyanobacteria and turbidity from surface waters (Baptista *et al.*, 2017; Camacho *et al.*, 2017). Its combination with other technologies can provide a powerful solution for the removal of water pollution. Its benefits have been noted in various studies, making it a promising solution for water treatment. One potential drawback of using certain substances is that they can contribute to elevated levels of organic matter in treated water. When this water is disinfected with chlorine, it can result in the formation of trihalomethanes, which are known to be carcinogenic. Using Moringa for water treatment can be concerning due to the organic load it may add to the water. The presence of albumin and globulin protein fractions in Moringa improves its coagulant potential, making it a more effective water treatment option. This process minimizes any negative impact on water, making Moringa a promising solution for water treatment. This coagulant can remove the water of color, turbidity, and UV254 nm without adding more organic content. Of all the coagulants tested, globulin was the most effective.

The extract of Moringa leaf is also useful in improving the growth performance of plants and crops and in managing environmental stresses. For example, the foliar application of Moringa leaf extract provided highly significant positive results for the growth and yield (*Cucurbita pepo*) of squash grown under water and salt stresses (Abd El-Mageed *et al.*, 2017), suggesting that Moringa leaf extracts support plant growth and yield under abnormal environmental conditions and stress. A study in Nigeria attempted to assess the role of Moringa plant in improving sweet potato yield through alley cultivation; however, due to the limited duration of the study, there was no significant effect of the use of *Moringa oleifera* on sweet potato yield and growth (Abdullahi *et al.*, 2014).

Pharmacological use

This study systematically excluded studies that mainly dealt with medicinal/pharmacological use, but included those that also talked about nutrition, ecology, and ethnopharmacology. The articles included suggest that *Moringa oleifera* is a rich source of phytochemicals and nutrients that are beneficial to human health (Amaglo *et al.*, 2010). Moringa leaf extracts were found to have several phytochemicals, such as tannins, steroids and triterpenoids, flavonoids, saponins, anthraquinones, alkaloids, and reducing sugars (Kasolo *et al.*, 2010). Moringa leaves are rich in hydroxycinnamic acids, a type of phenolic compound that has several health benefits for humans. Of this category, 3-caffeoylquinic acid is the most prevalent and beneficial for human consumption (Nouman *et al.*, 2016). The indigenous rural population also uses *Moringa oleifera* for the treatment of various diseases. A study in Uganda reported 24 different uses of *Moringa oleifera* among rural Ugandans, ranging from the treatment of HIV/AIDS-related symptoms, Malaria, Ulcer, to more

common ailments such as the use as an antiseptic, as well as vegetables, tea and soap (Kasolo *et al*., 2010).

In a Nigerian study (Popoola and Obembe, 2013), all included ethnic groups reported the medicinal use of Moringa as the most popular use. It was used to treat 30 diseases including malaria, typhoid fever, high blood pressure, arthritis, cuts, diabetes, cancer, and HIV/AIDS. In addition, it was used to promote lactation and strengthen the immune system. Leaves, bark, tuberous, and nontuberous roots (matured) were used for medicinal purposes (Popoola and Obembe, 2013).

Livelihood benefits

Moringa is a plant that people can use in many ways to make money. Its leaves, seeds, and other parts can be used in food, animal feed, medicine, and commercial products, such as oil and water treatments. Investing in this plant can provide numerous livelihood benefits to communities. The Nigerian community uses Moringa in seven ways: as food, medicine, animal feed, fencing material, firewood, gum, and to purify water (Popoola and Obembe, 2013). They also revealed a significant disparity in knowledge about the advantages of using Moringa between various age groups and ethnicities. The study showed that the elderly has the highest understanding of the advantages of using Moringa. Furthermore, the research found that there are differences in knowledge based on ethnicity.

DISCUSSION

Global distribution

The Moringa genus belongs to the monogenetic Moringaceae family, which comprises 13 different species (Pérez-Rivera *et al*., 2021). It is a hardy and fast-growing tree that can grow in various soils and climatic conditions. Among the 13 total Moringa species worldwide, *Moringa oleifera* is the most widely used and studied species, native to the sub-Himalayan tracts of northern India, mainly the Terai belts of Uttar Pradesh and Bihar (Varalakshmi and Verma 2017), distributed throughout the world in the tropics and subtropics and commonly used by humans. We retrieved 23 articles in total from different regions of Africa, Asia, the Middle East, and North America. Most of these studies reported *Moringa oleifera* Lam species, while one study (Manzoor *et al*., 2007) in Pakistan reported another *Moringa concanensis* species (also known as *Moringa concanensis* Nimmo and native to the sub-Himalayan tracts of northern India). Moringa thrives in areas with an average annual rainfall of 250-1500 mm and altitudes below 600 m, although it is found to grow at altitudes up to 2000 m in Nepal's midhills, and is environmentally well suited to tropical and subtropical climates, especially in regions with average summer temperatures ranging from 35 ° C- 43 ° C and altitude ranging from 300m-1400m such as Chure and Terai in Nepal and Uttar Pradesh and Bihar in India (Devkota and Bhusal, 2020).

The other 11 species out of 13, which are not reported in the reviewed studies but reported in various other records, are 1) *Moringa arborea* Verdc. native to Kenya, 2) *Moringa borziana* Mattei native to Somalia and Kenya, and 3) *Moringa drouhardii* Jum. native to Madagascar, 4) *Moringa hildebrandtii* Engl. native to Madagascar, 5) *Moringa longituba* Engl. native to Kenya, 6) *Moringa ovalifolia* Dinter and A. Berger native to Namibia and Angola, and 7) *Moringa peregrina* (Forssk.) Fiori native to the Red Sea and the Horn of Africa, 8) *Moringa pygmaea* Verdc. native to Somalia, 9) *Moringa rivae* Chiov. native to Kenya and Ethiopia, 10) *Moringa ruspoliana* Engl. native to Ethiopia and 11) *Moringa stenopetala* (Baker f.) Cufodontis, native to Kenya and Ethiopia (Olsona, 2017). Our analysis reveals that *Moringa oleifera* has been introduced in several regions of Africa and is well thriving, adapting to diverse climatic conditions. It has also gained popularity among locals due to its various benefits and uses. This indicates the potential of *Moringa oleifera* as a valuable resource in Africa. Moringa species have a broad geographical distribution, spanning 60 countries worldwide. The global extension of this plant highlights its potential as a valuable and adaptable resource.

Growing environments

Moringa grows well under a wide range of environmental conditions, such as various soil types, from sandy to loamy, and is drought-tolerant. Moringa is adaptable to different climates and can grow in poor soils without the need for much fertilizer (Mashamaite *et al*., 2021). Moringa plants require well-draining and sandy or loamy soil. Flooded or waterlogged conditions are not suitable for their growth. However, they are tough and can withstand a range of soil pH from 5.0 to 9.0 (Devkota and Bhusal, 2020). These qualities make it a hardy and reliable crop for farmers to cultivate. Moringa can be grown as a backyard tree, as an agricultural crop, or as a large-scale plant. In some regions of Africa, they are also cultivated as hedges to mark the boundary of the land and the fetish grove with a traditional priest in charge (Popoola and Obembe, 2013). Similarly, in South India, particularly in Tamil Nadu and Kerala, *Moringa oleifera* is commonly grown on homesteads, around cattle sheds, on farm boundaries, fences, and village wastelands, and as an intercrop (Pandey *et al*., 2011).

Moringa cultivation is viable from economic and social aspects because of its fast growth rate and great tolerance to variable environmental conditions. Environmental variation and types of cultivation influence the attributes of the Moringa plant and the quality of nutrient available in the plant parts (Sánchez-Machado *et al*., 2010). For instance, (Manzoor *et al*., 2007) mention that geology and soil characteristics influence the oil content in *M. concanensis*, while (Anwar and Bhanger, 2003) find that regular and sufficient water availability for the Moringa plant improves the oil content in the seeds. Moringa plants are highly tolerant to drought conditions, as they require little water and are widely grown in arid and semi-arid areas. Temperature is one of the crucial factors for the growth of Moringa. Temperature significantly determines the geographical distribution of the plant, growth performance, physiology, and yield (Anwar and Rashid, 2007), in which tropical and subtropical conditions with hot summers and mild winters are ideal for the

cultivation of Moringa trees (Muhl *et al*., 2011). *Moringa oleifera* thrives well at maximum mean temperature ranging from 25 to 35 degrees Celsius, but survives up to 48 degrees Celsius and winter frost for a limited period.

Ecological benefits

Moringa has been found to have a positive impact on the environment due to its ability to sequestrate carbon, fix nitrogen, reduce soil degradation, retain soil water, purify water, and serve as a biofertilizer and biodiesel, among others. The ability of the tree to absorb atmospheric carbon dioxide can contribute to mitigating climate change. Furthermore, (Abdullahi *et al*., 2014) suggested that the Moringa plant could also be useful for alley planting along with other legumes for increased yields of crops such as sweet potato. There are limited quality research studies on the contribution of Moringa plants to the carbon sequestration potential; however, the carbon sequestration potential of Moringa trees is found to be very high (Gedefaw 2015). To improve soil fertility, green Moringa leaves for mulching, dry shaded leaves can be used as organic manure, and seed cakes (or seed oil cakes) as soil conditioner and as fertilizer. Moringa seed powder is efficient in purifying impurities in water and performs similarly to alum during coagulation and seed oil can be used as environmentally friendly biodiesel (Varalakshmi and Verma 2017).

Diversification of income

Moringa is known as a multipurpose tree, and the *M. oleifera* species is a 'miracle tree' denoting its multiple uses and broad prospects. Its farming can provide a source of income for farmers, particularly in areas where agriculture is the main economic activity. The plant has many uses, including as a food source, a medicinal plant, and a raw material for various industries such as cosmetics and pharmaceuticals. Among the 13 Moringa species, four, namely *M. oleifera*, *M. stenopetala*, *M. concanensis*, and *M. peregrina*, are edible to any extent, and the rest are used for local medicine (Olsona, 2017). The finding of our review suggests the variation in knowledge of Moringa use based on ethnicity, gender, and age such that some ethnicities, older people, and women might have a better knowledge of use and benefits (Popoola and Obembe, 2013).

Many of the articles we reviewed have established that Moringa species can greatly help meet the nutrient requirements of rural and urban populations (Oduro *et al*., 2008; Moyo *et al*., 2011; Yameogo *et al*., 2011; Leone *et al*., 2015). Moringa capsule can increase breast milk volume (Fungtammasan and Phupong, 2021), and can treat malnutrition (Gopalakrishnan *et al*., 2016) with the high content of crude proteins, minerals, and vitamins in Moringa leaves. The leaves contain approximately 43% of amino acids such as methionine, cystine, tryptophan, and lysine (Montesano *et al*., 2019), and mature leaves are more nutritious than young leaves and shoots (Palada *et al*., 2017). Moyo *et al*. (2011) stated that Moringa leaves can be a supplement to protein sources for humans and livestock, while Kholif *et al*. (2015) and Sánchez *et al*. (2006) discussed the contribution of plants to livestock nutrition, since Moringa-based or Moringa-incorporated feed/fuel is found to be more palatable and digestible, increasing milk production, and improving milk composition to further support both income and nutrition for farmers. Moringa plantation is also believed to support beekeeping and the production of better-quality honey with its medicinal properties (Kasumbu and Pullanikkatil, 2019). The review article (Kasolo *et al*., 2010) illustrated the high preventive and curative properties of Moringa species, which is due to its antioxidant, anti-inflammatory, anticancer, antiulcer, antidiabetic, antimicrobial, and antihyperglycemic properties (Masih *et al*., 2019) resulting from the high content of flavonoids, glucosides, and glucosinolates (Rani *et al*., 2018).

There is very little research and consensus available on post-harvest nutrient loss in Moringa to draw a conclusion. Saini *et al*. (2014) mentioned that post-harvest methods can affect nutrient content and oxidation potential. Sun and microwave drying cause more nutrient losses compared to cabinet tray drying, oven drying, and lyophilization, which preserve more nutrients. Yet another study Ali *et al*. (2017) recommends oven drying at 50 degrees Celsius as the optimal condition for nutrient retention and color preservation in dried Moringa leaves. However, Montesano *et al*. (2019) stated that dried leaf powder can be stored at room temperature for several months without loss of nutrients. In general, Moringa, if processed properly after harvest, can significantly support food and nutrition security, particularly for vulnerable populations such as women and children.

The cultivation of Moringa on any scale will be helpful in diversifying income and food sources, and creating jobs. Growing and processing Moringa can be highly profitable while also improving self-sufficiency and nutrition security for impoverished communities and small-scale farmers. Despite the growing popularity and awareness of Moringa among farmers and consumers, promoting Moringa as a crop requires more attention to cultivation practices and systematic production on a commercial scale for profitable marketing and export of products in international markets (Pandey *et al*., 2011). Studies suggest that farming *Moringa oleifera* can improve smallholders' livelihoods in multiple ways. For example, Adikuru *et al*. (2012) highlighted the potential of *Moringa oleifera* for sustainability in the agroecosystem, as it can be used as green manure to supply essential nutrients to crops and increase yield; Nouman *et al*. (2014) mentioned its use as a feed crop for livestock farming and increases milk and meat production; and Oyeyinka & Oyeyinka (2018) discussed its application as a food fortification in food processing industries to help curb malnutrition; and Yadav & Ghimire (2019) described its role in food security and adaptation to climate change in the Hindu-Kush Himalayan region. The Moringa trunk is believed to be useful for papermaking (Varalakshmi and Verma, 2017). Studies (Sekhar *et al*., 2017; Balasubramaniam and Easwaran, 2019; Kudzinawo *et al*., 2022) found that Moringa cultivation is financially viable with benefit-cost ratio 1.72-1.63 and the internal rate of return 25-27%. Using Moringa leaf extract as growth hormone is cost effective and increases crop yield by 10 to 45%, depending on the crop type.

This is an excellent alternative for farmers who want to increase the quality of their crops without spending a lot of money, and it is also environmentally friendly. This, in turn, can raise the income of farmers and improve their livelihoods (Arshad and Takacsne, 2020). A review (Leone *et al.*, 2015) suggests that *Moringa oleifera* shows diversity in many of its characteristics, extensive morphological variability, and therefore variable nutrient content and bioactive compounds. The great genetic diversity between species provides sufficient diversity for genetic exploration and further genetic improvement efforts to produce nutritionally superior cultivars and improve the existing multipurpose benefits of *Moringa oleifera* (Shahzad *et al.*, 2013). Moringa farming is a practical approach to conserve fragile and degraded landscapes by offering a double-ended solution: soil preservation and economic opportunities for sustainable living. In areas such as the Chure landscape in Nepal or elsewhere in the world that are undergoing rapid geological and ecological degradation due to interactions between young mountains, natural livelihoods and associated encroachments, Moringa plantation potentially offers a symbiotic benefit to both nature and people by ensuring nutrition security, diversification of income by tapping its industrial value through supply chain management and microenterprise development, ecological restoration, soil conservation, and carbon sequestration.

Conclusion

Moringa leaves are known for their exceptional nutritional content, making them highly valuable in promoting health and combating malnutrition. Moringa seeds, on the other hand, offer potential for commercial oil production. The oil derived from these seeds contains high levels of oleic acid and low levels of palmitic acid, which makes it beneficial for patients with heart disease. In addition to its nutritional benefits, Moringa oil has excellent oxidative stability, making it a suitable option for cooking purposes. Its resistance to rancidity ensures that the oil remains fresh and retains its quality even when exposed to heat and cooking processes. The quality of Moringa leaves and oil can vary due to factors such as geographical location, soil texture, and moisture availability. Therefore, it is important to consider these variables when evaluating the effectiveness and potential benefits of Moringa. These factors play a crucial role in determining the overall composition and properties of the plant, which in turn affects the nutritional value and quality of the oil. Furthermore, Moringa leaves have been found to have a positive impact on lactating animals. When included in their diet, Moringa leaves can increase milk production and improve the quality of the milk produced. This benefit can be particularly valuable to farmers and communities that rely on dairy production for their livelihoods. In aquaculture, Moringa leaves have shown potential to support fish growth. By incorporating Moringa leaves as a feed supplement, fish farmers can improve the growth rates and general health of their fish stocks. This can lead to increased productivity and profitability in fish farming operations. The use of Moringa extracts in both water purification and foliar application for plant growth demonstrates the versatility and potential of this plant. It offers sustainable and environmentally friendly solutions to address water contamination issues and optimize agricultural productivity, particularly in challenging environments. The multifaceted uses of Moringa offer diverse opportunities for income generation and improving livelihood. Moringa has great potential to boost economic growth and promote sustainable development when utilized for its various applications in food, medicine, feed and commerce. Communities can fully harness the economic benefits of this plant and improve their well-being by capitalizing on its versatility. Much of the focus of previous studies has been on the medicinal value of the plant. The ecological and livelihood benefits of Moringa cultivation are less explored in different environmental and climatic scenarios. Therefore, we recommend future studies on the quantification of its ecological benefits and their role in improving the socioeconomic status of the poor. Planting Moringa trees on vulnerable land, including neglected farmland, is an effective method of improving the environment, fighting malnutrition and eradicating poverty in underdeveloped rural communities. However, we need strong favorable policies, field-based research evidence, and products development to support small-scale farmers in low-income countries.

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Declaration of interest statement

The authors declare that they have no conflicts of financial or non-financial interests.

Data availability and deposition

Not applicable, as the paper is based on a literature review.

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