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A valuable or a curse resource? A systematic review on expansion, perception of local community, benefits and side effects of *Prosopis juliflora*

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Introduction: *Prosopis juliflora* has posed a severe threat to human and animal life in arid and semi-arid areas of the world. Thus, this review intends to shed light on the potential use of Prosopis as a helpful resource and feasible management system.

Methods: This research employs a systematic review methodology.

Results: The review revealed that the species had been introduced to overcome deforestation and desertification. *Prosopis juliflora* has had different socioeconomic and environmental impacts on local communities. The most widely cited adverse impacts include out-competing native species and quickly reducing forage plants, being a harbour for predators, health problems and death of domestic animals, and being an ideal ground for mosquito breeding. On the other hand, the species provides multiple ecosystem services like the provision of construction materials, animal feed and charcoal; plays a role in soil conservation and rehabilitation of degraded and saline soils, good sources of nectar for honey production; contributes to reducing dust pollution; enhances carbon sequestration, and have medicinal value due to its antifungal and antibacterial features. The local community's attitude regarding the species is mixed.

Discussion: The consequent negative impacts are increasing quickly, making the urgent need to develop robust and practical management strategies necessary to both mitigate the adverse effects and fully use the benefits. Commercialization (with a notion of management through utilization) is a feasible way to minimize expansion. Cross-boundary endeavours for controlling *Prosopis juliflora* expansion to new regions, particularly in countries predicted as edges of high potential invasion, are required to manage the species invasion efficiently.

KEYWORDS

***Prosopis juliflora*, economic benefits, health benefits, environmental benefits, management through utilization, pastoral and agropastoral community**

1 Introduction

Globally, invasive species are the second most critical factor in reducing biodiversity, followed by habitat loss. While most of them were adopted to bring about positive socioeconomic and environmental effects (Laxén, 2007), they currently have complex effects on socioeconomic and ecological aspects, primarily affecting rural livelihoods, and some effects are irreversible (Eschen et al., 2023). One of the most predominant and dangerous invasive alien species, *Prosopis juliflora* (hereafter *Prosopis)*, is currently found in over 129 countries, mainly in arid and semi-arid regions of the world. The species is well adapted to harsh environmental conditions and has spread to most arid and semi-arid areas of the world, causing positive and negative impacts (Obonyo et al., 2017). These days, according to Kamiri et al. (2024), *Prosopis* has posed a severe threat to human and animal life in most East African countries, including Ethiopia, Somalia, Rwanda, Kenya, Djibouti, Eritrea, Sudan, and Tanzania. Dakhil et al. (2021) also underscored that *Prosopis* is among the most problematic invasive trees in tropical and subtropical regions. Kamiri et al. (2024) also labelled *Prosopis as* the most common alien invasive plant species in East Africa. As a result, the International Union for Conservation of Nature (IUCN) identified the species as one of the world's top 100 least-wanted species (Mwangi and Swallow, 2005; Kamiri et al., 2024). The species is a versatile tree that can be grown in various temperatures and soil conditions. It is also a fast-growing tree that can supply essential goods and has a nitrogen-fixing nature, which implies that it can improve soil fertility and increase crop yields. On the other side, *Prosopis* may also become an invasive species. It can produce dense thickets that reduce biodiversity by replacing native species.

Additionally, it may compete with crops for water and nutrients, which could reduce yields. The consequent negative impacts are increasing quickly, making the urgent need to develop robust and practical management strategies necessary to both mitigate the adverse effects and fully use the benefits (Shackleton et al., 2014; Patnaik et al., 2017; Bezaredie et al., 2023). Zeray et al. (2017); Abdulahi et al. (2017), and Shiferaw et al. (2022) are just a few of the well-documented examples of *P. juliflora*'s magnitude of proliferation and detrimental effects in different parts of arid and semi-arid areas. Not much comprehensive research has been done on its benefits other than using it as a source of fuelwood, fences, animal feed, and to make charcoal (Haji and Mohammed, 2013; Sola et al., 2021; Shiferaw et al., 2022). Thus, the debate is whether *Prosopis* ought to be eliminated or seen as a helpful resource that may be used. Thus, based on a large body of scientific literature and case studies, this review intends to shed light on the potential use of *Prosopis* as a helpful resource and feasible management system. Furthermore, the study evaluated whether controlling it through utilization could be a feasible alternative, presenting a paradigm shift from considering it as a "weed" to appreciating it as a "wealth." To that end, based on the literature, this systematic review would address the following issues:

1. How and why did *Prosopis spread* in different parts of the world?
2. What side effects and benefits do *Prosopis juliflora* have?
3. How does the local community perceive the spread effects and benefits of *Prosopis?*
4. What feasible management strategies are implemented globally to minimize the spread of the species?

2 Materials and methods

2.1 Review protocol

This research employs a systematic review systematically and scopingally analyzes prior studies and data from peer-reviewed published papers rather than conducting primary fieldwork or data collecting. This systematic review aims to critically examine the existing knowledge on the expansion of the *Prosopis* species, the attitudes of local communities towards *Prosopis*, and the documented side effects and benefits associated with *Prosopis*. Furthermore, the review aims to explore the feasible management strategies and options being implemented to address *Prosopis*-related issues. Thus, the study relied on published and grey literature. The systematic review process involved a comprehensive and purposive search of research outputs from published articles, grey literature, proceedings, reports, case studies, and books) focusing on the historical introduction and expansion of *Prosopis*, its socioeconomic and ecological impacts, species benefits, how the local community values the species, and management systems being implemented by different actors, we purposively included and critically reviewed them.

The search for peer-reviewed literature was conducted using the electronic databases "Agricola," "Science Direct", "Scopus", "Scispace", and "Google Scholar" and covered all literature indexed up to 2024. Key terms used in the searching process include "*Prosopis juliflora* + expansion", "*Prosopis juliflora* + historical background" "*Prosopis juliflora* + benefits", "*Prosopis juliflora* + side effects", "*Prosopis juliflora* + expansion + local community perception", "*Prosopis juliflora* + management systems", "*Prosopis juliflora* + management through utilization", "*Prosopis juliflora* + ecosystem services", "*Prosopis juliflora* + livelihoods", "*Prosopis juliflora* + pastoral and agropastoral communities". Research outputs focusing on the historical expansion of the *Prosopis juliflora*, the pros and cons of the species, the perception of local communities, management systems and prospects of the species were included in the review regardless of their time of publication. On the other hand, works on the species' physiology and biochemical features were not included in the systematic review. The extracted concepts and issues were coded and analyzed thematically. Practical case studies have substantiated the review. After pertinent sources were found and retrieved, the data and information were collected, and then a thematic method was used to code and evaluate it. As a result, the researchers could recognize important ideas, patterns, and recurrent themes in the available *Prosopis* literature. The analysis was further substantiated by including relevant case studies that provide practical illustrations and contextual insights. The extensive

and meticulous method used to evaluate the published and unpublished literature guarantees that the study's conclusions are firmly based on an awareness of the state of knowledge in this field.

3 Historical background of *Prosopis juliflora* and its expansion

Native to South and Central America over the past 200 years, *Prosopis* has been spread all over the world spreading from southern Mexico to Panama and from the Caribbean Islands to northern South America (Venezuela and Northern Peru) (Tewari et al., 2011; Hussain et al., 2021; Dakhil et al., 2021 and Kamiri et al., 2024). These days, it can be found in several semi-arid and arid climate zones, such as the Middle East, Australia the Arabic Peninsula, India, Pakistan, Sri Lanka, Senegal, Sudan, Ethiopia, Eritrea, Kenya, Namibia, and South Africa, as well as other parts of Southern America, India, Pakistan, Australia, and the Pacific (Abedelnoor et al., 2009; Tewari et al., 2011). *Prosopis* has been introduced to several hot tropical and arid regions of different countries with varied purposes like providing fodder, fuel wood and shade, for dune stabilization, combating desertification as well, and attacking deforestation (Hussain et al., 2021; Kamiri et al., 2024). For example, since *Prosopis* is drought-tolerant, the *Derg* regime deliberately introduced it to Ethiopia's arid and semi-arid areas in the 1970s and 1980s with the intention of environmental rehabilitation (considered an afforestation measure to reverse desertification) (Wakie et al., 2012; Haregeweyn et al., 2013; PENHA, 2015) (see Box 1). However, as of right now, it has had numerous unforeseen damaging social, economic, and ecological effects (Wakie et al., 2012; Haregeweyn et al., 2013; Rettberg, 2014; Ilukor et al., 2016; FDRE-MLF, 2017; Patnaik et al., 2017; Kamiri et al., 2024). Similarly, it was introduced in the late 1970s and 1980s to Kenya to address deforestation, desertification, fodder programs, and fuel shortage (Mwangi and Swallow, 2005; Maundu et al., 2009). Likewise, the species was introduced in arid areas of eastern Africa like Somalia to provide fuel wood and stabilize dune systems after prolonged droughts and deforestation in the 1970s and 1980s (Rembold et al., 2015).

Prosopis was introduced to Sudan in the early 19th century to combat desertification and as a source of fuel wood (Elfadl and Luukkanen, 2006). It was introduced to India by the end of the 20th century to recover salt and sodic-affected lands besides the need of the species for fuel wood, fiber and timber (Mishra et al., 2003; Sharma and Dakshini, 1998; Sato, 2013), and into the United Arab Emirates during the 1970s to combat desertification (El-Keblawy and Al-Rawai, 2007, and Howari et al., 2022). Similarly, it was introduced to Djibouti in the 1950s for shade and shelter and as a street tree in many towns. *Prosopis juliflora* was introduced to Djibouti in the 1980s and planted in different parts of the country to control desertification (Gianvenuti et al., 2018). *Prosopis* was introduced into Oman to combat desertification, enhance land productivity, and serve as a fast-growing ornamental tree in landscapes from Latin American countries in the 1970s (Al-Rawahy et al., 2003). Prosopis was introduced into South Africa in the 1980s for erosion control and windbreak and as a source of fuel wood (Maitre et al., 2002). Similarly, *Prosopis* was brought into Pakistan to provide a valuable source of income to people experiencing poverty and for the reclamation of dunes stabilization during the 1950s and 1960s. In comparison, it was dispersed into different country regions in the early 1970s (Essa et al., 2017).

Prosopis is a very robust invader that may swiftly take advantage of a suitable environment and control entire ecosystems due to its long life cycle, resistance to saline soils, ability to withstand droughts, high seed output, and dormancy of its seeds in the soil. Anywhere near human settlements, along highways and cattle trails, are suitable for growing *Prosopis* trees. Its main mechanisms for dispersing seeds are flooding and livestock (Mwangi and Swallow, 2005; Rembold et al., 2015). Due to possible future increases in temperature due to climate change, arid and semi-arid areas lands, mainly in Africa, are at the highest risk of invasion than other moist biomes (Dakhil et al., 2021). Since its introduction for environmental purposes in different parts of the world, *Prosopis* has been expanding alarmingly and now become a critical environmental concern, for instance. Alien invasive species have invaded much rangeland in Ethiopia's Somali and Afar regional states, and this invasion appears to continue (FAO, 2008; Eschen et al., 2023; FMECD, 2014; Zeray et al., 2017). Even in regions that seem to have been eradicated, soil-borne seeds can germinate, and trees can grow more quickly than under natural conditions due to previous insufficient attempts to restore reclaimed ground and avoid reinvasion by *Prosopis* seeds (Haregeweyn et al., 2013; FDRE-MLF, 2017).

4 Side-effects of *Prosopis juliflora*

Agropastoral communities' means of subsistence and food security are at risk due to *Prosopis*, which primarily affects the

BOX 1 Case study 1: expansion of *prosopis* in ethiopia

Ethiopia's semi-arid and dry regions suffer significantly from *Prosopis's* numerous adverse socioeconomic and environmental effects. It threatens the livelihoods of pastoralists, agropastoralists, and biodiversity as it spreads quickly through rangelands, croplands, forests, wildlife reserves, and national parks (Belay and Goshu, 2020). Unless swift action is taken to stop the species' spread, more areas may soon be invaded, increasing the likelihood that life-sustaining resources will be destroyed and that tribal conflict will break out for the remaining grazing and farming areas. This could lead to an unanticipated political crisis (Berhanu and Tesfaye, 2006; Bezaredie et al., 2023). The FMECD (2014) emphasized further that the loss of grazing ground by invasive species forces pastoralists to relocate to new grazing regions or look for new sources of income, which raises the possibility of confrontations with farmers and other pastoralists. Furthermore, the land degradation risk worsens by raising animal concentrations on the remaining grazing land. These could make pastoralists more susceptible to food insecurity and political instability.

arid and semi-arid lowlands of the Horn of Africa (Ethiopia, Sudan, Kenya, Eritrea, and Somalia are among the countries most severely affected) (FMECD, 2014). According to Shitanda et al. (2013); Haregeweyn et al. (2013), and Balcha (2022), the tree has widely expanded, taking up most of the grazing zones and creating impenetrable thickets that hinder the establishment of other plants. *Prosopis* thickets can completely cover an area, out-competing native species and quickly reducing forage plants; in the worst-case scenario, the pastoral community may be forced to relocate their villages as a result of the invasions; they also harbor predators and prevent undergrowth; animals that consume pods suffer from tooth loss and other health issues, which can sometimes lead to the death of domestic animals (significant assets of the pastoral community) (Pasiecznik, 2018; Edrisi et al., 2020). Study communities in Afar (Rogers et al., 2017) reported increasing proximity to wild animals, threatening their livestock and children. Besides, thorns make it difficult for pastoralists to penetrate the dense thickets to collect fuelwood, and thorns cause severe inflammation that may take a week to subside. *Prosopis* obstructed paths and roads used by both humans and livestock, making accessibility of grazing land and water points more complicated and requiring longer walking times to get to desired destinations (Mwangi and Swallow, 2005; Hussain et al., 2021; Shiferaw et al., 2022). Mehari (2015), on his part, stressed that the *Prosopis* invasion has hindered transhumance: seasonal migration of herds in search of feed and water (which is a common way of life in the pastoral community, and one of the risk management strategies being employed by pastoralists to maintain their livestock assets and also a feasible mechanism for the recovery of grazing lands).

Due to the lack of fodder in *Prosopis*-infested areas, a study conducted by Zeray et al. (2017) for the Dire Dawa city administration found a statistically significant difference in milk production revenue. Inkermann (2014) also noted that the size of the livestock herd, the primary source of income for pastoral communities, was declining in Ethiopia's pastoral areas as a result of recurring animal diseases and a reduction in grazing spaces, which was mainly brought on by *Prosopis* species' invasion of rangeland. *Prosopis* has also impacted the health of people and animals. Its thorns can cause lameness, blindness, infections, hand and leg ulcers, itching, and eye injuries. *Prosopis* pod consumption causes impaction and constipation in children. Long-term ingestion of the pod and excessive seed accumulation after feeding results in the death of cattle (Wakie et al., 2012; Inkermann, 2014; Abdulahi et al., 2017; Balcha, 2022). Thickets of *Prosopis* serve as excellent mosquito breeding grounds (Patnaik et al., 2017), and the most often cited issue was the prevalence of malaria linked to the thickets' growth (Wakie et al., 2012; Inkermann, 2014; Abdulahi et al., 2017). According to Hussain et al. (2021), its ability to flower more than once yearly enables *Prosopis* to cause health problems like allergies. Women should be responsible for looking for firewood and water, where the risk of being affected by the thorn is high (Inkermann, 2014). The species has a significant ecological impact; in Kenya, reports have indicated that it has reduced ground vegetation cover and reduced herbaceous species from regenerating (Muturi, 2012). A study by Tewari et al. (2011) reported that the invasion of *Prosopis juliflora* has turned the grazing lands into inaccessible hostile. *Prosopis's* thickets in the Afar region (Ethiopia) have decreased nearly 75% of the carrying capacity of arable lands in New Mexico, and around 60% of pasture land in the Banni area of Asia has vanished. *Prosopis* has an impact on birdlife as well. A study in India revealed a negative correlation between the diversity of bird species and non-native vegetation (Barhadiya et al., 2022). Another study also reported *Prosopis'* impact on birds through their chicks' mortality (Chandrasekaran et al., 2014). *Prosopis* also strains the infrastructure that pastoralism depends on: access is hindered by narrowed and blocked roads and tracks, and vehicles with inflatable tyres are more likely to puncture due to the thorns. This reduces opportunities to access markets because large vehicles cannot transport the livestock long distances, and herding options are complicated by the tendency to lose stock in the thickets as the roads become less visible (Rogers et al., 2017).

5 *Prosopis juliflora* as a valuable resource

5.1 Economic and socio-cultural benefits

Though the negative impacts of *Prosopis* are widely documented, the tree/shrub also produces valuable goods and services like construction materials, soil conservation and rehabilitation of degraded and saline soils, charcoal and animal feed production (and in some cases, food for humans) (Laxén, 2007; Mwangi and Swallow, 2005; Pasiecznik, 2018). Pasiecznik (2018) and Pandey et al. (2019) noted that charcoal production from *Prosopis* is the most popular and profitable activity in many developing nations, requiring no initial capital but only labour and conventional production methods. *Prosopis* produces exceptionally high-quality fuel wood that burns slowly, has a high calorific value, produces little smoke, and generates uniform heat (Pasiecznik et al., 2001; Preeti et al., 2015). *Prosopis* provides a hard and heavy wood that makes excellent firewood and superior charcoal (Tewari et al., 2011; Tessema, 2012; Shitanda et al., 2013; Abdulahi et al., 2017; Sola et al., 2021; Pasiecznik, 2018; Kamiri et al., 2024). Due to the large amount of biomass produced by *P. juliflora*, it is used in electricity generation. Recently, *Prosopis* pods have been known as an alternative substitute for ethanol production (Tewari et al., 2011). In Djibouti, for instance, *Prosopis* species have been becoming huge assets capable of supporting tree-based enterprises and livelihoods and providing conservation benefits (Gianvenuti et al., 2018).

Prosopis flowers are good sources of nectar, leading to high honey production (Wakie et al., 2012; Shitanda et al., 2013; Kamiri et al., 2024), and they flower throughout the year and provide nectar to bees. The flowers produce plentiful quantities of pollen and nectar, which can flourish for long periods and attract pollinators (Pasiecznik et al., 2001). It is a significant honey source in Bolivia, Jamaica, India, Pakistan, Sri Lanka, Peru, and Argentina (Tewari et al., 2011; Abdulahi et al., 2017). A study by Kumar et al. (2013)

found that *Prosopis* plantations can support up to 100 beehives per hectare. This makes the tree an essential source of honey for beekeepers. *Prosopis* is also a major gum and resin source (Wakie et al., 2012; Abdulahi et al., 2017). *Prosopis* pods may be used as dietary supplements for people and animals. According to Shitanda et al. (2013), the pods' high nutritional value demonstrated their potential for producing nutrient-dense goods such as juice, wine, gum, powder, essential oils, and drinks. *Prosopis* trees yield more fruit than other species that grow in comparable conditions. They began to produce fruit in the third or fourth year after germination (Pasiecznik et al., 2001). Because *Prosopis* pods have a high sugar and protein content, they make an excellent substitute food source for animals such as sheep, goats, cattle, pigs, and poultry (Tewari et al., 2011; Tessema, 2012; Wakie et al., 2012; Abdulahi et al., 2017; Ram et al., 2022). A study by Kumar et al. (2013) in India found an increase in milk production of up to 20% when pod flour was used for lactating animals.

Similarly, a study found that when 38% of grounded *Prosopis* pods were mixed with other ingredients, the body weight gain in goats increased by 38% (Tewari et al., 2011). Another study by Ali et al. (2012) confirmed that supplementation of the diet of Afar sheep with ground *Prosopis* pods resulted in growth performance and carcass parameters and improved their feed intake capacity. Consistent with this finding, a study in Oman (Mahgoub et al., 2005) revealed that *Prosopis*, a 200 g/kg proportion in goat diets, enabled improved feed intake, body weight gain, and feed conversion without compromising carcass yield or quality. According to a study conducted in Kenya, using *Prosopis* pods increased goat weight statistically compared to control groups (Kipchirchir et al., 2014). According to this study, feeding goats up to 200 grams of feed per day will improve their weight gain and have no adverse impact on their feed intake or digestibility.

Similarly, Ram et al. (2022) discovered that adding up to 20% of *Prosopis* pods to goat feed considerably increased the average daily weight gain and the overall weight gain. Another study in Kenya revealed that bread made with 20% *Prosopis* pods has a good taste and nutritional value (Wakie et al., 2012). For centuries, indigenous peoples in Latin America collected and stored pods in large baskets, which became important during droughts when food availability became a critical concern. Once the sun-dried pods are grained, bread, cakes, or rich gruels are prepared after mixing them with flours of maize or other grains (Pasiecznik, 2018). In addition to improving the feed value, the milling of the pods can be used as one of the mechanisms to control the invasion of the plants in the rangelands (Abdulahi et al., 2017). *Prosopis* also provided different cultural and artisan values. In certain cultures and indigenous communities, it may be used in traditional ceremonies, rituals, and storytelling, representing a connection to the land and ancestral heritage. It also provides valuable shade in hot and arid regions, relieving the scorching sun. This shade can create comfortable outdoor spaces for social gatherings, community events, and leisure activities (Alegi et al., 2010). Local artisans can create intricate carvings, sculptures, furniture, and other decorative items from *Prosopis* wood, showcasing the cultural heritage and skills of the community (Evans, 1998).

5.2 Environmental benefits

The leaves of the *Prosopis* plant are organic fertilizers (Shitanda et al., 2013). The leaves and pods of *Prosopis* considerably increased the amount of nitrogen, phosphate, and potassium in soils, according to research by Ilukor et al. (2016). Compared to other plant species, *Prosopis* has a deeper root system that aids in stabilizing the soil and reducing erosion (Kamiri et al., 2024). A study in Dire Dawa city administration proved that agropastoralists have good experience in converting some of the invaded grazing lands into cropland (especially for the production of sorghum) in gullies and degraded areas that are covered with good soil when invaded by *Prosopis* due to its ability to control gully erosion and soil retaining capacity (Haji and Mohammed, 2013; Kamiri et al., 2024). A considerable improvement in soil texture and organic matter under the tree canopy was also recorded. A study in Peru revealed that *Prospois* plays a crucial role in enhancing soil fertility and moisture, in microclimatic amelioration, and desalination (Beresford-Jones et al., 2009). A study in India also revealed that, due to its nitrogen-fixation nature, *Prosopis* could improve the soil quality of invaded areas (Edrisi et al., 2020)

Prosopis trees also help to remove heavy metals from contaminated soils, which is a sustainable and cost-effective method (Laxén, 2007; Walter and Armstrong, 2014; Pasiecznik, 2018). In this regard, Pasiecznik et al. (2001); Laxén (2007), and Pasiecznik (2018) found that *Prosopis* has an ameliorating effect on the soil under trees from nitrogen fixation and leaf litter that decays rapidly, which enables the improvement of soil physical and nutritional status; decreasing salinity and plays a significant role in reclaiming unproductive lands. Sharma et al. (2012) found that *Prosopis* can help to reduce soil salinity by up to 30% by absorbing salt from the soil, which makes practicing agriculture in saline soils possible. A study in India (Pandey et al., 2019) affirmed that the soil organic carbon, nitrogen, potassium, and soil moisture contents were higher under the *Prosopis* canopy than in open lands. Being evergreen all year round, even in arid conditions, it offers excellent shade in hot, dry areas, reducing the near-ground temperature (Laxén, 2007; Maundu et al., 2009). Because of its taproot structure, *Prosopis* can reach deep groundwater reserves. Plantations of *Prosopis* were found to enhance groundwater recharge by up to 200% in a study conducted by Singh et al. (2011). It also aids the environment by providing a range of species, such as birds, insects, mammals, food, and habitat. Kumar et al. (2013) say this may contribute to increased biodiversity and improved ecological function. *Prosopis* can enhance the water's quality by removing impurities from runoff water. Accordingly, a study by Singh et al. (2011) verified that the tree can lower runoff water's phosphate and nitrate levels by as much as 50%.

Prosopis also provides different ecosystem services like erosion control (used to arrest wind erosion and dune stabilization) and reclamation of lands (it is wildly planted for land reclamation because it is an aggressive colonizer, tolerant to impoverished, degraded, saline, alkaline soils); and nitrogen-fixing (it moderately enriches the soil with atmospheric nitrogen). For instance, a study in the Awash basin (Ethiopia) by Ayanu et al. (2014) reported that the dense shrubs of *Prosopis* physically shield soils from wind

erosion during dry seasons and from intense rainfall during wet ones. This lessens runoff in locations where grasses aren't present to cover the soil. In addition, during rainy seasons and when the Awash River overflows, the dense structures of the *Prosopis* shrubs stabilize the soil, regulate the flow of water, and promote the infiltration of water into the soil. Besides, *Prosopis* trees and woodlands play a significant role in sequestering carbon and combating desertification (Pasiecznik et al., 2001; Tewari et al., 2011; Walter and Armstrong, 2014; Abdulahi et al., 2017). A study by Tewari et al. (2011) found that, since *Prosopis* is a fast-growing tree, it can sequester up to 20 tons of carbon dioxide per hectare per year, which makes the resource a valuable tool for mitigating climate change. Another ecological role of *Prosopis* is its contribution to reducing dust pollution. A study by Singh et al. (2011) found that *Prosopis* plantations improved air quality and reduced dust pollution by up to 50%.

5.3 Health benefits

Prosopis wood is reported to have medicinal value due to its antifungal and antibacterial features (Tewari et al., 2011), while the leaves are widely used as herbal medicine due to their antibiotic nature (Shitanda et al., 2013), and the plant tissues are essential for oil extraction, mainly for beauty and medicinal products. *Prosopis* has been used for a long to produce bio-pesticides in India (Walter and Armstrong, 2014). In India, parts of *Prosopis* are used for medical purposes like treating skin infections, insect bites and bone injuries (Duenn et al., 2017). Henciya et al. (2017), on their part, revealed the medicinal value of *Prosopis* gum and smoke from leaves and pods to be used traditionally for anticancer, antidiabetic, anti-inflammatory, and antimicrobial purposes. A study by Ghasemi et al. (2015) found that leaves of *Prosopis* have anti-inflammatory and antioxidant effects, while the leaves are valuable in protecting against liver damage. Another study by Saleh and Abu-Dieyeh (2021) found that *Prosopis* bark has antimicrobial activity against various bacteria and fungi and can treat skin infections. Juliflorine compound extracted from the species is used to cure Alzheimer's disease (Henciya et al., 2017). Preeti et al. (2015) also reported that *Prosopis* contains antibacterial, antifungal, anticancer, antioxidant, and antimicrobial activity, which makes the resource valuable in pharmaceutical science. A study by Mutile et al. (2021) reported that leaf extracts of *Prosopis* have a significant inhibitory effect, exhibiting a higher splenic anti-amastigote effect. Alkaabi et al. (2020) further stated that the leaves of *Prosopis* have antimicrobial effect and are potentially helpful in treating infectious diseases. Pasiecznik et al. (2001) reported that the barks, leaves, flowers, and extracts of *Prosopis* are used to treat different diseases in different parts of the world, like treating pains, parasites and urinary disorders, skin disorders, dermatitis and parasitic infections, prevention of miscarriage, for the treatment of leprosy, dysentery, bronchitis, asthma, leucoderma, tremors, and rheumatism. Leaf smoke is used to cure eye infections, and extracts are recommended to treat snake bites and scorpion stings. *Prosopis juliflora* leaf methanol extract has been shown in an experimental study by Utage et al. (2018) to exhibit remarkable anti-breast cancer activity, particularly against triple-negative breast cancer cells. Additionally, studies have shown that *Prosopis* leaf extract significantly suppresses 4T1-induced tumour growth.

6 Perception of local community

Local communities in different parts of the world have varied outlooks towards *Prosopis*. A study by Tewari et al. (2011) affirmed that rural populations in arid and semi-arid tropics are a little apprehensive of the species as they consider that species adversely affects crop production and fear it may become a weed. Thorny stems and branches of the species, which often cause injuries to humans and animals and hinder agricultural operations, are the primary reasons for the villagers' dislike of the species. A study in India (Duenn et al., 2017) reported that the pastoralists do not perceive the *Prosopis* invasion as a significant problem. Mesfin (2006), on the other hand, reported that pastoral and agropastoral communities in Afar, Ethiopia, have come to recognize the ecological advantages of the species, such as enhanced saline lands, decreased wind damage, decreased erosion, and improved soil fertility.

Nevertheless, the overall harm caused by *Prosopis* surpasses these environmental advantages, and the people living in the area resent this and fiercely advocate for its destruction (Sweddy, 2015). According to Berhanu and Tesfaye (2006), the people who live in Somalia and Afar, Ethiopia, have different viewpoints. Pastoral communities usually have negative opinions toward the species because of its harmful consequences, which outweigh its benefits, on rangelands, farming regions, access to waterways, and health issues for humans and cattle. However, professionals, local urban populations, and specialists in natural resources all hold conflicting views regarding the species. According to Chekole (2014), the local community in the Afar region of Ethiopia has perceived *Prosopis* negatively due to its fast invasion rate and negative impacts like loss of biodiversity, physical harm to humans and livestock, blocking access roads to farms and irrigation canals, where the majority of people preferred complete eradication of the species. This is despite the plant's benefits in improving soil fertility and creating a microclimate for the plant. According to a Mehari (2015) survey study conducted in the Afar region of Ethiopia, even though the pastoral community frequently used the species for fuel wood, fencing homesteads, and house construction, 84% of the surveyed households rated the species as undesirable because it limited transhumance, occupied settlement areas, and affected the availability of grass and multipurpose trees and bushes. Similarly, a study by Seid et al. (2020) in the Afar region of Ethiopia reported that nearly 90% of interviewed respondents had disfavored the species due to its invasive nature.

In Kenya, the local population, particularly in rural areas compared to urban regions, holds a negative perception of *Prosopis* and would prefer not to live with it, even if it were used as a source of money in the form of charcoal, poles, and pods (Maundu et al., 2009). In South Africa, Shackleton et al. (2015) reported a negative attitude towards *Prosopis*, where costs associated with the species outweighed its benefits, and the local community recommends its reduction or eradication. In South

Africa, differing views were reported by Ravhuhali et al. (2021), where positive attitudes due to their potential as a source of good nutritional value and serve as an alternative source of protein and minerals for livestock during the dry season were reported. However, communities developed negative attitudes towards this species due to its adverse impact on the groundwater and its invasive effect on grazing lands.

7 Management systems of *Prosopis juliflora*

Regarding the management system of *Prosopis*, Shibru (2015) argued that there is limited knowledge and experience in managing and utilizing *Prosopis*, and there have been few policies or strategies for quick action. According to Shibru (2015) and Kamiri et al. (2024), the management system can be divided into four categories: mechanical control (which involves physically uprooting or removing plants from the site, often combined with burning, using hand-held or power-driven tools), chemical control (applying herbicides to prevent new growth or kill seedlings after cutting or burning), biological control (using living organisms to control pest species), and management through utilization (exploiting the economic potential of invasive species to meet basic human needs while controlling their spread and potentially eradicating them). Despite various attempts to eliminate *Prosopis* in different countries, the outcomes have not met expectations (Laxén, 2007; McConnachie et al., 2012). For instance, other efforts were made to eradicate the species using herbicides and mechanical measures in the USA, Mexico, Argentina, Sudan, Australia, and Pakistan, where little success was achieved. For example, common control measures in the Afar region (Ethiopia) include uprooting seedlings, cutting, and burning (Seid et al., 2020). As noted by Ayanu et al. (2014), eradication trials in Ethiopia (Awash region) using cutting and burning proved to be highly labor-intensive, expensive, and ineffective considering the rapid regrowth of the species that produces numerous sprouts shortly after clearing. Besides, due to failure in eradication, scientists worldwide started to explore the optimum utilization of *Prosopis*, where the species' benefits have been recognized recently (Tewari et al., 2011). Obonyo et al. (2017), for instance, recommended the commercialization of the plant seed for animal feed and human production as well as for medicinal use as a feasible way of minimizing *Prosopis*' expansion rate (see Boxes 2, 3). According to Pasiecznik et al. (2001) and Wise et al. (2012), if intentional management practices are not implemented, the shrubs will continue to spread to new areas and eventually become the dominant vegetation. By implementing further management and utilizing *Prosopis*, we can open up land for agriculture, promote the recovery of indigenous plant species, and reduce the risk of injuries to humans and animals.

Some scholars also argue that communities that depend on *Prosopis* as an alternative source of income may suffer if the plant is wholly eradicated (Tessema, 2012; Shitanda et al., 2013; Haregeweyn et al., 2013; Seid and Bekele, 2014; FDRE-MLF, 2017). As a result, a new management system with a notion of 'eradiation through utilization' has been promoted by different actors (Maundu et al., 2009; Borokini and Babalola, 2012; McConnachie et al., 2012; Haji and Mohammed, 2013; Wakie et al., 2012; Saleh et al., 2023). For instance, Chekole (2014) and Koech et al. (2021) revealed that, due to unsuccessful attempts made

BOX 2 Case study 2: *prosopis* management through utilization in the Afar region (using cooperatives)

Farm Africa, an NGO in Ethiopia's Afar area, introduced *Prosopis* pod grinding machines and organized cooperatives to handle pod harvesting, gathering, grinding, and selling. Four cooperatives were established in the Gewane and Amibara districts and were granted official licenses. Members were trained and technically supported mainly in *Prosopis* tree harvesting techniques to prevent coppicing; utilization of time and labour-efficient charcoal production techniques using metal kilns; pod collection, drying, and crushing using small hammer mills; and typical flour mills and cooperative leadership and financial management. The cooperatives were given hand tools, sample metal kilns, sample pod crushing mills, and "seed money" to initiate the charcoal trade. The activity benefited both local people and the cooperative selling the crushed pods. In addition to controlling the spread of *Prosopis* to new areas, the intervention provided high-quality animal feed. It helped local people raise additional income to better cope with the chronic food insecurity in the region caused by *Prosopis* in the first place. The business is a good alternative for animal feed processors and those who engage in dairy and fattening farms to secure highly nutritious animal feed at affordable prices. Households involved in charcoal production and sales obtained an excellent income and diversified their livelihood base to better cope with food insecurity. Cooperatives cleared *Prosopis* thicket from over 396 hectares in one year, providing pasture and cultivable land to local communities.

(Source: Admasu, 2008)

BOX 3 Case study 3: prosopis management through utilization in Kenya

In Northern Kenya, the extent of invasion has become so severe that a great deal of land has been invaded by the species, which causes the disappearance of indigenous plant and grass species. Local communities stated that their existence is threatened as they have lost valuable pastures and farmland to *Prosopis*. Despite several attempts to control the spread and further invasion of *Prosopis* in the Baringo region in Kenya, remarkable success was not attained. To overcome this challenge, training was given to charcoal producers and a primary school teacher regarding sustainable harvesting techniques. It was supported with a drum kiln and equipment to improve wood-to-charcoal production in the traditional earth mound kiln by the Center for International Forestry Research and World Agroforestry. Finally, continuous use of the plant through charcoal production has dramatically reduced its spread, and pruning the *Prosopis* shrub prevents it from taking over and limits seed production.

(Source: Koech et al., 2021)

to control the spread and further invasion of *Prosopis* in Baringo County of Kenya, a new strategy has been launched by the Center for International Forestry Research and World Agroforestry to produce charcoal from the species. According to this report, continuous use of the plant through charcoal production has dramatically reduced its spread, and pruning the *Prosopis* shrub prevents them from taking over and limits seed production, besides its economic benefits of being an alternative source of income. The Ministry of Agriculture, Water, Fishery, Livestock and Marine Resources in Djibouti developed a national Prosopis management strategy to manage Prosopis sustainably by fully exploiting its commercial potential and improving the livelihoods of the community (Gianvenuti et al., 2018). On similar notion, according to Wakie et al. (2012) and Shitanda et al. (2013), the Ethiopian government and non-governmental organizations are presently concentrating on managing the plant's proliferation through usage because total eradication of *Prosopis* is both challenging and costly (Tewari et al., 2011; Tessema, 2012; Walter and Armstrong, 2014; Ilukor et al., 2016; Assefa et al., 2023). In line with this notion, Intergovernmental Authority on Development (IGAD) countries declared the "Addis Ababa declaration" in 2014 with the motto of "effective management and utilization of *Prosopis* in the greater Horn of Africa" (PENHA, 2015).

8 Conclusion and policy recommendation

Prosopis juliflora, introduced into different parts of the world with environmental and economic intention, is among the widespread invasive species currently found in arid and semi-arid regions. It is a very versatile tree that can be grown in a wide range of temperatures and soil conditions, and due to its high adaptability to harsh environmental conditions, it can quickly spread into the drier areas of the world, causing both positive and negative impacts.

Prosopis presents a range of multifaceted adverse effects on ecosystems and local communities. It competes with native species, leading to a rapid decline in forage plants and inhibiting the growth of underbrush. Additionally, Prosopis can attract predators and obstruct pathways and roads utilized by humans and livestock, thereby complicating access to grazing lands and water sources. Animals that consume its pods frequently experience dental loss and various health complications. The thorns of *Prosopis* pose further risks, potentially causing lameness, blindness, infections, ulcers on extremities, itching, and ocular injuries. For children, pod consumption can lead to gastrointestinal impaction and constipation, while long-term ingestion may result in cattle mortality. Furthermore, excessive seed accumulation following feeding can lead to the death of goats and camels. *Prosopis* thickets also serve as breeding habitats for mosquitoes, contributing to public health concerns, and they deplete aquifers through their extensive root systems, which access deep water sources. This encroachment reduces ground vegetation cover and diminishes the diversity of herbaceous species, thereby hindering transhumance practices. Overall, the proliferation of *Prosopis* strains the infrastructure essential for pastoralism, primarily by narrowing and obstructing vital roads and tracks.

Besides all these side effects, *Prosopis* has a wide range of economic, social, cultural, health, and ecological benefits. It provides construction materials, poles, timber, windbreak, and charcoal; serves as soil conservation and rehabilitation of degraded and saline soils; and is used in animal feed production. It serves as an alternative substitute for ethanol production; its flowers are good sources of nectar, leading to high honey production; it is used as a significant source of gum and resin; it has a high potential for the production of nutrient-dense goods such as juice, wine, gum, powder, essential oils, and drinks; the animal feed prepared from *Prosopis* can increase milk production for lactating animals and enhances body weight gain in goats. The tree serves as a place where traditional ceremonies, rituals, and storytelling are practiced; it provides valuable shade in hot and arid regions, reducing near-ground temperature and offering relief from the scorching sun, and the shade can create comfortable outdoor spaces for social gatherings, community events, and leisure activities. Local artisans can create intricate carvings, sculptures, furniture, and other decorative items from *Prosopis*, showcasing the cultural heritage and skills of the community. The environmental benefits of *Prosopis* include, among others, the leaves are organic fertilizers and considerably increase the amount of nitrogen, phosphate, and potassium in soils; the species has a deeper root system that aids in stabilizing the soil and reducing erosion, decreasing salinity and plays a significant role in reclaiming unproductive lands. Plantations of *Prosopis* were found to enhance groundwater recharge; it provides food and habitat for birds, insects, and mammals; by removing impurities from runoff water, *Prosopis* can aid in improving the quality of the water; it plays a significant role in sequestering carbon and combating desertification; and it contributes in reducing dust pollution. *Prosopis* has different health benefits. The leaves, roots, tissues, parks, and fruits have antifungal, antibacterial, antibiotic, anticancer, antidiabetic, anti-inflammatory, and antimicrobial purposes.

Having both adverse effects and benefits gives the local community diverse attitudes toward this species. Occasionally, pastoral communities are a little apprehensive of the species as they consider that species adversely affect pasture lands and crop production. On the other hand, due to its ecological benefits like improvement in soil fertility, erosion prevention, improvement of saline lands, creation of cooler microclimate, and reduction of wind damage, they tend to consider the species beneficial. In areas where side effects outweigh its benefits, the local community members are bitter about it and firmly push the idea of its eradication. Environmentalists and scholars argue that the complete eradication of *Prosopis* might be costly and, in some cases, have unforeseen effects on the livelihood of the local community and the environment. However, the consequent negative impacts are increasing quickly, making the urgent need to develop robust and practical management strategies necessary to both mitigate the adverse effects and fully use the benefits. As a result, commercialization (with a notion of management through utilization) of the plant for animal feed and human production, as well as for medicinal use, is a feasible way of minimizing the rate of expansion of *Prosopis*. Using the pods of *Prosopis* for animal feed might be the best alternative for dry land areas where animal pasture is scarce and will become more severe with a changing climate. Besides, scholars advocate awareness

creation campaigns, which are very important to draw public attention and awareness regarding the management and control of the *Prosopis* invasion. Cross-boundary endeavors for controlling *Prosopis juliflora* expansion to new regions, particularly in countries predicted as edges of high potential invasion, are required to efficiently manage the species invasion, particularly in the tropical and subtropical broadleaf-forests and shrub lands.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Author contributions

AE: Conceptualization, Methodology, Writing – original draft, Writing – review & editing.

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