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Beyond eradication: Unveiling local voices and proactive management strategies for *Prosopis juliflora* in eastern Ethiopia's arid landscape

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ABSTRACT

The introduction of Prosopis for environmental rehabilitation in Ethiopia's arid regions led to unanticipated consequences. To overcome these challenges, OXFAM introduced a new technology with multiple benefits. This paper examines the local community's perception, the current Prosopis management system, and potential strategies using exploratory research. Data were collected from 55 purposively selected respondents through key informants (09), focus group discussion (05), survey scheduled interviews (13), in-depth household interviews (28), and direct field observation. Data were analyzed thematically and using descriptive statistics. The result of the study revealed that Prosopis is expanding alarmingly in the area. Pastoralist communities in the study area have a negative attitude towards this alien species. The pilot project was found to be essential and supports the government's effort to decrease the Prosopis invasion and provide alternative income sources. The most critical problems that cooperative members faced included access to credit (PCI=39), lack of technical support after the project exits (PCI=32), and the high price of Prosopis pods extraction and charcoal-making machines (PCI=25). The success of the new technologies depends on their acceptance and adoption by the beneficiaries. Therefore, it is crucial to integrate the various efforts made by stakeholders towards sustainable management of Prosopis juliflora. Providing a supportive environment for new businesses during their critical early stages regarding startup capital, market linkage, technical-skill training, and information can help them survive and grow through the vulnerable period. Further projects and interventions should consider using Prosopis for human nutritious foods, medicinal uses, and honey production.

Introduction

Globally, invasive species are the second most critical factor in reducing biodiversity, followed by habitat loss [1]. While most of them were adopted to bring about positive socioeconomic and environmental effects [2], they currently have complex, irreversible effects [1,3]. One of the most predominant and dangerous invasive alien species, *Prosopis juliflora* (hereafter *Prosopis*) is currently

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found in over 129 countries, mainly in arid and semi-arid regions of the world [4–6]. Because *Prosopis* is drought-tolerant, the Derg regime internationally introduced it to Ethiopia's arid and semi-arid areas in the 1970s and 1980s with the purpose of environmental rehabilitation as an afforestation measure to reverse desertification [7–9]. However, currently, it has had numerous unforeseen damaging social, economic, and ecological effects [5,7–12]. The alien invasive species invaded much rangeland in Ethiopia's Somali and Afar regional states, which appears to be ongoing [13]. Additionally, the invasion has moderately impacted areas in the dry lands of eastern, northeastern, and central Ethiopia [3,7,14]. *Prosopis* significantly threatens agropastoral communities' subsistence and food security [15]. The tree has expanded, occupying grazing zones and creating impenetrable thickets that hinder plant growth [10,16]. *Prosopis* has multiple ecological and social impacts like harbouring wild animals [17], obscured roadways [18], hindered transhumance [19], providing suitable mosquito breeding grounds [5], reduced ground vegetation cover and herbaceous species diversity [20], among others. *Prosopis* thickets can cover areas, out-competed native species, reduce forage plants, prevent undergrowth, cause tooth loss, and cause animal health issues [21]. The thorns in the forest hinder pastoralists from collecting fuel wood, causing inflammation, hindering transhumance, and causing various health issues like lameness, blindness, infections, ulcers, itching, and eye injuries [17,18,22]. *Prosopis* pod consumption can cause impaction and constipation in children, and long-term ingestion can lead to cattle mortality. Thickets also serve as mosquito breeding grounds, leading to malaria prevalence. Women are shouldering the burden of finding firewood and water in areas with high thorn risk [5,9,23,24].

Though the negative impacts of *Prosopis* are widely documented, they produce valuable goods and services such as construction materials, charcoal, soil conservation, and animal feed production. *Prosopis* trees have a deeper root system that stabilizes soil and reduces erosion while also helping to remove heavy metals from contaminated soils [2,16,17,21,25,26]. They can improve soil's physical and nutritional status, decrease salinity, and play a significant role in reclaiming unproductive lands [21,27–30]. *Prosopis* trees also provide food and habitat for various species [30,31], contributing to increased biodiversity and improved ecological function [16,25]. *Prosopis* trees' high nutritional value and large fruit yield make them potential for producing nutrient-rich goods [9,21,23, 31–34].

Prosopis pods have also been used in electricity generation, as an alternative substitute for ethanol production, and as a source of gum and resin [9,23,34], while the leaves and tissues are widely used as herbal medicine due to their antibiotic nature [16,26,35,36]. *Prosopis* provides a hard and heavy wood that makes excellent firewood and superior charcoal [16,21,23,33,34]. *Prosopis* flowers are good nectar sources, leading to high honey production [9,16,25,37]. *Prosopis* trees and woodlands also contribute to ecosystem services like erosion control, land reclamation, nitrogen-fixing, carbon sequestration, and combating desertification [23,25,26,34,38]. Additionally, *Prosopis* plantations improve air quality and reduce dust pollution by up to 50 % [30].

Regardless of the efforts made to control its invasion, the *Prosopis* invasion in Ethiopia has been spreading, especially in the dry and semi-dry districts of Afar and Somalia as well as in Dire Dawa city administration [15,19]. 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 [4,39]. The FMECD [15] highlights that loss of grazing land due to the invasive species leads to pastoralists relocating to new areas or seeking new income sources, increasing confrontations with farmers. The land degradation risk is exacerbated by increased animal concentrations on remaining grazing land, increasing susceptibility to food insecurity, and political instability. Once *Prosopis* is established, it is expensive and difficult to eradicate; attempts have not been successful globally [2,40]. Pastoral communities that depend on *Prosopis* as an alternative source of income may suffer if the plant is wholly eradicated [8,10,16,33,41]. Alternatively, it is possible to control *Prosopis* by using sustainable management techniques [42]. Development organizations and non-governmental organizations in Ethiopia assist with adopting suitable management methods for *Prosopis* [8,10]. According to Wakie *et al.* [9] and Shitanda et al. [16], the Ethiopian government and non-governmental organizations are presently concentrating on managing the plant's expansion through usage because total eradication of *Prosopis* is both challenging and costly [11,26,33,34,43,44]. Moreover, Zeray *et al.* [19], Abdulahi *et al.* [23]0, Wudad [45], Shiferaw *et al.* [46] and Shiferaw *et al.* [18] are just a few of the well-documented examples of *Prosopis's* magnitude of proliferation and detrimental effects in Ethiopia. Eradication trials in Ethiopia using cutting and burning proved ineffective [47]. On the other hand, management of the species through utilization has been reported in Northern Kenya [48]. This approach, though not well practiced in Ethiopia, has been recommended by scholars [27,40,42,44,49]. In the case of Ethiopia, not much research has been done on its benefits other than using it as a source of fuelwood and to make charcoal [18,42]. Thus, the debate is whether *Prosopis* ought to be eliminated or seen as a valuable resource that may be used. Besides, the available studies focus on the quantitative expansion of the species with little attention to the perception and voices of the community [10,22,43,45,46]. This study relied on a case study and existing empirical evidence to shed light on the potential use of *Prosopis* as a helpful resource. Furthermore, the study intended to evaluate whether controlling it through utilization could be a feasible alternative for Ethiopia, presenting a paradigm shift from considering it as a "weed" to appreciating it as a "wealth." OXFAM, an international non-governmental organization, had implemented an integrated *Prosopis* management system to control the expansion of the species through utilization in the Somali regional state. Thus, this study aimed to investigate the perception of the local community on the innovation, the significant benefits earned from the project, the prominent actors involved, the challenges faced, and lessons learned from the pilot project, mainly using qualitative research design to unveil the voices of the community. To that end, the following research questions were forwarded from the outset. 1) How do the local community and stakeholders perceive the role of the innovation technology, and what are the benefits of *Prosopis*? 2) How do the local community and stakeholders understand the possible feasible management strategies of *Prosopis? 3)* What problems were faced? What lessons were learned from the pilot project? 4) To what extent were *Prosopis* management practices implemented based on the needs of the beneficiaries and local communities? 5) What new practices could be scaled up to the broader community regarding *Prosopis* management?

Research methods

Description of the study area

Ethiopia has a diverse topography with abundant flora and fauna resources [13,50,51]. Its rangeland ecosystem, covering 70 % of its total area, provides essential ecosystem services [13,52]. However, since the 1960s, the size of the rangeland has decreased due to unmanaged expansion, population pressure, lack of firm national policy, climate change, and invasive species like *Prosopis*, which threatens livelihoods and biodiversity [13,53].

Somali regional state, one of the regions in Ethiopia highly affected by *Prospois*, is located in the east and southeast of Ethiopia (Fig. 1) with a predominantly pastoral ecosystem, where about 90 % is classified as rangeland [54]. Geographically, it is located between 39° and 48° East longitudes and between 4° and 11° North latitudes with an approximate total area of 376 073.37 km^2. The Somali region of Ethiopia experiences hot summers with mean temperatures ranging from 15 to 40 °c and three major moisture zones: hyper-arid, arid, and semi-arid. Annual rainfall varies from 150 to 1,000mm. Drought is a common occurrence due to declining rainfall and rising mean temperature. The region has altitudes ranging from 200 to 1,800 m, with 62 % being lowland and 38 % highland. The Somali region is rich in large rivers and groundwater resources and is expected to meet future domestic and irrigation needs. Major land types include grassland (42.56 %), wood/shrub/bushland (35.14 %), barren land (20.08 %), and farming/cultivation [55]. The Somali region's young population, comprising 64 %, has a high potential for a productive labour force. Occupations include pastoralism, agropastoralism, and urban-based occupations, with income sources including livestock, crops, firewood, and remittances. The Siti administrative zone, located in the north-west, has a low-lying flat terrain, stony outcrops, loose soil, bush, woody grasses, and steeply dissected mountains [54,55].

Somali region is among the areas in Ethiopia where *Prosopis* has widely invaded the rangelands and where the invasion has been growing out of control regardless of the efforts made to control its expansion [15,19]. Considering the challenge exerted on the livelihood of pastoral communities, OXFAM Great Britain implemented a pilot project, namely, 'Integrated *Prosopis* Management Pilot Project' in the Somali regional state (Siti zone, *Shinile* woreda of *Marmarsa kebele*) from November 2020 to April 2023 [56]. The ultimate objective of the proposed innovation project was to pilot the effectiveness and scalability of the new and innovative *Prosopis* management technique. Specifically, the project intended to prevent the expansion of *Prosopis* to uninvaded areas; reclaim and reuse invaded areas for productive purposes and to increase the biodiversity; promote commercial use of *Prosopis* by creating entrepreneurial and economic opportunities for women and youth; and facilitate the establishment of *Prosopis* management council at different levels [56].

Research approach

Research design, sampling techniques and data sources

A concurrent mixed methods research approach (mainly of exploratory research type) with cross-sectional survey and case study research designs was employed in this study. *Shinile* Woreda of Siti zone (where the pilot project is found) in the Somali regional state of Ethiopia was selected purposively as a research site. After properly developing data collection guidelines and evaluating their reliability, ethical clearance was obtained from Wollo University. Then, after potential data sources were identified with the help of concerned officials at woreda and zonal levels, informed consent forms were developed and communicated to participants. Data

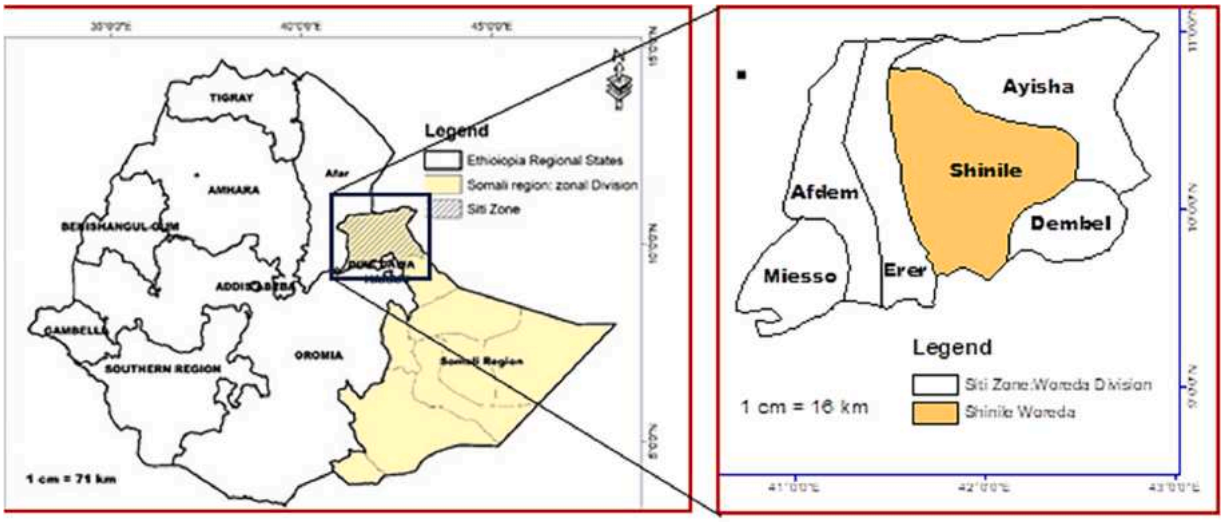

Fig. 1. Relative location of the study area: Siti zone and Shinile Woreda.
(Source: Wollo University Research Team, 2023)

collection procedures were strictly adhered to the approved protocols. Survey-scheduled interviews with thirteen cooperative members (chosen using a readily available sampling technique) were used to gather primary data. It was found during data collection that only thirteen selected youths participated in the pilot project, and our data collection relied only on these participants. Purposive sampling was used in a focus group discussion with five cooperative leaders. Nine deliberately selected stakeholders from *Shinile* Woreda and the Siti zone and project coordinators participated in key informant interviews. Key informants were chosen intentionally, considering their expertise in *Prosopis* management, from *Shinile* woreda (woreda deputy administrator and *Prosopis* Management Council Leader, head of woreda agricultural office, head of woreda pastoralist development office; head of woreda water and energy office, head of woreda cooperative office); Siti zone (zonal WASH coordinator, zonal head of livestock office) and OXFAM Project program officer.

To better understand the community's experiences and viewpoints, the researchers also performed in-depth household interviews with 28 community members (chosen by a convenient sampling technique) and direct field observations in addition to the interview-based data-gathering methods. Using a practical technique, these community members were selected, taking into account the inclusion of women, elders, and clan leaders. Trained data enumerators managed the survey schedule while the researchers carried out the KII, FGD, and in-depth interviews. The interview and survey questions include, among others, the skills and lessons obtained from the pilot project, the degree of implementing the *Prosopis* management practices based on the needs of the beneficiaries, the linkage created with different stakeholders during the implementation of the pilot project, the problems encountered; their perception regarding the benefits of the innovation as well as the effects of *Prosopis*, their views on the sustainability and compatibility of the innovation, and unintended benefits that the innovation provides. To further enhance the data sources and allow for a more thorough comprehension of the project's context and execution, the researchers also thoroughly examined all the project-related documents.

Data analysis techniques

A combination of Qualitative and quantitative data analysis techniques was employed. Tables, figures, and numerical values were used to present the quantitative data analysis results, which were done using the mean, percentage, and index. The researchers recognized and investigated significant themes that emerged from the observation, FGD, and interview data; they employed a thematic analysis approach to examine the qualitative data. The study began with the textual data being thoroughly coded. To do this, the researcher carefully examined the corpus and assigned brief labels or codes to summarize pertinent text segments effectively. After coding, the researcher proceeded to an iterative process of classifying the different codes into higher-order categories by identifying patterns and frequencies in the data. This categorical structure enabled extracting overarching themes that described the main concepts, ideas, and phenomena in the studied textual materials. The main obstacles encountered during project implementation were analyzed using the problem confrontation index (as shown in Eq. 1) based on Uddin et al. [57].

$$PCI = \ (most\ important\ problem * 3) \ + \ medium\ problem * 2) \ + \ (less\ important\ problem * 1)] \quad (1)$$

Where 0=Not encountered at all; 1=Encountered to limited extent; 2=Encountered in medium extent, and 3=Encounter most frequently

A five-level Likert scale was used to examine respondents' perceptions of the implementation practices of value-addition innovations. Finally, the researchers used a triangulation approach to obtain a more comprehensive picture of the study, combining the findings from various data sources. This triangulation process aimed to enhance the validity and reliability of the study's conclusions.

Results

Perception of respondents on the role of the pilot project and the expansion of Prosopis

Any new project's likelihood of success depends on the beneficiaries' attitudes. It was asked how respondents felt about the advantages of the integrated *Prosopis* management project that OXFAM had implemented. It failed to have the desired impact on their lives to enable them to create resilient livelihoods. Their lives did not significantly change due to the project, except for the skill

Table 1
Perception of respondents on the implementation practices of value addition innovations ($N = 13$).

Participation in the OXFAM project enabled to:	(1=strongly disagree; 2=disagree; 3=Neutral; 4=agree; 5=strongly agree) (%)					
	1	2	3	4	5	mean
Increase income from the sale of charcoal and animal feed	30.8	53.8	15.4	0	0	1.85
Increase the size of farming/grazing land	30.8	53.8	7.7	7.7	0	2.00
Practice *Prosopis* management	7.7	30.8	338.5	23.1	0	2.77
Get better charcoal from *Prosopis* wood	23.1	53.8	23.1	0	0	2.00
Become a member of charcoal producer cooperatives	0	38.5	15.4	46.2	0	3.08
Save money from the sale of charcoal and feed	15.4	76.9	7.7		0	1.92
Gain knowledge and skill in *Prosopis* management and processing	0	0	23.1	76.9	0	3.77
Engage in the trading of charcoal and animal feed	7.7	53.8	38.5		0	2.31
Share knowledge and skills with neighbouring farmers	0	7.7	46.2	46.2	0	3.38

(Source: Survey output, 2023).

development and a little profit from selling charcoal. Their ability to produce charcoal from *Prosopis* was improved by technical training. It did not significantly lessen the impact of *Prosopis* expansion because of the project's brief lifespan and low production volume. People's perceptions of invasive species and innovation technologies depend upon whether their economic needs are met [17]. As presented in Table 1, the overall perception of cooperative members was not promising. Positive responses were found only on its role as a member of a cooperative association, its contribution to attaining knowledge and skill through training, and its role in creating a conducive plate form for sharing knowledge and skill. The majority of respondents either strongly disagreed or disagreed regarding the project's contribution to increasing their income from the sale of charcoal/briquette and animal feed, as well as its role in improving the size of farmland. Besides, their ability to save money, though a bank account was issued, was not as expected due to the failure to trade charcoal/briquette, animal feed, and vegetables and fruits from the reclaimed land.

In surveys, KII, and in-depth interviews, participants were asked to share their personal experiences regarding the extent of the expansion of *Prosopis*. Unequivocally, almost all replied that *Prosopis* has been expanding alarmingly since the recent past at the expense of their pasture lands. Agricultural experts from *Shinile* Woreda and Siti administrative zone (KII3, KII4, and KII5) boldly underlined that the alien invasive species have already invaded most of the grazing lands in the Siti zone, making the pastoral way of life very challenging. A 65-year-old clan leader shared his experience: "*…in my life, I have never seen such type of plant which invaded the whole pasture land within a short period*". Similarly, a pastoralist in Marmarsa *Kebele* narrated that *Prosopis* (called *Wonaye-zaf* locally) has wholly invaded their surroundings, where their small village is becoming an island surrounded by an ocean of *Prosopis*.

Because this species harms most households interviewed, they have negative attitudes towards it. Most respondents stated that it is getting harder for their livestock to find pasture and water, that the thorny bushes are making their movements more complex (see Fig. 2), and that predators are making homes out of the dense bushes. Because there is not enough fodder, they are forced to decrease their livestock number. Supporting their responses, a study by Zeray et al. [19] for the Dire Dawa city administration found a statistically significant difference in milk production revenue mainly due to the lack of fodder in *Prosopis*-infested areas. Inkermann [24] 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.

Local communities were asked to share their experiences regarding the benefits obtained from the species. Unlucky, positive responses were rare. Except for firewood and fences, using the plant for different economic benefits like animal feed and charcoal production for the market is rare. Despite OXFAM's and Woreda agricultural and cooperative offices' best efforts to engage young people in producing animal feed, charcoal, and vegetables using the new technology, the intended goals were unmet. Diverse parties hold differing opinions in this regard. KII09 argued that the failure of cooperative members is a cumulative effect of the following factors:

Fig. 2. Expansion of *Prosopis* (rural path-ways are blocked out and range lands are invaded) (Photo credit: Wollo University Research Team, 2023).

- ✓ Newness: the technology is new, and some components, like carbonizers, have been fixed very late. This contributes a lot to being very late in starting the business. Besides, its newness demanded time to pass the research-designing-production processes successfully. OXFAM mainly uses locally produced machines which were fixed after tireless trial-and-error efforts
- ✓ Animal feed production was started almost at the last minute of the pilot due to the difficulty of grinding the pod. Due to the jelly nature of the pod, it was challenging to gride as intended, and lots of trial-and-error attempts (with the help of Dire Dawa Polytechnique College) were undertaken to fix the problem.
- ✓ Urban encroachment: the project site is very close to Dire Dawa town, and land value has recently increased. Most residents, including the cooperative members, tend to sell their land (and act as land brokers), which enabled them to secure better income than engaging in charcoal production and other agricultural activities.
- ✓ Working habits of the members: since the cooperative members are from pastoral communities, it was challenging for them to embark on such labour-intensive activities. It demands time to convince them and sustain the business as an alternative source of income. Due to their undetermined commitment and since there is a need to reorganize the association, the legalization process of cooperatives is already pending at the regional level.
- ✓ Extremely high expectations of cooperative members: most youths expected a modern machine to cut the shrubs and clear the land (expecting machine-based operation rather than a labour-intensive one). Besides, they expected the release of the money that OXFAM held until they proved good business runners.

On the other hand, the cooperative members have pointed out the following bottlenecks that hindered them from continuing the production of charcoal/briquette and animal feed.

> *Animal feed production needs a Prosopis pod as a significant input, which is unavailable throughout the year (the pod is only accessed whenever there is adequate rain, which is rare in our locality). Besides, the demand for sample products was not evaluated, and we were discouraged by the situation. The collection of pods in Thorny Bushland is very tiresome and demands more labour, and we do not have the financial capacity to hire daily labourers.* We *stopped charcoal production due to different reasons. Firstly, frequent machine failure discourages us from continuously producing the product. The collection of wood for charcoal production is laborious and requires sufficient initial capital. Charcoal production requires lengthy time (time-consuming); timber and pod collection using manual labour is impractical in making and sustaining the business. Perhaps it might be possible to do so for small-scale production. However, if the objective is to maintain the business as an alternative source of livelihood for us, large-scale production of animal feed and charcoal is mandatory. OXFAM promised a remarkable amount of seed money but did not realize it. All these factors have their role in limiting our efforts to produce charcoal for business.*

To keep the business going, cooperative members suggested the following strategies. The efficiency of machines should be improved to increase their productivity with less human labour and more production in less time. Significant market connections must be made, primarily for animal feed, and intensive marketing efforts are required. Government and non-governmental organizations should continue to support the business until it reaches a mature stage. Maintaining the business also heavily depends on offering the cooperative's members ongoing training, including machine maintenance.

Benefits of the pilot project and stakeholder engagement

Oxfam, an international NGO, has implemented an integrated *Prosopis* management project intending to control the expansion of the species through proper utilization. The pilot project mainly produced charcoal and briquettes from *Prosopis* trees and shrubs using an electrically carbonized system and animal feed production from *Prosopis* pods. It cleared land for fruit and vegetable production. Walter and Armstrong [26] pointed out that *Prosopis* improves the income of households through natural resource-based activities like the collection of fuelwoods for own use as well as for the market and enables people to increase financial capital through non-farm activities such as charcoal and animal feed production. Furthermore, it leads to livelihood diversification and thus protects households from environmental and economic shocks. For the landless people from the low social strata, *Prosopis* is the indispensable resource that saved them from starvation. On the other scenario, KII02, KII03, and KII08 agreed that when the invasive species is used for charcoal production (which is the primary source of energy in urban areas), besides its role in slowing down its expansion in uninvaded regions, it will help to reduce the pressure on indigenous trees which has currently destroyed natural forests and land degradation.

Regarding the role of the new technology in handling the expansion of *Prosopis* and its resultant adverse effects and its contribution as an alternative source of income, KII 02 has explained that high coppicing ability and effective dispersal mechanism are factors that help for its rapid invasion. Besides, livestock, camels, and goats are significant in spreading *Prosopis* seeds through their faeces by carrying them into different areas. He added that "*milling and using the pods as animal feed would be an alternative strategy to control the rapid invasion of the alien species*." Besides, as the respondents stressed, the innovation project can create employment opportunities for the pastoral communities where their primary livelihood is dependent mainly on animal husbandry (which is currently impeded by recurrent drought and shortage of forage). As pointed out by KII04 and KII05, solar panels primarily provide a multi-purpose function (as power for charcoal production and animal feed processing, and they are a renewable energy source for pumping water, which was done using natural gas). Besides, a demonstration plot for vegetable production on reclaimed land motivated the local community regarding the possibility of shifting from a pastoral way of life into at least an agro-pastoralist (attitudinal change).

One significant benefit, which the in-depth interview participants and key informants admired, is the unintended output of the project. OXFAM has upgraded the supply of water from boreholes using solar energy. According to KII09, the installed solar supply

power for the borehole has solved the challenge of frequent damage to the generator. As a result, the community water supply system is improved, and a continuous water supply (for home and livestock consumption) has been attained without any power interruption. >2000 HHs living in the project's surrounding area benefit from this intervention. In an in-depth interview, participants appreciated the project's contribution to providing water supply. Projects with such positive externalities are more likely to be adopted and help to develop a sense of ownership in the community (see Fig. 3). Interviewed women are delighted with the supply of water, which was long among their critical problems as a pastoralist community.

Participants in KII and FGD have a positive attitude towards the project. They unequivocally responded that when the invasive species is used for charcoal production (which is the primary source of energy in urban areas), besides its role in slowing down its expansion in uninvaded regions, it will help to reduce the pressure on indigenous trees, which has currently destroyed natural forests and land degradation. The project introduced a solar panel that provides multi-purpose functions (as a power source for charcoal production and animal feed processing and as a renewable energy source for pumping water, which was done using natural gas). Besides, a demonstration plot for vegetable production on reclaimed land motivated the local community regarding the possibility of shifting from a pastoral way of life into at least an agro-pastoralist (attitudinal change). OXFAM has upgraded the water supply from boreholes using solar energy, which has improved the water supply. Projects with such positive externalities are more likely to be adopted and help to develop a sense of ownership in the community.

During the pilot phase of the integrated Prosopis management project, various stakeholders took part and were involved. Higher education institutions took part in the manufacturing, testing, and formulation of animal feed made from *Prosopis* pods; they designed and produced briquette extruders, electrical and manual carbonizers, and grinding mills; they trained cooperative members and offered technical support; they lobbied for change and solved new issues. In addition to manufacturing machinery, the private sector is also engaged in advocacy, influence, and solar panel installation. Local administrators have worked on several projects, including solar system and water supply management, community mobilization, asset security, cooperative organization, monitoring, and technical support. They have also developed a draft guideline for the *Prosopis* Management Council and provoked cooperative members. Individuals and members of the community have also made significant contributions in the form of land for the machine's installation and demonstration, labour for clearing the demonstration area, security services for the project's properties, material mobilization, sharing of indigenous knowledge, and elder involvement in the problem-solving process related to site change. Although various stakeholders have been actively involved in bringing the idea to life, little has been done to support the cooperatives and keep the business afloat. Regretfully, no one helped the cooperative members establish market connections for their products or obtain startup funding. The lack of support for market linkage was mentioned as one of the main obstacles preventing cooperative members from continuing their production. KII03, KII05, and KII07, on their part, explained the level of stakeholder participation as:

> ……..*Even while various stakeholders, including the local community and officials at various levels, agree on the detrimental effects of invasive species, a strong and dedicated approach has not yet been taken. So far, the local community has only been producing charcoal on a small scale using traditional methods; no other activities have been done. Government authorities, mostly at the woreda level, have been motivated by OXFAM's creative idea of transforming the shrub into a productive resource and a source of alternative revenue and awareness. As a result, we are already assembling a task force of concerned officials who will be in charge of preventing the species' spread and expanding the new project. The Prosopis is already being cleared out by the national cement mill, which will use it as energy instead of coal to produce cement. Another effective strategy to combat invasive species is this one. We anticipate that a significant portion of the range land will be free of invasive species due to the large-scale operation, and the recovered land will be put to productive use, mostly for irrigation.*

KII04 and KII05 ascertained that though the technology is innovative and appropriate, failure to organize youth and sustain the business was not attained due to a lack of government support and commitment from the cooperative members. Sustained support at

Fig. 3. Reliable water supply for the local community and farm demonstration plot on reclaimed land.
(Photo Credit: Wollo University research Team (8/9/2023)

the early stage of such businesses (mainly for those youth from pastoral communities) is crucial. KII01, KII02, KII07, and KII09 have strongly recommended the need for follow-up and continuous support for cooperative members. They stressed that since the idea and the business are new for the pastoral communities and cooperative members, constant follow-up and support are needed to nurture such beginners. The kebele administration, the woreda cooperative office, and other stakeholders have planned to reorganize the association and provide technical support for cooperative members to continue their business (charcoal production, animal pod production, and engagement in fruit/vegetable production on reclaimed land). Charcoal is in high demand, and there is no concern in the market if it is produced on a large scale. However, the demand for animal feed from *Prosopis* pod has not yet been studied and tested. In producing animal feed from the pod, only 30 % of the ingredients are expected to be in pods, while the remaining components should come from other inputs. This might increase the final price of the feed and might have implications on its overall demand.

There is a need to integrate all the isolated efforts made by different stakeholders to arrive at sustainable *Prosopis* management and prove the feasibility of the business. Without concrete evidence regarding the business's profitability, its degree of adaptability and scalability is less likely. Since production terminated immediately after selling the first trial products, evaluating the business's sustainability and profitability was impossible. As a result, we did not get evidence regarding the benefits obtained from the project in terms of increase in production, improving the productivity of livestock production, increasing the availability of grazing land, increasing productivity of crop production, creating job opportunities for the local community and enhancing the livelihood of the beneficiaries. Cooperative members strongly mentioned a lack of support from government officials and OXFAM, mainly in creating market linkage and financial access, as the significant constraints that hold them back. The main factors mentioned as factors responsible for cooperative members not being successful in their business include, among others, a lack of modern machines to clear *Prosopis*, frequent failure of the machine, shortage of seed money, absence of linkage with microfinance institutions, loose collaboration among different stakeholders (mainly cooperative office and financial institutions), the newness of the technology and some components like carbonizer were fixed very lately, urban encroachment (securing better income from selling land than engaging in charcoal production), undetermined commitment and weak working habit of the members to embark such labour-intensive activities, and high expectation of cooperative members (a modern machine for cutting the shrub and clearing the land and early release of the money).

KII03 has narrated the importance of the project, mainly the use of the reclaimed land for irrigation, as follows:

> *Shinile woreda in the Siti zone of the Somali regional state has huge underground water potential. The innovative project mainly uses solar power for charcoal and animal feed production. Solar panels can also generate energy for water pumping (a* triple function of the technology*). In the future, land reclaimed from this invasive species could be used for medium-scale (private investors and cooperatives) and small-scale (residents) irrigation, making the production of fruit and vegetables very attractive. Shinile woreda is found near a large city (Dire Dawa), which is a significant market for products produced through irrigation due to its accessibility and since the area's climate is very suitable for fruit and vegetable production. These golden opportunities, coupled with the availability of groundwater and the new technology, make the area potentially rich for expanding irrigation. One major challenge we expect is changing the local community's attitude. For centuries, a mobile pastoral way of life has persisted in the area, and transforming such a way of life might be challenging, if not impossible. OXFAM, though very small, had demonstrated the production of fruits on the reclaimed land, which inspired the local community and proved the possibility of engaging in agropastoral activities. Surprisingly, some pastoralists try to cultivate fruits in their home yards. This is a good start, and the woreda and zonal government should work with NGOs and institutions to scale up such initiatives.*

KII01 has a positive attitude towards innovative technology, mainly its role in overcoming major social problems. He pointed out that:

Table 2
Perceived benefits of the value-addition innovation.

Perceived benefits	Description of the benefits
Benefits of converting *Prosopis* into charcoal and briquette	✓ Income source and alternative livelihood for the pastoral community ✓ Satisfy the ever-increasing charcoal demand of urban dwellers at reasonable prices ✓ Cleared land could be used for productive purposes-like production of cereals, fruits, and vegetables through irrigation ✓ The pressure on indigenous trees for charcoal production would reduce
Benefits of converting *Prosopis* pods into animal feed	✓ Provide sustainable feed and encourage animal fattening ✓ Reduces mobility of folks and free grazing ✓ Increases animal productivity (milk and meat) ✓ Become an alternative source of income (business/employment opportunity in collecting the pod, processing the animal feed from the pod, selling the animal feed, utilizing the animal feed for poultry/fattening purposes)
Using reclaimed land for small-scale irrigation	✓ Source of income (selling of fruits and vegetables) ✓ Attaining food security for the rural poor ✓ Enriching nutritional demand of rural poor ✓ Transforming the livelihood system (from pastoral into agropastoral) ✓ Better and affordable access to fruits and vegetables for the urban population

Source: Compiled from own thematic analysis (2024).

…. the project brings a new and innovative idea that would help to overcome the expansion of the invasive species, Prosopis. OXFAM tried to convert the Prosopis shrub or tree into charcoal production while the pod was intended to be processed into animal feed. The project has also provided additional benefits for the local community by pumping water for home consumption and domestic animals using solar panels (environmentally friendly energy system). Training given to cooperative members and skill development gained were appreciable, but the actual business created for them was unsuccessful due to different factors.

According to KII participants, the project so far has enabled the attainment of attitudinal change (the possibility of changing the invasive species into something that benefits the society (as a new source of income and alternative source of livelihood for those who are entirely engaged in a pastoral way of life); awareness creation (the possibility of clearing and reclaiming their land which *Prosopis* already invade. The demonstration success in using the cleared land for small-scale irrigation is something new for the rural pastoralist, and there are encouraging attempts to produce vegetable fruit on private lands) and self-empowerment (those who were organized as cooperative members had gained technical skills through continuous training which enables them to be self-confident in running business besides animal husbandry). Based on the findings from FGD, KII, in-depth household interviews, and actual field observation, the cumulative effects of implementing the project at a large scale are summarised in Table 2.

The prominent problems identified during KII and FGD include access to credit, lack of technical support after the project exits, and high prices of *Prosopis* pod extraction and charcoal-making machines. Besides, limited access to the market for *Prosopis* pod products, limited technical know-how of *Prosopis* pod extraction and processing technology, and lack of market information were significant constraints.

Problems faced while implementing the pilot project

In any course of project implementation, it is common to encounter different expected and unforeseen problems. Investing in such issues helps to learn and design appropriate remedial action in upcoming projects. A four-level Likert scale was employed to assess the significant problems encountered by the beneficiaries during the lifespan of the project period. The results were analyzed using the problem Confrontation Index (PCI), and ranking was applied to prioritize the most critical challenges (Fig. 4). The first three problems that cooperative members faced included access to credit, lack of technical support after the project exited, and the high price of Prosopis pod extraction and charcoal-making machines. Besides, limited access to the market for *Prosopis* pods products, limited technical know-how of *Prosopis* pods extraction and processing technology, insufficient or/ incompatible training on *Prosopis*

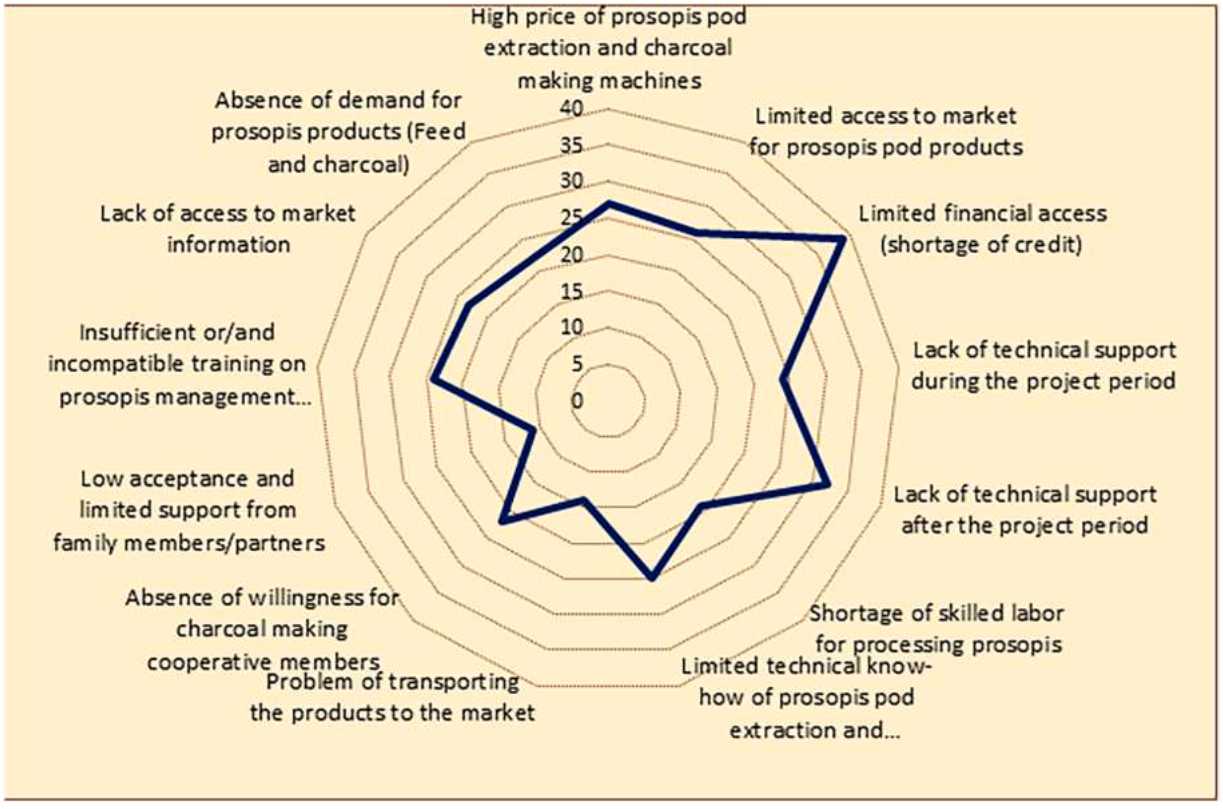

Fig. 4. Major problems faced during the implementation of Prosopis management and processing [PCI= (most important problem*3) + medium problem*2) + (less important problem*1)].

management and processing, and lack of access to market information were worth mentioning as significant constraints. Lack of transportation and absence of demand for products were the least mentioned problems.

Discussion

Prosopis provides few economic benefits in the study area, so the community views the species negatively. The result implies that much more work is left to create awareness regarding the economic and environmental benefits of *Prosopis* in the study area. According to Pasiecznik [21] and Pandey et al. [28], 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 [25,36]. Another study by Ali et al. [58] confirmed that supplementation of the diet of Afar sheep with ground *P. juliflora* pods resulted in growth performance and carcass parameters and improved their feed intake capacity. Though the species have such benefits, using the resource for producing charcoal for business is not well practiced in the study area (though some interviewed residents replied that the production of charcoal from *Prosopis* for home consumption has started recently). Besides, animal feed processing from pods is not well practiced. If such business opportunities are well expanded, the community's attitude towards this species will change, and it will be considered a valuable resource.

Deciding whether to classify *Prosopis* as a weed species or a valuable resource is controversial [25]. The vast majority of the agropastoral community views *Prosopis* negatively and considers it undesirable despite the species' many benefits. In Ethiopia, it is only used for firewood, charcoal, forage, fencing, shade for livestock, windbreak, and soil protection, and to a lesser extent, for traditional medicinal purposes and ornamental purposes [18,39,42]. Rather than viewing *Prosopis* as a beneficial resource to be used, they consider it a curse of Allah brought on by the misdeeds of their ancestors [22,24,39]. According to a study conducted in the Afar regional state by Chekole [59], the community has a negative perception of the species' beneficial effects on soil fertility and microclimate. It favours its complete eradication due to its fast invasion rate and negative impacts, including loss of biodiversity, physical harm to humans and livestock, obstruction of access roads and irrigation canals, and the enormous financial costs of clearing. According to Maundu et al. [27], the local community has a negative attitude towards *Prosopis* despite the plant being employed as a source of income primarily for the supply of lumber, charcoal, and pods. Because it depletes grassland habitats and water systems, ranchers and pastoralists have a negative attitude toward this resource [36]. A study in South Africa by Shackleton et al. [60] reported a negative attitude of the local community towards *Prosopis* due to the high costs associated with the species rather than the benefits. The community considered it to be invasive and wanted to be eradicated. However, the rural communities, who depend on *Prosopis* for fuelwood, acknowledged the tree as a valuable resource [25]. Governmental and non-governmental organizations working on *Prosopis* management should, therefore, strive towards changing the local community's attitude and focusing on harnessing the benefits of the species. Due to its versatile benefits, governments, researchers, and NGOs have been working to find alternative uses for *Prosopis* instead of controlling or completely eradicating it [27]. Thus, encouraging 'control through utilization' will have a win-win outcome (minimizing the spread of the invasive and enhancing the livelihood of the pastoral community through providing alternative sources of income) (see Case Studies 1 and 2). In this regard, further projects, research works, and interventions should consider using *Prosopis* for human nutritious foods, medicinal uses, honey production, furniture production, and gum extraction based on the experiences of other countries.

Prosopis is expanding alarmingly in the Somalia region and study areas. Consistent with the qualitative results, quantitative research outputs confirm similar findings. For example, a study by Mehari [22] in the Afar region found that most pastoral

Case Study 1: *Prosopis* Management through Utilization in Afar Regional State (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 normal 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 area 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 a good 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: [61])

communities examined had lost over half of their grazing pastures due to *Prosopis* invading their pasture land. Haregeweyn *et al.* [10] also revealed that *Prosopis* invaded new areas at an average rate of 3.48 km^2 per year in the Amibara area (Afar regional state of Ethiopia), mainly at the expense of grassland and open acacia bushland. A study by Wudad and Abdulahi [45] in the Korahey Zone of the Somali Regional State also revealed an increase in coverage of *Prosopis* with an annual rate of 3.3 percent between 1989 and 2019. According to this study, grazing land, which is the primary food source for livestock, is highly invaded by *Prosopis*. Land-use-land-cover change analysis in the Afar regional state by Shiferaw *et al.* [46] using a Random Forest algorithm estimated the average annual rate of change of *Prosopis* invasion between 1986 and 2017 as 31,127 ha per year, mainly at the expense of grassland, bush-shrub-woodland, and natural forests. Assefa *et al.* [43] estimated the expansion rate of *Prosopis* in Ethiopia's dry lands. They found that the coverage of the species has increased by 40 % between 2016 and 2021, with an estimated annual rate of increase of 8 % per year. According to this study, *Prosopis* has spread alarmingly, accounting for 69 % of the available vegetation coverage of the study area. As Paliwal [62] recommended, integrating artificial intelligence and remote sensing with local knowledge enables better detection of *Prosopis* invasion. Takaya et al. [63] also emphasized that continuous surveillance is necessary to effectively manage and control invasive alien species. In doing so, modern AI and machine learning are robust and less time-consuming tools [64]. To that end, Jensen et al. [65], Takaya *et al.* [63], Ali [66], and Magomedov et al. [64] applied and recommended different AI, remote sensing and machine learning techniques as practical tools. For instance, Takaya et al. [63] applied action camera images using the chopped picture, where the model enabled the detection of alien plants with 89 % accuracy. Similarly, Jensen et al. [65] employed machine learning to detect invasive species in the United States, where 97 % internal accuracy was achieved, enabling accurate imagery classification.

Projects implemented in the Afar region by FARM-AFRICA [9] and a pilot project in *Shinile* woreda of the Somali region by OXFAM are archetypal innervation that focuses on management of the *Prosopis* through utilization -a paradigm shift from 'weed' to 'wealth.' Besides, the land ownership system in the Afar and Somali regions is clan-based, while a significant proportion of range land is communal land. In such cases, due to the tragedy of the commons, communities become reluctant to protect such communal lands from invasion. Thus, land tenure security has to be maintained, incentivizing the local community to protect and manage their lands from invasion. Overall, *Prosopis* is a complex species with both benefits and drawbacks. However, when managed sustainably, *Prosopis* can be a valuable asset for rural communities in arid and semi-arid regions, providing a wide range of ecological, economic, and social benefits. Since livelihood transformation takes a more extended period, providing credit and technical support, creating market linkage, and providing timely market information for those cooperative members organized from the pastoral community play a paramount role in sustaining their businesses.

Conclusion and policy implication

OXFAM introduced Integrated *Prosopis* management in *Shinile* woreda to control the expansion of alien species and provide income opportunities for affected communities. The pilot project supported the government's efforts to decrease the *Prosopis* invasion and provided alternative income sources for people dependent on animal husbandry. OXFAM offered extensive training, including machine operation, business skills, financial management, and women leadership. The machine was tested for its functionality in producing charcoal, briquette, and animal feed. The successful demonstration of vegetable production inspired the local community, leading to individuals growing vegetables and fruits in their home gardens. However, little effort has been made to support and sustain the cooperative members. If scaled up, the project could transform and diversify the livelihood of the pastoral community, ultimately achieving food security. The local communities in the study area suffer from invasive species (*Prosopis*) in different ways: pasture lands are invaded, mobility is becoming difficult, predatory wild animals are attacking their domestic animals, and their way of life is significantly impeded. The innovation is feasible and based on the prior problems of the society, and it is amenable to scaling up. The pilot project has created linkages among higher institutions and private companies to solve local community problems. The pilot project enabled the development of attitudinal change among government officials and the local community regarding the possibility of converting the "weed' into 'wealth.' Despite the strong commitment and collaboration of different stakeholders to realize the new technology in producing charcoal, briquette, and animal feed, little attempt has been made to support and coach cooperative members to be successful in their business. The new technology resulted in an unintended benefit: solar power-driven potable water pumping for

Case Study 2: *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, and local communities stated that their existence is under threat 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 the 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: [48])

consumption and domestic animals. Projects with such positive externalities and multiple outcomes are more likely to be adopted by host communities and will have a positive attitude towards the project (helps to develop a sense of ownership).

Based on the ongoing analysis and discussion, we suggest that reducing the rate of further expansion and enhancing the utilization of the *Prosopis* for economic benefits urges a well-planned and organized collaboration among concerned stakeholders, including governmental organizations at all levels, NGOs, higher institutions, research centers, local institutions, costumery institutions as well as the local community with their indigenous knowledge. Besides, since the cooperative members had no prior experience or exposure to similar businesses, close supervision and intact support was crucial to passing the take-off stage. As a result, support in providing information (input, output, market), business handling, and similar issues is indispensable.

The production and transfer of new technologies is not an end; the beneficiaries should acknowledge and adopt the new technologies [67]. As a result, there is an urgent need to integrate all the isolated efforts made by different stakeholders to arrive at sustainable *Prosopis* management and prove the feasibility of the business. Unless there is concert evidence regarding the business's profitability, its degree of adaptability and scalability is less likely [2,42]. The support from cooperative offices, financial institutions, and enterprise development offices in providing startup capital and creating market linkages for their products was weak. As a result, synergy should be created among stakeholders to nurture the cooperative members to be profitable and sustainable in their businesses. Providing a supportive and conducive environment to new businesses during their critical early stages can significantly improve their chances of survival and growth, especially during the difficult and precarious times. The value-addition innovation technology of processing charcoal/briquettes from *Prosopis* and animal feed from *pods* is relatively new for the study area. Thus, to speed up the technology adoption rate and for better scalability, there is a need to provide continuous training to project beneficiaries on the utilization and essential maintenance of equipment and its role in building resilient livelihood.

Moreover, a continuous campaign is needed to create public awareness about the adverse effects of *Prosopis* on animal husbandry, agricultural activities, ecosystem and biodiversity, health-related problems, and its potential benefits (overcoming the negatives and harnessing the benefits). Lastly, based on the experiences of other countries, further projects, research works, and interventions should consider the use of *Prosopis* for human nutritious foods, medicinal uses, and honey production. Future research works should focus on the economic and environmental valuation of *Prosopis* using a relatively large geographical area and large sample size. Besides, the dynamics and drivers of expansion need to be studied with the help of artificial intelligence and remote sensing technologies. The local community's perception and the change through time should also be assessed using a large sample size.

Limitation of the study

Since the study was conducted in a small geographical area, generalization of the findings is difficult for Ethiopia's arid regions. With a limited number of participants, the results may not accurately represent the broader population, potentially leading to biased conclusions. As a result, future research with a larger, more diverse sample is necessary to validate these findings and enhance their applicability. Besides machine learning, Artificial Intelligence (AI) and remote sensing-based analysis are required to estimate the species' expansion rate.

Ethical consideration, ethical approval, and consent to participate

Before conducting the study, an ethical clearance approval letter (CD/007–313/2023) was written by Wollo University. Informed verbal consent was obtained from each study participant. Confidentiality was maintained by giving codes to each respondent rather than recording their name. Study participants were informed they had full rights to discontinue or refuse to participate. Therefore, all participants involved in the research, including survey households, enumerators, supervisors, and key informants, were fully informed of the study's objectives. Additionally, the study adheres to all the necessary research regulations and ethical considerations.

Consent for publication

Not applicable

Declaimer

The author's views and opinions are their own and do not necessarily reflect the official policy or position of the authors' funding organizations or affiliated institutions.

Availability of data

The necessary data about this work will be available from the corresponding author upon formal request

CRediT authorship contribution statement

Amogne Asfaw Eshetu: Conceptualization, Methodology, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. **Asart Mulat Asegie:** Conceptualization, Methodology, Funding acquisition, Writing – review & editing. **Samuel Tadesse Addisalem:** Conceptualization, Methodology, Writing – review & editing, Supervision. **Faris Hailu:** Conceptualization, Methodology,

Writing – review & editing, Supervision. **Tinsaye Tamerat:** Conceptualization, Methodology, Funding acquisition, Writing – review & editing, Supervision.

Declaration of competing interest

The writers have not disclosed any conflicts of interest.

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