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Assessing the feasibility of the socioeconomic benefits of *Colophospermum mopane* under climate change in north-central Namibia

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Colophospermum mopane (*C. mopane*) is a drought-tolerant deciduous tree that provides essential ecosystem services for local communities. Despite its socioeconomic importance, the feasibility of these benefits under changing climatic conditions remains understudied, particularly in sparsely forested regions such as north-central Namibia. In this study, we assess the feasibility of *C. mopane*'s socioeconomic contributions in Namibia's Kunene and Omusati regions by focusing on subsistence and commercial use. Using a semi-structured questionnaire, we collected data from local communities at four Forestry offices: Outapi, Tsandi, Opuwo, and Okahao-yielding 117 responses. We employed descriptive statistics to analyse data using IBM SPSS combined with Microsoft Excel. The results revealed that firewood was the most common product of *C. mopane*, primarily harvested for subsistence purposes. The products were mainly harvested from crop fields. Household income from *C. mopane* products ranged from <1,000 to 5,000 Namibian Dollars (NAD) per sale, with peak earnings recorded in 2019 and 2020. Key climate-related challenges affecting these benefits included floods, thunderstorms, and erratic rainfall. Respondents highlighted the need for improved wood-processing skills, better market access, and financial support to enhance the sustainability of *C. mopane*-based livelihoods. We recommend targeted climate adaptation strategies such as agroforestry, tree planting projects, drought-resistant crops, and community education on sustainable resource use and promoting alternative energy sources such as solar power for cooking and heating. Future studies should evaluate the effectiveness of climate adaptation and mitigation strategies in managing mopane woodlands for long-term socioeconomic resilience.

KEYWORDS

firewood, community forests, income generation, marketing, permits, wood processing

Highlights

- Forest products of *C. mopane* are primarily used for firewood and poles at the subsistence use level.
- The income generated from *C. mopane* products between 2010 and 2022 was relatively low, ranging from <1,000 to 5,000 Namibian Dollars (NAD).
- Erratic rainfall and tree mortality are the main climate-related challenges impacting socioeconomic benefits from *C. mopane* forest products in the Kunene and Omusati regions.

1 Introduction

The impact of climate change on forest ecosystems is a trending subject that has captured the attention of researchers, forest managers, and policymakers worldwide. Increasing disturbances such as forest fires, erosion, pest and insect outbreaks, floods, and prolonged seasons of drought are all attributed to climate change (Seidl et al., 2017). These phenomena reduce forest productivity, damage tree populations and affect forest ecosystem services (Gebeyehu, 2019; Nunes et al., 2021). Consequently, the effects of climate change also influence how communities benefit from the forests. Therefore, rural communities that depend on forests for fuel, construction materials, food, and income face increasing challenges in securing these resources. Namibia is regarded as the most arid country in sub-Saharan Africa (Naftal et al., 2024; Van Rensburg and Tortajada, 2021). This makes it the most vulnerable country to the impacts of climate change in the region (Lotfy, 2019; Mapaure, 2022). The country's forests are characterised by sparsely distributed trees and shrubs, which form woodland ecosystems that provide essential services such as firewood, poles, and non-timber forest products (Vrabcová et al., 2019).

Globally, forest products are recognised as vital contributors to livelihoods and human well-being, especially in rural areas of developing countries (Mugari et al., 2024). Local communities use forest products for various purposes, particularly in the form of non-wood forest products (NWPs). It is a well-known fact that NWPs play a vital role in the livelihoods and economies of many rural communities, particularly in rural areas (Asamoah et al., 2023; Nakanyala et al., 2022). In Namibia, the commercialisation of NWPs is often promoted to improve rural livelihoods, especially for vulnerable communities (Nakanyete et al., 2023; Nikodemus and Hájek, 2015). However, it is worth noting that the role of forest products has been significantly influenced by climate change. For example, it has been established that the increasing climate change effects on crop production and other livelihoods have resulted in NWPs playing a safety net role for communities to sustain their livelihoods (Tieminie et al., 2021). In the same vein, the available quantities of forest products, including NWPs, are declining due to climate change effects, such as drought, fire, pest outbreaks, hydro-geomorphic, and wind (Altman et al., 2024; Saffa et al., 2024).

In the far northern regions of the country, communities rely on forest resources for daily needs, including cooking, heating, and construction (Nikodemus et al., 2023; Vrabcová et al., 2019). Forests also provide NWPs such as medicine, fruits, mushrooms, and mopane worms. Mopane worms are particularly common in the far northern regions such as Kunene and Omusati. *Colophospermum mopane (C. mopane)* is among the dominant tree species in these regions, and it plays a crucial role due to its drought tolerance and high wood quality.

Dry and warm climatic conditions characterise the two far northern regions of Kunene and Omusati. In these regions, irregular annual rainfall ranges from less than 50 mm in the west to 415 mm in the east (Awala et al., 2019; Nikodemus et al., 2023). Seasonal variations in average daily temperatures range from 5 °C to 35 °C (Inman et al., 2020). Summertime temperatures can be extremely hot, with average lows of 14 °C and highs of 35 °C. The temperature range for winter is 5 °C to 26 °C (Inman et al., 2020).

These extreme climatic conditions in the two regions limit the survival of many tree species. Yet, the regions are primarily dominated by *C. mopane*. This suggests that *C. mopane* has adapted to the harsh climatic conditions, making it a critical resource for subsistence and commercial use. The species provides firewood, construction materials, and food, which all contribute to local livelihoods (Krug, 2017). Due to its high economic and ecological value, *C. mopane* is a protected tree species in Namibia (Laws Africa, 2015).

Despite extensive research on forest provisioning services (Kamwi et al., 2020; Nikodemus et al., 2023), few studies have examined their long-term socioeconomic feasibility in sparsely forested areas, particularly under climate change (Leonard and Iileka, 2024; Nikodemus et al., 2023; Vrabcová et al., 2019). Unlike previous studies that broadly documented the socioeconomic role of *C. mopane* in Namibia (Nikodemus et al., 2023; Vrabcová et al., 2019), this paper uniquely assesses the feasibility under climate change from a household livelihood perspective using both subsistence and commercial utilisation data. Specifically, our study introduces a baseline socioeconomic dataset across 73 villages in Kunene and Omusati, explicitly linking perceived climate challenges with mopane-based incomes. This provides a sharper understanding of local-level adaptation gaps, which previous studies did not quantify. While forests are known to support rural livelihoods (Shahi et al., 2022; Wunder et al., 2014), the sustainability of these benefits in arid regions remains uncertain. Therefore, this study aims to assess whether the provisioning services of *C. mopane* remain viable for both subsistence and commercial use under changing climatic conditions in north-central Namibia.

2 Methods and materials

2.1 Study area

As mentioned above, the study was conducted in two of the 14 political regions of Namibia: The Omusati and Kunene regions (Figure 1). These two regions were selected primarily because they have a high abundance of *C. mopane*. The Omusati region is situated in the far north of Namibia, bordering the Ohangwena region to the east, the Oshana region to the south, and the Kunene region to the west.

The Omusati region has a total surface area of 26,573 km^2 (Mapaure and Ndeinoma, 2011). The Oshiwambo people primarily inhabit the region. The Omusati region, for example, is Oshiwambo name, derived from *C. mopane* (Nikodemus et al., 2023).

The Kunene region is geographically located in the north-western part of Namibia, covering an area of 115,616 km^2 (Namibia Statistics Agency, 2022). The Kunene region borders the Omusati region in the

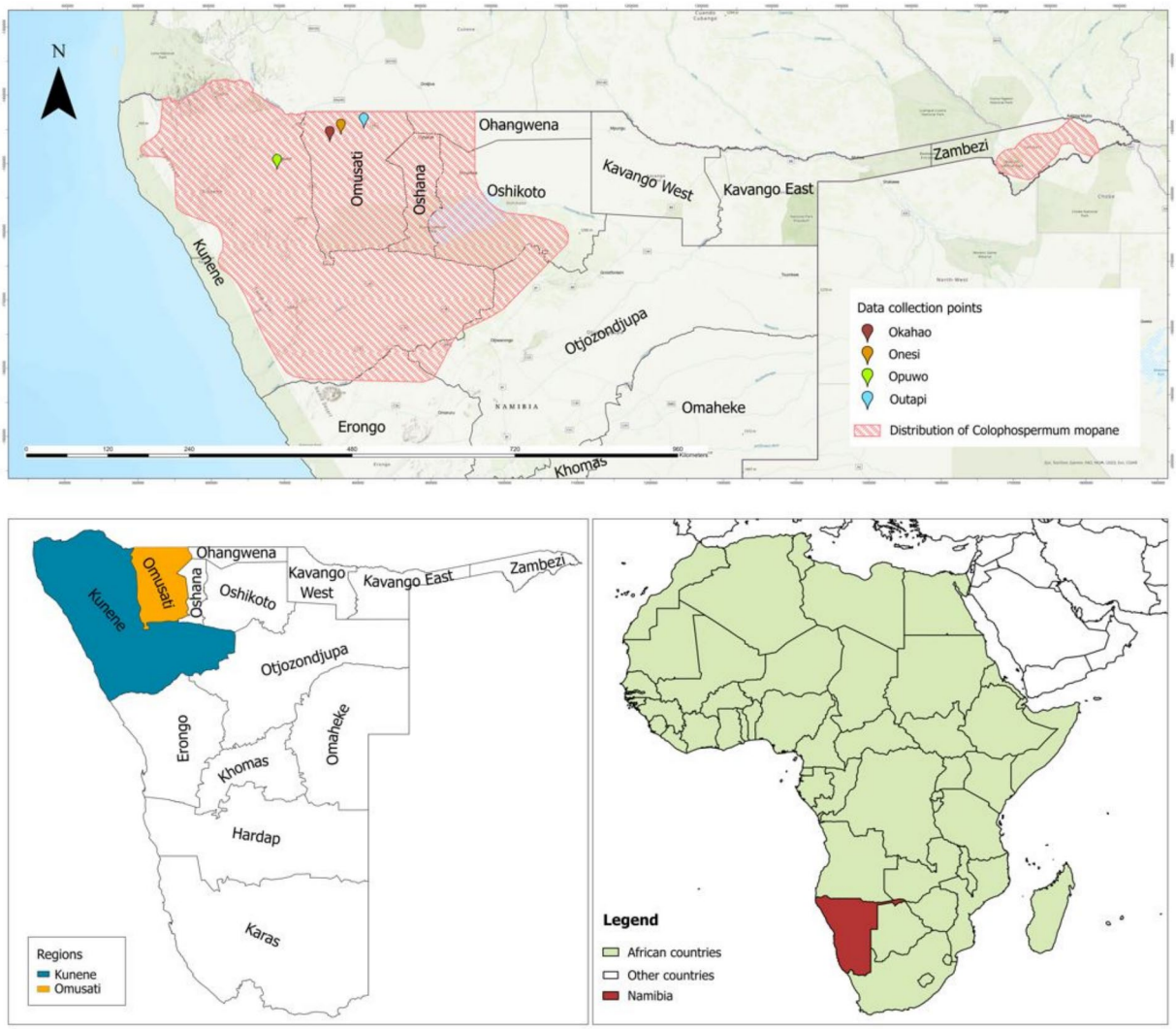

FIGURE 1
Study area and the distribution of *C. mopane*.

east, the Erongo and Otjozondjupa regions in the south and the Namib Desert in the west.

Colophospermum mopane is an indigenous tree or shrub species typically found in areas with low to moderate rainfall, high temperatures, low altitudes, and various soil types (Krug, 2017). Hence, *C. mopane* species is distributed over a large geographic area, spanning from south-western Angola and into Namibia as far south as Brandberg mountain, the highest peak in Namibia. *Colophospermum mopane* prefers fine-grained sand and clay-loam sites formed from basalt, alluvial material, and lime (Krug, 2017). It is predominantly found in areas with low to moderate rainfall, high temperatures, low altitudes, and various soil types (Makhado et al., 2018).

2.2 Data collection and analysis

Data were collected through a structured questionnaire administered to household representatives. The questionnaire covered demographic characteristics, utilisation of *C. mopane*, income derived, and perceptions of climate-related challenges. A purposive stratified sampling design was adopted, targeting 73 villages across Kunene and Omusati, with respondents selected to reflect gender, age, and income diversity. Enumerators were trained to ensure consistency in administration. Responses were coded into categorical variables (e.g., income groups, education levels), interpreted, and analysed. Descriptive statistics were complemented with inferential tests (chi-square and Spearman correlations) to examine associations between socioeconomic characteristics, mopane income, and climate perceptions.

3 Results

The socioeconomic results focused on the regions, gender, age, marital status, level of education, employment status, family size, and length of stay in the region (Table 1).

There were slightly more respondents from the Kunene region (n = 58; 51%) than from the Omusati region (n = 55; 49%). Regarding

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TABLE 1 Socio-demographic characteristics of the respondents (n = 117).

Characteristics		Frequency (N)	Percentage (%)
Regions	Kunene	58	51
	Omusati	55	49
Gender	Male	58	51
	Female	55	49
Age	18–24	8	7
	25–30	15	13
	31–35	17	15
	36–40	27	24
	41–45	13	11
	46–50	14	12
	51–55	6	5
	56–60	8	7
	>60	6	5
Marital status	Divorced	7	6
	Married	47	40
	Single	56	48
	Widowed	7	6
Level of education	Primary education (grades 1–7)	14	12
	Secondary education (grades 8–12)	45	38
	Diploma	17	15
	Bachelor's degree	17	15
	Master's degree	2	2
	None	22	19
Employment status	Employed	25	23
	Self-employed	26	23
	Student	5	5
	Unemployed	55	50
Family size	1–5 people	40	36
	11–15 people	18	16
	6–10 people	42	38
	>16 people	11	10
Length of stay	<1 year	8	8
	1–5 years	26	26
	6–10 years	35	35
	>10 years	31	31

gender, male respondents slightly dominated the participation (n = 58; 51%) compared to females (n = 55; 49%). The age ranged from 18 to >60 years, with the age category 36–40 years old (n = 27; 24%) recording the highest number of respondents. Most respondents were single (n = 56; 48%), while in the level of education sphere, secondary education (grades 8–12) was dominant (n = 45; 38%). Nearly half of the respondents were unemployed (n = 55; 50%). Family sizes ranged from 1 to >16 people, with most families comprising 6–10 people (n = 42; 38%). Lastly, the length of stay in the study area (villages represented) ranged from 1 to >10 years, and it was indicated that the longest stay was 6–10 years.

3.1 Products

The main types of products from *C. mopane* recorded in this study included firewood, poles/droppers, woodcraft, bark-ropes, and mopane worms (Figure 2A). These products were further classified according to the purpose of use, mainly subsistence and commercial use (Figure 2B).

Our results indicated that firewood (n = 40; 33.3%) was the most used product obtained from *C. mopane*. The second most used product was poles/droppers (n = 29; 24.2%). Woodcraft (n = 8; 6.7%) was identified as the least significant product. Furthermore, most respondents (89%) used *C. mopane* for subsistence, primarily for

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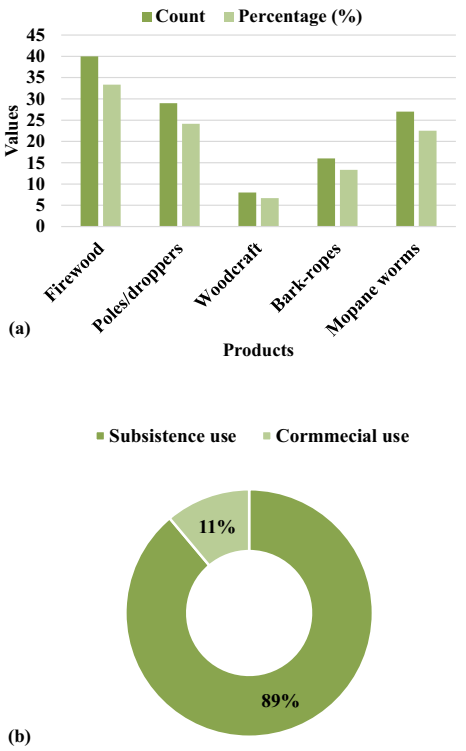

FIGURE 2
(A) *Colophospermum mopane* products. **(B)** The classification of the utilisation of the products.

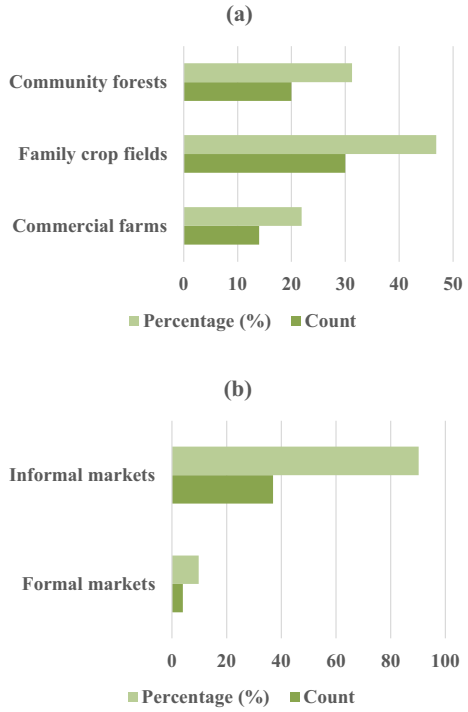

FIGURE 3
(A) Product sources. **(B)** Market types.

firewood. On the other hand, commercial use was relatively the most common/used (11%).

3.2 Product sources and market types

Our results showed that *C. mopane* products are primarily harvested from community forests, family crop fields, and commercial farms (Figure 3A). Some of the products are sold at informal and formal markets (Figure 3B).

Respondents revealed that the primary sources of *C. mopane* products were family crop fields ($n = 30$; 46.9%), followed by community forests ($n = 20$; 31.3%). Commercial farms were another source of the products, but relatively low ($n = 14$; 21.9%). Our results further highlighted the two main market types where local communities sell their products. Informal markets were the highest ($n = 37$; 90.2%), while formal markets were relatively low ($n = 4$; 9.8%).

3.3 Income generation and expenditures

Our results highlighted the income generated from *C. mopane* products (Figure 4A) and the expenditure (Figure 4B) on which respondents spend the income. Income generated ranged from 0 to >16,000 Namibian Dollars (NAD) per sale.

The results showed that income generation from *C. mopane* products fluctuated over the years. The highest income was generated in 2019 and 2020. Among all the participants, 50% indicated that their

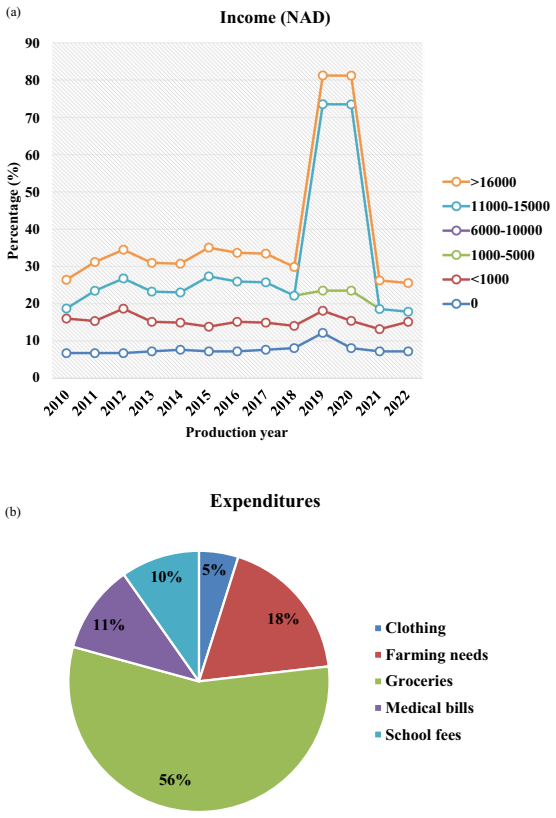

FIGURE 4
(A) Income generation. **(B)** Expenditures.

TABLE 2 Income generated from *C. mopane* products between 2010 and 2022.

Production year	0		<1,000		1,000–5,000		6,000–10,000		11,000–15,000		>16,000	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
2010	15	6.8	14	9.3	1	2.7	0	0.0	0	0.0	1	7.7
2011	15	6.8	13	8.6	3	8.1	0	0.0	0	0.0	1	7.7
2012	15	6.8	18	11.9	3	8.1	0	0.0	0	0.0	1	7.7
2013	16	7.2	12	7.9	3	8.1	0	0.0	0	0.0	1	7.7
2014	17	7.7	11	7.3	3	8.1	0	0.0	0	0.0	1	7.7
2015	16	7.2	10	6.6	5	13.5	0	0.0	0	0.0	1	7.7
2016	16	7.2	12	7.9	4	10.8	0	0.0	0	0.0	1	7.7
2017	17	7.7	11	7.3	4	10.8	0	0.0	0	0.0	1	7.7
2018	18	8.1	9	6.0	3	8.1	0	0.0	0	0.0	1	7.7
2019	27	12.2	9	6.0	2	5.4	1	50.0	0	0.0	1	7.7
2020	18	8.1	11	7.3	3	8.1	1	50.0	0	0.0	1	7.7
2021	16	7.2	9	6.0	2	5.4	0	0.0	0	0.0	1	7.7
2022	16	7.2	12	7.9	1	2.7	0	0.0	0	0.0	1	7.7
Total	222	100.0	151	100.0	37	100.0	2	100.0	0	0.0	13	100.0

TABLE 3 Inferential results.

Variable comparison	Test	χ^2 ρ	*p*-value	Interpretation
Gender × main product use (subsistence vs. commercial)	Chi-square	$\chi^2(1) = 3.41$	0.065	No significant difference between men and women in product use.
Education level × income category	Chi-square	$\chi^2(4) = 11.32$	0.023	Higher education levels associated with greater likelihood of earning >NAD 5,000.
Age and perceived climate impact severity	Spearman's ρ	0.29	0.004	Older respondents more likely to perceive climate-related declines in mopane benefits.

income from *C. mopane* products ranged from 6,000 to 10,000 NAD in 2019 and 2020, respectively. Income generated throughout the study period ranged from <1,000 to 5,000 NAD per sale.

Table 2 presents figures for income generation during the study period more explicitly.

3.4 Inferential results

The inferential results focused on socioeconomic demographic information and income generation (Table 3).

Inferential analysis revealed that respondents with higher education levels were significantly more likely ($p < 0.05$) to generate higher mopane-related incomes (>NAD 5,000 per sale). Similarly, age was positively correlated with perceptions of climate impacts ($\rho = 0.29$, $p = 0.004$), indicating that older respondents observed more pronounced declines in mopane benefits. These findings underscore the role of education and age in shaping adaptation capacity.

3.5 Marketing strategies and selling points

Marketing strategies identified in this study included trade fairs/expos, social media, radio, and one-on-one (Figure 5A). Selling points identified included rest camps, open markets, farm gates, and along the road (Figure 5B).

Most respondents indicated that they did not engage in marketing or selling ("*I do not market*" = 36.1%). However, most respondents who marketed their products revealed that they used a one-on-one strategy (35.2%). Another notable marketing strategy was social media (19.4%). Radio (19.4%) and trade fairs/expos (2%) were the least effective strategies to market their products. Our results further revealed that most respondents did not sell *C. mopane* products (36.4%). Respondents who sold the products indicated that door-to-door was the most effective selling point (30%), followed by farm gates (19.1%). Rest camps and along the roads were the least significant points (2% each).

3.6 Types of permits and costs

Different types of permits (harvesting, marketing and transportation) varied in fees (Figures 6A,B).

Our results showed that harvesting was the highly demanded type of permit (42.2%), followed by transportation (25.6%). Marketing was relatively low (3.3%). Regarding the costs, our results showed that transportation permits cost the highest per year (136.00 NAD) on average, followed by harvesting permits (85.00 NAD) per year on average.

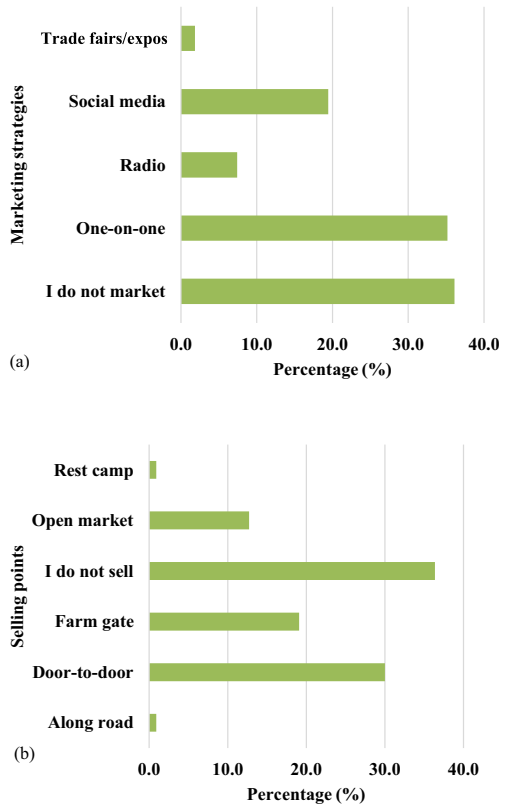

FIGURE 5
(A) Marketing strategies. **(B)** Selling points for *C. mopane* products.

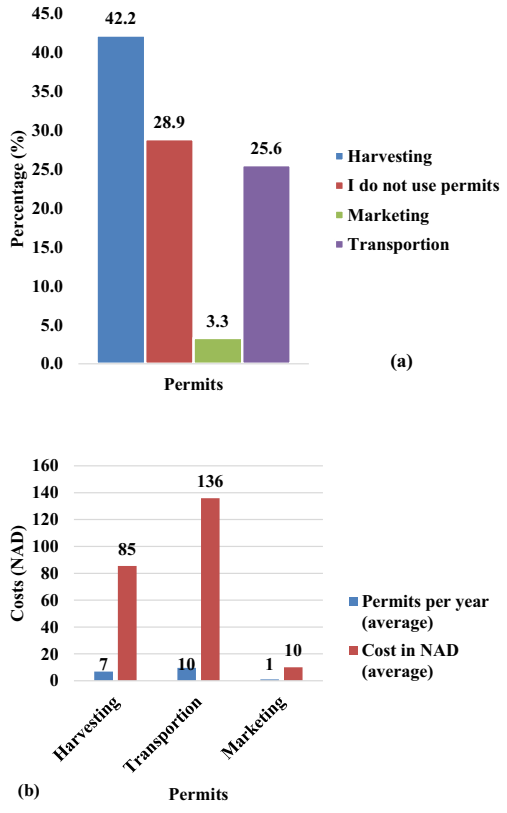

FIGURE 6
(A) Types of permits for *C. mopane*. **(B)** Permits cost.

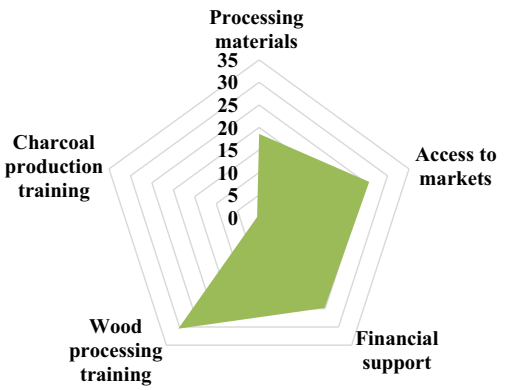

FIGURE 7
Recommended solutions to maximise socioeconomic benefits of *C. mopane*.

3.7 Climate-related challenges

Our results highlighted climate-related challenges affecting the socioeconomic benefits of *C. mopane* (Table 3).

The most prevalent climate-related challenges were floods and thunderstorms (*Strongly Agree*: $n = 52$; 44.4%) and erratic rainfall (*Strongly Agree*: $n = 47$; 40.2%). By contrast, the tree mortality rate (*Strongly Disagree*: $n = 58$; 49.6%), adaptation and mitigation measures, and forestry restrictions (*Strongly Disagree*: $n = 50$; 42.7%) were the least notable effects. Importantly, these findings reflect community perceptions of climate challenges rather than direct meteorological measures).

3.8 Proposed improvements

Our study highlighted the recommended solutions to address the existing challenges facing the socioeconomic benefits of *C. mopane* (Table 3) and maximise the potential socioeconomic benefits (Figure 7).

Most respondents expressed that training in wood processing (30%) was the most important area that needed prioritisation. The second most critical areas recommended for improvement were access to markets (26%) and financial support (25%). Processing materials (for forest products) (19%) was the least significant recommendation made by the respondents.

4 Discussion

Forests continue to support the livelihoods of e livelihoods of disadvantaged indigenous communities that are forest dependent (Nakanyete et al., 2023). On the global level, it was estimated that approximately 1.14 billion (71.3%) people from low- to middle-income countries live in or around forests where they can derive some benefits from forest products (Newton et al., 2020). The same is true for the rural communities within the *C. mopane* woodlands in the Kunene and Omusati regions of the northern part of Namibia.

Colophospermum mopane is a unique tree/shrub species with strong adaptation characteristics to dry conditions (Krug, 2017; Teshirogi et al., 2017). Therefore, the species is valuable for ecological

TABLE 4 Climate-related challenges (n = 117).

Climate change-related challenges	Agree		Strongly agree		N/A		Disagree		Strongly disagree		Total	
	n	%	*n*	%	*n*	%	*n*	%	*n*	%	*n*	%
Prolonged hot and dry seasons resulting in a high mortality rate for *C. mopane* (hot weather/ temperatures, fires, pests, and diseases	11	9.4	16	13.7	5	4.3	27	23.1	58	49.6	117	100
Erratic rainfalls resulted in the stunted growth of *C. mopane*	25	21.4	47	40.2	5	4.3	14	12.0	26	22.2	117	100
Floods and thunderstorms cause severe damage to the forests	19	16.2	52	44.4	9	7.7	13	11.1	24	20.5	117	100
Climate change adaptation and mitigation measures have tightened restrictions on accessing forestry resources	19	16.2	22	18.8	9	7.7	17	14.5	50	42.7	117	100

and socioeconomic benefits. The species supports local communities' livelihoods in many ways (Madzibane and Potgieter, 1999; Nikodemus et al., 2023; Vrabcová et al., 2019). However, like other plant species, the feasibility of the socioeconomic benefits of *C. mopane* is affected by several factors (Blanco et al., 2021), including climate change. For example, the notable changes have several impacts on forest ecosystems through the extinction of species (including plants and animals), long-term growth and fluctuations of seasons and changes in forest fires (Saffa et al., 2024). In this current study, we assess the feasibility of the socioeconomic benefits of this valuable species under the changing climate in north-central Namibia.

Our results showed a wide range of products that local communities can extract from *C. mopane*. Local communities extract products such as firewood, poles/droppers, woodcraft, bark-ropes, and mopane worms (Figure 2A) from *C. mopane*. Firewood, for example, is critically important in rural areas (villages) without electricity. Poles and droppers are significant construction and fencing materials for the homesteads and fencing of crop fields and livestock kraals (Table 4).

This is no surprise, as several studies have indicated that the local rural communities in many developing countries depend heavily on forests for their livelihoods (Nikodemus and Hájek, 2015; Shahi et al., 2022; Wunder et al., 2014). However, our results showed that firewood and poles/droppers were the most significant products of the species. The species has strong wood, making it suitable for multiple uses (Madzibane and Potgieter, 1999; Musvoto et al., 2006), including firewood and poles/droppers. Furthermore, it has been established that *C. mopane* is a good source of firewood, and it is commonly preferred for this purpose in most rural communities (Madzibane and Potgieter, 1999). It is also worth highlighting that the dominance of firewood as a product type of *C. mopane* is attributed to the poor electrification in most rural areas of north-central Namibia. It has been reported that a significant 70%–80% of Namibia's rural households remain unelectrified (Mpako and Ndoma, 2024).

Forests contribute to the rural livelihoods and economy in a number of ways: directly as a user of land and resources (Slee, 2004). This overwhelming reliance on mopane for subsistence (89%) highlights the resource's role as a safety net for rural households, consistent with findings in Botswana (Mogotsi et al., 2022). However, such dependence also underscores vulnerability to climate-related declines, as no equivalent substitute exists on this scale. This implies that the commercialisation of forest products was low. Several factors may have contributed to the poor commercialisation of the products. For example, *C. mopane* is registered as a protected species in Namibia (Laws Africa, 2015). This implies that to ensure sustainability, forestry policies and legislation restrict the utilisation of its products (Hinz and Ruppel, 2022; Nikodemus et al., 2023). Forestry restriction measures in the harvesting and use of the products significantly influence the products' source. This study discovered that local communities mainly harvest *C. mopane* products from family crop fields (Figure 3A). All these factors, and possibly many others, resulted in poor income generation from *C. mopane* products. Our results showed that income generated throughout the study period (2010–2022) was relatively low, ranging from <1,000 to 5,000 NAD per sale (Figure 4A).

Although the results did not highlight the factors associated with poor commercialisation, it is worth pointing out that climatic conditions, slow growth rates, harvesting restriction measures, limited resources and high desertification rates could have affected the poor commercialisation of the products. The harvesting restrictions, in particular, are emphasised due to the escalating loss of biodiversity through deforestation and forest degradation processes, which is a major development challenge in most developing countries (Kamanga et al., 2009). Furthermore, a full cost–benefit or enterprise analysis was not attempted due to a lack of detailed expenditure and labour input data. Future research should address this gap.

Furthermore, the study revealed that access to the market was one of the significant recommendations made by the respondents to maximise the feasibility of the socioeconomic benefits of *C. mopane* (Figure 7). This concurs with the literature, revealing that poor access to the market is among the factors affecting livelihood incomes in other developing countries, for example, Cambodia (Felkner et al., 2022). Hence, local communities primarily use the products for household needs (subsistence). However, the results further indicate that the insignificant commercialisation of *C. mopane* products is mainly practiced in informal markets (Figure 3B). In the same view, due to poor access to the market, local communities use informal markets to sell their products. This includes selling points such as door-to-door and farm gates (Figure 5B).

To contextualise perceptions, regional studies confirm declining rainfall and increasing variability in north-central Namibia (Awala et al., 2019; Inman et al., 2020). However, since our analysis relied on perceptions, caution is needed when interpreting causality between climate variables and mopane benefits.

5 Conclusion

Our finding that 89% of mopane is used for subsistence (Figure 2B) suggests that policies should prioritise household energy alternatives, such as solar cookers, to reduce firewood dependence. Similarly, since 50% of respondents earned <NAD 5,000 annually from mopane (Table 2), expanding market access and training (Figure 7) is directly aligned with income diversification needs. Importantly, culturally acceptable alternatives, such as marula (*Sclerocarya birrea*) products and agroforestry with indigenous species, should be promoted rather than generic substitutions.

Furthermore, our results highlight several climate-related challenges that have potentially severe long-term effects on the forest products of *C. mopane*. These climate-related challenges, such as erratic rainfall and tree mortality rates (Lindner et al., 2010), provide evidence of the effects of climate change on the socioeconomic benefits of *C. mopane*. Given these potential effects, it will be safer to implement measures to discourage the dependence of local communities on mopane products.

It has been established that there is increasing pressure on and declining mopane woodlands as a result of increasing use and competition for *C. mopane* resources in Namibia (Musvoto et al., 2006). In the same view, it is worth highlighting that the expanding human population exerts pressure on the forest ecosystems (Alam et al., 2024; Rodrigues et al., 2016). However, more studies are critically required to appropriately quantify the demands and risks of using woody products in mopane woodlands.

Therefore, our study recommends that, in collaboration with relevant stakeholders, including researchers, traditional authorities and potential donor funders, MEFT may intensify efforts to educate rural communities on the negative effects of relying on forest products for socioeconomic benefits. Furthermore, priority may be given to alternatives, such as solar energy for cooking, lighting and heating, and bricks for construction. Regarding income generation, communities may be encouraged through well-monitored support to plant and sell tree seedlings, such as fruit trees, including *Berchemia discolour, Sclerocarya birrea* (marula tree), and other native tree species, such as *Terminalia* spp., *Combretum* spp., and timber species (*Baikiaea plurijuga, Burkea Africana, Guibourtia coleosperma*, and *Pterocarpus angolensis*), instead of harvesting products from mature trees, which leads to desertification. To reduce the pressure on forests, we further recommend that local communities should be supported and encouraged to engage in agroforestry and tree planting projects, as well as the cultivation of drought-resistant crops. This approach will restore forests, and the effects of climate change will be minimised. We recommend that future studies assess the effectiveness of climate change adaptation and mitigation measures in managing forest resources and utilisation in mopane woodlands.

Several minor limitations exist in this study. First, due to the lack of long-term climatic data, our current study did not quantify the extent to which climate change affects socioeconomic benefits. However, our results show that the socioeconomic benefits of *C. mopane* are viable to some extent under the changing climate. Furthermore, our study could have provided strong evidence of the effects of climate change on forest ecosystem services, particularly on the socioeconomic benefits of *C. mopane*. However, unlike integrated climate-socioeconomic studies, we did not statistically link climatic time-series data to household outcomes. Therefore, this paper should be framed as primarily a socioeconomic baseline with climate perceptions, rather than a climate-impact attribution study. It is also worth highlighting that the lack of long-term climatic data resulted in the exclusion of a correlation between climatic time-series data and household outcomes. We assessed climate-related effects such as erratic rainfalls and tree mortality rates to address this challenge. Furthermore, using a self-administered questionnaire may reduce the reliability of the collected data due to social bias. We made the questionnaire anonymous to alleviate this bias and emphasised this aspect during the administration of the survey items. Lastly, despite the efforts to explain the main concepts and goals of the study, some parts of the questionnaire were incomplete due to the low level of education among the respondents. However, since our sample size was significantly representative, we obtained ample responses, and the data obtained for each question could yield reliable results.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by National Commission on Research Science and Technology of Namibia (Permit No. RPIV13322022). The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants.

Author contributions

AnN: Methodology, Writing – original draft, Investigation, Data curation, Visualization, Software, Writing – review & editing, Conceptualization. MH: Validation, Conceptualization, Supervision, Project administration, Resources, Writing – review & editing, Funding acquisition. DB: Visualization, Writing – original draft, Investigation, Conceptualization, Methodology, Formal analysis. NW: Writing – review & editing, Methodology, Investigation, Formal analysis, Software. EM: Investigation, Writing – review & editing, Methodology. PN: Writing – original draft, Conceptualization, Methodology. AlN: Conceptualization, Writing – review & editing, Validation, Investigation. RS: Writing – review & editing, Conceptualization, Validation.

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Conflict of interest

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

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