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Fègbawè Badanaro,
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Togo
Alok Singh Bargah,
Mahatma Gandhi Udyanikee and Vanikee
Vishwavidyalaya, India

*CORRESPONDENCE

Tejaswi Boyapati
✉ tejaswi.boyapati@jacks.sdstate.edu

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Non-timber forest products and the bioeconomy: linking livelihood security and biodiversity conservation (2015–2025 trends)

Tejaswi Boyapati* and Kasiviswanathan Muthukumarappan

Department of Agricultural and Biosystems Engineering, South Dakota State University, Brookings, SD, United States

Non-timber forest products (NTFPs), wild foods, fibres, medicines, resins, and animal products are critical to the economies and cultures of rural people in South Asia, sub-Saharan Africa, and Latin America. Data compiled and Meta-analysis from literature and published between 2015 and 2025 indicate that these products are frequently utilized at the household level (approximately 77% usage frequency) and significantly enhance incomes, particularly for land-constrained households and Indigenous populations. In contrast, booms in markets for açai, shea, and medicinal plants indicate new opportunities but also variable patterns. NTFPs also possess powerful ritual value (e.g., frankincense, kava, babassu) and can incentivize forest stewardship. However, their commercialization without appropriate safeguards may result in the over-extraction of species and ecological degradation. Climate change amplifies pressures. Improvements in post-harvest handling, drying, modified atmospheric packaging, cold chains, and better packaging enhance quality, extend shelf life, and reduce waste, thereby increasing returns and mitigating extraction pressure. Sustainability is underpinned by appropriate policies to secure tenure, recognise community rights, regulate trade, and promote cooperative value addition. Targets revolved around rights-based governance, flexible and responsive monitoring, diversified markets, scalable and efficient processing techniques, and certification schemes, as well as integration of cultural values and biodiversity goals, and climate adaptation. By reframing NTFPs as central to bio economies, we connect livelihood security to biodiversity conservation at multiple scales and across regions.

KEYWORDS

non-timber forest products, sustainable harvest, value chains, post-harvest handling, bioeconomy, indigenous rights, climate adaptation, conservation

1 Introduction

Nontimber forest products (NTFPs) are natural resources obtained from forests, other woodlands, or non-forest ecosystems that are used by people and can be consumed. That includes the full suite of wild plants and animals, from fruits, nuts, and berries to spice plants and bushmeat mammals and birds that are hunted for food or fur. It also includes reptiles, especially poisonous snakes that have medicinal and insecticidal applications. Unlike industrial timber, in which fewer laborers are needed, but for more valued species, many NTFPs are harvested, gathered, and transported from the wild to be used locally around home or villages (for use, e.g., as food/ craft materials) and/or traded within regional networks (Hariharan et al.,

2025; Windley et al., 2012). Others (like bamboo) travel through larger urban markets. NTFPs meet the daily needs of millions, especially in rural low and middle-income countries, for food, medicine, energy, and income. Across 24 developing countries, comparable evidence suggests that about three-quarters of rural households ($\approx 77\%$) collect wild foods, highlighting the importance of NTFPs in household subsistence (Asamoah et al., 2025; Hickey et al., 2016; Oparin et al., 2023). In the public health domain, many reports and reviews issued by WHO address traditional plant-based medicines used extensively (often harvested from wild or semi-wild situations) by some Member States and in large part derived from natural resources (Smith et al., 2013; Steel et al., 2022). In general, NTFPs are important factors in the local economy and cultural practices that contribute to food security; however, sustainable management is necessary for improving community livelihoods and biodiversity conservation.

Non-timber forest products (NTFPs) play a crucial role in the livelihoods of rural households. They provide wild fruits, vegetables, seeds, nuts, edible roots, bushmeat, and honey, which are essential foodstuffs for communities. They also serve as feed for livestock, fuel (in the form of firewood and charcoal), construction materials, and as raw materials for carpentry (including thatching leaves, bamboo, rattan canes, vines, and wood carving) among the people in the region. NTFPs also include medicines, dyes, poisons for fishing and hygiene (Minakata), as well as items of cultural value. Given their multiple uses, NTFPs are commonly described as “minor” or “non-wood forest products” (Min et al., 2024; Shackleton et al., 2024). However, they are an important part of people’s livelihoods in many places, providing numerous essentials and serving as a crucial buffer. For instance, a synthesis of evidence from South Africa revealed that wild spinach (wild leafy vegetables), fuelwood, wooden utensils, edible fruits, and weaving/craft materials were utilized by at least 85% of rural households. Over half relied on wild game meat, wild honey, reeds for weaving, and wood for building. These products bring daily savings, and in case of emergency (failed crops, drought, or seasonal food shortages), are lifelines. Throughout Bangladesh, approximately 27% of households around protected areas gain some cash income through the collection, processing, and marketing of non-timber forest products (NTFPs). These goods are estimated to contribute approximately 18% of the total annual income of these households and, for about 18% of them, NTFPs constitute a principal source of income (Mukul et al., 2015). Approximately 24.41% of rural household income is estimated to be from NTFPs according to a six (6) nation survey (2023). Major NTFPs that are known to grow in these countries include fruits, vegetables, medicine, firewood, and woodland products (Derebe and Alemu, 2023). In mountain areas of Nepal, households benefit from several provisioning services of NTFPs such as food, fodder, bamboo products, fiber and fuelwood which cushions them against seasonal shortages or failures in the market. Taken together these studies underscore the multiple roles that NTFPs serve in providing day-to-day necessities (food, fuel and building materials); income sources during ordinary time as well as emergencies; and risks when other means of earning fail. Likewise, in the absence of resources such as palm leaves for roofing, natural fibers for baskets and mats,

medicinal plants for treatment, or fuelwood for cooking, life would be almost unfeasible in many rural areas (Gurung et al., 2021; Luswaga, 2023). These wild resources help save money that would otherwise be spent on commercial alternatives, effectively allowing households to stretch their scarce cash incomes. Table 1 summarizes the extent of household reliance on NTFPs across regions. The interlinkages between these domains are conceptualized in Figure 1. This review synthesizes evidence from literature published between 2015 and 2025 across South Asia, sub-Saharan Africa, and Latin America to examine (1) livelihood dependence, (2) market trends, (3) cultural values, (4) ecological aspects, (5) post-harvest innovations, and (6) policy frameworks. This time frame represents the scope of the systematic literature review and includes empirical findings, policy analyses, and short-term market outlooks that discuss events occurring within this period decade.

2 Importance of NTFPs

The importance of NTFPs is most immediately evident in their profound contribution to the daily livelihoods of local people, their growing significance in global trade, cultural and ritual significance and environmental and ecological aspects.

2.1 Livelihoods of local people

Globally, people depend on forests for their livelihoods and food security. Non-timber forest products are found in both forests and home gardens. Recent research has shown that a significant proportion of rural dwellers in tropical regions derive income, food, or other assets from wild forest commodities. Estimates suggest, for example, that some 2.77 billion people in the Global South make use of non-timber forest products in one way or another (Angelsen et al., 2014; Hickey et al., 2016). Some 77 per cent of rural households in a survey encompassing 24 low and middle-income countries report collecting wild foods, fruits, vegetables, roots, and the like. However, the money earned from such work is limited, averaging just 4% of total household earnings. In India, for example, non-wood forest products contribute to the livelihood of almost 275 million people (Sardeshpande and Shackleton, 2019). Studies in some African and Asian countries have revealed that NTFPs constitute a considerable share of rural household incomes, varying from 7.4% (Zambia) to 40.2% (Myanmar), depending on the nature of products, market accessibility, and degree of commercialization (Derebe et al., 2023). Such cash and in-kind transfers can help reduce poverty by substituting for out-of-pocket spending on food, medicine, fuel, building materials, or main household expenses, and provide a safety net during the time of shocks when other sources of income disappear (Hariharan et al., 2025; Mondo et al., 2024; Wells et al., 2024).

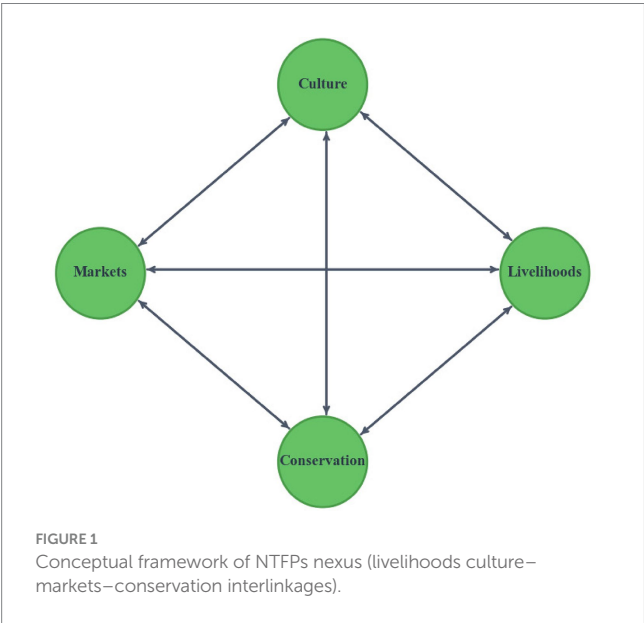
Non-timber forest products (NTFPs) serve as significant economic cushions, but they also provide more than just the essentials. When crops fail or jobs are scarce, those forest products become a crucial fallback option. In times of crises such as droughts or market failures, families in rural areas may have to go to food collection, firewood gathering, and craft products to make up for (Angelsen et al., 2014; Hickey et al., 2016). It is this buffering impact (from Asia and Africa 2015–2025) that features most prominently, with communities

Abbreviations: NTFPs, Non-timber forest products; FAO, food and Agriculture Organisation; CBD, Convention on biological diversity; GDP, Gross domestic product; UN, United Nations.

TABLE 1 Contribution of NTFPs to rural livelihoods in selected regions (2015–2025).

Country/Region	% of households using NTFPs/wild foods	Avg. share of household income from NTFPs	Typical products/ notes	Sources
24 LMICs (multi-country)	~77% of rural households gather wild foods	—	Broad basket of wild foods & NTFPs	Angelsen et al. (2014); Hickey et al. (2016)
Six-country review (Horn of Africa & beyond)	—	24.41% (mean)	Wild fruits/veg, medicinal plants, fuelwood, craft materials	Derebe and Alemu (2023)
Bangladesh (PA-adjacent HHs)	27% earn NTFP cash income	~18% (of annual HH income)	Mixed NTFPs; ~18% of HHs rely on NTFPs as primary income	Mukul et al. (2015)
India (national/tribal)	Widespread participation	Up to 40% for IPLC/tribal communities	NWFPs incl. Tendu, bamboo, mahua, honey	Hariharan et al. (2025); Sardeshpande and Shackleton (2019); Sharma and Thoudam (2025)
Myanmar (case study)	—	40.2%	Mixed NTFPs with market access	Derebe and Alemu (2023)
Zambia	High participation in wild foods	—	Wild foods from forests	Steel et al. (2022)
South Africa (review)	≥85% use multiple NTFPs	—	Leafy veg, fuelwood, fruits, weaving materials, honey	Shackleton et al. (2024)

Dashes (—) indicate not quantified. HH, household; IPLC, Indigenous Peoples and Local Communities; LMICs, low- and middle-income countries.



resorting to sales of baskets, medicinal herbs, bushmeat, and other wild products in response to income gaps being caused (Belton et al., 2021). Wild foods and forest products became vital in South Asia and parts of Africa during the COVID-19 pandemic, when supply chains for staples were disrupted. The safety net role of NTFPs is well documented: income and savings from forest products serve as an important supplement to the livelihoods of many poor people, and in several studies, it has been shown to protect against severe hardship. For instance, on a 6 country review, households generated an average of 24.4% of the total income harvested through NTFPs (Derebe and Alemu, 2023; Luswaga, 2023). A further comparison carried out in 24 developing countries (about 8,000 h.) suggests that environmental

incomes, NTFPs among them, are essential and in many places significant sources of total income earned (Angelsen et al., 2014; Hickey et al., 2016). Although NTFPs hardly serve as poverty alleviators, they help alleviate poverty by providing a consistent source of additional income and materials to households. Dependence is most significant for those with few alternatives, such as land-poor farmers, tribal or indigenous people, women, and migrants. It is even carried out by relatively affluent rural households practicing the collection of wild foods, medicinal plants, and/or ritual items for cultural or economic reasons (Sharma and Thoudam, 2025).

The empowerment of local people in the NTFP sector has made significant strides over the last 10 years. In India, the government's initiatives, such as the Pradhan Mantri Van Dhan Yojana, launched in 2018, have taken the lead in forming co-ops and VDVKs (Van Dhan Vikas Kendras) for the value addition of MFPs by tribal gatherers. As of 2025, over 11.83 lakh tribal beneficiaries have benefited from the scheme, which provides support including training, infrastructure for value addition to forest produce (such as honey and Kendu leaf), storage and marketing facilities, along with seed capital. The beneficiaries are directly paid based on procurement prices. This provides training, infrastructure for value addition, storage and logistics support, and marketing of their produce. The scheme seeks to increase income by encouraging members of tribal households to move from gathering raw materials to processing, branding, and marketing (Rosenfeld et al., 2024; Srivastava, 2022). Likewise, a 2021 study in the Brazilian Amazon found that smallholder producers affiliated with cooperatives and engaged in company community partnerships with cosmetics companies had significantly higher total household incomes compared to those who were not (Antunes et al., 2021). These illustrations reveal a trajectory from 2015 to 2025, where NTFPs are being utilized to promote rural development as community enterprises and as an instrument for market integration, thereby reinforcing their conventional role in livelihoods. Community

enterprises help NTFPs play a bigger role in local and rural development. At the same time, these products are becoming increasingly important to global trade, where their market value shifts from being necessary for survival to being high-value international goods.

2.2 International market significance

Non-Timber Forest Products (NTFPs): More than just subsistence for local forest-dependent communities, NTFPs are also a keystone component of global trade. A majority of NTFPs are popular, high-value items sought after throughout the world, such as wild fungi and truffle species, plant extracts such as herbs, spices, and flavors, natural dyes that can be used by World curling services for dying fabrics among other purposes, raw materials including rubber taps, resins such as frankincense, and many ornamental plants. First, trade of many NTFP is informal and underreported, but potentially economically important. Recent studies indicate that the market for medicinal and aromatic plants alone was valued at approximately \$201 billion in 2023 and is projected to continue growing (Zamani et al., 2025). Key global NTFP trade items and their estimated market values are presented in Table 2. The Food and Agriculture Organization (FAO) estimates that the broader NTFPs sector contributes about \$88 billion annually, with recent growth rates of around 15–25% (Peerzada et al., 2021). According to FAO/TRAFFIC data, demand for wild plant ingredients has increased by over 75% in value over the past two decades. For example, a global overview of “wild plant ingredients” revealed that in 2015, the reported global trade for medicinal plants alone exceeded \$3 billion, a threefold increase since 1999. However, actual figures are likely much higher due to incomplete reporting. Major global hotspots of NTFP production and their trade flows are illustrated in Figure 2.

Despite being of great economic importance, NTFPs are generally underreported in official statistics compared to timber. Most NTFP exports and domestic trade are not accurately recorded as they occur below the levels of major timber or agricultural commodities in customs codes or national accounts. Only a few relatively high-value products, such as some types of gums, resins, spices, or medicine preparations, are listed in trade statistics. However, the informal medicinal plant trade is unquantified, while most of the local trade in African city markets consists of seasonal wild fruits and traditional handicrafts. This lack of visibility has great importance for trade and the economy, given that NTFP products are highly traded all over the world (Morsello et al., 2012). Case studies have exposed a pulsating but fickle market. For example, the trade in wild plants was estimated to be worth USD 88 billion a year by FAO/TRAFFIC (cited in a Wild Plants value chains brief), much of which is produced from plant-based NTFPs, with approximately 60–90% of species being wild harvested rather than cultivated (Anastasiya and Drinkwater, 2021). The intoxicating kava (*Piper methysticum*) is a classic example of boom and bust. Demand for kava extracts outstripped supply from Western markets around 1999–2002, but reports of liver toxicity caused Germany to ban sales in 2002, followed by Switzerland and other EU countries. The bans had considerable economic effects on Pacific Island growers, many of whom depend on the kava trade as a source of income (Gruenwald and Skrabal, 2003; Prasad and Raj, 2012). The regulation of kava has even evolved. Recent reports (2025) indicate shifts in the way kava is being classified and licensed by governments, often differentiating between traditional use and extract preparations, limiting dosages (e.g., to levels of kavalactones contained in commercial products), and similar. Boom and bust cycles of this nature are not one-offs: they serve as a reminder of the risks communities face when their livelihoods depend on NTFPs, emphasising the need for data improvements, diversification,

TABLE 2 Selected international NTFP markets and value-chain characteristics (2015–2025).

Product/group	Approx. market value & trend	Main producing regions	Key issues (risks/governance)	Sources
Medicinal & Aromatic Plants (MAPs)	~US\$201B (2023); growing	Asia, Africa, Latin America	Underreporting; quality control; sustainability & CITES compliance	Zamani et al. (2025)
Wild plant ingredients (broad)	~US\$88B/yr.; +75% in value (2000–2020s)	Global	60–90% wild-harvested; traceability gaps	Angelsen et al. (2014); Hickey et al. (2016); Peerzada et al. (2021)
Açaí (<i>Euterpe oleracea</i>)	~US\$140 M/yr.; Brazil >1.5 M t; +39% (2016–2022)	Brazilian Amazon	Certification; floodplain forest dependence	da Silva et al. (2025); Fernandes Martins and Teixeira (2024)
Shea butter (<i>Vitellaria paradoxa</i>)	>US\$2B (2022); exports ~US\$90–200 M/yr	West Africa (Sahel)	Women's co-ops; local value addition; climate stress	Opoku-Mensah (2023)
Tendu leaves (<i>Diospyros melanoxylon</i>)	~US\$2B bidi-wrapper trade	India (central/eastern)	MSPs, cooperatives, reduce middlemen	Hazari et al. (2023)
Frankincense (<i>Boswellia</i> spp.)	Significant but underreported	Horn of Africa, Arabia	Overharvest; climate stress; sustainable tapping	Cherenet et al. (2020); DeCarlo et al. (2020)
Kava (<i>Piper methysticum</i>)	Volatile; boom–bust cycles	Pacific Islands	Quality standards; evolving regulations	Gruenwald and Skrabal (2003); Kuchta et al. (2015); Mills (2025)

Market values are approximate and vary by reporting coverage. MSP, Minimum Support Price.

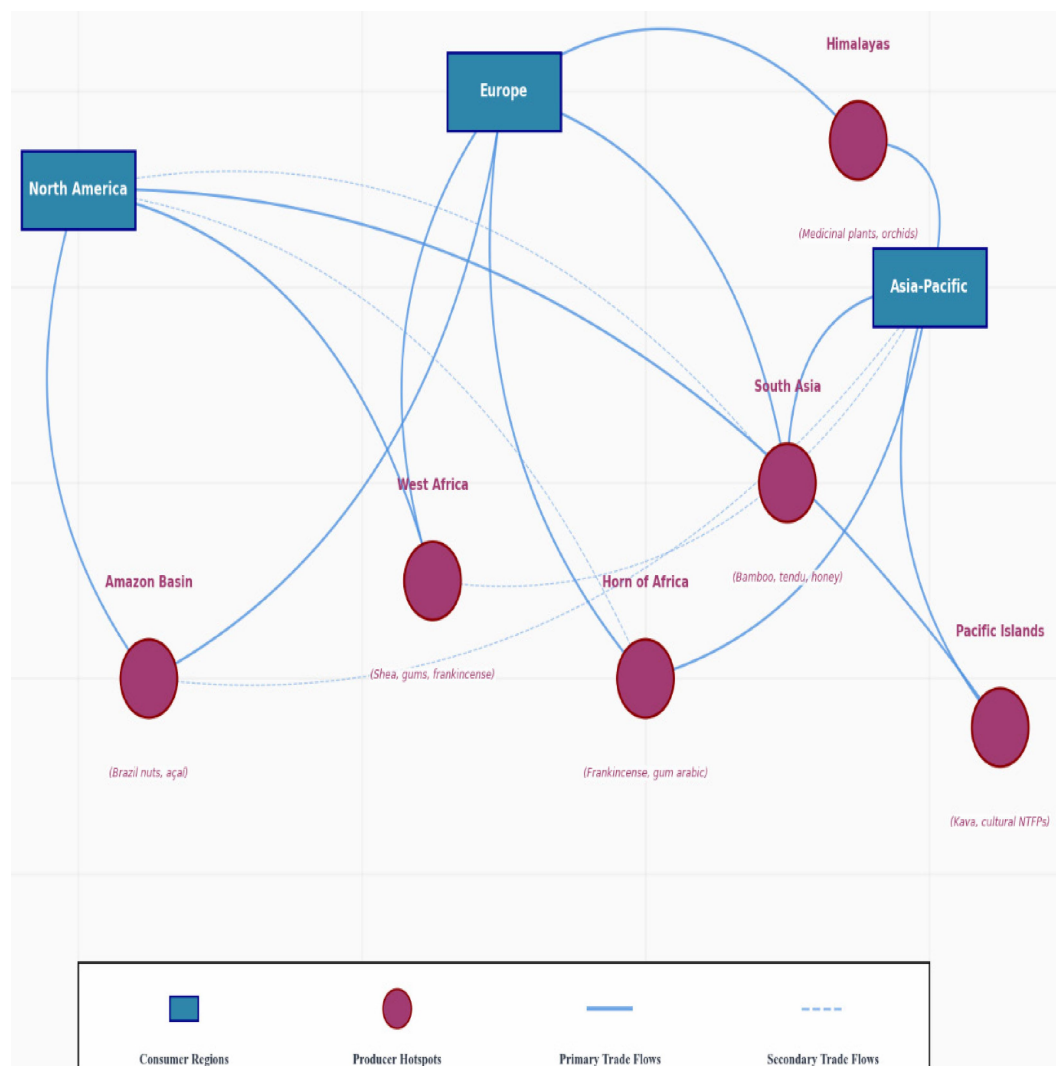


FIGURE 2
Global NTFP hotspots and trade flows (schematic map with key producing regions and export hubs).

quality control, traceability, reliable regulation, and well-monitored markets (Mills, 2025; Pollock, 2009).

Many non-timber forest products (NTFP) value chains have progressed considerably over the last decade. One popular example is açai, which is from the Amazon region (*Euterpe oleracea*). Açai has become an international superfood superstar after centuries as a dietary staple in the Amazon River region. By the early 2020s, the açai industry was valued at an annual \$140 million, with its largest producer, Brazil, churning out over 1.5 million tons each year. Between 2016 and 2022, Brazilian açai production increased by approximately 39% in response to the growing export trend. This growth benefits approximately 150,000 Amazonian family producers, organized in nearly 200 community projects, which are cooperatives and associations that supply both local and international markets. The açai boom has demonstrated that marketing NTFPs can lead to substantial cash income for remote forest communities, while also contributing to conservation measures, as açai palms grow only in healthy preserved floodplain forests (da Silva et al., 2025; Fernandes Martins and Teixeira, 2024; Moraes and Mello, 2023). In Pará, Brazil,

regulated Brazil-nut harvesting zones showed a 40% higher tree regeneration rate compared to unregulated areas (Wadt et al., 2008).

Shea butter (from *Vitellaria paradoxa* nuts) is a major NTFP in West Africa. Shea has grown into an international business that caters to cosmetics and food companies. The global market for shea butter surpassed \$2 billion in 2022, with annual exports from West Africa estimated to be between \$90 million and \$200 million. Notably, shea is sometimes called “women’s gold” because approximately 3 million African women are engaged in its collection and processing throughout the Sahel region. Over the last decade, projects implemented by organizations such as United States Agency for International Development (USAID) and United Nations Development Programme (UNDP) have aimed to increase the profit share for women’s cooperatives from the export of raw nuts to the locally processed butter, thereby providing rural communities with a larger share of the added value. This NTFP trade trend is towards shortening supply chains and adding value locally through community processing, fair trade certification, and geographic indications, resulting in a greater share of the final product revenues going to harvesters (Opoku-Mensah, 2023).

India also holds a high share of the non-timber forest products (NTFP) market, being one of the largest exporters of medicinal plants, aromatic oils, gums, and fibres in the world. One of the significant NTFPs includes the tendu leaf (*Diospyros melanoxylon*) used for packing bidis. India alone generates around 350,000 tons of tendu leaves a year, and its export earnings from tendu leaf wrappers for the bidi (local cigarette) industry amount to about \$2 billion annually (Hazari et al., 2023). In Madhya Pradesh, household income from tendu leaf collection increased more than 25% following the implementation of community-based forest management (Thakur and Malkan, 2024).

In many parts of central and eastern India, it is a significant source of seasonal income for the tribal and forest dwellers, as there are no purchasable alternatives in such remote areas where local forests or forest departments do not run these mills. Policy reform measures revolve around ensuring greater community control over tendu leaf collection, which will help reduce middleman exploitation, having MSP in place for specific regions, and promoting transparency in payments. As such, NTFPs constitute a significant generator of forest-dependent employment and export earnings in India. NTFPs contribute to nudging 55% forest-based employment (Sharma and Thoudam, 2025) and 40–70% export earnings from forest products. A recent analysis (Hariharan et al., 2025) also noted that, in some areas, the majority of rural households obtain 20–40% of their annual income from NTFP collection. These results highlight the economic significance of tendu leaves and other NTFPs (lac, gum, bamboo, bamboo tools, and honey) in the rural economy in India. They are also not just adding to the valuable export income but also being livelihood-sustaining for millions, especially tribal people.

The production and commercialisation of NTFPs in global markets can provide revenue and development options to rural producers, but it also creates difficulties. NTFP markets are flash-in-the-pan, quality driven. Demand is erratic, and for small-scale harvesters, such amounts are usually impossible to obtain legally because the export regulations are harsh or pay market prices for a wild product in a region where everyone otherwise has access to it. Products such as wild coffee, cocoa, nuts, or medicinal herbs can command high prices abroad if their supply chains are efficient and resources are harvested sustainably. Between 2015 and 2025, there was an increasing focus on generating so-called “win-win” value chains with positive effects for the community through sustainable gathering (with, e.g., an organic or fair-trade label), accompanied by consumer education about the cultural and ecological importance of these products. The search for new wild products with reliable commercial potential is a primary concern for the research community and development organizations, aiming to increase the availability of such products without overexploiting resources. Internationally, developments such as the Fair Wild standard for wild ingredients of a medicinal plant nature and the Ethical Trade in Wildlife initiative have come to light over the last 10 years with objectives to help ensure that growths in trade value associated with NTFPs contribute (and do not detract from) conservation and people at source (Jones et al., 2024; Nguyen et al., 2021; Rubio-Jovel et al., 2023). The economic potential of NTFPs in global markets is clear; however, this commercial value often masks their deep, non-market aspects. For many communities, NTFPs are even more significant due to their cultural, spiritual, and ritual importance. This significance is also crucial for managing and protecting them.

2.3 Cultural and ritual significance

For most indigenous communities, NTFPs have extreme cultural, spiritual, and ritual value, the importance of which is much more significant compared to their economic or nutritional dimension. Forests have always served us not just for resources, but also as identity and cultural source, a place where we connect with the divine. Since 2015, there has been an increasingly important dialogue in policy and academia around biocultural diversity, the understanding, modeled by people that traditional communities’ knowledge, beliefs, and languages are intricately connected to the biodiversity of their physical localities, including NTFPs (DeCarlo et al., 2020; DeCarlo et al., 2023). A few among the arboreal species are also significant in mythology, religious practices, and social customs. The resin of frankincense is the primary way *Boswellia* trees in sub-Saharan Africa and Arabia have been cultivated for thousands of years. It was one of the gifts presented by the Magi and is still used in churches, temples, and mosques (Cherenet et al., 2020). In Ethiopia and Eritrea, where wild frankincense growth is a source of national pride, local people tap trees for their resin, which is used in the liturgy of the Orthodox Christian Church as well as traditional medicine, a practice that may date back thousands of years but that now runs the risk of overharvesting and climate stress on *Boswellia* populations. Sustainable tapping techniques have been implemented through harvesting programs. Since 2020, efforts have been made to train harvesters in sustainable tapping techniques and cultivate *Boswellia* in community woodlots to help preserve this culturally vital NTFP (DeCarlo et al., 2020; Negussie et al., 2021).

Another interesting case is that of kava (*Piper methysticum*) in the Pacific Islands. As noted, aside from its recent market surge, kava is deeply rooted in the cultural dimensions of Vanuatu, Fiji, Samoa, and Tonga (Bian et al., 2020). Drinking from a bowl of kava, or bilum as it is referred to in some PNG groups, is an essential ritual for these societies for ceremonies and other social occasions, including conflict resolution, and aids the achievement of a relaxed, community oriented atmosphere so prized in Pacific cultures. Rural Pacific Island communities resisted the ban, and local economies remained rooted in kava production, a case study in how traditional cultural practices can persevere even under such circumstances (Kuchta et al., 2015). In the past decade, Pacific governments have tried to negotiate a path between cultural preservation and commercial opportunity as kava exports have taken off again (Germany lifted its ban in 2015). They have, for example, established quality criteria for kava that is exported to preclude future health problems and inform foreign buyers about its safe traditional use. This case clearly demonstrates the potential conflict and/or support between global market forces and local cultural economies. This example highlights how global market forces can either clash with or support local cultural economies (Lebot et al., 2019).

Most of these NTFPs have high value in the local culture and religion of South Asian countries. In India, certain fig tree leaves, including those of the peepul (*Ficus religiosa*), are symbolically associated with special deities and contribute to religious ceremonies as a form of gratuity offered by priests and worshippers to their gods, spirits, and ancestors. The mahua flowers are collected, then the pastry dough made from them is placed in an earthen pot (which looks like a big cup) for fermentation. Then this liquid is distilled to get an alcoholic liquor known as Mahua, which can be offered to god(s)

during jatras or enjoyed otherwise. Wild turmeric and aromatic herbs from forests in India's northeast are an integral part of traditional weddings and healing rituals. Ended in a few localities from 2015 to 2025, as young indigenous people recover traditional wisdom and even market cultural products like handmade incense or ritual teas (this contributes to their livelihoods while protecting tradition), which get sold commercially and keep tradition alive (Kropi et al., 2024). In many African nations, sacred forest goods remain important. In some West African cultures, the kola nut is a sign of NTFP, such that it is given as gifts at weddings, funerals, and social engagements to show respect and build relationships. This practice persists where kola nuts are available commercially and is the origin of the soda cola. This use of baobab fruit is not only to provide food but also plays a symbolic role in Sahelian folklore: the fruit, at which the length of up to 25 cm (10 in) are present depending on region and tree, is one of several that non-Muslim societies have used with a belief that it has mystic powers: he invokes rain in West African cultures. Anthropological research (such as the Mali study of 2019) shows that traditional leaders protecting sacred groves may impose temporal restrictions on baobab fruit collection, reflecting spiritual values in their management with some conservation value infrastructure. However, informal regimes seem to be weak and inadequate for SLM in most cases (Adeyanju et al., 2022; Avtzis et al., 2018).

Many indigenous cultures have inherent conservation ethics related to non-timber forest products (NTFPs). The temple could be associated with the taboo or selective capture of revered species. For instance, in parts of Southeast Asia, the eagle-wood tree, which produces agarwood used for incense, is believed to be a habitat for spirits. Local collectors follow rituals and refrain from felling trees to avoid provoking the spirits, which helps maintain the species in situ (Sinthumule, 2022). In the Indian Himalayas, a particular class of shamans collect alpine medicinal plants solely for ceremonial purposes, and local councils assign them quotas. Nevertheless, there are examples where local cultural values align with sustainable regeneration or harvest practices, and empowering cultural institutions is a tool to promote conservation of NTFPs (Gerber and Bhaduri, 2017). When a key NTFP becomes commercially valuable (as with the peyote cactus in North America or exotic orchids for festivals in East Asia), it can potentially be overharvested if traditional means of control outside access are compromised. This is generating demands to include indigenous knowledge-holders in the management of commercialization. For example, the Māori in New Zealand, who have cultural claims over wild honey and medicinal fern harvests, have been working with the government since 2015 on biocultural protocols that ensure any commercial use respects sacred limits and shares benefits with the community (as seen in the Wai 262 claim outcomes; Gale et al., 2019; Masters et al., 2020).

Over the last decade, a clear understanding has emerged that non-timber forest products (NTFPs) are not only commodities, but moreover a cultural heritage and identity. Whether it is a farmer in the Amazon reciting prayers to the “spirit of the açaí palm” before cutting down its fruit, or a hunter-gatherer in Cameroon thanking the forest after digging up medicinal roots, these rituals reveal a world where people and forest products are deeply interconnected. Understanding such cultural aspects is now considered an important factor for the sustainable management of NTFPs. Conservation programs such as UNESCO's cultural landscapes and several FAO-CIFOR initiatives have begun to integrate cultural values and traditional knowledge into

natural resource management plans. Through the acknowledgement and aiding of indigenous practices, involved parties hope to promote sustainable use that could be of benefit to people as well as the forest (Asamoah et al., 2025; Palacio and Goli, 2025; Paloma and Cathy, 2025; FAO, 2024; Wahlén, 2017).

An example that illustrates how culture affects rights to resources in Brazil is the Babassu Palm (*Attalea speciosa*). Known as “the mother palm,” babassu is critical to the Afro-Brazilian and close communities of the Amazon and Cerrado, particularly for women who traditionally collect the nuts. For these women, who have babassu as a cultural staple and a means of financial freedom for generations, the products include oil, flour, bran, charcoal, and dried leaves. In the state of Maranhão, they have successfully passed the so-called “Free Babassu Laws” that grant them the right to access and extract babassu fruit from any property. The shift in policy was motivated, at least in part, by cultural respect for a plant that has strong symbolic associations with local customs but also posed a threat to the way of life when access rights were limited. More than 20 municipalities in Brazil that have adopted Free Babassu ordinances by 2025 will not only save the palm species but also preserve the unique cultural practices of these communities. This illustrates how cultural importance encourages legal changes for the sustainable use of non-timber forest products (Puppim de Oliveira et al., 2022; Ressorio et al., 2024).

Finally, the cultural and ritual value of NTFPs demonstrates that these products are more than just an economic commodity; they are deeply ingrained in identity, tradition, and community welfare. This must be considered in any efforts to conserve or develop NTFPs. A distinctive feature of the period between 2015 and 2025 is represented by another pattern: the inclusion of indigenous voices in NTFP debates to ensure that policies take into consideration traditional knowledge and cultural values, addressing this as a key element for promoting sustainable use (Astolfi et al., 2025; Zurba and Papadopoulos, 2023). A summary of examples of such k-enabling policies in various countries is provided in Table 3. It is further consistent with international processes for harmonization of legal categories, such as the UN declaration on rights to nature in conservation (Nelson and Reed, 2025). Hence, conservation of NTFPs is not only an environmental and economic issue but also a question of cultural issues (Sangha et al., 2024; Zhu and Lo, 2021). In the end, the cultural and legal recognition of NTFPs is linked to their physical environment. The next key aspect of long-term sustainability is understanding the complex environmental and ecological factors, such as how cutting down trees and selling them impacts the health of the forest and the species themselves.

2.4 Environmental and ecological aspects

The linkage between NTFP use and environmental conservation is multifaceted and context-dependent. On the one hand, NTFPs are frequently presented as a means to conservation by sustainable use. The thinking is that, to the extent local communities can earn a decent livelihood by collecting fruits, nuts, resins, or other such products from forests without destroying them, they will have an incentive to conserve and manage the ecosystem sustainably. There are cases where a positive association exists between robust NTFP economies and the conservation of other forest values. For example, the Western Amazon is a hotspot of uncontrolled commercial Brazil nut harvesting that has

TABLE 3 Policy and legal reforms supporting NTFPs (2015–2025).

Country/region	Policy/instrument	Provisions for NTFPs	Outcomes/significance	Sources
Brazil	Extractive Reserves (RESEX); National Bioeconomy Strategy (2020)	Community rights to harvest/ manage; socio-biodiversity emphasis	Lower deforestation in RESEX; NTFP population stability	Araujo et al. (2024) ; Capelari et al. (2020a)
India	Forest Rights Act (2006, ongoing); Van Dhan Yojana (2018–)	Legal collection & sale rights; MSP; co-ops for value addition	Increased incomes; reduced middlemen exploitation	Lee and Wolf (2018) ; Reddy et al. (2024)
Kenya	Community Land Act (2016)	Recognizes communal land/forest rights	Local control over gums/resins	Alden Wily (2018a)
Liberia	Land Rights Act (2018)	Customary tenure; community forest governance	Legal basis for NTFP use; poverty alleviation potential	Alden Wily (2018b)
Ethiopia	Forest Law (2018)	Recognizes community management; NTFP commercialization allowed	Strengthens local economies; safeguards against clearing	Mengie and Szemethy (2025)
D. R. Congo	Community Forest Concessions (2018)	50,000 ha community concessions for NTFPs	First concessions benefitted >10,000 people	Kusters et al. (2022)
Global	CITES Appendix II listings (e.g., <i>Prunus africana</i> , <i>Aquilaria</i> spp.)	Quotas, permits, cultivation encouraged	Resource protection; transitional livelihood risks	Cunningham et al. (2016) ; Lai et al. (2025)

enabled much of this region to remain forested for decades. The trees are worth more each year in nuts than for timber, and Brazil nut gatherers closely monitor and prevent logging and fires in their territory to conserve their livelihoods ([Brouwer et al., 2021](#); [Guariguata et al., 2017](#); [Ribeiro et al., 2014](#)). Additionally, collecting wild honey in Kenyan community forests and gathering rattan cane in Southeast Asia have been recognized as fostering a mutualistic relationship between local communities and forest health, since both resources come from healthy, biodiverse habitats ([Capelari et al., 2020b](#)). Evidence from the Amazon supports this link: a 2020 comparative study found that sites with extensive Brazil nut harvesting, managed by local communities, had 2.5 times more tree seedlings and saplings than nearby unmanaged forest patches ([Capelari et al., 2020b](#)). These examples support integrating NTFP-based enterprises to meet both economic and ecological objectives, creating a win-win situation that promotes poverty alleviation and conservation.

Also, the harvesting of wild honey in Kenyan community forests and rattan cane gathering activities in Southeast Asia have been identified as being able to create a mutualistic relationship between local people and forest vitality, because both can be acquired only from healthy biodiverse habitats ([Mpaayei and Park, 2025](#)). These cases thus lend support to placing NTFP-based enterprises at the service of both economic and ecological objectives, in a win-win situation that combines poverty alleviation and conservation.

However, the best outcome is not assured. The exploitation of NTFPs is not inherently sustainable, and, in the case of higher-value commodities, there is a danger of over-exploitation, even for non-timber products (especially for slow-growing or sensitive species). Commercialisation-induced resource exhaustion has been witnessed in various studies (2015–2025). For instance, African cherry (*Prunus africana*), whose bark is used in an expensive prostate cancer medication, became endangered due to overharvesting in Central Africa. It was included in CITES Appendix II by 2017, and exporting

countries were required to develop limits on collection and encourage bark farming to safeguard against over-harvesting ([Cunningham et al., 2016](#); [Upreti et al., 2016](#); [Ticktin et al., 2023](#)). Infliction of stress on ecosystems under duress because of the overcollection of wild plants for value, such as was recently reported in the Himalayas: Parallels between intentional environmental insults and unintentional environmental misery. Clearly when we imagine environments becoming de-stabilized or disrupted due to human extraction (e.g., of orchids, medicinal herbs) the variables generally considered interfere with any assumption that there is always sustainable planning by humans about their environment. Poor harvest practices exacerbate the impact: tapping a tree for its resin or picking fruit has little effect, although stripping off the bark or uprooting entire plants can be highly damaging. Uncontrolled hunting of wild yams (a major NTFP) by animals and humans in West Africa has been shown to impact the composition of the forest's understory. In a review of NTFP case studies, it was concluded that small-scale harvesting was often ecologically harmless and nondestructive. In contrast, unsustainable collection for trade may have adverse effects on species regeneration or population structure (and even community composition in some cases) if not sufficiently regulated. The point, of course, is that there are biological limits to NTFP use; they cannot be harvested faster than they regenerate (again, a function of research and monitoring; [Peerzada et al., 2022](#); [Rubegeta et al., 2024](#)).

Another risk is that if the economic value of an NTFP suddenly drops (due to price fluctuations, regulatory changes, or loss of market access), communities may abandon sustainable use and turn to more damaging land uses. As one report cautions, if gathering wild products becomes unprofitable or gatherers are blocked from traditional areas, they may switch to logging, cash crop farming, or livestock grazing activities with much greater environmental impact. For instance, during the kava export ban (2002–2008), some Pacific Island farmers cleared kava plots to grow other cash crops ([Mohanty, 2017](#)). In the Brazilian Amazon, if prices for rubber or açai decline, there is concern

that extractives may resort to selling timber or leasing land for ranching. This reinforces the role of market stability and secure resource rights as indirect levers for conservation. These give communities confidence that sustainable collection of NTFPs will continue to confer benefits upon them and are more likely to allow them to resist the temptation of making short-term financial gains through deforestation. On the other hand, insecure land tenure, or no access rights, can lead to a “tragedy of the commons”, where people race as much as they can before others do so unsustainably. Secure community forestry rights (as seen in Nepal, Tanzania, Guatemala, and others) have shown better results for both livelihoods and forest cover, including for NTFPs (Bocci et al., 2018; Casse and Milhøj, 2011; Kusters et al., 2022).

In recent times, climate change has become one of the most significant pressure factors impacting NTFPs and their ecosystems globally. Globally, forests are facing stress from various sources, including prolonged droughts, intensified wildfires, invasions by pests and pathogens, and altered rainfall patterns. These changes directly affect the availability of NTFPs; for instance, higher temperatures and less rainfall in West Africa have been associated with reduced production levels of wild shea nut and locust bean yields (Adelesi, 2024). When considering the impacts on female-headed households in Nigeria, climate variability, notably erratic rainfall, was responsible for more than a 10% reduction in household NTFP incomes and underscored the fact that users of forest products are at a high risk from climate (Baileygunhi et al., 2025). In the Himalayas, villagers report that in some areas of the mountains, medicinal herbs are now flowering earlier or at higher altitudes than they did decades ago, disrupting foresters’ carefully calibrated schedules for when to collect them. Particularly, wildfires from 2019 to 2020, such as those in the Amazon and Australia, destroyed large areas of forest, which released carbon and ultimately led to local depletion of sources for wild foods and materials used by populations (Bourgoin et al., 2025). Climate change is increasing the vulnerability of forest resources, says the New FAO report, *State of the World’s Forests 2024: The state of knowledge on forests*, released by FAO. According to the new report, *The State of the World’s Forests 2024*, published by the FAO, climate change is making forest resources increasingly vulnerable (Basiru et al., 2022; Tee et al., 2015).

Work done between 2015 and the beginning of the decadal period in 2025 shows very clearly that commercial NTFPs are not an endpoint in themselves for conservation or development. Instead, success is a function of many things. Some well-meaning NTFP projects were unable to attain “triple wins” (income, equality, and conservation) due to over-promising markets, high levels of elite capture of benefits, or unsustainable levels of harvest once profits rose (Asamoah et al., 2025). Frequently, the move from subsistence use to cash-based removal can create ambitions that stoke more pressure on resources and demand stronger management (e.g., harvest quotas, season closures, or cultivation of high-value species) to alleviate harvesting pressure on wild stocks (Leite et al., 2025; Schmidt et al., 2011). These challenges have led to numerous new resource management practices. Now people are just beginning to pay attention to community-based forests and what is known as co-managed forests, where local inhabitants have some say over harvest levels and monitor ecological impact. Agroforestry and NTFP domestication initiatives are being promoted, e.g., programs to persuade farmers to cultivate medicinal herbs, rattan or wild fruit trees in their home gardens or on degraded land for production markets rather than wild harvesting. Researchers

are also developing better tools to estimate scientifically sustainable yields, including projecting the population trajectory of overharvested species to determine how much can be harvested without a collapse (Kahsay and Bulte, 2021; Ticktin, 2005; Wong et al., 2020).

Another issue is the right to land and resources. What is evident, particularly in Asia, Africa, and Latin America, is that the management of NTFPs at community levels was recognized as important if sustainable solutions were to be identified. The more individuals who have legal title to these resources, the greater their incentive to protect them. For example, an 18-year study in the Brazilian Amazon found that more game hunting and fruit tree cultivation, but less deforestation, occurred where extractive reserve areas, where communities can use resources, were created compared to those located within open-access forests (Capelari et al., 2020a; Carvalho et al., 2019; McGunnigle et al., 2025). Similarly, in Namibia’s conservancies and Nepal’s community forests, granting local groups the authority to manage wildlife and NTFPs has led to improved resource conditions and biodiversity outcomes, including fewer wildfires and the recovery of endangered medicinal plants, while also benefiting the communities (Milien et al., 2021; Poudyal et al., 2023). These experiences have shaped policy, as discussed in the next section, with more countries updating laws to grant or strengthen community rights to NTFPs.

NTFP-based use and management can be either supportive or destructive of conservation. Properly managed, however, they pull people and ecosystems together by linking conservation and development goals. To unleash their positive potential, recent studies emphasize four main criteria: (1) good management plans which agree on sustainable harvest levels and monitor resource status; (2) empowerment of local communities through secure land rights, benefit-sharing and use of traditional knowledge; (3) additionality without depletion (e.g., upgrading processing/marketing rather than just adding more extraction); and (4) agreement that some products should not be heavily commercialized at all, particularly those associated with slow-growing species or “key” species where strict protection may work best. A study on the piassava palm in Brazil shows that the value chain can have adverse effects on ecological conditions if there is no monitoring and community engagement, even when economic steps are improved (Araujo-Santos et al., 2025; Leite et al., 2025). Furthermore, models developed for fragmented landscapes also predict that high harvest intensity, without consideration of recruitment or juvenile and adult stages, leads to population loss. Analysis of commercialization in forest-adjacent communities reveals that formal market linkages can increase pressure if not properly governed, constrained by considerations of benefit sharing and sustainability (Miranda-Gamboa et al., 2024). Other scenarios, such as further successful examples, involve institutions that work, value is added in a conserving manner, and settings exist to manage slow-growing species in a sustainable manner (Rosenfeld et al., 2024). As one summary puts it, the goal is to strike a balance, ensuring that current NTFP use does not threaten their future availability or the ecological roles they play. Given the climate change and global biodiversity loss we are facing, careful stewardship of NTFP species, many of which are wild relatives of crops, pollinator-dependent, or crucial to food webs, is vital (Meinhold and Darr, 2019). It takes more than just managing the fields to achieve a balance between market demand and ecological limits. It also requires efficiency after the product is collected. Therefore, reducing extraction pressure and increasing returns largely depend on improvements in how NTFPs are handled and packaged after harvesting.

3 Post-harvest handling and packaging of NTFPs

The NTFP value chain is generally end-user-driven, and the post-harvest sectors (processing, storage, packaging) are largely ignored. Because most NTFPs are wild-collected, seasonal, and perishable, effective post-harvest management is urgently needed to minimize spoilage, poor product quality, and subsequent income loss. From 2015 to 2025, increasing priority is being placed on developing post-harvest technology, including simple interventions that can increase the shelf life and ensure the quality of agricultural produce, thereby further boosting local incomes (Maurizzi et al., 2023; Meinhold and Darr, 2019). Controlled post-harvest management enables NTFPs to be sold for extended periods or in distant markets without spoiling, resulting in reduced raw material wastage and higher prices. The contribution of post-harvest technology towards value retention is presented in Figure 3. This is especially relevant in the context of harvesters of NTFPs increasingly adopting more modern extraction techniques and aspiring to sell in urban or even international markets, where consistency and quality are important (Gouda and Duarte-Sierra, 2024; Mondo et al., 2024; Nath et al., 2024; Venkatesan and Muniyan, 2024).

Wild fruits, veggies, and flowers are examples of highly perishable non-timber forest products (NTFPs) that have benefited from post-harvest innovations. Jackfruit, a nutritious tropical fruit common in

South Asia, for instance. It ripens quickly and traditionally has a short market window. Recent studies in India have demonstrated that using Modified Atmosphere Packaging (MAP) and refrigeration can significantly extend the shelf life of jackfruit arils and bulbs. Innovations across multiple NTFPs are summarized in Table 4. For example, Saxena et al. (2008) found that MAP with 3% O₂ + 5% CO₂ (balance N₂), combined with pretreatment (calcium chloride, ascorbic acid) at 6 °C storage, preserved sensory quality and firmness for 35 days (Rahman et al., 2025). Compared to just a few days under ambient conditions. Another study also found that preservative-treated jackfruit bulbs stored at 0–5 °C or in the freezer retained acceptable quality for up to 28 days. Other treatments, such as dipping with ascorbic acid + calcium chloride, vacuum packaging, or using silica gel and MAP, have extended the shelf life of jackfruit portions to 15–20 days (Udayasoorian et al., 2019). Furthermore, reduced physiological loss of weight, microbial decay, and loss of firmness. These techniques, piloted in the late 2010s, are now promoted by agricultural extension services in India and Bangladesh to help farmers reduce jackfruit waste and access urban markets (Gana and Mini, 2023).

Take, for instance, jamun, a wild Indian berry that has diabetic control properties but is highly perishable. Jamun has traditionally been converted into syrup or squash for off-season use. A jamun syrup recipe (35% juice, 65° Brix sugar and 1.5% acidity) was standardized in a recent study in 2020, which can be kept for up to 6 months with

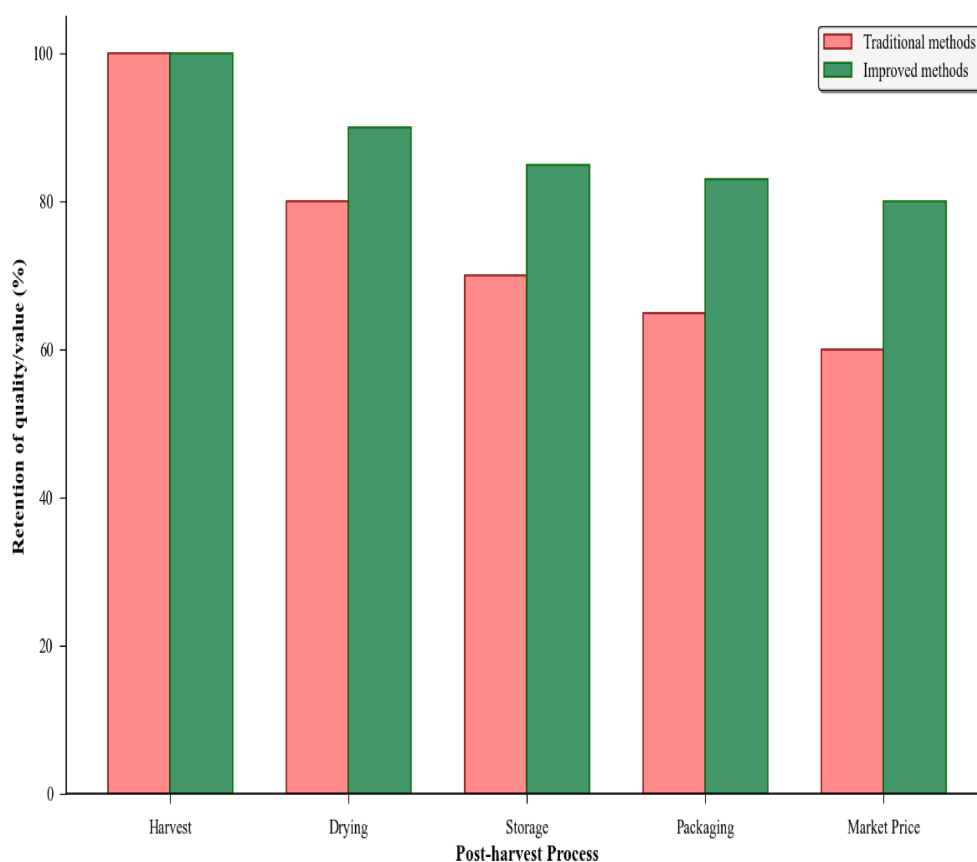


FIGURE 3
Impact of post-harvest innovations on NTFPs (comparison of quality/value retention with traditional vs. improved methods).

TABLE 4 Post-harvest and packaging innovations for selected NTFPs (2015–2025).

Product	Technique	Shelf-life gain	Value-chain impact	Sources
Jackfruit arils	MAP (3% O ₂ + 5% CO ₂ at 6 °C) + pretreatments	Up to 35 days (vs. 2–3 days ambient)	Market access, reduced waste	Rahman et al. (2025); Saxena et al. (2008)
Jackfruit portions	Dips (ascorbic acid + CaCl ₂); vacuum/ MAP storage	15–20 days	Better prices; reduced microbial decay	Udayasoorian et al. (2019)
Jamun syrup	Glass bottles + optimized recipe	≤6 months stable	Off-season sales; premium packaging	Jan et al. (2025); Sharma et al. (2020)
Brazil nuts	Drying + multilayer vacuum packs	Longer stability; reduced aflatoxin	Export compliance; price premiums	Lorini et al. (2018)
Dates/nuts	Moisture control; CA/vacuum packs	Reduced spoilage fungi; texture retained	Better quality, reduced losses	Ribeiro et al. (2021); Sarraf et al. (2021)
Honey	Airtight glass/plastic jars; temperature control	Stable ≥90 days	Quality assurance; premium branding	Belay et al. (2017); Yigit et al. (2024)
Pumpkin flowers	Vacuum-packed + – 18 °C freezing	~30 days	Seasonal smoothing for niche buyers	Toro-Vélez et al. (2022)
Dragon fruit	5 °C storage in perforated bags	~15 days (2 × ambient)	Transport/export feasibility	Chen et al. (2024)
Banana blossoms	Wrapped + 4°C storage	Up to 4 weeks	Higher marketable share	Chen et al. (2024)
Mushrooms	Freeze/hybrid drying	Higher nutritional retention	Premium dried products	Moutia et al. (2024)
Spices, fruits	Solar dryers (indirect/hybrid)	Faster, safer dehydration	Community-scale processing	Afzal et al. (2023)

MAP, Modified Atmosphere Packaging; CA, Controlled Atmosphere; O₂, oxygen; CO₂, carbon dioxide.

little loss of quality, among the study's more significant findings: what packaging material matters syrup stored in glass bottles, especially if it was refrigerated, held onto its color and antioxidant content better than when stored in PET plastic bottles. Glass is heavier but offers a superior moisture and oxygen barrier, is non-reactive with the product, and remains the preferred material for many NTFP products, such as honey, jams, or herb tinctures. This result suggests that certain traditional packaging forms, such as glass jars, may be more effective at protecting specific forest products than their modern plastic counterparts (Jan et al., 2025; Sharma et al., 2020).

Moreover, even storable NTFPs, such as nuts, seeds, and dried goods, could benefit from improved packaging. Dates, from the *Phoenix dactylifera* tree to dried forest nuts, can last for months, for example, but shifts in moisture levels may cause them to spoil. It was further observed that date fruit was also kept flexible, preventing over-drying (Sarraf et al., 2021). The lining of storage boxes with polyethylene or moisture-proof bags, as seen in a study conducted in North Africa (2016), helped reduce hardness by retaining an appropriate level of moisture. Conversely, insertion of desiccant packets can guard against conditions conducive to mold development (Ribeiro et al., 2021). In the Amazon, locally harvested Brazil nuts have high initial moisture but are increasingly being dried to safe levels and vacuum-packed in multi-layer plastic bags. This minimizes aflatoxin exposure and exports without spoilage. In some cases, simple preservation techniques such as waxing cartons, use of ventilated crates, and vacuum packing are reported to maintain the quality of different NTFPs, for example, spices, teas, and dried mushrooms, by regulating humidity and exposure to air (Lorini et al., 2018; Oladzad et al., 2021).

Between shrub honeys and wild honeys, a time-honored non-timber-forest product with an unlimited shelf life thanks to its low water content and inherent antimicrobial properties. Even so, good packing is necessary to avoid the absorption of any moisture that

could cause leavening or taint the flour. Studies in Africa and the Asia region have established the use of hermetically sealed, air-tight food-grade containers (glass or high-quality plastic) to maintain quality attributes (enzymes, HMF (5-hydroxymethylfurfural), sugars) over storage periods of months, particularly when temperature is controlled (Belay et al., 2017; Yigit et al., 2024). For instance, honey stored in light- or dark-colored glass jars and tin cans retained most of its physicochemical and antioxidant properties for over 90 days. Heterogeneity was small between types of containers, regardless of whether at room temperature or refrigerated conditions (Belay et al., 2017). The effect of moisture content, storage temperature, and container material on HMF accumulation and enzyme activity has been demonstrated in Ethiopian monofloral honeys, where glass and well-sealed plastic exhibit superior stability. Because consumers of premium markets prefer glass bottles for their associations with purity, aesthetics, and tradition, scientific proofs that glass is a better investment than food-grade plastic do not necessarily exist if the storage is aseptic and dry, and the containers are hermetically sealed, as both material types can preserve honey quality through time (Katsara et al., 2022; Yigit et al., 2024).

Let us take a closer look at a small case study of three perishable products: pumpkin flowers, dragon fruit, and banana blossoms. We will examine how post-harvest techniques impact their availability. Pumpkin flowers (*Cucurbita moschata*), which are highly perishable, can benefit from cool storage and modified atmosphere packaging (MAP). For instance, a study in Puerto Rico found that storing tropical pumpkin flowers under active or passive MAP at 5 °C significantly improved their appearance and delayed deterioration compared to storing them at 10 °C. However, even with the best packaging, most flowers became unmarketable by day (Toro-Vélez et al., 2022). Dragon fruit (*Hylocereus polyrhizus*), which typically lasts about a week at warm temperatures, saw its shelf life extended to 4–6 weeks at 5 °C when stored in non-perforated PE or PP plastic

films under MAP and low-temperature conditions. This resulted in reduced weight loss and shrivelling compared to non-MAP packaging (Mondol et al., 2025; Rashvand et al., 2023; Sharma et al., 2024). Unfortunately, data on banana blossoms was not found with the exact storage times. However, other short-lived wildflowers and inflorescences exhibit the same phenomenon: cool temperatures, protective packaging, and sometimes edible coatings or vacuum treatments can help preserve them in fine form. Among those cases, storage at low temperature (e.g., about 5 °C) and use of an adapted packaging (MAP, plastic packaging) significantly contribute to weight color changes, texture preservation, as well as to a reduction in waste and spoilage (Chen et al., 2024; Toro-Vélez et al., 2022).

Enhancing post-harvest has two significant advantages: economic and environmental. By preserving products and reducing waste, many lesser-known forests that produce raw NTFPs can be tapped, keeping minimal pressure on the wild population. If, for example, more efficient drying or packaging allows 80% of the aggregate harvest to reach consumers rather than 50%, then similar levels of income can be earned from smaller harvests, leaving more to rot (Meinhold and Darr, 2019). Moreover, community-based value-added activities, such as drying, jam making, oil production, and craftwork, lead to higher profits, allowing sustainable harvesting to be relatively more rewarding compared to alternatives involving the removal of forests. Therefore, many countries have increased the training of NTFPs processing technology through government and NGO efforts. India, Nepal, Kenya, and Bolivia were sites of programs from 2015 to 25 in which groups learned how to make herbal teas, essential oils, fruit jams, nut butter, and handicrafts, along with instruction on hygienic packaging and branding. One such case is UNIDO (United Nations Industrial Development Organization) shea butter project in Guinea (2014–2018), which rehabilitated and equipped five village cooperatives with improved boiling kettles, crushers, and storage for shea nuts, as well as intensive training for women on quality control and packaging. This effort led to more consistent, higher-grade shea butter that these co-ops could sell at better prices to cosmetic companies, directly boosting the incomes of the women while also reducing post-harvest losses (unprocessed nuts previously rotted or sold at a low cost; Alonge and Adesoji, 2007; Dawson et al., 2014; Yadav and Dugaya, 2012).

The significance of this commercial NTFPs phase (post-harvesting) can scarcely be overstated and remains so even today. Better storage and packaging mean that the quality of these products can be extended, such as with solar dryers for wild fruits or vacuum-packing bags for spices. For example, the work on solar dryers in food processing demonstrates that closed-type, indirect, and mixed-mode dryers are suitable for moisture removal in tropical regions (Afzal et al., 2023). These are enhancements, not automatic devices for rural producers to connect with more markets and get better prices. They help promote sustainability by decreasing waste from overharvesting. There is much scope for the further development and improvement of conservation technologies in such a diverse universe of other NTFP. Many wild things are tricky; some leafy greens, for instance, are best suited for pickling or fermentation, while certain nuts are ideal for roasting and airtight packing, and various fungi are best suited for drying or freeze-drying. Research on mushroom drying using different dehydration technologies has shown that modern methods of drying (hybrid, freeze, etc.) are significantly better in retaining nutritional and antioxidant properties, as well as sensory acceptability,

compared to traditional local sun or shade-dried products. Traditional methods such as indigenous smoking or sap fermentation have proven effective in innovating with modern food technology. It is anticipated that research will drive efforts to enhance post-harvest systems for NTFP through innovations and investments by 2025 (Luft and Mazutti, 2025; Moutia et al., 2024; Nwankwo et al., 2023; Oladeji et al., 2025; Sangeeta et al., 2024). Innovations in the post-harvest chain, such as new methods for food preservation and new value-added products, help local people earn more money and reduce pressure on wild stocks. However, for these benefits to be expanded and fairly distributed, a policy and legal framework is needed to make access, ownership, and trading easier.

4 Policy and legislation

Effective management and sustainable use of NTFPs are not a local issue; they also require enabling policies, rules, and directives. Historically, the forest laws of most countries have focused on timber and land use, with little regard given to NTFPs, or, if considered, in a gray area for which there may be no specific provisions. Yet, in the last decade or so, policymakers have realized that unambiguous regulation and rights to harvest NTFP are imperative if communities' livelihoods need to be reconciled with conservation (Aggarwal et al., 2021; Kusters et al., 2022). Critical policy issues are who should have the rights to pick and sell NTFPs (tenure/access rights), whether permits/quota for NTFP harvest is needed for transactions in markets, how best to include NTFPs in forest management plans, and how to regulate trade, particularly of endangered species covered by CITES (Araujo et al., 2024; Hariharan et al., 2025; Peerzada et al., 2021).

Take Brazil, for instance. These areas are characterized by an abundance of NTFPs, including aguapé, açaí, andiroba, castanha-do-pará (Brazil nuts), cacau (cocoa), seringa (rubber), and medicinal plants. These are more economically significant populations (Silva et al., 2020). A bibliometric study observed a progressive advancement in the research and attention given to NTFP in Brazil since the 1990s. However, by the time Amazon's promises were published, Brazilian forest laws had not reflected the increased significance of NTFPs. Many legislations were designed with timber or large-scale agriculture in mind, rather than considering the peculiarities of NTFPs. For instance, disaster and product regulations would not likely meet the same standards as fruit tree or vine control (Silva et al., 2020). Calls for stricter regulation of products, reviewers suggest that this should consider various biomes (the rainforests of the Amazon and the grasslands of the Cerrado are not the same), species biology (fast-growing bamboo cannot be compared to slow-growing medicinal bark), as well as harvesting methods. The standard definition of classifying NTFPs as a minor product in the forestry industry is not satisfactory. The good news is that Brazil has made major experiments with innovative institutional arrangements for governing NTFPs. The country established Extractive Reserves (RESEX), protected areas reserved for the sustainable use of traditional communities, primarily for extracting NTFPs such as rubber, nuts, açaí, and babassu, since the late 1980s. As of 2025, the Brazilian nation has 95 extractive reserves occupying more than 156,000 km² (60,292 miles). For example, under RESEX, there are instances where local cooperatives are given the exclusive right to extract certain products and apply either a

self-managed or plan-based approach (as approved by bureaucrats) in practical conservation, ranging from management for livelihood perspectives. Studies show that RESEX areas typically experience less deforestation and better maintain NTFP populations than unregulated areas. The ongoing challenge is to update national laws to recognize and strengthen community-based systems for all major NTFPs, and to address gaps (like many RESEX facing funding and enforcement issues). In 2020, Brazil also launched a National Bioeconomy Strategy, focusing on “socio-biodiversity products” (mainly non-timber forest products, or NTFPs), to encourage research, value addition, and market access for forest communities. The aim is to expand NTFP benefits while ensuring the sustainability of resources (Araujo et al., 2024; Capelari et al., 2020a; Orioli et al., 2025; Silva et al., 2020).

Access to and benefit sharing of NTFPs with communities has therefore been a central policy objective in many regions. In the past, there have been state monopolies or permits for cherished NTFPs, such as gums, sandalwood, and bushmeat, leaving local harvesters marginalized in favor of multinationals. This resulted not only in conflict and poaching but also often did little to help conservation. Several reforms occurred between 2015 and 2025. For example, India's Forest Rights Act (2006), rolled out slowly over the last decade, recognized the rights of forest-dwelling communities to collect and sell “Minor Forest Produce” (MFPs) from their community forests. In 2020, scores of tribal villages throughout India had received title to the forest resources that lie within, enabling them to cultivate and market NTFPs like tendu leaves, bamboo, and mahua flowers rather than being exploited by sardars (middlemen; Lee and Wolf, 2018). Building on such models, India's Van Dhan Vikas Yojana (2018), for instance, explicitly aims to transform tribal NTFP collectors into entrepreneurs by federating them and providing marketing and value addition support. This conceptual shift, from framed foresters to stewards and producers, is critical for the Indian NTFP sector. Early outcomes are increased incomes and better management of resources in communities that hold secure tenure with support (Reddy et al., 2024).

Regional and transboundary collaborations are becoming more important in NTFP governance, along with national and international policy frameworks. The Central African Forests Commission (COMIFAC) and other groups work to promote consistent certification, traceability, and guidelines for sustainable harvesting of products like rattan, gum arabic, and medicinal plants across Central Africa. Similarly, Association of Southeast Asian Nations (ASEAN) member countries have set up ways to work together on the trade of bamboo, rattan, and resin. They have also set up ways to monitor the trade to stop overharvesting and make sure everyone has fair access to the market. In South Asia, the South Asian Association for Regional Cooperation (SAARC) and Bay of Bengal Initiative for Multi-Sectoral Technical and Economic Cooperation (BIMSTEC) frameworks have facilitated regional dialogue that has prioritized collaboration on forest product trade, capacity enhancement, and biodiversity preservation. Such cooperation across borders encourages the sharing of information, the harmonization of policies, and the integration of regional markets. This makes sure that managing NTFPs helps both the environment and the economy at the same time. In some African countries, land and forest tenure reform has indirectly contributed to enhanced NTFP management. In Kenya and Liberia, for example, the Community Land Act (Community Land Act of 2016) and the Liberian Land Rights Acts of 2018,

respectively, strengthen local recognition and governance of statutory communal lands and forests that allows communities greater say over what happens there as well as access to resources derived from it including NTFPs such as gums & resins in Kenya's drylands or bush mangoes and rattans in Liberian forests (Alden Wily, 2018a). Another major reform is the Ethiopian forest law of 2018, which officially recognizes all existing community-based forest management and authorizes communities to use and sell NTFPs in accordance with management plans. This departure from older policies that allowed only informal extraction of NTFPs by communities does allow them to become legal partners in forest management, with stewardship over some timber if they practice sustainable practices. Early evidence by Anon., Ethiopia's law, developed with CIFOR scientists' input, enables forests to be part of local economies alongside protection measures: penalties for unlawful clearing and rewards for planting (Mengie and Szemethy, 2025). Likewise, in the Democratic Republic of Congo, a decree was issued in 2018 enabling communities to apply for up to 50,000 hectares as their own forest concessions for local use. By the end of 2018, the first of these had been granted and covered about 300 sq. km (115 square miles), helping over 10,000 people who are now legally in control of these woods. It is anticipated that these community forests will be managed for sustainable livelihoods, which involve the collection of bushmeat, caterpillars, and medicinal plants, as well as other NTFPs (non-timber forest products), thereby combining conservation of such resources with poverty reduction. This young policy is already being applauded as a model for the entire Congo Basin, which has in excess of half its population (approximately 40 million in the DRC) depending on forests and will be the primary beneficiaries of secure tenure (Alden Wily, 2018b; Kusters et al., 2022; Santini, 2025).

Global trade regulations have a significant impact on conservation efforts. Over the past decade, the Convention on International Trade in Endangered Species (CITES) has listed or uplisted a variety of high-volume nontimber forest products (NTFPs) to control their extraction. These include agarwood (*Aquilaria* spp.) Nuts of the banded kaffir mango, African cherry (*P. africana*), and certain cycads or cacti are used as food or medicine. For CITES Appendix II species, exporting countries must have in place a management plan for the species and grant permits to ensure that harvests will not be detrimental to the survival of the species. Furthermore, while the bans are crucial to saving endangered animals, they can also cause tremendous harm if not paired with other efforts. When *Prunus africana* was included, for example, countries like Cameroon had to stop exporting it until they had established management plans for sustained yield. Domestication promoted (to date, there are some *Prunus* allocation units-PAUs), which now allow extraction following quotas given and Non-Prejudicial Trade Notice under a CITES/ITTO facility (Alden Wily, 2018b; Kusters et al., 2022; Tassiamba et al., 2022). In the case of agarwood, studies indicate that despite regulatory protections, a significant portion of the trade still relies on wild-harvested trees, characterized by weak reporting and enforcement. Cultivation and regulation efforts are underway in places like Indonesia to provide alternatives (Santini, 2025). Similarly, hoodia and pygeum bark have faced legal scrutiny under benefit-sharing agreements in Southern Africa as part of broader access and benefit frameworks. However, evidence of how healthy income has been maintained is less abundant. These rules ensure that if Western companies profit from these NTFPs, a fair portion of the

benefits return to the source communities, an application of the Nagoya Protocol on Access and Benefit Sharing (Abensperg-Traun, 2009; Lai et al., 2025).

Experts suggest several policy shifts to bolster a conservation-oriented NTFP sector. The explicit integration of NTFPs in national laws is essential for a valid development practice that integrates supply chains for these products, and for achieving the objectives contained in forest management plans. Countries like Mexico and Brazil have begun requiring management plans for community NTFP use areas, such as those for timber, which is a positive step (Hazari et al., 2023). Certification programs, such as Brazil's organic açai certification or the FSC's Non-Timber Forest Product certification pilot, can also promote best practices by recognising sustainably harvested NTFPs in the market. Another key area is supporting community businesses and cooperatives, which includes providing microloans or grants for processing equipment, forming marketing groups, and simplifying product approval requirements for small producers. For example, governments in India and Nepal now offer minimum support prices for certain NTFPs to protect gatherers from price drops and have streamlined transport permit requirements to facilitate legal trade (Hariharan et al., 2025; Maharjan and Dangal, 2020; Sherpa, 2025).

The NTFP policy must be coherent with the wider goals of rural development and conservation. It also means recognising

the fact that securing local people's tenure, capacities, and participation in decision-making leads to better outcomes for both people and forests. These relations can be conceptualised as four policy pillars for sustainable NTFPs (Figure 4). Many nations are drawing lessons from one another to inform their own policies. South Asian countries are exchanging knowledge on joint forest management and bamboo sector reform, and African nations have been cooperating over protocols for herbal medicine and wildlife use. The country is thus a pacesetter in community forestry models and biocultural rights for Latin America. International agencies such as FAO, UNEP, and CIFOR have held policy dialogues on NTFPs under the rubric of sustainable landscapes and green economies between 2015 and 2025. For example, the FAO (2018) report "Building a Sustainable Bioeconomy in Africa" identified NTFPs, like shea, gum Arabic, and medicinal plants as under used resources and advocates policy support for their value chains (Asamoah et al., 2025; Atinga and Bannor, 2024).

In general, the policy and legal framework for NTFPs is progressing toward greater recognition and integration. Reforms in countries such as Brazil, India, and several African nations have been undertaken to acknowledge community rights, promote sustainable use, and add value to NTFPs. There is a growing perspective that NTFPs should be more closely integrated into core forest policies

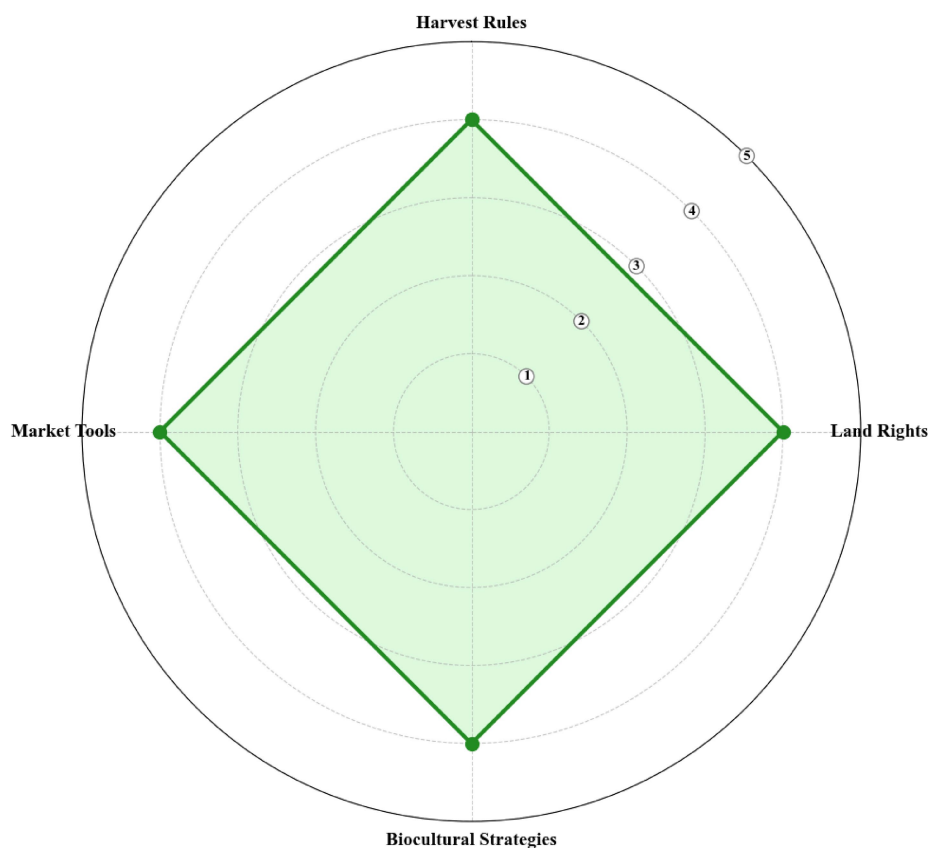


FIGURE 4

Policy pillars for sustainable NTFPs: (1) Land Rights—secure tenure and co-management; (2) Harvest Rules—species-specific quotas and monitoring; (3) Market Tools—MSP, certification, cooperatives; (4) Biocultural Strategies—customary knowledge and indigenous rights.

rather than remaining on the fringes. When rights are clearly defined, sustainability is demonstrated, and benefits are shared fairly, NTFPs can be managed to support local livelihoods and forest conservation. In the coming years, these developments may deepen, including more detailed harvest regulations for various species, increased community forestry rights, and stronger links between conservation laws and development initiatives or alternative livelihoods. These changes will help ensure that policy recognizes NTFPs as key drivers of rural development and biodiversity conservation. These trends indicate that forest management is evolving, but balancing the protection of livelihoods, market dynamics, and environmental health remains a challenge. The final area emphasizes the importance of future research and policy directions to fully realize the potential of NTFPs within sustainable landscapes.

5 Conclusion and future directions

NTFPs are crucial where local livelihoods, conservation, and markets intersection. They offer a lot of benefits, like food, medicine, and croplands that are important to their culture, which helps rural families. The sustainability of the NTFP economy is contingent upon local factors, including species biology, collection methods, market dynamics, and governance structures. Consequently, while many locations may facilitate sustainable management, not all will. The evidence compiled in this review (2015–2025) demonstrates that secure land rights and inclusive institutions, exemplified by Brazil's extractive reserves and India's Forest Rights Act, can effectively reconcile conservation efforts with poverty alleviation. On the other hand, not having secure tenure and insufficient regulations can lead to overfishing and environmental damage.

Future research and policy should focus on six priority areas:

1. Secure Tenure and Governance: Expand secure land rights and co-management structures for communities, to ensure inclusive access and transparent dialogue.
2. Adaptive management tools would include species-specific limits by use of participatory monitoring and Traditional Ecological Knowledge.
3. Stabilise and diversify markets, promote fair pricing, certification programs, and cooperative businesses that enable communities to better weather shocks.
4. Scaling post-harvest and value addition: Cheap technologies for drying, storage, and packaging can lead to higher product quality and incomes, and reduced pressure on wild stocks.
5. Biocultural integration: Incorporate cultural values, indigenous rights, and customary institutions into policies for conservation and trade.
6. Responding to climate change impacts: Include adaptation options to address changes in species distribution and timing of biological events, as well as increasing threats from wildland fire and drought.

Working together will enable us to reposition NTFPs as more than minor forest products, allowing us to see them as the essential building blocks they are in sustainable landscapes and green economies. To

ensure their ability to protect Biodiversity and Rural Welfare, we should strike a delicate balance between ecological constraints, market options, and cultural values.

Author contributions

TB: Conceptualization, Data curation, Methodology, Visualization, Writing – original draft, Writing – review & editing. KM: Funding acquisition, Resources, Supervision, Writing – original draft, Writing – review & editing.

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