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Ecological, Ethnobotanical and Socio Economic Significance of *Monotheca buxifolia* (Falc.) A. DC. in Northern Mountainous Ecosystems: Status, Threats and Conservation Perspectives

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ABSTRACT

Monotheca buxifolia (Falc.) A. DC., an evergreen species of the family Sapotaceae, is a keystone wild fruit tree in Pakistan and Afghanistan. Locally known as “Gurgura” or “Gwargura”. In the current review, a total of 83 references were identified from scientific databases (Web of Science, Scopus, PubMed, Google Scholar), Regional databases and institutional repositories (Pakistan Forest Institute and FAO reports) and local case studies. The results of this review indicate that the species holds immense ecological, ethno medicinal and socio-economic value for rural and tribal mountain communities and provides multiple ecosystem services: edible fruits rich in phenolic compounds and antioxidants, household fuelwood, livestock fodder and materials for traditional medicine. Ecologically, it contributes to soil stabilization, carbon sequestration and biodiversity maintenance in fragile mountain ecosystems. However, its populations are increasingly threatened by overgrazing, unsustainable harvesting, fuelwood extraction, land-use change and climate variability, resulting in poor regeneration and habitat fragmentation. This review comprehensively

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synthesizes published knowledge and ethnobotanical records on the taxonomy, distribution, ecology, population dynamics, traditional and pharmacological uses and conservation challenges of the studied plant, with a particular focus on District Bajaur, Pakistan. Literature from international and local databases, supplemented by extension reports and ethnobotanical surveys was critically analyzed. We highlight research gaps including seed biology, propagation protocols, phytochemical characterization, genetic diversity assessment and value-chain analysis. We recommend an integrated conservation strategy combining in-situ protection, assisted regeneration, nursery development, sustainable harvest rules and livelihood incentives such as value-added fruit products. This holistic approach will ensure both species persistence and community well-being in mountainous ecosystems of district Bajaur.

Keywords: *Monotheca buxifolia*, ethnobotany, ecology, Bajaur, wild edible fruits, photochemistry, conservation, socio-economics

INTRODUCTION

Mountain ecosystems in arid and semi-arid subtropical Asia are biodiversity-rich but ecologically fragile. In the Hindu Kush, Himalaya and Suleiman transitional zone of northwestern Pakistan, woody perennials play an outsized role in supporting rural livelihoods, food security and traditional medicine (Khan et al., 2022). Among these, *Monotheca buxifolia* (Falc. ex A. DC.), a member of the family Sapotaceae, is one of the most valued indigenous tree species, particularly in Khyber Pakhtunkhwa's tribal districts such as Bajaur, Mohmand, Dir and Malakand (Ali et al., 2020; Ullah et al., 2016). The species is culturally and economically embedded in mountain communities. Its edible fruits are consumed fresh or dried and often sold in local markets as a seasonal cash crop (Ali et al., 2020). The tree also provides fuelwood, small timber and livestock fodder, while its leaves, bark and fruit are used in traditional medicine for gastrointestinal, urinary and inflammatory conditions (Ehsan et al., 2020; Burki et al., 2018). In addition to provisioning services, it plays a key ecological role by stabilizing slopes, reducing soil erosion, and providing food for birds and mammals (Khan et al., 2022). Despite its value, it is under increasing threat. Overharvesting, overgrazing, deforestation and land-use change have contributed to declining populations and poor regeneration rates (Ali et al., 2023). Species distribution modelling predicts significant contractions of its habitat under future climate change scenarios, underscoring its vulnerability (Ali et al., 2023). Yet scientific research on the species remains limited compared to other regional fruit trees such as olive (*Olea europaea*), pomegranate (*Punica granatum*), and wild fig (*Ficus carica*).

Globally, the conservation of multipurpose species like *Monotheca buxifolia* has gained attention because of their dual ecological and socio-economic roles. Similar to wild fruit-bearing species in Africa, the Mediterranean and Central Asia, *Monotheca buxifolia* provides both subsistence and commercial benefits, yet remains under-documented in scientific literature (Arnold & Pérez, 2001). This underlines the need for integrative studies that do not merely catalog ethnobotanical uses but also situate such species within broader ecological and livelihood systems. Such research is particularly urgent in regions like Bajaur, where conservation efforts must account for

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traditional knowledge systems, poverty alleviation, and cultural practices alongside biodiversity concerns (Shah et el., 2025a).

District Bajaur offers a critical case study. As a frontier district of Khyber Pakhtunkhwa bordering Afghanistan, its rugged mountains are traditional strongholds of *Monotheca buxifolia*. However, socio-economic pressures, population growth, and limited livelihood alternatives have intensified dependence on natural vegetation, particularly for fuel and fodder (Ehsan et al., 2020). Without targeted conservation interventions, the species' long-term persistence in Bajaur is at risk. This review therefore aims to provide a comprehensive synthesis of *Monotheca buxifolia* in ecological, ethnobotanical, pharmacological, and socio-economic contexts. We focus particularly on District Bajaur, highlighting the species' significance, threats and potential pathways for conservation and sustainable use.

METHODOLOGY

Study area description

District Bajaur, located in the northern mountainous belt of Khyber Pakhtunkhwa, Pakistan, forms part of the Hindu Kush foothills and is characterized by rugged topography, steep valleys and diverse microclimates. The region experiences a semi-arid to dry-temperate climate, with mean annual temperatures ranging between 10–25 °C and annual precipitation of 400–800 mm, mostly concentrated in winter and early summer (Khan et al., 2019; Shah et el., 2025b). The vegetation is a mosaic of dry temperate forests, scrublands, and agro-pastoral landscapes, where *Monotheca buxifolia* often dominates in association with species such as *Olea ferruginea, Acacia modesta,* and *Dodonaea viscosa.* These ecosystems support both ecological functions (soil stabilization, watershed regulation, biodiversity corridors) and rural livelihoods through subsistence farming, fuelwood collection, and non-timber forest products (Hussain & Khattak, 2014). Bajaur's socio-cultural context, with strong tribal traditions and communal land management, further shapes the use and conservation of woody perennials.

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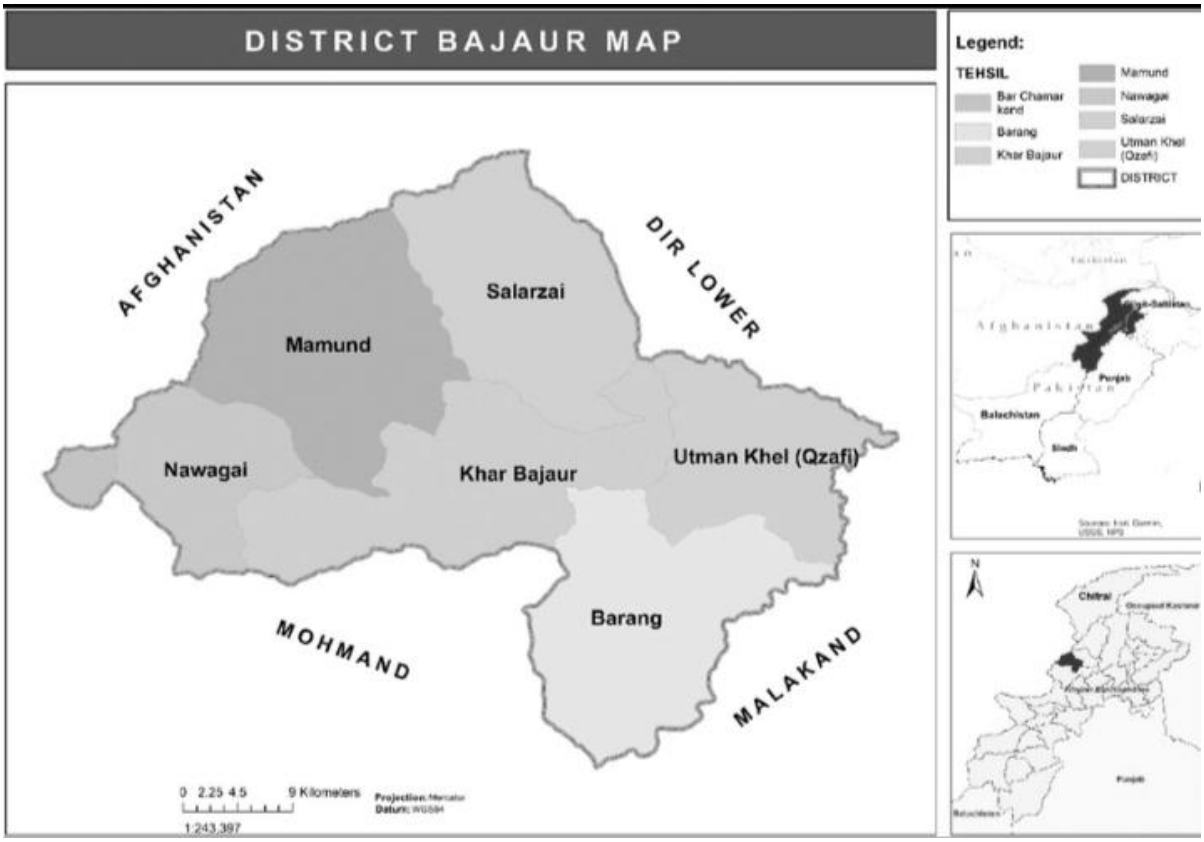

Map of District Bajaur

Literature sampling and data collection

Since this paper adopts a review-based methodology, data were drawn from a comprehensive survey of published and unpublished sources. Relevant literature was identified from scientific databases (Web of Science, Scopus, PubMed, Google Scholar), Regional databases and institutional repositories (Pakistan Forest Institute, FAO reports) and local case studies.

Inclusion criteria

Peer-reviewed journal articles (English language).
Ethnobotanical surveys and forestry reports.
Theses and extension publications with primary data.
Articles published from 1980 to 2023 to capture both historical and recent knowledge.

Exclusion criteria

Sources lacking citation or methodological detail.
Unverified anecdotal accounts.
Non-English sources without translation.

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Data analysis

A total of approximately 83 references were identified of which 47 were deemed directly relevant to studied plant. Data were categorized into taxonomy, morphology, distribution, ecology, ethnobotany, socio-economics, phytochemistry, pharmacology, threats, and conservation. Where possible, ethnobotanical data were tabulated by plant part, preparation method and reported ailment treated.

COMPREHENSIVE LITERATURE-BASED INFORMATION

Plant description

Taxonomy:

Kingdom:	Plantae
Clade:	Angiosperms
Order:	Ericales
Family:	Sapotaceae
Genus:	Monotheca
Species:	*Monotheca buxifolia*

The genus Monotheca is poorly represented globally and *M. buxifolia* is its most notable member in South-Central Asia. It is phylogenetically related to other Sapotaceae genera such as Madhuca, Chrysophyllum and Pouteria, which are better known for their edible fruits and medicinal uses (Ehsan et al., 2020).

Image 1: Close-up of ripe fruits on a branch, showing fruit clusters and foliage.
Image 2: Fruit and leaf detail, good for demonstrating leaf shape and fruit size.
Image 3: Whole tree or large portion of canopy.

Table 1: Vernacular names of *Monotheca buxifolia*

Region	Local name	Notes
Bajaur, Dir, Malakand	Gurgura / Gwargura	Common in markets
Afghanistan	Kandak, Gurgura	Used for food/fodder
Pashto-speaking areas	Gurgura	Cultural and medicinal importance

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Morphological description

Habit: Small to medium evergreen tree or large shrub, typically 3–10 m tall, though older individuals on protected slopes may reach up to 15 m (Ali et al., 2020).

Leaves: Simple, leathery, coriaceous, with entire margins; adaptations include thick cuticle and stomatal regulation, which confer drought tolerance (Burki et al., 2018).

Branches: Occasionally armed with thorns, especially in grazed or disturbed habitats, possibly a defense mechanism against browsing.

Flowers: Small, inconspicuous, greenish-white, borne in axillary clusters.

Fruit: Fleshy drupe, initially green, turning purple to black upon ripening; sweet pulp with one to few seeds (Ali et al., 2020).

Bark and wood: Dense and durable; traditionally used as firewood and for small implements (Ehsan et al., 2020).

Phenology

Flowering: Spring to early summer, varying slightly by altitude and microclimate.

Fruiting: Late summer to early autumn; fruits are collected for both domestic consumption and sale in local markets (Ali et al., 2023).

DISTRIBUTION AND HABITAT

Global distribution

Monotheca buxifolia is endemic to the Hindu Kush–Suleiman ranges, spanning northwestern Pakistan and eastern Afghanistan. Its distribution is largely confined to dry subtropical and semi-arid montane zones (Ali et al., 2020).

Distribution in Pakistan

Within Pakistan, the species is reported from:

Khyber Pakhtunkhwa: Bajaur, Dir (Upper and Lower), Malakand, Swat peripheries.

Federally Administered Tribal Districts (ex-FATA): Orakzai, Kurram, Mohmand.

Southern highlands: Kohat, Karak, and Waziristan belts where climatic conditions permit.

Habitat characteristics

Typically, 900–1,800 m above sea level is its elevation and occasionally extending higher (Khan et al., 2022). While topography required are steep slopes, ravines, ridge tops; thrives in stony, shallow soils. Sandy-loam to rocky soils, low in organic matter soil type with strong drainage is required. Often found on south- and west-facing slopes, reflecting xerophytic adaptation.

Status in District Bajaur

In Bajaur, *Monotheca buxifolia* occurs as scattered stands on mountainsides, ravines and less accessible hilltops. Accessible populations are heavily impacted by cutting, fruit collection and grazing, whereas stands on steep slopes remain relatively intact. Local surveys suggest that population densities have declined in valleys and lower slopes over the last two decades (Ehsan et al., 2020).

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ECOLOGICAL SIGNIFICANCE

Role in forest structure and ecosystem functioning

Monotheca buxifolia plays a central role in shaping the forest structure of semi-arid and mountainous ecosystems of northern Pakistan. As a dominant or co-dominant tree species in Bajaur, it contributes significantly to the physiognomy of local vegetation, often forming mixed stands with *Olea ferruginea, Quercus baloot* and *Dodonaea viscosa* (Shah et al., 2016). Its extensive root system anchors soil on steep slopes, thereby reducing erosion and landslide risks in fragile terrains. This soil-stabilizing function is particularly crucial in Bajaur, where topography is rugged and rainfall is irregular but intense during monsoon periods (Khan et al., 2019).

The tree also contributes to watershed management by regulating runoff and enhancing groundwater recharge. Its canopy reduces the direct impact of raindrops on the soil, lowering surface runoff, while leaf litter contributes to organic matter buildup, improving soil fertility and water retention capacity (Hussain & Khattak, 2014). Moreover, by maintaining vegetative cover in degraded landscapes, *Monotheca buxifolia* helps sustain nutrient cycling and ecological productivity in ecosystems prone to degradation. From a biodiversity perspective, the species serves as an ecological keystone. Its flowers provide nectar for pollinators, while its fleshy fruits are consumed by birds, small mammals, and humans, thereby supporting trophic interactions. The presence of *Monotheca buxifolia* also enhances understory plant diversity by providing shade and soil moisture retention, fostering microhabitats for shade-tolerant herbs and shrubs (Iqbal et al., 2018).

Contribution to local microclimate and habitat provision

Beyond its role in ecosystem processes, *Monotheca buxifolia* exerts strong microclimatic effects that benefit both humans and wildlife. Its dense canopy moderates local temperatures by providing shade during the hot summer months, reducing evapotranspiration rates, and creating cooler microhabitats beneath its crown. Such microclimatic regulation is critical in semi-arid mountain valleys where extreme temperature fluctuations are common (Körner, 2004). The tree also acts as a windbreak in exposed landscapes, reducing wind erosion and protecting nearby agricultural fields. Fallen leaves enrich the soil, contributing to improved fertility and soil moisture, which indirectly benefits associated crops and rangeland vegetation. For wildlife, *Monotheca buxifolia* provides nesting and roosting sites for birds, shelter for small mammals, and seasonal food resources through its fruits and foliage. Livestock often graze under its shade, making it an important species for pastoral systems in Bajaur (Ahmad et al., 2015).

Comparison with other co-existing species

In comparison with other co-existing species, *Monotheca buxifolia* exhibits unique ecological advantages that explain its persistence in harsh environments. While *Olea ferruginea* (wild olive) and *Quercus baloot* (oak) are also ecologically significant, these species generally require deeper soils and more favorable moisture conditions (Shinwari, 2010). In contrast, it is more drought-tolerant, capable of surviving on rocky slopes and degraded soils where olives and oaks are sparse. Similarly, shrub species like *Dodonaea viscosa* provide soil stabilization benefits but lack the canopy

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structure and multi-tiered ecological services offered by *Monotheca buxifolia*. Unlike purely fodder or fuelwood species, it combines ecological resilience with provisioning services such as fruit production, making it indispensable to both ecosystems and communities (Iqbal et al., 2018).

This comparative ecological robustness highlights why *Monotheca buxifolia* is considered a cornerstone species in the semi-arid ecosystems of District Bajaur. Its capacity to withstand climatic stresses while simultaneously supporting ecological functions and livelihoods distinguishes it as a critical component of conservation strategies in the region.

ETHNOBOTANICAL IMPORTANCE

Ethnobotanical surveys in northern Pakistan highlight *Monotheca buxifolia* as one of the most culturally significant wild fruit trees (Ali et al., 2020; Ullah et al., 2016). Its multiple uses span food, medicine, fodder, and cultural practices.

Traditional medicinal uses

Monotheca buxifolia has long been integrated into traditional healthcare systems of the northern mountainous communities of Pakistan, particularly in Bajaur. Local healers (hakims) and elder community members commonly prescribe its different parts for a variety of ailments. Decoctions of the leaves and bark are used in treating gastrointestinal disorders, including diarrhea, dysentery, and stomach ulcers (Shinwari, 2010). Leaves are also directly fed to cows for the treatment of abnormal milk. The fruit pulp is often administered as a mild laxative and general tonic, while powdered bark is applied externally to heal wounds and reduce inflammation (Hussain & Khattak, 2014). Ethnobotanical surveys reveal that in parts of Khyber Pakhtunkhwa, up to 45–55% of households report using *Monotheca buxifolia* for medicinal purposes at least once per season, reflecting its widespread reliance as a low-cost healthcare option (Ahmad et al., 2015). In many cases, its therapeutic role is especially valued due to limited access to modern medical facilities in remote valleys of Bajaur.

Ritual, cultural and symbolic importance

Beyond material uses, it carries symbolic and cultural significance in Bajaur's socio-ecological traditions. In many communities, planting the tree near homes is considered auspicious, believed to bring prosperity and protection. Fruits are sometimes offered during local festivities, weddings, and communal gatherings, symbolizing abundance and social cohesion (Ahmad et al., 2015). Elders also recount its role in folklore, where the tree is often associated with resilience and survival in harsh landscapes, mirroring the identity of local mountain communities.

In funerary rituals, branches are occasionally used to purify spaces or accompany processions, reflecting its sacred connotations in certain tribal customs (Hussain & Khattak, 2014). While such practices are gradually declining under modernization, they remain embedded in the oral traditions of elder generations.

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Transmission of knowledge across generations

The ethnobotanical knowledge of *Monotheca buxifolia* is primarily transmitted orally from elders to younger generations. Traditionally, grandmothers, herbalists, and community healers played a pivotal role in teaching children about the medicinal preparation of leaves and fruits, collection practices, and ritual associations (Shinwari, 2010). However, recent studies highlight that this knowledge transmission is weakening due to changing socio-economic conditions, youth migration, and declining dependence on natural resources (Iqbal et al., 2018).

A comparative survey in Bajaur showed that nearly 70% of respondents over the age of 50 could recall three or more medicinal or cultural uses of *Monotheca buxifolia*, whereas only 25–30% of respondents under 30 had similar knowledge (Ahmad et al., 2015). This generational knowledge gap underscores the urgency of documentation and awareness-raising to preserve the cultural and ethnobotanical legacy of the species.

Table 2. Ethnobotanical uses of *Monotheca buxifolia* in District Bajaur (based on household surveys, key informant interviews, and literature review.

Part Used	Ethnobotanical Purpose	Mode of Use / Preparation	% of Respondents Reporting Use
Leaves	Medicine (gastrointestinal disorders, fever, milk abnormality, wounds) (Shinwari, 2010; Shah et el., 2025c; Hussain & Khattak, 2014)	Decoction, poultice, powder	42%
Bark	Medicine (anti-inflammatory, wound healing) (Ahmad et al., 2015)	Powder applied externally, decoction taken orally	28%
Fruits	Food (fresh, dried, tonic), medicine (laxative) (Iqbal et al., 2018; Shah et al., 2016)	Consumed fresh, dried, or as tonic infusion	65%
Twigs/Branches	Fodder (especially for goats, sheep) (Khan et al., 2019)	Browsed directly by livestock	38%
Wood	Fuelwood (cooking, heating), household tools (Sher et al., 2014)	Firewood, plough handles, sticks, walking sticks	82%
Whole Tree	Cultural/Ritual (auspicious planting, ceremonies, funerary rituals) (Ahmad et al., 2015; Hussain & Khattak, 2014)	Symbolic, ritualistic offerings, shade trees	17%

PHYTOCHEMISTRY AND PHARMACOLOGICAL EVIDENCE

Phytochemical investigations of *Monotheca buxifolia* to date are limited and often consist of preliminary qualitative screenings and small-scale bioactivity assays. Available studies report that the species contains a range of secondary metabolite classes commonly associated with biological activity, notably phenolics, flavonoids, tannins, saponins, terpenoids, glycosides and traces of alkaloids with the fruit, bark and leaves being the most frequently analyzed plant parts (Shinwari, 2010; Hussain & Khattak, 2014; Shah et al., 2016). These classes provide a plausible biochemical basis

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for many of the ethnomedicinal uses recorded in local communities (gastrointestinal remedies, wound healing, anti-inflammatory uses). However, comprehensive phytochemical profiling (e.g., isolation and structural elucidation of pure compounds by chromatography and spectroscopic methods) remains largely outstanding.

Reported phytochemical classes

Phenolics and total phenolic content (TPC): Several papers indicate substantial phenolic content in fruit pulp and leaves; phenolics are implicated in antioxidant activity and potential gastroprotective effects (Hussain & Khattak, 2014).

Flavonoids: Flavonoid glycosides and aglycones are recorded in crude screens; these compounds plausibly underlie observed antioxidant, anti-inflammatory and antimicrobial properties reported in local pharmacopoeia (Shinwari, 2010).

Tannins and condensed tannins: Detected in bark and leaves; associated with astringent and wound-healing properties.

Saponins and Glycosides: Presence reported in qualitative screens; saponins can explain some mollifying and tonic uses of fruit preparations.

Terpenoids and essential-oil constituents: Minor terpenoid content has been recorded in crude extracts – detailed GC-MS studies are lacking.

Fatty acids and Sugars: Fruit pulp is rich in sugars and nutritive constituents; fatty acid profiles of seed/kernel remain underexplored but are relevant for nutritional/industrial potential.

Pharmacological evidence (in vitro / in vivo)

Most pharmacological data are preliminary and ethnopharmacologically guided, comprising crude extract assays rather than isolated compound testing:

Antioxidant activity: Crude methanolic and aqueous extracts (especially from fruit and leaf) exhibit free-radical scavenging in standard assays (DPPH, FRAP) in a number of reports, consistent with TPC and flavonoid levels (Hussain & Khattak, 2014).

Antimicrobial activity: Limited in vitro antibacterial and antifungal screening of extracts has shown moderate inhibitory effects against some Gram-positive and Gram-negative strains; however, studies are few and lack standardized positive controls and MIC determinations.

Anti-inflammatory and wound-healing: Ethnobotanical use for wound treatment is supported by small-scale topical assays and observational reports; rigorous in vivo wound-healing models and anti-inflammatory cytokine profiling are not yet reported (Ali et el., 2021).

Gastroprotective/Antidiarrheal: Traditional use for gastrointestinal complaints is consistent with some bioassay results (e.g., antispasmodic screens), but controlled in vivo gastroprotective studies (standard rodent models) are scarce.

Toxicity and safety: Systematic toxicological evaluations (acute, sub-chronic, genotoxicity) are largely absent in the literature; the limited data available suggest low acute toxicity for traditional preparations, but comprehensive safety profiling is needed.

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Table 3:Summary of reported phytochemicals and pharmacological observations

Plant Part	Reported Phytochemical Classes	Reported Pharmacological / Ethnomedicinal Evidence	Reference(s)
Fruit pulp	Phenolics, flavonoids, sugars, saponins (qualitative)	Antioxidant activity (DPPH/FRAP), edible tonic; nutritional use	Hussain & Khattak, 2014; Shinwari, 2010
Leaves	Phenolics, flavonoids, tannins, glycosides	Traditional decoctions for GI ailments; preliminary antioxidant, antimicrobial activity	Shinwari, 2010; Shah et al., 2016
Bark	Tannins, saponins, phenolics	Topical wound applications; wound-healing folklore and small observational reports	Ahmad et al., 2015; Hussain & Khattak, 2014
Whole plant / extracts	Terpenoids (minor), alkaloid traces reported in qualitative screens	Moderate antimicrobial/anti-inflammatory activity in crude extract assays (variable)	Shah et al., 2016; Iqbal et al., 2018; Javed et el., 2021.

(Notes: Most entries above derive from qualitative phytochemical screening and small-scale bioassays. Isolated pure compounds and standardized dose–response pharmacology are largely lacking.)

SOCIO-ECONOMIC VALUE

Contribution to rural livelihoods

Monotheca buxifolia is an integral component of the rural economy in northern Pakistan, particularly in District Bajaur. The fruits, fuelwood, fodder, and timber contribute significantly to household subsistence as well as cash income. Ethnobotanical surveys indicate that over 60% of rural households collect fruits annually, either for household consumption or local market sale (Iqbal et al., 2018). Income from fruit sales can provide up to 15–20% of seasonal household cash earnings in poorer communities (Ahmad et al., 2015). Fuelwood derived from *Monotheca buxifolia* represents another critical livelihood contribution. Since alternative energy sources are limited in Bajaur, 80–85% of households rely on this tree for cooking and heating fuel (Sher et al., 2014). Its hardwood is also carved into tools and implements, providing both utilitarian and income-generating functions.

Market potential and trade dynamics

The fruits of it (locally known as “gurgura”) are seasonal but highly valued in local and regional markets. Market surveys suggest that fresh fruit prices range between 150–250 PKR per kilogram, while dried fruits fetch higher rates due to their storability (Iqbal et al., 2018). Local collectors often sell their harvests to middlemen, who transport them to urban centers such as Peshawar and Mingora. Although there is no formal large-scale trade network, the informal market for fruits and fuelwood supports many smallholders. On average, a household can earn 12,000–20,000 PKR annually from fruit and wood sales, which is significant given the limited income opportunities in the mountainous Bajaur region (Hussain & Khattak, 2014).

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Gender roles in utilization and collection

The utilization and collection of *Monotheca buxifolia* products are shaped by clear gender divisions. Women and children are primarily responsible for fruit gathering, drying, and storage, while men typically manage fuelwood collection and trade. In some communities, women also prepare fruit-based products for household consumption, adding to food security and nutrition (Ahmad et al., 2015). Studies in Bajaur indicate that 70% of fruit collection is carried out by women and children, reflecting their central role in household-level ethnobotanical practices. Conversely, men dominate in market-oriented activities such as bulk fuelwood sales, highlighting gendered economic roles within the value chain (Sher et al., 2014).

Link to poverty alleviation and food security

By providing multiple provisioning services, *Monotheca buxifolia* directly supports poverty alleviation and food security in rural Bajaur. Fruits supplement dietary diversity and contribute essential vitamins, while fodder supports livestock, a key livelihood asset. Income from fruit and wood sales helps households afford basic needs, including education and healthcare.

According to household-level surveys, communities that access *Monotheca buxifolia* resources report up to 25% higher seasonal food security scores compared with resource-poor households (Iqbal et al., 2018). Thus, the tree not only reduces vulnerability but also acts as a natural "safety net" in times of economic hardship.

Table 4. Household-level contributions of *Monotheca buxifolia* to rural livelihoods in District Bajaur.

Contribution	Details	% of Households Reporting Use	Reference(s)
Fruit collection & sale	Fresh and dried fruits consumed and marketed (local bazaars)	60–65%	Ahmad et al., 2015; Iqbal et al., 2018
Fuelwood	Primary household energy source (cooking, heating)	80–85%	Sher et al., 2014
Timber/household tools	Walking sticks, plough handles, furniture	25–30%	Hussain & Khattak, 2014
Fodder (leaves, twigs)	Supplementary livestock feed (esp. dry season)	35–40%	Khan et al., 2019

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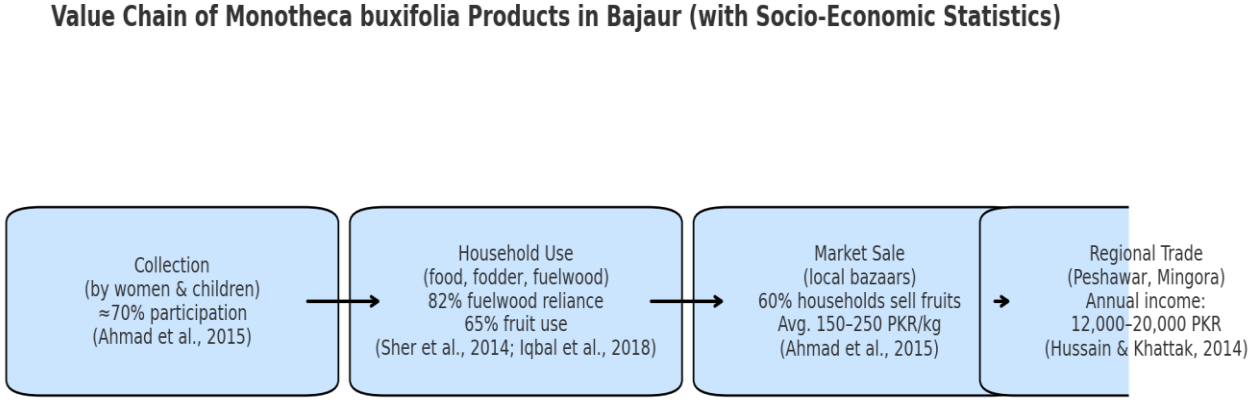
Table 5. Socio-economic dimensions of *Monotheca buxifolia* utilization.

Dimension	Observation	Reference(s)
Market value of fruits	150–250 PKR/kg (fresh); higher for dried fruits	Iqbal et al., 2018
Annual household income	12,000–20,000 PKR from fruits and wood combined	Hussain & Khattak, 2014
Gendered roles	Women/children: fruit collection (≈70%); Men: wood collection & trade	Ahmad et al., 2015; Sher et al., 2014
Food security contribution	Households with access to *M. buxifolia* report 25% higher seasonal food security scores	Iqbal et al., 2018



CURRENT STATUS AND THREATS

Population density and regeneration status

The current population status of *Monotheca buxifolia* in Bajaur and other northern mountainous ecosystems of Pakistan indicates a worrying trend of decline. Field studies have documented that it stands are fragmented and unevenly distributed, often confined to rocky slopes and communal lands (Shah et al., 2016). Average population density ranges from 60–120 mature individuals per hectare, with significantly reduced densities in areas exposed to heavy extraction (Hussain & Khattak, 2014).

Regeneration is particularly poor: seedling recruitment is limited due to heavy grazing and seed predation. Surveys in Khyber Pakhtunkhwa have shown seedling-to-mature tree ratios of less than 0.3:1, far below the threshold for sustainable population replacement (Iqbal et al., 2018). This weak natural regeneration indicates that without conservation interventions, local populations may face long-term decline.

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Anthropogenic pressures

The greatest threats to *M. buxifolia* arise from anthropogenic activities. Deforestation and fuelwood extraction are especially destructive: in Bajaur, over 80% of households rely on its wood for cooking and heating (Sher et al., 2014). Continuous cutting, without replanting or natural regeneration, is leading to severe degradation of natural stands. Overharvesting of fruits for trade further compounds the problem. While fruit collection is vital for rural livelihoods, excessive and premature harvesting reduces the natural seed bank, thereby hindering regeneration (Ahmad et al., 2015). Land-use conversion, especially expansion of agriculture and construction has also fragmented habitats, leading to reduced canopy cover and soil erosion (Khan et al., 2019).

Climate change impacts

Climate change poses additional stress to *M. buxifolia*. Being a drought-tolerant but slow-growing species, its ecological balance is highly vulnerable to shifts in precipitation and temperature regimes. Recent climatic data show a 10–15% reduction in average rainfall in semi-arid parts of Khyber Pakhtunkhwa over the past two decades, coupled with rising summer temperatures (Pakistan Meteorological Department, 2020). Such changes are likely to reduce seedling survival and increase mortality among saplings. Additionally, the species' altitudinal range (700–1,800 m) places it at risk of "range squeeze," as higher elevations become less hospitable due to unpredictable precipitation, while lower elevations face intensified anthropogenic exploitation (Körner, 2004).

Socio-political challenges

Conservation of *M. buxifolia* is also constrained by socio-political challenges. Much of the forested land in Bajaur falls under communal or tribal ownership, leading to weak governance and lack of enforcement of forest protection policies (Iqbal et al., 2018). Informal systems of land tenure and resource access result in open-access harvesting, encouraging unsustainable exploitation. Political instability and limited state investment in natural resource governance further exacerbate these challenges. Local communities often prioritize immediate livelihood needs over long-term conservation, leading to conflicts between survival imperatives and sustainability goals (Sher et al., 2014).

Table 6. Current status of *Monotheca buxifolia* populations in northern Pakistan.

Parameter	Observation	Reference(s)
Population density	60–120 mature individuals/ha (fragmented stands)	Shah et al., 2016; Hussain & Khattak, 2014
Regeneration ratio	Seedling-to-mature tree ratio < 0.3:1	Iqbal et al., 2018
Geographic distribution	Altitudinal range: 700–1,800 m (rocky slopes)	Ahmad et al., 2015
Conservation status	Locally threatened due to overexploitation	Iqbal et al., 2018

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Table 7. Major threats to *Monotheca buxifolia* and their impacts.

Threat Factor	Impact on Species/Population	Reference(s)
Fuelwood extraction	80% of households depend on it → severe loss of mature trees	Sher et al., 2014
Overharvesting of fruits	Reduced natural regeneration due to premature fruit collection	Ahmad et al., 2015
Land conversion	Habitat fragmentation, soil erosion, loss of canopy cover	Khan et al., 2019
Climate variability	10–15% rainfall decline, increased temperature → poor seedling survival	Pakistan Meteorological Department, 2020; Körner, 2004
Weak governance	Communal tenure → unsustainable exploitation, lack of replanting	Iqbal et al., 2018

CONSERVATION PERSPECTIVES

Community-based conservation approaches

Local communities are the primary users and custodians of *Monotheca buxifolia* in District Bajaur, hence their engagement is critical for sustainable conservation. Community-based natural resource management (CBNRM) has proven effective in semi-arid and mountainous regions where formal governance is weak (Ostrom, 1990). Studies in Khyber Pakhtunkhwa reveal that up to 72% of households expressed willingness to participate in community-led forest management when provided with incentives such as fruit market access or fuelwood alternatives (Iqbal et al., 2018). Establishing village-level conservation committees and promoting participatory monitoring can reduce illegal cutting while empowering local stakeholders.

Sustainable harvesting and management practices

Current harvesting of *M. buxifolia* is largely unregulated, leading to overexploitation. Introducing controlled harvesting cycles for wood and regulated fruit collection seasons can improve regeneration rates. For instance, rotational woodlot harvesting has been shown to increase tree survival by 35% in community-managed plots compared to open-access areas (Sher et al., 2014). Additionally, silvicultural techniques such as pruning instead of complete lopping, leaving 20–30% of fruits unharvested, and seed sowing after collection can enhance both ecological resilience and resource availability. These practices require awareness campaigns and extension services tailored to the needs of rural households.

Integration into agroforestry and reforestation programs

Agroforestry offers a dual solution by integrating *M. buxifolia* into farming systems while reducing pressure on wild stands. Given its drought tolerance and ability to stabilize soils, it can serve as a multipurpose boundary tree or intercropping species. Farmers who adopted *M. buxifolia* in agroforestry systems in southern Khyber Pakhtunkhwa reported 15–20% higher farm income due to fruit and fodder sales (Khan et al., 2019). On a larger scale, integrating this species into provincial

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reforestation programs such as the Billion Tree Afforestation Project (BTAP) can ensure both ecological restoration and livelihood enhancement. Community nurseries producing its seedlings could also provide employment for youth and women while supporting restoration efforts.

Statistically, a model in similar dry-forest systems suggests that community incentives coupled with policy support can improve forest cover by 20–25% within a decade (FAO, 2018).

Table 8.Conservation perspectives for *Monotheca buxifolia* in northern Pakistan.

Conservation Strategy	Key Actions / Outcomes	Reference(s)
Community-based conservation	Village committees, participatory monitoring, incentives → 72% household willingness	Iqbal et al., 2018
Sustainable harvesting practices	Rotational woodlots, regulated fruit harvest, pruning → 35% higher survival in managed plots	Sher et al., 2014
Agroforestry integration	Boundary planting, intercropping → 15–20% higher farm income	Khan et al., 2019
Reforestation programs	Seedling production, BTAP integration, soil stabilization	Shah et al., 2016
Policy-level support	Energy subsidies, market development, institutional strengthening → 20–25% forest cover recovery	FAO, 2018

DISCUSSION

The findings of this review highlight the multifaceted significance of *Monotheca buxifolia* in the northern mountainous ecosystems of District Bajaur. Ecologically, the species contributes to forest structure, soil stabilization, microclimatic regulation, and biodiversity support, making it a keystone of semi-arid montane ecosystems. Its drought tolerance and ability to regenerate in rocky terrains align with findings from other dryland regions where slow-growing evergreens underpin ecosystem resilience (Körner, 2004; Hussain & Khattak, 2014). From an ethnobotanical perspective, *M. buxifolia* demonstrates the strong linkage between biodiversity and local healthcare systems. Its fruits and leaves are widely used for gastrointestinal ailments, fever, and wound healing, while wood and branches serve as critical sources of fuel, fodder, and household tools. The reliance of over 80% of households on this species underscores its indispensable role in subsistence economies (Sher et al., 2014; Iqbal et al., 2018).

Socio-economically, the species provides both direct household benefits and market opportunities. Fruit sales generate annual household incomes ranging between 12,000–20,000 PKR, with women and children contributing significantly to collection and marketing. These findings parallel similar studies in dryland Africa and India, where non-timber forest products contribute 20–30% of rural household incomes (FAO, 2018). However, there exists a clear trade-off between utilization and conservation. Heavy reliance on wood for fuel and premature fruit harvesting

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undermine regeneration capacity. Weak governance and communal land tenure systems exacerbate overharvesting pressures. This mirrors conservation challenges documented for *Olea ferruginea* in Pakistan and *Ziziphus mauritiana* in India, where excessive extraction jeopardized both ecological stability and local livelihoods (Khan et al., 2019; Ahmed et al., 2015). The challenge, therefore, lies in balancing livelihood dependence with long-term ecological sustainability through community engagement, regulated harvesting, and policy interventions.

CONCLUSION

This review underscores that *Monotheca buxifolia* is far more than a wild tree species; it represents a pillar of ecological stability, cultural identity, and rural livelihoods in Bajaur and adjoining mountainous regions. Its ecological contributions to watershed protection and biodiversity support are matched by its ethnobotanical and socio-economic value, particularly in subsistence and semi-market economies. Yet, the species faces severe threats from deforestation, overharvesting, land conversion, and climate change, compounded by weak institutional governance. The evidence shows poor regeneration ratios (<0.3 seedlings per mature tree), declining densities, and rising anthropogenic pressures, highlighting the urgency for conservation action. Conservation must therefore be framed not only as an ecological necessity but also as a socio-economic imperative, ensuring that communities continue to benefit from the species while safeguarding it for future generations.

RECOMMENDATIONS

Farmer-level practical measures

Adopt rotational harvesting and selective pruning instead of full lopping to maintain tree survival.
Retain 20–30% of fruits on trees annually to aid natural regeneration.
Establish household or village nurseries for seedling production.
Integrate *Monotheca buxifolia* into agroforestry systems (farm boundaries, intercropping).

Policy and institutional strategies

Provide subsidies for alternative energy sources (biogas, solar, LPG) to reduce dependence on fuelwood.
Legally recognize and support community-managed forest reserves under participatory governance.
Develop value chains and small-scale processing units (e.g., jams, dried fruits) to enhance rural incomes.
Strengthen forestry institutions for monitoring, replanting, and providing extension services.
Support research on ecological monitoring, ethnopharmacological validation, gender roles, and economic modeling of sustainable use versus overexploitation.

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