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Agrobiodiversity Assessment Along an Altitudinal Gradient in District Nainital, Uttarakhand: Crop Inventory, Agroforestry Systems and Conservation Challenges

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Abstract: *District Nainital in the Kumaon Himalaya of Uttarakhand harbours a diverse range of traditional agroecosystems that have sustained mountain communities across centuries. This paper presents a systematic inventory of agrobiodiversity in three development blocks — Dhari, Okhalkanda and Ramgarh — covering 30 villages and approximately 2,000 marginal rural households. The study documents crop diversity along an altitudinal gradient from 1,000 to 1,600 m above sea level, encompassing cereals, millets, pulses, oil seeds, vegetables, spices, fodder trees and horticultural fruit crops. A total of 18 agricultural crops, 19 vegetable and spice crops, 15 fodder tree species and 18 fruit tree species were recorded. The study further assesses the status of horticultural biodiversity, climate change impacts on traditional orchards — particularly the documented decline in apple cultivation — and the biodiversity context of the district including its avifaunal richness. The findings reveal a rich legacy of traditional agrobiodiversity that is currently under threat from climate variability, male out-migration, declining institutional support and market-driven monoculture transitions. The paper concludes with a SWOT analysis and recommendations for community-based conservation, organic value chain development and area-specific agri-horti tourism as pathways toward livelihood security and biodiversity preservation.*

Keywords: *agrobiodiversity; Himalayan agroforestry; altitudinal gradient; Kumaon; Nainital; traditional crops; horticultural diversity; climate change; organic farming; Uttarakhand*

1. Introduction

1.1 Land Resources and Agrarian Context of India

India accounts for approximately 2 percent of the world's land resources yet supports around 16 percent of the global human population and 18 percent of its livestock (Pratap, 2001). Smallholder farming is practised across three broad agroecosystems — rainfed (the dominant category), plantation agriculture and irrigated fields — spanning a wide range of agroecological zones. In the Indian Himalayan region, these land systems have historically been the primary support for community sustenance (Pratap, 1999). Rainfed areas, which constitute the majority of mountain terrain, were largely bypassed during the Green Revolution in India. To cope with fragile environmental conditions and sustain livelihoods, farmers have instead adopted diverse agroforestry practices spanning a wide variety of habitats and climatic conditions (Pratap, 2001).

1.2 Uttarakhand: State Profile and Agricultural Significance

Uttarakhand state forms the major part of the Central Himalaya and comprises diverse agroforestry systems (Maikhuri et al., 2000; Pratap, 2001). The state spans 53,483 sq. km, representing 1.67 percent of the country's total area and lies between 28° 43' and 31° 27' N latitudes and 77° 34' and 81° 02' E longitudes. Approximately 34,662 sq. km — representing 64.81 percent of the total geographical area — is under forest cover. Agriculture comprises 12.5 percent of the total geographical area and constitutes the main occupation of local people, with over 80 percent of the population dependent on it (Government of Uttarakhand, 2006–07). Only 11 percent of the total agricultural area is irrigated, of which almost 64 percent is fed by natural springs.

Land holdings are predominantly marginal (below 1 ha — approximately 70 percent of all holdings) and small (1–2 ha) and are often scattered at multiple locations within a single village. The state climate varies greatly from subtropical in the valleys to temperate and alpine at high elevations, with average annual rainfall ranging from 1,200 to 1,600 mm. The traditional agro-ecosystems of the Himalaya are highly complex, with crop husbandry and forest management constituting interlinked production systems that have evolved over thousands of years.

1.3 Challenges to Mountain Farming Systems

Mountain farming in Uttarakhand today faces a serious dilemma of decadence. The trends are visible in depleting agrobiodiversity, stagnant or declining productivity, reduced carrying capacity of agricultural fields and accelerated soil erosion, all of which are contributing to the erosion of the region's production base. Smallholder farming systems in the Himalayan region face the compounded pressures of climate

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change and socio-demographic shifts. Continuous out-migration of the male population — a characteristic feature of this region — adversely affects household agricultural labour, increasing the workload of women manifold. Water scarcity is a major constraint, as the majority of farming remains rainfed (Pratap, 1999).

Other critical challenges include the paucity of updated agricultural information, limited access to improved inputs such as certified seeds and suitable varieties, weak infrastructure for processing and marketing and the absence of technology appropriate for marginal mountain conditions. There is an urgent need to evaluate and introduce sustainable resource utilisation practices that are ecologically stable, culturally adapted and environmentally enduring.

1.4 Gaps in the Agriculture and Horticulture Sector

A review of the existing agricultural and horticultural production systems in the study area reveals the following key structural gaps: limited marketable yield, with only approximately 25 percent of produce reaching A-grade standards; price manipulation by intermediaries and centralised marketing systems that restrict direct farmer-to-consumer linkages; ecological imbalance arising from yield-centric modern farming that compromises biodiversity and ecosystem function; weak post-harvest infrastructure including the absence of quality control, cold storage, packaging and transport facilities; no local processing units, leading to high spoilage rates; limited farmer training in food processing and value addition; and poor awareness of the nutritional significance of traditional local produce.

1.5 About Aarohi and the Study Context

Aarohi is a non-governmental organisation that has worked with farming communities in rural Uttarakhand for over 30 years. Its landmark contributions include establishment of rainwater harvesting facilities, advanced horticulture models, cultivation and processing of medicinal and aromatic plants, brand development for local produce and training and capacity-building of local farmers. The organisation currently works with a network of over 5,000 farmers, directly and indirectly. The present study forms part of Aarohi's broader initiative to enhance value chain development, promote climate-resilient sustainable agriculture and support livelihood transformation for marginal hill communities, particularly in the context of the post-COVID-19 socio-economic recovery and alignment with UN Sustainable Development Goals.

1.6 Objectives of the Study

The study was undertaken with the following objectives: (1) to assess agrobiodiversity by evaluating the variety of crops and agricultural practices in the project area; (2) to survey faunal and floral diversity and document species present in the region; (3) to analyse horticultural diversity including the range of fruit and vegetable crops grown across altitudinal bands; (4) to document the climate change impacts on horticulture, particularly apple cultivation; and (5) to assess the potential for agri-horti tourism based on the documented biodiversity.

2. Study Area

The study was conducted in District Nainital, Uttarakhand, covering three development blocks: Dhari, Okhalkanda and Ramgarh. The study area encompasses 30 villages and approximately 2,000 marginal rural households primarily dependent on agriculture and allied activities for their livelihoods. The area addresses the challenge of reverse migration — a phenomenon increasingly observed as urban job uncertainties prompt individuals to return to their villages — which places renewed pressure on local agricultural systems.

Special focus was placed on women, who bear a disproportionate vulnerability to climate change owing to their central role in agriculture and natural resource management in the Himalayan region. The initiative is designed to enhance livelihood security, climate resilience and sustainable economic growth within this community.

The study location of Mukteshwar (District Nainital) experiences a subtropical highland climate (Köppen Cfb), characterised by distinct summer, monsoon and winter seasons. Due to its elevation, the area is spared the intense heat of lower-lying regions. Winters are cold with temperatures frequently below freezing; snowfall occurs occasionally in December and January. Summers are warm with moderate rainfall, while the monsoon season (July to September) brings heavy precipitation. This climatic profile is critical to understanding the altitudinal variation in crop calendars documented in this study (Peel et al., 2007).

3. Methodology

The study adopted a field survey–based inventory methodology. Following identification of the three development blocks (Dhari, Okhalkanda and Ramgarh) in District Nainital as the study area, a reconnaissance survey was conducted to select representative villages within each block. A total of six villages were selected, two per block, based on altitudinal representation across three bands: 1,000–1,200 m, 1,200–1,400 m and 1,400–1,600 m above sea level (asl).

Data were collected through structured and semi-structured interviews with farmers, participatory rural appraisals (PRAs) and direct field observation of cropping systems. Crop inventories were prepared for each of the following categories: (1) Cropping patterns; (2) Agricultural crop inventory (cereals, millets, pulses, oil seeds); (3) Vegetable and spice inventory; (4) Horticultural crop inventory; (5) Fodder tree species in agroforestry systems; and (6) Faunal diversity assessment. Scientific names of all species were verified against the Plants of the World Online (POWO) database (Kew, 2023) and regional botanical references. Sowing and harvesting schedules were compiled from farmer knowledge and corroborated with secondary literature on Himalayan cropping calendars. The survey was conducted during 2021–22 as part of Aarohi's field programme in the study blocks.

4. Biodiversity Status of District Nainital

District Nainital is remarkable for its ecological amplitude and biodiversity richness. The district supports over 1,000 species of resident and migratory birds, more than 20 species of mammals, over 525 species of butterflies and more than 11,000 species of moths, beetles, bugs and other insects. The flora encompasses a wide and diverse range ranging from bryophytes, orchids, rare climbing plants, ferns, lichens, fungi and medicinal herbs to shrubs. Each lake in the district possesses a unique diatom assemblage; the Trophic Diatom Index, which uses the composition of freshwater diatom communities to assess water quality and ecological status, has been applied in the region to document ecological health (Nainital Tourism Development Authority, 2020).

The unique avifauna of the district includes a remarkable diversity of resident and migratory species, reflecting the range of forest types and altitude-dependent habitats present. Recorded species include the red-billed blue magpie, several kingfisher species, barbets (lineated, golden-throated, crimson-fronted, coppersmith), parakeets (plum-headed, slaty-headed), cheer pheasant, Kalij pheasant, Koklas pheasant, dollarbird, flycatchers, sunbirds (Mrs. Gould's, green-tailed, black-throated, fire-tailed, crimson) and raptors including the lammergeier, Himalayan griffon, crested serpent eagle, mountain hawk eagle and black eagle, among many others. This avian richness is indicative of the district's broader ecological integrity and the role that traditional agroforestry systems play in supporting habitat heterogeneity.

5. Agrobiodiversity of the Study Area

The farming system in the Uttarakhand Himalaya encompasses agricultural crops, horticulture, herb culture, tea garden practices, nurseries, fruit plantations and reforestation. These practices reflect diversity in all respects and crop farming remains predominantly traditional. Traditional agroecosystems in the Himalayas are characterised by high complexity, as crop husbandry and forest management constitute interlinked production systems. Inaccessibility, environmental heterogeneity and ecological fragility have together favoured the evolution of subsistence production systems sustained by organic matter and nutrients derived from forests. Increased population pressure and the consequent rapid depletion of natural resources represent the primary anthropogenic threat to this system (Maikhuri et al., 2000).

The survey documented crop diversity across agricultural crops, vegetables, spices, fodder tree species and fruit trees, catalogued along an altitudinal gradient across the three study blocks. The complete inventories are presented in Tables 1 through 4.

Table 1. Sowing (S) and Harvesting (H) Schedule of Important Agricultural Crops Along an Altitudinal Gradient of the Study Area

Crop (Scientific Name)	English Name	Local Name	Sowing 1000–1200 m	Harvest 1000–1200 m	Sowing 1200–1400 m	Harvest 1200–1400 m	Sowing 1400–1600 m	Harvest 1400–1600 m
			Cereals & Millets					
Amaranthus spp.	Amaranthus	Chaulai	Feb–Mar	Sep–Oct	May–Jun	Sep–Oct	May	Oct
Echinochloa frumentosa	Barnyard Millet	Jhangora	Feb–Mar	Sep–Oct	Mar–Apr	Aug–Sep	Apr	Aug
Eleusine coracana	Finger Millet	Madwa	Feb–Mar	Sep–Oct	May–Jun	Sep–Oct	May	Sep
Hordeum vulgare	Barley	Jau	Oct–Nov	Mar	–	–	Nov	May
Oryza sativa	Paddy	Dhan	Feb–Mar	Sep–Oct	May–Jun	Nov	–	–
Setaria italica	Foxtail Millet	Kauni	Feb–Mar	Sep–Oct	–	–	–	–
Triticum aestivum	Wheat	Gehu	Oct–Nov	Mar–Apr	Oct–Nov	May	Apr	May
Zea mays	Maize	Makka	May–Jun	Sep–Oct	–	–	–	–

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Crop (Scientific Name)	English Name	Local Name	Sowing 1000–1200 m	Harvest 1000–1200 m	Sowing 1200–1400 m	Harvest 1200–1400 m	Sowing 1400–1600 m	Harvest 1400–1600 m
				Pulses				
Glycine max	Soyabean	Soyabean	May–Jun	Sep–Oct	May–Jun	Sep–Oct	May	Oct
Glycine soja	Soyabean (desi)	Bhatt	May–Jun	Sep–Oct	May–Jun	Sep–Oct	May	Oct
Lens culinaris	Lentil	Masoor	Oct–Nov	Mar–Apr	Oct–Nov	Apr	Oct	Apr
Macrotyloma uniflorum	Horse Gram	Ghahat	Jun–Jul	Sep–Oct	May–Jun	Sep–Oct	–	–
Pisum sativum	Pea	Matar	Oct–Nov	Mar–Apr	Oct–Nov	Sep–Oct	Oct	Apr
Vigna mungo	Black Gram	Urd	May–Jun	Sep–Oct	–	–	–	–
Vigna radiata	Green Gram	Mung	May–Jun	Sep–Oct	–	–	–	–
				Oil Seeds				
Brassica campestris	Mustard	Lai	Oct–Nov	Mar–Apr	–	–	–	–
Brassica napus	Mustard (Toria)	Toria	Oct–Nov	Mar–Apr	–	–	Oct	Apr
Sesamum indicum	Sesame	Til	May–Jun	Sep–Oct	–	–	–	–

Source: Field survey data, Aarohi (2021–22).

Table 2. Sowing (S) and Harvesting (H) Schedule of Important Vegetable and Spice Crops Along an Altitudinal Gradient of the Study Area

Crop (Scientific Name)	English Name	Local Name	Sowing 1000–1200 m	Harvest 1000–1200 m	Sowing 1200–1400 m	Harvest 1200–1400 m	Sowing 1400–1600 m	Harvest 1400–1600 m
Zingiber officinale	Ginger	Adrak	Dec	Oct	Dec	Oct	–	–
Colocasia esculenta	Elephant Ear	Gaderi	Dec	Oct	Dec	Jan	–	–
Curcuma longa	Turmeric	Haldi	Dec	Oct	Dec	Oct	–	–
Solanum tuberosum	Potato	Alu	Feb	Jul	Nov	Feb	Oct	Feb
Allium cepa	Onion	Pyaz	Nov	Jun	Nov	Jul	–	–
Allium sativum	Garlic	Lahsun	Nov	Jun	Nov	Jun	–	–
Capsicum frutescens	Chilli	Mirch	Apr	Oct	May	Nov	Mar	Sep
Abelmoschus esculentus	Lady Finger	Bhindi	Apr	Jul	May	Nov	Mar	Sep
Solanum lycopersicum	Tomato	Tamater	Apr	Aug	May	Nov	Mar	Sep
Solanum melongena	Brinjal	Baingan	Apr	Jul	May	Nov	–	–

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Crop (Scientific Name)	English Name	Local Name	Sowing 1000–1200 m	Harvest 1000–1200 m	Sowing 1200–1400 m	Harvest 1200–1400 m	Sowing 1400–1600 m	Harvest 1400–1600 m
Lagenaria siceraria	Bottle Gourd	Lauki	Apr	Aug	May	Nov	Nov	Jan
Cucurbita pepo	Pumpkin	Kaddu	Mar	Jul	May	Nov	–	–
Cucumis sativus	Cucumber	Kakdi	Mar	Jul	May	Nov	–	–
Coriandrum sativum	Coriander	Dhanya	Nov	Mar	May	Nov	–	–
Brassica juncea	Mustard Leaf	Lai	Oct	Nov	Oct	Jan	Apr	Aug
Spinacia oleracea	Spinach	Gager	Nov	Feb	Nov	Jan	Apr	Aug
Raphanus sativus	Radish	Muli	Feb	Jul	Nov	Jan	–	–
Phaseolus vulgaris	French Beans	Beans	Apr	Jul	Apr	Jul	–	–
Brassica oleracea var. capitata	Cabbage	Gobhi	Oct	Feb	Apr	Aug	–	–

Source: Field survey data, Aarohi (2021–22).

Table 3. Harvesting Schedule of Fodder Tree Species Along an Altitudinal Gradient in the Agroforestry System

Species (Scientific Name)	Local Name	Harvest: 1000–1200 m asl	Harvest: 1200–1400 m asl	Harvest: 1400–1600 m asl
Ficus auriculata	*Timla*	November	December	Feb–May
Celtis australis	*Kharik*	April	Apr & Jun	Apr–Jun
Grewia optiva	*Bhimal*	December	Dec & Mar	Dec–Feb
Quercus leucotrichophora	*Banj Oak*	–	Nov & Mar	Nov–Mar
Ougeinia oojeinensis	*Sanan*	April	May–Jun	May–Jun
Melia azedarach	*Dainken*	April	Apr–Jun	Apr–Jun
Morus alba	*Sahtoot*	May	May–Jul	May–Jun
Morus serrata	*Kemu*	–	May–Jul	May–Jul
Ficus palmata	*Bedu*	April	Apr–May	Apr–May
Mallotus philippensis	*Ruwan*	Jan & Jul	–	–
Ficus semicordata	*Khinda*	May–Jun	May–Jul	–
Bauhinia variegata	*Kwral*	Mar–Apr	Nov–Dec	–
Grewia asiatica	*Pharsul*	Jan–Mar	Dec–Apr	–
Quercus semecarpifolia	*Kharsu*	–	May–Jun	May, Jun & Jan
Ficus subincisa	*Chahri*	–	–	–

Source: Field survey data, Aarohi (2021–22).

Table 4. Harvesting Schedule of Fruit Trees Along an Altitudinal Gradient in Traditional Agroforestry Systems

Species (Scientific Name)	Local Name	Harvest: 1000–1200 m asl	Harvest: 1200–1400 m asl	Harvest: 1400–1600 m asl
Artocarpus heterophyllus	*Kathal*	May–Jun	–	–
Carica papaya	*Papita*	Apr–Jun	Whole Year	–
Citrus aurantifolia	*Kagji Lime*	Whole Year	–	–
Citrus maxima	*Chaktora*	Nov–Dec	Nov–Dec	Dec
Citrus limonia	*Bada Nimbu*	Oct–Nov	Nov–Dec	Dec
Citrus reticulata	*Santara*	Oct–Nov	Nov–Dec	Sep–Nov
Citrus sinensis	*Malta*	June	–	–
Mangifera indica	*Aam*	July	August	–
Prunus persica	*Peach / Aru*	July	July	Aug–Sep
Prunus armeniaca	*Khumani*	–	June	July
Prunus domestica	*Plum*	–	Jun–Jul	Jun–Jul
Psidium guajava	*Guava*	Oct–Nov	November	–
Musa paradisiaca	*Banana*	Whole Year	–	–
Pyrus communis	*Pear*	August	July	Aug–Sep
Juglans regia	*Akrot*	–	October	September
Malus domestica	*Apple*	–	July	August
Actinidia deliciosa	*Kiwi*	November	December	December
Diospyros kaki	*Persimmon*	October	October	–

Source: Field survey data, Aarohi (2021–22).

6. Horticultural Biodiversity and Climate Change Challenges

The Himalayan mountain ecosystem is presently confronting challenges arising from increasing aridity, warmer winter seasons, variability in precipitation and unexpected frost events and storms (Renton, 2009). These climatic shifts affect the entire range of biodiversity, including agriculture and horticulture (Kala, 2013). Data across multiple studies indicate a decline of approximately 50 percent in the productivity of apple farming in Uttarakhand, with similar slumps recorded in Jammu & Kashmir and Himachal Pradesh. As climate change manifests in altered weather patterns, farmers respond by modifying their cropping systems, which may compromise access to diverse and nutritious foods (Sen, 1983; Ericksen, 2008; Kristjanson et al., 2012).

The well-documented ascent of apple-growing regions in Himachal Pradesh to higher altitudes — driven by rising annual mean temperatures at lower elevations — is a canonical example of climate-induced crop range shifting (Rana et al., 1996). In contrast, peaches, which have higher temperature tolerances, are increasingly prevalent at lower elevations. Peaches also command higher market prices than most temperate fruits other than apples, making them an economically rational substitute for farmers (Sati & Kumar, 2004).

In Uttarakhand, where apple production accounts for only approximately 3.7 percent of national output, state horticulture authorities have made sustained efforts to expand apple cultivation area, but face mounting challenges from climate variability — particularly declining snowfall in key hill districts. In response, apple growers are progressively shifting to stone fruits such as peach, plum and apricot, which require less winter chilling. The need of the hour is an organised, planned approach to horticulture sector management. High-Density Plantation (HDP) techniques, which maximise productivity per unit area, represent the most suitable option given the declining average land holdings. Adoption of clonal and tissue-culture-derived rootstocks for apple — rather than conventional seedlings — is recommended to address both re-plantation challenges and canopy management in existing orchards.

7. Findings and Discussion: SWOT Analysis

The field survey and secondary data synthesis reveal a complex picture of a biologically diverse but institutionally underserved agrobiodiversity system. The following SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis summarises the key findings across the four dimensions and is presented in tabular form in Table 5.

Table 5. SWOT Analysis of Agrobiodiversity and Agroforestry Systems in the Study Area

Strengths	Weaknesses	Opportunities	Threats
Diverse crop agrobiodiversity across altitudinal zones	Predominantly rainfed farming; irrigation facilities limited	Development of area-specific farming technologies for livelihoods	Development of area-specific farming technologies for livelihoods
Traditional landraces of cereals, pulses and oil seeds maintained	Declining interest in farming among Himalayan communities	Organic certification potential for national and global markets	Organic certification potential for national and global markets
Rich gene bank of indigenous seed varieties	Low productivity of traditional varieties	Food processing and value addition enterprises	Food processing and value addition enterprises
Niche-specific agroforestry systems well-preserved	Inadequate market access and storage facilities	Cluster-based cultivation of vegetables, pulses and horticulture	Cluster-based cultivation of vegetables, pulses and horticulture
Availability of land for agri-horti expansion	Losses from wild animals and climate variability	Agri-tourism and heritage seed tourism possibilities	Agri-tourism and heritage seed tourism possibilities
–	Limited extension services and modern inputs	–	–

Source: Authors' field assessment, Aarohi (2021–22).

8. Conclusion and Recommendations

The modern techno-farming paradigm has developed chemical-intensive, market-oriented agriculture primarily optimised for maximum food yield. While productive gains have been achieved, such systems have simultaneously degraded traditional agricultural diversity, disrupted land use patterns and heavily polluted agro-ecosystems. The present study demonstrates that within the surveyed blocks of District Nainital, crop diversification remains substantive — a strength that must be systematically nurtured. Preservation of local varieties, traditional landraces and indigenous seed systems must be accorded priority in any conservation strategy.

Development of markets for traditional organic produce is critical and can be achieved through effective value chain systems linking producers directly to consumers. This requires easy transportation arrangements, responsive distribution networks, quality control and certification systems and appropriate labelling and packaging infrastructure. Techniques of traditional produce management must be widely disseminated. While farmers employ traditional methods effectively, their awareness of certified organic agriculture protocols remains limited; targeted training can ease their transition to recognised organic cultivation standards and thereby open premium market channels.

Agricultural credit and subsidy systems should be realigned to support organic farming and traditional variety cultivation. At present, credit mechanisms are biased towards fertilisers, high-yielding variety seeds and conventional inputs. Reorientation toward traditional farming can sustain both biodiversity and long-term agricultural productivity. Furthermore, it is imperative to develop a robust diagnosis and design (D&D) methodology for the diverse traditional agroforestry systems already practised in the study villages, so that each intercropping arrangement not only yields optimal returns from crops and tree products but also sustains the structural and functional integrity of Himalayan agro-ecosystems over the long term. Agri-horti tourism, anchored in the district's exceptional biodiversity and traditional crop heritage, represents a significant and as yet underutilised livelihood diversification opportunity for the region.

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