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Agrobiodiversity under Agroforestry Systems in Garhwal Himalayan Region: A Case Study

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***Abstract*:** Agrobiodiversity refers to the variety and variability of all living organisms that form part of agricultural ecosystems. It encompasses crops, livestock breeds, soil organisms, pollinators, and wild relatives. The present investigation was conducted to assess agrobiodiversity in two agroforestry systems (Apple and Oak) across three districts (Tehri, Uttarakashi and Rudraprayag) of Uttarakhand, within two elevation ranges: 1500-2000 m and 2000–2500 m amsl. Data were collected through questionnaire surveys, field observations, and quadrat sampling. The results revealed that agrisilviculture, agrihorticulture, and silvipasture systems were present in all three districts at both elevations, except in the higher elevation zone of Uttarkashi district. Interestingly, a unique agroforestry system, aquaculture, was recorded only in Rudraprayag district at the upper elevation. In total, five crop categories were documented under apple- and oak-based agroforestry systems within the two elevation ranges. These included cereals and pulses (7 species), millets (2 species), oilseeds (3 species), and vegetables (28 species), with vegetables representing the highest diversity. Additionally, a total of 106 wild plant species were recorded across the study sites, comprising 49 herbs, 19 shrubs, 13 grasses, 4 vines, and 21 tree species across both agroforestry systems and elevation ranges in all three districts. Pollinator diversity was represented by five insect orders. The highest number of pollinators (11 species) belonged to Hymenoptera, followed by Diptera (6 species) and Lepidoptera (6 species), while the lowest diversity was observed in Hemiptera. Order-wise analysis indicated that Hymenoptera contributed the highest proportion of pollinators, whereas Hemiptera accounted for the least across all districts. Overall, the study highlights the rich agrobiodiversity within the agroforestry systems of Uttarakhand, with notable variations in crop composition, wild vegetation, and pollinator diversity across districts and elevation ranges.

***Keywords*:** Agrobiodiversity, Pollinator, Vegetation, Species, Himalayan, Crop category

Agrobiodiversity refers to the variety of species and genetic resources present in agroecosystem. All biotic factors related to agriculture, such as, plants, animals, fish, reptiles, insects, birds and microbes are components of agrobiodiversity (Mohapatra 2016). It plays a crucial role in ensuring global food security, enhancing the resilience of ecosystems, and encouraging sustainable agricultural practices. This diversity comprises a wide range of crops, livestock, and microorganisms that provide different food options, aid in nutritional well-being, and contribute to the preservation of cultural heritage. Agricultural biodiversity or agrobiodiversity is a subset of biodiversity including all crops and livestock and all interacting species of pollinators, symbionts, pests, parasites, predators, and competitors (Nair et al., 2022). Agricultural landscapes with substantial agroforestry activities are effective for the conservation of biodiversity in managed ecosystems and play a significant role in conserving and even enhancing biodiversity from farms to the landscape level (Abebe et al., 2013).

India is recognized as the center of origin for several important crops, including rice, brinjal, citrus, banana, and cucumber. It is also exceptionally rich in food crops, oilseeds, horticultural crops, spices, lichens, algae, fungi, insects, and medicinal plants. The country possesses nearly 15,658 rice landraces and is the world's largest exporter of Basmati rice. In addition, India produces numerous indigenous and local varieties of wheat, pulses, and millets, many of which are valued for their high nutritional content (Jacob et al., 2020). As one of the 12 mega-diverse regions of the world, India harbors approximately 127,000 species of animals, plants, and microbes. It contributes about 6% of global insect diversity, with nearly 51,000 identified insect species. The country is also the center of domestication for around 25 crop species and supports over 18,000 species of higher plants, including 160 major and minor crops and 325 of their wild relatives. Furthermore, indigenous communities make extensive use of biodiversity, with about 1,500 wild edible plant species utilized comprising 145 roots and tubers, 521 leafy vegetables, 647 fruits, and 118 species of seeds and nuts (Anderson 2008).

The mountain region exhibits diverse agro-climatic conditions, ranging from the flat foothill areas known as the *tarai* to mid-mountain zones and high-altitude lands approaching the snow line. Although the mountainous areas of the state are food deficient, they maintain a rich repository of diversified agricultural traditions and products (Rais and Farooquee 2013). Agroforestry systems (AFS), which generally sustain much higher species diversity than conventional agriculture or plantation forestry (Toky et al.

1989), are increasingly facing biodiversity losses due to system simplification. For instance, traditional shaded coffee and cacao production systems are being transformed into un shaded monocultures under intensive management, a process often referred to as agro-deforestation. Despite such challenges, tropical AFS particularly multi-strata systems remain highly significant for biodiversity conservation and possess an inherent capacity to promote both aboveground and belowground diversity (Nair et al., 2022).

This invaluable gift of nature is increasingly under threat and being indiscriminately degraded by human activities, particularly tropical deforestation, developmental projects, road widening etc., which has led to severe ecological consequences (Bhagwat et al., 2008). According to the Convention on Biological Diversity (CBD), to which India is a signatory, the major threats to biodiversity include habitat fragmentation, degradation and loss, overexploitation of natural resources, erosion of genetic diversity, invasive exotics species, declining forest resources, climate change and desertification, the impacts of development projects, and various forms of pollution. Given the diverse socio-cultural context and the often competing demands of different stakeholders, there is an urgent need to intensify and expand efforts aimed at biodiversity conservation and sustainable utilization through nature based solution. Equally important is ensuring the fair and equitable sharing of benefits derived from the use of genetic resources (Dobson 2005).

MATERIAL AND METHODS

Sampling area: The study was carried out in three hilly districts of Uttarakhand, namely Tehri Garhwal, Rudraprayag and Uttarkashi. For assessing the plant (trees, shrubs and herbs) diversity in the agroforestry systems (Oak and Apple based agroforestry system) four villages from each district were chosen for assessment of agrobiodiversity in agroforestry systems (Table 1). These districts lie in the middle and upper Himalayan ranges, with elevation ranging from approximately 900 to over 6,000 meters, encompassing steep mountain slopes, river valleys, and alpine meadows. Major rivers such as the Bhagirathi, Alaknanda, and Mandakini traverse these districts, playing a crucial role in shaping the landscape and supporting livelihoods. The region is predominantly agrarian, where traditional farming of crops like paddy, wheat, millets, barley, pulses, and vegetables is practiced along with animal husbandry and horticulture. Assessment of various agricultural crops, type of trees species, herbs, shrubs, wild plants and pollinators was carried out in all three selected district.

Assessment of agro-biodiversity: The study was carried out in the oak and apple based agroforestry system in all three districts with both elevation ranges, and field survey was conducted in each selected village for data collection. Thirty households were selected from each village engaged in agroforestry practices. Household surveys, questionnaires, and direct field observations was done to collect agrobiodiversity information from study sites. Information was collected like cultivated agriculture crops, horticulture crops and agroforestry tree species under selected agroforestry systems, and pollinator diversity at the household/village level, diversity of useful wild plants at each selected sites. Also, interviews were conducted with the local farmers that has specialized knowledge about agrobiodiversity. The major objective of the study is to explore the agro-biodiversity of selected areas. So there is a prerequisite that the respondent should be closely related to agriculture, either directly or indirectly. The random sampling was applied for the selection of household as well as the study of vegetation.

Table 1. Details of study sites

District	Name of village	Latitude (N)	Longitude(E)	Elevation range
Tehri Garhwal	Jhakogi	30.44432	78.30450	1500-2000 m amsl
	Chopdiyal gaun	30.38621	78.36339	
	Thangdhar	30.41903	78.33199	2000-2500 m amsl
	Digothi (Rueskhet)	30.28921	78.41716	
Rudraprayag	Chaunra (Satoli)	30.41038	78.89346	1500-2000 m amsl
	Chirbatiya (Budna)	30.38909	78.83717	
	Hilanai (Bajeera)	30.43133	78.86068	2000-2500 m amsl
	Taleda (Palakurali)	30.41478	78.83502	
Uttarkashi	Kimmi	30.77189	78.12351	1500-2000 m amsl
	Naini	30.77993	78.14284	
	Bingsi (Syunri)	30.76540	78.15591	2000-2500 m amsl
	Kandau	30.76235	78.13100	

RESULTS AND DISCUSSION

In Garhwal Himalayan region the major traditional agroforestry systems are agrisilviculture (AS), agrihortisilviculture (AHS) agrihorticulture (AH) and homegarden with main trees *Grewia optiva*, *Celtis australis*, *Melia azedarach*, *Ficus* and citrus fruit along with agricultural crops (Dadhwal et al., 1989).

The maximum (6) number of agroforestry system was in Uttarkashi district at lower elevation followed by Tehri Garhwal (5) at lower elevation and Rudraprayag (5) at upper elevation while, minimum (3) number of agroforestry system was also in Uttarkashi district at upper elevation. Among the Agroforestry system agrisilviculture, agrihorticulture and silvipasture system were found in all three district at both elevation except upper elevation of Uttarkashi district. A unique agroforestry system aqua culture was found only in Rudraprayag district at upper elevation. Similar agroforestry system was also observed in earlier studies (Bijalwan et al., 2011, Vikrant et al., 2016, Kumar et al., 2025). The main traditional agroforestry systems in the Narendranagar and Thauldhar block were agrisilviculture, agrihortisilviculture and agrihorticulture.

The 5 crop category were found in all 3 selected district under apple and oak based agroforestry system within two elevation ranges (1500-2000 m amsl) and (2000-2500 m amsl) (Table 3). The maximum (28) crops were recorded under vegetable category. In cereal category *Triticum aestivum* and *Hordeum vulgare* was cultivated by all 3 selected districts under both agroforestry systems in lower and upper elevation. However, *Chenopodium quinoa* was only in Tehri district under Oak based Agroforestry system at lower elevation. In pulses category *Phaseolus vulgaris* and *Lens culinaris* were in all 3 districts under both agroforestry system and elevation ranges. *Vigna sinensis* was found only in Rudraprayag district under oak based agroforestry system at lower elevation. Two millets crops namely *Eleusine coracana* and *Echinochloa frumentacea* was the common millet crop in both elevation and all selected site under oak and apple based agroforestry system. *Brassica campestris* was in all three study districts under both agroforestry systems at lower and upper elevation under oil seed crop category. However, *Sesamum indicum* was found only at lower elevation under Oak based Agroforestry system at selected districts. In vegetable crop category *Pisum sativum, Solanum tuberosum* and *Phaseolus vulgaris* are found majorly in all three districts covering both Agroforestry system and elevation. *Abelmoschus esculentus, Allium cepa, Brassica oleracea var-botrytis* and *Zingiber officinale* only found under Oak based Agroforestry system at lower elevation in all 3 selected districts. *Trichosanthus dioica, Lagenaria siceraria* found only at lower elevation under oak based agroforestry system., *Amaranthus viridis* was reported only under oak based agroforestry system at upper elevation. Crop diversity within agroforestry, regarded as a cornerstone of food security, is essential for sustaining agricultural systems (Sati 2012). The diverse cropping contributes significantly to maintaining the stability and resilience of agro ecosystems through multiple mechanisms. Number of crops and variety in particular sites is mainly depend on various factor like preference of growers, land holding, availability of irrigation, transportation, migration, wildlife interaction and market accessibility. Similar crop diversity was also reported in Garhwal Himalaya by Mahato et al. (2016). Kala et al. (2010) in an agroforestry of the middle Himalaya region in Tehri Garhwal observed 26 herbaceous food crop species out of them 12 crop were species, 5 cereals and 6 pulses. Crops diversity under cash crops was higher than the cereals. Maximum number of vegetable crop was found under agroforestry system in all district might be due to favorable condition for vegetable cultivation and nature of cash crop (Singh et al., 2023).

Wild vegetation makes more diversity in any agro ecosystem and helps to enhance agrobiodiversity of that region. Total 106 wild vegetations was recorded from studied sites in which 49 herbs, 19 shrubs, 13 grasses, 04 vines and 21 tree species was recorded under both agroforestry system and elevation in all 3 selected districts (Table 4). *Rubus niveus* was found in all selected district under both agroforestry systems and *Oxalis corniculata* was in all

Table 2. Existing agroforestry system in studied districts

District	Elevation	Agroforestry system	Number of Agroforestry system
Tehri Garhwal	Lower elevation (1500-2000 m)	(AS), (AH), (SP), (ASH), (HG)	05
	Upper elevation (2000-2500 m)	(AS), (AH), (SP), (ASP)	04
Rudraprayag	Lower elevation (1500-2000 m)	(AS), (AH), (SP), (HG),	04
	Upper elevation (2000-2500 m)	(AS), (AH), (SHP), (SP), Aqua culture	05
Uttarkashi	Lower elevation (1500-2000 m)	(AS), (AH), (HA), (SP),(HG), (ASP)	06
	Upper elevation (2000-2500 m)	(AS), (HA), Horti-pastoral	03

Agrisilviculture (AS), Agrihortisilviculture (AHS), Agrihorticulture (AH), HG= homegarden, SP= Silvopastoral, ASP= Agrisilvopastoral, HA= Hortiagri

Table 3. Agrobiodiversity under agroforestry system at Tehri, Rudraprayag and Uttarkashi district

Scientific name	Family	Tehri District (Agroforestry system)				Uttarkashi (Agroforestry system)				Rudraprayag (Agroforestry system)			
Crop name		Oak based		Apple based		Oak based		Apple based		Oak based		Apple based	
	Elevation	L	U	L	U	L	U	L	U	L	U	L	U
Triticum aestivum	Poaceae		√	√	√	√	√	√	√	√	√	√	√
Perilla frutescens	Lamiaceae	√	-	-	-	√	√	√	√	√	√	√	√
Zea mays	Poaceae	√	-	-	-	-	√	-	√	√	√	√	-
Fagopyrum esculentum	Polygonaceae	√	-	-	-	-	√	-	-	-	-	-	-
Hordeum vulgare	Poaceae	√	√	√	√	√	√	√	√	√	√	√	√
Amaranthus caudatus	Amaranthaceae	√	√	-	-	√	√	-	-	√	√	-	√
Chenopodium quinoa	Chenopodiaceae	√	-	-	-	-	-	-	-	-	-	-	-
Vigna sinensis	Fabaceae	-	-	-	-	-	-	-	-	√	-	-	-
Vigna umbellata	Fabaceae	√	√	-	-	√	√	√	-	√	√	-	-
Vigna mungo	Fabaceae	√	-	-	-	√	-	√	-	√	-	-	-
Phaseolus vulgaris	Fabaceae	√	√	√	√	√	√	√	√	√	√	√	√
Lens culinaris	Fabaceae	√	√	√	√	√	√	-	√	√	√	-	√
Dolichos uniflorus	Fabaceae	√	-	-	-	√	-	√	-	√	-	-	-
Cajanus cajan	Fabaceae	√	-	-	-	√	-	-	-	√	-	-	-
Eleusine coracana	Poaceae	√	√	√	-	√	√	√	√	√	√	√	√
Echinochloa frumentacea	Poaceae	√	√	-	√	√	√	-	-	√	√	-	√
Sesamum indicum	Pedaliaceae	√	-	-	-	√	-	-	-	√	-	-	-
Glycine max	Fabaceae	√	√	-	-	√	√	√	-	√	√	√	-
Brassica campestris	Brassicaceae	√	√	√	√	√	√	√	√	√	√	√	√
Abelmoschus esculentus	Malvaceae	√	-	-	-	√	-	-	-	√	-	-	-
Allium cepa	Liliaceae	√	-	-	-	√	-	-	-	√	-	-	-
Allium sativum	Liliaceae	√	√	√	√	-	√	-	√		√	√	√
Amaranthus viridis	Amaranthaceae	-	-	-	-	-	-	-	-		√	-	-
Brassica juncea	Brassicaceae	√	√	√	-	-	√	-	√	√	√	√	√
Brassica oleracea var-botrytis	Brassicaceae	√	-	-	-	√	-	-	-	√	-	-	-
Brassica oleracea var-capitata	Brassicaceae	√	√	√	-	√	√	√	-	√	-	√	√
Capsicum annum	Solanaceae	-	-	-	-	-	-	√	-	√	-	√	-
Capsicum frutescens	Solanaceae	-	-	-	-	√	√	-	-	√	-	-	-
Colocasia antiquorum	Areceae	√	-	-	-	√	-	-	-	-	√	-	-
Colocasia esculenta	*Araceae*	-	-	-	√	-	-	-	-	-	√	-	-
Coriandrum sativum	Apiaceae	√	√	-	-	-	√	√	√	-	√	√	-
Cucumis sativus	Cucurbitaceae	√	-	√	-	√	√	-	-	√	√	-	-
Cucurbita maxima	Cucurbitaceae	√	√	√	-	√	√	-	-	√	√	-	-
Curcuma longa	Zingiberaceae	√	√	-	-	-	√	-	-	√	√	-	-
Daucus carota	Apiaceae	-	-	-	-	-	-	-	-	-	√	-	-
Lagenaria siceraria	Cucurbitaceae	-	-	-	-	-	-	-	-	√	-	-	-
Luffa acutangula	Cucurbitaceae	-	-	-	-	-	-	-	-	√	-	-	-
Lycopersicon esculentum	Solanaceae	-	-	√	-	-	-	√	-	√	-	√	-
Momordica charantia	Cucurbitaceae	-	-	-	-	√	-	-	-	√	-	-	-
Pastinaca sativa	Brassicaceae	√	√	-	-	-	√	√	√	√	√	-	-
Phaseolus vulgaris	Fabaceae	√	√	√	√	-	√	√	√	√	√	√	√
Pisum sativum	Fabaceae	√	√	√	√	√	√	√	√	√	√	√	√
Solanum melongena	Solanaceae	-	-	-	-	√	√	-	-	-	-	√	-
Solanum tuberosum	Solanaceae	√	√	√	√	√	√	-	√	√	√	√	√
Spinacea oleracea	Brassicaceae	√	√	√	-	√	√	-	√	√	√	√	-
Trichosanthus dioica	Cucurbitaceae	-	-	-	-	√	-	-	-	-	-	-	-
Zingiber officinale	*Zingiberaceae*	√	-	-	-	√	-	-	-	√	-	-	-

L= Lower elevation, U= Uppper elevation, √ = presence of species, - = absence of species

Table 4. Wild vegetation in three selected districts

Scientific name	Family	Life form	Tehri District (Agroforestry system)				Uttarkashi (Agroforestry system)				Rudraprayag (Agroforestry system)			
			Oak		Apple		Oak		Apple		Oak		Apple	
			L	U	L	U	L	U	L	U	L	U	L	U
Achyranthes aspera L.	Amaranthaceae	Herb	-	√	-	-	-	√	-	-	√	√	-	-
Achyranthes bidentata Blume	Amaranthaceae	Herb	√	-	-	-	-	-	-	-	√	√	-	-
Aechmanthera gossypina	Acanthaceae	Shrub	-	-	√	√	√	-	√	-	-	-	-	-
Ageratum conyzoides	Asteraceae	Herb	√	√	-	√	-	√	√	-	√	-	-	-
Agrimonia pilosa	Agavaceae	Herb					-	√	-	√	-	-	-	-
Amaranthus viridis	Amranthaceae	Herb	√	√	-	-	-	√	-	√	√	√	√	√
Anaphalis contorta (D.Don) Hook f.	Asteraceae	Herb	-	-	-	-	-	-	-	-	-	√	-	-
Anisomeles indica (L.) Kuntze	Lamiaceae	Herb	-	-	-	-	-	-	-	-	-	√	-	-
Apluda mutica L	Poaceae	Grass	-	-	-	-	-	-	-	-	√	√	-	-
Artemisia capillaris Thunb.	Asteraceae	Herb	-	-	-	-	-	-	-	-	-	-	-	-
Artemisia nilagirica (Clarke) Pamp.	Asteraceae	Herb	-	-	-	-	-	-	-	-	-	√	-	-
Avena fatua L.	Poaceae	Grass	√	-	-	-	-	-	-	-	√	√	√	√
Avena sativa L.	Poaceae	Herb	-	-	-	-	-	-	-	-	-	-	-	-
Berberis aristata	Berberidaceae	Shrub	-	-	-	-	-	-	-	-		√		√
Bidens pilosa L.	Asteraceae	Herb	√		√	√	-	-	-	-	√	√	√	√
Campylotropis eriocarpa	Fabaceae	Shrub	-	-	-	-	-	√	-	-	-	-	-	-
Cannabis sativa	Cannabaceae	Shrub	-	-	-	-	√	-	√	-	-	√	-	√
Carissa opaca	Apocyanaceae	Shrub	-	-	-	-	√	-	-	-	-	-	-	-
Carpinus viminea			-	-	-	-	-	-	-	-	-	-	-	-
Cassia occidentalis L.	Caesalpiniaceae	Herb	-	-	-	-	-	-	-	-	-	√	√	√
Cedrus deodara	Pinaceae	Tree	-	-	-	-	-	√	-	-	-	-	-	-
Celtis australis	Ulmaceae	Tree	-	-	-	-	√	-	-	-	√	-	-	-
Centella asiatica	Apiaceae	Herb	-	√	-	-	-	√	-	√	-	√		√
Chenopodium album L.	Chenopodiaceae	Herb	√	√	√	-	-	-	-	-	√	√	√	√
Chenopodium ambrosioides	Chenopodiaceae	Herb	√	√	-	-	-	-	-	-	-	-	-	-
Cirsium wallichii DC.	Asteraceae	Herb	-	-	-	-	-	-	-	-	-	√	-	√
Citrus aurantifolia	Rutaceae	Tree	√	-	-	-	-	-	-	-	-	-	-	-
Citrus sinensis	Rutaceae	Tree	√	-	-	-	-	-	-	-	-	-	-	-
Cleome viscosa L.	Cleomaceae	Herb	√	-	-	-	-	-	-	-	√	-	√	-
Commelina benghalensis L.	Commelinaceae	Herb	√	√	-	-	-	-	-	-	-	-	-	-
Convolvulus arvensis L.	Convolvulaceae	Vine	-	√	√	√	-	-	-	-	√	√	√	-
Conyza bonariensis	Asteraceae	Herb	√	-	-	-	-	-	-	-	-	-	-	-
Cornus capitata	Cornaceae	Tree	-	√	-	-	-	-	-	-	-	-	-	-
Cuscuta reflxa	Cuscutaceae	Vine	-	-	-	-	-	-	-	-	-	√	-	-
Cynodon dactylon (L.) Pers.	Poaceae	Grass	-	√	√	√	-	-	-	-	√	√	√	√
Cyperus compressus	Cyperaceae	Grass	√	√	-	√	-	-	-	-	-	-	-	-
Cyperus rotundus	Cyperaceae	Grass	√	√	√	√	-	-	-	-	√		√	
Dactyloctenium aegypticum (L.) P. Beauv.	Poaceae	Grass	-	-	-	-	-	-	-	-	√	√	-	√

Cont...

Table 4. Wild vegetation in three selected districts

Scientific name	Family	Life form	Tehri District (Agroforestry system)				Uttarkashi (Agroforestry system)				Rudraprayag (Agroforestry system)			
			Oak		Apple		Oak		Apple		Oak		Apple	
			L	U	L	U	L	U	L	U	L	U	L	U
Datura stramonium	Solanaceae	Herb	-	-	-	-	√	-	-	-	√	-	-	√
Desmodium elegans	Fabaceae	Shrub	-	-	-	√	√	√	-	-	-	-	-	-
Dichanthium annulatum (Forsk.) Stapf	Poaceae	Grass	-	-	-	-	-	-	-	-	-	√	-	√
Digitaria sanguinalis (L.)	Poaceae	Grass	√	√	-	-	-	-	-	-	-	-	-	-
Duchesnea indica	Rosaceae	Herb	-	√	-	-	-	-	-	-	-	-	-	-
Echinochloa colona (L.) Link	Poaceae	Grass	-	-	-	-	-	-	-	-	√	√	-	-
Eleusine indica (L.) Gaertn	Poaceae	Grass	√	√	-	-	-	-	-	-	√	√	-	√
Emilia sonchifolia	Asteraceae	Herb	-	-	-	-	√	√	-	-	-	-	-	-
Eupatorium adenophorum	Asteraceae	Shrub	√	√	-	-	-	-	-	-	√	√	√	√
Euphorbia hirta	Euphorbiaceae	Herb	√	√	-	√	-	√	-	-	√	√	√	
Euphorbia prostrata Aiton	Euphorbiaceae	Herb	-	-	-	-	-	-	-	-	√	-	-	-
Ficus roxburghii	Moraceae	Tree	-	-	-	-	√	-	-	-	√	-	-	-
Fumaria indica	Fumariaceae	Herb	√	√	-	-	-	-	-	-	-	-	-	-
Galinsoga ciliate	Asteraceae	Herb	√	√	√	√	-	-	-	-	-	-	-	-
Galinsoga parviflora Cav.	Asteraceae	Herb	√	√	√	√	-	-	-	-	√	√	√	√
Galium acutum	Rubiaceae	Herb	-	-	-	-	-	-	-	-	-	-	-	-
Geranium nepalense Sweet	Geraniaceae	Herb	-	-	-	-	-	-	-	-	-	√	-	√
Grewia optiva	Tiliaceae	Tree	√	-	-	-	√	-	-	-	√	-	-	-
Himalrandia tetrasperma	Rubiaceae	Shrub	-	-	-	-	-	√	-	-	-	-	-	-
Imperata cylindrica (L.) P. Beauv.	Poaceae	Grass	-	-	-	-	-	-	-	-	-	√	-	√
Indigofera heterantha	Fabaceae	Shrub	√	-	-	-	-	-	-	-	-	-	-	-

L= Lower elevation, U= Uppper elevation, √ = presence of species, - = absence of species

selected districts except oak based agroforestry system in Tehri Garhwal. *Prunus cerasoides* was only in Oak based agroforestry system in both elevations at all 3 selected districts. *Anaphalis contorta, Anisomeles indica, Artemisia nilagirica* and *Pyracantha coccinea* was only in upper elevation under oak based agroforestry system in Rudraprayag district. However, *Zanthoxylum armatum* was recorded only at Tehri District under oak based agroforestry system in upper elevation. *Cyperus rotundus, Galinsoga ciliate, Galinsoga parviflora* and *Trifolium repens* was recorded in both elevation and Agroforestry system in Tehri Garhwal district. *Oxalis corniculata, Rubus niveus* and *Urtica dioica* was in Uttarkashi district under both agroforestry system and elevation. However, *Amaranthus viridis, Bidens pilosa, Chenopodium album, Eupatorium adenophorum* and *Oxalis corniculata* was at both elevation under apple and oak based agroforestry system in Rudraprayag district. Kala (2010) recorded that the total of 26 herbaceous foods crop species and 21 woody species that were raised by farmers in the selected villages of Uttarakhand. Thirty seven plant species available in the agro-forestry system and used for curing various ailments by traditional healers were also documented during the survey which is lower than in present study. Gopal et al. (2017) observed 53 species in agrisilviculture system at mid altitude in Garhwal Himalaya while under silvipasture system there were about 27 species of tree, shrub and grass species. Bijalwan et al. (2016), Atul and Khosla (1990) in the AH system greater number of trees were observed at mid-elevations.

The insect pollinator diversity in selected district under agroforestry system indicated 5 order of insect was reported, maximum (11) number of pollinator was from Hymenoptera order followed by Diptera and Lepidoptera and lowest pollinator in Hemiptera (Table 5). Out of total pollinator in parenthesis only 25 pollinator species was reported in Tehri District, 23 insect pollinator species in Rudraprayag district however in Uttarkashi district 17 insect pollinator species was

recorded. Among the insect pollinator Carpenter bees was found only in Uttarkashi district. Eleven insect pollinators were common among the all three district, while Coleoptera order pollinator was in all districts except *Montipora spp.in* Uttarkashi district. Keasar (2010) and Kumar et al. (2024) observed five major insect orders were with Hymenoptera contributing the highest number of pollinator species. The lower diversity in Uttarkashi may be attributed to management practices, variations in altitude, microclimatic conditions, and floral resources, which influence pollinator abundance and distribution. Common insect pollinator indicating a core group of pollinators that are well adapted to the agroforestry landscapes of the Garhwal Himalaya. Such patterns of presence and absence are likely shaped by local management practices, vegetation types, resource availability, and climatic gradients. Kumar et al. (2024) reported a similar pattern of insect pollinator diversity at their study sites, with most species belonging to the orders Coleoptera, Diptera, Lepidoptera, and Hymenoptera. However, the introduction of hybrid crop varieties has

Table 5. Pollinator's diversity in study sites under apple based agroforestry system.

Common name	Species	District		
		Tehri	Rudraprayag	Uttarkashi
Order- Hymenoptera				
Asian honey bee	*Apis cerana indica*	✓	✓	✓
Dwarf bee	*Apis florea*	✓	✓	×
European bee	*Apis mellifera*	✓	✓	✓
Solitary bee	*Andrena coitana*	✓	×	✓
The red paper wasp	*Polistes canadensis*	✓	✓	✓
Yellow jacket wasp	*Polistes sp.*	✓	✓	×
Carpenter ant	*Camponotus sp.*	✓	✓	✓
Bumble bee	*Bombus sp.*	✓	✓	✓
Asian hornet	*Vespa velutina*	✓	✓	×
Matianense sweat bee	*Lasioglossum (Evylaeus) matianense*	√	×	✓
Carpenter bees	*Xylocopa sp.*	×	×	✓
Diptera				
Green bottle fly	*Lucilia sericata*	✓	✓	×
Housefly	*Musca domestica*	✓	✓	✓
Drone fly	*Eristalis tenax*	✓	×	✓
Syrphid flies		✓	✓	✓
The marmalade hoverfly	*Episyrphus balteatus*	×	✓	✓
Blue bottle fly	*Calliphora sp.*	✓	✓	×
Coleoptera				
Asian lady beetle	*Harmonia axyridis*	✓	✓	✓
Altica (blue beetle)	*Montipora spp.*	✓	✓	×
Common Red Soldier Beetle	*Rhagonycha fulva*	✓	✓	✓
Hemiptera				
Red cotton bug	*Dysdercus koenigii*	✓	✓	×
Lepidoptera				
Cabbage white	*Pieris brassicae*	✓		×
Grass yellow	*Eurema daira*	✓	✓	✓
Common spotted flat	*Celaenorrhinus leucocera*	✓	✓	×
Tricolored pied flat	*Coladenia indrani*	✓	✓	×
Lemon enigrant	*Catopsilia pomona*	✓	✓	✓
Great black vein	*Aporia agathon*	✓	✓	✓

Note- ✓ = presence of species, x = absence of species

Table 6. Percentage of pollinators in each Order under Apple base Agroforestry system

Order	Tehri Garhwal			Rudraprayag			Uttarkashi		
	Number of pollinators order	Number of pollinator species	% of pollinator species per order	Number of pollinators order	Number of pollinator species	% of pollinator species per order	Number of pollinators order	Number of pollinator species	% of pollinator species per order
Coleoptera	3	25	12.00	3	23	13.04	2	17	11.76
Diptera	5	25	20.00	5	23	21.73	4	17	23.52
Hemiptera	1	25	4.00	1	23	4.34	0	17	0.00
Hymenoptera	10	25	40.00	8	23	34.78	8	17	47.05
Lepidoptera	6	25	24.00	6	23	26.08	3	17	17.64

disrupted the natural interactions between crops and their pollinators. In addition, the extensive use of synthetic pesticides has caused significant mortality among pollinator species, pushing some of them towards the brink of extinction.

The highest number of pollinator was from Hymenoptera and lowest from Hemiptera order for all 3 selected district (Table 6.) In District Tehri Garhwal highest percentage of pollinator species was recorded from Hymenoptera order (40%) followed by Lepidoptera (24%) order. Minimum (4%) pollinator was from Hemiptera order. Similar trend was observed in Rudraprayag district Uttarkashi district recorded maximum (47.05%) pollinator from Hymenoptera order followed by Diptera (23.52 %) order while, no pollinator was recorded from Hemiptera order. The variations suggest that while Hymenoptera consistently dominate pollination across districts, the relative contribution of other orders is influenced by local ecological and environmental conditions (Dhawan 2013, Verma et al., 2021).

CONCLUSION

The study highlights that the highest number of agroforestry systems was recorded in Uttarkashi district at lower elevations, while a unique aquaculture-based agroforestry system was identified in Rudraprayag district at higher elevations. Agrobiodiversity was richer in oak-based agroforestry systems compared to apple-based systems across all selected districts and both elevation ranges. Vegetable species diversity was highest at all study sites, indicating the favorable climate and microclimatic conditions provided by agroforestry for off-season vegetable cultivation. Among cultivated crops, the highest diversity was observed in the Fabaceae family, followed by the Cucurbitaceae. Within wild vegetation, herbs represented the dominant life form. In terms of pollinator diversity, significant pollinators in apple-based agroforestry systems belonged to the Hymenoptera order, with the highest abundance in Tehri district. Conversely, pollinators from the Hemiptera order were in very low numbers across all districts.

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