agriculture

MDPI

Article

Diversity Distribution Analysis of Guava (*Psidium guajava* L.) Populations in Cultivated and Wild Habitats in the Mid-Hills of Uttarakhand, India

Dinesh P. Semwal [1], Soyimchiten Longkumar [1], Puran Chandra [1], Ranbir S. Rathi [1], Krishna M. Rai [2], Mamta Arya [2], Sudhir P. Ahlawat [1] and Praveen K. Singh [1,*]

[1] Division of Plant Exploration and Germplasm Collection, ICAR-NBPGR, New Delhi 110012, India
[2] ICAR-NBPGR Regional Station Bhowali, Nainital 263132, India
* Correspondence: praveen.singh1@icar.gov.in; Tel.: +91-011-25802885; Fax: +91-011-25842495

Abstract: Guava is an exotic fruit crop in India, and its occurrence in wild forests in the mid-hills of the Himalayas is a rare and unique phenomenon in its distribution. In the Ramganga valley of Pithoragarh district, Uttarakhand, a naturalized population of guava (in wild habitat) was chanced upon beside cultivated guava, hence a study was conducted to assess the population structure, phytosociology, diversity distribution patterns, and fruit variability of the guavas. Various ecological parameters like frequency, density, abundance, and A/F ratio were used to study the guava and associated species including tree seedlings in five selected sites. The highest Shannon diversity values (H = 0.367) for guava were found at Pipaltar village. Significant variability was recorded for the fruit color (pale yellow, dark yellow, pink, and whitish), fruit shape (long, round to pear-shaped), fruit length, fruit diameter, fruit weight, pulp color (white to pink), fruit maturity, and total soluble solids (TSS) content of fruits sampled from different sites. The population of maximum similarities and divergence was categorized. The present study highlights that guava is regenerating successfully in the mid-hills of Uttarakhand and that the introduction of guava in the region is not affecting the diversity of other indigenous species.

Keywords: *Psidium guajava*; mixed forest site; population structure; diversity indices; IVI

check for updates

Citation: Semwal, D.P.; Longkumar, S.; Chandra, P.; Rathi, R.S.; Rai, K.M.; Arya, M.; Ahlawat, S.P.; Singh, P.K. Diversity Distribution Analysis of Guava (*Psidium guajava* L.) Populations in Cultivated and Wild Habitats in the Mid-Hills of Uttarakhand, India. *Agriculture* **2024**, *14*, 575. https://doi.org/10.3390/agriculture14040575

Academic Editor: Massimiliano Renna

Received: 22 November 2023
Revised: 7 January 2024
Accepted: 9 January 2024
Published: 4 April 2024

Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Guava (*Psidium guajava* L.) originated in tropical America, where it is still found cultivated and wild [1–4]. It has spread across the globe, particularly in tropical regions such as Brazil, Bangladesh, China, India, Indonesia, Egypt, the Philippines, Nigeria, and Thailand. It is a shallow-rooted small tree that can grow up to 30 feet tall. It has spreading branches that sometimes reach close to the ground, especially when the tree is heavily laden with fruit. In many parts of the world, including India, guava is known as "poor man's fruit" or the "apple of the tropics" and is consumed both fresh and processed [5]. The genus *Psidium* comprises approximately 153 species of trees, including 20 species that produce edible fruits [6].

In India, guava is known by various local names such as "Amrud" in Hindi, "Peraka" in Malayalam, "Jamrukh/Jam phal" in Gujarati, "Jama pandu" in Telugu, "Seebe/Sibe hannu/perale" in Kannada, "Payara" in Bengali, "Amrud" in Punjabi, "Peroo" in Marathi, "Koyyapazham" in Tamil, "Peron" in Konkani, and "Pijuli" in Oriya.

In India, guava was first introduced by the Portuguese in the 17th century [3]. It has regenerated and spread in India and diverse populations have evolved over the last four centuries. Guava is reported to be self-pollinated to the tune of 35–40% [7]. Cross-pollination yields substantially more fruit than self-pollination and restricted pollination [8]. Researchers [9] have reported the maximum fruit set (87.72%) under open pollination. Cross-pollination has resulted in rich population diversity, and the species has now spread

to most of the tropical and subtropical regions of the country. The evolved diversity has been screened by various workers and several varieties of guava have been developed for different agroclimatic zones through simple selection. The available diversity in India has been studied by various workers using molecular markers. Naga Chitanya [10] studied the available diversity of 72 accessions of guava from India using SSR markers and reported the rich diversity of guava germplasm in the country. Gangappa [7] studied 28 guava germplasm lines maintained at IARI New Delhi for 33 morpho-biochemical traits using molecular markers and reported sufficient genetic variability for the studied traits.

Guava is a cost-effective and rich source of various nutrients and minerals. Guava fruits contain 13% carbohydrates and significant amount of vitamin C (228 mg ascorbic acid/100 g), vitamin A (140 mg retinol equivalent/100 g) and minerals such as calcium, phosphorus and iron [11]. The vitamin C content is three times higher than that of citrus [12]. Researchers [13] have reported that during fruit processing, 30 percent of the by-products are a useful source of dietary fiber (soluble and insoluble), vitamins (A, E, β-carotene), minerals (selenium, zinc), proteins (transferrin, ceruloplasmin, albumin), antioxidants, flavonoids, flavonols, and condensed tannins. Some of them are present in higher concentrations in the by-products than in the pulp; they force us to reconsider the current use of by-products. India is the largest producer of guava in the world, producing 45.82 105 metric tons of fruits from a 3.08 105 ha area [14]. The major guava-growing states in India include Bihar, Chhattisgarh, Madhya Pradesh, Odisha, Uttar Pradesh, and West Bengal. The highest guava productivity is in Andhra Pradesh (24.12 t/ha), followed by Punjab (22.5 t/ha), Assam (21.84 t/ha), Madhya Pradesh (19.52 t/ha), and Uttar Pradesh (18.75 t/ha) and Uttarakhand 5.63 t/ha [15].

In Uttarakhand, horticultural crops such as guava, mango, banana, apple, peach, oranges, citrus, and mulberry are grown extensively. Agriculture, forest products, and wild edible plants form the major sources of livelihood and food security for the state's inhabitants. The state's plant richness, particularly the diversity of forest species, is used for various purposes, including edible vegetables, fruits, medicine, aromatics, wood, and several non-woody forest products [16,17]. In the Pithoragarh region, forests are dominated by *Pinus roxburghii* and *Quercus* spp., particularly in the mid-hills as a pure patch but mostly mixed with other broad-leaved species in hills and valley areas where they are closely associated with *Mallotus philippensis*, *Sapium insigne*, *Pyrus pashia*, *Murraya koenigii*, and *Woodfordia fruticosa*, etc. In November 2021, a team of NBPGR scientists conducted an exploration in the Muwani and Pipaltar areas of Pithorgarh, wherein a naturalized population of guava was identified in the wild habitat along with the forest community in the Ramganga valley of the Pithoragarh district, Uttarakhand. Guava has also been naturalized in several countries [18,19]. It has spread quickly in most of the areas of its introduction, and in some countries, it is now considered as an invasive weed threatening the endemic flora. The species was introduced into the Galapagos Islands in the late 19th century [20]. It has spread both in cultivated as well as non-cultivated and forest areas and is now considered as an invasive weed in the Galapagos Islands [20–23]. In the New Zealand archipelago also, *P. guajava* has become as invasive weed and a threat to the native species diversity [24]. In Tanzania and Kenya, guava is regarded as one of the worst invaders invading unused sites [25].

In view of the importance of guava germplasm and the associated risk of its introduction, this study was conducted with the following objectives: (i) to understand the history and habitat status of the naturalized guava population in the wild; (ii) to assess variability in fruit parameters; (iii) to conduct a phytosociological analysis of the vegetation; and (iv) to carry out a quantitative assessment of ecological parameters.

2. Materials and Methods

2.1. Study Area

The study was conducted in the Ramganga valley in the Pithoragarh district of Uttarakhand, where a naturalized population of guava (*P. guajava*) coexists with mixed forest

species located between 28.48° and 30.68° N latitude and 79.53° to 81.19° E longitude. The area features a narrow altitudinal gradient ranging from 750 m to 1350 m above mean sea level, with a sub-montane climate and undulating topography with gentle slopes on the north, north-eastern, and north-western faces and somewhat steep slopes on the south and south-western faces. It is situated in the middle Himalayan region of the state, about 150 km away from the plains of the Gangetic region. These valleys are rich in agro-diversity, wild edibles, crop wild relatives, and cultural/ethnic diversity.

The study area was divided into three habitats: cultivated land (used by farmers for growing agri-horticultural crops), abandoned land (previously used agricultural lands but no longer in use due to farmer relocation or degradation from intensive land use), and wild habitat (natural vegetation with guava populations on steep hill slopes). Five sites were investigated for fruit variability parameters, plant community structure, and population dynamics: Site-I (Barla, wild habitat), Site-II (Pipaltar, abandoned land), Site-III (Barla village, cultivated land), Site-IV (Murti, abandoned land), and Site-V (Gaina, cultivated land) (Figure 1).

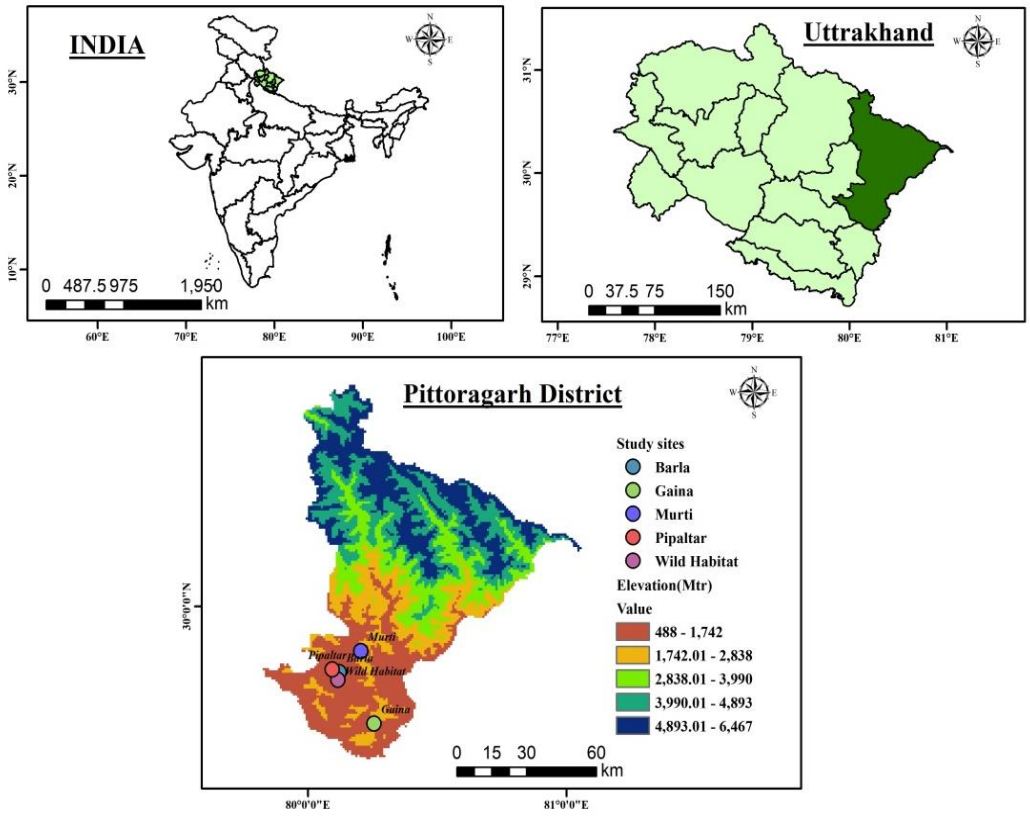


Figure 1. Study sites in Pithoragarh district, Uttarakhand.

The area receives about 2000 mm of annual rainfall, with the rainy season (July–August) accounting for roughly 60% of overall rainfall. The relative humidity varies from 30 to 80% annually. The mean maximum temperature varies between 4.5 °C (December–January) and 34.5 °C (May–June), with soil types ranging from sandy to course silty, fine silty, and fine loamy to fine-textured soils among the sites [26]. The study area has a rich diversity of agri-horticulture crops that have been grown in traditional agroecosystems since time immemorial. The principal traditional crops are cereals: *Oryza sativa*, *Triticum aestivum*, and *Hordeum vulgare*; minor millets: *Echinochloa frumentacea*, *Eleusine coracana*, and *Setaria italica*; pulses: *Phaseolus vulgaris*, *P. lunatus*, *Vigna mungo*, and *Glysine max* (Kala bhatt); oilseeds: *Brassica rapa* var. *yellow sarsaon*, and *B. rapa* var. *brown sarsaon*; spices and condiments: *Curcuma longa*, and *Zingiber officinale*; vegetables: *Benincasa hispida*, *Cucurbita moschata*, etc.,

and fruits: *Mangifera indica*, *Citrus limon*, *C. sinensis C. reticulata*, *Psidium guajava*, *Prunus armeniaca*, *P. domestica*, *P. persica*, *Musa* spp., etc.

2.2. Socio-Economic Data Recorded

To comprehend the socio-economic status of the local people, a questionnaire was developed based on the parameters used by various institutions [27]. The purpose of this questionnaire was to gather data on the status of the guava crop, baseline information on various parameters for on-farm conservation, and information related to the management of plant genetic resources (PGRs). The questionnaire covered a wide range of parameters including geographical position, village population, crops grown, guava fruit production, local consumption, labor cost, distance to markets from villages, the socio-economic status of villagers, and income derived from guava, among others.

During the field study, farmers were interviewed to gather information on the introduction of guava in the region, the history of wild guava habitats in the area, the quantity of guava collected from the wild and cultivated areas, the period of availability and regeneration of species, and the cropping systems being followed in the area. The study was conducted across five sites and ten villages, with two villages studied in each site.

2.3. Ecological Sampling and Quantitative Data Analysis

In the selected sites, transects (200 m^2 to 400 m^2) were laid out and random sampling was conducted using the quadrat method [28,29]. In each site, all trees were individually measured at breast height (1.37 m from the ground) to record diameter. Across the five sites, trees were sampled by randomly placing ten quadrats (10 m × 10 m sizes), and shrubs and seedlings were sampled by 20 quadrats (5 m × 5 m sizes) within the same transect. The tree and shrub species were identified according to *Flowers of the Himalaya* and *Flora of Chamoli* [30,31]. Data analysis was performed following standard ecological methods [32]. Vegetation quantitative parameters were estimated based on the ecological formulae given below:

$$\text{Frequency}(\%) = \frac{\text{Total number of quadrats in which species present} \times 100}{\text{Number of quadrats sampled}}$$

$$\text{Density} = \frac{\text{Total individual of a species}}{\text{Total number quadrat studied}}$$

$$\text{Abundance} = \frac{\text{Number of individuals of a species}}{\text{No. of quadrats in which species present}}$$

The importance value index (IVI) was calculated using the formula given by Curtis and McIntosh [33].

IVI = Relative frequency (RF) + Relative density (RD) + Relative dominance (RDOM)

The ratio of abundance to frequency (A/F ratio) was used to represent the distribution pattern [34] of the species. A/F ratio values less than 0.025 indicate a normal or uniform distribution, values between 0.025 and 0.05 indicate a random distribution, and values above 0.05 indicate a clustered or contagious distribution [34]. The diversity values of each species and from each site were calculated by using the Shannon diversity index and Simpson index of dominance [35].

$$H = -\sum [(ni/N) \ln (ni/N)]$$

where H = Shannon diversity index, ni = individuals of a species, N = total individuals of all species, and ln = natural log.

Simpson's index (SD) is a measure of diversity that considers the number of species present and the relative abundance of each species [36].

$$SD = \Sigma (ni/N)^2$$

where SD = Simpson index of dominance, ni is the importance value index of a species, and N is the importance value index of all the species.

2.4. Fruit Morphological Parameters Recorded

A total of 200 guava fruit samples were gathered from 40 trees across the sites, with five fruits sampled per tree and eight trees per site. The physical characteristics of the guava fruits were assessed following the standard scientific protocols from Sinha and Sinha [37]. A digital Vernier caliper was employed to measure the linear dimensions of the fruits, providing the size in millimeters. The total soluble solids (TSS), expressed as °Brix, were determined using a digital refractometer (PAL-3, ATAGO, Tokyo, Japan). Variability was recorded for various aspects of the fruit, including maturity, skin color, shape, length, diameter, weight, pulp color, total soluble solids (TSS), and the number of seeds per fruit.

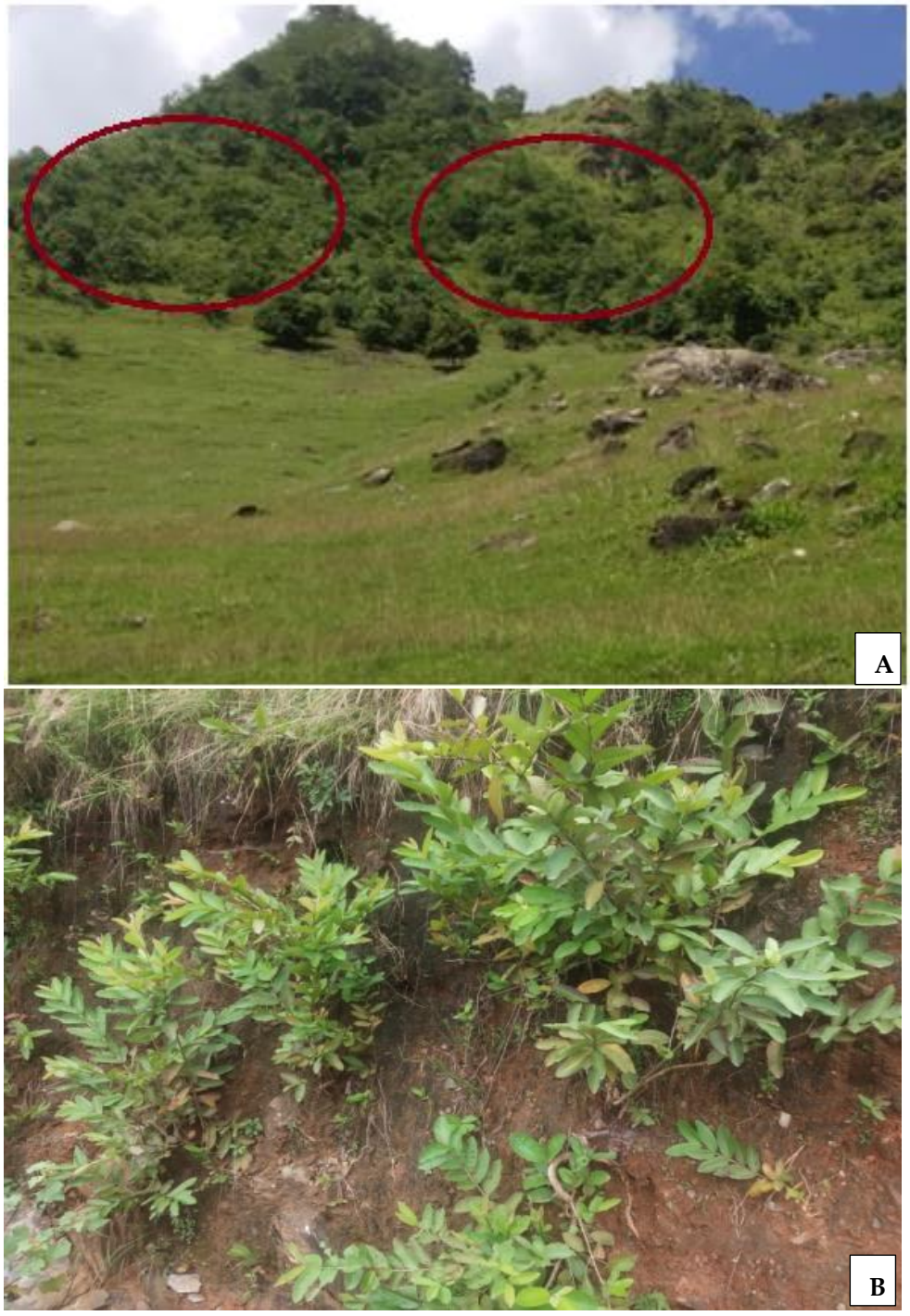
3. Results

3.1. Guava Cultivation and Socio-Economic Status of the Local People

The questionnaire data reveal that guava was introduced into the area around 120–130 years ago. The seeds were dispersed to forest areas and by birds, monkeys, shepherds, and fodder gatherers and the species started regenerating in the area, leading to the naturalization of cultivated guava in the region (Scheme 1). In Pipaltar and Murti villages, guava trees were observed regenerating naturally in forest areas through root suckers (Scheme 1).

The fruit season begins in September with early maturity types and ends in December with late maturity types. The guava fruit pulp was either white or pink, with local people mainly preferring the pink-colored, sweet-fleshed fruits for daily consumption. Most of the local people grow guava for their own consumption and only a few farmers sell it in the local market at a price of INR 10–15/kg. In the region, some of the problems associated with guava cultivation were infestation by fruit flies and damage by monkeys and birds. Farmers expressed interest in continuing its cultivation but desired some incentives in the form of price support due to fluctuations as the prices go down during a market glut. They also expressed the need for better market facilities.

In the study area, the survey revealed that the guava population is found in three major habitats—(i) guava in natural population/forest sites, (ii) guava in the abandoned land areas near the villages, and (iii) guava in individual home vegetable gardens and adjoining cultivated land/fields. Both white pulp and pink pulp guava fruits are commonly found in the area. In the Pipaltar area, during peak production period (September–November) the local supply of guava is higher than the demand. Moreover, transportation to nearby cities such as Pithoragarh, Haldwani, Tanakpur, etc., incurs high labor charges (for transporting to road head) and transportation costs. The survey included the response of communities regarding the conservation of guava diversity on farms and in wild habitats. Local farmers have shown their willingness to extend guava cultivation and expressed interest in high-yielding varieties. They also felt the need for small scale food processing units in the villages for making jam, jelly, and other processed food items.



Scheme 1. Guava in a wild habitat at Barla (**A**). Saplings and seedlings of guava at the Murthi site (**B**).

3.2. Variability Analysis in Fruit Characteristics

During the field study, various types of guava fruits were collected to analyze the variability in different parameters. Both the qualitative and quantitative characteristics of guava fruit parameters were recorded for a comparative assessment of fruit variability. Variability was observed in pulp color (white to pink), fruit maturity (early September to late December), TSS content (7.2–12.2 brix) fruit color (ranging from pale yellow, dark yellow, pink, to whitish), fruit shape (long, round to pear-shaped), fruit length (34.35–80.7 mm), fruit diameter (34.05–70.78 mm), and fruit weight (34.45–79.78 g) (Supplementary Material).

3.3. Analysis of Phytosociological Characteristics and Population Structure

The study quantitatively analyzed three types of guava habitats at five sites on frequency, density, abundance, species association, dominance–diversity pattern, and regeneration status. Guava was found distributed in all three habitat types across the five sites. The highest frequency of guava was observed in an abandoned site at Pipaltar village (40%), followed by Barla village (cultivated field), and Gaina (cultivated field). In wild habitats, the frequency was found to be 30%. Other associated tree species had a frequency ranging from 10% (*Aegle marmelos*) to 80% (*Mallotus philippensis*) (Table 1).

Table 1. Population structure of guava and their associate species in different sites of Pithoragarh, Uttrakhand.

Study Sites	Vegetation (Tree/Shrub/ Seedling/Sapling)	Common Name	Frequency (%)	Density (Trees/100 m^2)	Distribution Pattern (A/F Ratio)	IVI
I. Barla (Wild habitat)	Trees					
	Psidium guajava L.	Guava	30	0.8	0.089	33.64
	Mallotus philippensis (Lam.) Muell. Arg.	Kamela dye	80	4.5	0.070	137.07
	Murraya koenigii (L.) Spreng.	Curry leaf	70	2.6	0.053	82.13
	Sapium insigne (Royle) Benth. Hook.f.	Khinna, Khirun	50	0.9	0.036	47.17
	Shrubs					
	Colebrookia oppositifolia	Pansre, Binda	60	2.2	0.061	126.45
	Woodfordia fruticosa	Dhavari	50	1.2	0.048	87.33
	Murraya koenigii	Curry leaf	60	1.0	0.028	86.22
II. Pipaltar (Abandoned land)	Trees					
	Psidium guajava L.	Guava	40	1.1	0.069	83.40
	Jatropha curcus L.	Ratanjot	20	0.5	0.125	29.47
	Murraya koenigii (L.) Spreng.	Curry leaf	40	0.7	0.044	34.07
	Mallotus philippensis (Lam.) Muell. Arg.	Kamela dye tree	40	0.7	0.044	42.23
	Sapium insigne (Royle) Benth. Hook.f.	Khinna, Khirun	50	0.8	0.032	63.87
	Pyrus pashia Buch.-Ham. ex D. Don.	Mahul, wild pear	40	0.4	0.023	34.82
	Aegle marmelos (L.) Correa	Bael, stone apple	10	0.1	0.100	12.14
	Shrubs					
	Agave americana	Gwarpatha	20	0.3	0.075	300.00
III. Barla village (Cultivated)	Trees					
	Psidium guajava L.	Guava	40	0.7	0.044	52.17
	Mangifera indica L.	Aam, mango	30	0.3	0.033	26.02
	Emblica officinalis L.	Aonla	20	0.2	0.050	22.36
	Celtis australis L.	Kharik	40	0.6	0.038	44.42
	Grewia optiva J.R. Drumn. Ex Burret	Bhimal	70	1.1	0.022	78.50
	Toona ciliata M.Roem.	Toon	30	0.3	0.033	24.41
	Litsea monopetala (Roxb. Ex Baker) Pers.	Katmarra	20	0.3	0.075	21.20
	Ficus semicordata Buch.Ham.ex Roxb.	Timla, Timul	30	0.4	0.044	30.91
	Seedling					
	Psidium guajava L.	Guava	30	0.3	0.033	300.00

Table 1. *Cont.*

Study Sites	Vegetation (Tree/Shrub/ Seedling/Sapling)	Common Name	Frequency (%)	Density (Trees/100 m^2)	Distribution Pattern (A/F Ratio)	IVI
IV Murti (Abandoned land)	Trees					
	Psidium guajava L.	Guava	30	2.2	0.244	103.59
	Woodfordia fruticosa (L.) Kurz	Dhavari	50	1.3	0.052	69.79
	Madhuca longifolia (J.Koenig ex (L.) J.F.Macbr.	Mahua	50	0.7	0.028	51.15
	Syzygium cumini (L.)	Jamun, black plum	40	0.4	0.024	35.07
	Erythrina indica Lam.	Indian coral tree	40	0.5	0.031	40.39
	Shrubs/Saplings					
	Psidium guajava L.	Guava	50	2.9	0.116	204.37
	Woodfordia fruticosa (L.) Kurz	Dhavari	70	1.3	0.026	95.63
	Seedlings					
	Psidium guajava L.	Guava	30	1.1	0.122	300.00
Site V. Gaina (Cultivated)	Trees					
	Psidium guajava L.	Guava	40	0.6	0.038	57.87
	Ficus semicordata Buch.Ham.ex Roxb.	Timla, Timul	20	0.2	0.050	22.92
	Celtis australis L.	Kharik	50	0.7	0.028	67.51
	Grewia optiva J.R. Drumn. Ex Burret	Bhimal	60	0.8	0.022	77.10
	Toona ciliata M.Roem.	Toon	20	0.2	0.050	24.41
	Litsea polyantha Juss.	Katmarra	40	0.5	0.031	50.19

The maximum density of guava (2.2 trees/100 m^2) was found in an abandoned land at Murthi village, whereas the minimum density (0.6 trees/100 m^2) was obtained at Gaina village. A total of 19 higher plant species were documented within the sampling area, comprising 15 trees and 4 shrubs, namely *Mallotus philippensis*, *Murraya koenigii*, *Grewia oppositifolia*, *Sapium insigne*, and *Woodfordia fruticosa* (Table 1). In other associate species of guava, the maximum density was estimated for *Mallotus philippensis* (4.5), followed by *Murraya koenigii* (2.6), *Woodfordia fruticosa* (1.3), *Grewia optiva* (1.1), and *Sapium insigne* (0.9) in the study sites (Table 1).

The study also analyzed the distribution or dispersion of species, providing valuable insights into the interaction between individuals of a species and their biotic and abiotic environments. The contagious distribution, also called the grouped distribution pattern (ratio of A/F values), is the most common type of dispersion found in nature. It was observed that guava trees in the naturalized population follow a contagious distribution (>0.05), whereas most of the cultivated species were distributed randomly (0.025–0.05) and some species were distributed uniformly, such as *Grewia oppositifolia* (0.022), *Pyrus pashia* (0.023), and *Syzygium cumini* (0.024) (Table 1).

The study also assessed the population structure, i.e., densities of seedlings, small and large trees of various species in different habitats, and sites, to understand the vegetation structure and regeneration patterns. The presence of a sufficient number of seedlings, saplings, and trees in a wild habitat indicates successful regeneration. The maximum seedling density (1.1 trees/100 m^2) was estimated for guava in an abandoned site at Murthi village, whereas the minimum density (0.3 trees/100 m^2) was obtained in Barla village (Table 1). The analysis revealed good regeneration of guava in wild habitats, indicating good scope for an in situ conservation site for guava.

3.4. Diversity Indices among the Sites

Plant communities vary according to the number of species they contain (richness) and the relative abundances of those species (evenness). A diversity index is a quantitative measure that reflects the number of different species and how evenly the individuals are distributed among those species.

The Shannon diversity (H) values, which were calculated for the five sites of the study area, ranged from 1.03 to 1.97 for trees and 1.23 to 2.55 for shrub species. The highest Shannon diversity (H) was found at the Barla (cultivated) Site-III (H = 1.97), followed by the Murthi (abandoned) Site-IV (H = 1.81) and the Gaina (cultivated) Site-V (H = 1.70) (Figure 2).

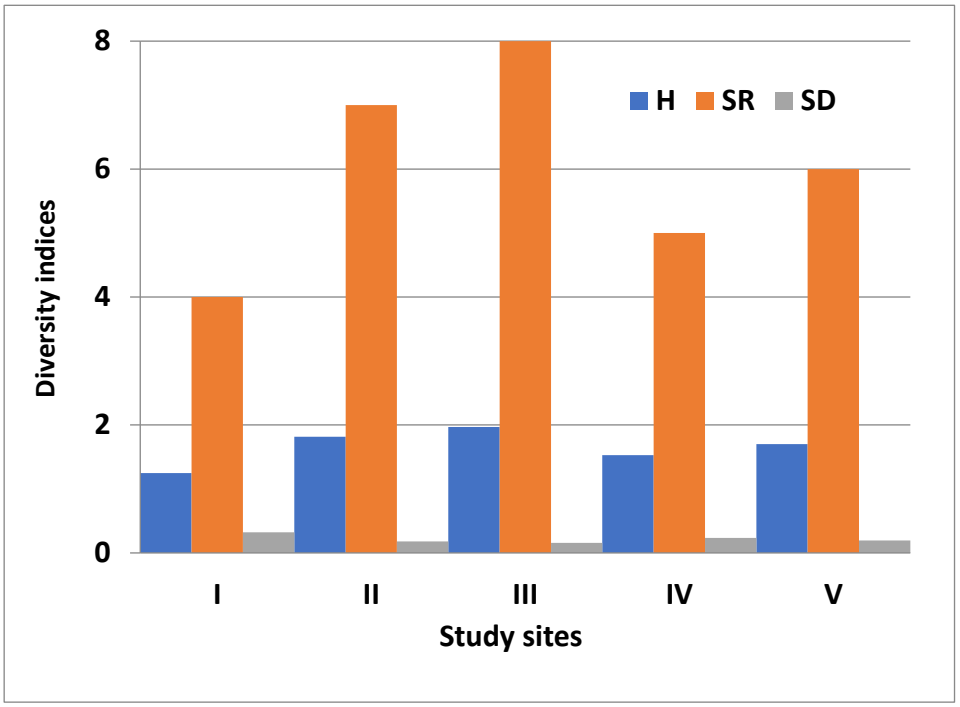
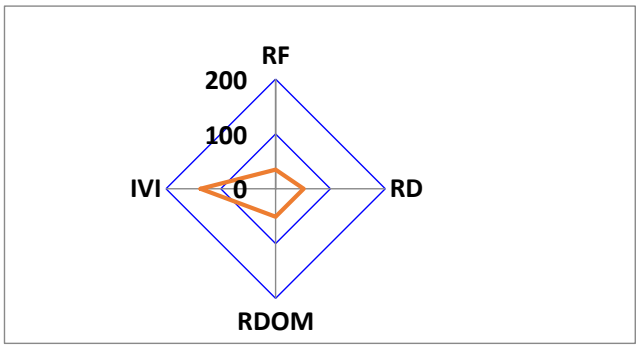


Figure 2. Species richness (SR), Shannon diversity index (H), and Simpson index of dominance (SD) values in different sites of the study area (Site-I: Barla, wild habitat; Site-II: Pipaltar, abandoned land; Site-III: Barla, cultivated; Site-IV: Murthi, abandoned; Site-V: Gaina, cultivated).

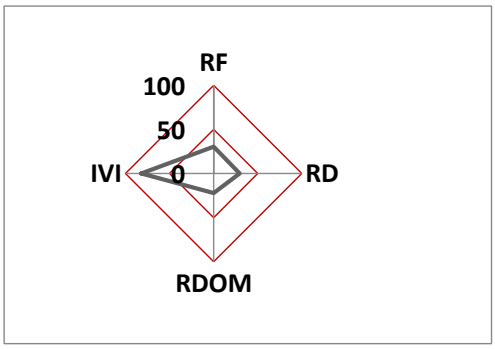
The Shannon diversity values for guava varied across different sites and habitat types. The maximum diversity value for guava (H = 0.367) was found at the Pipaltar (abandoned) Site-II, whereas the minimum diversity (H = 0.245) was observed at the Barla (wild) Site-I.

Among the associated species, the highest diversity was observed for *Mallotus philippensis* (H = 0.357), followed by *Murraya koenigii* (H = 0.354) and *Woodfordia fruticosa* (H = 0.339). The values for dominance are the reverse of those for Shannon diversity (Figure 2). It is concluded that species-wise diversity values were highest for guava, which shows that guava has successfully adapted to the natural habitat of the study area.

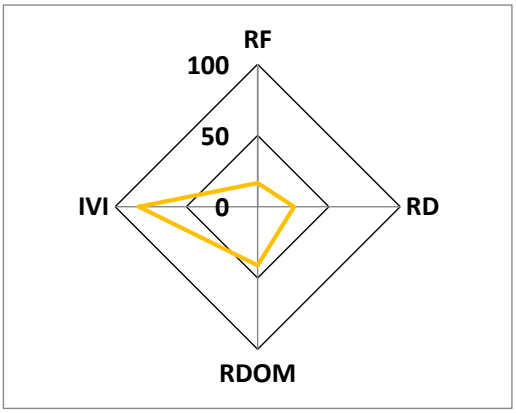
The importance value index (IVI) was used to determine the relative dominance scores for species within the study area. The IVI of the guava population varied between 19.94 and 103.59 among all the study sites, with the maximum in Murti village and the minimum in Barla village (Table 1; Figure 3). Among the other associate species, the maximum IVI value was estimated for *Mallotus philippensis* (137.06), followed by *Murraya koenigii* (82.13), *Grewia oppositifolia* (77.1), *Woodfordia fruticosa* (69.78), and *Sapium insigne* (63.87) in different sites (Figure 3). A high importance value indicates a particular species is well represented in that particular site due to its large number of individuals compared with other species on that site.



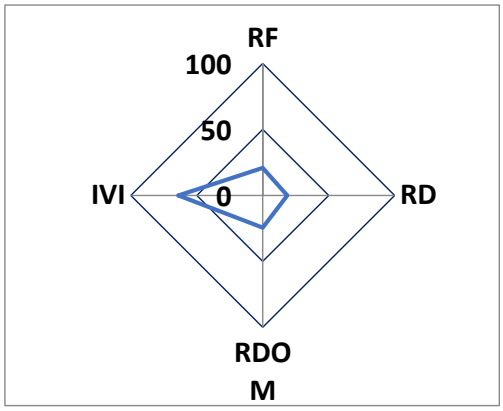
I—Wild habitat—*Mallotus philippensis*



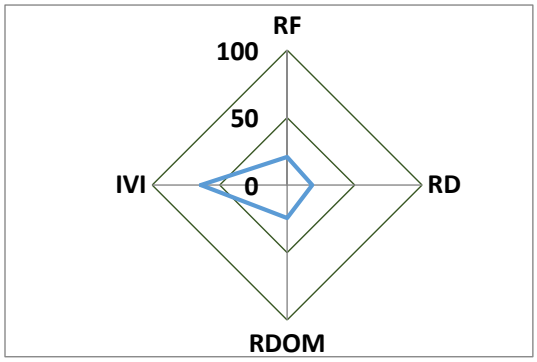
Wild habitat—*Murraya koenigii*



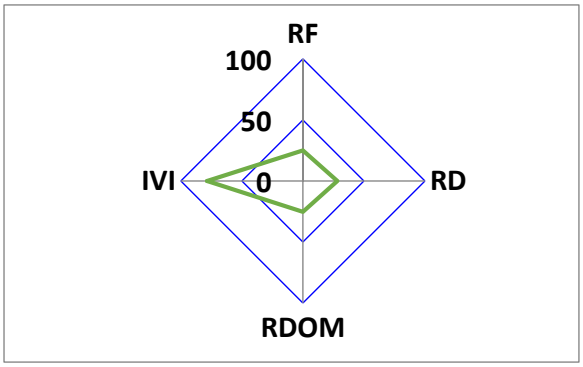
II—Pipaltar, abandoned land—*Psidium guajava*



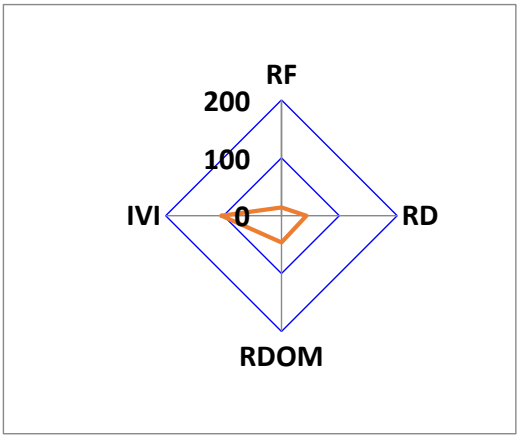
Sapium insigne



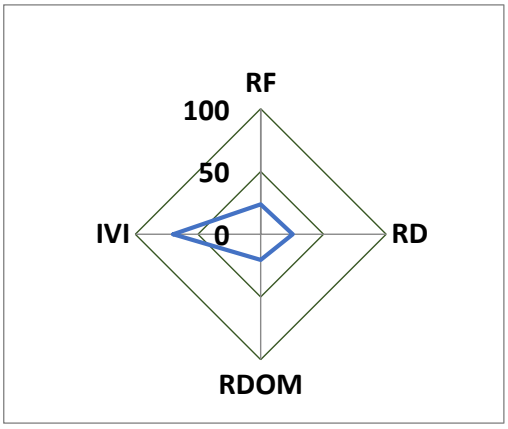
III—Barla, cultivated—*Psidium guajava*



Grewia oppositifolia



IV—Murthi, abandoned land—*Psidium guajava*



Woodfordia fruticosa

Figure 3. *Cont.*

V—Gaina, cultivated land—*Celtis australis* *Grewia oppositifolia*

Figure 3. Phytographs of dominant and co-dominant species in different sites showing relationships of relative frequency, density, dominance, and importance value index.

3.5. Participatory Approach in Guava Conservation and Management Planning

Agriculture is the main livelihood in the study areas, with most farmers cultivating cereals/pseudo cereals/millets (such as rice, wheat, maize, and finger millet), pulses/grain legumes, and fruit crops. They supplement their income and diet with locally grown crops, vegetables, fruits, animal husbandry, and related trades.

Farmers in the study area are particularly concerned about the costs of transportation and labor, especially when it comes to harvesting guava fruit from distant and steep slopes and tall trees. The survey revealed that the Pipaltar area is dominated by guava trees but that they do not make much profit, except for in the Gudoli village where a farmer earns a substantial income (over INR 2.0 lakh rupees per year) from selling guavas.

The local community is willing to participate in the guava on-farm management and conservation and is ready to provide community land for this purpose. There is a need for initiatives to scale up the promising guava germplasm through improved community participation and by adding value to the local germplasm. The highly perishable nature of fruits limits their storage and transportation period; moreover, the transportation cost is high in hilly and remote areas. Therefore, alternative ways to earn from the guava can be achieved through value addition by sorting and grading and by establishing a guava juice extraction, jam making, and jelly making plant to enhance the socio-economic condition of the local people.

4. Discussion

Guava was introduced onto farmer's fields and, following seed dispersal mechanisms, was established in adjoining areas that provided space and continues to thrive. In the present study, guava trees were found growing in home gardens, cultivated and abandoned fields, and open pasture areas. The species exhibits pioneer characteristics and canonizes new sites devoid of any tree growth, mainly steep hill slopes occupied by grasses. In Kenya, the study conducted by Otuoma [38] shows that guava has displaced native plant species; however, he also concluded that the presence guava as overhead shade trees in ecological restoration areas has supported the growth of shade-tolerant native tree species.

The success of plants that have naturalized is closely associated with the similarities and differences in niches and the genetic relationships between alien and native species [39]. Darwin's "naturalization hypothesis" also suggests that alien species that are phylogenetically distinct from the native flora are more likely to naturalize because of their ability to exploit the unoccupied ecological niches in native communities. Conversely, Darwin's "pre-adaptation hypothesis" proposes that exotic species closely related to indigenous ones may establish more successfully due to their affinity to the local environment [40,41].

According to Darwin, plants with close relatives tend to colonize the same habitat because of their similar requirements. Introduction, establishment, naturalization, and subse-

quent impact are the four major stages of the invasion process of unfamiliar species [39,42]. Habitat filtration, niche differentiation, and interspecific competition are the three important processes shaping community species composition and structural dynamics.

The diversity index provides valuable information about community composition, rarity, and commonness in a community, taking into account the relative abundances of different species to understand community structure. In the present study, the maximum Shannon diversity index (H = 1.97) was found in cultivated land (Barla, Site III). The high Shannon diversity value is owed to the fact that the site is a home garden maintained near a house with variety of multipurpose trees and shrubs that are maintained by farmers on a small piece of land. In the studied sites, the diversity was found to be lowest in wild habitats (1.25). The low diversity is mainly attributed to the site quality and high biotic pressure. The site is characterized by undulating topography, rocky land, steep slopes, and shallow soil depths. This site is a panchayat land used by the community for grazing their animals. Guava and a few other species are able to survive the harsh climatic conditions and biotic pressure. It is evident that guava, having adapted to the wild habitat, integrates with other associated forest species and maintains their frequency, density, and diversity. The local dispersal mechanism of fruits/seeds and climatic similarities to its cultivated habitat may be the key drivers in the successful naturalization of guava in this part of Uttarakhand.

The IVI for guava and other associated species reveals that in the wild habitat studied guava had the lowest IVI value (33.64). The maximum IVI was recorded for *Mallotus philippensis* (137.06), followed by *Murraya koenigii* (82.131) and *Sapium insigne* (47.17). The low IVI value for guava in the studied area shows that it is not an invasive species and that the local floral diversity of the region has not been affected much by the introduction of guava. The IVI of guava on abandoned sites was found to be highest in Murti (103.59) and Pipaltar (83.40). These sites were previously guava orchards planted by farmers and later abandoned due to the migration of the farmers from the area. In cultivated sites, the IVI was highest for *Grewia optiva* at Barla (78.50) and Gaina (77.10). *Grewia optiva* is the preferred multipurpose tree species of the mid-hills of Uttarakhand and is the most common tree species cultivated in the farmer's fields.

In forest areas, or lands with good numbers of woody perennials, the species is rarely found. It is a hardy tree, suitable for growing in unproductive lands, and it can be a valuable alternative to shifting cultivation areas in the north-east Indian region, where forest land is cleared for the cultivation of ginger, vegetables, and pulses. A guava-based production system is a useful economic, viable, and ecologically sustained agroforestry system for the mid-hills of the eastern and western Himalayas [43,44]. This multi-purpose tree provides varieties of tangible as well as intangible benefits. The fruits are used for household consumption, market sale, jam and jelly making, and byproducts for food industry. The wood is also used as firewood and in charcoal making. The wood is used for making wood carvings, spear handles, chisels, catapults, fishing rods, treenails, household and agricultural implements, posts for small houses, and fence posts. The overhead shade of guava is suitable for shade-loving crops such as ginger and turmeric, improving production system productivity [43]. Agroforestry is one of the Nature based Solutions (NbS) that create co-benifits that include envirommental, economic and social benifits [44,45]. In the present investigation, apart from the planted areas of orchards, home gardens, and cultivated fields, the species was found colonizing mainly pasture wasteland, where the factors of locality and not conducive for the growth of luxuriant vegetation. Guava is a hardy species, and the seeds are spread to new areas by birds, monkeys, rodents, etc. The chances of it becoming an invasive weed are very small. The reported invasive weeds of India such as *Prosophis julifora*, *Eupatorum ordoratum*, *Lantana camera*, and *Parthenium hysterophorus* were introduced before 1977, during World War II, in the period 1809–10, and in 1956, respectively [46,47]. Guava was introduced much earlier, i.e., in the 17th century by the Portuguese, and there is now very little chance of it becoming an invasive weed and posing a threat to the native biodiversity. It is also absent from the priority list of alien

invasive weeds given by the National Biodiversity Authority [48]. Reddy [47] has also excluded the species from list of 173 invasive species in India. On a positive note, in India, the species has exhibited a beneficial evolutionary trend and several useful verities have been selected from the evolved diversity of guava in the country. Moreover, guava-based production systems in the mid-hills of the Himalayas are more productive and sustainable and provide a viable alternative to mono-cropping and shifting cultivation [43,44].

5. Conclusions

The present study reported the naturalization of guava (*P. guajava*) in a distant hilly area of Pithoragarh district, Uttarakhand and investigated its natural plant community structure, population dynamics, and fruit variability parameters across the sites. In the studied wild site (Barla), the dominance of guava was lowest as compared to the indigenous species, and the chances of becoming invasive weed are rare. Guava has adapted in the region and is generating additional income for the farmers from unproductive lands. The available diversity should be conserved and the site may be useful for understanding evolutionary studies of guava in the region. The available diversity of guava will be augmented by importing new exotic germplasms from their native regions. Suitable local genotypes within the country should also be introduced for the enrichment of guava diversity.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agriculture14040575/s1, Table S1: Guava fruit characteristics growing in different habitat in the mid hills of Uttarakhand.

Author Contributions: Conceptualization, D.P.S., S.L., P.C. and S.P.A.; methodology, D.P.S. and S.L.; formal analysis, D.P.S., S.L. and P.C.; writing, original draft preparation, D.P.S. and S.L.; writing, review and editing, D.P.S., S.L., P.C., S.P.A., P.K.S., K.M.R., R.S.R. and M.A.; supervision, D.P.S., S.P.A. and P.K.S. All authors have read and agreed to the published version of the manuscript.

Funding: This study was supported by ICAR-Indian Agricultural Research Institute, New Delhi-110012 and ICAR-National Bureau of Plant Genetic Resources through the Indian Council of Agricultural Research, India.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article and Supplementary Materials.

Acknowledgments: The authors are thankful to the Director, ICAR-National Bureau of Plant Genetic Resources for continuous support and for providing the opportunity to undertake the present study. We acknowledge the help rendered by the organization Rahwasi, Pithorgarh. The knowledge shared by the informants/farmers of the village Barla (Pipaltar) is also acknowledged.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. De Candolle, A.P. *Origin of Cultivated Plants*; Kegal Paul: London, UK, 1904.
2. Purseglove, J.W. *Tropical Crops: Dicotyledons*; John Wiley and Sons, Inc.: New York, NY, USA, 1968.
3. Hayes, W.B. *Fruit Growing in India*; Kitabistan: Allahabad, India, 1953.
4. Pontikis, C.A. *Psidium guajava* L. (Guava). In *Trees IV. Biotechnology in Agriculture and Forestry*; Bajaj, Y.P.S., Ed.; Springer: Berlin/Heidelberg, Germany, 1996; Volume 35.
5. Baloda, S.; Sharma, S.K.; Sehrawat, V.P.; Ahlawat, S.; Bhatia, K.; Dahiya, D.S. Present status of Guava Research JR and Future Thrust in India. *Haryana J. Hortic. Sci.* **2011**, *40*, 105–116.
6. Yadav, I.S. *Germplasm Collection of Mango, Grape, Guava, and Litchi in India. Report of All India Coordinated Research Project on Sub-tropical Fruits*; CIHNP: Lucknow, India, 1990.
7. Gangappa, N.D.; Singh, C.; Verma, M.K.; Thakre, M.; Sevanthi, A.M.; Singh, R.; Srivastava, M.; Raghunandan, K.; Anusha, C.; Yadav, V.; et al. Assessing the genetic diversity of guava germplasm characterized by morpho-biochemical traits. *Front. Nutr.* **2022**, *9*, 1017680. [CrossRef]
8. Alves, J.E.; Freitas, B.M. Pollination requirements of guava. *Cienc. Rural* **2007**, *37*, 1281–1286. [CrossRef]

9. Sarkar, T.; Sarkar, S.K. Pollination characteristics and intervarietal hybridization of *Psidium guajava*. *J. Crop Weed* **2022**, *18*, 96–103. [CrossRef]
10. Naga Chaithanya, M.V.; Dinesh, M.R.; Vasugi, C.; Lakshmana Reddy, D.C.; Sailaja, D.; Aswath, C. Assessment of genetic diversity in guava (*Psidium guajava*) germplasm using microsatellites. *J. Hortic. Sci.* **2014**, *9*, 117–125. [CrossRef]
11. Naseer, S.M.; Rahman, M.; Pervaiz, N.; Naeem, N.; Hussain, S. The phytochemistry and medicinal value of *Psidium guajava* L. (guava). *Clin. Phytosci.* **2018**, *4*, 8. [CrossRef]
12. Gill, K.S. Guavas. In *Encyclopedia of Food and Health*; Caballero, B.C., Paul, M.F., Fidel, T., Eds.; Academic Press: London, UK, 2016; pp. 270–277.
13. Angulo-Lopez, J.E.; Flores-Gallegos, A.; Torres-Leon, C.; Ramirez-Guzman, K.N.; Martinez, G.A.; Aguilar, C.N. Guava (*Psidium guajava* L.) Fruit and Valorization of Industrialization By-Products. *Processes* **2021**, *9*, 1075. [CrossRef]
14. National Horticulture Board (NHB). Indian Production of Guava: 1st Advance Estimate 2021-22. 2022. Available online: https://agriexchange.apeda.gov.in/India%20Production/India_Productions.aspx?cat=fruit&hscode=1046 (accessed on 28 December 2023).
15. Government of India. *Horticultural Statistics at a Glance—2018*; Horticulture Statistics Division Department of Agriculture, Cooperation & Farmers' Welfare Ministry of Agriculture & Farmers' Welfare, Government of India: New Delhi, India, 2018; 460p.
16. Dhar, U.; Rawal, R.S.; Samant, S.S. Structural diversity and representativeness of forest vegetation in a protected area of Kumaon Himalaya, India, Implications for conservation. *Biodiv. Conser.* **1997**, *6*, 1045–1062. [CrossRef]
17. Singh, J.S.; Singh, S.P. *Forests of Himalaya: Structure, Functioning, and Impact of Man*; Gyanodaya Prakashan: Nainital, India, 1992.
18. Menzel, C.M. Guava: An exotic fruit with potential in Queensland. *Queensl. Agric. J.* **1985**, *111*, 93–98.
19. Howard, R.A. *Flora of the Lesser Antilles, Leeward and Windward Islands. Volume 5. Arnold Arboretum*; Harvard University: Jamaica Plain, MA, USA, 1989; 604p.
20. Walsh, S.J.; McCleary, A.L.; Mena, C.F.; Shao, Y.; Tuttle, J.P.; González, A.; Atkinson, R. Quick Bird and Hyperion data analysis of an invasive plant species in the Galapagos Islands of Ecuador: Implications for control and land use management. *Remote Sens. Environ.* **2008**, *112*, 1927–1941. [CrossRef]
21. Mauchamp, A. Threats from Alien plant species in the Galápagos Islands. *Conserv. Biol.* **1911**, *11*, 260–263. [CrossRef]
22. Tye, A.; Atkinson, R.; Carrion, V. Increase in the number of introduced plant species in Galapagos (No. 2006–2007; pp. 133–135). DPNG, GCREG, FCD, GC. DPNG, GCREG, FCD, GC. 2007. Available online: http://www.galapagos.org/wp-content/uploads/2012/04/biodiv7-introduced-plants-increase.pdf (accessed on 21 November 2023).
23. Urquia, D.; Gutierrez, B.; Pozo, G.; Pozo, M.J.; Espin, A.; Torres, M. *Psidium guajava* in the Galapagos Islands: Population genetics and history of an invasive species. *PLoS ONE* **2019**, *14*, e0203737. [CrossRef] [PubMed]
24. Sheppard, C.S.; Burns, B.R.; Stanley, M.C. Predicting plant invasions under climate change: Are species distribution models validated by field trials? *Glob. Chang. Biol.* **2014**, *20*, 2800–2814. [CrossRef]
25. Witt, A.; Luke, Q. (Eds.) *Guide to the Naturalized and Invasive Plants of Eastern Africa*; CABI: Wallingford, UK, 2017; 601p. Available online: http://www.cabi.org/cabebooks/ebook/20173158959 (accessed on 21 November 2023).
26. Compendium on Soils. *Compendium of Soil Resources for Sustainable Land Management of Uttarakhand*; Soil and Land Use Survey of India (Department of Agriculture, Co-operation & Farmers Welfare) Ministry of Agriculture & Farmers Welfare Government of India: New Delhi, India, 2018.
27. Bisht, I.S.; Rao, K.S.; Bhandari, D.C.; Nautiyal, S.; Maikhuri, R.K.; Dhillon, B.S. A suitable site for in situ (on-farm) management of plant diversity in traditional agro-ecosystems of western Himalaya in Uttaranchal state: A case study. *Genet Resour. Crop Evol.* **2006**, *53*, 1333–1350. [CrossRef]
28. Kershaw, K.A. *Quantitative and Dynamic Plant Ecology*; American Elsevier Publishing Company: London, UK, 1974; 308p.
29. Misra, R. *Ecology Work Book*; Oxford and IBH Publishing Company: New Delhi, India, 1968; p. 244.
30. Polunin, O.; Stainton, A. *Flowers of the Himalaya*; Oxford Press: New Delhi, India, 1984.
31. Naithani, B.D. *Flora of Chamoli*; Botanical Survey of India: Howrah, India, 1984.
32. Curtis, J.T.; Cottam, G. The use of distance measures in phytosociological sampling. *Ecology* **1956**, *37*, 151–160.
33. Curtis, J.T.; McIntosh, R.P. The interrelations of certain analytic and synthetic phytosociological characters. *Ecology* **1950**, *31*, 434–455. [CrossRef]
34. Whitford, P.B. Distribution of woodland plants in relation to succession and colonal growth. *Ecology* **1949**, *30*, 199–208. [CrossRef]
35. Magurran, A.E. *Ecological Diversity and Its Measurement*; Croom Helm: London, UK, 1988.
36. Simpson, E.H. Measurement of diversity. *Nature* **1949**, *163*, 688. [CrossRef]
37. Sinha, M.; Sinha, A.M.P. Value addition of guava cheese cv. Allahabad safeda by medicinal herbs. *J. Pharmacogn. Phytochem.* **2017**, *6*, 856–859.
38. Otuoma, J.; Nyongesah, J.M.; Owino, J.; Onyango, A.A.; Okello, V.S. Ecological manipulation of *Psidium guajava* to facilitate secondary forest succession in tropical forests. *J. Ecol. Eng.* **2020**, *21*, 210–221. [CrossRef]
39. Li, S.P.; Cadotte, M.W.; Meiners, S.J.; Hua, Z.S.; Shu, H.Y.; Li, J.T.; Shu, W.S. The effects of phylogenetic relatedness on invasion success and impact: Deconstructing Darwin's naturalization conundrum. *Ecol. Lett.* **2015**, *18*, 1285–1292. [CrossRef]
40. Park, D.S.; Feng, X.; Meitner, B.S.; Ernst, K.C.; EnQuest, B.J. Darwin's naturalization conundrum can be explained by spatial scale. *Proc. Natl. Acad. Sci. USA* **2020**, *117*, 10904–10910. [CrossRef] [PubMed]
41. Qian, H.; Sandel, B. Darwin's pre-adaptation hypothesis and the phylogenetic structure of native and alien regional plant assemblages across North America. *Glob. Ecol. Biogeogr.* **2021**, *31*, 531–545. [CrossRef]

42. Cadotte, M.W.; Campbell, S.E.; Li, S.P.; Sodhi, D.S.; Mandrake, N.E. Preadaptation and naturalization of non-native species: Darwin's two fundamental insights into species invasion. *Annu. Rev. Plant Biol.* **2018**, *89*, 661–684. [CrossRef] [PubMed]
43. Chandra, P.; Mohapatra. Development of agroforestry system for mid-hills of north east region. *Ann. Ag. Res.* **2022**, *43*, 1–5.
44. Rathore, A.C.; Abhishek, K.; Toman, J.; Jayaprakash, J.; Mehta, H.; Kaushal, R.; Alam, N.M.; Gupta, A.K.; Raizada, A.; Chaturvedi, O.P. Predictive models for biomass and carbon stock estimation in *Psidium guajava* on bouldery riverbed landsin North-Western Himalayas, India. *Agrofor. Syst.* **2018**, *92*, 171–182. [CrossRef]
45. Dhyani, S.; Thummarukuddy, M. Ecological engineering for disaster risk reduction and climate change adaptation. *Environ. Sci. Pollut. Res.* **2016**, *23*, 20049–20052. [CrossRef] [PubMed]
46. Kushwaha, S.P.S.; Ramakrishnan, P.S.; Tripathi, R.S. Population Dynamics of *Eupatorium odoratum* in Successional Environments Following Slash and Burn Agriculture. *J. Appl. Ecol.* **1981**, *18*, 529–535. [CrossRef]
47. Reddy, S.; Bagayanarayana, G.; Reddy, K.N.; Raju, V.S. *Invasive Alien Flora of India*; US Geological Survey: Reston, VA, USA, 2008; pp. 1–28.
48. NBA. *Invasive Alien Species of India—Technical Report*; NBA: Chennai, India, 2018.

Disclaimer/Publisher's Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.