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Research Article

Composition of Stand and Growth Dynamics of Black Cardamom (*Amomum subulatum*) in Different Agroforestry Habitats in Bhutan

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Abstract
The composition and arrangement of tree species at different altitudes play a vital environmental role in the growth of Black Cardamom *(Amomum subulatum)* in Bhutan. The present study assesses agroforestry tree species composition and factors affecting the growth of *A. subulatum* in different habitat types. Altitudes were sorted into three different altitudinal bands (low, mid, and high) and each altitudinal band in three different habitats (timber tree, fodder tree, and mixed tree habitat) was assessed. The sampling of 48 plots was made for each habitat and the plot size was 20×20 m. In total, 144 plots were sampled systematically within the selected altitudinal bands in three different habitats. The 56 ecologically important agroforestry shade tree species were used for growing *A. subulatum*. Tree species preference of *A. subulatum* changed based on different altitudes and habitat types [$F(2, 33) = 45.672$, $P = .001$]. Critical factors affecting the growth are tree canopy cover ($r = –0.461$) and infested *A. subulatum* stems ($r = –0.765$). The increasing number of infested stems retarded the growth and dense canopy cover or open canopy reduces the growth rate of *A. subulatum*. Overall, growth was suitable in timber tree habitat at mid altitudes, where *Alnus nepalensis* was the dominating species having 41.40% canopy cover with low pest and disease-infested *A. subulatum* stems. Significantly, the lower altitudinal band and the fodder tree habitats were found to be unsuitable for growth ($p < 0.05$). Thus, appropriate site selection, canopy cover and altitude could provide optimum growth.

Keywords: agroforestry, altitude, *Amomum subulatum*, composition, growth

1. INTRODUCTION

Globally agroforestry land covers 43% of the agricultural field and more than 900 million people have been working in the agroforestry system [1] [2]. It is a dynamic system of growing crops, raring livestock, and raising trees; producing tangible benefits to rural people and the environment [3]. Agroforestry has been a traditional practice continued in different agroecological conditions and agro-climatic zones of South Asia [4]. More than one-third of land has been covered by pasture and agricultural land whereby 70% of Asian depends on agriculture and natural resources for sustenance [5]. Additionally, more than 55% of land is suitable for agroforestry [6] and 25% of South Asians agriculture land is under tree cover [7].

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The combination of trees, crops and animals maximizes the biological interaction under agroecological systems [8] conserving nature [9] and generating socio-economic benefits for the users [10]. Still, the agricultural lands are expanded leading to biodiversity loss and deforestation [11]. Around 17% of global greenhouse gas emissions through deforestation can be reduced by investing in agroforestry [12] demonstrating its potential application to mitigate global climate change [13], microclimate enhancement [14], increase socio-ecological sustainability [15], and food security during shifting weather patterns [16].

The enormous benefits of indigenous agroforestry tradition of collecting firewood, fodder and non-wood forest products are still followed by people of Asian region but the pattern of agroforestry farming has been changed based on the agro-ecological zones according to their residence and cash crops production [17]. In Bhutan, the shade-loving crop, Black cardamom *(Amomum subulatum)* was cultivated in the 1970s [18] with varieties of agroforestry tree species as it reduces soil erosion, improves nitrogen fixation [19] and most importantly it provides income for the people. The commonly grown shade trees are *Alnus nepalensis*, *Schima wallichii* and *Ficus* sp. [20].

The composition of tree species makes

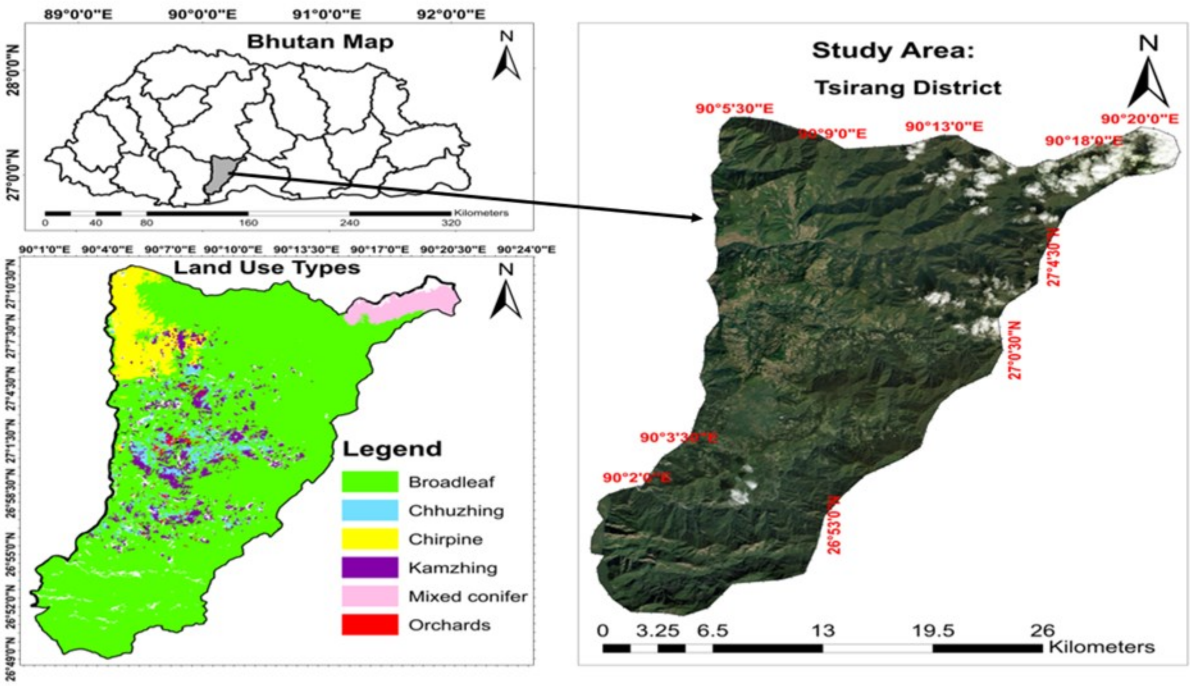

Figure 1. Map representing the study site.

agroforestry a desirable habitat for the productivity of associate species [21] such as *A. subulatum*. However, the change in the agroforestry farming system can alter the composition and structure of tree species before it is assessed [15]. Thus, the productivity of *A. subulatum* under different composition of these tree species in various agroforestry habitats and altitudes need to be studied. As it is unclear whether different agroforestry habitat types vary in species composition, diversity and density, and their effect on *A. subulatum* growth. Thus, the present study was conducted to assess the species composition of agroforestry tree species and to determine the factors influencing the growth of *A. subulatum*.

2. MATERIALS AND METHODS

2.1. Study area

The study was conducted in Tsirang District (Figure 1) which falls within the latitude of 27º 01' 18.84'' N and longitude of 90º 07' 22.48'' E and lies at an altitude between 300 to 4,200 m. The district has an area of 637.83 km^2 with 87.5% of the land covered with forest. The forest is dominated by broadleaf (77.64%) with very few areas under chirpiness and mixed conifer. Out of 5,704.64 ha (9.03%) of agricultural land, 1,659.34 ha represents wetland (chhuzhing) and 3,143.09 ha dry land (kamzhing). The 707.95 ha of land is used as agroforestry for cultivating *A. subulatum* [22]. There are around 23,493 individuals residing in the District [22], of which about 8,427 individuals are engaged in agriculture farming [23].

The annual rainfall ranges from 1,000 to 3,000 mm and the average temperature varies between 7 to 26 °C and it is rarely below 5 °C or above 28 °C making a suitable habitat for *A. subulatum* growth [24]. The district has gentle slope terrain. Summer is hot, humid and cloudy while during winter weather becomes moderately cold and dry. The

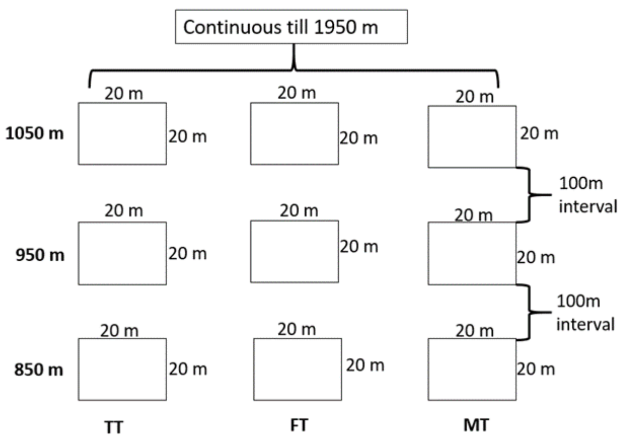

Figure 2. Sampling plot design illustrating the plot size replicated after a certain interval.

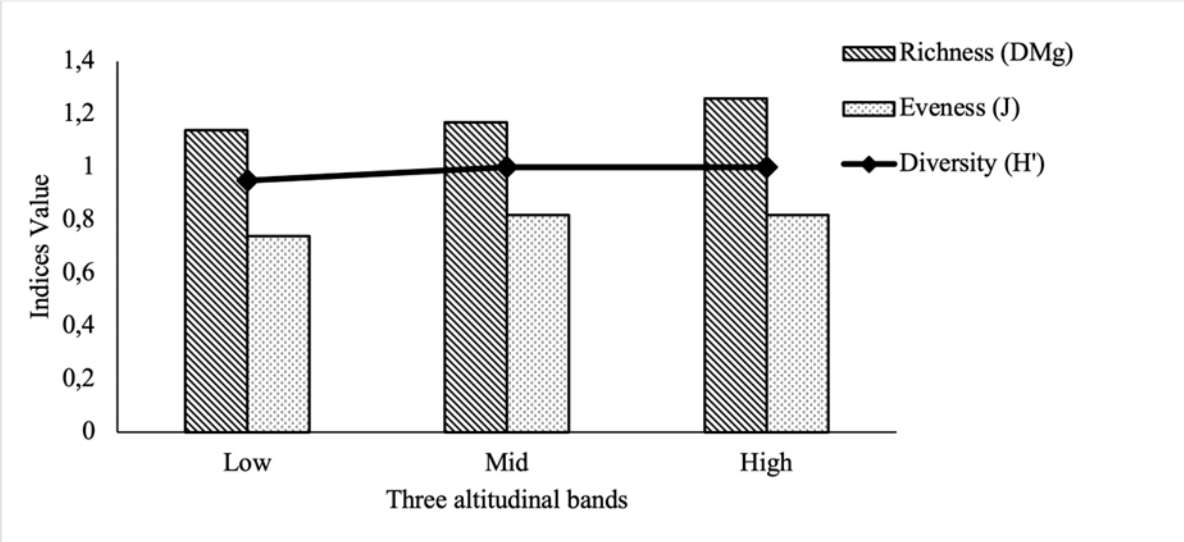

Figure 3. Indices comparison showing the strength of similarities between three altitudinal bands.

forest and agricultural land have sandy loam black soil and clay loamy soil with some red soil [23].

2.2. Sampling design and techniques

The data were collected along an altitudinal gradient from 850 to 1950 m (Figure 2) in three different agroforestry habitat types [25]. A cross-sectional study design was used followed by a systematic sampling method where the distance between each altitude was kept at 100 m [26]. The altitudes were divided into three bands: low (850–1150 m), mid (1250–1550 m), and high (1650–1950 m). In each altitudinal band, three different agroforestry habitats were assessed: timber tree habitat (TT), fodder tree habitat (FT), and mix tree habitat (MT). The TT habitat means *A. subulatum* grew specifically with 90% tree species that are used as timber for building materials such as *S. wallichii*, *Terminalia myriocarpa,* and *A. nepalensis*. The FT habitat means *A. subulatum* grew with the presence of 90% fodder species such as *Ficus roxburghii*, *Ficus auriculata,* and *Ficus nervosa* that are used for livestock. The MT habitat means *A. subulatum* grew with fruit trees (Guava,

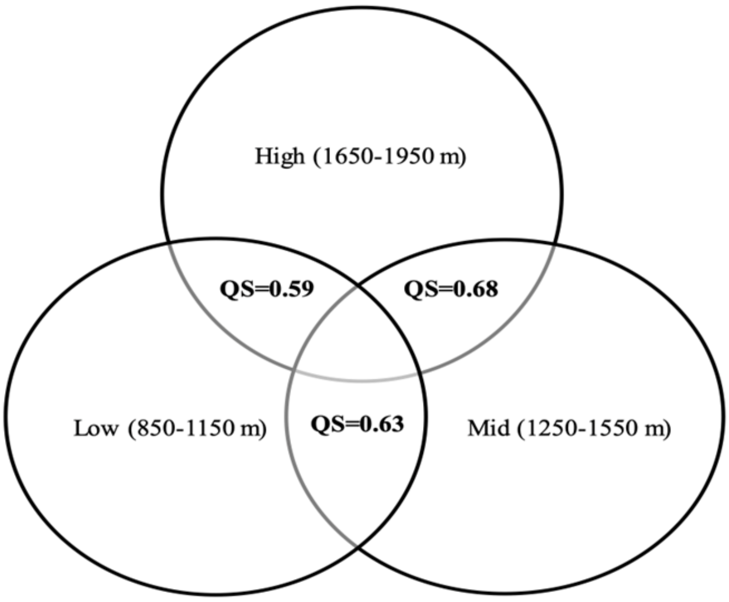

Figure 4. Sorensen's similarity (QS) shows the resemblance of tree species in three different altitudinal bands.

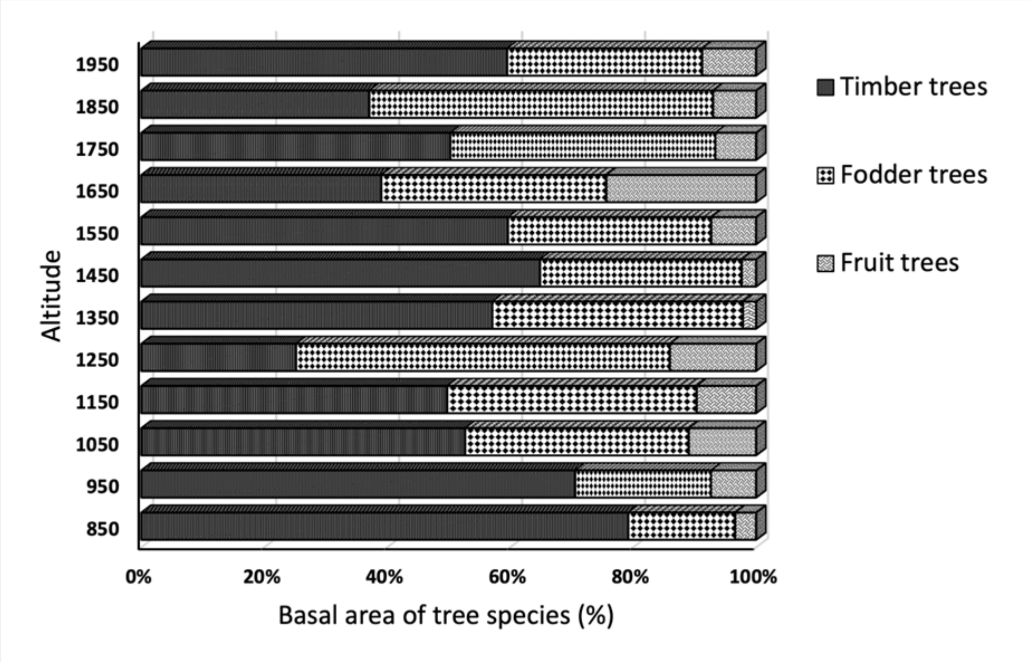

Figure 5. Tree species composition based on three different life forms along the altitudinal gradient

Orange, Avocado) and other forest species (*Gmelina arborea*, *Alnus* sp.) [27]. The habitat was sorted into three types as the *A. subulatum* was grown widely in these three habitats and to know the effect of different habitats and agroforestry tree species on the growth of *A. subulatum*.

In each altitudinal band, 16 plots were made for each habitat (TT = MT = FT = 16) with a total of 144 plots sampled within three altitudinal bands (Low = Mid = High = 48). Further, the sampling size of each plot was made 20×20 m whereby the number of trees present, percent canopy cover, diameter at breast height (DBH), and height above 2 m were recorded [28]. In the same plot, the number of *A. subulatum* clumps, number of pest and disease infested stem, height and diameter of 10 selected stems was recorded [29]. The instruments used in the field are GPS, peg, digital vernier caliper, spherical densitometer, Hypsometer, camera, stationary and measuring tape.

2.3. Data analysis

Shannon diversity (*H*), Margalef richness (D_{mg}), Pielou evenness (*J*), and Sorensen similarity index (QS) were calculated to observe the similarity and difference in tree species present in the different

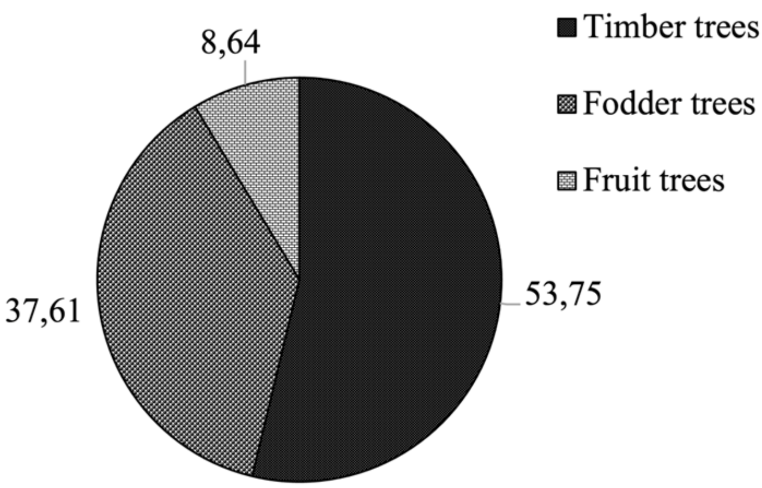

Figure 6. Overall life form (%) indicating the dominant group present with *A. subulatum*

Table 1. Top three ecologically important agroforestry tree species for *A. subulatum* in different altitudes and habitats

Altitude	TT	IVI	MT	IVI	FT	IVI
Low	*Schima wallichii*	99.88	*Citrus reticulata*	61.92	*Ficus semicordata*	71.01
	Alnus nepalensis	89.80	*Schima wallichii*	56.61	*Ficus auriculata*	56.82
	Albizia lebbeck	41.02	*Ficus semicordata*	28.57	*Bauhinia purpurea*	31.12
Mid	*Alnus nepalensis*	98.94	*Citrus reticulata*	67.30	*Ficus concinna*	61.69
	Schima wallichii	87.59	*Schima wallichii*	29.11	*Ficus auriculata*	44.14
	Albizia lebbeck	36.75	*Alnus nepalensis*	28.97	*Ficus semicordata*	36.07
High	*Alnus nepalensis*	141.33	*Ficus auriculata*	46.38	*Ficus auriculata*	118.09
	Schima wallichii	41.59	*Alnus nepalensis*	46.21	*Ficus semicordata*	43.17
	Engelhardia spicata	15.88	*Ficus semicordata*	36.98	*Ficus neriifolia*	37.22

Note: *TT: Timber Tree, MT: Mix Tree, FT: Fodder Tree, IVI: Important Value Index*

altitudinal ranges. Important Value Index (IVI), basal area and relative dominance, relative frequency, and relative density of agroforestry tree species were calculated to know the species composition and tree species preferred by *A. subulatum* in different habitats and altitudes. Even the clump density and stem density of *A. subulatum* were calculated for knowing the growth patterns in various altitudes and habitats [28][30]. The statistical test was performed in R-studio and OriginLab. Based on the normality of data, the Kruskal-Wallis test (H) was performed to compare the diversity indices in three different altitudinal ranges. One-way ANOVA was used to compare the difference in mean dominance of agroforestry tree species along the altitudinal gradient. The two-way MANOVA (*F*) was used to observe the effect of habitat and altitude on dependent variables (*A. subulatum* height, diameter, clump and Stem density, density of infested stem, tree height, basal area, and canopy cover). Principal Component Analysis (PCA) and Pearson correlation were used to know the important factors affecting the growth of *A. subulatum*.

3. RESULTS AND DISCUSSIONS

3.1. Agroforestry species structure

In total 56 agroforestry tree species from 32 families were recorded from three different *A. subulatum* growing habitats (TT, FT, and MT) within the altitudinal range of 850–1950 m (Supplementary 1). The Moraceae family had the highest species count (n = 7) followed by Rosaceae and Fabaceae with five species. The diversity of agroforestry tree species tends to be almost similar in all three altitudinal bands (Figure 3) with no significant difference H (2,143) = 0.250, p = 0.883. Similarly, there was no significant difference in the richness of agroforestry tree species grown with *A. subulatum* H (2,143) = 0.660, p = 0.719 as the species count in the three altitudinal bands was almost the same.

Moreover, the tree species were evenly distributed within the altitudinal bands but not significantly different from each altitudinal band H (2,143) = 2.395, p = 0.302. Further, the QS index (Figure 4) showed *A. subulatum* preference for shade tree species such as *A. nepalensis*, *S. wallichii*, *Albizia* sp., and *Ficus* sp. were found to be common in almost all the sampling plots and it could be the reason for having a similar pattern of diversity, richness, and evenness. Further, shade trees are more vital for *A. subulatum* growth than

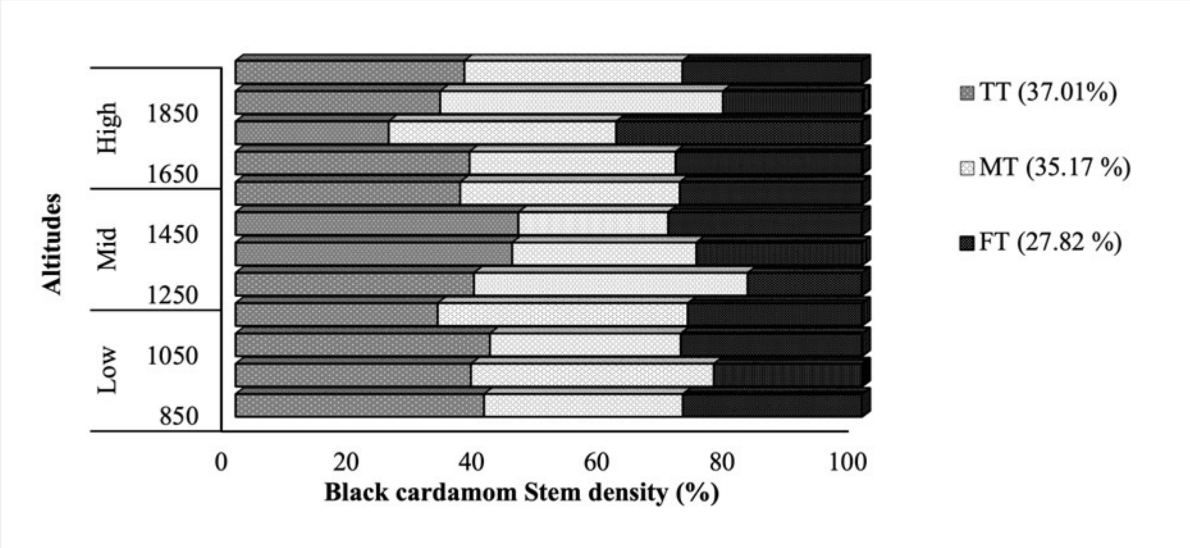

Figure 7. *A. subulatum* growth pattern based on stem density (%) in different altitudes and habitats

other tree species [31][32]. Moreover, the constant maintenance of undestroyed vegetation and weeding in cardamom orchards reduces the regeneration of other tree species than shade trees, making the habitat have similar diversity and richness [33]-[35].

3.2. Stand structure based on basal area composition in A. subulatum-agroforestry habitats

The agroforestry tree species present in different habitats were sorted into three life forms (Figure 5). The basal area of three different life forms was found to be significantly different along the altitudinal gradient [F (2, 33) = 45.672, p = 0.001] (Supplementary 2). The basal area composition of tree species is usually influenced by the altitude and habitat types [30][36][37]. Timber trees were found to be the most dominating species compared to fodder and edible fruit tree species in all the altitudes except in 1250 and 1850 m where the basal area of fodder trees was more as there were fewer matured timber tree species. Timber trees tend to be the preferred species for *A. subulatum* cultivation in all altitudes (53.75% ± 14.99) followed by fodder tree species (37.60% ± 12.26).

The edible fruit trees were found to be the least preferred species for the growth of *A. subulatum* with a total basal area of 8.64% ± 6.04 (Figure 6) showing the unsuitability characteristics of fruit tree species for *A. subulatum* growth. The larger basal area of timber tree species provides better canopy cover [38][39] than the other species of fodder and fruit trees making the crop prefer timber species. Moreover, the tree preference of *A. subulatum* depends on the dominance of trees in different habitats and the availability of tree species in various altitudes [40][41].

3.3. Tree preference of A. subulatum in different altitudes and habitats based on IVI of tree species

The IVI index of each species in different habitats and altitudes showed that the tree species have different IVI (Supplementary 3) and in different habitats the agroforestry tree preference of *A. subulatum* was different. In low-altitude timber tree habitat, *S. wallichii* with an IVI of 99.88 was found to be an important agroforestry tree species grown along with *A. subulatum*. In mix tree habitat, *Citrus reticulate* with an IVI of 61.92 was used as a shade tree for *A. subulatum*. In the fodder tree habitat, *Ficus semicordata* having an IVI of 71.01 was grown along with *A. subulatum*.

In the mid-altitude TT habitat, *A. nepalensis* with an IVI of 98.94 showed a close association with *A. subulatum*. In MT and FT habitats, *A. subulatum* was found to depend on *C. reticulate* (67.30) and *F. concinna* (61.69). In high-altitude TT habitat, *A. nepalensis* had the highest IVI 141.33 showing the importance of the species for *A. subulatum* productivity more than other species. In MT and FT habitats, *F. auriculata* with

Table 2. Black Cardamom growth based on clump and stem density, and height and diameter in different altitudes and habitat types

	Alti-tude	TT	MT	FT	Total	*F*	*P*
clump density/ plot	Low	10 ± 3	9 ± 2	9 ± 2	28 ± 7	3.73	0.001
	Mid	15 ± 4	14 ± 4	13 ± 4	42 ± 12		
	High	11 ± 5	11 ± 3	12 ± 6	34 ± 14		
	Total	36 ± 12	34 ± 9	34 ± 12			
Stem density/ plot	Low	185 ± 82	175 ± 107	136 ± 40	496 ± 229	2.85	0.006
	Mid	272 ± 89	223 ± 126	180 ± 91	675 ± 306		
	High	194 ± 74	175 ± 86	221 ± 95	590 ± 255		
	Total	651 ± 245	573 ± 319	537 ± 226			
Height (cm)	Low	96.66 ± 16.65	92.66 ± 14.65	87.32 ± 9.47	276.63 ± 40.77	4.47	0.001
	Mid	113.82 ± 16.05	97.33 ± 12.76	94.76 ± 12.86	305.91 ± 41.68		
	High	93.41 ± 18.91	88.56 ± 10.66	95.89 ± 13.01	277.86 ± 42.58		
	Total	303.89 ± 51.62	278.55 ± 38.07	277.97 ± 35.34			
Diame-ter (mm)	Low	12.76 ± 1.10	12.23 ± 1.28	11.75 ± 1.33	36.74 ± 3.70	3.19	0.002
	Mid	13.19 ± 1.27	12.42 ± 1.65	12.00 ± 1.96	37.62 ± 4.88		
	High	11.87 ± 1.64	11.67 ± 1.48	13.54 ± 1.30	37.08 ± 4.42		
	Total	37.83 ± 4.01	36.32 ± 4.41	37.29 ± 4.22			

IVI of 46.38 and 118.09 was a greatly preferred tree species by *A. subulatum* over other species (Table 1).

3.4. Growth of A. subulatum in agroforestry habitats

In 5.76 ha of the area surveyed, 26,756 clumps and 443,125 *A. subulatum* stem were observed. The growth of *A. subulatum* was found to be significantly different in agroforestry habitats and three altitudinal bands (Figure 7). The variation in altitude alters the composition and dominance of agroforestry tree species in different habitats leading to a change in the growth pattern of associate crop species [40]. The clump density (42 ± 12), stem density (675 ± 306), height (305.91 cm ± 41.68), and diameter (37.62 mm ± 4.88) were found to be more in mid-altitudinal band followed by high altitude (Table 2). Similarly, it was stated that the best growth of Black cardamom can be found at 1000–2000 m [42]. Moreover, within mid-altitude, the TT habitat was the most preferred environment for *A. subulatum* followed by the MT habitat.

In the TT habitat, the average clump found per plot was 15 with a stem count of 272 per plot. Even the average height of the stem stands up to 113.82 cm and has a diameter of 13.19 mm compared to other habitats within the altitude, making it the preferred habitat for *A. subulatum* growth. The dominance of *A. nepalensis* in that habitat could be an important factor in its growth (Table 2). *A. nepalensis* is one of the most preferred shade trees as it creates the specialized bioclimatic condition for *A. subulatum*. It has a mechanism of fixing nitrogen that can be uptake by the associate species [42][43]. The height and basal area of *A. nepalesis* showed a strong association with *A. subulatum* growth (Table 1) and a similar result was reported from Tadong, Sikkim [29].

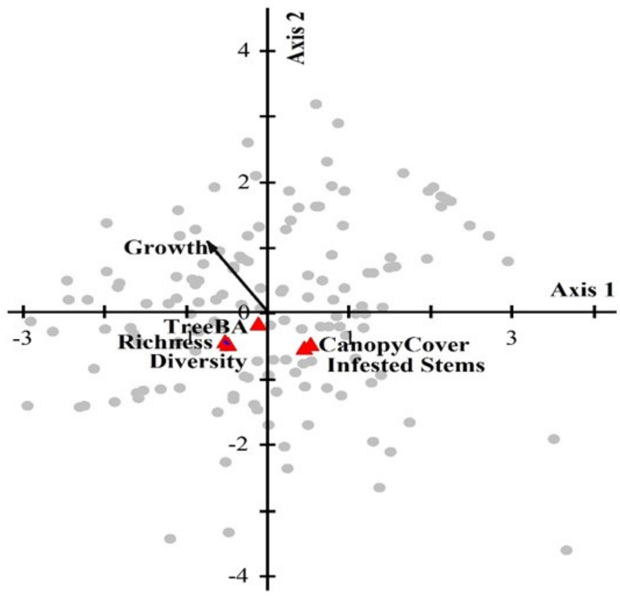

Figure 8. PCA shows the possible factors affecting the growth of *A. subulatum*. Note: the red triangle represents the variables, light gray dots are the sampling plots, and the arrow represents the strength of association between growth and variables.

In higher altitudes, fodder tree habitat tends to be the preferred environment for *A. subulatum*. There was the presence of more clumps (12 nos.) and stems per plot (221 nos.), and the height (95.89 cm) and diameter (13.54 mm) were also higher making it a suitable habitat for *A. subulatum* growth than other habitats. The lower altitudinal band was found to be unsuitable for the *A. subulatum* growth than other altitudinal bands. The low growth performance of *A. subulatum* in the lower altitudinal band could be due to hot microclimatic conditions. *A. subulatum* prefers a moist and cool environment for its optimum growth [44][45]. Lower altitudes being hot, it is not suitable for the crop [42]. However, there were some possibilities of growing *A. subulatum* in lower altitudes mainly in TT habitats where the growth was found to be higher than the other habitats in lower altitudes.

The MT habitat was found to have a low growth rate of *A. subulatum* in all the altitudinal bands. It could be due to competition among the varieties of tree species and *A. subulatum* for nutrients and energy. Different tree species have different requirements for nutrients for their growth, leading to nutrient competition with associated crops [46]. Moreover, the energy fixation, net energy allocation to *A. subulatum*, and heat release from the habitat were found to be low in MT habitats [29][47].

3.5. Factor influencing the growth of A. subulatum

The PCA based on a correlation matrix showed that the growth of *A. subulatum* had a relationship with associate factors (Figure 8). Axis 1 (1.910) and axis 2 (1.446) were used for the PCA as they had Eigenvalue greater than 1. The tree basal area (r = –0.039), species richness (r = –0.008) and diversity (r = –0.021) did not affect the growth of *A. subulatum* as the variables had an inversely weak influence on the growth of the crop. Further, it depicts the crop adapting to be grown with varieties of tree species. The most influencing growth variables were tree canopy cover (r = –0.461) and infested *A. subulatum* stems (r = –0.765) which showed a significant (p = 0.001) inverse relationship with *A. subulatum* growth in different habitats and altitudes.

The increase in the number of infested stems retards the growth of *A. subulatum*. Similarly, dense canopy cover or open canopy reduces the growth rate of *A. subulatum*. Thus, the overall growth was found to be better in mid-altitude in timber tree habitat, where the average tree species height was 11.89 m, basal area of 12.93 having 41.40% tree canopy cover with 16 stems infested per plot (Supplementary 4). Despite regulating temperature by increasing canopy cover at a lower altitude for *A. subulatum*, there was more pest and disease infestation on *A. subulatum*. It showed that the increase in canopy cover increases the number of pests and diseases in lower altitudes altering the growth. The dense canopy cover increases the shade favoring pests and diseases to survive hot weather feeding on shade crops [48] and a minimum of 50% filtered sunlight showed the best growth of *A. subulatum* [46].

Despite the MT habitat having better growth it was found that the habitat had more canopy cover and infested stems that can retard the growth in the long term. The MT habitat attracts varieties of pests and diseases that can infest due to the dense canopy [49]. The moderate growth in the fodder tree habitat than in other habitats at higher altitudes was due to low canopy cover (23.94%). It showed that at higher altitudes, the *A. subulatum* requires less shade and more sunlight for photosynthesis and growth. At higher altitudes, frostbite can severely retard the growth with denser canopy cover and need more sunlight [50]. The dense canopy cover reduces the intensity of sunlight declining the rate of photosynthesis, nutrient assimilation and chlorophyll content in the leaf causing stunted growth [49][50]. Choosing the appropriate amount of shade, tree species, and habitat was found to be important for *A. subulatum* growth [44][46].

4. CONCLUSIONS

The combination of tree species with Black Cardamom (*A. subulatum*) had led to the conservation of nature along with the utilization of natural resources for socio-economic benefits. The composition of agroforestry tree species in different altitudes and habitats provide significant information that needs to be considered while cultivating *A. subulatum*. The timber tree habitat at mid-altitude was the desirable site for the growth of *A. subulatum*. The crop prefers moderate shade and, the low and high altitude was unsuitable for the crop. Thus, the current findings can be implemented by policymakers and extension field staff for improving the socio-economy of rural people engaged in *A. subulatum* cultivation for sustenance. Furthermore, habitat and altitude-based genetically modified *A. subulatum* need to be explored to improve the livelihood of rural people growing *A. subulatum* in the current scenario of climate change.

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Conflicts of Interest

The author(s) declared no conflict of interest

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