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Morphology and habitat of wild tea *Gaultheria cumingiana* in Mountain Province, Philippines

JULIE P. GARSI[1], LICHELYN M. NASUNGAN[1,♥], ALEXANDER T. BALDIC[2], ROLANDO TAWANNA JR.[3], JOYCE D. CUYANGOAN[4], EPIPHANIA MAGWILANG[1], EDGAR G. CUE[5], BRENT JOSEPH D. BANGAO[1]
[1]Department of Science Education, School of Teacher Education, Mountain Province State University. Tabuk Road, Bontoc, Mountain Province, Philippines. Tel.: +63-74-602-1014, ♥email: lichelynnasungan@gmail.com
[2]Department of Agroforestry, School of Agriculture and Forestry, Mountain Province State University. Tabuk Road, Bontoc, Mountain Province, Philippines
[3]Department of Technical Vocational Education, School of Teacher Education, Mountain Province State University. Tabuk Road, Bontoc, Mountain Province, Philippines
[4]Department of Agribusiness, School of Agriculture and Forestry, Mountain Province State University. Tabuk Road, Bontoc, Mountain Province, Philippines
[5]University President, Mountain Province State University. Tabuk Road, Bontoc, Mountain Province, Philippines

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Abstract. *Garsi JP, Nasungan LM, Baldic AT, Tawanna Jr. R, Cuyangoan JD, Magwilang E, Cue EG, Bangao BJD. 2026. Morphology and habitat of wild tea* Gaultheria cumingiana *in Mountain Province, Philippines. Asian J For 10 (1): r100133. https://doi.org/10.13057/asianjfor/r100133. Gaultheria cumingiana* is an important indigenous wild tea species valued in Mountain Province, Philippines, for its aroma, flavor, and medicinal properties. This study aimed to characterize the morphology and habitat features of *G. cumingiana* and assess the relationship between key soil properties and the plant's essential morphological characteristics. A descriptive quantitative research design was employed across five distinct locations in Bontoc and Barlig, Mountain Province. At each site, ten individual plants were sampled (N = 50 total). Data collection included morphometric and reproductive morphology, as well as soil variables. One-way ANOVA, DMRT, and Pearson r test were utilized to analyze data. The results showed that *G. cumingiana* was a small, aromatic shrub, exhibiting significant site-based variation in growth with an overall mean of 1.07 m, meanwhile the mean Apical Dominance Index (ADI) ranged from 7 to 14, $p<0.05$, and the leaf area had an overall mean of 10.89 cm^2. Reproductive morphology showed highly significant differences for the number of flowers per peduncle and fruit weight, while not significant for corolla diameter. Soil analysis revealed not significantly different and moderately acidic with the overall mean 5.65, while the % moisture content is highly significant (mean 37.9%). Analysis established a significant negative correlation between soil N concentration and measured leaf area (mean 10.89), indicating that it develops smaller leaves in challenging environments. The species is a strong candidate for focused conservation, sustainable wild tea production, and domestication due to its inherent resilience.

Keywords: *Gaultheria cumingiana*, habitat, Mountain Province, soil properties, wild tea

INTRODUCTION

The rapidly expanding global market for functional and medicinal beverages is fueling intense interest in botanical research and the sustainable domestication of wild tea species (Wambulwa et al. 2021). Wild teas possess significant cultural and economic value throughout Asia, serving as crucial elements in traditional medicine systems and regular household consumption (Hwang et al. 2020). Ramphinwa et al. (2023) reported that the health benefits of these teas are often linked to their high concentration of bioactive phytochemicals, such as polyphenols, which confer desirable antioxidant and antimicrobial properties. The Philippine Cordillera, recognized as a regional center of biodiversity, is home to numerous endemic wild tea species as Nasungan et al. (2025) documented 18 wild tea species. These plants are frequently utilized by local communities for their perceived medicinal properties, particularly in treating common ailments like cough and cold (Barcelo et al. 2022). Furthermore, research highlights the potential of these local wild teas to serve as a commercially viable source of functional compounds, given that some extracts show high radical scavenging activity and antibacterial efficacy, urging their promotion and domestication for wider consumption and germplasm conservation (Mashimbye et al. 2006).

Among these valuable indigenous species is *Gaultheria cumingiana* (Ericaceae), which has gained popularity in the Cordillera Administrative Region, Philippines, due to its desirable minty aroma and traditional use as a flavorful beverage. Recent pharmacological investigations support its traditional value, reporting that extracts of the speciesexhibit significant antioxidant, antibacterial, and antiquorum-sensing properties (Nasungan 2022; Nasungan et al. 2025). Anatomically, *G. cumingiana* exhibits typical dicot shade-leaf characteristics, featuring prominent air spaces and an exceptionally high abaxial stomatal density. Its vascular organization consists of a eustele stem and a protostele root structure. The species' distribution is shaped by specific edaphic factors and its association with distinct floral communities. Elevation and solar exposure are the primary determinants of its range; while lower-elevation populations are restricted to shaded environments, those at higher altitudes demonstrate broader tolerance, successfully inhabiting areas with full sunlight (Alfag and Napaldet 2022).

Despite its known value and potential, the scientific understanding of *G. cumingiana* is fragmented. Morphological characteristics are essential for accurate taxonomic identification, comparative analysis, and understanding how plant species adapt to diverse environments (Gangmei et al. 2024). Prior research has identified morphological plasticity and taxonomy discrepancies in *G. cumingiana*, especially important characteristics like fruit color and leaf size, which vary greatly according on the region (Abdusalam and Li 2018). Importantly, the specific populations of *G. cumingiana*, which are widely distributed and harvested in the Bontoc and Barlig, Mountain Province, Philippines, remain ecologically and morphometrically uncharacterized, and no quantitative study has looked at the relationship between soil properties and morphological variation among local populations, despite the characterization of some populations in nearby regions. This lack of localized data hinders efforts to establish appropriate protocols for conservation and cultivation.

Determining plant functional characteristics of *G. cumingiana*provide a better understanding of the constraints and opportunities of plants found in different habitats than taxonomic identification alone. Accordingly, these provide knowledge of how functional diversity in the broad sense underpins ecosystem processes and the benefits that people derive from them (Pérez-Harguindeguy et al. 2013). Further, characterization provides information, if not a complete description, of wild tea plants, which are valued by the local folks of Mountain Province. Conservation measures may be effective with adequate knowledge about these species, thereby continuously providing ecosystem services to the people. Therefore, this study aimed to characterize the morphology and natural environment of *G. cumingiana* and analyze how specific soil properties influence its growth characteristics. The findings will be instrumental in formulating methodologies for the species' conservation and its eventual integration into agricultural production systems.

MATERIALS AND METHODS

Study area

The sampling areas were determined based on baseline information gathered from key informants (KIIs) in the municipalities of Barlig and Bontoc, Mountain Province, Philippines. The five study sites selected for data collection were Barangays Dalican and Bayyo in the municipality of Bontoc, and Barangays Macalana, Lingoy, and Lias in the municipality of Barlig (Figure 1 and Table 1). These sites were chosen specifically due to the known and reported abundance of wild *G. cumingiana* populations. The study sites are situated within an area defined by significant topographic relief, characteristic of the Cordillera Central Mountain range. The municipality of Barlig is home to Mount Amuyao (also known as Finaroy), one of the highest peaks in the province, with a documented summit elevation of approximately 2,702 m above sea level (Peakbagger.com 2026), with Barangay Macalana located on its slopes. Meanwhile, the municipal center of Bontoc lies at a lower elevation (approximately ~863 m), but the surrounding upland areas, including the chosen study sites, climb steeply to elevations exceeding 1,700 m (National Mapping and Resource Information Authority (NAMRIA 2026), https://isportal.namria.gov.ph/eMapa). This pronounced vertical gradient, spanning from approximately 780 m up to 1,703 m in Bontoc alone, establishes the high-altitude and steep-sloped environment that characterizes the natural habitat of *G. cumingiana* in the Mountain Province.

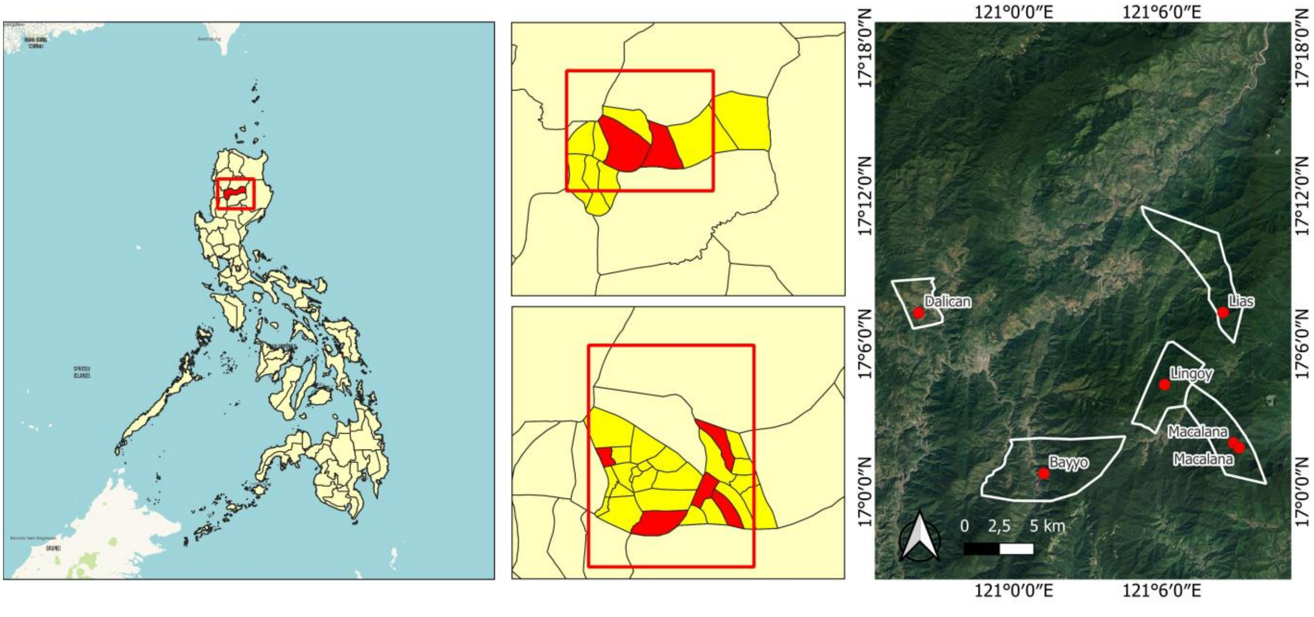

Figure 1. Study sample sites of *Gaultheria cumingiana* in Barlig and Bontoc municipalities, Mountain Province, Philippines

Permission for the study was first secured from the municipal mayor of each site and the barangay captains of the specific study areas. Additionally, to comply with Republic Act (RA) 9147, the law concerning the conservation and protection of wildlife resources and habitats, a Gratuitous Permit (DENR-CAR-01-2024) was obtained from the Department of Environment and Natural Resources, Cordillera Administrative Region (DENR-CAR).

Procedures

Sampling

The determination of morphological characteristics relied on mature plants that had fully developed flowers or were currently bearing fruits. Sampling frequency for plant parts and individual organisms followed the established replicate guidelines proposed by Pérez-Harguindeguy et al. (2013). A total of 10 individual plants were purposively sampled in each of the sampling location, totaling to 50 plant samples for this study. Ten samples of leaves, flowers, and fruits were randomly selected from each plant for morphological assessment.

Soil analysis was conducted across five representative sites to characterize the natural habitat of *G. cumingiana*. A total of 10 soil samples was taken from each area, and an aggregate of this collection was used to analyze the soil properties. Soil analysis involved both an integrated digital device and separate digital testers for nutrient assessment. Specifically, the integrated digital device was used to measure soil pH and moisture content (%). Subsequently, separate digital testing devices were employed for assessing the concentration (mg/ppm) of key nutrients: nitrogen (N), phosphorus (P), and potassium (K).

Soil analysis

The habitat of *G. cumingiana* was characterized by measuring environmental factors at the specifically soil pH, soil moisture (%), and soil nutrient (Nitrogen, Phosphorus, and Potassium) content (mg/ppm) using a digital soil tester device that determines the pH, moisture, and nutrient content. The digital NPK concentration sensor was used by inserting the probes directly into the sampled soil at the specified depth (Ackerson 2018) and allowing the device to take separate digital readings for N, P, and K contents. These measured soil properties were subsequently correlated with the plant's morphometric characters (mean of plant height, ADI, and LA) to determine the favorable soil conditions necessary for the optimal growth of *G. cumingiana*. The degree of acidity was based on the Natural Resource Conservation Service (1993) and is presented in Table 2.

Morphological observation

Plant height (m) was determined by measuring the height from its base to the top foliage. Height measurement was taken from mature plants per species. Stem habit pertains to the position of the stem or shoot of the plant (Thiers 2020). Branching architecture was described by the determination of the Apical Dominance Index (ADI), which was adapted from Pérez-Harguindeguy et al. (2013). The ADI is an indication of branching architecture and is computed as follows:

$$ADI = \frac{\text{Number of ramifications}}{\text{Total length of the branch (m)}}$$

Leaf characteristics were first determined qualitatively by recording the typical morphological traits, such as venation type, leaf shape, margin, and arrangement on the stem. Subsequently, the quantitative parameter of mean Leaf Area (LA), expressed in cm^2 was determined by employing the grid method using standard graphing paper. For this procedure, 30 fully expanded, healthy leaves (three leaves per replicate, ten replicates across five sites) were selected and carefully traced onto a piece of graphing paper pre-marked with a 1 × 1 mm grid. The total leaf area was then calculated by counting the number of grid squares covered by the leaf tracing. Full squares completely enclosed within the leaf outline were counted as 1 mm^2. The final leaf area in mm^2 was obtained by summing the total count of full squares and the calculated count of partial squares (Miller and Levine 2002). This value was then converted to cm^2 (LA in cm^2 = Area in mm^2/ 100) for reporting.

Table 2. Interpretation of the degree of acidity

Scale	Description
4.5-5.0	Very strongly acidic (VSA)
5.1-5.5	Strongly acidic (StA)
5.6-6.0	Moderately acidic (MA)
6.1-6.5	Slightly acidic (SA)
6.6-7.3	Neutral (N)

Table 1. Description of the study sites

Site Parameter	Description				
	Bontoc		Barlig		
	Bayyo	Dalican	Lias	Lingoy	Macalana
Elevation (m asl.)	1830-1844	1434-1437.49	1435	1470-1940	1635-2019
Annual precipitation (%)	4	3	43	74	70
Average temperature (°C)	22	31	22.7	21	21
Average humidity (%)	59	50	88	89	86
Topography/landform	gentle to steep	gentle slope	very steep	steep	steep to very steep
Vegetation type	forest	grassland	forest	forest	forest
Land usemanagement	forestry	forestry	forestry	forestry	forestry
Protected status	indigenous land	indigenous land	indigenous land	indigenous land	indigenous land

Reproductive characteristics were based on the International Plant Genetic Resources Institute (IPGRI) (1997) and Simpson (2010). Flower characteristics include diameter, calyx margin and type, receptacle shape, corolla color and shape, number of petals, number of stamens, and ovary type. Fruits will be described as simple (fleshy or dry fruit), aggregate (follicle, achene, berry, or drupe) or multiple/composite fruit type (sorosis or sycosis) (Simpson 2010). Fruit characteristics, such as the fruit color of unripe and ripe fruits, were described qualitatively based on a color chart. Fruit shape was based on the ratio of the length to the width of the fruit. Length (cm) was measured using a Vernier caliper from its base to apex, excluding the stalk, while width (cm) was measured along the equatorial line of the fruit. Fruit weight (g) was determined using a digital weighing scale. Ten fruits per plant sample per species were weighed to determine the mean fruit weight. Seed color of the wild edible fruits was qualitatively described, while shape was described as ovate, ovoid, oblong, obovate or reniform.

Data analysis

The data analyzed in this study comprised two primary categories: plant morphometric characters and soil physicochemical properties. Morphometric data included measurements of plant height, ADI, LA, number of flowers per peduncle, corolla diameter, and fruit weight. Soil data consisted of pH levels, moisture content, and macronutrient (NPK) content sampled across ten distinct areas. To determine if significant variations existed among these parameters across the different sampling locations, a One-way Analysis of Variance (ANOVA) was employed (Zar 2010). Duncan's Multiple Range Test (DMRT) was applied as a post hoc procedure to identify specific mean differences and rank the sampling sites (Duncan 1955). Following the assessment of variance, the Pearson correlation coefficient (*r*) was utilized to evaluate the relationship and strength of association between the measured plant morphometric characteristics and the specific soil variables (Hauke and Kossowski 2011). All statistical computations and data processing were performed using IBM SPSS Statistics version 25.0.

RESULTS AND DISCUSSION

Morphological characteristics

Gaultheria cumingiana is characterized as a small, perennial sub-shrub indigenous to the montane areas of Bontoc and Barlig, Mountain Province (Figure 2). The image illustrates the dense, decumbent habit of the small shrub, characterized by numerous woody and ramified stems. Note the significant leaf color variation: mature leaves are deep green, while new growth and stressed foliage exhibit vivid red and bronze pigmentation. The plant develops numerous lignified stems that exhibit a prostrate to decumbent habit, often forming dense, low-lying mats. The stems are notably devoid of defensive structures, such as spines or thorns, and the branches display a slightly ramified or branching architecture. It is a distinctly leafy shrub, retaining a significant amount of persistent foliage. A critical chemical trait is the emission of a pronounced, minty aroma upon crushing the leaves, a characteristic attributed to the presence of volatile essential oils. It's scapose inflorescence has small pendulous whitish-pinkish unscented flowers. The fruit is small, rounded, berry-like, which are generally considered inedible due to palatability or toxicity factors. Its reproductive potential is high, resulting in an abundance of fruits in some individuals. However, the number of mature fruits can be highly variable, with some plants bearing only a few, a phenomenon that was potentially influenced by resource allocation or localized pollination success.

The taxonomic distinction of *G. cumingiana* in the Barlig and Bontoc regions represents a significant shift from traditional classification, moving beyond superficial resemblances to *G. leucocarpa*. Both taxa share the "wild tea" archetype, characterized by leathery, serrated leaves, and urceolate flowers. The divergence is most pronounced in their quantitative morphometrics and reproductive biology. Alfag and Napaldet (2022) provide a critical foundation for this separation, demonstrating that while qualitative traits like ovate leaves may overlap, the pollen architecture and specific *matK* gene sequences reveal a distinct evolutionary lineage. In Mountain Province, this differentiation is physically manifested through specific adaptations to the local microclimate; for instance, *G. cumingiana* typically exhibits a higher stomatal density and more compact floral clusters than the broader *G. leucocarpa* complex found in less rugged terrains.

Figure 2. Morphology of *G. cumingiana* in its natural habitat (Lingoy, Philippines). Scale bar = 5 cm

This transition from a variety to a full species status is further supported by the unique reproductive output observed in the Cordillera populations. Unlike the white-fruited varieties of *G. leucocarpa* common in other parts of Southeast Asia, the Barlig and Bontoc populations consistently produce dark purple to blackish-blue berries. This pigmentation is likely an adaptive response to high-altitude UV radiation and serves as a visual cue for specific local avian dispersers. By establishing *G. cumingiana* as a distinct species, researchers can more accurately map its ecological niche, which appears to be far more specialized than previously recorded. This higher level of endemism suggests that the Mountain Province populations are not merely a geographical extension of a widespread species, but a unique genetic resource shaped by the specific edaphic and climatic pressures of the Philippine highlands. Consequently, conservation strategies must be tailored to this specific taxon, as its localized adaptation means it may not be easily replaced by related varieties if its native habitat is degraded.

Plant height

Gaultheria cumingiana is a small shrub that grows from 0.53 to 1.72 m tall. The plant height of *G. cumingiana* sampled in the five areas showed a highly significant difference in the mean plant height, which means that this species grows differently in these areas. Plants sampled in Dalican, Bontoc were found to be taller than those sampled in other study areas. However, this is a significantly similar observation in plants sampled in Macalana, Barlig. The smallest plants were observed in Bayyo, Bontoc, and Lias, Barlig.

The morphological structure of *G. cumingiana* as a small sub-shrub reaching a maximum height of 1.72 m serves as a primary indicator of its specialized adaptation to the high-energy, high-stress environments of the Cordillera Central Range. This vertical limitation is not merely a genetic constraint, but a strategic response to the altitudinal gradients and high-velocity winds characteristic of montane ridges. By maintaining a compact stature, the species minimizes transpirational water loss and physical damage from wind shear. The highly significant height variations observed across the five sampling sites (Table 3) point toward phenotypic plasticity, where the plant reallocates its energy based on resource availability. In nutrient-poor and high-altitude zones, the plant likely prioritizes a prostrate or decumbent habit to exploit the relatively stable boundary layer of air near the soil surface, whereas in lower-elevation, shaded forest understories, it may trend toward an erect habit to compete for light.

This plasticity is further validated by comparing local populations with those in Indonesia and other parts of Southeast Asia. The documented range of 0.25 to 2 m in Indonesian populations (Chua and Sunarti 1999) and the "climbing or decumbent" habit suggest that *G. cumingiana* possesses a high flexible growth architecture. This allows it to occupy diverse ecological niches, ranging from open, rocky slopes to dense thickets. Furthermore, the correlation between height and edaphic factors, specifically the observed acidic pH and low moisture suggests that the species has evolved a conservative growth strategy. Instead of rapid vertical extension, which would require high nutrient uptake, the species invests in lignified, reddish stems and woody branching, ensuring long-term persistence in marginal habitats (Pérez-Harguindeguy et al. 2013). This structural resilience confirms that the species' "stunted" growth is an evolutionary advantage, allowing it to survive where more robust, fast-growing flora would succumb to nutrient stress or environmental exposure. Species in the family Ericaceae and various serpentine-endemic shrubs exhibit similar dwarfism and high wood density to survive mineral imbalances and physiological drought (Wright et al. 2017).

Stem and branching habit/architecture

Gaultheria cumingiana was noted to have numerous reddish woody stems, being a frutescent, and was observed to have a horizontal-spreading growth habit, sometimes erect. Stems lack spines or thorns. In some plants, thorns act as protection from browsing herbivores. Nevertheless, in this study, this species seemed to deter grazing animals. As to branching pattern or architecture, the ADI values of *G. cumingiana* sampled in Bayyo, Bontoc was found to be significantly higher compared to those sampled in other locations (Table 3). This result indicates that stems of *G. cumingiana* in this area are ramified compared to those in other locations. A value of zero ADI means the plants have no branching, and >100 m^{-1} means extremely ramified.

The branching architecture of plant species is intrinsically susceptible to alteration by various environmental pressures, including herbivory, light regime, resource stress (e.g., water), and pathogen load, alongside a general adaptational response to the forest ecosystem (Pérez-Harguindeguy et al. 2013). Consistent with this principle, *G. cumingiana* exhibited a tendency toward reduced branching density in sites characterized by high conspecific population density, such as the habitat sampled in Bayyo. This morphological response is physiologically linked to intense intraspecific competition for sunlight, where dense populations impose a strong selective pressure that inhibits the development of secondary stems or leads to the premature senescence of latent buds, a phenomenon known to minimize non-productive investment in shaded environments (Hay and Porter 2006). This observation highlights the plasticity of the plant's growth form in optimizing its light interception strategy within crowded microenvironments.

The morphological characteristics observed in *G. cumingiana,* specifically its infrutescence, horizontal-spreading growth habit and numerous reddish woody stems reflect a highly adaptive architectural strategy. While the species lacks physical defenses such as spines or thorns, which are common anti-herbivory traits in many woody shrubs (Agrawal and Fishbein 2006), it effectively deters grazing. This suggests the presence of alternative defense mechanisms, likely chemical constituents such as secondary metabolites common in the family Ericaceae, which render the foliage unpalatable or toxic to herbivores.

The significant variation in the ADI across sampling sites, particularly the higher ramification observed in

Bayyo, Bontoc, indicates a plastic response to localized environmental stressors. A higher ADI reflects a reduction in apical dominance, leading to a more branched or "ramified" architecture. This transition from an erect to a more spreading, branched habit is often an evolutionary response to high-exposure environments or nutrient-poor soils, where a decumbent growth form protects the plant from wind damage and maximizes light interception in patchy canopies.

Leaf morphology

The leaves of *G. cumingiana* exhibit a distinctive ovate shape characterized by a simple arrangement and pinnate venation. Figure 3 illustrates the simple leaf type and alternate to sub-opposite arrangement of the leaves on the stem. The bottom image shows two representative leaves, which are predominantly ovate to lanceolate with crenate margins, demonstrating the dimensions used for area calculation. The margins are notably serrate, featuring fine, saw-like teeth that contribute to the leaf's sharp texture. A defining characteristic of this species is its alternate phyllotaxy, where individual leaves are attached singly at different nodes along the stem rather than in pairs. The leaf surfaces are glabrous, they are entirely smooth and lack any form of pubescence or hair-like structures. A striking visual transition occurs during development, i.e., newly emergent shoots and young leaves display a vibrant reddish to pinkish hue. As the leaves mature and their photosynthetic capacity increases, this pigmentation fades, and the foliage gradually turns a deep, stable green. This color shift often serves as a protective mechanism against intense solar radiation in young, vulnerable tissues before they fully harden. The leaves of this plant are ranged from 8.30 cm^2 to 18.79 cm^2 in size. Leaves collected from Lingoy, Barlig had the highest leaf area, while smaller leaves were noted in Bayyo and Dalican, Bontoc, and Macalana, Barlig. These differences were found to be significant, which may suggest that the leaf development of this species may be dependent on its location.

A key quantitative indicator in plant ecology, the LA has a direct impact on canopy-level light interception, a crucial factor in photosynthetic efficiency and the subsequent generation of carbohydrates (Landsberg and Sands 2011). As a result, the observed comparatively greater LA in *G. cumingiana* populations is very useful because they appear to have a greater ability to absorb incident light, which improves the physiological processes required for healthy growth and development. Beyond these ecophysiological benefits, maximizing the area of each leaf also has a direct practical benefit: since the leaves of this species are the main ingredient used to make a local tea beverage, larger leaves naturally boost the amount of biomass that is harvested, supporting the plant's ethnobotanical and commercial potential.

Table 3. Mean of plant height, Apical Dominance Index (ADI), and Leaf Area (LA) of *Gaultheria cumingiana* in the research sites

Sites	**General Morphology**		
	Plant height (m) **	**ADI** *	**Leaf area (cm^2)** *
Bayyo	0.56^{a}	14.00^{a}	8.30^{a}
Dalican	1.72^{b}	7.40^{b}	9.28^{a}
Macalana	1.34^{b}	9.91^{ab}	9.66^{a}
Lingoy	1.21^{ab}	10.41^{ab}	18.79^{b}
Lias	0.53^{a}	9.11^{ab}	10.94^{ab}
Overall Mean	1.07	10.17	10.89
F value	9.653**	3.347*	2.914*
Df	(4,37)	(4,37)	(4,37)
P Value	.000	.020	.034

Note: *: Significant, **: Highly significant. Dissimilar superscript means significant difference

Figure 3. Leaf type and arrangement of *G. cumingiana* in Lingoy, Philippines

Flower characteristics and reproductive morphology

Flower morphology is one crucial diagnostic feature in the characterization of angiosperms. *Gaultheria cumingiana* flowers are simple, have male and female organs, and are capable of self-pollination (Figure 4). The *G. cumingiana*'s inflorescence is technically categorized as scapose, since it has several flowers on a peduncle that is mostly devoid of leaves. It was noted that most of these flowers developed into fruits, indicating high pollination. The arrangement is typically axillary, although terminal positioning may also be observed. The entire inflorescence structure is described as glabrous (smooth, lacking hairs). The corolla is gamopetalous (petals fused) and exhibits a distinctive campanulate (bell-shaped) or urceolate (urn-shaped) structure, composed of at least five fused petals. While the fully bloomed corolla is predominantly white, observations confirm a transient pinkish pigmentation in the flower buds prior to anthesis, which fades as the flower reaches full bloom. The characteristic of scapose inflorescence is a multiple small and pendulous flowers. The corolla is campanulate (bell-shaped) and predominantly white at anthesis, with a noticeable pinkish hue on the flower buds. The leaves shown are ovate to elliptical with entire margins.

Statistical analysis results on the reproductive morphology of *G. cumingiana* across the five study locations revealed significant differences in two out of the three parameters assessed (Table 4). The number of flowers per peduncle showed highly significant differences across the sites. Specifically, Dalican recorded the highest mean value, which is statistically distinct from the sites of Bayyo, Macalana, and Lingoy. Conversely, the corolla diameter exhibited a high degree of phenotypic stability, showing no statistically significant difference across all study areas. This indicates that flower size in G. *cumingiana* is a highly conserved trait, largely independent of the habitat variations present among the different sampling areas. Finally, the fruit weight also displayed highly significant differences between locations, with Lingoy having the lowest mean fruit weight. This mean was statistically distinct from the weights recorded at the other four locations, which were not significantly different from each other. The reduced fruit mass in Lingoy, even though the corolla size was the same at all sites, suggests that water stress or nutritional shortages unique to this area had a major effect on the final fruit filling and maturation process.

Gaultheria cumingiana draws attention to a distinct contrast between reproductive flexibility and stability. The study found that edaphic parameters connected to location play a major role in the significant phenotypic flexibility of reproductive output, notably the number of flowers per peduncle and fruit weight. Sites like Dalican, Lias, and Macalana, which had greater soil moisture, nitrogen (N), and potassium (K) levels, also produced noticeably better reproductive metrics, indicating a clear correlation between this variation and soil fertility. The corolla diameter of *G. cumingiana* on the other hand, defies the common rule that flower size varies significantly within and among species (Erwin 2007). *Gaultheria cumingiana* exhibited exceptional floral consistency, with no discernible variation among the sampling locations in the Mountain Province.

Fruit characteristics

The fruits of *G. cumingiana* are classified as fleshy berries and have numerous tiny seeds enclosed by an accrescent calyx. It has a circular shape, sometimes orbicular, green when younf and turn purple to black when ripe (Figure 5). Significantly heavier fruits were observed in Dalican, Bayyo, Macalana, and Lias. Smaller fruits were noted in the collected samples from Lingoy.

Table 4. Reproductive morphology of *Gaultheria cumingiana* according to location and its differences

Parameters	Reproductive morphology		
	No. of flowers/peduncle **	Corolla diameter (cm^2)	Fruit weight (g) **
Bayyo	4.75^{a}	6.51	0.27^{a}
Dalican	7.20^{b}	5.85	0.31^{a}
Macalana	5.12^{a}	6.39	0.30^{a}
Lingoy	4.78^{a}	6.35	0.24^{b}
Lias	6.50^{ab}	6.25	0.25^{a}
Overall Mean	5.46	6.27	0.29
F value	9.278**	2.099^{ns}	5.394**
Df	(4,37)	(4,37)	(4,37)
P Value	.000	.101	.002

Note: ^{ns}: Not significant, **: Highly significant. Dissimilar Superscript means a significant difference

Figure 4. Inflorescence and floral morphology of *G. cumingiana* in Lingoy, Philippines. Scale bar = 1 cm. Scale bar = 5 mm (or 1 cm) applies to all depicted structures

The same color was also noted by Alfag and Napaldet (2022) on the same species growing in the mountains of Benguet. Fruit weight can indicate fruit size. Fruit growth is dependent on the development of seeds inside the fruit, where fruit size is said to be proportional to the number of seeds per fruit (Sardeshpande and Shackleton 2019). That is, fruits that have multiple seeds require adequate pollination, fertilization, and seed development to produce regularly shaped fruits. This may explain the variation in fruit size of *G. cumingiana*. Aside from these, light intensity, temperature, and rainfall may subsequently affect fruit growth. However, the available soil nutrients in the sampling areas may have a great impact on the fruit development and growth of this wild tea.

The observed variations in the morphology among the *G. cumingiana* in the mountains of Bontoc and Barlig, which were discussed above, further demonstrated phenotypic plasticity within the species. De Witt and Scheiner (2004) noted that this plasticity, or the ability of one genotype to produce different phenotypes, is based on environmental differences. Variations, slight as may be, in edaphic and microclimatic factors in the sampling areas would have defined the morphology of *G. cumingiana.* This somehow added phenotypic complexity brought about by genetic and plant development (Bucksch et al. 2017), such as those phenotypic variations with *G. cumingiana* as noted in this study.

Habitat description

Elevation

In Barlig and Bontoc, the elevation at which these plants were found ranges from 1,434 to 2,091 m asl., generally along slopes along with other short shrubs, and in some areas under taller shrubs and trees. These are also found in previously eroded slopes where soil was observed to be stony or loose. In most places, they are found growing in clusters (Figure 6), suggesting that some fallen seeds somehow germinate and survive. This finding means that these species of wild tea thrive at this elevation and that their growth and survival may be affected when grown beyond this range. This is because elevation influences environmental pressures such as solar energy and temperature, among others. These factors influence the morphology and reproduction of this plant. For instance, plants situated at higher elevations may be exposed to longer solar radiation that may define plant height, leaf size, branching, and fruit development. The image shows the plant forming a dense, low-lying cluster on a sloping, mossy substrate. Note the phenotypic plasticity in foliage color, with mature leaves in deep green and new or stressed growth displaying vivid red and bronze pigmentation.

Kiełtyk et al. (2025) reported that species that occur in high elevations exhibit lower morphological variations compared to species growing in lower elevations. The influence of light was also observed in evergreen broad-leaved trees, such as *Sarcandra glabra* and *Ardisia crenata*, where these species were found to grow favorably and tolerate up to 95% shading (Bae et al. 2016). *Gaultheria cumingiana* in Bontoc and Barlig commonly thrive in partial shade from neighboring plants, though some on steep slopes were exposed to full sun. Li et al. (2023) recorded *G. leucocarpa* in East Asia to be found in montane forest, in open exposed areas among some brushwood and shrubs at an elevation of 500 to 3,300 m asl. Alfag and Napaldet (2022) found a variant of this plant in roadside soil-stripped areas and woodland borders with partial to moderate shade in Benguet. The aforementioned findings would suggest that this species is well-suited to high-elevation marginal regions. It could be noted further that environmental factors, such as topography and elevation, along with edaphic factors, influenced the community distribution of patterns of this wild plant. This observation was also reported by Sachula et al. (2020), where the distribution of wild forest fruits in the mountain region of China was controlled by these factors. Therefore, it must be considered when attempting domestication as a means of conserving *G. cumingiana* in the region.

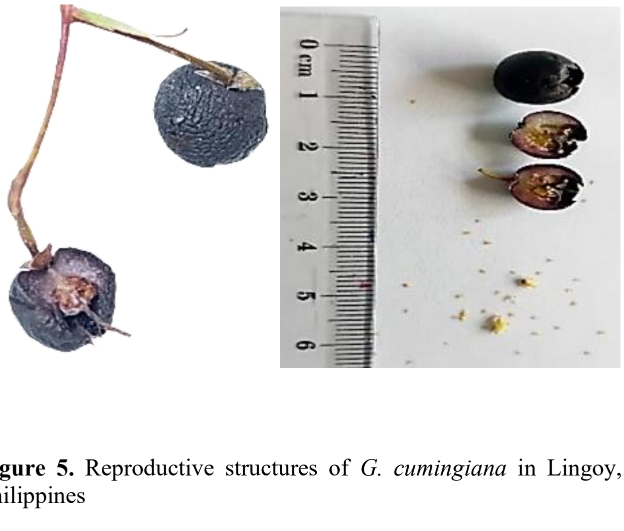

Figure 5. Reproductive structures of *G. cumingiana* in Lingoy, Philippines

Figure 6. Clustered habit of *G. cumingiana* in its natural habitat. Scale bar = 5 cm

Edaphic factors

The ecosystem is influenced by edaphic factors, which define species distribution, ecosystem development, plant growth, and nutrient cycling. All of these factors are equally worthy in the investigation on how wild teas, specifically *G. cumingiana*, survive in their natural habitat. It is, however, a limitation of the study to only consider some physical and chemical properties. Thus, data on soil acidity/alkalinity, percentage moisture content, nitrogen, phosphorus, and potassium content were used to analyze the morphology of *G. cumingiana* thriving in the province.

The soil properties across the five study locations are presented in Table 5. The results indicate that the nutrients and moisture content of the sampled habitats of *G. cumingiana* varied significantly, indicating that environmental conditions are not consistent. The parameters of soil pH and phosphorus content showed no statistically significant differences across the sites ($P=0.060$ and $P=0.059$, respectively), with an overall mean soil pH of 5.65 and a mean Phosphorus content of 3.10 mg/ppm. It was also noted that the pH of most of the study locations was moderately acidic. This suggests that the underlying acidity and available phosphorus levels are largely constant, even in the face of geographical changes, and could serve as a baseline condition for the species' growth. On the other hand, there were statistically significant variations in the moisture content, nitrogen, and potassium concentration among the sampling sites. Soil moisture was highly significant ($P=0.004$), with Dalican and Lias recording the highest mean values, a mean statistically different from the lowest moisture recorded at Bayyo. Similarly, nitrogen content was significant ($P=0.049$), where Dalican presented the highest concentration, differing statistically from the lower-concentration sites like Bayyo, Macalana, and Lingoy. Most notably, potassium content was highly significant ($P=0.001$), with Dalican exhibiting the highest mean concentration, a value significantly distinct from the potassium levels found in Bayyo, Macalana, and Lingoy. Based on morphometric data, Dalican has the highest concentration of N, P, and K, indicating that it provides the most nutrient-rich environment. This is probably why it can promote greater plant growth or reproductive growth. Similarly, soil moisture and acidity in this area may favor the morphological development of this species.

The findings on the soil properties suggest that *G. cumingiana* tolerates low fertility, requires moderate to strongly acidic but well-drained soil. This wild tea was generally found in gentle slopes to very steep areas on mountain sides, some along eroded portions, where the soil is usually stony and loose. In such conditions, soil fertility is generally poor, but is well-drained, which could be favorable for this plant. This observation is similar to the habitat of its variety *G. cummingiana* surveyed in Benguet by Alfag and Napaldet (2022).

Correlation between general morphology and soil properties

The correlation between the morphometric characteristics of *G. cumingiana* and the pH, moisture content, and NPK content of the soils obtained from the various sampling regions is presented in Table 6. As to soil pH, it was found to be negatively correlated to plant height, LA, number of flowers, flower diameter, and fruit weight; however, this correlation was not significant. It had a highly significant correlation to branching architecture in terms of its ADI. Soil moisture was significantly and positively correlated with ADI. All other morphological characters were not significantly correlated to soil moisture.

As to soil nitrogen and phosphorus content, analysis revealed no significant correlation to plant height, branching architecture (ADI), LA, number of flowers, and fruit weight. Flower diameter, however, was found to have a highly significant negative correlation with nitrogen, and a significant negative correlation with phosphorus content. On the other hand, potassium content had a significant negative correlation to corolla diameter, while a significant positive correlation with ADI. Other morphological characters were not significantly correlated with potassium content.

Table 5. Soil pH, moisture content, and NPK of soil from the different sampling sites

Location	**Soil properties**				
	pH^{ns}	**Moisture content (%)****	**N (mg/ppm)***	**P (mg/ppm)^{ns}**	**K (mg/ppm)****
Bayyo	6.06^{a} (MA)	3.00^{a}	1.80^{a}	1.50^{a}	2.50^{a}
Dalican	5.56^{a} (MA)	4.50^{b}	5.70^{b}	2.00^{a}	14.90^{b}
Macalana	5.49^{a} (StA)	3.70^{ab}	2.60^{a}	1.40^{a}	3.30^{a}
Lingoy	5.59^{a} (MA)	3.80^{ab}	2.40^{a}	1.80^{a}	6.30^{ab}
Lias	5.15^{a} (StA)	4.50^{b}	3.00^{ab}	1.50^{a}	9.50^{ab}
Overall Mean	5.65^{a} (MA)	3.79	3.12	3.10	6.88
F value	2.489^{ns}	4.633**	2.636*	2.497^{ns}	6.185**
Df	(4,37)	(4,37)	(4,37)	(4,37)	(4,37)
P Value	.060	.004	.049	.059	.001

Note: ^{ns}: Not significant, **: Highly significant. Dissimilar superscript means a significant difference. Very Strongly Acidic (VSA), Strongly Acidic (StA), Moderately Acidic (MA), Slightly Acidic (SA) (see Table 2)

Table 6. Correlation between morphology of *Gaultheria cumingiana* and soil properties

General Morphology	Soil properties				
	pH^{ns}	Moisture content**	N (mg/ppm)*	$P(mg/ppm)^{ns}$	K (mg/ppm)**
Plant height	-0.177^{ns}	0.266^{ns}	0.238^{ns}	0.359^{ns}	-0.19^{ns}
ADI	-0.843^{**}	$.700^{*}$	0.192^{ns}	-0.151^{ns}	$.672^{*}$
Leaf area	-0.386^{ns}	0.424^{ns}	-0.127^{ns}	0.009^{ns}	0.069^{ns}
Number of peduncles	-0.137^{ns}	-0.069^{ns}	0.241^{ns}	0.300^{ns}	0.403^{ns}
Corolla diameter	-0.173^{ns}	0.145^{ns}	$-.782^{**}$	$-.708^{*}$	$-.608^{*}$
Fruit weight	-0.11^{ns}	0.151^{ns}	0.441^{ns}	0.37^{ns}	0.422^{ns}

Note: ^{ns}: Not significant, *: Significant, **: Highly significant

The above findings suggest that the ADI and corolla diameter are related to the soil properties. The negative correlation between ADI and pH suggests that increasing pH or lowering soil acidity tends to restrict apical shoot growth but promote side buds, resulting in ramified branches. On the other hand, higher moisture and potassium content seem to promote apical growth, resulting in less ramified branches. This behavior affects the development of leaves in axillary branches, which may provide sources for young leaves. Young leaves of *G. cumingiana* are usually preferred for a tea beverage. Thus, these factors may be considered when aiming for sustainable leaf sources for the production of tea beverages. On the other hand, corollas attract pollinators, thereby ensuring fruit development and reproduction. The negative correlation noted between corolla diameter and soil NPK suggests that larger flowers may develop, even in low amounts of these nutrients. This could be an advantage for this wild tea plant, having a higher chance of fruit set.

Several environmental conditions, which are also interrelated to several factors, may influence the variation in plant morphologies, as noted in this study. As much as the observed variations on *G. cumingiana* are of phenotypic plasticity in response to local environmental conditions (Lopez-Laphitz et al. 2015), these different factors cannot be neglected. For instance, elevation may not directly influence plant morphologies, but involves related factors such as light and temperature (Olejniczak et al. 2018). Such that, *G. cumingiana* in open higher elevations tend to be more exposed to higher light, but can tolerate lower light intensities. Moreover, while soil properties may have a direct impact on the morphology of this wild tea plant, associated factors may have an indirect influence. The overall soil health does not only depend on the physical properties, but includes chemical and biological components that contributes to plant growth and development (Riaz et al. 2021). With the above findings, it is still worthy to note that, *G. cumingiana* can tolerate variations in soil properties, thus their survival in the wild habitat. This also suggests its adaptability for domestication and integration to agroecological areas for biodiversity conservation.

To ensure the sustainable utilization and conservation of *G. cumingiana*, management strategies should focus on the following: first, ex-situ cultivation must replicate natural habitat conditions by maintaining partial shade, acidic soils (pH 5.15-6.06), and moisture levels between 3.00% and 4.50%; second, domestication programs should prioritize high-yielding genotypes, such as those from Dalican that exhibit superior reproductive traits like higher flowering rates (7.20 flowers per peduncle) and optimal fruit weight (0.31 g). Finally, in-situ conservation zones should be established within the species' natural altitudinal range (1,434-2,091 m asl) to protect the unique genetic diversity that enables its resilience in nutrient-poor environments.

In conclusion, the study characterized *G. cumingiana* as a small, aromatic shrub that exhibits significant morphological plasticity in response to its environment. Reproductive traits, specifically the number of flowers per peduncle and fruit weight varied significantly across sites, whereas vegetative growth is heavily influenced by localized conditions, with an overall mean height of 1.07 m and an ADI ranging from 7 to 14 ($p<0.05$). Although soil pH remained consistently and moderately acidic (mean 5.65), the highly significant variation in moisture content (mean 37.9%) and the significant negative correlation between soil Nitrogen (N) concentration and leaf area suggest a specialized survival mechanism. The species adopts a conservative growth strategy, developing smaller, more resilient leaves (mean 10.89 cm^2) in challenging, nutrient-stressed environments. Ultimately, these findings confirm that the structural variations in *G. cumingiana* are adaptive responses that facilitate its persistence in the marginal habitats of the Cordillera region.

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