



Study on the morphological and ecological distribution characteristics of single-flowered red camellia (*Camellia rubriflora*) in Tam Dao National Park, Vinh Phuc Province

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Abstract

This study investigated the morphological characteristics, ecological distribution, and natural regeneration of *Camellia rubriflora* in Tam Dao National Park, northern Viet Nam. Field surveys conducted from 2023 to 2024 revealed that the species is a small, slow-growing evergreen tree occurring mainly in low-elevation evergreen moist forests at 300–700 m a.s.l. *C. rubriflora* is sparsely distributed, with very low population density and a non-dominant role in forest stand structure. The species is closely associated with intact forest canopies and exhibits high ecological specialization. Natural regeneration occurs predominantly through seeds, while vegetative regeneration is very limited. Regenerated individuals are mainly concentrated in lower height classes, reflecting slow growth and shade tolerance. Overall, the results indicate that *C. rubriflora* is highly dependent on stable natural habitats, underscoring the urgent need for in situ conservation combined with habitat protection and regeneration support.

Keywords: *Camellia rubriflora*, single-flowered red camellia, Tam Dao, morphology, ecology, conservation

Introduction

The genus *Camellia* (family Theaceae) is a large group of flowering plants comprising more than 200 described species, distributed mainly in East Asia, particularly in China and Viet Nam—regions recognized as major centers of diversity for this genus [1, 10]. Many *Camellia* species possess high ecological, ornamental, and economic value, including *Camellia sinensis* (tea plant), *Camellia japonica* (ornamental camellia), as well as numerous rare endemic species with potential applications in medicine and genetic conservation.

Camellia species are primarily distributed in tropical Asia, with centers of diversity located in southern China and northern Viet Nam [2, 10]. To date, more than 200 *Camellia* species have been reported worldwide, making this genus the largest within the family Theaceae [6, 10].

In Viet Nam, tropical evergreen forests provide ideal ecological conditions for the growth and development of *Camellia* species. According to Nguyen Tien Hiep and Phan Ke Loc (2000), more than 70 species and infraspecific taxa of *Camellia* have been recorded in the country, many of which exhibit a high degree of endemism and are currently threatened by habitat degradation [3]. Among these, *Camellia rubriflora*, commonly known as the red-flowered camellia, is a particularly rare and poorly studied species, distinguished by its characteristic red flowers and its narrow distribution within Tam Dao National Park [5, 8].

The single-petaled red-flowered camellia, *Camellia rubriflora* Ninh & Hakoda, is a plant species belonging to the genus *Camellia* L., family Theaceae, order Ericales. The scientific name of this species was first published in the *International Camellia Journal* in 1998 [5]. In Vietnamese, the species is commonly referred to as “Trà hoa đỏ cánh đơn.” The specific epithet *rubriflora* originates from Latin, in which “*rubri-*” means “red” and “*flora*” means “flower,” reflecting the distinctive ruby-red coloration of its flowers [1, 7].

However, *C. rubriflora* is currently facing a high risk of extinction in the wild. According to assessments by the International Union for Conservation of Nature (IUCN), this species is classified as Critically Endangered (CR) on the Red List, based on field survey data conducted in the Tam Dao area [8].

Tam Dao National Park, located at the junction of Vinh Phuc, Thai Nguyen, and Tuyen Quang provinces, is one of the most biodiverse protected areas in northern Viet Nam. The park experiences a humid subtropical climate year-round, with elevations ranging from 100 to 1,597 m above sea level, providing favorable conditions for the growth of many endemic plant species, including *Camellia rubriflora* [8]. Nevertheless, existing data on the morphological characteristics, ecological requirements, and habitat distribution of this species remain limited, posing challenges for species identification, management, and conservation.

Therefore, this study was conducted to provide a detailed description of the morphological characteristics and ecological distribution of the red-flowered camellia (*Camellia rubriflora*) in Tam Dao National Park. The findings are expected to enrich the botanical database of the region and serve as a scientific basis for proposing effective conservation and sustainable utilization strategies for this valuable plant species.

Materials and Methods

1. Study object

The study focuses on the morphological and ecological characteristics of the single-flowered red camellia (*Camellia rubriflora*) in Tam Dao National Park.

Study area and duration

Study area: The research was conducted in Tam Dao National Park, located within Thai Nguyen and Vinh Phuc provinces, Viet Nam. The park is characterized by complex

mountainous terrain, with elevations ranging from approximately 100 m to 1,000 m above sea level.

Study period: Field surveys and specimen collection were carried out from January 2023 to December 2024.

Time and location of field surveys: Field investigations were conducted from January 2023 to December 2024 in Tam Dao National Park, spanning areas within Thai Nguyen and Vinh Phuc provinces. This region provides suitable ecological conditions and has previously recorded the presence of the single-flowered red camellia (*Camellia rubriflora*).

2. Methods

2.1. Literature review

This study was conducted based on the review and synthesis of both domestic and international publications related to the taxonomy, morphological characteristics, ecology, and distribution of the genus *Camellia*, with particular emphasis on *Camellia rubriflora*. Published studies were used as the

scientific basis for field survey design, species identification, and comparative analysis of research results.

2.2. Transect-based field survey

Field surveys were conducted using the transect method in areas where the natural distribution of *C. rubriflora* has been recorded within Tam Dao National Park. Transects were established along mountain slopes and valleys to encompass representative habitat types. Along each transect, data were recorded on species occurrence, elevation, topographic conditions, habitat characteristics, and the number of individuals.

Transect surveys

Transect surveys were carried out in potential areas where red camellia was expected to occur, based on information provided by forest rangers and local residents (Table 1). Along each transect, population census, specimen collection, photographic documentation, and GPS coordinate recording were conducted for *Camellia rubriflora*.

Table 1: Survey transects for single-flowered red camellia (*Camellia rubriflora*) in Tam Dao National Park, Thai Nguyen and Vinh Phuc provinces

TT	Province	Starting point coordinates		Ending point coordinates		Transect length (km)
		X coordinate	Y coordinate	X coordinate	Y coordinate	
1	Thai Nguyen	21.440,197	105.737,281	21.442,811	105.704,453	3,6
		21.445,759	105.39,950	21.464,093	105.666,515	8,1
		21.517,464	105.671,675	21.542,288	105.610,831	8,4
		21.473,599	105.658,080	21.522,163	105.619,065	5,3
2	Vinh Phuc	21.449,762	105.604,067	21.492,778	105.610,449	4,1
		21.444,076	105.598,996	21.472,081	105.629,424	4,4
		21.511,618	105.543,982	21.521,402	105.590,685	5,1
		21.477,055	105.573,136	21.499,320	105.605,480	4,2
		21.450,623	105.601,094	21.519,308	105.588,400	7,5
		21.527,082	105.528,734	21.517,749	105.585,171	5,6
		21.499,471	105.557,928	21.490,827	105.606,501	5
		21.475,280	105.597,116	21.533,433	105.562,044	6,1

2.3. Sample collection and morphological description

Representative plant samples were selected in the field for observation, measurement, and description of the main morphological characteristics of the species, including the stem, branches, leaves, flowers, and fruits (if present). Morphological descriptions were conducted based on standard botanical taxonomic criteria, combined with photographic documentation and comparison with published taxonomic references to accurately identify the diagnostic characteristics of *Camellia rubriflora*.

2.4. Analysis of ecological distribution

Ecological factors at the distribution sites of *C. rubriflora* were analyzed, including elevation above sea level, slope, topography, soil type, canopy cover, and associated plant species. Based on these data, the relationships between ecological conditions and the growth and distribution of the species were evaluated, providing a scientific basis for conservation planning and genetic resource development.

2.5. Data processing

Collected data were compiled and analyzed using descriptive statistical methods. Results were presented in tables and figures to clearly illustrate the morphological, ecological, and distributional characteristics of *C.*

rubriflora. Data consistency was checked and compared with previously published studies to ensure scientific reliability.

Results and Discussion

1. Morphological and ecological characteristics of single-flowered red camellia (*Camellia rubriflora*)

1.1. Morphological characteristics of single-flowered red camellia (*Camellia rubriflora*)

Camellia rubriflora is a small evergreen tree with slow growth, reaching an average height of 2.0–5.0 m under natural conditions. The species branches from a low height, with a narrow to moderately broad crown, and is well adapted to growth under low-elevation moist forest canopies. This life form is consistent with the original description by Ninh and Hakoda (1998) and corresponds to the group of red-flowered *Camellia* species classified by Gao *et al.* (2005) as small, semi-shade-tolerant trees.

The stem is cylindrical, with bark ranging from grayish brown to dark brown; the surface is smooth when young and becomes slightly longitudinally fissured with age. Young branches are light green, lignify early, and are glabrous or bear very sparse short hairs at early developmental stages. Internodes are distinct and of moderate length. These stem and branch characteristics are generally consistent with the

description of Ninh and Hakoda (1998); however, the degree of early lignification and the coloration of young branches observed in this study are more pronounced than those reported by Gao *et al.* (2005).

Leaves are simple and alternate; leaf blades are ovate to elliptic-ovate, averaging 7–12 cm in length and 3–5 cm in width; the apex is acute, the base narrowly cuneate; margins are finely and regularly serrate. The adaxial surface is dark green and glossy, while the abaxial surface is paler; the midrib is prominent on the lower surface, with lateral veins evenly distributed. Petioles are short, measuring 0.5–1.0 cm in length. Leaf morphological traits are consistent with the description of Ninh and Hakoda (1998). Compared with other red-flowered *Camellia* species described by Gao *et al.* (2005), *C. rubriflora* exhibits finer serrations and thicker leaf blades.

Flowers are solitary, borne in the leaf axils or at branch terminals, with a diameter of 6–8 cm. Petals are bright red, arranged in a single whorl, numbering 5–7; petals are thick

with entire margins. Stamens are numerous and arranged in whorls; filaments are yellow and anthers are pale yellow. The ovary is superior, with a well-developed pistil. The single-petaled floral type and characteristic red coloration are fully consistent with the original description by Ninh and Hakoda (1998). Compared with the red-flowered *Camellia* group described by Gao *et al.* (2005), *C. rubriflora* shows more stable petal numbers and less floral structural variation.

The fruit is a capsule, subglobose and slightly flattened, 2.5–4.0 cm in diameter, turning dark brown at maturity; fruits usually contain two to three locules. Seeds are nearly spherical, with a hard, dark brown seed coat; each locule contains one to two seeds. Fruit and seed characteristics are consistent with the description of Ninh and Hakoda (1998); however, fruit size observed in this study tends to be larger than that reported by Gao *et al.* (2005), possibly reflecting local ecological conditions.

Figure 1. Photograph of *Camellia rubriflora* in Tam Dao National Park.

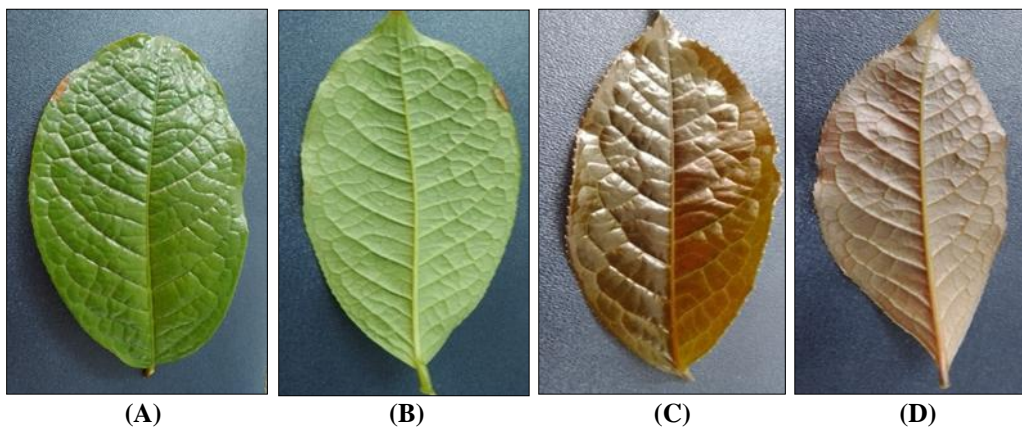


Fig 2: Adaxial (A) and abaxial (B) surfaces of mature leaves; adaxial (C) and abaxial (D) surfaces of young leaves of *Camellia rubriflora*

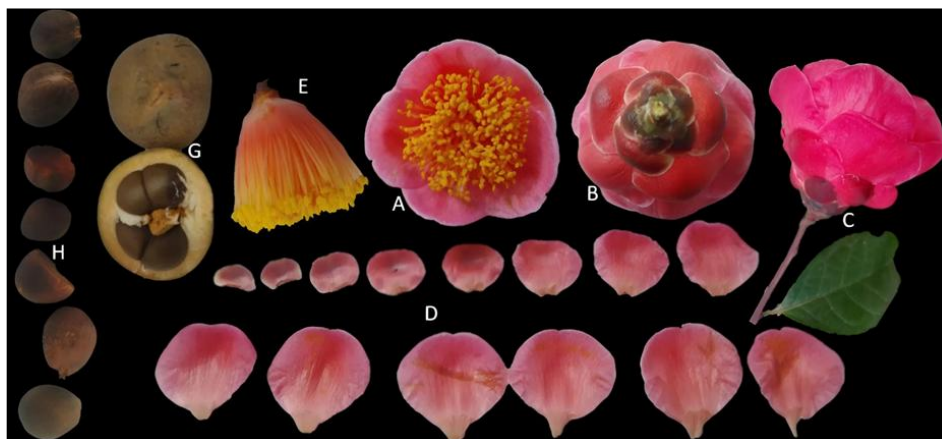


Fig 3: Frontal view of the flower (A); dorsal view of the flower (B); lateral view of the flower (C); morphology of floral organs (D: sepals and petals); stamens and pistil (E); external view and cross section of the fruit (G), and seeds (H) of single-flowered red camellia (*Camellia rubriflora*)

1.2. Natural distribution characteristics of *Camellia rubriflora*

In the study area, *Camellia rubriflora* occurs naturally at elevations ranging from approximately 300 to 700 m above sea level, mainly on soil-based mountains and mixed soil–rock terrains. The species typically grows under the canopy of low-elevation evergreen moist forests, on mountain slopes, lower ridges, and streamside valleys, where

humidity is high and humus-rich soil layers are well developed.

Camellia rubriflora is distributed either as scattered individuals or in small clusters and rarely forms dense or continuous populations. Mature individuals usually grow under forest canopies with moderate to high cover, indicating that *C. rubriflora* is a semi-shade-tolerant species with limited tolerance to prolonged exposure to direct

sunlight.

Field surveys were conducted along 15 transects with a total length of approximately 68.5 km, with an average length of 4.6 km per transect. The transects were arranged to cover a range of topographic conditions and forest states within the potential distribution area of the species. Survey results recorded 96 mature individuals of *Camellia rubriflora* on 14 out of 15 transects, all occurring in relatively intact natural forest areas.

The encounter frequency of *Camellia rubriflora* ranged from 0.22 to 4.85 individuals per kilometer. The highest encounter frequency (4.85 individuals km⁻¹) was observed in closed, humid forest areas with minimal human disturbance,

whereas the lowest frequency (0.22 individuals km⁻¹) occurred mainly in forests with reduced canopy cover. The mean encounter frequency across all transects was 1.40 individuals km⁻¹.

Overall, the results indicate that *Camellia rubriflora* has a relatively narrow distribution range, low population density, and uneven spatial distribution. These characteristics clearly reflect the species' high ecological specialization and suggest a risk of population decline if habitat disturbance continues. Therefore, in situ conservation combined with propagation research and habitat restoration is essential to maintain and develop the valuable genetic resources of this species.



Fig 1: *Camellia rubriflora* individuals in Tam Dao National Park

2. Structural characteristics of species composition based on stem number (N) and importance value index (IV%)

Camellia rubriflora is distributed in low-elevation evergreen moist forest ecosystems in the Tam Dao area, mainly on soil-based mountains and mixed soil-rock terrains. Due to differences in geological substrate, elevation, canopy cover, and microclimatic conditions, forest stand composition in areas where *C. rubriflora* occurs exhibits a certain degree of diversity and variation. Therefore, in this study, the structure of the tree layer was analyzed separately for two main ecosystem types: (i) soil-based mountain ecosystems and (ii) mixed soil-rock mountain ecosystems.

Along survey transects where *Camellia rubriflora* was recorded, a total of 28 sample plots were established, including nine plots in soil-based mountain areas and 19 plots in mixed soil-rock mountain areas. Within each plot, upper-canopy tree species were surveyed and the number of individuals (N) was recorded, from which the importance value index (IV%) was calculated to evaluate the ecological role of each species within the forest community.

The results of stand structure analysis show that the number of tree species participating in the upper tree layer ranged

from 30 to 42 species, depending on the ecosystem type. However, only 5 to 14 species directly contributed to the main stand composition formula, characterized by high N and IV% values, while the remaining species were classified as secondary species, occurring sporadically at low densities.

In mixed soil-rock mountain ecosystems, the dominant tree layer was mainly composed of species such as *Lithocarpus* spp., *Schefflera* spp., *Garcinia* spp., *Michelia* spp., *Canarium* spp., and *Liquidambar formosana*. These species exhibited high stem densities and large IV% values, reflecting their dominant structural and ecological roles within the forest community.

In contrast, soil-based mountain ecosystems showed a distinctly different stand composition, with dominance by species such as *Lithocarpus* spp., wild longan (*Dimocarpus longan*), *Syzygium* spp., *Gironniera cuspidata*, and *Saraca dives*. This indicates differential adaptation of tree species to site conditions and microclimatic environments across ecosystem types.

Notably, *Camellia rubriflora* did not participate in the main stand composition formula in either ecosystem type, as indicated by its low stem number and small IV% values. This demonstrates that the species does not play a dominant

role in the upper tree layer structure but instead occurs as an associated species, sparsely distributed beneath the forest canopy. Nevertheless, its presence in species-rich and structurally stable forest communities clearly reflects its high degree of ecological specialization and strong dependence on natural habitat conditions.

Overall, the tree-layer composition structure in areas where *Camellia rubriflora* occurs is characteristic of mixed, multi-species forests with high species diversity and clear differences between ecosystem types. This diversity contributes to the stability and sustainability of forest ecosystems, while also highlighting the urgent need for habitat conservation to maintain *Camellia rubriflora*

populations under ongoing environmental changes and anthropogenic pressures.

2.3. Accompanying tree species associated with *Camellia rubriflora* in natural forests

Survey results indicate that *Camellia rubriflora* occurs in low-elevation evergreen moist forest communities with a relatively diverse assemblage of accompanying tree species, reflecting the characteristics of mixed, multi-species forest ecosystems in the Tam Dao area. The composition of tree species associated with *Camellia rubriflora* by ecosystem type is summarized in Table 3.

Table 3: Composition of tree species associated with *Camellia rubriflora* in natural forests

Ecosystem type	Dominant associated tree species	Number of recorded species (species)	Key ecological characteristics
Mixed soil - rock mountains	<i>Lithocarpus spp.</i> ; <i>Schefflera spp.</i> ; <i>Garcinia spp.</i> ; <i>Michelia spp.</i> ; <i>Syzygium spp.</i> ; <i>Gironniera cuspidata</i> ; <i>Liquidambar formosana</i> ; ...	16 -18	umid evergreen forest with medium to tall canopy layers, high canopy cover, and moist forest humus soils.
Soil mountains	<i>Lithocarpus spp.</i> ; <i>Dimocarpus longan</i> ; <i>Saraca dives</i> ; <i>Canarium spp.</i> ; <i>Schefflera spp.</i> ; ...	13 -15	Deep, moist soils with good water-holding capacity; relatively closed forest canopy.

Accompanying species composition by ecosystem type

In mixed soil–rock mountain ecosystems, where *Camellia rubriflora* mainly occurs under relatively intact natural forest canopies, the accompanying tree species composition comprises approximately 16–18 species. Among these, species with high occurrence frequency and clear ecological associations with *Camellia rubriflora* include oaks (*Lithocarpus spp.*), Schefflera (*Schefflera spp.*), mangosteen relatives (*Garcinia spp.*), magnolias (*Michelia spp.*), brush cherries (*Syzygium spp.*), *Gironniera cuspidata*, and sweetgum (*Liquidambar formosana*). These species form the dominant tree layer, contributing to moderate to high canopy cover and creating suitable ecological conditions for the growth and development of *C. rubriflora*.

In soil-based mountain ecosystems, the accompanying species composition associated with *Camellia rubriflora* tends to be simpler, with approximately 13 - 15 species recorded. Species commonly found together with *C. rubriflora* include *Lithocarpus spp.*, wild longan (*Dimocarpus longan*), *Saraca dives*, *Canarium spp.*, and *Schefflera spp.* The presence of these species reflects site conditions characterized by deep soil layers, high moisture availability, and good water-holding capacity, factors favorable for moisture-loving and semi-shade-tolerant tree species.

Ecological characteristics of accompanying species

Overall, the species accompanying *Camellia rubriflora* are native tree species, belonging mainly to evergreen or semi-

evergreen groups, well adapted to low-elevation moist forest conditions. *Camellia rubriflora* typically occurs in scattered individuals or small clusters and does not dominate in terms of abundance; instead, it persists as an associated understory species, closely dependent on the structure and stability of the surrounding forest community.

Differences in accompanying species composition among ecosystem types indicate a close relationship between *C. rubriflora* and habitat conditions, reflecting the species’ relatively high ecological selectivity. This also explains why *Camellia rubriflora* is usually found only in minimally disturbed natural forests with relatively intact canopy structures.

The results on accompanying species composition suggest that, when developing in situ conservation models or habitat restoration programs involving enrichment planting of *Camellia rubriflora*, particular attention should be given to the selection of appropriate companion tree species for each ecosystem type. Reconstructing mixed forest structures similar to natural forests, with the presence of commonly associated native tree species, will contribute to enhancing the survival, growth, and long-term sustainability of *Camellia rubriflora*, while also increasing ecological value and long-term stability of forest ecosystems.

2.4. Density structure

The density of the tree layer and the density of *Camellia rubriflora* in the study areas are summarized and presented in Table 4.

Table 4: Tree-layer density and density of *Camellia rubriflora* in the study area

Ecosystem type	Tree-layer density (trees/ha)	Density of <i>C. rubriflora</i> (trees/ha)	Proportion relative to the tree layer (%)
Rocky Mountains	560	2,1	0,38
Soil mountains and mixed soil - rock mountains	720	3,6	0,50

Survey results indicate that in the Tam Dao area, *Camellia rubriflora* exhibits a relatively low population density compared with the overall density of the tree layer in natural forest communities. The proportion of *C. rubriflora*

individuals accounts for only about 2–3% of the total number of trees per hectare, reflecting its role as a sparsely distributed species that does not dominate the forest community in terms of abundance.

A comparison among ecosystem types shows that the density of *Camellia rubriflora* is higher in soil-based and mixed soil–rock mountainous areas than in rocky mountain areas. This suggests that the species tends to grow and persist better in sites with deeper soil layers, higher moisture retention capacity, and more favorable nutrient conditions, whereas the harsher site conditions of Rocky Mountains limit its regeneration and development.

Although occurring at low density, the relatively wide distribution of *C. rubriflora* across different forest conditions indicates that the species has a narrow ecological niche and is strongly dependent on stable, minimally disturbed natural forest structures. This characteristic is common among many rare red-flowered *Camellia* species, which tend to persist sustainably only in forest communities that retain a relatively high degree of naturalness.

Based on the analysis of density structure, it can be concluded that reductions in natural forest area or alterations in canopy structure would directly affect the survival of *Camellia rubriflora*. Therefore, conservation and restoration efforts should prioritize habitat conservation measures, maintaining appropriate tree-layer density and structure, and minimizing disturbances that degrade site quality in the natural distribution areas of the species.

3. Characteristics of natural regeneration of *Camellia rubriflora*

The summarized results of the survey on naturally regenerated *Camellia rubriflora* individuals in 31 sample plots, comprising 155 subplots, are presented in Table 5.

Table 5: Summary of the survey on natural regeneration of *Camellia rubriflora* in sample plots

OTC	<50 cm	50–100 cm	100–200 cm	>200 cm	Total number of individuals	Sprout regeneration (%)	Seed regeneration (%)
1	1	1	0	0	2	0,0	100,0
2	1	1	1	0	3	0,0	100,0
3	2	1	1	0	4	0,0	100,0
4	2	1	1	1	5	20,0	80,0
5	1	1	0	0	2	0,0	100,0
6	1	0	1	0	2	0,0	100,0
7	1	1	0	0	2	0,0	100,0
8	2	1	0	0	3	0,0	100,0
9	1	1	0	0	2	0,0	100,0
10	1	1	1	0	3	0,0	100,0
11	1	1	0	0	2	0,0	100,0
12	1	0	0	0	1	0,0	100,0
13	1	1	0	0	2	0,0	100,0
14	2	1	1	0	4	0,0	100,0
15	2	1	1	0	4	0,0	100,0
16	1	1	0	0	2	0,0	100,0
17	1	1	1	0	3	0,0	100,0
18	2	1	0	0	3	0,0	100,0
19	1	1	0	0	2	0,0	100,0
20	1	1	0	0	2	0,0	100,0
21	1	0	0	0	1	0,0	100,0
22	1	0	0	0	1	0,0	100,0
23	1	1	0	0	2	0,0	100,0
24	2	1	0	0	3	0,0	100,0
25	1	1	0	0	2	0,0	100,0
26	1	1	1	0	3	0,0	100,0
27	1	0	0	0	1	0,0	100,0
28	1	1	0	0	2	0,0	100,0
29	1	0	0	0	1	0,0	100,0
30	1	0	0	0	1	0,0	100,0
31	2	0	0	0	2	0,0	100,0
32	0	1	0	0	1	0,0	100,0

The synthesized results of the survey on natural regeneration of *Camellia rubriflora* in 32 sample plots recorded a total of 79 regenerated individuals, accurately reflecting the characteristics of a species with a small population size, narrow distribution, and low density in natural forests. The number of regenerated individuals was unevenly distributed among the plots; many plots recorded only one to two individuals, while plots containing four to five regenerated individuals were very limited. This indicates that the regeneration process of the species is scattered and discontinuous, strongly dependent on micro-environmental conditions beneath the forest canopy.

In terms of height classes, regenerated individuals were mainly concentrated in the <50 cm and 50-100 cm classes,

with a total of 65 individuals, accounting for 85.5% of the total regenerated population. The height class >200 cm included only two individuals (1,3%), indicating that very few regenerated individuals are able to survive the juvenile stage and develop into mature trees. This distribution structure reflects typical ecological characteristics of shade-tolerant *Camellia* species, which exhibit slow growth and are highly susceptible to competition under closed-canopy forest conditions.

Regarding regeneration origin, *Camellia rubriflora* regenerated predominantly from seeds (97,4%), while vegetative regeneration from sprouts accounted for only 2.5%. The low proportion of sprout regeneration suggests a limited capacity for vegetative recovery and a lack of

resilience following mechanical disturbances (e.g., stem breakage or cutting), in contrast to many other evergreen forest tree species. Seed-based regeneration is the primary pathway; however, seed germination and seedling survival are strongly influenced by moisture conditions, light availability, and the forest litter layer.

Overall, the regeneration structure of *Camellia rubriflora* indicates that the population is in a vulnerable state, characterized by low regeneration density, scattered distribution, and a very limited number of individuals with

the potential to develop into mature trees. This confirms the risk of continued population decline in the absence of appropriate conservation and regeneration-supporting measures.

These results provide an important scientific basis for proposing in situ conservation strategies, including limiting human disturbances in natural distribution areas, in combination with ex situ propagation to conserve and restore the valuable genetic resources of *Camellia rubriflora* in the future.

Table 6: Species composition of the regeneration layer in areas where *Camellia rubriflora* occurs

Ecosystem type	Regeneration Layer Species Composition Formula
Rocky mountain	1,62Chc + 1,48Crf + 1,31Bbpl + 1,12Ror + 0,95Bb + 0,78Nga + 0,55Bl + 2,19Lk (13 loài)
Soil mountains and mixed soil–rock mountains	1,85Crf + 1,34Bbpl + 1,22Chc + 1,05G + 0,92Va + 0,86Nh + 0,74Q + 0,68D + 1,64Lk (11 loài)

Note

Crf: *Camellia rubriflora*; **Chc:** *Schefflera petelotii*; **Bbpl:** *Ba bet philippin*; **Ror:** *Ruoi ô rô*; **Bb:** *Bung buc*; **Nga:** *Ngam*; **Bl:** *Bang lang*; **G:** *Gioi*; **Va:** *Vang anh*; **Nh:** *Nhoi*; **Q:** *Quao*; **D:** *De*; **Lk:** other species.

In rocky mountain ecosystems, the species composition of the regeneration layer in areas where *Camellia rubriflora* occurs comprised seven main species. Among them, *Chân chim* (*Schefflera petelotii*) had the highest proportion (1,62%), followed by *Trà hoa đỏ Tam Đảo* (*Camellia rubriflora*) with 1,48%. The remaining species, each with lower-than-average individual abundance, collectively accounted for a relatively high proportion (2,19%), reflecting the typical characteristics of natural forest regeneration on rocky substrates, where shallow soils and low habitat stability limit the absolute dominance of any single species.

In soil-based and mixed soil–rock ecosystems, the regeneration layer consisted of eight main species, among which *Camellia rubriflora* showed the highest proportion (1,85%), indicating its relatively prominent role in the regeneration layer. Associated species were mainly native shade-tolerant or shade-adapted tree species commonly found in low-elevation evergreen moist forests, such as *Ba*

bét philippin, *Chân chim*, *Giỏi*, *Vàng anh*, and *Dẻ*.

A comparison between the two ecosystem types shows that both the proportion and ecological role of *Camellia rubriflora* in the regeneration layer were relatively high, particularly in ecosystems with deeper soils and better moisture conditions. This highlights the species' ecological adaptability to evergreen moist forest environments and emphasizes the importance of site conditions in natural regeneration processes.

Most regenerated individuals of *Camellia rubriflora* originated from seeds, while only a small proportion regenerated from sprouts, mainly at sites where parent trees had broken stems or experienced mechanical damage. These results indicate that seed germination and seed-based regeneration of the species under the natural forest canopy are relatively effective, providing an important biological basis for in situ conservation and population restoration under suitable habitat conditions.

The height-class distribution of naturally regenerated *Camellia rubriflora* individuals is presented in detail in Table 7, clearly showing a concentration in lower height classes and a gradual decline in abundance in higher height classes.

Table 7: Height-class distribution of naturally regenerated *Camellia rubriflora* individuals in Tam Dao National Park

Species	Height (cm)				Total
	<50	50 - 100	100 - 200	>200	
<i>Camellia rubriflora</i>	2	8	39	27	76
(%)	2,6	10,5	51,3	45	100

The results showed that the number of naturally regenerated *Camellia rubriflora* individuals was mainly concentrated in the 100–200 cm height class, with 39 individuals accounting for 51.3% of the total regenerated population. This group represents newly established seedlings, reflecting a relatively good germination capacity of seeds under the natural forest canopy.

Regenerated individuals were relatively evenly distributed across the subsequent height classes. Notably, seedlings taller than 200 cm accounted for 45% (27 individuals) and

are considered promising regeneration with the potential to transition into the sapling stage under stable habitat conditions.

The presence of regenerated individuals across multiple height classes indicates that *Camellia rubriflora* is highly shade-tolerant during its early growth stages and well adapted to understory conditions in evergreen moist forests. This provides an important scientific basis for proposing selective silvicultural interventions to facilitate stable growth and development of natural regeneration in situ.

Table 8: Distribution of naturally regenerated *Camellia rubriflora* individuals by quality class and regeneration origin

Species	Total individuals	Quality			Regeneration origin	
		Good	Moderate	Poor	Sprout	Seed
<i>Camellia rubriflora</i>	76	46	20	10	1	75
(%)	100	61,0	26,3	13,2	1,3	98,7

Among the 76 naturally regenerated individuals of *Camellia rubriflora* recorded, seedlings of good quality accounted for the highest proportion (61.0%), followed by those of medium quality (26.3%), while poor-quality seedlings represented only a small proportion (13.2%). This pattern indicates that the ecological conditions in the study area are relatively favorable for the natural regeneration and early growth of the species.

Regarding regeneration origin, seed-derived individuals overwhelmingly predominated (98.7%), whereas vegetative regeneration from sprouts accounted for only 1.3. Sprout-origin seedlings were mainly observed at sites where parent trees had experienced mechanical damage, such as broken stems or windthrow associated with human activities.

These results confirm that sexual reproduction via seeds is the primary and most sustainable regeneration pathway of *Camellia rubriflora* in natural forests, highlighting its considerable potential for in situ conservation and the development of effective population restoration strategies under suitable habitat conditions.

Conclusions

This study provides a comprehensive characterization of the morphology, ecological traits, natural distribution, and regeneration of *Camellia rubriflora* in Tam Dao National Park, northern Vietnam. The species is a small evergreen tree with slow growth, adapted to shaded conditions in low-elevation evergreen forests at 300–700 m a.s.l. *C. rubriflora* occurs sparsely with very low population density and does not play a dominant role in the overstory structure, functioning mainly as an accompanying species. The associated forest communities are species-rich and structurally stable. Natural regeneration is predominantly seed-based, with low regeneration density but a relatively high proportion of healthy seedlings. These results indicate that *C. rubriflora* has a narrow ecological niche and is highly dependent on intact forest habitats. Habitat degradation is therefore likely to pose a significant threat to the long-term persistence of the species, highlighting the importance of conserving natural forest ecosystems for its survival.

Acknowledgments: This research was funded by the Ministry of Science and Technology under the National-Level Project Code: NVQG-2022/DT.10. The authors sincerely thank the Ministry of Science and Technology for their support.

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