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Research article

Morphological Variability, Seed Germination and Vulnerability in Sapote (*Colicodendron scabridum* [Kunth] Seem.)

Guillermo E. Delgado-Paredes[1,2], Cecilia Vásquez-Díaz[2]*, Boris Esquerre-Ibañez[2] and Felipe Zuñe-Da Silva[3]

[1]Faculty of Biological Sciences, Pedro Ruiz Gallo National University, Juan XXIII No 391, Lambayeque 14013, Peru
[2]Institute of Biotechnology, Pedro Ruiz Gallo National University, Atahualpa No 423, Lambayeque 14013, Peru
[3]Department of Botany, Federal University of Rio de Janeiro, Quinta da Boa Vista 20940-040, Rio de Janeiro, Brazil

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Abstract

The "sapote" *Colicodendrum scabridum* (Kunth) Seem. is an emblematic coastal species in the seasonally dry tropical forest; however, it is highly vulnerable due to indiscriminate logging and habitat destruction resulting from agro-industrial expansion. This study aimed to characterize specially the morphological variability of fruits and seeds, evaluate seed germination percentage, and analyze the vulnerability status of C. *scabridum* collected from a 60-hectare area in the Salas District (Lambayeque, Peru). We collected fruits, seeds, and leaves from 12 accessions and assessed their morphological traits. The analysis revealed significant variations in fruit size and shape, leaf dimensions, fruit weight, and seed count. Additionally, germination rates exhibited considerable variability among the fruit samples. The species' vulnerability is underscored by the ongoing destruction of its natural habitat. This study highlights the urgent need for conservation efforts by rural communities, government and academic authorities.

Keywords: seasonally dry tropical forest; habitat fragmentation; threatened species; accessions; Lambayeque

1. Introduction

Colicodendron scabridum (Kunth) Seem. (Capparaceae), is a xerophytic tree primarily found in the coastal regions of the western Andes and inter-Andean valleys (Herz, 2007). Its distribution spans northern Peru (from Tumbes to Ancash) to southwestern Ecuador (from Manabí to Loja), thriving at altitudes between 0 and 2,500 meters within the Seasonally Dry Tropical Forest (SDTF) ecosystem (Cornejo & Iltis, 2008; Linares-Palomino et al., 2022). In Ecuador, it has various local names, including "sapote", "sapote de campo", and "zapote de perro". In Peru, it is known as "sapote" and "zapotillo" (Cornejo & Iltis, 2008).

*Corresponding author: E-mail: cvasquezdia@unprg.edu.pe
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Understanding the ecological significance and morphological variability of *C. scabridum* is crucial for its conservation, particularly given the pressures on its habitat.

In Lambayeque, a region in northern Peru, *C. scabridum* coexists with several other timber species of significant ecological and economic importance. These include *Neltuma limensis* (Benth.) C.E. Hughes & G.P. Lewis ("algarrobo") and *Vachellia macracantha* (Humb. & Bonpl. ex Willd.) Seigler & Ebinger ("faique”). These species have been heavily exploited, leading to the near-extermination of the most valuable genotypes. Furthermore, other species in Capparaceae family, characterized by bushy growth habits, inhabit the same ecological niche as *Beautempsia avicennifolia* (Kunth) Gaudich. ("vichayo") and *Capparicordis crotonoides* (Kunth) Iltis & Cornejo ("satuyo").

Colicodendron scabridum plays a crucial role in ecological networks, for example in Northern Peru, the Lomas del Cerro Campana Private Conservation Area supporting 51 wildlife species, including 20 insects, 5 arachnids, 2 gastropods, and 24 vertebrates, some of which are endemic (Tafur et al., 2021). While its sweet, aromatic fruits are consumed minimally by local populations, they are a preferred food source for birds like the sand owl (*Athene cunicularia*) and the Peruvian thick-knee (*Hesperoburhinus superciliaris*), as well as mammals such as the Sechuran fox (*Lycalopex sechurae*) (Tafur et al., 2021). The fruits are nutritionally rich, containing 19-25% proteins, 15% carbohydrates, 22% fats, vitamins A and C, and 182 calories per 100 grams. The seeds contain 34.7% oil, primarily oleic, palmitic, and stearic acids (Mejía et al., 1991), making them beneficial forage for livestock and potentially increasing milk production in cattle (Bussmann & Sharon, 2007). The Food and Agriculture Organization (FAO, 2007) notes that the oil is suitable for human consumption, with recent studies revealing *C. scabridum* seed oil as a potential source of eicosapentaenoic acid and an omega-6 to omega-3 ratio of 2.7:1 (Abreu-Naranjo et al., 2020). Additionally, this species is vital for ecosystem conservation, helping control dune expansion, prevent erosion, and capture moisture from mists (Pennington et al., 2004).

Colicodendron scabridum is an economically valuable wood species in the SDTF. Its yellow-ocher sapwood and brown-yellow heartwood are easy to carve, making it suitable for various crafts, including children's toys, kitchen utensils, and souvenirs. Artisans from Monsefú and Catacaos are particularly noted for their craftsmanship. Additionally, the wood serves as firewood and is used in the calcination of rocks to produce gypsum (hydrated calcium sulfate), as well as in brick manufacturing and firing clay vessels, especially in Mórrope, one of the oldest towns in Lambayeque. Beekeeping is another growing economic activity, with *C. scabridum* flowers providing essential inputs for honey production. Furthermore, the species produces a high-quality gum or resin, known as 'sapote gum,' which has emulsifying and stabilizing properties, and has been historically used as glue (Ferreyra, 1986; Varillas, 2023). Comprehensive information on these topics was provided by Rodríguez et al. (2007).

On the other hand, there are no studies on the secondary metabolites and biological activity of the vegetative and reproductive structures of *C. scabridum*. However, the Capparaceae family contains numerous species producing compounds of importance for human use, such as secondary metabolites with varied biological activities. *Capparis spinosa* L. is an important source of different secondary metabolites of medicinal interest with traditional therapeutic applications since the Roman civilization (Zhang & Ma, 2018). Likewise, in a recent literature review of the species, its nutritional value has been highlighted, especially due to the presence of vitamins and antioxidant and the uses of the plant in folk medicine against metabolic and infectious diseases (Annaz et al., 2022). *Capparis erythrocarpos* Isert. is another species of Capparaceae with numerous active phytochemical compounds such as flavonoids, alkaloids, terpenoids, glycosides, tannins and saponins and with antimicrobial, analgesic, antipyretic, anti-diabetic and antidyslipidemia activities (Kyene et al., 2022). *Capparis decidua* (Forssk.) Edgew. is important for its applications in folk medicine and its high nutritional value, possessing many pharmacological attributes such as antidiabetic, antibacterial and anti-inflammatory activities and containing a wide range of phytochemicals such as alkaloids and flavonoids (Nazar et al., 2022). It is possible that many of the secondary metabolites, attributes and biological activities of the species of Capparaceae family, especially the species of the genus *Capparis*, correspond to *Colicodendron scabridum*, where there exists a great gap in information.

Given that *C. scabridum* has been classified as critically endangered (CR) since 2006 according to Peru's Categorization of Threatened Species of Wild Flora (D.S. 043-2006-AG), and there is a proposal to declare it an Intangible Plant (Rodríguez et al., 2007). Thus, this study was aimed to characterize the morphological variability of *C. scabridum* fruits and seeds, assess seed germination percentage, and analyze the species' vulnerability status. Understanding these aspects is crucial for informing conservation strategies, given the species' critically endangered status and its ecological significance within the Seasonally Dry Tropical Forest. This research not only contributes to the scientific knowledge of *C. scabridum* but also provides essential data to support efforts in habitat preservation and sustainable management of this valuable species.

2. Materials and Methods

2.1 Study area

The study area covered 12 of the 16 km segments extending from the old north Pan-American highway to Salas town (Lambayeque Department, Peru) (6°17'58.56"S-79°45'20.82"W / 6°16'29.98"S-79°36'26.71"W) (Figure 1). This included a 25 m width on either side of the road, covering a total area of 60 hectares. A larger study area was not feasible due to private land ownership marked by barbed wire fences.

2.2 Plant material

In the study area, branches with mature leaves and fruits (pseudoamphisarcum) were collected from 12 different adult plants of *C. scabridum*, considering them as accessions (S-1 to S-12). The largest leaves were selected. The fruits were selected by size (length and diameter), shape and external characteristics. In some cases, the fruits were collected from branches of the few plants that emerged from the barbed wire fences towards the road and in other cases from regrowth of trees cut from the base. All the collected samples were of the best morphological, physiological and phytosanitary conditions, and the sampling were carried out in February and March 2023.

In the laboratory, for each accession, 10 samples were taken to measure the leaves, fruits and seeds from each organ. The size of fruits in length and diameter (together with the gynophore) were measured with a ruler and millimeter tape and the weight with a digital analytical balance (SF-400); the size of largest leaves in length and width (lamina), and the length (petiole) were also measured with a millimeter ruler, and the size and weight of seeds were taken with a Vernier caliper (MT-00851) and the same digital analytical balance. Likewise, although typically used for pollen morphology, the Erdtman classification (Erdtman, 1952) was adapted to determine the polar and equatorial axes of the fruits.

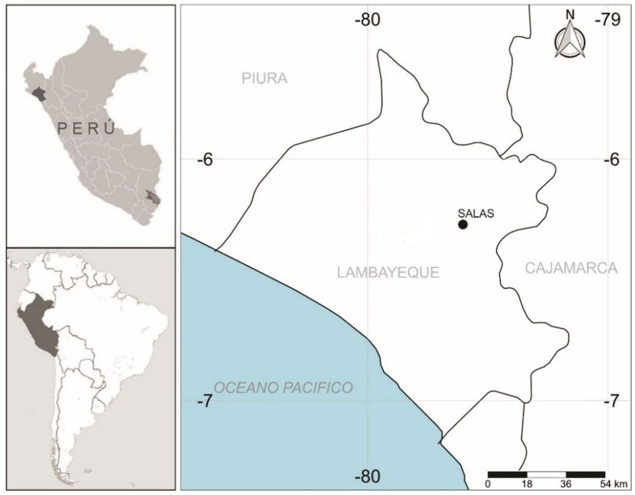

Figure 1. Map of Lambayeque Department, in Northern Peru and the location of the Salas town

2.3 Seed germination

The seed culture was carried out two weeks after the fruits were collected. In seed germination, two fruits per accession were randomly selected, selecting 30 seeds per fruit, considering their best morphological characteristics. Only in the case of accession S-5, three fruits were used to make up the number of 30 seeds. The seeds were sown in plastic trays containing culture soil-river sand (2:1) at a depth of one cm and watered periodically. The germination evaluations were carried out between 10 and 15 days after sowing with the emergence of the radicle and the apical shoot. After 30 days, the seedlings were established in 30x6 cm bags until their definitive transfer to field conditions.

2.4 Current conservation status and vulnerability of *C. scabridum*

In determining the current state of conservation and vulnerability of *C. scabridum*, not only the evaluation carried out on 600 ha along the road was considered, but we also demonstrated by photographic comparison the degradation of the habitat, using our own photographs (taken in 2023) versus images taken using the Google Maps - Street View tool, from previous years (data available on the platform) and purely using satellite photographic captures between past and recent periods, along with Google Maps images of the study area and territories that shared similar habitats where *C. scabridum* grew, within the Lambayeque region.

2.5 Statistical analysis

Firstly, we conducted a normality analysis on all data variables using the Shapiro-Wilk test. As the data did not meet the assumptions of normality and heteroscedasticity, even after applying logarithmic or square root transformations, we treated the variables as non-parametric and used the untransformed data for analysis. We calculated the median and interquartile range (IQR) for each variable related to the fruits, leaves, and seeds of each accession. To assess significant differences among the accessions and their variables, we performed an analysis of variance (ANOVA) utilizing the Kruskal-Wallis test, followed by pairwise comparisons with Duncan's Post-Hoc test.

Additionally, to examine relationships between the number, weight, and size of seeds across the 12 accessions of *C. scabridum*, we employed Pearson correlation analysis. All analyses were conducted using R software version 4.3 (R Core Team, 2023).

3. Results and Discussion

3.1 Morphological characteristics

Figure 2 shows the morphological variation of the fruits sampled from 12 accessions of *C. scabridum* collected on the detour route to the Salas locality (Lambayeque). Details about the length and diameter of fruits, length of the gynophore, length and width of the leaf, as well as number, weight, size and length of seeds are shown in different Tables prepared for this purpose.

Figure 2. Morphological variation of *C. scabridum* fruits from 12 accessions (S-1 to S-12) collected in Salas, Lambayeque (scale bar: 4 cm)

3.1.1 Fruit size and shape

The Kruskal-Wallis test demonstrated the occurrence of significant differences between accessions for all fruit variables (Table 1 and Figure 3). For the variables, length and diameter of the fruit, the accessions S-3 and S-12 presented significant differences compared to other accessions. For the gynophore, accession S-4 was the most prominent and significantly different. The average length and diameter of the fruits and the average length of the gynophores were 10.5 cm, 5.4 cm and 7.0 cm, respectively.

The polar axis: equatorial axis relationship (P/E) of the fruits indicated that of the 12 accessions evaluated, six were of the prolate type, five were per prolate and only one was sub prolate. In no case was the prolate spheroidal type found (Table 2). The highest L:D ratio was found in accession S-6 with 2.61 and the lowest in accession S-1 with 1.32.

3.1.2 Leaf size

The Kruskal-Wallis test also demonstrated the occurrence of significant differences between accessions for all the leaf length and width variables (Table 1 and Figure 4). Contrary to the fruit variable results, leaf parameters were more homogeneous. However, the S-8 accession displayed superior prominence among all the evaluated accessions with 23.5 cm length and 4.0 cm width. Accession S-12 reached a leaf length similar to accession S-8 with 23.0 cm, but the width was significantly greater at 6.6 cm. Only the petioles, with an average 2.0 cm, did not show significant differences between accessions.

Table 1. Fruit and leaf medians of 12 accessions of *C. scabridum* collected in Salas, Lambayeque

Accession	Fruit			Leaf		
	Length (cm)	Diameter (cm)	Gynophore (cm)	Leaf Blade		Petiole
				Length (cm)	Width (cm)	Length (cm)
S-1	9.0(1.4)^{a}	6.5(0.5)^{a}	6.8(0.3)^{a}	17.5(2.3)^{ab}	4.7(0.2)^{ab}	2.0(0.0)^{a}
S-2	10.3(2.1)^{a}	5.9(1.1)^{abcd}	7.0(0.2)^{bcde}	17.2(0.8)^{abc}	5.1(1.0)^{abc}	2.1(0.4)^{a}
S-3	14.9(0.7)^{c}	6.8(0.4)^{a}	7.0(0.3)^{bce}	20.5(1.0)^{abc}	4.5(0.8)^{ab}	2.0(0.0)^{a}
S-4	8.9(0.5)^{a}	4.8(0.3)^{de}	9.2(0.3)^{d}	16.2(1.8)^{a}	5.0(0.2)^{abc}	2.0(0.0)^{a}
S-5	9.5(0.4)^{a}	4.0(0.3)^{e}	7.0(0.5)^{abe}	22.0(0.0)^{bc}	5.3(0.5)^{ac}	2.0(0.2)^{a}
S-6	13.3(0.5)^{bc}	5.1(0.7)^{cde}	7.0(0.2)^{abe}	19.5(1.0)^{abc}	5.5(0.2)^{ac}	2.0(0.2)^{a}
S-7	11(1.1)^{abc}	5.8(0.4)^{abcd}	6.7(0.4)^{ab}	17.4(3.2)^{abc}	4.1(0.4)^{b}	2.0(0.2)^{a}
S-8	9.0(1.2)^{a}	5.2(0.1)^{cde}	7.0(0.4)^{bcde}	23.5(0.8)^{c}	4.0(0.2)^{b}	2.0(0.0)^{a}
S-9	13.3(0.9)^{bc}	5.3(0.2)^{bcde}	8.2(0.9)^{cde}	17.2(0.5)^{abc}	4.9(0.2)^{abc}	2.0(0.1)^{a}
S-10	9.5(1.1)^{a}	5.2(0.6)^{cde}	4.0(0.1)^{f}	16.3(1.3)^{abc}	4.4(0.4)^{c}	2.1(0.1)^{a}
S-11	9.7(0.9)^{abc}	5.8(0.4)^{abc}	6.5(0.6)^{ab}	15.5(0.9)^{a}	5.0(0.2)^{abc}	2.0(0.0)^{a}
S-12	14.3(3.1)^{abc}	6.3(0.6)^{ab}	8.7(0.9)^{cd}	23.0(0.3)^{bc}	6.6(0.6)^{c}	2.0(0.0)^{a}
Average	10.5(2.2)	5.4(0.7)	7.0(1.2)	18.1(2.8)	4.8(0.7)	2.0(0.1)

Values with different superscript letters within the same column indicate significant differences (Kruskal-Wallis test for data with non-parametric distribution). Significance levels adapted by Duncan's Post-Hoc test P<0.05). The IQR (Interquartile range) can be seen between parentheses.

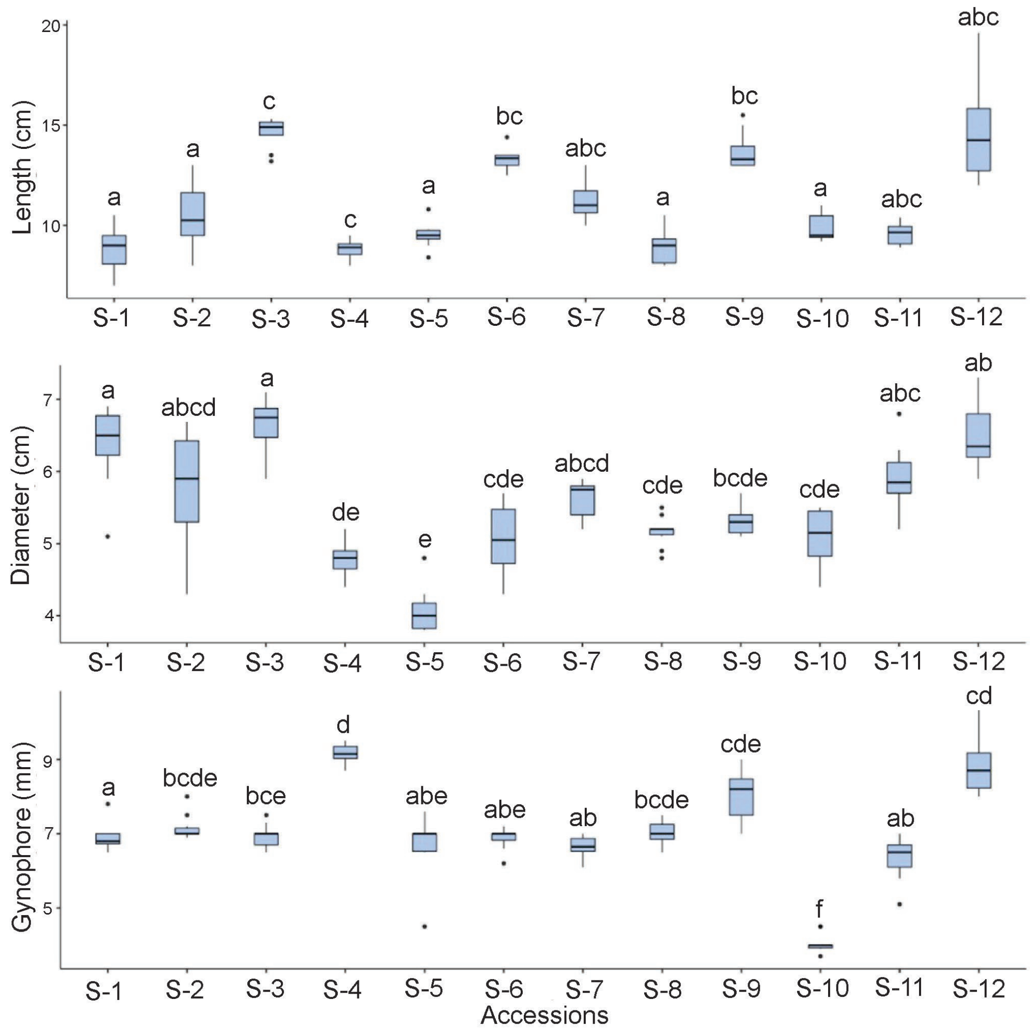

Figure 3. Boxplot of the Kruskal-Wallis ANOVA analysis for the fruit variables of each accession. For each boxplot, the center line represents the median. The limits represent the upper and lower quartiles, the black circles are outliers (a value above the interquartile range above or below the interquartile values), and the black lines outside the box are the whiskers, which extend from the interquartile ranges to the maximum values that are not classified as outliers. Different letters represent significant difference at $p < 0.05$.

Table 2. Polar axis (P) and equatorial axis (E) relationship in fruits of 12 accessions of *C. scabridum* collected in Salas, Lambayeque. The determination was adapted from Erdtman's classification established for the shape of pollen grains (Erdtman, 1952).

Accession	Fruit Length (cm)	Fruit Diameter (cm)	Length-diameter Relation P:E	Shape of Fruit
S-1	9.0±1.4[a]	6.8±0.5[a]	1.32	Sub prolate
S-2	10.3±2.1[a]	5.9±1.1[abcd]	1.75	Prolate
S-3	14.9±0.7[c]	6.8±0.4[a]	2.19	Per prolate
S-4	8.9±0.5[a]	4.8±0.3[de]	1.85	Prolate
S-5	9.5±0.4[a]	4.0±0.3[e]	2.36	Per prolate
S-6	13.3±0.5[bc]	5.1±0.7[cde]	2.61	Per prolate
S-7	11.0±1.1[abc]	5.8±0.4[abcd]	1.90	Prolate
S-8	9.0±1.2[a]	5.2±0.1[cde]	1.73	Prolate
S-9	13.3±0.9[bc]	5.3±0.2[bcde]	2.51	Per prolate
S-10	9.5±1.1[a]	5.2±0.6[cde]	1.83	Prolate
S-11	9.7±0.9[abc]	5.8±0.4[abc]	1.62	Prolate
S-12	14.3±3.1[abc]	6.3±0.6[ab]	2.27	Per prolate
Average	10.5±2.2	5.4±0.7	1.94	

Prolate spheroidal (P - E ratio between 1.0 and 1.14); Sub prolate (P - E ratio between 1.14 and 1.33); Prolate (P - E ratio between 1.33 and 2.0); Per Prolate (P - E ratio between > 2.0). ± = standard deviation.

3.1.3 Fruit weight

The fruit weight of *C. scabridum* also showed a wide variation between accessions. The highest weight was recorded in accession S-3 with 170.1 g on average and a range between 231 g and 109 g, followed by accession S-2 with 143.2 g. The lowest weight was recorded in accession S-5 with 35.0 g on average and a range between 50.0 and 22.0 g, followed by accession S-10 with 48.9 g (Figure 5).

3.1.4 Number, weight and size of seeds

In Table 3 and Figure 6, the Kruskal-Wallis test showed significant differences between accessions for all seed variables ($p<0.05$). Thus, the number of seeds per fruit is also another highly variable characteristic of *C. scabridum*, where the highest number of seeds, 126 and 124, were recorded in accessions S-3 and S-2, respectively, while the lowest number of seeds was recorded in accession S-5 with only 26 seeds per fruit. The variation in the seed weight was registered between 5.7 g, in accessions S-9 and S-10, and 3.1 g in accessions S-2 and S-11. Likewise, the seed size varied between 15.2 mm in accession S-1 and 12.1 mm in accession S-7.

On the other hand, the Pearson correlation for the seeds (Figure 7) demonstrated the existence of a positive correlation between weight and size of seeds (0.7), which indicated that the larger the size of seeds, the greater the seed weight. Likewise, a negative correlation was also observed between number of seeds and weight (-0.45), which indicated that the fewer seeds the fruit has, the lower the weight of seeds.

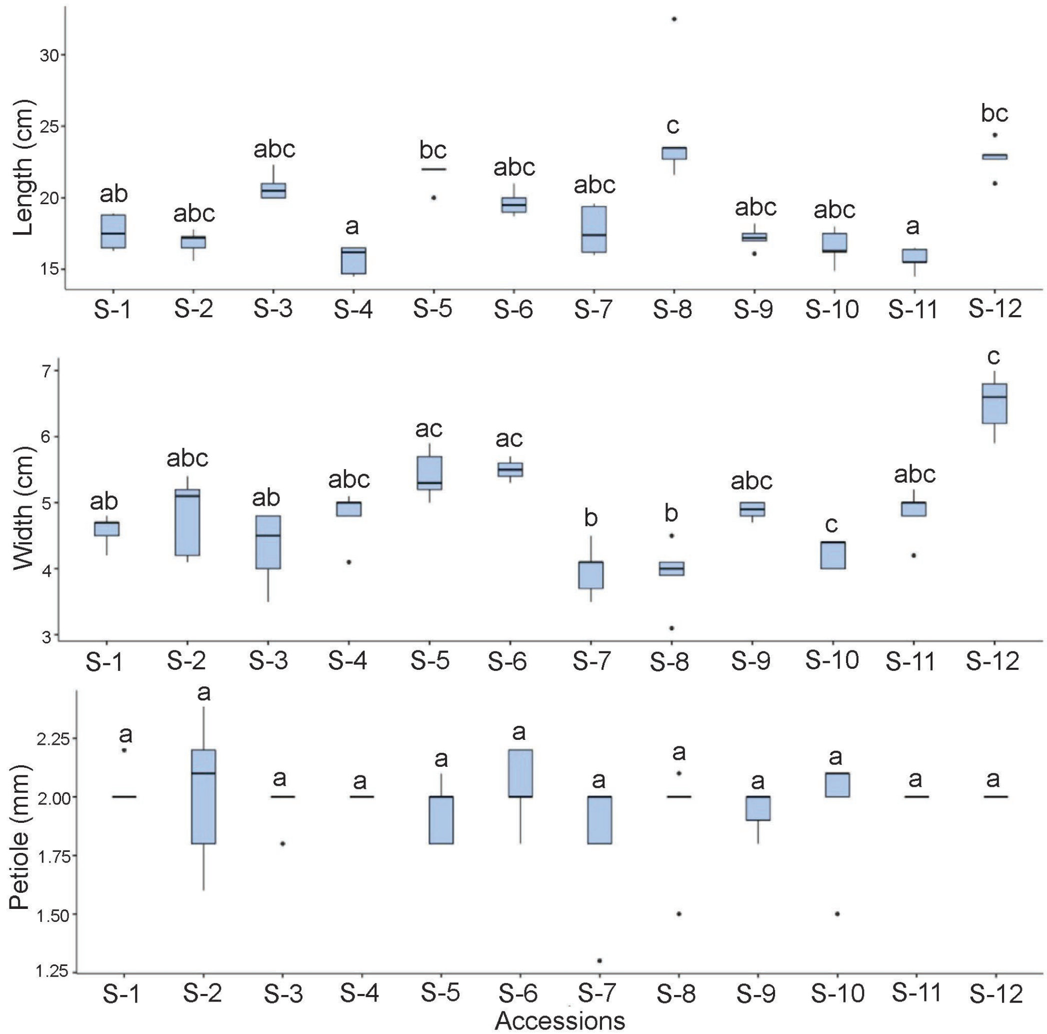

Figure 4. Boxplot of the Kruskal-Wallis ANOVA analysis for the leaf variables of each accession. For each boxplot, the center line represents the median. The limits represent the upper and lower quartiles, the black circles are outliers (a value above the interquartile range above or below the interquartile values), and the black lines outside the box are the whiskers, which extend from the interquartile ranges to the maximum values that are not classified as outliers. Different letters represent significant difference at $p < 0.05$.

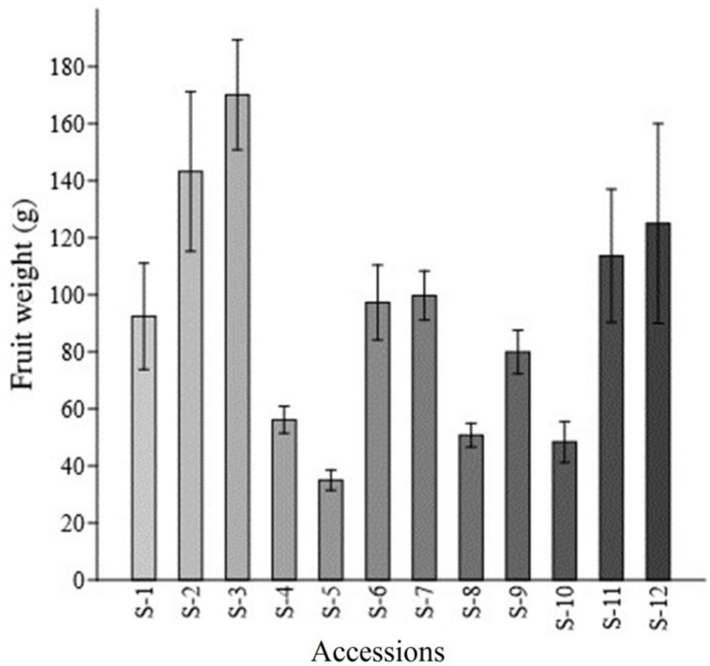

Figure 5. Histogram of the weight of the fruits of 12 accessions of *C. scabridum* collected in Salas, Lambayeque, Peru. Whiskers inside and outside the bars represent the minimum and maximum values for each accession.

Table 3. Quantitative characteristics of the *C. scabridum* seeds of 12 accessions collected in Salas, Lambayeque

Accession	Seeds/Fruit (No)	Seed Weight x 10 (g)	Seed Size (mm)
S-1	95(19.8)^{ab}	3.7(0.5)^{a}	14.9(0.2)^{ab}
S-2	124(12)^{a}	3.1(0.3)^{ab}	13.1(0.3)^{ab}
S-3	126(10.5)^{a}	3.5(0.5)^{ab}	13.3(0.8)^{ab}
S-4	76(13.5)^{a}	3.3(0.3)^{ab}	13.4(0.4)^{ab}
S-5	26(8)^{b}	4.1(0.5)^{ab}	13.7(0.7)^{ab}
S-6	107(11.5)^{ab}	3.7(0.1)^{ab}	13.0(0.2)^{ab}
S-7	74(16.5)^{ab}	3.5(0.3)^{ab}	12.1(0.6)^{a}
S-8	64(10.5)^{ab}	4.3(0.2)^{ab}	13.5(0.2)^{ab}
S-9	53(6)^{ab}	5.7(0.5)^{a}	15.2(0.4)^{b}
S-10	53(8.5)^{ab}	5.7(0.8)^{a}	14.5(0.6)^{ab}
S-11	99(19.5)^{ab}	3.1(0.1)^{b}	13.0(0.2)^{ab}
S-12	95(17)^{ab}	3.9(0.4)^{ab}	12.8(0.2)^{ab}
Average	**80(29.8)**	**3.7(0.8)**	**13.3(0.7)**

Values with different superscript letters within the same column indicate significant differences (Kruskal-Wallis test for data with non-parametric distribution, significance levels adapted from Duncan's Post-Hoc test P<0.05). The IQR (interquartile range) can be seen between parentheses.

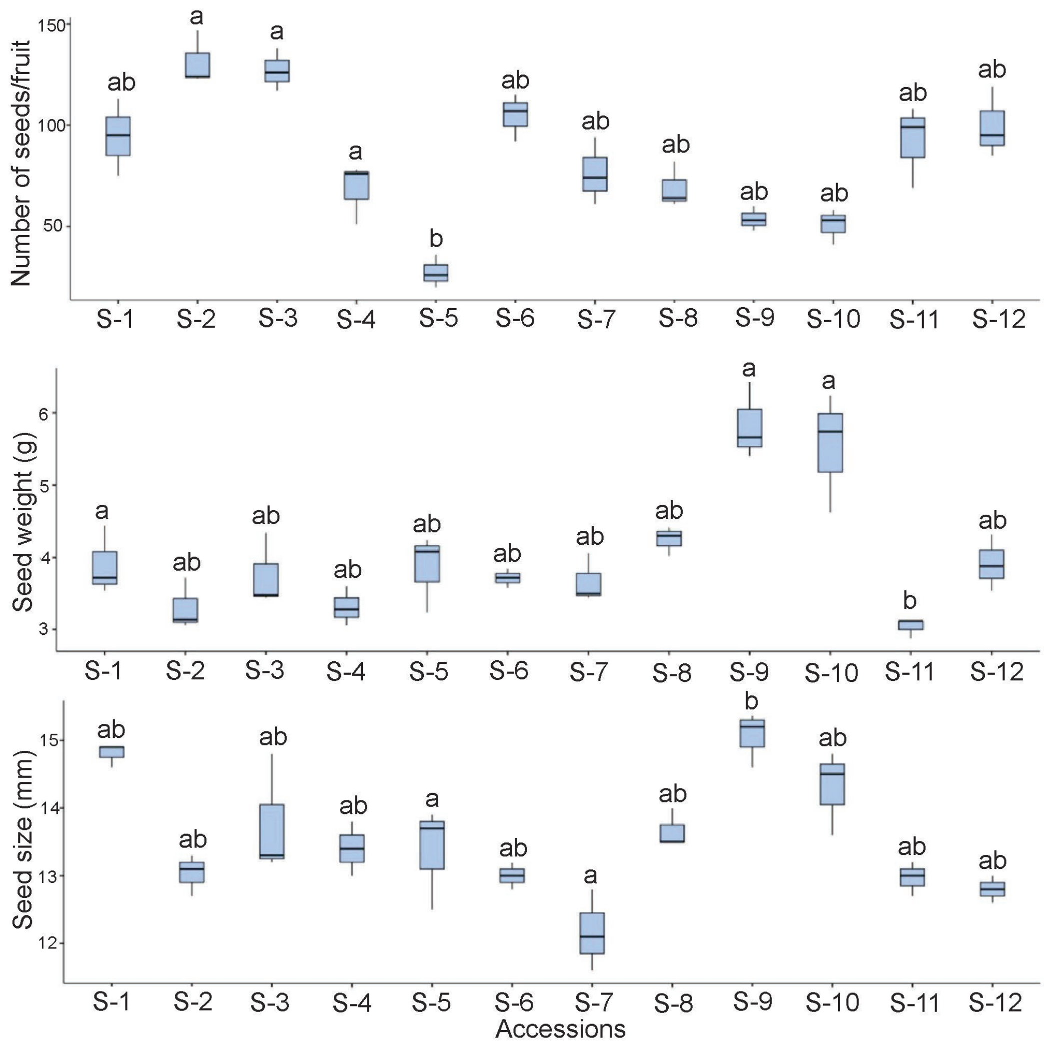

Figure 6. Boxplot of the Kruskal-Wallis ANOVA analysis for the seed variables of each accession. For each boxplot, the center line represents the median; the limits represent the upper and lower quartile; black circles are outliers (a value above the interquartile range above or below the interquartile values); and the black lines outside the box are the whiskers, which extend from the interquartile ranges to the maximum values that are not classified as outliers. Different letters represent significant difference at $p < 0.05$.

3.2 Seed germination

Seed germination varied significantly between accessions and even between the fruits of each accession. In accession S-6, 100% seed germination was reached on average and in accession S-12 the lowest germination rate was 25% on average. However, the average germination rate in all evaluated accessions was similar in each fruit with 70.3% and 73.1%, respectively (Table 4 and Figure 8).

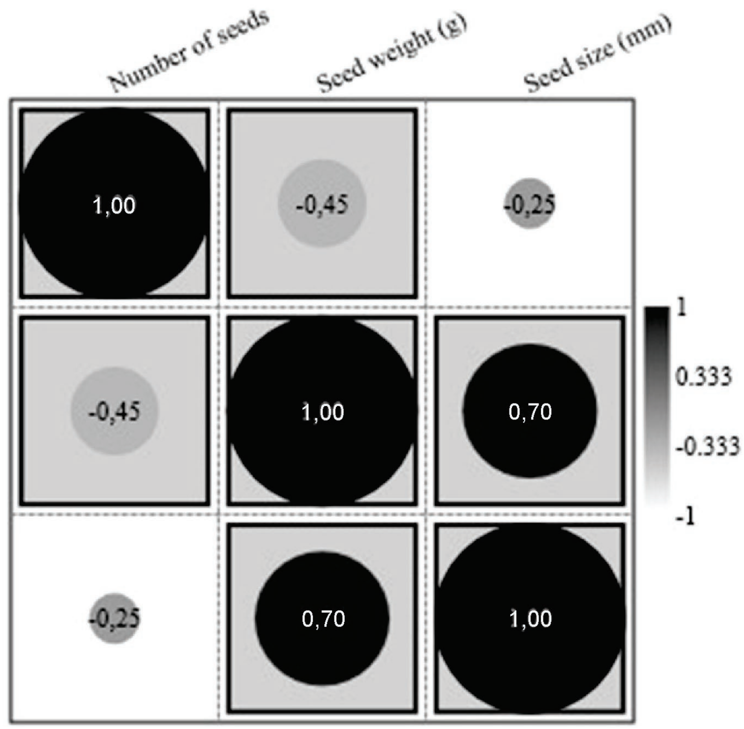

Figure 7. Pearson correlation between the number, weight and size of the seeds of 12 accessions of *C. scabridum*, collected in Salas, Lambayeque. Circles with highlighted squares indicate significant correlation (P<0.05).

Table 4. Seed germination of two fruits of *C. scabridum* of 12 accessions, collected in Salas, Lambayeque

Accession (No)	Evaluation No (%)		Total Evaluation (%)
	Fruit 1	Fruit 2	
S-1	18 (60.0)	27 (90.0)	75.0
S-2	15 (50.0)	12 (40.0)	45.0
S-3	19 (63.3)	26 (86.7)	75.0
S-4	26 (86.6)	30 (100.0)	93.3
S-5	21 (70.0)	9 (30.0)	50.0
S-6	30 (100.0)	30 (100.0)	100.0
S-7	25 (83.3)	21 (70.0)	76.7
S-8	30 (100.0)	25 (83.3)	91.7
S-9	21 (70.0)	30 (100.0)	85.0
S-10	11 (36.7)	25 (83.3)	60.0
S-11	26 (86.7)	24 (80.0)	83.4
S-12	11 (36.7)	4 (13.3)	25.0
Average	**70.3**	**73.1**	**71.7**

Evaluation: 10 to 15 days after culture of 30 seeds per accession

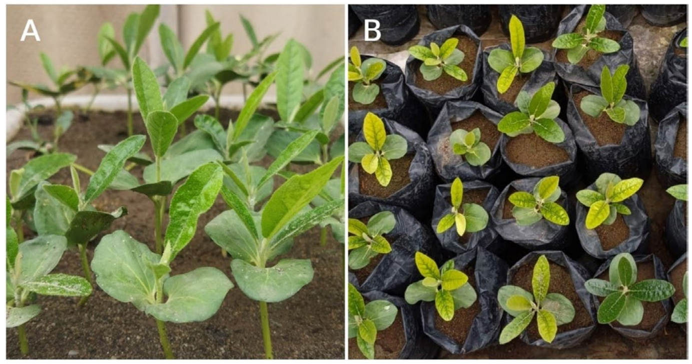

Figure 8. Seed germination of *C. scabridum* from 12 accessions, collected in Salas, Lambayeque, Peru. (A) Seedlings after 15 days of germination, (B) Seedlings after 60 days of germination.

3.3 Deforestation and vulnerability

Figure 9 (A, C, and E) shows images from the Google Street View tool depicting a section of the SDTF along the diversion route to Salas, Lambayeque, in 2014. These images reveal forest formations and isolated individuals of *C. scabridum*, along with *Neltuma limensis* and *Vachellia macracantha*, indicating that deforestation processes had begun years prior. In contrast, Figure 9 (B, D, and F), taken in 2023, illustrates the current state of the forest, which is nearly entirely depredated, with land being cleared for cultivation of various food crops. Figure 9E highlights a mound of recently cut *C. scabridum* trunks and branches, while Figure 9F features a *Zea mays* L. plantation in the background. Additionally, Figure 10A presents a panoramic aerial view (from Google Maps) of a still-consistent but fragmented forest formation, whereas Figure 10B reveals significant tree cover loss.

Deforestation was observed not only in the Salas locality but also in other areas of the Lambayeque region. Figure 11 illustrates several localities that have experienced significant deforestation over the past 20 years (2002-2022), with *C. scabridum* being one of the most affected species.

The shape of fruits in *Colicodendron scabridum* was described by some authors as ovoid-oblong (Macbride, 1938; Mendoza, 2012), oblong or narrowly ovoid (Rodríguez et al., 2007), oblongoid ovoid or slightly asymmetrical ellipsoidal shape of 8-15 x 5-9 cm (Cornejo & Iltis, 2008), or 5-10 x 4-8 cm (Salazar, 2014), which are measures that coincide with the data shown in this study, which was 8.9-14.9 x 4-6.8 cm (average 10.5 x 5.4 cm), Gynophore of 7-10 x 0.4-0.6 cm reported by Cornejo & Iltis (2008) was similar to the findings in the present study, which was 4-9.2 cm (average 7 cm). In this regard, Font Quer (1985) indicates that oblong means longer than wide or excessively long; ovoid is an egg-shaped figure and applies to solid fruits and seeds, three-dimensional and ellipsoidal refers to the shape of an ellipse. As for definition of oblong, ovoid and ellipsoidal was too imprecise to define a shape, so an adaptation of Erdtman's classification used to determine the shape of pollen grains was proposed: spheroidal with the main variants, oblate and prolate (Erdtman, 1952). Thus, most of the fruits of the 12 evaluated accessions of *C. scabridum* were classified as prolate and per prolate.

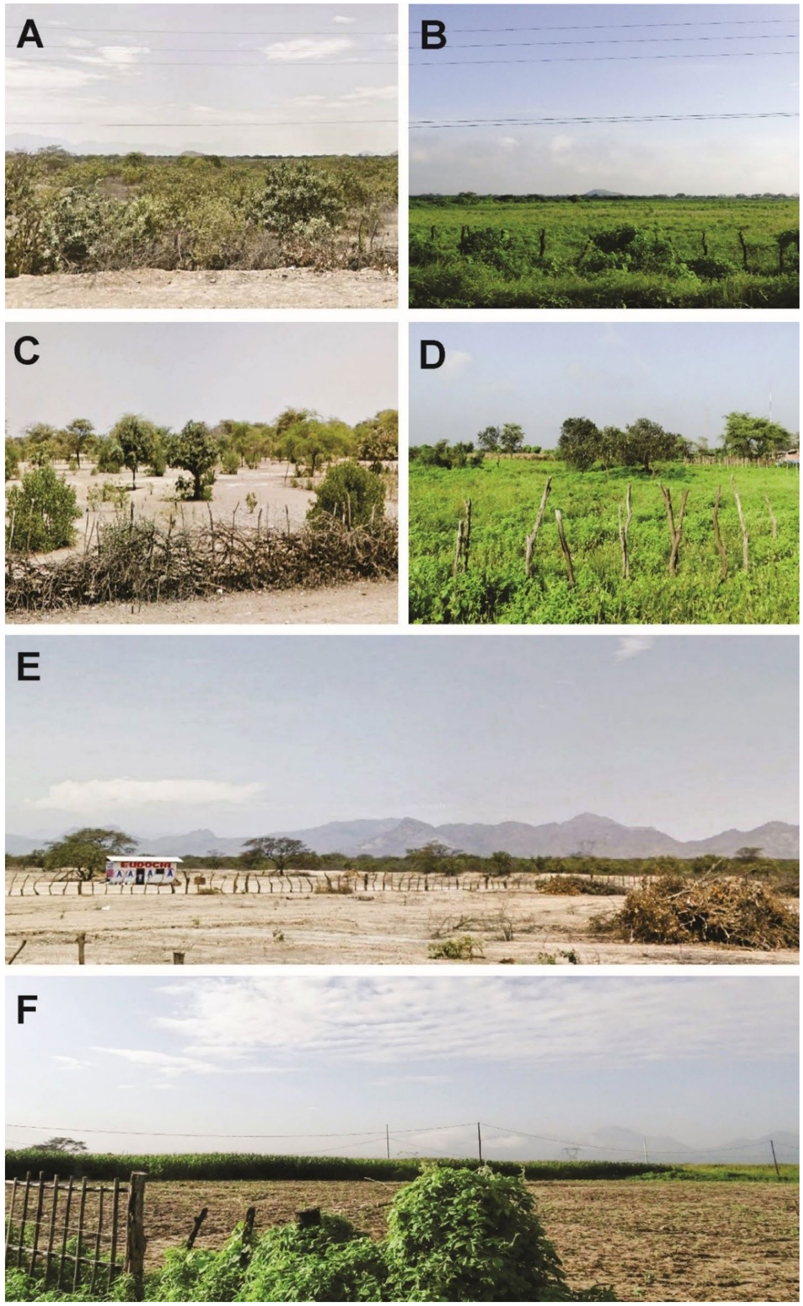

Figure 9. Change of use of SDTF areas in Salas District in 9 years, period 2014 from Google Maps Street View (A, C and E) and 2023 with own photographs (B, D and F) with deforestation of "sapote" and other tree species: A-B. Near Humedades town (6°17'47.69"S 79°42'57.23"W), (C-D) Near to the Salas Crossing (6°17'59.42"S 79°45'13.24"W), (E-F) Salas-Humedades Detour Route (6°17'54.64"S 79°44'8.31"W)

Figure 10. Decrease in SDTF forest cover on the Salas-Humedades bypass road route, Lambayeque, Peru (6°18'5.36"S 79°44'17.10"W) from Google Maps: (A) Year 2010, (B) Year 2019.

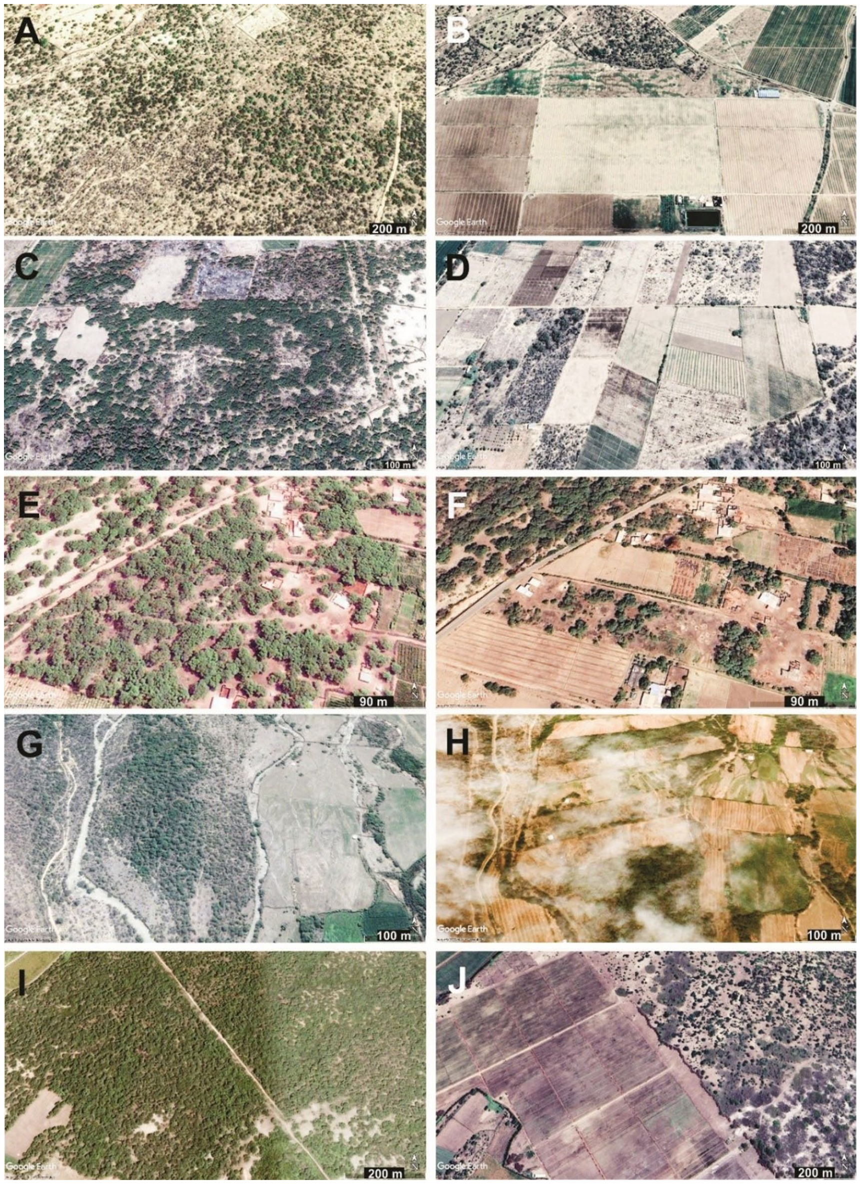

Figure 11. Samples of SDTF deforestation in the habitat of *C. scabridum*, in Lambayeque region: (A) May 2007, 4 km east of Santa Rosa, Olmos District, (B) February 2023, 4 km east of Santa Rosa, Olmos District (16 years later), (C) December 2001, 1 km south of Tambo Real, Pítipo District, (D) April 2021, 1 km south of Tambo Real, Pítipo District (20 years later), (E) March 2010, Las Salinas, Túcume District, (F) February 2023, Las Salinas, Túcume District (13 years later) (G) September 2002, 1 km west of Cerrillos, Chongoyape District, (H) December 2022, 1 km west of Cerrillos, Chongoyape District (20 years later), (I) January 2003, 5 km southwest of La Otra Banda, Zaña District, (J) January 2023, 5 km southwest of La Otra Banda, Zaña District (20 years later).

In relation to the leaves, Cornejo & Iltis (2008) indicated that they were lanceolate to oblong in shape, measuring (6-)8-23 x 2-7 cm and petioles 8-30 mm, while in this work the leaves measured 15.5-23.5 cm length x 4.0-6.6 cm width (average 18.1 x 4.8 cm), with petioles of 20 mm. These results indicated slightly differences in leaf size, especially in the size of the petiole.

Fruit weight was one of the characteristics with the greatest variability among the accessions evaluated, registering an average as high as 170.1 g in the S-3 accession and an average as low as 35.0 g in the S-5 accession, where only five accessions exceeded 100 g in weight. Unfortunately, fruit weight is a parameter that is rarely reported in plant descriptions, and none was available for *Colicodendron scabridum*, which was unlike other well-known species of the family such as *Capparis spinosa* (Pascual et al., 2008).

Moreover, the number of seeds per fruit, among accessions, also showed a wide variability, with an average as high as 126 seeds in the S-3 accession and an average as low as 26 seeds in the S-5 accession, establishing a direct relationship between fruit weight and the number of seeds formed. Some authors reported only between 15 to 60 seeds (Cornejo & Iltis, 2008) and 50 to 100 seeds per fruit (Rodríguez et al, 2007). Meanwhile, the weight and shape of the seeds in this study coincided with the results presented by Cornejo & Iltis (2008), with seeds of subspherical-reniform shape and size between 1 x 1.5 cm. An extensive study on the morphology of fruits, seeds and embryos of Argentinian Capparaceae was carried out by Franceschini and Tressens (2004), although none of the species studied had fruits similar to *C. scabridum*.

The germination rate of *C. scabridum* seeds, whether recently collected or naturally detached from the plant, was approximately 100%, without the need for scarification or growth regulators. It was found that soaking the seeds in cold water for 24 h was sufficient before sowing them directly into substrate-filled bags (Ferreyra, 1986). Seed viability was oberved to range from 3 to 8 years, and propagation through cuttings was feasible, demonstrating significant natural regeneration and regrowth capacity, albeit with a slow growth rate (Ferreyra, 1986; Cossíos, 2006). A recent study investigated the germination of viable *C. scabridum* seeds using three types of residual biomass—corncob, coffee husk, and shrimp exoskeleton—at varying concentrations to assess their impact on seed germination and seedling growth under greenhouse conditions. The findings indicated that only the type and concentration of biochar significantly influenced seed germination and increase in seedling biomass (Herrera et al., 2018).

It is possible that the dimensional variations is because individual plants have an adaptability to the environment where they develop, being able to show phenotypic plasticity, as has been evidenced in other species such as *Cynophalla flexuosa* (Torrecilla et al., 2009) and *Capparis spinosa* L. (Chedraoui et al., 2017) where these characteristics have even led to the establishment of infraspecific taxa (Fici, 2014).

Regarding seed germination, in the study presented, the germination rate, after 10 to 15 days of evaluation, was around 70.0%, without performing any type of scarification and without prior soaking of the seeds. There were reports on germination rates of up to 98%, under optimal conditions of temperature, humidity and light, in fruits recently detached from the plant, and 65% with physical scarification treatments by softening with distilled water at various temperatures and with sulfuric acid conc., without any of these tests surpassing the control (FAO, 2007). Tests carried out in our laboratory showed that *C. scabridum* seeds, collected 2 to 3 years ago, showed germination rates around 40% (data not shown in the Table). On the other hand, tests carried out under laboratory conditions with various concentrations of gibberellic acid (GA3) reached germination rates between 86% and 94%, although the germination speed was greater than 31 days (Paredes, 1993).

Although interactions between plants and animals are very important in the dispersal and germination of seeds, there have been very few studies carried out in this area for *C. scabridum*. In a study carried out in the Lomas del Cerro Campana Private Conservation Area, La Libertad, Peru, around 43% of vertebrate species were reported, including reptiles, birds and mammals, where several of these species would act as seed dispersers through their digestive tracts (Tafur et al., 2021). In *Capparis spinosa*, the effects of the passage of seeds through *Teratoscincus roborowskii Bedriaga* lizard digestive tracts on the seed coats, water uptake rates and germination rates were studied, and it was observed that the process improved the permeability of the seed coats, promoted fast water uptake, broke seed dormancy and increased the seed germination rate (Yang et al., 2021).

The vulnerability and risk of genetic erosion of a species can occur due to several factors such as overexploitation for domestic and commercial uses, reduction in the extent of the forest with indiscriminate logging, and the entry of so-called industrial crops mostly for export, overgrazing, the increase in informal and illegal mining, the attack of pests and diseases, among others. This situation can be aggravated by difficulties or peculiarities that a species has in its sexual and vegetative propagation. *Capparis spinosa*, a shrubby, xerophytic and perennial Capparaceae, and widely distributed in the Mediterranean basin, has been considered at risk due to very low or unsatisfactory seed germination rates, hybridization between wild and cultivated genotypes, overgrazing and overexploitation for domestic uses (Sottile et al., 2020), on the contrary, the seed germination rate in *Colicodendron scabridum* was quite high (Rodríguez et al., 2007). Regarding vegetative propagation, Guzmán and Testaseca (1986) obtained root cuttings of *C. scabridum* with indole-3-butyric acid (IBA) 4,000 ppm, and 6,000 and 9,000 mg L^{-1} (IBA) with leafy and leafless semi-hardwood cuttings of *Capparis spinosa* (Ramezani-Gask et al., 2008).

Thus, it is interesting to know that *Colicodendron scabridum* is highly propagated by both seed and asexually, these indications should set the guidelines for the establishment of afforestation and reforestation plans, where the Peruvian State should participate with commitment, as well as the companies directly responsible for the main drivers of change in the habitat of this species detected in the region: crops of *Vaccinium corymbosum* L. (blueberry), *Selenicereus undatus* (Haw.) D.R.Hunt, *S. megalanthus* (K.Schum ex Vaupel) Moran ("pitahaya"), *Vitis vinifera* L. (grape), *Persea americana* Mill. (avocado), *Musa* spp. (banana), and *Oryza sativa* L. (rice), being highly required in the international market for organic fruit trees and grains.

4. Conclusions

This study demonstrated significant morphological variability of *Colicodendron scabridum* samples collected from Salas, Lambayeque, Peru. This variability was observed in fruit (greatest): size, shape, weight, seed count, and leaf (lowest). The average seed germination rate was 70%, though it varied between 25% and 100% among accessions.

Despite the species' effective seed dispersal mechanisms, which are aided by its edible fruits consumed by various vertebrates in the SDTF, *C. scabridum* faces significant threats. These include habitat destruction due to industrial agriculture and unsustainable logging practices aimed at exploiting its wood for local crafts. The study provides compelling evidence of habitat degradation over the past 10 to 15 years, not only in Salas but also across the broader Lambayeque region.

This alarming trend is echoed in other northern coastal regions of Peru, such as Cajamarca, Piura, and Tumbes, where the SDTF extends. Given the urgency of the situation, it is crucial to implement protective measures and promote reforestation efforts to preserve this vital ecosystem, especially in the Pampas de Olmos (Lambayeque), Chulucanas and Morropón (Piura) and Jaén (Cajamarca) as well as the Protected Natural Areas (SDTF) in these regions.

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6. Authors' Contributions

GEDP designed and performed research; collected data; wrote, revised paper, coordinated logistical support and maintained research facilities. CVD collected data, perform the experiment, BEI collected data, perform map tools, revised paper, submiting corrections. FZD analytic tools, statistical analysis, analyzed data.

7. Conflicts of Interest

The authors declare no conflict of interest.

ORCID

Guillermo E. Delgado-Paredes https://orcid.org/0000-0001-5769-8209

Cecilia Vásquez-Díaz https://orcid.org/0000-0002-3229-5048

Boris Esquerre-Ibañez https://orcid.org/0000-0003-2283-8106

Felipe Zuñe-Da Silva https://orcid.org/0000-0001-5810-9031

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