Research Square

Preprints are preliminary reports that have not undergone peer review.
They should not be considered conclusive, used to inform clinical practice,
or referenced by the media as validated information.

The agrobiodiversity functional types of shagras (Indigenous home gardens) in the Cumbal Indigenous Reserve, Nariño, Colombia

Claudia Patricia Villota Caicedo
claudia.villota@uned.cr
Distance State University
Israel Navarrete
International Potato Center
Olga Yanet Pérez Cardona
Corporación Colombiana de Investigación Agropecuaria – AGROSAVIA
Zahara L. Lasso-Paredes
Corporación Colombiana de Investigación Agropecuaria – AGROSAVIA
Maryory Maricela Cadena Guerrero
Corporación Colombiana de Investigación Agropecuaria – AGROSAVIA
Bayardo Yepes Chamorro
Corporación Colombiana de Investigación Agropecuaria – AGROSAVIA
Maria Gladys Rosero Alpala
Corporación Colombiana de Investigación Agropecuaria – AGROSAVIA
Fabio Ernesto Martínez Maldonado
Corporación Colombiana de Investigación Agropecuaria – AGROSAVIA
Vilma Hualla
International Potato Center
Javier Ochoa
International Potato Center
Stef de Haan
International Potato Center

Research Article

Keywords: shagra, home gardens, agrobiodiversity, use typology, in situ conservation

Posted Date: November 16th, 2026

DOI: https://doi.org/10.21203/rs.3.rs-11570476/v1

License: This work is licensed under a Creative Commons Attribution 4.0 International License.
Read Full License

Additional Declarations: No competing interests reported.

The agrobiodiversity functional types of shagras (Indigenous home gardens) in the Cumbal Indigenous Reserve, Nariño, Colombia

Claudia Patricia Villota Caicedo[1,2], *Israel Navarrete[4], Olga Yanet Pérez[2], Zahara L. Lasso-Paredes[2], Maryory Cadena Guerrero[2], Bayardo Yepes Chamorro[2], María Gladys Rosero Alpala[2], Fabio Ernesto Martínez-Maldonado[2], Vilma Hualla[3], Javier Ochoa[3], Stef de Haan[3]*

[1] Doctorado en Ciencias Naturales para el Desarrollo (DOCINADE), Universidad Estatal a Distancia (UNED), Costa Rica.

[2] Corporación Colombiana de Investigación Agropecuaria (AGROSAVIA), Km 14 Vía Mosquera, Bogotá, Cundinamarca, Colombia.

[3] International Potato Center (CIP), Lima, Peru.

[4] International Potato Center (CIP), Quito, Ecuador.

Corresponding author: Claudia Patricia Villota Caicedo, cvillota@agrosavia.co; claudia.villota@uned.cr ORCID: https://orcid.org/0000-0002-9677-7716

Abstract

Background: Shagras, the traditional diversified home gardens of the Pastos Indigenous people, are important for the *in situ* conservation of Andean agrobiodiversity. However, the internal structure of their diversity and the factors that sustain it remain poorly documented.

Methods: The agrobiodiversity of 262 shagras belonging to 202 households located between 3,077 and 3,522 m a.s.l. in the Cumbal Indigenous Reserve (Nariño, Colombia) was characterised through household surveys, GIS-measured areas, species inventories and associated practices. Shagra types were identified by hierarchical clustering (Ward.D2) of the proportion of species in each of 12 use groups.

Results: A total of 236 species or local names were recorded, with a median of 29 species per shagra distributed over 12 use groups; native trees are the richest group (mean of 8.0 species per shagra, present in 84.7% of shagras) and 48.7% of names appear in five shagras or fewer. Species richness increased with shagra area (about 70% more species per tenfold increase in area) and varied more among veredas than with altitude (no linear effect). Within each vereda, the number of tuber varieties per household increased by about 40% per 100 m of altitude. Four shagra types were identified that form a continuum: single-purpose Andean (T1; 28 shagras, median of 4 species from a single use group, almost only tubers and faba bean), dual-purpose (T2; 33 shagras, 15 species from three groups, mainly native trees and cold-climate crops), domestic multipurpose

(T3; 96 shagras, 25 species from seven groups) and multipurpose with pastures (T4; 105 shagras, 40 species from ten groups, with the largest area, median 1,021 m²). Household characteristics were weakly associated with shagra type. Moreover, 42 of 46 households with several shagras have them of different types, so type reflects the role of the shagra rather than the household. More than 94% of households reported having lost varieties of potato, oca and ulluco, and 11 (5.4%) have a profile compatible with agrobiodiversity custodians.

Conclusions: These non-causal results and associations point to the need to strengthen *in situ* conservation at the plot and community scales, for which concrete measures are proposed.

Keywords: shagra; home gardens; agrobiodiversity; use typology; *in situ* conservation

Background

Worldwide, home gardens are small-scale multifunctional production systems whose structure and management are defined by households to fulfil ecological, economic and sociocultural purposes (Avilez-López et al., 2020; Galluzzi et al., 2010; Gbedomon et al., 2017; Korpelainen, 2023; Kumar & Nair, 2006; Kunhamu, 2013). This multifunctionality is directly linked to agrobiodiversity. For Indigenous communities, home gardens take on a special meaning because they simultaneously operate as productive units, repositories of traditional ecological knowledge and spaces of cultural reproduction, where plant diversity is passed from one generation to the next (Coomes et al., 2015; Niñez, 1984). Studying the variation in plant diversity at the household, community and plot-type levels across a landscape is an incipient and poorly documented area in Indigenous Andean systems.

In the Cumbal Indigenous Reserve (municipality of Cumbal, Nariño, Colombia), the shagra (a local variant of chagra, from the Quechua chakra, "cultivated plot") is the traditional home garden of the Pastos people, who inhabit the Colombian Massif. Recognised as a traditional agroecological system inherent to the Andean worldview, the shagra goes beyond its productive function and becomes a multifunctional space where diversified food production, agrobiodiversity conservation and the transmission of ancestral knowledge through family and community work converge (Asociación de Shaquiñan, 2017; Escobar et al., 2013; Loaiza et al., 2023; Rosero et al., 2015). It is also considered a biocultural heritage that integrates food crops, medicinal plants, native trees and ancestral knowledge, oriented mainly to family food rather than commercial

production, and used for the transmission of knowledge and for food sovereignty (Asociación de Shaquiñan, 2017; Cuastumal Leitón, 2019; Miranda & García, 2022; Rosero et al., 2015). The communities of the veredas (rural territorial units) of Boyera and Cuaical, with whom processes of revaluing the shagra began in 2008, consider shagras important learning spaces for conserving agrobiodiversity and the knowledge associated with its management and use, thus reducing the risk of displacement by monocultures (Rosero et al., 2015). Previous research in the territory has addressed the use and management of vegetation (Rosero Alpala, 2006), the in situ conservation of native cultivars and traditional knowledge in home gardens (Agredo et al., 2018) and the phenotypic diversity of native potatoes in the shagra (Rosero Alpala et al., 2020). For their part, Vernooy et al. (2025) identified forgotten and underutilised species.

Differences among Andean communities are frequently explained by altitude: greater diversity of potato cultivars in the central Peruvian Andes was concentrated in high belts close to the upper limits of crop production (Arce et al., 2019), whereas in India tree species diversity decreased weakly with elevation (Kumar, 2023). In Ethiopia, woody species richness did not differ among low, middle and high elevations (Jegora et al., 2025). Through a limited participatory diagnosis, Vernooy et al. (2025) recorded fewer cultivated species in the highest and coldest zone of the Reserve of Cumbal, an observation not yet tested on a representative sample of shagras.

Because of their particular interest for food security, the Andean tubers potato (*Solanum tuberosum* L.), oca (*Oxalis tuberosa* Molina), ulluco (*Ullucus tuberosus* Caldas) and mashua (*Tropaeolum tuberosum* Ruiz & Pav.) become relevant. Lüttringhaus et al. (2021) confirm that households in the Peruvian Andes that participate in potato fairs conserve a greater number of varieties, while many varieties recovered through germplasm repatriation programmes are abandoned over time (Lüttringhaus et al., 2021); in this regard, Arce et al. (2019) report that many native varieties are present in few households. These studies point to the importance of seed networks and exchange spaces for maintaining diversity. Cumbal has dynamics of this kind, such as the community seed house El Talkal, which brings together 15 active families who have identified more than 70 varieties of potato, 15 of oca, 12 of faba bean and 7 of mashua (Asociación de Shaquiñan, 2017), and the seed house Yar Pue Cumbe, created in 2024, which manages a network of community seed banks at the vereda level (Vernooy et al., 2025). However, how the seed practices of households relate to the structure of their shagras has not been documented.

One way of organising the diversity of production systems is by defining typologies, which in turn facilitates their description and the identification of representative cases to guide interventions (Alvarez et al., 2018). Each type summarises a variation that may be continuous, and its usefulness depends on the research question to be resolved. Experiences with typologies of Andean farm households indicate that household characteristics combine with sustainable livelihoods and are associated with the age and education of the household head and with household composition, as well as with access to irrigation and markets (Caulfield et al., 2021). This study transfers that approach to the composition of the shagra and examines whether the age, education and composition of the household, together with other household and plot characteristics, are associated with the type of shagra.

This study is descriptive and exploratory and addresses three questions. The first is how the agrobiodiversity of the shagras of the Cumbal Indigenous Reserve is characterised and how it varies among veredas, with area and with altitude; the second, which types of shagra are distinguished by their mixture of uses; and the third, which tuber varieties households maintain and which of them have a profile compatible with that of custodian farmers of agrobiodiversity (large collection, rare varieties, seed source and motivation; Byrnes & Sthapit, 2016).

Methods

Study area

The Cumbal Indigenous Reserve belongs to the ancestral territory of the Pastos people and is located in the western cordillera of Colombia, in the south-west of the department of Nariño. Its area is 52,194 ha, calculated on IGAC cartography at a scale of 1:25,000, distributed over an altitudinal range of 1,500 to 4,700 m a.s.l., from the Pacific piedmont to the Cumbal volcano (Belalcázar & Puerres, 2016). The shagras are located in the municipality of Cumbal, in the Túquerres and Ipiales plateau and the Nudo de los Pastos area, at a mean altitude of 3,032 m, with a mean monthly temperature of 10.8 °C (9.8 °C in July, the frost season) and a bimodal rainfall regime, with rainy periods from March to May and from October to December and dry periods from June to September and from December to February. In 2023 the municipality had 38,599 inhabitants, 97% of whom identify as Indigenous; its agriculture is dominated by potato, which occupies 50.9% of the planted hectares (plus 9.4% of criolla potato), followed by faba bean (2.5%) and ulluco (1.0%), according to AGRONET figures for 2021 (White et al., 2024). The Reserve

comprises nine veredas (i.e., rural territorial subdivisions); in this study, seven were covered: Boyera, Cuaical, Cuaspud, Cuetial, Guan, Quilismal and Tasmag (Fig. 1).

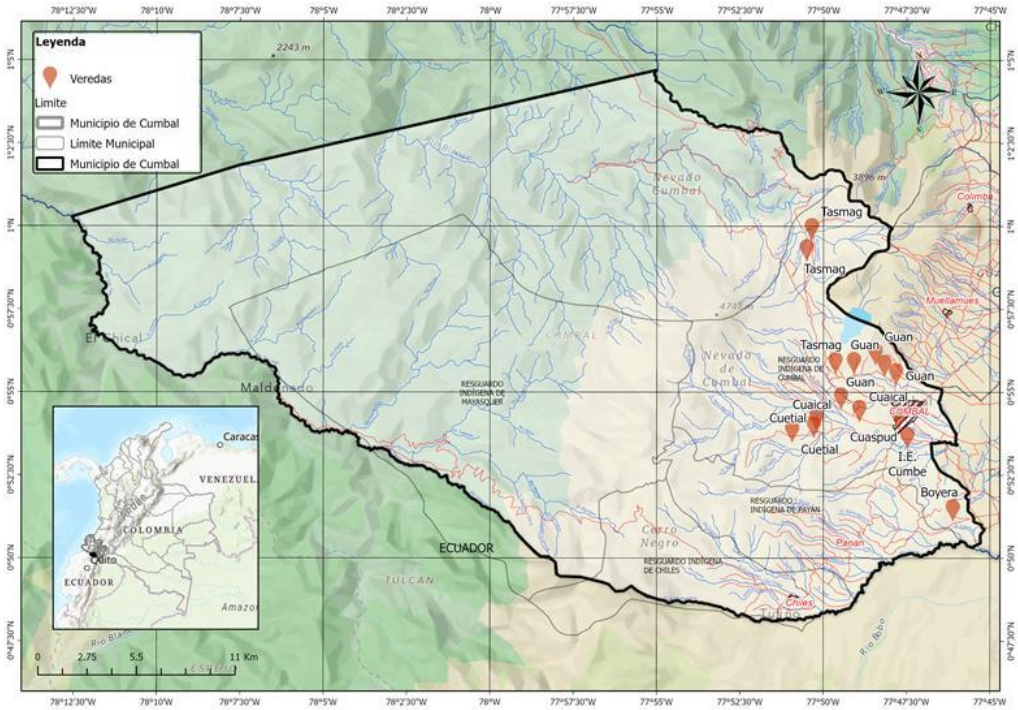


Fig. 1. Location of the Cumbal Indigenous Reserve and of the study veredas (municipality of Cumbal, Nariño).

Data and unit of analysis

Through structured surveys carried out between October 2023 and January 2024, shagras were documented in seven veredas: Tasmag (n = 71), Guan (n = 45), Cuaical (n = 41), Cuetial (n = 36), Quilismal (n = 34), Boyera (n = 24) and Cuaspud (n = 11). The data analysed come from four modules of a structured instrument built in ArcGIS Survey123: Module A describes the 202 households (35 sociodemographic variables: location, gender, age and education of the household head, children, type of labour, economic activities and household area), and Module B describes the 264 shagras (with presence/absence records by species, which were integrated into a catalogue of 288 entries, of which 279[1] are present in at least one shagra). The area of each shagra comes

[1]The 279 entries include 219 determined to species (with hybrids), 12 to variety or subspecies, 4 at a higher or ambiguous level and 44 undetermined morphotypes, differentiated by their local name. Counting only once the 43 entries that the catalogue marks as variants of the same name leaves 236 counting units. In the text they are called "species or local names": they are taxa and morphotypes, not botanical species in the strict sense, and some names could correspond to the same species, so richness measures names recognised by families. Scientific names were

from polygons measured with GIS. Modules E1 and E2, recorded per household, allowed the description of the diversity of Andean crops and their varieties (E1) and the reasons for conservation, losses, fairs and seed management (E2).

The shagra was the unit of analysis, and the 262 that have at least one species were included. Households have between one and five shagras: of the 202 households, 156 (77.2%) have a single shagra, equivalent to 59.5% of all shagras, whereas 46 households (22.8%) have two or more, totalling 106 shagras (40.5%). Shagras of the same household share data; therefore, statistical analyses were carried out at the household level and not for shagras separately.

Use groups and indicators per shagra

Based on the literature on tropical and Andean home gardens (Díaz et al., 2007; Galluzzi et al., 2010; Gbedomon et al., 2017; Kumar & Nair, 2006), the recorded species were classified into 12 functional groups according to their main use: vegetables, aromatic plants, condiment plants, cold-climate crops, medicinal plants, fruit trees, forest trees, native trees, wild plants, pastures and forages, ornamentals, and other plants. This assignment was validated with key participants of the Reserve and with experts of the research team. Each species was assigned to a single functional group; medicinal or ritual use was recorded in the catalogue as a second use, as suggested by Joshi and Shrestha (2019), who propose that medicinal or ritual uses cut across the different functional groups.

Measurements and analysis

Table 1 summarises the questions, measures and methods used; statistical details are given in the supplementary material. The indicators are the richness of each shagra (number of species), the evenness among use groups (Pielou), the frequency of each species in shagras and households, the number of groups present and the area. Diversity was calculated at three scales: alpha, beta and gamma. Alpha diversity is that of each shagra and was measured as its richness. To find out whether a shagra distributes its species among many uses or concentrates them in a few, the Shannon (Shannon, 1948) and Simpson (Simpson, 1949) indices and Pielou's evenness (Pielou,

checked against taxonomic databases (Bernal et al., 2012; Bernal et al., 2015–2020; Biovirtual UNAL, n.d.-a, n.d.-b; Royal Botanic Gardens, Kew, n.d.; Missouri Botanical Garden, n.d.), herbarium specimens (Herbario Nacional Colombiano, n.d.; Herbario PSO, n.d.) and local references (Herbario de Chaquiñanes; Guía de Flora del Páramo de Cumbal; Rosero Alpala, 2006). On crop origins, see Piperno (2011), Khoury et al. (2016), Pathania et al. (2022) and Coppens d'Eeckenbrugge et al. (2001).

1966) were calculated using the number of species in each of the 12 use groups; they were not calculated with species because they depend on richness and only presence or absence was recorded. For each vereda, incidence-based Hill numbers were used, which consider the frequency of each species among shagras (Chao et al., 2014; Jost, 2006).

Beta diversity, which indicates how much species change from one place to another, was calculated among veredas and among shagras. Among veredas, the seven were compared in pairs (21 pairs) using the Jaccard (1912) and Sørensen (1948) similarities, whose values range from 0 (no shared species) to 1 (the same species). The similarities were contrasted first using all shagras and then using subsamples of 10 shagras, because both increase with the number of shagras. Among shagras, within each vereda and in the Reserve, Whittaker's beta was used ($\gamma/\bar{\alpha} - 1$, where γ is the total number of species and $\bar{\alpha}$ the mean richness per shagra; Whittaker, 1960); it equals 0 if all shagras have the same species and increases the more they differ.

Gamma diversity is the total number of species of each vereda and of the Reserve. It was described with the observed species and the Chao2 estimator for incidence data (Chao, 1987), which estimates how many species remain unrecorded, and with inventory completeness (observed/Chao2). Additionally, for the Reserve, the expected accumulation curve was used (Colwell & Coddington, 1994), which shows how many species are added with each sampled shagra; if the curve flattens, new shagras would contribute few additional species.

The altitude of each household was obtained from the Copernicus GLO-90 digital elevation model (ESA, 2021), queried through the Open-Meteo elevation service (Open-Meteo, 2026), using a single coordinate per household, which was assigned to all its shagras when it had more than one; therefore, altitude corresponds to the household and not to each shagra. Because veredas differ in the number of shagras sampled, they were compared as if the same number of shagras had been sampled in all of them, by calculating how many species would be expected in 10 shagras of each one (incidence-based rarefaction).

To explain the richness of a shagra, it was related (log10-transformed) to area, altitude and vereda using linear mixed models with household as a random effect, since shagras of the same household are not independent (R package nlme; Pinheiro & Bates, 2000). For tubers, the number of varieties per household was related to altitude using quasi-Poisson regression with vereda as a factor.

Table 1. Questions, measures and methods of the study.

Question	Measure	Method
1. How is the agrobiodiversity of the shagras characterised, and how does it vary among veredas, with area and with altitude?	Richness, use groups and species frequency; Shannon, Simpson and Pielou by use group; beta diversity (Jaccard, Sørensen, Whittaker) and gamma diversity (Chao2, completeness); area and household altitude	Kruskal–Wallis with household permutation; rarefaction to 10 shagras; linear mixed models with household as a random effect; accumulation curve
2. Which shagra types are distinguished by their mixture of uses, and which household characteristics are associated with them?	Proportion of species in the 12 use groups; 46 household characteristics	Ward classification with Hellinger distance (k = 4, validated by subsampling); IndVal; associations with household permutation and Spearman
3. Which tuber varieties do households maintain, and which have a profile compatible with that of custodians?	Varieties of potato, oca, ulluco and mashua; seed origin and management; criteria C1 to C4 (collection, rare varieties, seed source, motivation and network)	Frequencies and household typology (Ward); quasi-Poisson with altitude; Spearman with Benjamini–Hochberg; core (Tukey) and extended (90th percentile) thresholds

Shagra types

Each shagra was described by the proportion of its species in each of the twelve use groups. The difference among shagras was measured with the Hellinger transformation and Euclidean distance (Borcard et al., 2018), and hierarchical clustering was applied, or Ward's method (Ward.D2; Murtagh & Legendre, 2014), which joins shagras that are similar in their mixture of uses, but not in their number of species; the result is represented in a dendrogram. From two to eight types were tested and four were chosen on the basis of their stability by subsampling households (Hennig, 2007), the agreement with a partition by medoids (Kaufman & Rousseeuw, 1990), measured with the Adjusted Rand Index (ARI; Hubert & Arabie, 1985), and the condition that no type had fewer than 28 shagras. The mean silhouette (Rousseeuw, 1987) allowed the evaluation of the separation between types. The types were categorised by ordering them from lowest to highest on the basis of the median richness of the indicators and of the characteristic species, that is, those that are frequent in one type and infrequent in the others, with an indicator value of 0.40 or more (indicator values range from 0 to 1, IndVal; Dufrêne & Legendre, 1997).

Tubers and compatible custodian profile

The sum of varieties of potato, oca, ulluco and mashua listed in module E1 allowed the tuber diversity of each household to be determined; faba bean was excluded because of inconsistent answers across modules B, E1 and E2, which complement and/or triangulate each other. Following Byrnes and Sthapit (2016) and Sthapit et al. (2013), a compatible custodian profile was defined through four criteria. C1, large collection of varieties, when the household exceeds the upper limit

of the distribution (third quartile plus 1.5 times the interquartile range), which was 50 varieties for all crops and 41 for tubers; for the extended list, the 90th percentile was used. C2 relates to the conservation of rare varieties: the number of varieties present in two households or fewer is equal to or higher than the 90th percentile. C3, seed source, is based on the household having given away at least half of its varieties and having acquired at most 10% in the last 12 months. C4 is based on the number of reasons and the motivation to sow native varieties, in the upper quartile, and on the household's participation in seed fairs. A household has a compatible custodian profile if it meets C1 and at least two of the other three criteria. The term compatible profile is used, and not custodian, because the household was not validated with the community, a central criterion in the literature. In addition, households were classified into four types (A1 to A4) according to their varieties of potato, oca, ulluco and mashua, transformed with $\log(1 + x)$ and standardised, using Euclidean distance and Ward clustering (Ward.D2), the details of which are presented in the supplementary material. In the Spearman correlations among household variables, the p-values were corrected for multiple comparisons using the method of Benjamini and Hochberg (1995).

Scope and software

The analyses are descriptive and exploratory: they order the observed variation and detect associations, but they do not test hypotheses posed initially nor establish their causes. The typology is a simplification of the variation among shagras and is reported with its quality measures. R 4.5.1 (R Core Team, 2025) was used for data processing, supported by the packages cluster (Maechler et al., 2022), nlme (Pinheiro & Bates, 2000), nnet (Venables & Ripley, 2002), readxl and writexl; figures were made with R base graphics; the random number generator seed was set with set.seed 2026.

Use of AI-assisted tools

An AI language model (Claude, Anthropic) was used for language editing, searching for and formatting bibliographic references, translation from Spanish into English, and adjustment of the R scripts. The authors reviewed and edited all outputs and take full responsibility for the content of the article.

Results

What the shagras contain

The 262 shagras have a median of 29 species (range 1 to 107; quartiles 16 and 43), spread over 8 of the 12 use groups (quartiles 5 and 9). Evenness among groups is high and almost constant (Pielou, median 0.91; quartiles 0.88 and 0.94; n = 242, because it is not defined for a shagra with a single group). Shagras differ in their number of species, but these are distributed similarly among uses. The Shannon index calculated with the species of each use group has a mean of 1.60 per shagra (Simpson 0.71), equivalent to about 5.8 effective groups out of 12. The median shagra area is 661 m² (range 24 to 17,641 m²; quartiles 336 to 1,303 m²), and richness increases moderately with area (Spearman = 0.35; Fig. 2b).

By use group, native trees have the most species per shagra (mean of 8.0, present in 84.7% of shagras), followed by medicinal species (4.5) and cold-climate crops (4.5). Ornamentals, other plants and wild plants are the groups with the lowest presence (5.0%, 12.2% and 24.0%, respectively). Of the 236 species or local names, 57 appear in a single shagra belonging to one household and 58 appear in two to five shagras; that is, 115 (48.7%) are in five shagras or fewer. In contrast, only 14 species are in half of the shagras or more, the most common being potato (88.2%), oca (80.5%), faba bean (76.3%), ulluco (75.2%), acacia (68.3%) and onion (67.2%); mashua is in 48.1%, and 39.7% of shagras have all four Andean tubers. Seen by household, 84 names (35.6%) appear in two households or fewer and 61 (25.8%) in more than a quarter of households.

What changes among veredas

The 202 households are located between 3,077 and 3,522 m a.s.l. (median 3,280; quartiles 3,215 and 3,373 m). Ordered by median altitude, the veredas are Cuaspud (3,101 m), Boyera (3,122), Guan (3,239), Cuaical (3,262), Tasmag (3,310), Cuetial (3,354) and Quilismal (3,408); altitude differs among them (Kruskal–Wallis, $\chi^2 = 116.2$; $p < 0.001$), and the ranges of several veredas overlap (Table 2).

Table 2. Characterisation of the shagras by vereda.

Vereda	Altitude, m	Shagras (households)	Species	Groups	Pielou	Area, m²	Cold-climate crops
Cuaspud	3,101	11 (11)	36 (32–42)	9 (8–9)	0.94	1,021 (356–1,562)	5 (5–6)

Vereda	Altitude, m	Shagras (households)	Species	Groups	Pielou	Area, m²	Cold-climate crops
Boyera	3,122	24 (20)	44.5 (35–69)	9 (8–10)	0.90	613 (420–1,459)	6 (5–7)
Guan	3,239	45 (37)	33 (25–45)	8 (7–9)	0.90	830 (387–1,279)	5 (4–7)
Cuaical	3,262	41 (27)	23 (14–39)	8 (4–9)	0.92	667 (356–1,640)	4 (2–5)
Tasmag	3,310	71 (49)	15 (5–32)	6 (2–8)	0.90	617 (366–1,006)	4 (3–5)
Cuetial	3,354	36 (29)	25 (21–30)	7 (6–8)	0.91	691 (424–1,243)	4 (2–4)
Quilismal	3,408	34 (29)	38 (22–50)	9 (7–10)	0.91	543 (264–1,363)	4.5 (4–5)
Total	**3,280**	**262 (202)**	**29 (16–43)**	**8 (5–9)**	**0.91**	**661 (336–1,303)**	**4 (3–5)**

Note: Values are medians with quartiles 1 and 3 in parentheses, except for shagras (households) and evenness (Pielou, median).

Richness differs among veredas (Kruskal–Wallis, $H = 51.6$; $p < 0.001$, permuting households), with a median of 15 species per shagra in Tasmag and 44.5 in Boyera, showing wide variation among veredas (Fig. 2a).

Evenness does not change among veredas (0.90 to 0.94). The altitudinal order does not order richness: the two lowest veredas (Cuaspud and Boyera) and the highest one (Quilismal) have medians of 36, 44.5 and 38 species, respectively, whereas the intermediate ones are below 35 (Table 2).

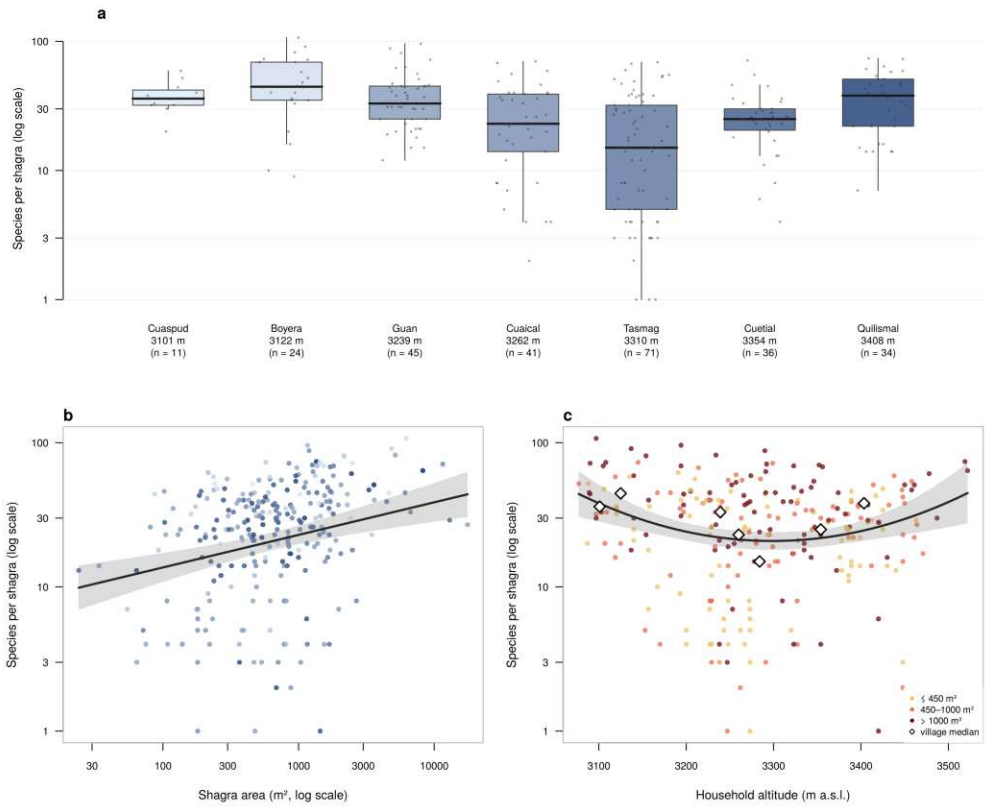


Fig. 2. Species richness per shagra (n = 262) by vereda (a), shagra area (b) and household altitude (c).

Note: (a) Veredas ordered by the median altitude of their households; the thick line is the median, the box the quartiles 1 and 3, and the whiskers reach 1.5 times the interquartile range. (b) Each point is a shagra, coloured by the altitude of its household (darker, higher); the line is the model relationship with household as a random effect, at mean altitude, with its 95% confidence interval. (c) The curve is the model relationship (altitude and altitude squared), at median area, with its 95% confidence interval; diamonds are the median of each vereda, and points are coloured by shagra area class (≤ 450, 450–1,000 and > 1,000 m²). The species and area axes are logarithmic.

Native trees (Fig. 3) are the group with the most species in all seven veredas, from 5.1 species per shagra in Tasmag to 11.7 in Boyera. Medicinal plants (from 2.9 in Tasmag to 7.5 in Boyera) and vegetables (1.5 to 6.6) vary more than cold-climate crops (3.5 in Cuetial to 6.4 in Boyera), which are present in all veredas with similar values (Table 2). An illustrative radial version of the figure is presented in the supplementary material (Fig. S4).



Fig. 3. Mean number of species per shagra in each use group (rows, groups ordered by type of use) and vereda (columns, ordered by the median altitude of their households, with the number of shagras). Shagras (n = 262). Colour follows the square root of the value.

Guan has the highest number of species (184) at the vereda scale, followed by Boyera (158) and Tasmag (146), figures that depended on the number of shagras visited. The rarefaction exercise (expected species) gave 128.3 in Boyera, 117.9 in Guan, 94.5 in Cuaspud, 93.8 in Quilismal, 85.9 in Cuaical, 85.2 in Tasmag and 83.1 in Cuetial. Rare species, those present in five shagras or fewer in the whole Reserve, make up from 5.2% of the species of Cuaspud to 35.9% of those of Guan, identifying Guan and Boyera (35.9% and 27.2%, respectively) as the veredas with the largest share of infrequent species (Table S4; Fig. S2). Between pairs of shagras, the difference in composition is high (mean Jaccard index of 0.77), divided almost equally between species turnover (49%) and differences in richness (Fig. S1).

How much diversity there is and how much it changes among veredas

The Shannon index per shagra, calculated with the number of species in each use group, indicates how many groups each shagra has and how evenly its species are distributed among them. It was highest in Cuaspud (2.02), indicating that its shagras spread their species over almost all groups

and more evenly. In contrast, it was lowest in Tasmag (1.21), where the species of the shagras are concentrated in few use groups. In Boyera, Guan and Quilismal it ranged between 1.78 and 1.82 (Table 3). This index differed among veredas, as did richness (Kruskal–Wallis, $H = 36.5$; $p < 0.001$). The order given by rarefaction is maintained when rare species are given less weight: with Hill numbers ($q = 1$), which count each species according to its frequency, and with 10 shagras per vereda, the effective number of species is 93 in Guan and 104 in Boyera, making them the most diverse, compared with a range of 65 to 76 in the other veredas (Table 3).

In general, the veredas share a good part of their species, but each keeps some that are its own. The Jaccard similarity between pairs of veredas, which ranges from 0 (no species in common) to 1 (the same species), goes from 0.49 (Cuaspud–Guan) to 0.74 (Cuaical–Quilismal and Cuaical–Cuetial; Fig. 4b), and the Sørensen similarity from 0.65 to 0.85. These values increase when veredas have more shagras; if all are compared with 10 shagras, the Jaccard index lies between 0.56 (Boyera–Tasmag) and 0.71 (Cuaical–Quilismal), a narrower range. Whittaker's beta indicates how much species change from one shagra to another. In the Reserve it is 6.6: there are 236 species in total and 30.9 on average per shagra, that is, the Reserve has about 7.6 times the species of an average shagra. By vereda, it goes from 1.6 in Cuaspud, where shagras are very similar to each other, to 6.1 in Tasmag, where they are little alike (Table 3).

A total of 236 species were observed; 57 are in a single shagra and 26 in exactly two. The Chao2 estimator gives 295 species (298 without the bias correction), so the inventory covers about 80% of what is expected, with a minimum of 68.5% in Cuetial and a maximum of 85.7% in Tasmag (Table 3). The accumulation curve does not flatten: it goes from 221 expected species with 200 shagras to 236 with 262 (Fig. 4a).

Table 3. Diversity indicators by vereda, ordered by the median altitude of their households.

Vereda	Shagras	Shannon	S obs.	Chao2	Compl., %	β Whittaker	Hill q1
Cuaspud	11	2.02	97	120	81.0	1.6	73.7
Boyera	24	1.80	158	209	75.7	2.2	104.0
Guan	45	1.82	184	258	71.4	3.8	92.8
Cuaical	41	1.61	116	141	82.2	3.3	69.6
Tasmag	71	1.21	146	170	85.7	6.1	68.7
Cuetial	36	1.68	114	167	68.5	3.3	65.4
Quilismal	34	1.78	123	151	81.2	2.3	76.2
Reserve	**262**	**1.60**	**236**	**295**	**80.0**	**6.6**	**80.8**

Note: Shannon: mean per shagra using the species of each use group; S obs.: observed species (gamma); Chao2: incidence-based estimated richness; Compl.: S obs. / Chao2; β: Whittaker's beta ($\gamma/\bar{\alpha} - 1$); Hill q1: effective number of species with 10 shagras per vereda.

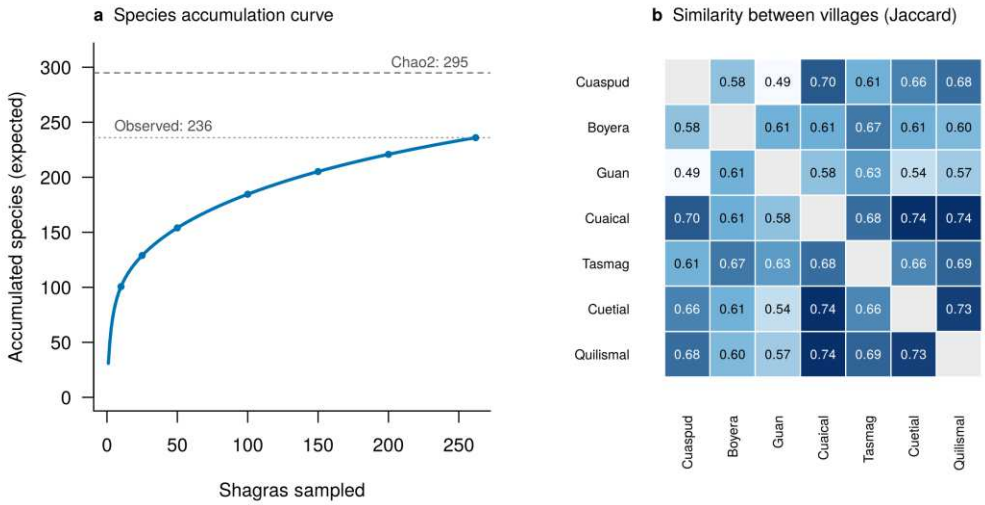


Fig. 4. Gamma and beta diversity of the shagras.

Note: (a) Expected cumulative species according to the number of shagras sampled (exact incidence-based curve; 236 observed species, dotted line) and Chao2 estimator of total richness (295, dashed line). (b) Jaccard similarity between pairs of veredas with all their shagras, ordered by the median altitude of their households; it ranges from 0.49 (Cuaspud–Guan) to 0.74 (Cuaical–Quilismal).

Altitude

The richness of a shagra depends mainly on its size and on the vereda, and very little on altitude (linear mixed models of log richness, with household as a random effect; Table S3). A shagra with ten times the area has on average 1.7 times more species (95% confidence interval: 1.3 to 2.1; Fig. 2b). Richness does not rise or fall continuously with household altitude. The model suggests a slight curve, with fewer species around 3,300 m and more at the extremes (Fig. 2c); however, it does not match the medians of some veredas. Thus, the vereda is a better predictor of richness than altitude. In this sense, a shagra in Tasmag has on average 62% fewer species than one in Cuaspud of the same area, and the other veredas do not differ clearly from Cuaspud. The shagras of a same household resemble each other because they are in the same vereda; household explains only 26% of the variation in the model with altitude and 14% in the model with vereda. Because altitude was measured once per household and there are only seven veredas, altitude cannot be separated from differences among veredas.

In contrast, the number of tuber varieties does increase with altitude. Within the same vereda, a household located 100 m higher has on average 1.42 times more varieties (quasi-Poisson regression with vereda as a factor; interval 1.23 to 1.64; 202 households). If vereda is not taken into account, the effect is smaller, at 1.10 times per 100 m (p = 0.048).

Shagra types

The dendrogram of the 262 shagras (Fig. 5) shows that the joins of the first four groups occur at high heights; from the fifth group onward, with similar heights, each split separates smaller groups. With four groups, stability is acceptable (0.78; minimum per type 0.69), while agreement with the medoid partition is high (ARI = 0.79). The mean silhouette is low (0.24), that is, the types are not clearly separated and form more of a continuum than natural groups; the best-defined group is T1 (0.65) and the least defined is T3 (0.03). When the aromatic, condiment and medicinal groups are merged (10 use groups), the partition changes substantially (ARI = 0.34) and groups T3 and T4 almost completely merge (Table S1; Fig. S3); that is, the separation between them depends on how those uses are grouped. The group sizes are 28, 33, 96 and 105 shagras.

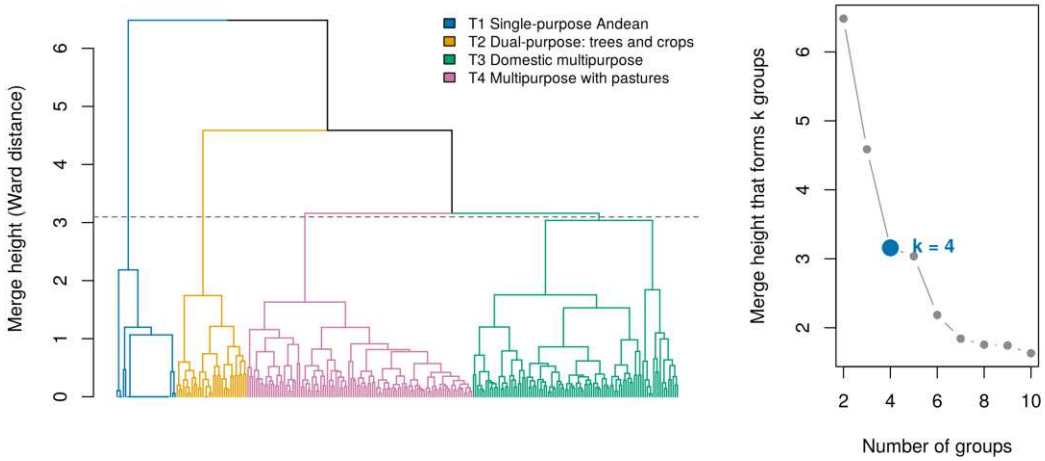


Fig. 5. Dendrogram (Ward.D2 on Hellinger-transformed richness proportions by use group) of the 262 shagras (left) and joining height for each number of groups (right).

Note: The dotted line marks the cut at four types: T1, single-purpose Andean; T2, dual-purpose: trees and crops; T3, domestic multipurpose; T4, multipurpose with pastures.

Table 4. Shagra types according to the mixture of use groups (12 groups).

Type	Shagras (households)	Species	Groups (median)	Area, m²	Composition and characteristic species
T1 single-purpose Andean	28 (23)	4 (3–5)	1	483 (210–917)	Cold-climate crops, 87% of richness (potato, oca, ulluco, faba bean); no characteristic species
T2 dual-purpose	33 (29)	15 (12–20)	3	590 (277–837)	Native trees, 58% of richness, and cold-climate crops (19%); punde, cuasa, colla, pichanga, capote and rama blanca (IndVal 0.25–0.30, below the threshold)
T3 domestic multipurpose	96 (91)	25 (19.8–36)	7	451 (247–829)	Mixture of native species (23%), cold-climate crops (20%), medicinal (14%), vegetables (12%) and condiment plants (11%); faba bean (IndVal 0.28, below the threshold)
T4 multipurpose with pastures	105 (104)	40 (33–54)	10	1,021 (548–1,718)	As T3 plus pastures and forages (9%): white clover (0.83), Acrobat (0.70), common grass (0.65), dandelion (0.54), rue, turnip, cabbage and blue grass

Note: Median (quartiles 1 and 3), unless indicated. Percentages: mean richness per group. Only T4 has characteristic species (8 with IndVal of 0.40 to 0.83, adjusted $p < 0.05$).

T1 groups shagras with few crops (median of 4 species from a single use group), 87% of them almost all potato, oca, ulluco and faba bean. It is called single-purpose Andean, and not "cold-climate", to avoid confusion with the use group of the same name, which appears in all four types (12 to 20% of richness in the others). T2 is dual-purpose, where native trees make up 58% of richness and cold-climate crops 19%. T3 and T4 are multipurpose: T3 is the domestic shagra that mixes native species (23%), cold-climate crops (20%), medicinal plants (14%), vegetables (12%) and condiment plants (11%), and T4 adds pastures and forages (9%) and wild plants (1%), with white clover (IndVal = 0.83), Acrobat (0.70), common grass (0.65) and dandelion (0.54) as the most characteristic species. Only T4 has characteristic species (IndVal ≥ 0.40; eight species); those most associated with T2 (punde, cuasa, colla, pichanga, capote and rama blanca, with IndVal of 0.25 to 0.30) and with T3 (faba bean, 0.28) do not reach that threshold. Richness rises in steps between types (medians of 4, 15, 25 and 40 species), although it was not used to form them.

Types of shagra are distributed differently among veredas. In Cuaspud, T4 dominates (64% of its eleven shagras), as in Boyera (54%) and Quilismal (50%). In Guan (53%) and Cuetial (47%), T3 dominates; in Cuaical, T2 weighs more (22%), as in Boyera (21%); T1 is concentrated in Tasmag (23 of its 28 shagras), which correspond to 32% of the shagras of that vereda (71 shagras).

Relationship of shagra types with household characteristics

Of the 46 household characteristics tested, only six were related to type in four sensitivity scenarios (varieties of all crops and of tubers, causes of potato loss, minga, and causes of loss due to social change and to the market), with small effect sizes (ε^2 or V^2 of 0.06 to 0.11); age, education, number of children, gender of the household head and altitude were not associated. Household characteristics explain little of the type. The mean richness of the household's shagras was also unrelated to the age of the household head (Spearman = −0.04; p = 0.55), education (0.05; p = 0.48) or number of children (−0.04; p = 0.58).

The type reflects the structure of the holding more than the household (Fig. 6a). Thus, among the 156 shagras of households with only one, 84 are T4 (54%) and 60 are T3 (38%). T2 hardly appears, whereas T2 and T1 appear more frequently among the 106 shagras of households that manage two or more. On the other hand, 42 of the 46 households with several shagras (91%) have shagras of different types (Fig. 6b). The most frequent combinations are native trees with the domestic shagra (T2+T3 in 13 households) or with the pasture shagra (T2+T4 in 12 households) and cold-climate crops with the domestic shagra (T1+T3 in 9 households); therefore, the type describes the role of each plot within the household, for example a plot of native trees next to a plot of crops, but not the household. Measured as the total number of species per household (the union of all its shagras), median richness was 29 in households with several shagras and 36.5 in those with one; per shagra, the median in households with several was 18.3. Spreading diversity across several plots therefore does not appear to increase it.

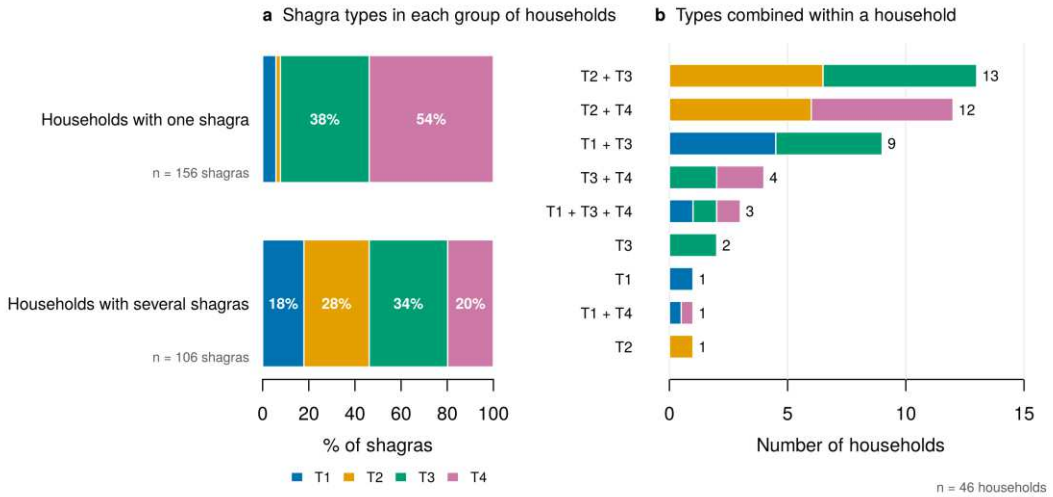


Fig. 6. Shagra types by household: (a) percentage of shagras and (b) types combined within households.

Note: (a) Percentage of shagras of each type (T1, single-purpose Andean; T2, dual-purpose: trees and crops; T3, domestic multipurpose; T4, multipurpose with pastures) among the 156 shagras of single-shagra households and the 106 of households with several. (b) Types combined in the 46 households with several shagras: 42 have shagras of more than one type; each bar shows one combination and its number of households.

Tubers, seed practices and possible custodians

A total of 635 different varieties corresponding to 25 crops were mentioned by households, with potato having the highest number (334), followed by oca (73), ulluco (62) and mashua (24). The median of the sum of varieties of the four tubers is 16 per household (quartiles 11 and 23; range 2 to 162), of which 11 correspond to potato (7 to 16), 2 to oca (1 to 3), 2 to ulluco (1 to 3) and 1 to mashua (0 to 2). The information declared in module E1 largely coincides with that recorded in the shagras (module B) in 92 to 97% of households depending on the tuber (potato 97%; oca 95%; ulluco 93.6% and mashua 91.6%). This again confirms that the number does not depend on how many shagras the household has (Spearman = −0.03; median of 16 with one and with several shagras).

Over the last 15 years, almost all households report having lost varieties: 98.5% for potato, 95.5% for oca, 94.6% for ulluco and 78.2% for mashua, while 73.3% reported having lost all four tubers. Regarding potato records per household, 86.9% declare their origin, and of these 94.8% are native and 5.2% improved (127 records); for the other crops, the instrument did not record origin. Among the reasons for planting native varieties, conservation and food security stand out (89.1%), followed by cultural reasons or inheritance (84.6%) and culinary uses (61.7%); prestige is rarely mentioned (8%). Households attribute the loss of potato varieties mainly to climate (79.4%), to seed availability or pests (54.8%), to displacement by other crops (52.8%), to market reasons (47.2%) and to social change (39.7%). Of all households, 35.1% participate in seed fairs, 70.4% store seed differently from how they did before, 40.8% apply treatments and 9.7% use external seed.

The diversity of tuber varieties in households was associated above all with the shagras themselves: with the species accumulated in them (Spearman = 0.56) and with their mean richness (0.50). Household practices and characteristics were moderately associated with the area of the holding (0.25), the number of reasons for planting native varieties (0.25), the proportion of varieties given to others (0.24), the frequency of seed fairs (0.21) and livestock (0.19), and negatively with seed treatment (−0.22); there was no relationship with age (−0.01), with number

of shagras (−0.03) or, when considering all households, with altitude (0.08). These are relationships of small to moderate size, cross-sectional, and the associations with loss are partly mechanical, because a household with few varieties of a tuber has less to lose.

With the criteria described, 8 households (4%) were found to have a compatible custodian profile across all crops, 10 households (5%) as tuber custodians, and 11 households are in at least one of these two groups; if C1 is defined with the 90th percentile instead of the upper limit, the figure can rise to 13 households. Households with a tuber-custodian profile are in Boyera (3), Guan (3), Tasmag (2), Cuetial (1) and Quilismal (1), and none in Cuaical or Cuaspud. The list varies with the cut-off for collection size; with all crops, from the 75th to the 95th percentile the number of households goes from 20 to 11 (Table S6; Table 5). Household H1 (Tasmag, lead custodian), with 123 potato varieties and 162 tuber varieties in total (2.6 times the value of the next household), gave away 98% of the varieties it listed and acquired none in the previous 12 months; it was kept in the analyses and the results are reported with and without it (7 and 9 households without the leader). A descriptive typology separates four household types by their tuber varieties (A1, almost only potato, 56 households; A2, potato, oca and ulluco, 59; A3, with mashua, 70; and A4, of high variety diversity, 17), but it is weak (silhouette of 0.26) and the types should be read as segments of a gradient (Table S5; Fig. S5).

Table 5. Households with a profile compatible with agrobiodiversity custodians in at least one of the two core lists (all crops or tubers), identified by an anonymised code.

Household	Vereda	Varieties, all / tubers	Rare, all / tubers	Given away	Acquired	Lists
H1	Tasmag	173 / 162	94 / 90	98%	0%	4
H2	Guan	74 / 58	15 / 10	42%	0%	4
H3	Cuetial	63 / 63	10 / 10	100%	0%	4
H4	Quilismal	63 / 62	8 / 8	100%	0%	4
H5	Boyera	60 / 50	19 / 13	84%	0%	4
H6	Boyera	57 / 48	8 / 4	98%	0%	4
H7	Boyera	54 / 42	10 / 2	85%	0%	2
H8	Guan	52 / 49	4 / 4	94%	0%	2
H9	Guan	52 / 47	7 / 6	47%	0%	4
H10	Boyera	48 / 48	5 / 5	89%	0%	3
H11	Tasmag	48 / 48	6 / 6	98%	2%	3

Note: Varieties: number of varieties listed (all crops without faba bean; tubers); rare: varieties present in 5 households or fewer in the whole set (4 or fewer for tubers); given away and acquired: proportion of varieties given

to others and acquired in the previous 12 months; lists: number of the four lists (all crops and tubers, core and extended) in which the household meets the profile. Household H1 is the lead custodian.

Discussion

The results confirm that the shagras of the Cumbal Reserve are highly heterogeneous systems, consistent with the description of home gardens as multispecies systems (Kumar & Nair, 2004), as reservoirs of agrobiodiversity (Galluzzi et al., 2010; Gbedomon et al., 2017) and with their role in conserving native crops in the territory of the Pastos (Agredo et al., 2018; Rosero Alpala et al., 2020). Their agrobiodiversity is not concentrated in one type of household or in one vereda; it is distributed across many plots, among veredas that complement each other, and among a few households that support the circulation of varieties. Because this study rests on a sample of presence/absence data, the results present variation and not conservation status; from them, which areas to cover, whom to work with and what to monitor are discussed, in line with what the data allow to be stated and with aspects that require validation.

The shagra and the vereda as conservation units

Of the species or local names, 48.7% are in five shagras or fewer, so a large part of the diversity depends on very few plots, and the vereda with the most species (Guan, 184) holds only 78% of the total. When effort is equalised at 10 shagras, Boyera (128 expected species) and Guan (118) exceed the others (83 to 94) and also concentrate more of the Reserve's rare species (27% and 36% of their species, versus 5% to 21% in the others). The inventory covers about 80% of the 295 species estimated by Chao2 and the accumulation curve does not flatten, so more shagras would continue to add species, especially rare ones. Tasmag has the lowest median per shagra (15 species), but when effort is equalised it falls to the level of Cuaical and Cuetial, because its shagras resemble each other little (Whittaker's beta of 6.1, versus 1.6 to 3.8 in the other veredas; Table 3).

About half of the difference in composition between shagras corresponds to species turnover (Baselga, 2010), a component organised by vereda as well as by shagra type; the other half is due to differences in richness and follows the gradient of types. Consequently, no vereda or small set of rich shagras holds what is found in the rest. It is hypothesised that the richest shagras sustain the *in situ* conservation of species within each vereda and that complementarity among veredas sustains that of the Reserve, which should be tested with a new, expanded sampling.

It is recommended, at a minimum, to draw up a strategy that covers all veredas, consolidating a traceable inventory of rare species with information on the shagras and the household that maintains them. For this inventory to become a baseline, the botanical identification of the morphotypes must be completed, given that local names largely do not equate to species. This hypothesis could be included and tested in complementary studies with sampling across the veredas of the Reserve and with a larger number of shagras per vereda.

Altitude and vereda

The participatory diagnosis of Vernooy et al. (2025) recorded fewer cultivated species in the highest and coldest zone of the Reserve. In the 262 shagras this gradient is not reproduced: the linear effect of household altitude was null and the quadratic effect, although significant, is weak.

This agrees with home gardens in other mountainous areas, where tree diversity decreased only weakly with elevation in Kerala (Kumar, 2023; Jegora et al., 2025). In contrast, tubers did show a larger number of varieties within a same vereda: higher households list more varieties (1.42 times per 100 m), as reported in the central Peruvian Andes (Arce et al., 2019). In this study, because the altitude of the household was recorded, this can be confounded with vereda, where the range is only 445 m, so this pattern must be confirmed in the field with the altitude of each shagra. Through the history of projects and institutional support, access to markets or tourism, and seed exchange spaces, the vereda may become the organising axis of richness (Asociación de Shaquiñan, 2017; Vernooy et al., 2025). This statement is put forward as something to be contrasted with the authorities and leaders of each vereda.

The shagra typology describes the plot, not the household

Household characteristics explain little of the shagra type (associations of up to 0.11): neither the age, gender or education of the household head nor family composition differentiate the types, whereas the structure of the plot and the holding (area, number of shagras, minga and livestock) and the vereda do. Therefore, targeting efforts according to household profile might not be appropriate. The shagra type responds to its structure, that of the holding and the vereda, more than to the household profile. In other Andean studies, by contrast, household characteristics do influence management, together with other livelihood-support activities, among them access to markets and to means of production such as irrigation (Caulfield et al., 2021).

The type describes the plot and not the household: 42 of the 46 households with several shagras have them of different types, for example one plot of native trees and another of crops. The unit of monitoring should then be the plot, with the function each household assigns to it. In addition, the types are segments of a continuum (silhouette of 0.24) and not categories with fixed limits: no clear cut is observed between T3 and T4 and, if native trees, pastures and wild plants are not considered, diversified shagras no longer separate into types. The types thus serve to describe the role of each plot, but not to fix management categories.

Native trees defined type T2; without them, these plots would have fewer than half of their species, which suggests protecting them explicitly. Kumar and Nair (2004) point out that the tree component is frequent in tropical home gardens, described as multispecies systems close to agroforestry, so the weight of native trees should be contrasted with inventories of other Andean home gardens. In páramo areas, the tree component would fulfil a structural and cultural function linked to soil and water management and to the worldview of the Pastos people (Rosero et al., 2015), a hypothesis this study does not resolve.

Custodian households: validate, replicate and accompany

The diversity of tuber varieties is mobilised by few households: 11 (5.4%) have a compatible custodian profile in at least one of the core lists and 13 in the extended ones, mainly in Boyera and Guan; the lead household, in Tasmag, with 123 potato varieties, gave away 98% of what it listed. This agrees with what has been described in Cumbal, where 77 farmers who conserved native cultivars varied widely in the number of cultivars and 84% obtained seed through the community (Agredo et al., 2018), and with the concentration of diversity in few households in Amazonian home gardens (Perrault-Archambault & Coomes, 2008). From this, three actions are derived.

First, validate before supporting. A custodian maintains, adapts and shares diversity and is recognised by their community, but is easily confused with leaders or progressive farmers (Byrnes & Sthapit, 2016). Therefore, the list of candidates obtained with the module E1 criteria must be validated with the community through focus groups, visits to the holdings and verification of the continuity of the practice.

Second, reduce the risk of depending on a single household. The varieties of the Tasmag custodian and of the other candidates should be multiplied and copies distributed among other households and the seed houses, after contrasting the names recorded in E1 with those of those houses and

555 removing synonyms. The El Talkal seed house, for example, reports more than 70 potato varieties
556 maintained by about 15 custodian families (Asociación de Shaquiñan, 2017).

557 Third, sustain support over time without creating dependency. In the Peruvian Andes, most
558 households stop cultivating repatriated varieties after a few years (Lüttringhaus et al., 2021), so
559 accompaniment must be permanent, but under the leadership and effective participation of the
560 community. According to Agredo et al. (2018), Cumbal farmers have been invited to train children
561 and young people to ensure generational renewal, to document the names and characteristics of
562 cultivars and to strengthen seed fair networks; more recently, Navarrete et al. (2024) propose
563 creating regional networks of custodians, linking rural schools and paying for conservation
564 services. In any case, projects external to the territory must be prevented from increasing the
565 dependency and vulnerability of the shagra (Wagner Medina, 2012). Experiences with custodians
566 in five Asian countries offer useful references for designing this support (Sthapit et al., 2013).

567 ***Seed exchange: fairs, community banks and networks***

568 This study documented that 35% of households participate in seed fairs, and participation is only
569 weakly associated with having more varieties (rho = 0.19), a relationship that falls at the limit
570 when the Tasmag household is excluded (adjusted p from 0.054 to 0.078) and that, being cross-
571 sectional, does not allow the conclusion that fairs increase diversity, since it shows the
572 participation of households that already have more varieties; in the Peruvian Andes, participation
573 in fairs was also associated with more varieties per household (Lüttringhaus et al., 2021). With
574 that caveat, the fairs and community seed banks proposed for the Reserve (Vernooy et al., 2025)
575 deserve evaluation. This proposal is consistent with the role attributed to community governance
576 and traditional knowledge in the conservation of Indigenous systems (Hernandez Marentes et al.,
577 2022). It also agrees with the literature that considers seed exchange networks central (Pautasso et
578 al., 2013) and that questions the idea that they are inefficient or closed (Coomes et al., 2015). In
579 this sense, two concrete actions are proposed, capitalising on the E1 information that records to
580 whom and where each variety was given: first, mapping the Cumbal exchange network, identifying
581 who the nodes are, which veredas are disconnected and which varieties depend on a single
582 household; and second, fairs and banks should incorporate elements that allow their efficiency and
583 management to be compared, implementing them in some veredas and tracking in all of them the
584 number of varieties per household and the number of households that maintain each variety.

Scope of the instrument: gender, minga and livestock

The instrument records who heads the household, whether the household takes part in the minga and whether it engages in other economic activities; however, it does not fully capture the role of gender, which gives rise to three limitations. The first concerns plot management: although the gender of the household head was not related to the shagra type, this does not imply that gender is irrelevant. Among the Pastos, women hold a prominent place in the knowledge, conservation and management of the plants of the shagra (Rosero et al., 2015), a circumstance echoed by Tapia and De la Torre (1998), who documented in the Andes that women take part in all stages of the crop cycle and frequently decide which varieties are planted; likewise, Molina et al. (2022) state that gender norms determine the management of native potatoes and who benefits from them. Under these scenarios, capacity-strengthening actions and recognition should not by default be directed to the household head, and in a subsequent study it should be recorded who makes decisions about each plot and who manages it.

The second concerns the minga, whose practice is associated with diversified shagras without pastures: this study reports the practice in 26% of households with T3 shagras, versus 2% of households with T4 shagras. However, the instrument only asked whether the household takes part in the minga, not what tasks are carried out in it, in which shagras or whether it includes seed sowing or exchange. Among the Pastos, the minga renews bonds and memory (López Cortés, 2018), so it could be a favourable space for collective work with seeds. To verify this, it will be necessary to look more closely at where it is practised.

The third concerns livestock, where a paradox arises: it is present in 74% of households and is associated with the type of use and with a larger number of tuber varieties; however, households with pasture and wild-plant shagras (T4) report it less frequently (67%, versus 82% to 97% in the other types).

As a hypothesis for a later study, it is proposed that the explanation may lie in the agroecological context of the Ipiales and Túquerres plateau. There, livestock is mainly dairy, and in the Nariño basin farms of less than five hectares predominate, with about 80% of their surface under kikuyu grass (Lerma-Lasso et al., 2023; Jurado-Gámez et al., 2020). If milk is produced in the paddocks and commercial potato in other plots, the shagra, of small area, would occupy a different place within the holding, that of diversity destined for consumption, seed and exchange.

However, the data from the modules processed do not allow this to be verified. In 74% of households, the total area recorded in module A coincides with the sum of the areas of their shagras, so that variable does not capture information on paddocks or commercial potato; moreover, other modules of the instrument that could confirm or rule out the hypothesis were not analysed. Consequently, conservation strategies should not frame shagra management and livestock as competing activities. Both can be sustainable and complementary livelihoods, one oriented to income and the other to food, seed and culture. Therefore, actions that add work to the shagra should be designed taking into account how much of the household's time and income depends on milk.

Limitations

Important limitations can be inferred from this study and should be overcome in similar processes. The data analysed are presence/absence, with no information on abundance, area per species or number of plants, and the indicators describe the mixture of groups and not species dominance; for the same reason, the Shannon, Simpson and Pielou indices by species would add no information beyond richness.

Richness accounts for local names, and not all species have been determined; the 12 use groups are a classification developed in this study and each species belongs to only one. Shagras of the same household are not independent; the richness models include household as a random effect, but the Kruskal–Wallis test by vereda and Table 2 are descriptive.

Altitude is that of the household, taken from a 90-m model and one coordinate per household, and with only seven veredas it cannot be separated from other differences among them; moreover, the altitudes of the households (3,077 to 3,522 m) are higher than the mean of 3,032 m cited for the plateau, and the difference should be checked against cartographic sources.

The silhouette of the types is low (0.24) and choosing the number of types includes a subjective judgement. With 202 households, and only 46 with several shagras, the power to detect moderate effects is low. Modules E1 and E2 were cleaned with rules that involve decisions made by the authors, it was not verified that each distinct name is a different variety, and loss is declared as a 15-year perception.

The list of candidate households is a filter with criteria from E1 and E2; it does not include the reputation or knowledge that define a custodian and varies with the thresholds; a single household

concentrates a disproportionate share of the varieties, and the results are reported with and without it. Shagras were recorded with forms that differ (by use blocks or in a single list) and their effect was not separated. Likewise, it would be optimal to collect and analyse information over several periods and production cycles, in line with funding, the willingness of communities to participate and the support that technical teams and institutions can provide.

Conclusions

The shagras of the Cumbal Indigenous Reserve are heterogeneous systems: the mixture among use groups is very stable (evenness of 0.91), but richness varies greatly among shagras, and almost half of the 236 species or local names are in five shagras or fewer, so no vereda covers what is in the others; the inventory covers about 80% of the species estimated by Chao2. Richness increases with area, but less than proportionally, and differs more among veredas than among altitudes; household altitude does not predict how many species a shagra has, but it does predict how many tuber varieties a household lists within its vereda. Four shagra types are distinguished, which form a continuum and describe the role of each plot within the holding (42 of 46 households with several shagras have different types) and not the profile of the household head. The loss of tuber varieties is almost universal, and 11 households have a profile compatible with that of custodians. For *in situ* conservation, this suggests covering all veredas and the native-tree plots, validating custodian households with the communities, and mapping seed exchange before expanding fairs and banks.

List of abbreviations

AGROSAVIA: Colombian Corporation for Agricultural Research (Corporación Colombiana de Investigación Agropecuaria); ARI: Adjusted Rand Index; CIP: International Potato Center; GIS: geographic information system; IGAC: Instituto Geográfico Agustín Codazzi; IndVal: indicator value; a.s.l.: above sea level.

Declarations

Ethics approval and consent to participate: Formal approval from an institutional ethics committee was not obtained for this study. At AGROSAVIA, informed consent procedures are reviewed by the intellectual property office and the legal office, which reviewed the informed consent form used in this study. Before fieldwork, a meeting was held with the Cumbal Indigenous Reserve

(Resguardo) to present the project and agree on its development, and all participants signed the informed consent form before any research activity took place; consent was also recorded in the digital survey form.

Consent for publication: Not applicable.

Availability of data and materials: The anonymised survey datasets (species presence/absence by shagra, household characteristics and seed-variety records) generated and analysed during this study are not publicly available because they belong to the Indigenous community of the Cumbal Reserve, but they can be obtained from the corresponding author on reasonable request, subject to the approval of the authorities of the Cumbal Indigenous Reserve and of the institutions involved. The signed informed consent forms and the letter of the Cumbal Indigenous Reserve are not published, to protect the identity of the signatories, but the corresponding statements were recorded in the digital survey form, and the documents can be made available to the editors on request.

Competing interests: The authors declare that they have no competing interests.

Funding: This research was funded by the CGIAR Nature Positive Solutions Initiative during 2023–2026, with the support of the International Potato Center (CIP) and the Colombian Corporation for Agricultural Research (AGROSAVIA).

Authors' contributions: Conceptualization, C.P.V.C., S.d.H., I.N., Z.L.L.P., O.Y.P.C.; methodology, C.P.V.C., S.d.H., I.N., Z.L.L.P., O.Y.P.C., F.E.M.M.; formal analysis, C.P.V.C., I.N., S.d.H., Z.L.L.P., F.E.M.M.; investigation, C.P.V.C., Z.L.L.P., O.Y.P.C., M.M.C.P., B.Y.Ch., M.G.R.A., V.H., J.O., F.E.M.M.; resources, S.d.H., O.Y.P.C., I.N.; data curation, C.P.V.C., Z.L.L.P., O.Y.P.C., F.E.M.M.; writing – original draft, C.P.V.C.; writing – review and editing, C.P.V.C., I.N.; supervision, S.d.H., I.N., O.Y.P.C.; project administration, S.d.H., O.Y.P.C.; funding acquisition, S.d.H., O.Y.P.C. All authors read and approved the final manuscript.

Acknowledgements: This work is part of a broader project led by the Colombian Corporation for Agricultural Research (AGROSAVIA) and the International Potato Center (CIP), entitled *Multifunctional Landscapes*. We thank the Gran Cumbal Indigenous Reserve, the Cumbe Indigenous Educational Institution and the Municipality of Cumbal for their valuable support and contributions to fieldwork, community participation and the exchange of local knowledge. We also express our deepest gratitude to all the women and men custodians of the Gran Cumbal Indigenous

Reserve, whose lifelong dedication to conserving native potato agrobiodiversity safeguards biocultural heritage, local knowledge and food diversity for present and future generations.

Use of AI-assisted tools: An AI language model (Claude, Anthropic) was used for language editing, searching for and formatting bibliographic references, translation from Spanish into English, and adjustment of the R scripts. The authors reviewed and edited all outputs and take full responsibility for the content of the article.

References

Agredo, M., Raz, L., & González, O. (2018). Conservación in situ de cultivares nativos y el conocimiento tradicional en los huertos familiares de Cumbal, Nariño, Colombia [In situ conservation of native cultivars and traditional knowledge in home gardens of Cumbal, Nariño, Colombia]. In Y. Chirinos, A. Ramírez, N. Barbera, & L. Camejo (Coords.), *Tendencias en la investigación universitaria: Una visión desde Latinoamérica* (Vol. 4, pp. 82–98). Fondo Editorial Universitario Servando Garcés, Universidad Politécnica Territorial de Falcón Alonso Gamero.

Alvarez, S., Timler, C. J., Michalscheck, M., Paas, W., Descheemaeker, K., Tittonell, P., Andersson, J. A., & Groot, J. C. J. (2018). Capturing farm diversity with hypothesis-based typologies: An innovative methodological framework for farming system typology development. *PLOS ONE, 13*(5), Article e0194757. https://doi.org/10.1371/journal.pone.0194757

Arce, A., de Haan, S., Juarez, H., Burra, D. D., Plasencia, F., Ccanto, R., Polreich, S., & Scurrah, M. (2019). The spatial-temporal dynamics of potato agrobiodiversity in the highlands of Central Peru: A case study of smallholder management across farming landscapes. *Land, 8*(11), Article 169. https://doi.org/10.3390/land8110169

Asociación de Shaquiñan. (2017). La shagra, las semillas y el derecho fundamental a la soberanía alimentaria en el territorio indígena del Nudo de los Pastos [The shagra, seeds and the fundamental right to food sovereignty in the Indigenous territory of the Nudo de los Pastos]. *Semillas, 67/68*, 89. https://www.semillas.org.co/es/la-shagra-las-semillas-y-el-derecho-fundamental-a-la-soberana-alimentaria-en-el-territorio-indgena-del-nudo-de-los-pastos

Avilez-López, T., van der Wal, H., Aldasoro-Maya, E., et al. (2020). Home gardens' agrobiodiversity and owners' knowledge of their ecological, economic and socio-cultural multifunctionality: A case study in the lowlands of Tabasco, México. *Journal of Ethnobiology and Ethnomedicine, 16*, Article 42. https://doi.org/10.1186/s13002-020-00392-2

Baselga, A. (2010). Partitioning the turnover and nestedness components of beta diversity. *Global Ecology and Biogeography, 19*(1), 134–143. https://doi.org/10.1111/j.1466-8238.2009.00490.x

Belalcázar Benavides, P. A., & Puerres Puerres, O. A. (2016). *Caracterización biofísica del Resguardo Indígena de Cumbal, Nariño, mediante herramientas de información geográfica* [Biophysical characterization of the Cumbal Indigenous Reserve, Nariño, using geographic information tools] [Specialization thesis, Universidad de Manizales].

Benjamini, Y., & Hochberg, Y. (1995). Controlling the false discovery rate: A practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society: Series B (Methodological), 57*(1), 289–300. https://doi.org/10.1111/j.2517-6161.1995.tb02031.x

Bernal, R., Galeano, G., Rodríguez, A., Sarmiento, H., & Gutiérrez, M. (2012). *Nombres comunes de las plantas de Colombia* [Common names of the plants of Colombia]. Biovirtual, Universidad Nacional de Colombia. https://www.biovirtual.unal.edu.co/nombrescomunes/

Bernal, R., Gradstein, S. R., & Celis, M. (Eds.). (2015–2020). *Catálogo de plantas y líquenes de Colombia* [Catalogue of plants and lichens of Colombia]. Instituto de Ciencias Naturales, Universidad Nacional de Colombia. http://catalogoplantasdecolombia.unal.edu.co

Biovirtual UNAL. (n.d.-a). *Nombres comunes de plantas de Colombia* [Common names of plants of Colombia]. Universidad Nacional de Colombia. http://www.biovirtual.unal.edu.co/nombrescomunes/es/

Biovirtual UNAL. (n.d.-b). *Colecciones en línea: plantas* [Online collections: plants]. Instituto de Ciencias Naturales, Universidad Nacional de Colombia. https://www.biovirtual.unal.edu.co/es/colecciones/search/plants/

Borcard, D., Gillet, F., & Legendre, P. (2018). *Numerical ecology with R* (2nd ed.). Springer. https://doi.org/10.1007/978-3-319-71404-2

Byrnes, A., & Sthapit, B. (2016). *A guide to the identification and importance of custodian farmers*. Bioversity International. https://hdl.handle.net/10568/76296

Caulfield, M. E., Hammond, J., Fonte, S. J., Florido, M. A., Fuentes, W., Meza, K., Navarrete, I., Vanek, S. J., & van Wijk, M. (2021). Unpicking the inter-relationships between off-farm livelihood diversification, household characteristics, and farm management in the rural Andes. *Frontiers in Sustainable Food Systems, 5*, Article 724492. https://doi.org/10.3389/fsufs.2021.724492

Chao, A. (1987). Estimating the population size for capture-recapture data with unequal catchability. *Biometrics, 43*(4), 783–791. https://doi.org/10.2307/2531532

Chao, A., Gotelli, N. J., Hsieh, T. C., Sander, E. L., Ma, K. H., Colwell, R. K., & Ellison, A. M. (2014). Rarefaction and extrapolation with Hill numbers: A framework for sampling and estimation in species diversity studies. *Ecological Monographs, 84*(1), 45–67. https://doi.org/10.1890/13-0133.1

Colwell, R. K., & Coddington, J. A. (1994). Estimating terrestrial biodiversity through extrapolation. *Philosophical Transactions of the Royal Society B: Biological Sciences, 345*(1311), 101–118. https://doi.org/10.1098/rstb.1994.0091

Coomes, O. T., McGuire, S., Garine, E., Caillon, S., McKey, D., Demeulenaere, E., Jarvis, D., Aistara, G., Barnaud, A., Clouvel, P., Emperaire, L., Louafi, S., Martin, P., Massol, F., Pautasso, M., Violon, C., & Wencelius, J. (2015). Farmer seed networks make a limited contribution to agriculture? Four common misconceptions. *Food Policy, 56*, 41–50. https://doi.org/10.1016/j.foodpol.2015.07.008

Coppens d'Eeckenbrugge, G., Barney, V. E., Jørgensen, P. M., & MacDougal, J. M. (2001). *Passiflora tarminiana*, a new cultivated species of *Passiflora* subgenus *Tacsonia* (Passifloraceae). *Novon, 11*(1), 8–15.

Cuastumal Leitón, M. S. (2019). *La shagra: Propuesta pedagógica para fortalecer la identidad y el saber cultural con los estudiantes del grado 4° del Centro Educativo Cristo Bajo, Resguardo de Muellamues (Nariño)* [The shagra: A pedagogical proposal to strengthen identity and cultural knowledge with fourth-grade students of the Cristo Bajo Educational Center, Muellamues Reserve (Nariño)] [Undergraduate thesis, Universidad Nacional Abierta y a Distancia].

Díaz, S., Lavorel, S., de Bello, F., Quétier, F., Grigulis, K., & Robson, T. M. (2007). Incorporating plant functional diversity effects in ecosystem service assessments. *Proceedings of the National Academy of Sciences, 104*(52), 20684–20689. https://doi.org/10.1073/pnas.0704716104

Dufrêne, M., & Legendre, P. (1997). Species assemblages and indicator species: The need for a flexible asymmetrical approach. *Ecological Monographs, 67*(3), 345–366. https://doi.org/10.1890/0012-9615(1997)067[0345:SAAIST]2.0.CO;2

ESA. (2021). *Copernicus Global Digital Elevation Model (Copernicus DEM GLO-90)* [Data set]. European Space Agency. https://doi.org/10.5270/ESA-c5d3d65

Escobar, A., Rosero, D., Rosero, M., & Tapie, W. (2013). *Conservation and utilization of traditional Andean agriculture in the Indigenous Reservations of Gran Cumbal and Males, Córdoba, Department of Nariño*.

Galluzzi, G., Eyzaguirre, P., & Negri, V. (2010). Home gardens: Neglected hotspots of agro-biodiversity and cultural diversity. *Biodiversity and Conservation, 19*(13), 3635–3654. https://doi.org/10.1007/s10531-010-9919-5

Gbedomon, R. C., Salako, V. K., Fandohan, A. B., Idohou, A. F. R., Glèlè Kakaï, R., & Assogbadjo, A. E. (2017). Functional diversity of home gardens and their agrobiodiversity conservation benefits in Benin, West Africa. *Journal of Ethnobiology and Ethnomedicine, 13*, Article 66. https://doi.org/10.1186/s13002-017-0192-5

Hennig, C. (2007). Cluster-wise assessment of cluster stability. *Computational Statistics & Data Analysis, 52*(1), 258–271. https://doi.org/10.1016/j.csda.2006.11.025

Herbario Nacional Colombiano. (n.d.). *Herbarium specimens consulted* [Herbarium collection]. Instituto de Ciencias Naturales, Universidad Nacional de Colombia, Bogotá, Colombia.

Herbario PSO. (n.d.). *Herbarium specimens consulted* [Herbarium collection]. Universidad de Nariño, Pasto, Colombia.

Hernandez Marentes, M. A., Venturi, M., Scaramuzzi, S., Focacci, M., & Santoro, A. (2022). Traditional forest-related knowledge and agrobiodiversity preservation: The case of the *chagras* in the Indigenous Reserve of Monochoa (Colombia). *Biodiversity and Conservation, 31*, 2243–2258. https://doi.org/10.1007/s10531-021-02263-y

Hubert, L., & Arabie, P. (1985). Comparing partitions. *Journal of Classification, 2*(1), 193–218. https://doi.org/10.1007/BF01908075

Jaccard, P. (1912). The distribution of the flora in the alpine zone. *New Phytologist, 11*(2), 37–50.

Jegora, T., Hundera, K., Kebebew, Z., & Eneyew, A. (2025). Woody species composition and diversity of agroforestry homegardens along altitudinal gradient in southwest Ethiopia. *PLOS ONE, 20*, Article e0313520. https://doi.org/10.1371/journal.pone.0313520

Joshi, B. K., & Shrestha, R. (Eds.). (2019). *Working groups of APGRs in Nepal*. NAGRC.

Joshi, B. K. (2021). Agrobiodiversity indicators and measurement using R. *Agrobiodiversity & Agroecology, 1*(1), 47–64. https://doi.org/10.33002/aa010103

Jost, L. (2006). Entropy and diversity. *Oikos, 113*(2), 363–375. https://doi.org/10.1111/j.2006.0030-1299.14714.x

Jurado-Gámez, H. A., Solarte-Portilla, C. E., Burgos-Arcos, A. J., González-Rodríguez, A., & Rosero-Galindo, C. (2020). Relación entre la calidad composicional y sanitaria de la leche de bovinos Holstein del trópico alto de Nariño [Relationship between the compositional and sanitary quality of milk from Holstein cattle in the Nariño high tropics]. *Revista Mexicana de Ciencias Pecuarias, 11*(2), 421–434. https://doi.org/10.22319/rmcp.v11i2.5118

Kaufman, L., & Rousseeuw, P. J. (1990). *Finding groups in data: An introduction to cluster analysis*. Wiley.

Khoury, C. K., Achicanoy, H. A., Bjorkman, A. D., Navarro-Racines, C., Guarino, L., Flores-Palacios, X., Engels, J. M. M., Wiersema, J. H., Dempewolf, H., Sotelo, S., Ramírez-Villegas, J., Castañeda-Álvarez, N. P., Fowler, C., Jarvis, A., Rieseberg, L. H., & Struik, P. C. (2016). Origins of food crops connect countries worldwide. *Proceedings of the Royal Society B: Biological Sciences, 283*(1832), Article 20160792. https://doi.org/10.1098/rspb.2016.0792

Korpelainen, H. (2023). The role of home gardens in promoting biodiversity and food security. *Plants, 12*(13), Article 2473. https://doi.org/10.3390/plants12132473

Kumar, B. M., & Nair, P. K. R. (2004). The enigma of tropical homegardens. *Agroforestry Systems, 61*, 135–152. https://doi.org/10.1023/B:AGFO.0000028995.13227.ca

Kumar, B. M., & Nair, P. K. R. (Eds.). (2006). *Tropical homegardens: A time-tested example of sustainable agroforestry*. Springer. https://doi.org/10.1007/978-1-4020-4948-4

Kumar, B. M. (2023). Do carbon stocks and floristic diversity of tropical homegardens vary along an elevational gradient and based on holding size in central Kerala, India? *Agroforestry Systems, 97*, 751–783. https://doi.org/10.1007/s10457-023-00821-7

Kunhamu, T. K. (2013). Tropical homegardens. In A. J. Raj & S. B. Lal (Eds.), *Agroforestry: Theory and practice* (pp. 365–375). Scientific Publishers.

Lerma-Lasso, J. L., Bacca-Acosta, P. P., Obando-Enriquez, B. G., Castro-Rincón, E., & Cardona-Iglesias, J. L. (2023). Sistemas silvopastoriles: Una opción para la sostenibilidad de los sistemas ganaderos de alta montaña [Silvopastoral systems: An option for the sustainability of high-mountain livestock systems]. *Pastos y Forrajes, 46*, Article e15.

Loaiza Buitrago, D. F., Colimba Guadir, Y. L., Castro Cataño, M. E., & Zambrano Bermeo, R. N. (2023). Cultura alimentaria, tejidos que fortalecen el cuidado colectivo en una comunidad indígena [Food culture, weavings that strengthen collective care in an Indigenous community]. *Cultura de los Cuidados, 27*(66), 183–196. https://doi.org/10.14198/cuid.2023.66.13

López Cortés, O. (2018). Significados y representaciones de la minga para el pueblo indígena Pastos de Colombia [Meanings and representations of the minga for the Pastos Indigenous people of Colombia]. *Psicoperspectivas, 17*(3). https://doi.org/10.5027/psicoperspectivas-Vol17-Issue3-fulltext-1353

Lüttringhaus, S., Pradel, W., Suarez, V., Manrique-Carpintero, N. C., Anglin, N. L., Ellis, D., Hareau, G., Jamora, N., Smale, M., & Gómez, R. (2021). Dynamic guardianship of potato landraces by Andean communities and the genebank of the International Potato Center. *CABI Agriculture and Bioscience, 2*, Article 45. https://doi.org/10.1186/s43170-021-00065-4

Maechler, M., Rousseeuw, P., Struyf, A., Hubert, M., & Hornik, K. (2022). *cluster: Cluster analysis basics and extensions* (R package version 2.1.4) [Computer software]. https://CRAN.R-project.org/package=cluster

Miranda, Z., & García, L. (2022). La chagra: Una experiencia de enculturación hacia la soberanía alimentaria [The chagra: An experience of enculturation toward food sovereignty]. *Inclusión y Desarrollo, 9*(1), 87–96.

Missouri Botanical Garden. (n.d.). *Tropicos*. https://www.tropicos.org/

Molina, C. A., Dudenhoefer, D., Polar, V., Scurrah, M., Ccanto, R. C., & Heider, B. (2022). Gender roles and native potato diversity management in highland communities of Peru. *Sustainability, 14*(6), Article 3455. https://doi.org/10.3390/su14063455

Murtagh, F., & Legendre, P. (2014). Ward's hierarchical agglomerative clustering method: Which algorithms implement Ward's criterion? *Journal of Classification, 31*(3), 274–295. https://doi.org/10.1007/s00357-014-9161-z

Navarrete, I., Parra-Rondinel, F., Scurrah, M., Bonifacio, A., & Andrade-Piedra, J. L. (2024). Recent developments for robust potato seed systems through agrobiodiversity and farmers engagement in the Andes. *Current Opinion in Environmental Sustainability, 69*, Article 101454. https://doi.org/10.1016/j.cosust.2024.101454

Niñez, V. K. (1984). *Household gardens: Theoretical considerations on an old survival strategy*. International Potato Center.

Open-Meteo. (2026). *Elevation API* [Computer software]. Retrieved October 2026, from https://open-meteo.com/en/docs/elevation-api

Pathania, S., et al. (2022). *Horticulturae, 8*, Article 838.

Pautasso, M., Aistara, G., Barnaud, A., et al. (2013). Seed exchange networks for agrobiodiversity conservation: A review. *Agronomy for Sustainable Development, 33*, 151–175. https://doi.org/10.1007/s13593-012-0089-6

Perrault-Archambault, M., & Coomes, O. T. (2008). Distribution of agrobiodiversity in home gardens along the Corrientes River, Peruvian Amazon. *Economic Botany, 62*(2), 109–126. https://doi.org/10.1007/s12231-008-9010-2

Pielou, E. C. (1966). The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology, 13*, 131–144. https://doi.org/10.1016/0022-5193(66)90013-0

Pinheiro, J. C., & Bates, D. M. (2000). *Mixed-effects models in S and S-PLUS*. Springer.

Piperno, D. R. (2011). The origins of plant cultivation and domestication in the New World tropics: Patterns, process, and new developments. *Current Anthropology, 52*(S4), S453–S470. https://doi.org/10.1086/659998

R Core Team. (2025). *R: A language and environment for statistical computing* (Version 4.5.1) [Computer software]. R Foundation for Statistical Computing. https://www.R-project.org/

Rosero Alpala, M. G. (2006). *Aportes al conocimiento etnobotánico sobre el uso y manejo de la vegetación del páramo La Ortiga, Resguardo del Gran Cumbal (Nariño, Colombia)* [Contributions to ethnobotanical knowledge about the use and management of vegetation in La Ortiga páramo, Gran Cumbal Reserve (Nariño, Colombia)] [Thesis, Universidad de Nariño]. https://sired.udenar.edu.co/14174/

Rosero Alpala, M. G., Tapie, W. A., & Rosero Alpala, D. A. (2020). Diversidad fenotípica de papas nativas en las comunidades indígenas de la etnia de los Pastos (Nariño, Colombia) [Phenotypic diversity of native potatoes in the Indigenous communities of the Pastos ethnic group (Nariño, Colombia)]. *Revista Peruana de Biología, 27*(4), 509–516. http://www.scielo.org.pe/scielo.php?script=sci_arttext&pid=S1727-99332020000400509

Rosero, D., Rosero, G., Tapie, A., & Ortiz, A. (2015). *Procesos de revalorización de la shagra en el pueblo de los Pastos como base para la recuperación de la soberanía alimentaria, pervivencia y cultura de un pueblo* [Processes of revaluing the shagra among the Pastos people as a basis for recovering food sovereignty, endurance and culture] [Paper presentation]. V Congreso Latinoamericano de Agroecología, SOCLA. http://sedici.unlp.edu.ar/handle/10915/54427

Rousseeuw, P. J. (1987). Silhouettes: A graphical aid to the interpretation and validation of cluster analysis. *Journal of Computational and Applied Mathematics, 20*, 53–65. https://doi.org/10.1016/0377-0427(87)90125-7

Royal Botanic Gardens, Kew. (n.d.). *Plants of the World Online (POWO)*. Retrieved September 2026, from https://powo.science.kew.org/

Shannon, C. E. (1948). A mathematical theory of communication. *The Bell System Technical Journal, 27*(3), 379–423. https://doi.org/10.1002/j.1538-7305.1948.tb01338.x

Simpson, E. H. (1949). Measurement of diversity. *Nature, 163*, 688. https://doi.org/10.1038/163688a0

Sørensen, T. (1948). A method of establishing groups of equal amplitude in plant sociology based on similarity of species content. *Kongelige Danske Videnskabernes Selskab, Biologiske Skrifter, 5*(4), 1–34.

Sthapit, B., Lamers, H., & Rao, R. (Eds.). (2013). *Custodian farmers of agricultural biodiversity: Selected profiles from South and South East Asia* [Proceedings of a workshop held in New Delhi, India, 11–12 February 2013]. Bioversity International. https://hdl.handle.net/10568/68979

Tapia, M. E., & De la Torre, A. (1998). *Women farmers and Andean seeds* (Working paper). https://hdl.handle.net/10568/104293

Venables, W. N., & Ripley, B. D. (2002). *Modern applied statistics with S* (4th ed.). Springer.

Vernooy, R., Ramírez, M., Gangotena, E., & Chirán, A. (2025). *Las especies olvidadas y subutilizadas del Resguardo Indígena del Gran Cumbal, Colombia: Resultados del diagnóstico participativo* [The forgotten and underutilized species of the Gran Cumbal Indigenous Reserve, Colombia: Results of the participatory diagnosis]. Bioversity International.

Wagner Medina, E. V. (2012). *Understanding "La Shagra" (home garden) as a resilient strategy in the indigenous Pastos community in Nariño, Colombia* [Master's thesis, University of Hohenheim].

https://www.cervantesvirtual.com/obra/understanding-la-shagra-home-garden-as-a-resilient-strategy-in-the-indigenous-pastos-community-in-narino-colombia-860984/

White, L., Andrade, D., Montánchez, P., & Villarreal, J. (2024). *Contexto del municipio de Cumbal, Nariño* [Context of the municipality of Cumbal, Nariño]. Centro de Estudios Regionales (CEDRE).

Whittaker, R. H. (1960). Vegetation of the Siskiyou Mountains, Oregon and California. *Ecological Monographs, 30*(3), 279–338. https://doi.org/10.2307/1943563

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- SupplementaryMaterialEN.docx