DOI: 10.29298/rmcf.v17i95.1625
Research article

Selection of *Alnus acuminata* Kunth seed trees in the Northern Peruvian Andes

Selección de árboles semilleros de *Alnus acuminata* Kunth en los Andes del norte peruano

Kely Lizeth Vásquez Saldaña[1]*, Eiler Llatas Mires[2], Jim Jairo Villena Velásquez[1], Leyla Catherine Alarcón Alarcón[1], Yuli Anabel Chávez-Juanito[1], Duberli Geomar Elera Gonzales[2,3]

Fecha de recepción/Reception date: 18 de diciembre de 2025.
Fecha de aceptación/Acceptance date: 15 de abril de 2026.

---

[1]Escuela Profesional de Ingeniería Forestal y Ambiental, Facultad de Ciencias Agrarias, Universidad Nacional Autónoma de Chota (UNACH). Perú.
[2]Grupo de Investigación en Biometría y Geomática Forestal (BIGFOR), Escuela Profesional de Ingeniería Forestal y Ambiental, Facultad de Ciencias Agrarias, Universidad Nacional Autónoma de Chota, Perú.
[3]Northeast Ecology and Management Research Group (NOREMA), Programa de Pós-Graduação em Ciências Florestais, Departamento de Ciência Florestal (DCFL), Universidade Federal Rural de Pernambuco (UFRPE), Brasil.

*Autor para correspondencia; correo-e: 2017031037@unach.edu.pe
*Corresponding author; e-mail: 2017031037@unach.edu.pe

Abstract

The restoration of high-Andean ecosystems requires adapted and traceable genetic material to ensure sustainable outcomes under climate change. The study aimed to identify and select *Alnus acuminata* seed trees based on phenotypic attributes in a region of the northern Peruvian Andes, using morphological, dendrometric, health and seed-quality criteria. A total of 204 trees were assessed across 18 locations, and 34 seed trees were selected using a scoring system; whose consistency was evaluated with the Wilcoxon signed-rank test ($p<0.001$). The seeds exhibited high physical and physiological quality, with an average purity of 81.51 %, a germination rate of 82.64 %, and an average emergence time of 11 days. K-means cluster analysis ($K=3$) and ANOVA ($p<0.001$) identified three phenotypically distinct groups based on size and volume, enabling the definition of productive classes applicable to restoration and genetic improvement programs. Correlations between germination and environmental variables were low, suggesting a limited influence of this factors. These findings confirm the reliability of the selection criteria and demonstrate the potential the selected seed trees to provide traceable forest reproductive material (FRM) of consistent quality, thereby contributing to the sustainability and resilience of Andean forests.

Keywords: Seed trees, seed quality, morphological characteristics, selection criteria, genetic improvement, phenotypic variability.

Resumen

La restauración de ecosistemas altoandinos requiere material genético adaptado y trazable para garantizar impactos sostenibles frente al cambio climático. Este estudio tuvo como objetivo identificar y seleccionar árboles semilleros de *Alnus acuminata* con base en atributos fenotípicos en una región de los Andes del norte peruano, a través de criterios morfológicos, dasométricos, sanitarios y de calidad de semillas. Se evaluaron 204 árboles en 18 localidades, se seleccionaron 34 individuos arbóreos semilleros mediante un sistema de puntuación, cuya consistencia fue evaluada con la prueba de rangos con signo de *Wilcoxon* (p<0.001). Las semillas presentaron alta calidad física y fisiológica, con pureza promedio de 81.51 % y germinación de 82.64 % y tiempo medio de emergencia de 11 días. El análisis de conglomerados K-medias (K=3) y ANOVA (p<0.001) identificaron tres grupos fenotípicos diferenciados en tamaño y volumen, lo que permite definir clases productivas con aplicación en programas de restauración y mejoramiento genético. Las correlaciones entre germinación y variables ambientales fueron bajas, lo que sugiere influencia limitada de estos factores. Estos hallazgos validan la consistencia del criterio de selección y evidencian el potencial de los árboles semilleros para producir material forestal de reproducción (MFR) con trazabilidad y calidad homogénea, contribuyendo a la sostenibilidad y resiliencia de los bosques andinos.

Palabras clave: Árboles semilleros, calidad de semilla, características morfológicas, criterios de selección, mejora genética, variabilidad fenotípica.

Introduction

Seeds are a vital resource for ecological restoration and reforestation programs, as the genetic and physiological quality of the propagation material directly influences the establishment, growth, and resilience of restoration plantings (Pedrini & Dixon, 2020; Pedrini et al., 2020). However, the availability of seeds from native species that meet appropriate quality standards is often limited, which restricts the effectiveness of field interventions and compromises the long-term outcomes of restoration projects (Broadhurst et al., 2008; Pedrini et al., 2020). This limitation is particularly critical in countries where there are still no regulatory mechanisms in place to ensure that supply chains meet minimum standards, which facilitates the circulation of seeds with low viability and poor quality control (Mainz & Wieden, 2019). This issue has been confirmed by Marin et al. (2017), who found high variability in germination and vigor among seed lots of native species; this highlights the need to establish appropriate protocols for the selection and management of seed trees as potential seed sources to ensure their genetic and physiological quality.

Within this context, the identification of seed trees is a widely used strategy in forest genetic improvement programs to ensure the production of high-quality seeds. Among the most commonly used selection methods are the comparison with control trees method, the linear regression method, and the individual assessment method (Flores et al., 2005).

The comparison method using reference trees is based on evaluating the candidate tree in relation to other adjacent trees, enabling identification of those with superior phenotypic characteristics. In contrast, the linear regression method uses the individual age-volume relationship of the trees considered as candidate plus trees. Although the latter method can be used when there are time or resource constraints that prevent more detailed field assessments, the comparison with control trees is generally considered more accurate for selecting the best trees (Muñoz Flores et al., 2012). According to Muñoz Flores et al. (2012), approximately 75 % of studies on the selection of top trees use this method, while about 15 % use linear regression.

In addition to their importance in forest genetic improvement programs, the selected seed trees also contribute to the *ex situ* conservation of forest genetic resources, as they enable the establishment of seed sources that ensure the availability of high-quality germplasm for restoration, research and forest production programs (Food and Agriculture Organization of the United Nations [FAO], 2014). This approach is particularly relevant for native species used in ecological restoration programs, where the limited availability of native seeds and suitable reproductive material is one of the main factors limiting the implementation of large-scale restoration projects (Pedrini et al., 2020).

Among the native species used in restoration programs in the Andes, *Alnus acuminata* Kunth stands out for its ecological and functional importance. This pioneer species has the ability to fix atmospheric nitrogen, which promotes the recovery of degraded soils and improves ecosystem fertility (Dawson, 2008). Furthermore, its rapid growth, tolerance to adverse environmental conditions, and ability to stabilize soils make it a key species for the restoration of watersheds and degraded areas (Cyamweshi et al., 2021).

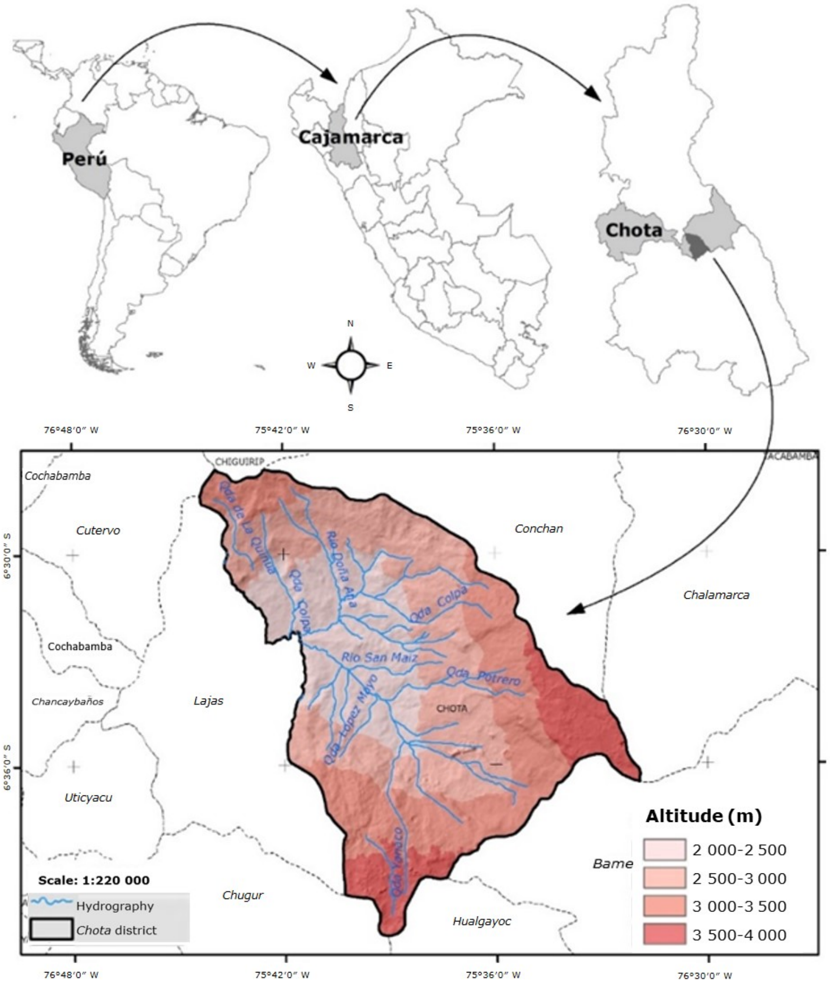
Studies on forest restoration have shown that *A. acuminata* plantations contribute to an increase in soil organic matter, an improvement in soil structure, and a reduction in surface erosion—processes that promote the functional recovery of degraded ecosystems (Lozano-Baez et al., 2019). In addition, the species is of socio-ecological importance in some Andean regions due to its use in agroforestry systems, timber production and traditional medicinal practices (Aguilar et al., 2011).

Despite its wide distribution in the Andean region of Northern Peru, there is limited information on seed trees for this species. Although natural populations and plantations have been recorded, there are still no systematic data documenting individuals with superior phenotypic characteristics that could be used as sources of high-quality germplasm. Within this context, the objective of this study was to identify and select seed trees of *A. acuminata* based on phenotypic attributes, by evaluating their mensuration and morphological characteristics, as well as the physical and physiological quality of their seeds. In addition, a map of the spatial distribution of the selected individuals was created to help establish a local genetic base, with the aim of strengthening the supply of high-quality seeds and supporting afforestation, reforestation and ecological restoration programs in the Andean region of Northern Peru.

Materials and Methods

Study area

The research was conducted in the *Chota* district, *Chota* province, department of *Cajamarca*, in northern Peru. The study area is located between 6°28′53″-6°39′14″ S and 78°42′15″-78°39′36″ W, with an approximate area of 261.75 km^2 and an altitude range of 2 395-3 460 m (Figure 1). The district was used as the spatial reference framework; assessments were conducted at specific sites where *A. acuminata* seed trees were identified.



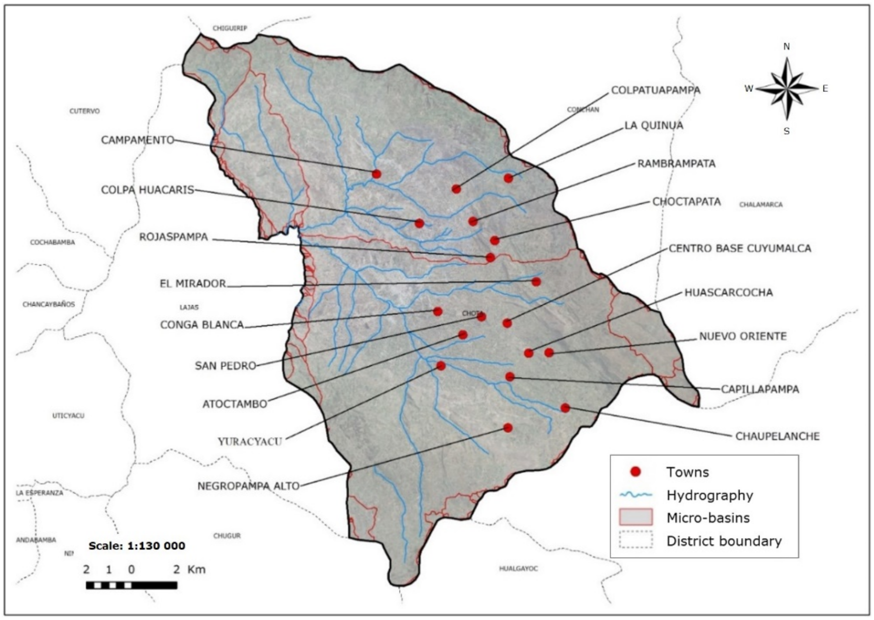
Perú = Peru; *Cajamarca* = Department of *Cajamarca*; Chota = *Chota* district.

Figure 1. Hydrography and altitudinal range of the study area.

According to Holdridge's life zone classification, the area comprises ecosystems corresponding to lowland tropical montane rainforest (bh-MBT) and lowland tropical montane evergreen forest (bmh-MBT) (Aybar-Camacho & Lavado-Casimiro, 2017). The climate is temperate subhumid, with an average annual temperature of 14-16 °C, average highs of 18-22 °C, and average lows of 8-10 °C. Annual precipitation ranges from 700 to 1 200 mm, occurring mainly between November and April, while the dry season extends from May to October, according to records from Peru's National Meteorological and Hydrological Service (Senamhi, 2020).

Identification and mapping of potential sampling areas

A preliminary mapping exercise was conducted to identify potential sampling areas representative of different altitudinal zones and soil conditions. The aim was to cover a wide environmental range that would facilitate the representation of genetic variability (Alves-Pimenta et al., 2023). The presence of *A. acuminata* was verified through field surveys, and—with the aid of geographic information systems (GIS)—a map was created identifying potential sampling sites, which served as the basis for guiding the selection and spatial distribution of candidate trees (Figure 2).



Campamento = *Campamento* Town; *Colpa Huacaris* = *Colpa Huacaris* Town; *Rojaspampa* = *Rojaspampa* Town; *El Mirador* = *El Mirador* Town; *Conga Blanca* = *Conga Blanca* Town; *San Pedro* = *San Pedro* Town; *Atoctambo* = *Atoctambo* Town; *Yuracyacu* = *Yuracyacu* Town; *Negropampa Alto* = *Negropampa Alto* Town; *Colpatuapampa* = *Colpatuapampa* Town; *La Quinua* = *La Quinua* Town; *Rambrampata* = *Rambrampata* Town; *Choctapata* = *Choctapata* Town; *Centro Base Cuyumalca* = *Centro Base Cuyumalca* Town; *Huascarcocha* = *Huascarcocha*

Town; *Nuevo Oriente* = *Nuevo Oriente* Town; *Capillapampa* = *Capillapampa* Town; *Chaupelanche* = *Chaupelanche* Town; *Cutervo* = *Cutervo* Town; *Chiguirip* = *Chiguirip* district; *Cochabamba* = *Cochabamba* district; *Chancaybaños* = *Chancaybaños* district; *Uticyacu* = *Uticyacu* district; *La Esperanza* = *La Esperanza* district; *Andabamba* = *Andabamba* district; *Chugur* = *Chugur* district; *Hualgayoc* = *Hualgayoc* province; *Chalamarca* = *Chalamarca* district; *Conchan* = *Conchan* district.

Figure 2. Identification of potential sampling sites for *Alnus acuminata* Kunth in the *Chota* district, Peru.

Sampling of candidate trees

During fall (March-June), 204 sexually mature *A. acuminata* trees bearing visible fruit were identified, drawn from both natural populations and plantations. For each individual, the diameter at breast height (*DBH*; 1.30 m) was measured using a model Mantax Blue Haglöf® caliper, and the total height (*TH*) and commercial height (*CH*) were measured using a model BL6 Blume-Leiss® hypsometer. Age was estimated using a Pressler increment borer (4.3 mm), and the geographic location of each tree was recorded using a model Montana 680 Garmin® GPS receiver. The total volume of the stem (*V*) was estimated from the variables *DBH* and *TH* using the equation: $V=0.0001468(ND^{2}TH)^{0.8610}$, proposed by Elera-Gonzales et al. (2023) for *A. acuminata* in forest plantations in northern Peru.

Phenotypic selection criteria

The selection of seed trees was based on mensuration, morphological and health criteria commonly used in forest genetic improvement and ecological restoration programs (Valladolid-Ontaneda et al., 2017). Characteristics of the stem, crown, and phytosanitary condition of both the tree and the fruit were evaluated; the scores assigned corresponded to the criteria set forth in Table 1. The final selection was made using the neighbor-tree comparison method, which involves comparing the candidate tree with the five best surrounding trees, giving priority to those that exhibited superior phenotypic traits and were free of morphological defects (García-Zárate et al., 2022).

Table 1. Criteria used for selecting *Alnus acuminata* Kunth seed trees.

Parameters	Description	Score
Shape of the stem	Straight	2
	Slightly twisted along the *CH*	1
	Twisted below the *CH*	0
Branching of the stem	Does not exhibit branching	2
	Branching at the height of the *DBH*	1
	Branching below the *DBH*	0
Crown symmetry	Symmetrical or regular	2
	Asymmetrical or irregular	1
Percentage of flowering shoots	>80 %	3
	80-20 %	2
	<20 %	1
Percentage of fruiting shoots	>70 %	3
	70-30 %	2
	<30 %	1
Tree health status	Healthy	2
	Biological damage	1
Fruit health status	Healthy fruits	2
	Biological damage in fruits	1

CH = Commercial height; *DBH* = Diameter at breast height. Source: García-Zárate et al. (2022).

Priority was given to trees located in areas with low intraspecific competition and adequate accessibility for seed collection, in accordance with technical recommendations for the selection of seed trees in ecological restoration and forest genetic improvement programs (Organización de las Naciones Unidas para la Alimentación y la Agricultura [ONUAA], 2021; Pedrini et al., 2020). Furthermore, to reduce the likelihood of collecting related individuals and to promote genetic representativeness, a minimum distance of around 200 m was maintained between selected trees within each sampling site, according to the spatial distribution criteria cited in similar studies (Wongwachimaphet et al., 2024).

Harvesting, drying and storing fruits

A. acuminata fruits were harvested during the dry season (June-August), when they had reached physiological maturity, as evidenced by the darkening and hardening of the fruit (López-Leiva & Montero, 2024). Trees aged ≥10 years were selected, as estimated using the Pressler increment borer drilling method (Imaña & Encinas, 2008), since seeds from younger trees tend to have lower viability (Salazar, 2000). After harvesting, the fruits were dried in the shade for 36 hours and then exposed to sunlight for 72 hours to encourage them to open naturally and release their seeds. These were manually separated, coded according to the parent tree, and stored in airtight bags in a dry, dark environment, according to the recommendations of the International Seed Testing Association (ISTA, 2016) and documented procedures for Andean species (Urretavizcaya et al., 2016).

Processing of the collected samples

Botanical *A. acuminata* samples (terminal branches with leaves, flowers and fruits) were collected with authorization from the National Forestry and Wildlife Service (Serfor; RA No. D000149-2024-MIDAGRI-SERFOR-ATFFS-CAJAMARCA). The specimens were labeled, pressed, and transported to the "*Pedro Coronado Arrascue*" Herbarium at the National Autonomous University of *Chota*, where they were dried naturally by periodically replacing the absorbent paper to prevent fungal growth and ensure uniform drying. The specimens were then mounted on Folcote cardstock (30×40 cm), labeled, and deposited at this institution, recognized as a National Scientific Depository Institution for Biological Material (code AUT-ICND-2019-003), in accordance with Resolution No. 503-2019-MINAGRI-SERFOR-DGGSPFFS.

Physical and physiological analysis of the seeds

Physical and physiological analyses of the seeds were conducted according to the protocols established by ISTA (2016). Physical purity was determined using two 4-gram subsamples. Moisture content was determined using two 5-g subsamples, dried at 105±2 °C for 17 hours in a model UN30 Memmert® oven. The weight of 100 seeds was determined based on eight replicates using a model BAS-31 Plus Boeco® analytical balance; the procedure was repeated when the Coefficient of variation (*CV*) exceeded 4 %. Germination was assessed using four replicates of 100 seeds per tree under controlled conditions of 25±2 °C, 70-80 % relative humidity (*RH*), and a 16/8-hour photoperiod (light/dark), following the methodology of ISTA (2016) and Ezau & Salazar (1998); seedling emergence was recorded daily for 21 days, based on which the germination percentage was calculated.

Data analysis

Validation of the phenotypic selection criterion

To validate the selection method based on the phenotypic criteria used, the Wilcoxon signed-rank test was applied to paired samples. This test allowed comparing the score obtained by each selected tree with the median (*M*) of the scores of the unselected trees within its respective group. The analysis was performed at a significance level of $\alpha=0.05$ using the "Wilcox.test()" function from the "stats" package in R (version 4.4.2) (R Core Team, 2025; Wilcoxon, 1945).

Tree-age analysis

The age of the selected seed trees was analyzed using descriptive statistics, with the mean, median, minimum and maximum values, as well as the interquartile range, being calculated. To visualize the age distribution and identify potential outliers, a boxplot was created. The analyses were performed using Microsoft Excel 2016.

Cluster analysis for phenotypic classification

A cluster analysis was performed to identify clusters among the selected trees based on their dendrometric traits: *DBH*, *TH*, *CH*, and *V*. Previously, the dasometric variables were scaled and standardized to avoid order-of-magnitude effects between variables. The optimal number of clusters (*K*) was determined using the silhouette method, for which the "fviz_nbclust()" function from the "factoextra" package in R (version 4.4.2) was used (R Core Team, 2025). This method evaluates the quality of the partition by maximizing the average silhouette width, which indicates high internal cohesion and adequate separation between clusters. Next, the K-means algorithm was applied to perform the clustering, using the previously determined number of clusters. The algorithm was run with 25 random initializations (*nstart*=25) to ensure convergence to a stable solution.

The differences among the identified clusters were assessed using an analysis of variance (ANOVA), with cluster membership as the grouping factor and the dasometric variables as response variables. When significant differences were detected, Tukey's *post hoc* test (*HSD*) was applied to identify the clusters that differed from one another for each variable. These analyses were performed using the "aov()" and "TukeyHSD()" functions from the "stats" package in R (version 4.4.2) (R Core Team, 2025).

Seed analysis

The data corresponding to the physical and physiological quality variables of the seeds were analyzed using descriptive statistics, with the recorded mean values, standard deviation, and Coefficient of variation. Since the evaluated variables correspond to descriptive parameters of seed behavior, no statistical hypothesis tests were performed. The analyses were performed using Microsoft Excel 2016.

Results

Selected trees

Of the 204 assessed trees, 34 *A. acuminata* seed trees were selected. Six of them came from natural stands and 28 from plantations. All selected specimens met the established criteria, namely: a straight stem, a symmetrical crown, a flowering rate of over 80 %, a fruiting rate of over 70 % and a good phytosanitary condition.

The comparative analysis showed that the selected trees had significantly higher scores than the non-selected trees, as evidenced by higher median values in the selected group ($MScore_{YES} > MScore_{NO}$). The Wilcoxon signed-rank test confirmed these differences (V=595, p<0.001), supporting the consistency of the phenotypic selection criterion applied (Figure 3).

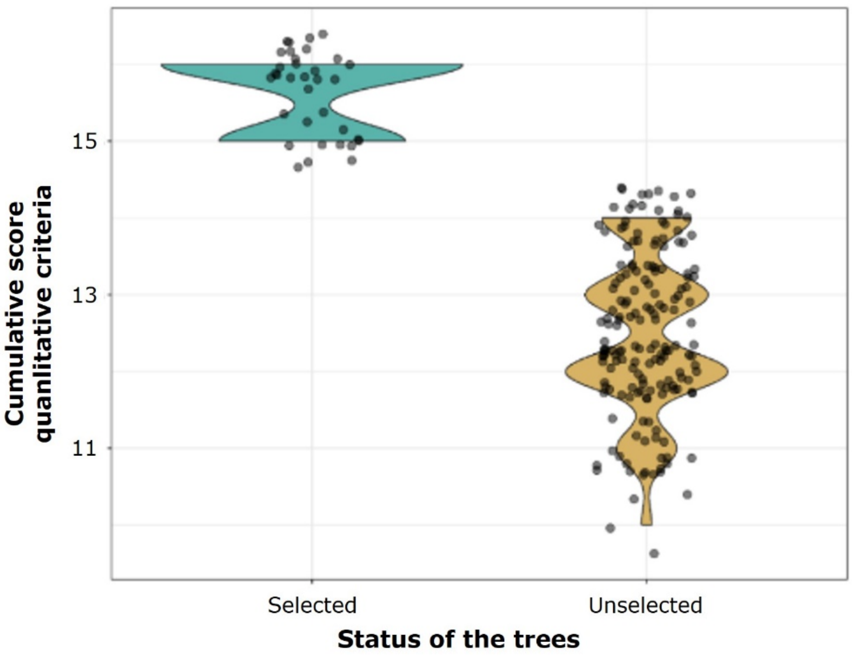
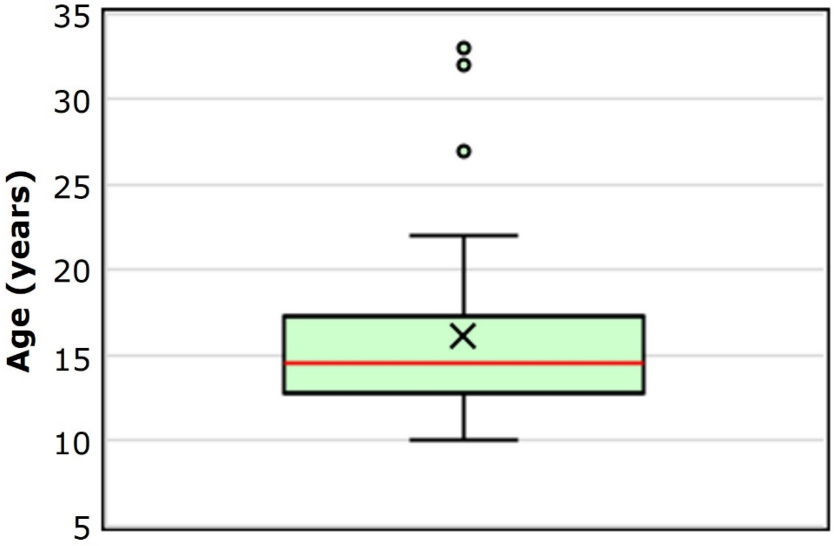


Figure 3. Distribution of scores for the group of selected and unselected trees.

Age of the selected trees

The ages of the seed trees showed a distribution concentrated in the intermediate age classes (Figure 4). The boxplot showed a median of 15 years, with an interquartile range of 13 to 17 years, indicating that 50 % of the individuals fall within this range. Ages ranged from 10 to 33, with a mean of 16 (n=34). Outliers were identified among older individuals (27, 32, and 33 years old), which fall outside the typical distribution range observed in the selected seed-tree population as a whole.



The horizontal line represents the median; the "X" indicates the mean; the whiskers represent non-outlier values, and the dots represent outliers.

Figure 4. Age distribution of *Alnus acuminata* Kunth seed trees selected in the study area.

Dendrometric characteristics of the selected seed trees

The 34 selected seed trees (Table 2) had an average *DBH* of 34.22 cm (range: 22.20-67.50 cm); tree height ranged from 14.50 to 35.50 m, with an average of 21.19 m. The coefficients of variation were 33.63 % (*DBH*), 23.10 % (*TH*), and 39.05 % (*CH*), indicating moderate to high variability in the mensuration dimensions.

Table 2. Height and diameter measurements of the 34 selected seed trees.

Tree code	**Dasometric variables**				**Cluster**
	***DBH* (cm)**	***TH* (m)**	***CH* (m)**	***V* (m^3)**	
A1	65.20	25.70	7.50	1.1074	3
A2	27.70	18.30	5.60	0.1972	1
A3	56.70	30.20	7.30	0.8506	3
A4	38.30	23.50	4.60	0.2908	2
A5	30.50	24.50	4.50	0.1928	2
A6	33.20	17.50	3.50	0.1797	1
A7	32.20	25.50	5.50	0.2516	2
A8	35.50	24.50	4.50	0.2504	2
A9	32.70	24.00	12.00	0.5058	2
A10	42.50	14.50	4.50	0.3414	1
A11	67.50	27.00	5.70	0.9281	3
A12	56.40	35.50	14.00	1.4765	3
A13	30.50	15.50	7.30	0.2924	1
A14	28.50	23.00	10.00	0.3412	2
A15	30.40	23.50	4.00	0.1732	2
A16	22.40	14.50	4.50	0.1133	1
A17	26.50	15.50	3.00	0.1067	1
A18	27.50	18.00	3.50	0.1299	1
A19	27.70	18.50	5.50	0.1941	1
A20	22.20	15.50	4.50	0.1116	1
A21	33.50	17.00	4.50	0.2266	1
A22	23.50	16.00	5.00	0.1347	1
A23	26.20	16.50	6.50	0.2037	1
A24	38.20	21.90	3.70	0.24	2
A25	45.20	27.50	7.80	0.6095	2
A26	33.30	19.50	4.50	0.2243	1
A27	33.50	24.50	6.00	0.2903	2
A28	32.60	22.50	6.50	0.2968	2
A29	25.40	17.50	4.50	0.1407	1
A30	28.40	18.50	6.50	0.234	1
A31	25.50	24.00	7.00	0.2072	2
A32	28.20	19.50	7.50	0.2615	2
A33	23.50	18.50	6.50	0.1689	1

A34	32.40	22.50	7.50	0.3321	2
Minimum	22.20	14.50	3.00	0.11	
Maximum	67.50	35.50	14.00	1.48	
Mean	34.22	21.19	6.04	0.34	
Standard deviation	11.51	4.90	2.36	0.31	
Coefficient of variation	33.63	23.10	39.05	90.26	

DBH = Diameter breast height; *CH* = Commercial height; *TH* = Total height; *V* = Volume.

Cluster analysis

The silhouette method identified three clusters as the optimal solution (*K*=3). The K-means cluster analysis applied to the selected trees enabled identification of the cluster to which each individual belonged (Table 2). Clusters 1, 2, and 3 consisted of 16, 14 and 4 trees, respectively (Table 3).

Table 3. *DBH*, *TH*, *CH* and *V* of the three clusters identified through cluster analysis.

Variable	Cluster	*n*	Mean	Minimum	Maximum	Standard deviation
DBH (cm)	1	16	28.4	22.2	42.5	5.3
	2	14	33.1	25.5	45.2	5.0
	3	4	61.5	56.4	67.5	5.7
TH (m)	1	16	17.0	14.5	19.5	1.6
	2	14	23.6	19.5	27.5	1.8
	3	4	29.6	25.7	35.5	4.4
CH (m)	1	16	5.0	3.0	7.3	1.2
	2	14	6.5	3.7	12.0	2.4
	3	4	8.6	5.7	14.0	3.7

V (m^3)	1	16	0.1875	0.1067	0.3414	0.0666
	2	14	0.3031	0.1732	0.6095	0.1199
	3	4	1.0906	0.8506	1.4765	0.2788

DBH = Diameter at breast height; *CH* = Commercial height; *TH* = Total height; *V* = Volume; *n* = number of seed trees.

The Analysis of variance (ANOVA) revealed significant differences between the means of the three clusters for all the assessed mensuration variables (*DBH*, *TH*, *CH*, and *V*; $p<0.001$) (Table 4).

Table 4. *DBH*, *TH*, *CH*, and *V* by cluster and identification of homogeneous groups (Tukey's test, $\alpha=0.05$).

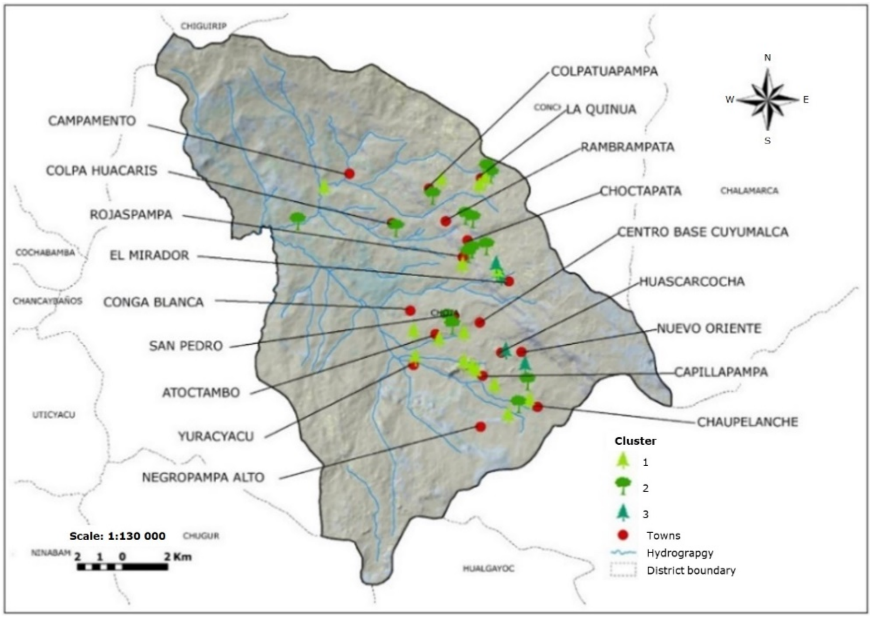
Cluster	***n***	***DBH* (cm)**	***TH* (m)**	***CH* (m)**	***V* (m^3)**
3	4	61.5^a	29.6^a	8.6^a	1.0906^a
2	14	33.1^b	23.6^b	6.5^{ab}	0.3031^b
1	16	28.4^c	17.0^c	5.0^b	0.1875^c
p-value (ANOVA)		<0.001	<0.001	<0.001	<0.001

DBH = Diameter breast height; *CH* = Commercial height; *TH* = Total height; *V* = Volume; *n* = Number of seed trees. Letters a, b and c indicate the homogeneous groups according to Tukey's test. Means with the same letter in the same column are not significantly different ($\alpha=0.05$).

The Tukey test for differences in means, applied *a posteriori*, identified and characterized the resulting groups. Taken together, the identified clusters represent phenotypic classes of trees that differ in their morphology and productive potential.

Geographic distribution of the seed trees

Based on the georeferencing of the seed trees, a spatial distribution map was created (Figure 5), identifying 34 *A. acuminata* seed trees distributed across 18 locations in the district of *Chota*. The highest concentrations were recorded in *La Quinua* (4 trees), *Rojaspampa* (3) and *Chaupelanche* (3). This information serves as a basis for planning strategies for management, conservation and seed collection.



Campamento = *Campamento* Town; *Colpa Huacaris* = *Colpa Huacaris* Town; *Rojaspampa* = *Rojaspampa* Town; *El Mirador* = *El Mirador* Town; *Conga Blanca* = *Conga Blanca* Town; *San Pedro* = *San Pedro* Town; *Atoctambo* = *Atoctambo* Town; *Yuracyacu* = *Yuracyacu* Town; *Negropampa Alto* = *Negropampa Alto* Town; *Colpatuapampa* = *Colpatuapampa* Town; *La Quinua* = *La Quinua* Town; *Rambrampata* = *Rambrampata* Town; *Choctapata* = *Choctapata* Town; *Centro Base Cuyumalca* = *Centro Base Cuyumalca* Town; *Huascarcocha* = *Huascarcocha* Town; *Nuevo Oriente* = *Nuevo Oriente* Town; *Capillapampa* = *Capillapampa* Town; *Chaupelanche* = *Chaupelanche* Town; *Chiguirip* = *Chiguirip* district; *Cochabamba* = *Cochabamba* district; *Chancaybaños* =

Chancaybaños district; *Uticyacu* = *Uticyacu* district; *Ninabamba* = *Ninabamba* district; *Chugur* = *Chugur* district; *Hualgayoc* = *Hualgayoc* province; *Chalamarca* = *Chalamarca* district; *Conchan* = *Conchan* district.

Figure 5. Distribution map of *Alnus acuminata* Kunth seed trees in the *Chota* district, Peru.

Physical and physiological analysis of seeds

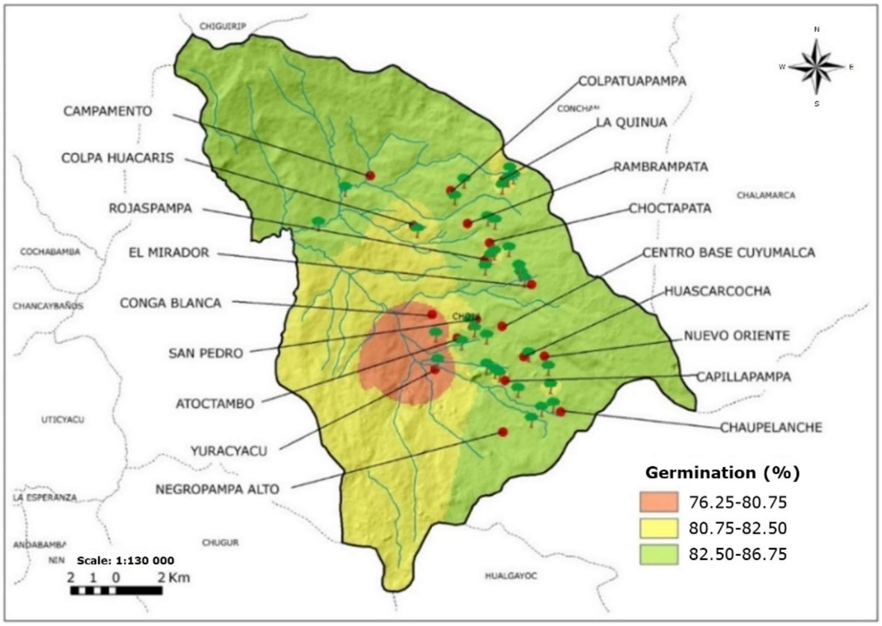
The seeds of *A. acuminata* showed consistent values for physical and physiological quality parameters (Table 5). The weight of 100 seeds, purity, moisture content, and germination rate all had low coefficients of variation (≤8.26 %), indicating low variability among seed trees. The average germination and purity values remained within ranges suitable for use in restoration programs and the production of forest reproductive material.

Table 5. Descriptive statistics on the physical and physiological quality of *Alnus acuminata* Kunth seeds.

Statistic	Weight of 100 seeds (g)	(%)		
		Purity	Moisture content	Germination
Maximum	0.0584	83.88	13.00	86.75
Minimum	0.0432	78.25	9.90	76.25
Mean	0.0509	81.51	11.54	82.64
Standard deviation	0.0029	1.50	0.95	1.98
Coefficient of variation (%)	5.74	1.84	8.26	2.39

Spatial distribution based on germination

Figure 6 shows the spatial distribution map of the 34 *A. acuminata* seed trees based on the germination rate of their seeds, classified into three intervals: high (82.50-86.75 %), medium (80.75-82.50 %) and low (76.25-80.75 %). The highest germination rates were recorded primarily in areas in the northeastern and eastern portions of the study area, indicating spatial variation in germination performance among the evaluated trees.



Campamento = *Campamento* Town; *Colpa Huacaris* = *Colpa Huacaris* Town; *Rojaspampa* = *Rojaspampa* Town; *El Mirador* = *El Mirador* Town; *Conga Blanca* = *Conga Blanca* Town; *San Pedro* = *San Pedro* Town; *Atoctambo* = *Atoctambo* Town; *Yuracyacu* = *Yuracyacu* Town; *Negropampa Alto* = *Negropampa Alto* Town; *Colpatuapampa* = *Colpatuapampa* Town; *La Quinua* = *La Quinua* Town; *Rambrampata* = *Rambrampata* Town; *Choctapata* = *Choctapata* Town; *Centro Base Cuyumalca* = *Centro Base Cuyumalca* Town; *Huascarcocha* = *Huascarcocha* Town; *Nuevo Oriente* = *Nuevo Oriente* Town; *Capillapampa* = *Capillapampa* Town; *Chaupelanche* = *Chaupelanche* Town;

Chiguirip = *Chiguirip* district; *Cochabamba* = *Cochabamba* district; *Chancaybaños* = *Chancaybaños* district; *Uticyacu* = *Uticyacu* district; *La Esperanza* district; *Andabamba* = *Andabamba* district; *Ninabamba* = *Ninabamba* district; *Chugur* = *Chugur* district; *Hualgayoc* = *Hualgayoc* province; *Chalamarca* = *Chalamarca* district; *Conchan* = *Conchan* district.

Figure 6. Map showing the spatial distribution of the germination rate of *Alnus acuminata* Kunth seeds in the study area.

Discussion

The selection of 34 *A. acuminata* seed trees from among 204 candidates evaluated in the *Chota* district represents the first systematic effort to establish a local germplasm base for a species that is key to Andean restoration. The integration of dendrometric, morphological, and health criteria, supplemented by an assessment of the physical and physiological quality of the seeds, made it possible to explicitly link the selection of mother trees to the quality of the forest reproductive material (FRM) available for restoration programs (Ivetić et al., 2016; Luna-Nieves et al., 2019).

From the perspective of genetic diversity, the number of individuals selected and their distribution across 18 locations is consistent with recommendations that suggest collecting seeds from 25-50 trees per population to balance their use and conservation (Ivetić et al., 2016; Pakkad et al., 2004). The proportion of selected seed trees (17 %) is comparable to that reported in phenotypic selection programs for native conifers and broadleaf trees, where only a fraction of the evaluated individuals meet strict criteria for form, health and fruit production (Pascual-López et al., 2020; Valladolid-Ontaneda et al., 2017).

The genetic diversity of propagation material is a crucial factor in ensuring the adaptive capacity of restored populations in the face of environmental changes and disturbances. In this regard, collecting seeds from multiple mother trees and different locations helps maintain greater genetic diversity in restoration programs (Nef et al., 2021). However, in the absence of genetic data, the adaptive representativeness of the selected material must be considered provisional, since trees that are geographically distant may be genetically similar (Alves-Pimenta et al., 2023; Pakkad et al., 2004). Therefore, the selection of seed stock for reforestation must take into account not only phenotypic superiority but also the genetic diversity of the populations to strengthen the resilience and long-term performance of forest plantations (Prakash et al., 2024).

Based on the cluster analysis, three distinct phenotypic groups were identified, primarily characterized by diameter, height, and volume, ranging from smaller individuals to trees with greater structural development. This pattern is consistent with studies conducted on *Pinus chiapensis* (Martínez) Andresen and other native species, whose phenotypic grouping has been used to define management classes and guide the establishment of stands and seed orchards (Pascual-López et al., 2020; Valladolid-Ontaneda et al., 2017). The inclusion of trees from different clusters helps capture a wider range of phenotypes, which may be associated with differential responses to changing environments (Cornelius et al., 2011; Gray & Whittier, 2014; Ivetić et al., 2016).

The physical and physiological quality of the seeds was high and uniform, exceeding the thresholds commonly used to select mother trees in forest restoration species such as *Spondias axillaris* Roxb. (synonym of *Choerospondias axillaris* (Roxb.) B. L. Burtt & A. W. Hill), *Prunus cerasoides* D. Don (synonym of *Prunus campanulata* Maxim.), and *Handroanthus impetiginosus* (Mart. *ex* DC.) Mattos (Alves-Pimenta et al., 2023; Pakkad et al., 2003, 2004). These results suggest that the phenotypic criteria used were effective in identifying seed trees capable of producing seeds with good physiological performance, consistent with findings for other woody species used for restoration and commercial purposes (Luna-Nieves et al., 2019; Ortiz Muñoz et al., 2016).

However, the relationship between the phenotype of the parent tree and the performance of its offspring is neither universal nor linear, as dasometric traits only partially explain the variation in reproductive characteristics, germination and early growth. The phenotypic superiority of parent trees does not always translate into higher yields in their offspring, due to the combined influence of genetic and environmental factors (Ray et al., 2022).

Since this study did not include progeny trials, the identified seed trees should be considered a preliminary basis, subject to validation through subsequent evaluations of vigor, survival and performance in the nursery and in the field.

Overall, the results are consistent with the current approaches that promote a shift from opportunistic collection methods to seed production systems based on the genetic and physiological quality of the FRM (Ivetić et al., 2016; Luna-Nieves et al., 2019). Including trees from both natural stands and plantations increases the likelihood of capturing variants adapted to different management conditions; however, future studies of genetic structure will be essential to verify the genetic representativeness of the selected material and avoid potential genetic bottlenecks.

Conclusions

Thirty-four *A. acuminata* seed trees with superior phenotypic traits were identified and selected after evaluating 204 individuals across 18 sites in the district of *Chota*, Peru. The integration of dendrometric, morphological, health and seed-quality criteria allowed the identification of trees suitable as sources of forest reproductive material. Cluster analysis reveals three distinct phenotypic groups, reflecting structural variability among the evaluated populations and providing relevant information for classifying trees with potential for use in restoration and genetic improvement programs.

Seeds from the selected trees exhibit high physical and physiological quality, with average germination rates exceeding 80 % and low variability among samples, which confirms the potential of these trees as reliable sources of germplasm. Furthermore, the spatial distribution of germination rates reveals areas of higher reproductive performance within the study area, information relevant to guiding future seed collection strategies. Taken together, the results provide an initial basis for establishing local *A. acuminata* seed sources and help strengthen ecological restoration, reforestation, and forest genetic resource management programs in the high Andean ecosystems of northern Peru.

Acknowledgments

The authors are grateful to the National Autonomous University of *Chota* (*UNACH*) for the funding provided through the 5th Research Project Competition—Thesis Level, using resources from the royalty tax, in accordance with Law No. 27506 (Royalty Tax Law).

Conflict of interest

The authors declare that they have no conflict of interest.

Contribution by author

Kely Lizeth Vásquez Saldaña: planning and conduction of the field and laboratory work, and drafting of the manuscript; Eiler Llatas Mires and Yuli Anabel Chávez-Juanito: data processing and cartography; Jim Jairo Villena Velásquez and Leyla Catherine Alarcón Alarcón: drafting and editing of the manuscript; Duberli Geomar Elera Gonzales: statistical analysis of data, drafting and revision of the manuscript.

References

Aguilar, M. I., Rovelo, R., Verjan, J. G., Illescas, O., Baeza, A. E., De La Fuente, M., Avila, I., & Navarrete, A. (2011). Anti-inflammatory activities, triterpenoids, and diarylheptanoids of *Alnus acuminata* ssp. *arguta*. *Pharmaceutical Biology*, *49*(10), 1052-1057. https://doi.org/10.3109/13880209.2011.564634

Alves-Pimenta, J. M., Andrade-Teixeira de Souza, W. M., dos Santos-Ferrari, C., de Almeida-Vieira, F., Gouvêa-Fajardo, C., & Vasconcelos-Pacheco, M. (2023). Selection of *Handroanthus impetiginosus* mother trees to support seed collection areas. *Revista Árvore*, *47*, Article e4706. https://doi.org/10.1590/1806-908820230000006

Aybar-Camacho, C., & Lavado-Casimiro, W. (2017). *Atlas de zonas de vida del Perú. Guía explicativa* [Nota Técnica 003]. Servicio Nacional de Meteorología e Hidrología del Perú. https://www.senamhi.gob.pe/load/file/01402SENA-9.pdf

Broadhurst, L. M., Lowe, A., Coates, D. J., Cunningham, S. A., McDonald, M., Vesk, P. A., & Yates, C. (2008). Seed supply for broadscale restoration: Maximizing evolutionary potential. *Evolutionary Applications*, *1*(4), 587-597. https://doi.org/10.1111/j.1752-4571.2008.00045.x

Cornelius, J. P., Sotelo-Montes, C., Ugarte-Guerra, L. J., & Weber, J. C. (2011). The effectiveness of phenotypic selection in natural populations: a case study from the Peruvian Amazon. *Silvae Genetica*, *60*(5), 205-209. https://doi.org/10.1515/sg-2011-0027

Cyamweshi, A. R., Kuyah, S., Mukuralinda, A., & Muthuri, C. W. (2021). Potential of *Alnus acuminata* based agroforestry for carbon sequestration and other ecosystem services in Rwanda. *Agroforestry Systems*, *95*, 1125-1135. https://doi.org/10.1007/s10457-021-00619-5

Dawson, J. O. (2008). Ecology of actinorhizal plants. In K. Pawlowski & W. E. Newton (Eds.), Nitrogen-fixing Actinorhizal Symbioses (pp. 199-234). https://doi.org/10.1007/978-1-4020-3547-0_8

Elera-Gonzales, D. G., Valdez-Campos, J. V., González-Acosta, M. Y., & Araújo-Silva, E. (2023). Estimación del volumen individual de árboles de *Alnus acuminata* Kunth en plantaciones forestales. *Revista Ciencia Nor@ndina*, *6*(2), 145-159. https://doi.org/10.37518/2663-6360X2023v6n2p145

Ezau, K., & Salazar, R. (1998). *Condiciones óptimas para la germinación de Alnus acuminata spp. arguta (Schlechtendal) Furlow y Pithecellobium saman (Jacq.) Benth*. Centro Agronómico Tropical de Investigación y Enseñanza. https://repositorio.catie.ac.cr/handle/11554/5935

Flores, F., Chávarry-Sánchez, L., & Veja-Isohuaylas, D. (2005). *Criterios y pautas para la selección de árboles plus: Caesalpinia spinosa (Molina) Kuntze "Tara o Taya"*. Asociación Civil para la Investigación y Desarrollo Forestal. https://scholar.google.com/scholar?hl=es&as_sdt=0,5&cluster=13853411209456358272

Food and Agriculture Organization of the United Nations. (2014). *The state of the world's forest genetic resources*. Food and Agriculture Organization of the United Nations. https://openknowledge.fao.org/server/api/core/bitstreams/1ca65f2b-dfae-44e0-9919-a8428d7ee7b7/content

García-Zárate, D., Marcelo-Bazán, F. E., & Dávila-Estela, L. (2022). Identificación y selección de árboles semilleros de *Cinchona officinalis* L. ("Quina") en el distrito de Querocoto, Chota–Cajamarca. *Revista Forestal del Perú*, *37*(1), 69-77. https://doi.org/10.21704/rfp.v37i1.1594

Gray, A. N., & Whittier, T. R. (2014). Carbon stocks and changes on Pacific Northwest national forests and the role of disturbance, management, and growth. *Forest Ecology and Management*, *328*, 167-178. https://doi.org/10.1016/j.foreco.2014.05.015

Imaña E., J., & Encinas B., O. (2008). *Epidometría forestal*. Universidade de Brasília. https://repositorio.unb.br/bitstream/10482/9740/1/LIVRO_EpidometriaForestal.pdf

International Seed Testing Association. (2016). *Reglas internacionales para el análisis de las semillas 2016. Introducción a las reglas ISTA, capítulos 1-7, 9*. International Seed Testing Association. https://vri.umayor.cl/images/ISTA_Rules_2016_Spanish.pdf

Ivetić, V., Devetaković, J., Nonić, M., Stanković, D., & Šijačić-Nikolić, M. (2016). Genetic diversity and forest reproductive material-from seed source selection to planting. *iForest-Biogeosciences and Forestry*, *9*(5), 801-812. https://doi.org/10.3832/ifor1577-009

López-Leiva, C., & Montero, G. (2024). Aliso, *Alnus glutinosa* L. RevForesta, (90), 6-15. https://www.forestales.net/revistas/articulos/747/completo/06_apunres_aliso_pdf.pdf

Lozano-Baez, S. E., Cooper, M., Meli, P., Ferraz, S. F. B., Ribeiro-Rodrigues, R., & Sauer, T. J. (2019). Land restoration by tree planting in the tropics and subtropics improves soil infiltration, but some critical gaps still hinder conclusive results. *Forest Ecology and Management*, *444*, 89-95. https://doi.org/10.1016/j.foreco.2019.04.046

Luna-Nieves, A. L., Meave, J. A., González, E. J., Cortés-Flores, J., & Ibarra-Manríquez, G. (2019). Guiding seed source selection for the production of tropical dry forest trees: *Coulteria platyloba* as study model. *Forest Ecology and Management*, *446*, 105-114. https://doi.org/10.1016/j.foreco.2019.05.020

Mainz, A. K., & Wieden, M. (2019). Ten years of native seed certification in Germany–a summary. *Plant Biology*, *21*(3), 383-388. https://doi.org/10.1111/plb.12866

Marin, M., Toorop, P., Powell, A. A., & Laverack, G. (2017). Tetrazolium staining predicts germination of commercial seed lots of European native species differing in seed quality. *Seed Science and Technology*, *45*(1), 151-166. https://doi.org/10.15258/sst.2017.45.1.03

Muñoz-Flores, H. J., Orozco-Gutiérrez, G., Coria-Avalos, V. M., Muñoz-Vega, Y. Y., & García-Magaña, J. (2012). Comparación de dos métodos de selección de árboles superiores en un área semillera de *Abies religiosa* (H.B.K.) Schltdl. et Cham. en Michoacán, México. *Foresta Veracruzana*, *14*(1), 1-8. http://www.redalyc.org/articulo.oa?id=49724122001

Nef, D. P., Gotor, E., Wiederkehr-Guerra, G., Zumwald, M., & Kettle, C. J. (2021). Initial investment in diversity is the efficient thing to do for resilient forest landscape restoration. *Frontiers in Forests and Global Change*, *3*, Article 615682. https://doi.org/10.3389/ffgc.2020.615682

Organización de las Naciones Unidas para la Alimentación y la Agricultura. (2021). *Guía técnica de buenas prácticas comunitarias para la selección de árboles semilleros y manipulación de semillas forestales*. Organización de las Naciones Unidas para la Alimentación y la Agricultura. https://doi.org/10.4060/cb3668es

Ortiz-Muñoz, E., Acosta-Hernández, C. C., Linares-Márquez, P., Morales-Romero, Z., & Rebolledo-Camacho, V. (2016). Selección de árboles semilleros de *Juglans* *pyriformis* Liebm. en poblaciones naturales de Coatepec y Coacoatzintla, Veracruz. *Revista Mexicana de Ciencias Forestales*, *7*(38), 43-58. https://doi.org/10.29298/rmcf.v7i38.3

Pakkad, G., Elliott, S., & Blakesley, D. (2004). Selection of *Prunus cerasoides* D. Don seed trees for forest restoration. *New Forests*, *28*, 1-9. https://doi.org/10.1023/B:NEFO.0000031326.36840.d3

Pakkad, G., Torre, F., Elliott, S., & Blakesley, D. (2003). Selecting seed trees for a forest restoration program: a case study using *Spondias axillaris* Roxb. (Anacardiaceae). *Forest Ecology and Management*, *182*(1-3), 363-370. https://doi.org/10.1016/S0378-1127(03)00092-6

Pascual-López, M. L., Rodríguez-Ortiz, G., Enríquez-del Valle, J. R., Campos-Ángeles, G. V., & Carrillo-Rodríguez, J. C. (2020). Selección de fenotipos de *Pinus chiapensis* en rodales naturales bajo manejo forestal al sur de México. *Revista Mexicana de Agroecosistemas*, *7*(2), 96-109. https://revistaremaeitvo.mx/index.php/remae/article/view/62

Pedrini, S., & Dixon, K. W. (2020). International principles and standards for native seeds in ecological restoration. *Restoration Ecology*, *28*(S3), S286-S303. https://doi.org/10.1111/rec.13155

Pedrini, S., Gibson-Roy, P., Trivedi, C., Gálvez-Ramírez, C., Hardwick, K., Shaw, N., Frischie, S., Laverack, G., & Dixon, K. (2020). Collection and production of native seeds for ecological restoration. *Restoration Ecology*, *28*(S3), S228-S238. https://doi.org/10.1111/rec.13190

Prakash, A., Capblancq, T., Shallows, K., Saville, D., Landau, D., Landress, C., Jacobs, T., & Keller, S. (2024). Bringing genomics to the field: An integrative approach to seed sourcing for forest restoration. *Applications in Plant Sciences*, *12*(3), Article e11600. https://doi.org/10.1002/aps3.11600

R Core Team. (2025). *R: A language and environment for statistical computing* (Version 4.4.2) [Computer software]. R Foundation for Statistical Computing. https://www.R-project.org/

Ray, D., Berlin, M., Alia, R., Sanchez, L., Hynynen, J., González-Martinez, S., & Bastien, C. (2022). Transformative changes in tree breeding for resilient forest restoration. *Frontiers in Forests and Global Change*, *5*, Article 1005761. https://doi.org/10.3389/ffgc.2022.1005761

Salazar, R. (Coord. Tecn.). (2000). *Manejo de semillas de 100 especies forestales de América Latina: volumen I* [Manual Técnico No. 41]. Centro Agronómico Tropical de Investigación y Enseñanza. https://repositorio.catie.ac.cr/handle/11554/2959

Servicio Nacional de Meteorología e Hidrología del Perú. (2020). *Clima/Mapa climático del Perú* [Mapa climático interactivo]. Servicio Nacional de Meteorología e Hidrología del Perú. https://www.senamhi.gob.pe/?p=mapa-climatico-del-peru

Urretavizcaya, M. F., Contardi, L., Oyharçabal, M. F., & Pasquini, M. (2016). Calidad de semillas de especies nativas del bosque andino patagónico de la provincia de Chubut y su importancia para la producción de plantines. *Revista de la Facultad de Agronomía*, *La Plata*, 115(1), 9-18. https://www.researchgate.net/publication/305409549_Calidad_de_semillas_de_especies_nativas_del_bosque_andino_patagonico_de_la_provincia_de_Chubut_y_su_importancia_para_la_produccion_de_plantines

Valladolid-Ontaneda, J., León-Mejía, Á., & Paredes-Tomalá, D. (2017). Selección de árboles semilleros en plantaciones forestales de la península de Santa Elena, Ecuador. *Revista Científica y Tecnológica UPSE*, *4*(2), 105-110. https://doi.org/10.26423/rctu.v4i2.261

Wilcoxon, F. (1945). Individual comparisons by ranking methods. *Biometrics Bulletin*, *1*(6), 80-83. https://doi.org/10.2307/3001968

Wongwachimaphet, P., Neimsuwan, T., Ishiguri, F., Nezu, I., & Diloksumpun, S. (2024). Seed source selection for improvement of growth and wood traits in 10-year-old *Fraxinus griffithii* C. B. Clarke trees planted in Northern Highlands of Thailand. *Forest*, *15*(11), Article 1974. https://doi.org/10.3390/f15111974