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Seed viability, germination and seedling quality patterns of three forest species for restoration in Amazonian conditions

(Patrones de viabilidad de semillas, germinación y calidad de plántulas de tres especies forestales para la restauración en las condiciones amazónicas)

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Abstract

The aim of this study was to evaluate the quality patterns of *Switenia macrophylla, Cedrelinga cateniformis* and *Ochroma pyramidale* seeds and seedlings in response to restoration. The seed viability test was performed using 1 % tetrazolium (2,3,5-triphenyl tetrazolium chloride) during three staining times and the percentage of viability and vigor levels were considered according to the topological staining pattern. Germination speed, germination capacity, and morphological indices of plant quality were determined using the aboveground belowground ratio, slenderness, degree of lignification and Dickson's quality. The highest percentage of viable seeds with the maximum staining time (3 hours) was verified. The medium vigor category was higher in the three species, as determined by a partial reddish staining pattern as an expression of their physiological quality, which was reflected in the response to germination. The morphological quality indices allowed us to identify the species' potential for growth and development for acclimatization to the area. The correspondence analysis was significant (p≤0.05), which facilitated the formation of quality groups, *C. cateniformis* was found to be of a high-enough quality as an indicator of its potential to cover restoration needs in Amazonian conditions.

Keywords

Topological patterns; tetrazolium; nursery; morphology; plant production.

Resumen

El objetivo de este trabajo fue evaluar patrones de calidad de semillas y plántulas de Switenia macrophylla King, Cedrelinga cateniformis (Ducke) Duckey y Ochroma pyramidale (Cav. ex Lam) Urb. como base para la restauración. Se realizó la prueba de viabilidad de semillas mediante Tetrazolio al 1 % (2,3,5- cloruro trifenil tetrazolio) durante tres tiempos de tinción, se consideró el porcentaje de viabilidad y niveles de vigor según el patrón topológico de tinción. Se determinó la velocidad de germinación, capacidad germinativa, e índices morfológicos de calidad de plantas, a través de la relación parte aérea-parte radical, esbeltez, grado de lignificación y calidad de Dickson. Se comprobó el mayor porcentaje de semillas viables con el máximo tiempo de tinción (3 horas). La categoría vigor medio fue superior en las tres especies, determinado por un patrón de tinción rojizo parcial como expresión de su calidad fisiológica, lo cual se reflejó en la respuesta a la germinación. Los índices de calidad morfológica permitieron identificar la potencialidad de crecimiento y desarrollo de las especies para su aclimatación al sitio. El análisis de correspondencia fue significativo (p≤0.05), lo cual facilitó la formación de grupos de calidad, resultando C. cateniformis de alta calidad como indicador de su potencialidad para cubrir las necesidades de restauración en las condiciones amazónicas.

Palabras clave

Patrones topológicos; tetrazolio; guardería; morfología; planta de producción.

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1. Introduction

In the Amazon Region of Ecuador, studies on indicators of the physiological quality of seeds, germination and obtaining quality plants that cover the needs of forest restoration programs are becoming increasingly important. The low germination rate of many forest species and the quality attributes of plants produced in nursery are one of the reasons for the failure of reforestation actions.

The germination tests that are commonly used to validate the physiological potential of a batch of forest seeds require long periods of time until the desired results are obtained, which is reflected in the final quality of the material and makes decision-making difficult (Marcos-Filho, 2015). An efficient alternative for reducing time is the tetrazolium test, because it allows one to interpret topological patterns (Espitia-Camacho et al., 2020) and to determine the seeds' viability and vigor which is compatible with the emergence of field seedlings (Kimmelshue et al., 2022). This allows for a detailed examination of the essential structures of the seed, which in turn contributes towards identifying factors responsible for the reduction of seed quality depending on the intensity and the staining pattern employed (Espitia-Camacho et al., 2017).

Plant quality is defined as the ability of individuals to adapt to and develop in the climatic and edaphic conditions where they are established (Davis & Pinto, 2021) and it should be a priority for the actors involved in the forest plantation establishment programs. Seedling quality is a critical component in ensuring restoration programs (Grossnickle & South, 2017).

The quality of the plant is determined by the recognition of the morphological attributes during cultivation in the nursery. These attributes are important in determining the initial yield during the field stage (Grossnickle & South, 2017). Several morphological attributes have been used to characterize the quality of a plant; among the most widely used are the height of the aboveground part, diameter at the base of the stem (root collar), dry weight of the root and aboveground part (Rojas-Arévalo et al., 2022) and all descriptors of the degree of development of the aboveground and belowground parts. In addition, morphological indices or relationships have been used, which are combinations of two or more morphological attributes, such as the relationship between dry weight of the aboveground part and belowground part, Dickson's index, and slenderness (heigh:diameter ratio at the base of the stem) (Grossnickle & South, 2017).

The development of modern plantation forestry is undoubtedly based on productivity, which requires techniques for handling seeds and quality attributes of nursery plants that guarantee greater establishment. *S. macrophylla*, *C. cateniformis* and *O. pyramidale* species are widely recognized for their economic and ecological importance for the Ecuadorian Amazon region. The quality of the genetic material of these species allows their propagation in the nursery, however they present limitations and information on viability, germination and production of plants in the nursery is scarce. *O. pyramidale*, belonging to the Malvaceae family, is a pioneer species that is used to recover degraded soils (Douterlungne et al., 2013). Due to its physical and chemical characteristics, its seeds have a compact structure and consistency impermeable to water and gases; mechanical and chemical inhibitor of germination (Marín et al., 2018).

C. cateniformis, belongimg to the Fabaceae family, is a species with a wide ecological distribution, its seeds lose their germinative power easily and quickly, so it requires the necessary care and favorable conditions to achieve good development (Pashanasi-Amasifuen et al., 2022). *S. macrophylla*, of the Meliaceae family, is a species with a wide ecological distribution, recognized as one of the most important commercial tree species in Tropical America that requires silvicultural attention for its appropriate growth (Negreros-Castillo et al., 2018).

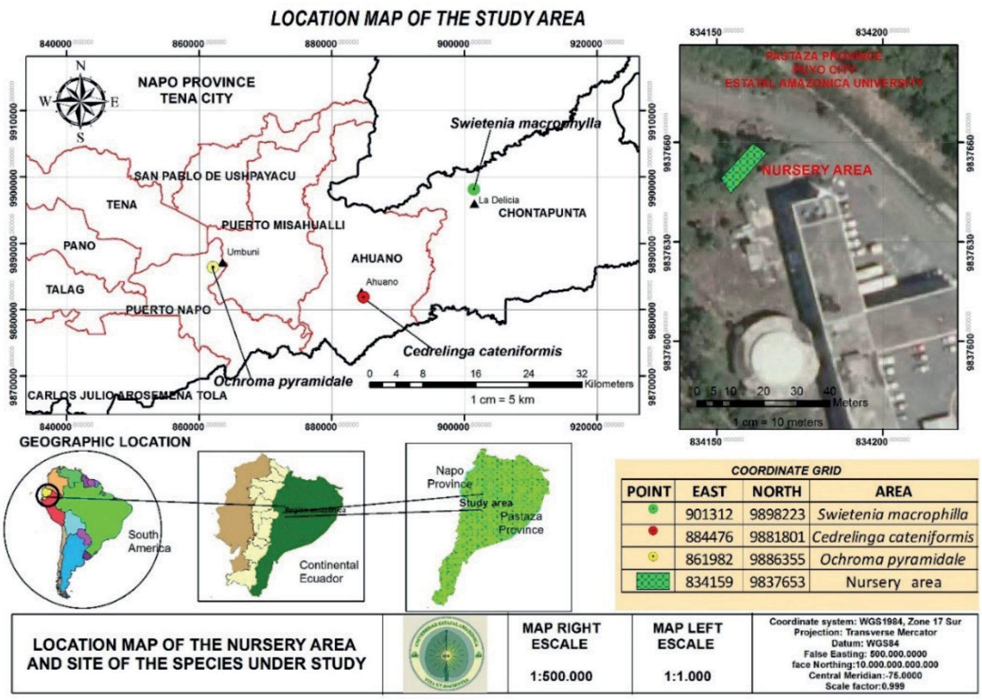
The use of *S. macrophylla, C. cateniformis* and *O. pyramidale* as well as other widely used forest species to reclaim areas or implement forest plantations under environmental conditions depends on seed availability, the seeds' physiological quality and the seedlings' attributes of high morphological quality. Therefore, it is necessary to guide studies that increase the probability of success in the establishment of forest plantations based on survival, growth and development in the poor soil conditions of the Amazon. Within that context, the aim of this study was to evaluate seed and seedling quality patterns of three forest species (*S. macrophylla, C. cateniformis* and *O. pyramidale*) in response to the needs of restoration programs in Amazonian conditions.

2. Methodology

2.1 Study area

The research was carried out using seeds and seedlings from three forest species of interest to the Amazon Region (*S. macrophylla, C. cateniformis* and *O. pyramidale*). The seeds were collected from three isolated trees in good phenotypic condition, located in the communities of Chontapunta, Ahuano and Puerto Napo, Tena canton, Napo province. The communities are situated in the Evergreen Foothills Forest ecosystem (Figure 1). Sufficient material was collected for the laboratory study and for planting in the nursery. The forest nursery area is at the Universidad Estatal Amazonica, 2 ½ km along the road between Puyo and Tena, Pastaza canton, Pastaza province. It is located in a tropical environment where average annual rainfall reaches up to 4,000 mm, the relative humidity is 80 % and temperatures vary from 15 to 25 °C.

Figure 1. Geographical location of the nursery area and seed collection site of the studied species.



Own elaboration

2.2 Seed viability

Seed viability was determined using the tetrazolium (2, 3, 5-triphenyl tetrazolium chloride) topographic test at a concentration of 1 %, as described by Quintana et al., (2019). The experiment was carried out by means of a completely randomized design with three treatments, corresponding to the staining times (1, 2 and 3 hours), with three repetitions of 25 seeds. 75 seeds were used for each staining time, for a total of 225 seeds per species. The seeds were immersed in water for 24 hours prior to the test, then placed in Petri dishes with the tetrazolium solution, and left in the dark at a temperature of 40 °C. Then the seeds were washed three times with distilled water to remove excess dye, and half of each seed was discarded, which allowed the embryo and essential parts to be totally exposed, during which we observed the reaction of the seeds as a result of the color change. The interpretation of topological patterns was carried out by quantifying viable and non-viable seeds with the help of a stereoscope to improve the visualization of internal structures considering that fully stained seeds are viable, totally stain-free seeds are not viable and partially stained seeds can be viable, depending on the intensity and pattern of staining. The percentage of viability was determined based on the total number of seeds that were viable in each staining period. Seed viability data by staining times were processed using ANOVA and Tukey's mean comparison test with 95 % reliability, using the SPSS ver. 22.0 program.

With the treatment of seeds submitted to the last staining time (3 hours), seed vigor was determined in levels (high, medium and low), based on the methodology proposed by (dos Santos et al., 2019), which facilitated the selection of viable and non-viable seeds expressed as a percentage, as follows.

High vigor: Seeds that were completely stained with a reddish appearance.

Medium vigor: Seeds with a small areas of a reddish color without staining, with shallow necrotic or flaccid tissues.

Low vigor: Seeds with the presence of large or multiple minor areas of reddish color without staining, with necrotic or flaccid tissues of a greater extension.

Not vigorous: Seeds with deteriorated radicle without coloration (milky white), indicating dead tissue.

2.3 Germination

In the nursery, 42.8 x 61.5 cm plastic germination trays were used with round tubes with a volume capacity of 115 cm^3. A completely randomized design was used with a seed sample of three species, considered as experimental units, with four replicates of 25 seeds, with a total of 100 seeds for each species. Balanced mixtures of 75 % compost and 25 % rice chaff were used. The germination control of the seeds was carried out daily from planting until the end of the germination period, which allowed us to determine the germination capacity (GC) based on the percentage of germinated seeds and speed of germination (SG). This was in turn based on the number of seedlings that emerged per day and number of days after planting (Staniak et al., 2021). For the germination speed, the following equation was used:

$$SG = \sum\left(\frac{x_i}{n}\right) \tag{1}$$

Where:
x_i : Number of seedlings that emerged per day
n: Number of days after planting
SG : Speed of germination

The data obtained from the GC and SG parameters were processed using ANOVA and Tukey's mean comparison tests at 95 % reliability with the use of SPSS ver. 22.0. Pearson's correlation analysis was also performed with seed viability data of the last staining time and germination capacity.

2.4 Nursery

The morphological parameters of the plant were measured at the end of the nursery cultivation period (three months) according to the methodology of (Fonseca et al., 2002). For this, a sample of 25 plants per species was randomly selected. Height (h) was measured with a ruler in cm. Root collar diameter (RCD) was measured at the base of the stem with a STANLEY digital caliper, expressed in mm. To obtain the aboveground and belowground biomass, the plant was divided into leaf, root and stem. The fresh and dry weight was determined with the use of a Sartorius analytical balance with an error of 0.01 g. The dry weight of the aboveground part (DWA) was obtained as an indicator of plant resistance, the dry weight of the belowground part (DWB) that characterizes the total mass of roots, and the total dry weight (TDW). The root volume (RV) was obtained from the volume of water displaced from the root in a 100 ml cylinder.

The following morphological indices of plant quality were determined: the aboveground-belowground ratio (R), slenderness (S), Dickson's quality index (QI), fibrosity index (FI) and degree of lignification (DL), according to what was proposed by various researchers (Jácome-Segovia et al., 2019; Villalón-Mendoza et al., 2016). R was determined as a function of the ratio between DWA and TDW. The value of S resulted from the relationship between h and RCD. FI was obtained from the relationship between the RV and DWB. DL was established by dividing the TDW by the total fresh weight (TFW). QI was calculated using the following equation:

$$IQ = {T_{dw}}\Big/\left(\frac{h}{d} + \frac{DWA}{DWB}\right) \tag{2}$$

Where:
Tdw: Total dry weight of the plant
h: Height
d: diameter at the root collar
DWA: Aboveground dry weight
DWB: Belowground dry weight

The data obtained from the morphological indices were processed using ANOVA and Tukey's mean comparison tests with 95 % reliability using SPSS ver. 22.0.

The quality of the plant was evaluated based on three levels: high, medium and low. "H" (high) was apparent if there was a total absence of undesirable characteristics and the maximum rating of 3 was given. "M" (medium) included plants with quality values in a lower proportion, leading us to assign the mean value of 2. "L" (low) included plants with lower suitability and these were assigned the minimum rating of 1. The characteristics considered for this evaluation were height, diameter, aboveground-belowground ratio, slenderness, Dickson's quality index, fibrosity index and degree of lignification. These characteristics were considered in quality ranges based on the value obtained and their level of acceptance for future planting conditions. A correspondence analysis was performed to determine the relationship between the nominal variables (species and plant quality levels), from which the dimensionality of the minimum solution was determined ([rows, columns] -1). This analysis was performed with the statistical package SPSS ver. 22.0.

3. Results

3.1 Topological Patterns of Seed Viability

Seed viability percentages were high at all staining times, with the exception of *O. pyramidale* species, which was low for the first staining time (1 hour). It was shown that staining time was not significant for *S. macrophylla*, however there were significant differences between the first and last staining times for *C. cateniformis*. In contrast, the three staining times were different for *O. pyramidale* (table 1). A higher percentage of viable seeds was obtained in the maximum staining time (3 hours).

Table 1. Percentage of seed viability of three forest species subjected to the tetrazolium topographic test with different staining times

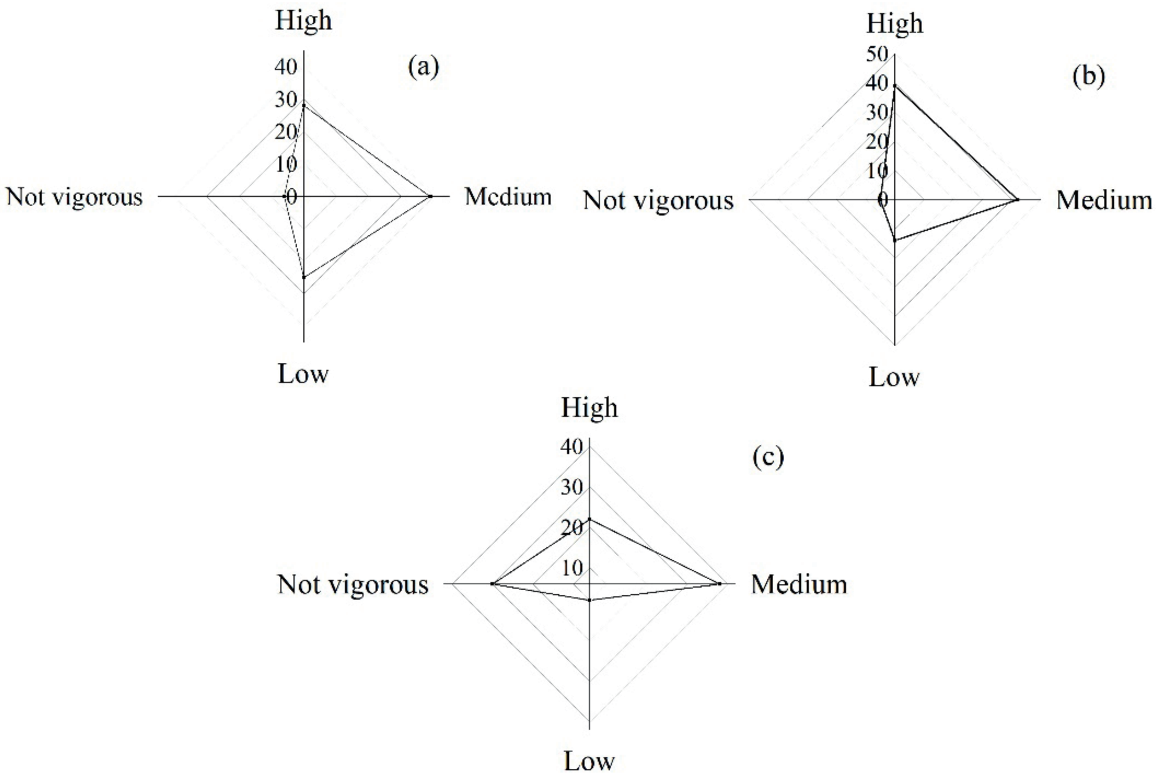
Species	Viability percentage by staining times (%)		
	1 hour	2 hours	3 hours
S. macrophylla	86.33±1.53^{a}	88.83±1.89^{a}	90.17±0.76^{ab}
C. cateniformis	88.57±1.10^{a}	93.50±50^{ab}	95.17±0.76^{b}
O. pyramidale	24.00±4.36^{a}	50.33±4.72^{b}	65.67±2.52^{c}

Legend: In each column, identical letters do not differ significantly using Tukey's test with $p \leq 0.05$.

The categories of evaluated vigor (high, medium, low and not vigorous) were variable (figure 2), with a higher percentage of mean vigor, the values of which exceed 38 %. The species with the highest percentage of seeds with a total reddish tinted appearance (high vigor) was *C. cateniformis* with 39.16 %, while 34.33 % of *O. pyramidale* was non-vigorous. In all three species, seeds were found with small areas of reddish color without staining, with shallow necrotic or flaccid tissues (medium vigor), with the presence of larger or multiple minor areas of reddish color without staining with necrotic or flaccid tissues of a greater extension (low vigor) and seeds with deteriorated radicle without coloration (milky white), indicating dead tissue (not vigorous).

The results of the interpretation of topological patterns by dissolving 1 % tetrazolium for the species *S. macrophylla, C. cateniformis* and *O. pyramidale* indicated that viable seeds with a predominance of totally and partially stained embryos are present. These results reflect the physical state and physiological quality of seeds that were collected recently, which provides relevant information for predicting a high seedling emergence in nursery conditions.

Figure 2. Percentage of viable seeds by vigor categories *S. macrophylla* (a), *C. cateniformis* (b) and *O. pyramidale* (c)



3.2 Germination Parameters

The results of the germination parameters provided high values for the three species studied (Table 2). GC and SG were higher ($p \leq 0.05$) for *C. cateniformis*. SG values were similar for *S. macrophylla* and *O. pyramidale*, indicating greater uniformity in germination time and seedling emergence.

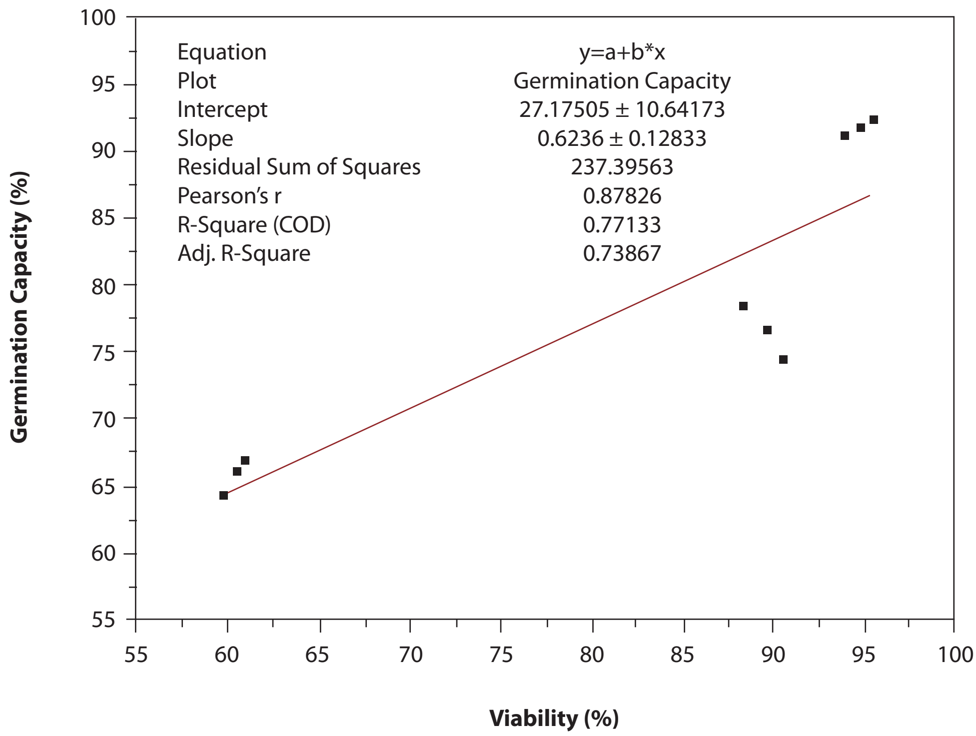
Table 2. Germination parameters of three forest species (*S. macrophylla*, *C. cateniformis* and *O. pyramidale*) of timber interest for Amazonian conditions

Specie	Germination parameters	
	GC	SG
S. macrophylla	75.5 ± 2.40^{b}	4.59 ± 0.62^{b}
C. cateniformis	89.5 ± 1.01^{a}	5.31 ± 0.77^{a}
O. pyramidale	62.5 ± 1.11^{c}	4.87 ± 0.91^{b}

Legend: In each column, disimilar letters differ significantly using Tukey's test with $p \leq 0.05$.

It was found that there is a high correlation between seed viability and germination capacity (r = 0.88) (figure 3). This indicates that viable seeds will guarantee a higher percentage of sprouted seeds, as an expression of the physiological quality of the seeds verified by the tetrazolium test.

Figure 3. Correlation between seed viability and germination capacity of three forest species (*S. macrophylla*, *C. cateniformis* and *O. pyramidale*)



3.3 Attributes and indices of morphological quality of the plant

C. cateniformis showed a significantly higher growth in h and RCD ($p \leq 0.05$) with adequate average values for the initial development of the plants in the nursery stage (Table 3). RCD is directly related to plant robustness, as it is a representative measure of resistance to climatic and biological factors. These results reflect information on this species' degree of robustness in terms of tolerating the conditions of the place where forest restoration programs are carried out, characterized by a dystrophic edaphic environment.

The accumulation of aboveground biomass represented by the attribute DWA was better represented by *O. pyramidale* as a reflection of the potential for nutrient utilization, while *C. cateniformis* and *S. macrophylla* presented lower values with similarities between them. The three species studied presented similar values for the morphological attributes DWB, TDW and RV, which is a reflection of the favorable root system predominant in all species.

Table 3. Morphological plant quality attributes of three nursery-grown forest species (*S. macrophylla*, *C. cateniformis* and *O. pyramidale*)

	Morphological attributes of plant quality					RV (cm³)
	h (cm)	d (mm)	DWA (g)	DWB (g)	TDW (g)	
Sm	13.66±1.09^{b}	2.85±0.06^{b}	1.17±0.05^{b}	1.24±0.08^{a}	2.41±0.04^{a}	1.50±0.02^{a}
Cc	18.25±1.09^{a}	3.85±0.06^{a}	1.17±0.05^{b}	1.24±0.08^{a}	2.41±0.03^{a}	1.50±0.02^{a}
Op	14.07±0.17^{b}	2.80±0.09^{b}	1.35±0.08^{a}	1.21±0.09^{a}	2.56±0.04^{a}	1.50±0.02^{a}

Legend: In each column, disimilar letters differ significantly using Tukey's test with p ≤0.05. S. macrophylla (Sm), C. cateniformis (Cc), O. pyramidale (Op).

The three species showed a variable behavior in terms of morphological indices (Table 4), as an appropriate criterion for identifying their potential in terms of growth and development in future conditions of the plantation. The aboveground-belowground ratio (R) allowed us to identify a heterogeneous stem / root relationship for the species with significantly higher values in *O. pyramidale* (p≤0.05). In this species, R was greater than 1, which indicates that there is no balance between the aboveground part and the belowground part. This shows that the species has a lower survival capacity in the field. Meanwhile, *S. macrophylla* and *C. cateniformis* presented lower values of less than 1, denoting a greater response to survival under plantation conditions as the transpiring surface was reduced with respect to the absorbent.

Table 4. Mean values and standard deviation of relationships and morphological indices of three forest species (*S. macrophylla*, *C. cateniformis* and *O. pyramidale*) grown in nurseries

	Morphological attributes of plant quality					RV (cm³)
	h (cm)	d (mm)	DWA (g)	DWB (g)	TDW (g)	
Sm	13.66±1.09^{b}	2.85±0.06^{b}	1.17±0.05^{b}	1.24±0.08^{a}	2.41±0.04^{a}	1.50±0.02^{a}
Cc	18.25±1.09^{a}	3.85±0.06^{a}	1.17±0.05^{b}	1.24±0.08^{a}	2.41±0.03^{a}	1.50±0.02^{a}
Op	14.07±0.17^{b}	2.80±0.09^{b}	1.35±0.08^{a}	1.21±0.09^{a}	2.56±0.04^{a}	1.50±0.02^{a}

Legend: In each column, disimilar letters differ significantly using Tukey's test with p ≤ 0.05. S. macrophylla (Sm), C. cateniformis (Cc), O. pyramidale (Op).

The slenderness index (S) was between 4.74 and 5 for the species analyzed. Significantly lower values (p≤00.5) were reported for *S. macrophylla* and *C. cateniformis*, providing a greater mechanical resistance to the plantation site for the mentioned species, while *O. pyramidale* obtained values higher than 5, so it is considered less resistant. This result provides key information for selecting suitable plant groups to resist strong winds and landslides, which are very common in the study area.

The results obtained from the QI allowed us to analyze the combination of attributes of the two aforementioned relationships (R and S). The QI values for the three studied species were homogeneous, which indicated a certain similarity in some attributes related to the plants' morphological quality.

The FI values were similar for the three species; the range varies from 0.58 to 0.62 with little standard deviation. This index refers to the relationship between RV and DWB, which suggests higher values to be a measure of the existence of a sufficient belowground system to supply energy to the aboveground part of the plant. This proposes that all species show similarity in belowground attributes.

Significant differences in relation to DL between the species (p≤0.05) were found, with higher values in *C. cateniformis*. It is notable that in all cases, the FI values are high, which nursery gardeners deem to be an indicator of high acclimatization to the adverse conditions of the plantation site.

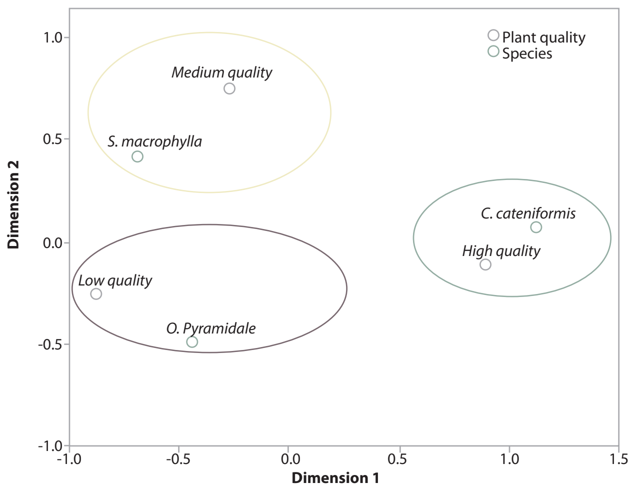
The correspondence analysis showed a significant correlation (p≤0.05) between species and morphological attributes and indices, with total inertia values of 0.437 and a chi-square value of 9.167. The solution indicated that only the first axis is significant (explained inertia ratio> 40 %), which explained 42 % of the total variance (table 5). This is attributed to the patterns of variation found in some morphological attributes and indices.

Table 5. Summary of the correspondence analysis between species and morphological attributes and plant quality indices

Dimension	Singular value	Inertia	Chi-square	Sig.	Inertia ratio	
					Explained	Accumulated
1	0.646	0.417			0.956	0.956
2	0.138	0.019			0.044	1.000
Total		0.437	9.167	0.047	1.000	1.000

C. cateniformis was associated with the group of high morphological quality, S. macrophylla of medium quality and *O. pyramidale* of low quality (figure 3). These results facilitated the differentiation of quality groups of species in relation to the attributes, relationships and indices that provide information on the potential for growth and development, regardless of their nature. The attributes that contributed the most in the analysis of morphological quality of plants were h, RCD, R, S and DL. This is useful when it comes to selecting priority species with high morphological quality standards to cover restoration needs in Amazonian conditions. This result constitutes a first approach to the study for the selection of high-quality taxa for plantation conditions, which requires the combination of morphological and physiological attributes.

Figure 4. Two-dimensional representation of the relationship between species and attributes and indices of morphological quality



4. Discussion

The high percentages obtained for seed viability for the species studied correspond to their physical state and physiological quality, as described by (Espitia-Camacho et al., 2017). These authors report that a viable seed indicates its capability to germinate and produce a normal seedling when it is not in a dormant season. The pattern found, which describes the highest percentage of viable seeds in the maximum staining time (3 hours), is due to the fact that it is a batch of viable and vigorous seeds. This result is in accordance with the study presented by (dos Santos et al., 2019) on the viability and vigor of *Genipa americana* seeds, which showed that increasing the staining time of the seeds produces higher percentages of viable seeds. In our experiment, it was observed that *O. pyramidale* requires a longer staining time to show high viability, so it would appear that this is the appropriate protocol to analyze the viability of seeds in this species. dos Santos et al., 2019; Espitia-Camacho et al., 2017; Jácome-Segovia et al., (2019), carried out seed viability studies in forest species to determine the favorable response in terms of concentration and staining time in tetrazolium.

The reported variation in staining intensity for the species studied could be due to the fact that the tetrazolium salt allows one to determine the presence, location and nature of the alterations of seed tissues (ISTA, 2003), producing a triphenyl formazan compound in living tissues. This identifies the respiratory activity of mitochondria, and as a result shows cell viability in tissues. The presence of a red color in the embryos is a positive indicator of the viability of the seeds and those weakly colored regions reflect decreased respiratory activity in the cells and, consequently, less activity of dehydrogenase enzymes (Staniak et al., 2021). Consequently, a partial seed coloration indicates the existence of dead tissue areas, which could be due to the seed's physical deterioration.

The results obtained in terms of germination capacity and germination speed can influence the maintenance of the species in natural conditions, given that these parameters are important factors for forest species due to the high competition that occurs in early stages of growth (Rodríguez-Sosa & Aguilar-Espinosa, 2019). The mechanisms regulating the start of germination are under selective pressures; thus, the variation of the germination capacity between and within the species is interpreted as an adaptation to the specific conditions of the local and regional habitat (Meyer et al., 1997). The reported percentages of GC for *C. cateniformis* are similar to the results obtained by Valencia et al., (2010), while for *O. pyramidale* the results are similar to what (García et al., 2017; Toledo-González et al., 2019), reported, and the results for *S. macrophylla* correspond to what and (Jácome-Segovia et al., 2019) described in their studies.

The relationship found between the percentage of seed viability and the germination capacity indicates the consistency of the results regarding the behavior of *S. macrophylla, C. cateniformis* and *O. pyramidale* seeds. It was observed that *O. pyramidale* presented the least amount of viability, and as a consequence it had a lower germination capacity. These results agree with the study described in (Tola, 2016).

The diagnosis performed on the morphological attributes associated with plant growth provided valuable information from a practical point of view for the producers, since it allows one to select priority species in accordance with the morphological attributes that permite a plant to withstand the adverse conditions of the plantation site in the Amazon Region. It is recognized that h is an indicator of the degree of development of the aboveground part and one should try to obtain plants whose height maximizes survival (Noguera-Talavera et al., 2016), an attribute that was most favorable in *C. cateniformis*, thus positively influencing photosynthetic capacity. Among the most widely used morphological attributes in the characterization of plant quality and survival prognosis is RCD due to its low cost of measurement and its predictive capacity for response in the field (Barnett, 1984). The high RCD values obtained for *C. cateniformis* is a characteristic that defines the robustness of the stem and is associated with vigor and survival in the field. The larger the diameter, the more resistant the plants are to bending and the more tolerant they are to the effects of pests and herbivores (Rueda-Sánchez et al., 2013). The dry biomass of the aboveground part for the three species presented values within the recommended range proposed by Rueda-Sánchez et al., (2013), while the belowground part was below the values indicated by these authors, with similar values for the species. These results show the existence of poorly developed roots in relation to the aboveground part of the plants, a characteristic that can decrease resistance to water stress in the field (Rueda-Sánchez et al., 2013). These results are interesting considering the conditions of the site where most forest restoration programs are carried out.

O. pyramidale presented an R value greater than 1, which agrees with the study described in (Rueda-Sánchez et al., 2013), manifesting an imbalance between the aboveground part and the belowground part. The values obtained from R are considered of good quality for both *S. macrophylla* and *C. cateniformis*. The three evaluated species obtained low slenderness values; only *O. pyramidale* obtained S values greater than 5. (Rueda-Sánchez et al., 2013) reported that when S exceeds 6, it means that the specimens are very elongated, which is a feature that nursery gardeners wish to avoid. It has been asserted that the weaker the relationships between height and diameter is, the greater the plant vigor is, and this is the case for tropical species. Based on this, one can infer that the three plant species presented an adequate proportion. The values of QI were similar in the three species, ranging from 0.41 to 0.42, which can be considered inadequate for deciding on the quality of the plant in relation to its potential and growth, according to (Rueda-Sánchez et al., 2013). These authors propose 0.2 as a minimum QI value for considering plants to be of good quality. Accordingly, the three species exceeded this value. In relation to FI, (Davis & Jacobs, 2005) conclude that an abundant emission of secondary roots denotes high quality and guarantees rapid growth after planting when plants are established in favorable environmental conditions for their growth. In this sense, our results were similar for all three species with low values, suggesting little development in the root system. In contrast, the variation found in DL implies a level of species differentiation in relation to this morphological attribute with a more accepted criterion for predicting survival in the field (Ureta et al., 2018) for *C. cateniformis*. However, in all species the values were high, which suggests that it is a group of plants with high possibilities of acclimatization to the adverse conditions of the plantation site.

Differenting plant quality groups based on morphological attributes provides key information for selecting priority taxonomic groups in restoration programs in response to acclimatization. The process of recovering degraded areas in the Amazon Region is not an easy task; it requires not only achieving a massive production of plants but also a successful establishment based on the nursery diagnosis of morphological and physiological attributes (Grossnickle & South, 2017). Knowledge of the morphological attributes analyzed in this study will provide a solid basis for developing an efficient management and restoration strategy. These results demonstrated that knowledge of seed viability, germination, and plant quality attributes provide basic information to develop an efficient management and restoration strategy in the Amazon region. It provides relevant information for decision-making regarding the restoration of degraded ecosystems, which aids the conservation of Amazonian biodiversity (García-Quintana et al., 2020). Alternative restoration targets, genetic diversity, genetic structure, and future adaptability need to be considered in restoration programs (Pedrini & Dixon, 2020).

The results obtained in this research provide valuable information to consider *S. macrophylla*, *C. cateniformis* and *O. pyramidale* as potential species for reforestation for commercial purposes that allow the recovery of degraded soils in the Ecuadorian Amazon. These results are a first approximation for the selection of high-quality taxonomic groups, which will allow, through the correct selection of different properties of the seeds and morphological and physiological characteristics of the plants grown in nurseries, to control the possibilities of development and growth in the plants under forest site conditions. This way, an appropriate material in optimal conditions for its acclimatization to the conditions of the Ecuadorian Amazon will be possible. Several authors indicate that the quality of the plant is the result of the integration of numerous physiological and morphological characteristics that control the possibilities of development and subsequent growth of the plants (Grossnickle & South, 2017; Peñuelas R., 2000; Reyes-Reyes et al., 2021; Ureta et al., 2018).

5. Conclusions and recommendations

Topological patterns of seed viability using the 1 % tetrazolium test and different staining times provided a high percentage of viable seeds at 3 hours; the medium category predominated as a criterion of physiological quality, which was reflected in the germination percentages *C. cateniformis* presented greater viability, because it had total reddish staining in the structural components of the seed and, at the same time, greater germination capacity and germination speed.

The attributes and morphological quality indices of the plants grown in the nursery (*S. macrophylla, C. cateniformis* and *O. pyramidale*) allowed us to identify ideal species with better post-transplant responses, survivability, mechanical resistance, growth potential and development in Amazonian conditions.

The correspondence analysis between species groups and attributes and indices of morphological quality was significant ($p \leq 0.05$), which facilitated the formation of quality groups. *C. cateniformis* presented a high-enough quality to meet the needs of forest restoration programs. This result demonstrated that knowledge of morphological attributes provides basic information in order to develop an efficient management and restoration strategy.

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