

Effect of variety and seed origin altitude on emergence and early seedling development of *Coffea arabica* L.

Efecto de la variedad y la altitud de procedencia de la semilla en la emergencia y desarrollo temprano de plántulas de *Coffea arabica* L.

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Abstract

Early development of coffee seedlings constitutes a critical stage for the establishment and successful of the crop, in which both genetic and environmental factors play a key role. The objective of this study was to evaluate the effect of variety and seed origin altitude on the emergence and early development of *C. arabica* L. seedlings during the germination and nursery stages. The Geisha and Red Caturra varieties were evaluated from two altitudes of origin (1,600 and 1,900 m a.s.l.) under a randomized complete block design with a 2×2 factorial arrangement. The variables analyzed included emergence percentage, primary root length, mortality, root deformation, and plant height. The results showed that variety significantly influenced emergence, root development, and plant height, with Red Caturra presenting higher emergence percentage, greater root length, and greater shoot growth. Seed origin altitude significantly affected primary root length, while the variety $\times$ altitude interaction had a determining effect on nursery mortality, with the lowest mortality recorded in the Red Caturra $\times$ 1,900 m a.s.l. combination. These findings highlight the importance of jointly considering genotype and seed origin environment to optimize the production of vigorous coffee seedlings with greater establishment capacity in nursery conditions.

Keywords: initial growth, nursery, root development, seed provenance, seedling quality.

Resumen

El desarrollo temprano de plántulas de café constituye una etapa crítica para el establecimiento exitoso del cultivo, en la cual influyen tanto factores genéticos como ambientales. El presente estudio tuvo como objetivo evaluar el efecto de la variedad y la altitud de origen de la semilla sobre la emergencia y el desarrollo temprano de plántulas de *C. arabica* L. durante las etapas de semillero y vivero. Se evaluaron las variedades Geisha y Caturra rojo, provenientes de dos altitudes de procedencia (1.600 y 1.900 m s.n.m.), bajo un diseño de bloques completos al azar con arreglo factorial 2×2 y seis repeticiones por tratamiento, para un total de 24 unidades experimentales. Se analizaron variables de emergencia, longitud de la raíz principal, mortalidad, deformación radicular y altura de planta. Los resultados mostraron que la variedad influyó significativamente en la emergencia, el desarrollo radicular y la altura de planta, destacándose Caturra rojo por presentar mayor porcentaje de emergencia, mayor longitud de raíz y mayor altura de planta. La altitud de origen de la semilla afectó de manera significativa la longitud de la raíz principal, mientras



que la interacción variedad $\times$ altitud tuvo un efecto determinante sobre la mortalidad en vivero, registrándose la menor mortalidad en la combinación Caturra rojo $\times$ 1.900 m s.n.m. Estos resultados evidencian la importancia de considerar conjuntamente el genotipo y el ambiente de origen de la semilla para optimizar la producción de plántulas de café vigorosas y con mayor capacidad de establecimiento en vivero.

Palabras clave: calidad de plántulas, crecimiento inicial, desarrollo radicular, procedencia de semilla, vivero.

1. Introduction

Coffee (*C. arabica* L.), a perennial fruit tree belonging to the Rubiaceae family, is native to the highlands of Ethiopia, where it develops optimally at altitudes between 1,350 and 2,000 m a.s.l. (Alulima Cornejo, 2012). This shrub species is characterized by smooth, glossy leaves and is one of the most widely cultivated species worldwide, due to its high cup quality, lower caffeine content, and good adaptation to altitude conditions (Instituto Interamericano de Cooperación para la Agricultura [IICA], 2020).

On a global scale, in 2023 more than 11 million hectares of arabica coffee were cultivated, with production exceeding 9 million tons, led by Brazil and Vietnam (Food and Agriculture Organization of the United Nations [FAO], 2023). In Ecuador, coffee cultivation represents an activity of economic and social importance for thousands of producers; according to the Continuous Agricultural Surface and Production Survey, that same year 34,931 ha of coffee were planted, of which 29,481 ha were harvested, with an average yield of 0.26 t ha⁻¹ of green coffee. (Instituto Nacional de Estadística y Censos [INEC], 2023).

Coffee propagation is predominantly carried out sexually by means of seeds, which requires the installation of germination chambers and nurseries to obtain seedlings suitable for final transplanting. This method is widely used in *C. arabica* L. production systems, since it allows a relatively uniform establishment of commercial crops when quality seed is used (Acosta-Trinidad et al., 202; Zhirvi Ordóñez, 2017).

Seed genetic quality constitutes a determining factor in the early physiological performance of seedlings, and in this regard, the variety and its origin influence processes such as emergence, root growth, and shoot development, affecting the vigor and quality of the plant material obtained in the nursery (Picon Tafur, 2025). Genetic variability among coffee varieties plays an important role in the physiological response during the early growth stages. Genetic differences can influence processes associated with germination, such as imbibition speed, enzymatic activity related to reserve mobilization, and seedling metabolic efficiency, which can translate into differentiated responses during emergence and initial plant growth (Cerdeza Cruz, 2021).

The Geisha variety is recognized for its exceptional cup quality and tolerance to certain diseases, for example partial resistance to rust, performing optimally in areas located above 1,200 m a.s.l. (Silva Rincon et al., 2024). Red Caturra, in turn, derived from a natural mutation of Bourbon, is characterized by its short stature, early maturation, and high production potential, characteristics that have favored its wide adoption in coffee production systems (Santacreo Ponce, 2012).

In tropical mountain agricultural systems, altitudinal conditions influence average temperature, daily thermal amplitude, solar radiation, and the length of the fruit ripening period, variables that can modify reserve accumulation and the hormonal balance of the seed (Flechas-Bejarano & Medina-Rivera, 2021; Guzmán Vidal, 2013). Consequently, the maternal environment in which the fruit develops can generate persistent effects on germinative performance and the initial vigor of seedlings, a phenomenon known as the “environmental maternal effect” (Valarezo Rivera et al., 2021). Several studies have shown that the environmental conditions experienced by the mother plant can modify the physiological quality of seeds and their establishment capacity during the early stages of development (Lopes et al., 2025; Paima Flores, 2017).

In *C. arabica* L., root development constitutes a fundamental component of seedling vigor, since it determines the substrate exploration capacity, water and nutrient absorption, and tolerance to biotic and abiotic factors present in the nursery (Guilcapi Pacheco, 2010). A well-developed root system reduces the period of susceptibility to soil pathogens associated with damping-off (*Rhizoctonia solani*) and favors plant survival after transplanting (Membreño Hernández & Téllez Castellón, 2021). Due to its importance for the initial establishment of the crop, several factors can influence its development, including the interaction between the genotype and the seed formation environment, which can affect root architecture and the early allocation of biomass between root and shoot (Valarezo Rivera et al., 2021).

Despite the relevance of variety and environmental conditions during seed formation, there is limited information about the interaction between both factors on the emergence and early development of coffee seedlings (Gil & Díaz, 2016). Several studies

have contributed to understanding seedling growth in the nursery; however, the joint influence of seed origin altitude and variety on the initial establishment of plants has been scarcely studied (León-Burgos et al., 2022). This limitation restricts the identification of the most favorable combinations of variety and seed origin to produce high-quality seedlings.

In this context, the objective of the present study was to evaluate the effect of seed origin altitude (1,600 and 1,900 m a.s.l.) and variety (Geisha and Red Caturra) on the emergence and early development of coffee seedlings during the germination and nursery phases.

2. Materials and Methods

2.1. Experimental site

The research was conducted at Centro Experimental Alonso Tadeo [CEAT], belonging to the Universidad Politécnica Estatal del Carchi [UPEC], located in the Mira river basin, La Concepción parish, Mira canton, Carchi province, in northern Ecuador. The experimental area was located at an altitude of 1,373 m a.s.l. and had an average annual temperature of 26 °C.

2.2. Plant material

Parchment coffee seeds (*C. arabica* L.) corresponding to the Geisha and Red Caturra varieties were used. The plant material was collected simultaneously from eight-year-old mother plants, established at two altitudes of origin (1,600 and 1,900 m a.s.l.), with good productive and sanitary performance.

To obtain the seeds, fruits were selected considering only those that were healthy, uniform in size, and from branches in the middle third of the plant. Harvesting was carried out at the harvest ripeness stage, corresponding to the uniform red cherry stage, equivalent to BBCH stages 85–88 for coffee (*Coffea spp.*), according to the phenological scale described by Arcila-Pulgarín et al. (2002). This stage ensures complete fruit development and the physiological viability of the seeds used in the experiment.

2.3. Phase I. Evaluation of emergence and primary root length in the germination chamber

2.3.1. Germination chamber establishment

Seeds were sown in germination chambers previously fitted with shade netting with 80% solar radiation

interception, which ensured a reduction in direct light incidence and conservation of substrate moisture. Sifted sand was used as substrate, arranged in germination beds with an approximate thickness of 20 cm. Sowing was carried out uniformly in furrows 1 cm deep, with a 5 cm separation between rows and 1 cm between seeds. The seeds were subsequently covered with a layer of sand, and adequate moisture conditions were maintained through periodic irrigation, in order to favor germination and the initial development of the seedlings.

2.3.2. Experimental design

The experiment was conducted under a randomized complete block design [RCBD] with a 2×2 factorial arrangement. This design was used to control the environmental variability present in the germination chamber, associated with microclimatic differences generated by the presence of walls and other physical structures that could affect light incidence, temperature, humidity, and air circulation.

The factors evaluated were: Factor A, coffee variety (Geisha and Red Caturra), and Factor B, seed origin altitude (1,600 and 1,900 m a.s.l.). The combination of both factors resulted in four treatments: T1 (Geisha – 1,600 m a.s.l.), T2 (Geisha – 1,900 m a.s.l.), T3 (Red Caturra – 1,900 m a.s.l.), and T4 (Red Caturra – 1,600 m a.s.l.).

Six replications per treatment were established, for a total of 24 experimental units. Each block was made up of the four treatments, which were randomly distributed within each block.

In the germination chamber phase, each experimental unit corresponded to an area of 0.168 m² and consisted of 300 seeds, of which 100 seeds made up the net evaluation plot.

2.3.3. Evaluated variables

- **Seed emergence (%):** determined in the germination chamber at 60 days after sowing [DAS], evaluating 100 seeds per experimental unit. This evaluation time was selected because, under germination chamber conditions, germination and emergence of *C. arabica* L. occur gradually and can extend over several weeks. By 60 days, a sufficiently stable emergence level is reached that allows precise estimation of seedling establishment (Cevallos Cantos, 2022).
- **Primary root length (cm):** determined at 90 DAS, when the seedlings reached the chapola stage, corresponding to the early stages of vegetative development (BBCH 10–11) according to the phenolo-

gical scale for coffee described by Arcila-Pulgarín et al. (2002). The measurement was taken from the plant collar to the apex of the primary root, in 25 chapolas per experimental unit.

2.4. Phase II. Evaluation of plant mortality, primary root deformity, and plant height in the nursery

2.4.1. Nursery establishment

The seedlings obtained in the germination chamber phase were transplanted to the nursery, maintaining the identity of each experimental unit. The seedlings were established in 24×13 cm polyethylene bags with a 1.5 mm gauge, which contained a substrate composed of 25% sifted sand and 75% black mountain soil. The black soil is characterized by its high organic matter content, granular structure, dark color, and good moisture retention capacity, while the sifted sand provides drainage and aeration to the substrate, allowing adequate root development of *C. arabica* L. during the initial growth phase.

During this stage, homogeneous management conditions were maintained, with periodic irrigation to keep the substrate at field capacity and the application of soil fertilization at a rate of 6 g per plant of formulated fertilizer $15\text{ N} - 15\text{ P}_2\text{O}_5 - 15\text{ K}_2\text{O}$, with the aim of ensuring uniform seedling growth. The nursery was kept under shade netting with 80% solar radiation interception throughout the experimental period, reducing direct light incidence and favoring stable microclimatic conditions.

2.4.2. Experimental design

The experiment was conducted under an RCBD

design with a 2×2 factorial arrangement. This design was used to control the environmental variability present in the nursery, associated with microclimatic differences generated by the presence of walls and other physical structures that could affect light incidence, temperature, humidity, and air circulation.

The factors evaluated were: Factor A, coffee variety (Geisha and Red Caturra), and Factor B, seed origin altitude (1,600 and 1,900 m a.s.l.). The combination of both factors resulted in four treatments: T1 (Geisha – 1,600 m a.s.l.), T2 (Geisha – 1,900 m a.s.l.), T3 (Red Caturra – 1,900 m a.s.l.), and T4 (Red Caturra – 1,600 m a.s.l.).

Six replications per treatment were established, for a total of 24 experimental units. Each block was made up of the four treatments, which were randomly distributed within each block. In the nursery phase, the seedlings from the germination chamber were transplanted while maintaining the same experimental structure, and each experimental unit consisted of 196 plants, of which 100 made up the net plot.

2.4.3 Evaluated variables

The following variables were evaluated:

- **Plant mortality (%):** evaluated during the nursery phase at 60 days after transplanting [DAT], relating the number of live seedlings to dead plants, in the net plot of each experimental unit.
- **Primary root deformity (%):** determined at 90 DAT, by identifying curvatures or bulges in the primary root (Figure 1), evaluating 50 plants per experimental unit.
- **Plant height (cm):** measured in the nursery using a tape measure, from the plant collar to the apex, at 60 and 120 DAT, in 25 plants corresponding to the

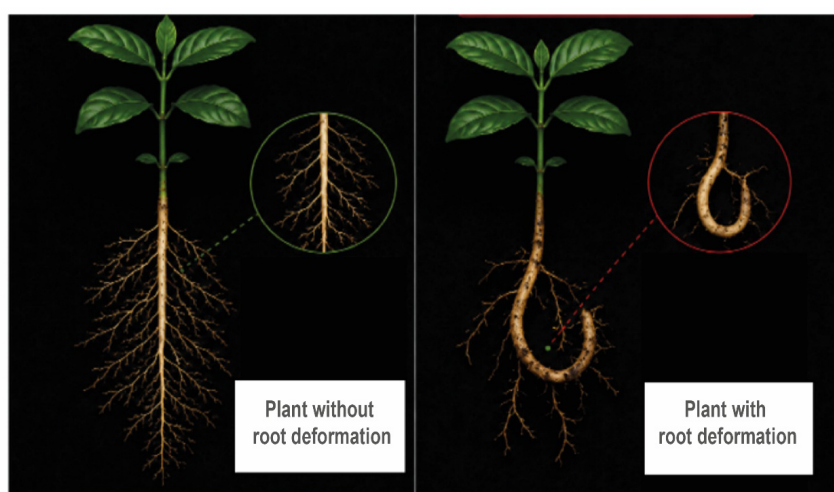


Figure 1.- Comparison of the root systems of *C. arabica* L. seedlings with healthy and deformed roots.

net plot of each experimental unit. These evaluations were carried out at these times because they represent key stages of early vegetative growth of coffee seedlings. The measurement at 60 days allowed quantification of the initial response to transplanting and nursery establishment, while the evaluation at 120 days allowed determination of accumulated growth and the most stable expression of vegetative vigor (León-Burgos et al., 2022).

2.5. Statistical analysis

As a preliminary step, compliance with the assumptions of normality of residuals (Shapiro-Wilk) and homogeneity of variances (Levene) was verified; the data obtained in the germination chamber and nursery phases were then analyzed separately by analysis of variance [ANOVA] for a randomized complete block design with a 2×2 factorial arrangement. The factors evaluated were coffee variety and seed origin altitude. When significant differences were detected ($p \leq 0.05$), means were compared using Tukey's test. Additionally, the mean and coefficient of variation were calculated for each variable evaluated. Statistical processing was performed using InfoStat software (Di Rienzo et al., 2020).

3. Results and Discussion

3.1. Influence of variety and seed origin altitude on emergence and primary root length in the germination chamber

Table 1 presents the ANOVA results for the variables evaluated, and statistically significant differences at 1% were observed for the variety factor in seed emergence and root length. For seed origin altitude, a statistically significant difference at 5% was found for the root length variable. The experimental average for seed emergence was 80.11% and for root length 9.53 cm; the coefficient of variation recorded in the experiment was 13.79 and 3.3%, respectively.

Table 2 shows Tukey's test, and the Red Caturra variety recorded an emergence percentage of 87.17%, higher than the 73.05% observed in Geisha. For root length, different statistical behaviors were also observed: the Red Caturra variety has a root length of 9.76 cm versus the Geisha variety, which recorded 9.30 cm in length. Likewise, for the seed origin altitude factor, those from 1,900 m a.s.l. recorded a root length of 9.68 cm, a value higher than that recorded for seeds from 1,600 m a.s.l., which reached a value of 9.37 cm.

The higher emergence percentage of Red Caturra compared to Geisha can be attributed to genetic

Table 1. Analysis of variance for emergence and root length in *C. arabica* L. seedlings evaluated in the germination chamber.

	Seed emergence (%)		Root length (cm)	
	60 DAS		90 DAS	
	F value	p value	F value	p value
Variety	9.799	0.0068**	12.584	0.0029**
Seed origin altitude	0.468	0.5045	5.839	0.0288*
Variety x Seed origin altitude	0.189	0.6698	0.720	0.4096
Average	80.11		9.53	
CV (%)	13.79		3.3	

Table 2. Tukey's test for emergence and root length in *C. arabica* L. seedlings evaluated in the germinator.

Variables evaluated	Emergence (%)*	Root length (cm)*
	60 DAS	90 DAS
Factor: Variety		
Red Caturra	87.17 a	9.76 a
Geisha	73.05 b	9.30 b
Factor: Seed origin altitude		
1,900 m a.s.l.	-	9.68 a
1,600 m a.s.l.	-	9.37 b

* Means with the same letter do not differ significantly from each other, according to Tukey's test ($p \leq 0.05$).

differences associated with seed vigor and physiological stability. Red Caturra, being a natural mutation of Bourbon, is characterized by greater genetic uniformity and a historical adaptation to a wide range of production conditions, which translates into seeds with greater vigor and germinative capacity (Gutiérrez Baque, 2023). In contrast, the Geisha variety generally shows slower and more heterogeneous germination, particularly under nursery conditions, which can affect emergence percentages (Mallitasig Cajas et al., 2024; Wintgens, 2004).

Several studies have indicated that seedling emergence in *C. arabica* L. is closely related to seed vigor, imbibition speed, and the efficiency of reserve mobilization during the early stages of development, factors that tend to be more favorable in short-statured, early-maturing varieties such as Red Caturra (Silva et al., 2020). In this context, the higher emergence observed in Red Caturra suggests a more favorable physiological response during germination, which could contribute to a more uniform establishment of seedlings in the nursery.

The results show significant differences in primary root length both between varieties and across seed origin altitudes, confirming that early root development in *C. arabica* L. is conditioned by genetic and environmental factors (Villafuerte Soledispa, 2023). The greater root length observed in the Red Caturra variety compared to Geisha suggests greater physiological vigor during the early stages of growth, an attribute that has been reported in studies as a key component for producing uniform, high-quality seedlings in the nursery (Alixandre et al., 2021). In this regard, differences in seed physiological quality at the variety level can be directly reflected in primary root elongation, influencing substrate exploration capacity and early water and nutrient uptake (Vidal-Tejeda, 2023). On the other hand, the significant influence of seed origin altitude on primary root length is consistent

with studies that have shown that environmental conditions associated with higher altitudes, particularly lower temperatures, prolong the fruit ripening period and modify physiological and biochemical characteristics of the coffee bean (Joët et al., 2010; Soares Ferreira et al., 2022). Likewise, the physiological quality of coffee seeds can be influenced both by genetic material and by environmental conditions during their formation (Alixandre et al., 2021). In this context, the greater root length observed in seeds from 1,900 m a.s.l. suggests that altitudinal origin can influence the initial growth of seedlings. Taken together, the results obtained show that both variety and seed origin altitude influence early root development in seedlings, aspects that should be considered in the production of quality plant material for the nursery.

3.2. Influence of variety and seed origin altitude on mortality, primary root deformity, and seedling height in the nursery.

The analysis of variance for plant height at 60 and 120 DAT showed statistically significant differences at 1% for the variety factor, and at 5% for seed origin altitude at 60 DAT ($p = 0.047$), although this effect should be interpreted with caution since the value is close to the upper statistical limit (0.05). Root deformation showed no statistically significant differences for any source of variation, and when analyzing mortality, only the Variety x Seed origin altitude interaction showed statistical differences at 1%. (Table 3) The comparison of means using Tukey’s test (Table 4) indicated that the Red Caturra × 1,900 m a.s.l. combination showed the lowest mortality percentage (8.94%), differing significantly from Geisha × 1,900 m a.s.l. (10.17%), while the Red Caturra × 1,600 m a.s.l. and Geisha × 1,600 m a.s.l. combinations showed intermediate values (9.45%), with no statistical differences from the other treatments. This behavior sug-

Table 3. Analysis of variance for root deformation, plant height, and mortality in *C. arabica* L. seedlings evaluated in the nursery.

Source of Variation	Dependent variable							
	Root deformation (%)		Height 60 DAT (cm)		Height 120 DAT (cm)		Mortality (%)	
	F value	p value	F value	p value	F value	p value	F value	p value
Variety	0.000	1.00	40.941	<0.0001**	0.270	<0.0001**	0.270	0.6107
Seed origin altitude	0.000	1.00	5.015	0.047*	9.344	0.0551	9.344	0.0899
Variety x Seed origin altitude	0.882	0.362	0.050	0.826	9.344	0.7479	9.344	0.0079**
Average	0.89		17.42		29.94		9.50	
CV (%)	0.31		3.16		3.11		5.17	

gests that the seedlings' response during nursery establishment depended on the interaction between genotype and the altitudinal origin of the seed, rather than on the independent effect of each factor. (Bewley et al., 2013; Wibowo et al., 2023).

During the nursery phase, symptoms compatible with damping-off were observed in dead seedlings, both in the aerial part and in the root system. This symptomatology is consistent with that described for diseases caused by soil pathogens associated with damping-off, including *Rhizoctonia solani* (Membreño Hernández & Téllez Castellón, 2021). However, identification of the causal agent was not carried out in the present study. The symptoms occurred mainly in early stages of development, causing the collapse of the root system and the subsequent death of the seedlings (World Coffee Research, 2021); the mortality percentage recorded in the experiment did not exceed 10.17%.

Regarding plant height at 60 DAT, the Red Caturra variety showed a greater average height (18.14 cm) than Geisha (16.70 cm). Likewise, seedlings from seeds collected at 1,900 m a.s.l. reached a greater height (17.67 cm) than those from 1,600 m a.s.l. (17.17 cm), consistent with the significant effects detected for both factors in the analysis of variance.

The behavior of plant height at 60 DAT associated with the variety factor indicates that the vegetative growth of coffee in the nursery was conditioned by the genetic characteristics of each cultivar. In this regard, Red Caturra showed a greater average height (18.14 cm) compared to Geisha (16.70 cm) at 60 DAT. This behavior may be related to the greater early root deve-

lopment observed in Red Caturra, which would have favored greater water and nutrient absorption and, consequently, greater plant height during the initial establishment stage. Consistently, at 120 DAT plant height continued to show significant differences attributable to the variety factor (Red Caturra: 31.22 cm; Geisha: 28.65 cm), suggesting that the genetic characteristics specific to each cultivar maintain their influence on plant height as seedling development progresses, once the initial nursery establishment phase has been overcome.

The results obtained highlight the importance of seed origin in the early development of *C. arabica* L. seedlings; the greater root length observed in seeds from 1,900 m a.s.l. suggests that higher altitudinal conditions could favor slower fruit ripening and a more balanced accumulation of reserves, improving metabolic efficiency during germination. According to Bewley et al. (2013), seed physiological quality is closely related to the efficient mobilization of reserves during germination, which directly affects initial vigor. Likewise, studies on arabica coffee have indicated that differences in seed quality significantly influence early root growth and establishment uniformity (Alixandre et al., 2021; Vidal-Tejeda, 2023). From an ecophysiological perspective, greater root development increases water and nutrient absorption capacity and reduces vulnerability to fluctuations in substrate moisture, favoring initial establishment in the nursery (Wibowo et al., 2023).

It is important to highlight that variety mainly influenced the emergence and initial growth of seedlings, while seed origin altitude affected root

Table 4. Tukey's test for root deformation, plant height, and seedling mortality in *C. arabica* L. evaluated in the nursery.

Variables	Mortality* (%)	Height 60 DAT* (cm)	Height 120 DAT* (cm)
Factor: Variety			
Red Caturra	-	18.14 a	31.22 a
Geisha	-	16.70 b	28.65 b
Factor: Seed origin altitude			
1,900 m a.s.l.	-	17.67 a	-
1,600 m a.s.l.	-	17.17 b	-
Interaction			
Red Caturra * 1,600 m a.s.l.	9.45 ab	-	-
Geisha * 1,600 m a.s.l.	9.45 ab	-	-
Geisha * 1,900 m a.s.l.	10.17 a	-	-
Red Caturra * 1,900 m a.s.l.	8.94 b	-	-

* Means with the same letter do not differ significantly from each other, according to Tukey's test ($p \leq 0.05$).

development and survival during the nursery phase. These findings show that seed physiological quality constitutes a strategic factor for the production of uniform, vigorous seedlings, particularly in mountain coffee-growing systems, where small differences in initial establishment can influence nursery homogeneity and efficiency.

4. Conclusion

The early performance of *C. arabica* L. seedlings was influenced by variety and seed origin altitude. In addition, the interaction between both factors significantly affected seedling mortality during the nursery phase.

The Red Caturra variety showed a higher emergence percentage, greater root development, and greater plant height during the germination and nursery stages, evidencing greater initial vigor compared to Geisha. Origin altitude, in turn, mainly influenced primary root length, suggesting that the seed formation environment can modify its physiological quality. The lower mortality observed in the Red Caturra × 1,900 m a.s.l. combination highlights the importance of jointly considering genotype and altitudinal origin when selecting planting material. In practical terms, these results provide technical criteria for optimizing the production of vigorous, uniform seedlings in Andean coffee-growing nurseries, contributing to improved initial crop establishment.

Contributor roles

- Carlos David Herrera Ramírez: conceptualization, data curation, formal analysis, investigation, methodology, writing – original draft, writing – review & editing.
- Guillermo Alexander Jácome Sarchi: conceptualization, data curation, formal analysis, investigation, methodology, writing – original draft.
- Freddy Richard Quinde Sari: conceptualization, methodology, project administration.

Data Availability

The data will be available on request.

Use of Artificial Intelligence

During the preparation of this manuscript the authors used ChatGPT 5.2 for writing purposes, at 15%, and for Figure 1 elaboration. After using this tool/service/software, the authors reviewed and edited the content as needed, to avoid bias, errors, or fabrication of references, and take full responsibility for the content of the published article.

Ethical implications

The authors declare that there are no ethical implications.

Conflict of interest

The authors declare that he has no affiliation with any organization with a direct or indirect financial interest that could have appeared to influence the work reported.

References

- Acosta-Trinidad, L., Soplin-Villacorta, H., & Chura-Chuquija, J. (2022). Remoción del endocarpio en la emergencia, vigor y fenología pre-trasplante de plántulas de semillas de nueve genotipos de cafeto, en Oxapampa. *Anales Científicos*, 83(1), 67–77. <https://doi.org/10.21704/ac.v83i1.1885>
- Alixandre, F. T., Lopes, J. C., Ferreira, A., Alexandre, R. S., de Lima, P. A. M., Guarçoni, R. C., Kroling, C. A., Dias, R. da S., Favarratto, L. F., Alixandre, R. D., & Fornazier, M. J. (2021). Physiological quality of seeds from traditional and new recommended groups of Arabic coffee cultivars to highland regions. *International Journal of Advanced Engineering Research and Science*, 8(7), 114–120. <https://doi.org/10.22161/ijaers.87.13>
- Alulima Cornejo, M. V. (2012). *Alternativas agroecológicas para el manejo del café (Coffea arabica)*. Universidad de Cuenca. <http://dspace.ucuenca.edu.ec/handle/123456789/3251>
- Arcila-Pulgarín, J., Buhr, L., Bleiholder, H., Hack, H., Meier, U., & Wicke, H. (2002). Application of the extended BBCH scale for the description of the growth stages of coffee (*Coffea* spp.). *Annals of Applied Biology*, 141(1), 19–27. <https://doi.org/10.1111/j.1744-7348.2002.tb00191.x>
- Bewley, J. D., Black, M., Halmer, P., & Bradford, K. J. (2013). *Seeds: Physiology of development, germination and dormancy* (3rd ed.). Springer New York. <https://doi.org/10.1007/978-1-4614-4693-4>
- Cerda Cruz, K. L. (2021). *Modelos de germinación, crecimiento y parámetros de calidad de Schizolobium parahybum (Vell) en vivero bajo diferentes sustratos orgánicos*. Universidad Estatal Amazónica. <https://repositorio.uea.edu.ec/handle/123456789/1045>
- Cevallos Cantos, J. J. (2022). *Evaluación del crecimiento de plántulas de Coffea arabica L. Acawa en condiciones de vivero con diferentes sustratos y bioestimulantes*. Universidad Estatal del Sur de Manabí. <https://repositorio.unesum.edu.ec/handle/53000/3683>
- Di Rienzo, J. A., Casanoves, F., Balzarini, M. G., González,

- L., Tablada, M., & Robledo, C. W. (2020). InfoStat (Versión 2020). Grupo InfoStat, Facultad de Ciencias Agropecuarias, Universidad Nacional de Córdoba. <http://www.infostat.com.ar>
- Flechas-Bejarano, N., & Medina-Rivera, R. (2021). Efecto del almacenamiento en la viabilidad, germinación y vigor de semillas de *Coffea arabica* L. *Revista Cenicafé*, 72(2), e72206. <https://doi.org/10.38141/10778/72206>
- Food and Agriculture Organization of the United Nations [FAO]. (2023). *FAOSTAT*. <https://www.fao.org/faostat/es/#data/QCL>
- Gil, A. I., & Díaz, L. J. (2016). Evaluación de tipos de contenedores sobre el crecimiento radical de café (*Coffea arabica* L. cv. Castillo) en etapa de vivero. *Revista Colombiana de Ciencias Hortícolas*, 10(1), 125–136. <https://doi.org/10.17584/rcch.2016v10i1.4461>
- Guilcapi Pacheco, E. D. (2010). *Efecto de Trichoderma harzianum y Trichoderma viride, en la producción de plantas de café (Coffea arabica) variedad caturra a nivel de vivero*. Escuela Superior Politécnica del Chimborazo. <http://dspace.esPOCH.edu.ec/handle/123456789/334>
- Gutiérrez Baque, J. J. (2023). *Aptitud combinatoria general y específica de parentales de café en las cruces de Catimor CIFC x Borbón Amarillo y Catimor CIFC x Caturra Roja en vivero*. Universidad Estatal del Sur de Manabí. <http://repositorio.unesum.edu.ec/handle/53000/5760>
- Guzmán Vidal, F. F. (2013). *Evaluación del impacto del cambio climático en el cultivo de café en la cuenca alta del río Sisa – provincia de Lamas y El Dorado, región San Martín*. Universidad Nacional Agraria la Molina. <https://hdl.handle.net/20.500.12996/1075>
- Instituto Interamericano de Cooperación para la Agricultura [IICA]. (2020). *Guía práctica de caficultura*. <https://hdl.handle.net/11324/13191>
- Instituto Nacional de Estadística y Censos [INEC]. (2023). *Encuesta de Superficie y Producción Agropecuaria Continua 2023*. https://anda.inec.gob.ec/anda5/index.php/catalog/1037/variable/F21/V1177?name=ct_codcultiv2_int
- Joët, T., Salmona, J., Laffargue, A., Descroix, F., & Dussert, S. (2010). Use of the growing environment as a source of variation to identify the quantitative trait transcripts and modules of co-expressed genes that determine chlorogenic acid accumulation. *Plant, Cell & Environment*, 33(7), 1220–1233. <https://doi.org/10.1111/j.1365-3040.2010.02141.x>
- León-Burgos, A. F., Ramírez, C., Rendón Sáenz, J. R., Imbachí-Quinchua, L. C., Unigarro-Muñoz, C. A., & Balaguera-Lopez, H. E. (2022). Fitting growth curves of coffee plants in the nursery stage of growth: A functional approach. *Agronomía Colombiana*, 40(3), 344–353. <https://doi.org/10.15446/agron.colomb.v40n3.101333>
- Lopes, E. C. S., dos Santos, M. S., Allaman, I. B., Dalmolin, Á. C., Sousa-Santos, C., Cerqueira, A. F., Mello, D. L. N., & Mielke, M. S. (2025). Growth and biomass-allocation responses of arabica coffee young plants subjected to the interactive effects of root deformation and light availability. *Acta Physiologiae Plantarum*, 47(1), 4. <https://doi.org/10.1007/s11738-024-03749-2>
- Mallitasig Cajas, J. S., Macías Campuzano, K. W., Luna Murillo, R. A., Chuquitarco Esmeralda, V. A., & Cedeño Aristega, M. J. (2024). Respuesta morfométrica de seis variedades de café (*Coffea arabica* L.) durante las épocas lluviosa y seca. *Revista ESPAMCIENCIA*, 15(e), 33–38. https://doi.org/10.51260/revista_espamciencia.v15iE.518
- Membreño Hernández, L. N., & Téllez Castellón, P. Y. (2021). *Distribución espacial y temporal del mal de talluelo (Rhizoctonia solani) y pudrición blanca (Sclerotium rolfsii) en el cultivo de tomate (Solanum lycopersicum) en el Campus Agropecuario de la UNAN-León, en el ciclo agrícola 2010*. Universidad Nacional Autónoma de Nicaragua, León. <http://riul.unanleon.edu.ni:8080/jspui/handle/123456789/1941>
- Paima Flores, J. K. (2017). *Influencia de tres pisos altitudinales en las características físicas y sensoriales del café (Coffea arábica L.) variedad Catimor en los distritos de Lamas y Alonso de Alvarado Roque*. Universidad Nacional de San Martín. <http://repositorio.unsm.edu.pe/handle/11458/3236>
- Picon Tafur, E. C. (2025). *Influencia del lugar de procedencia en la germinación y características morfo-estructurales de semilla botánica de Tithonia diversifolia*. Universidad Nacional Toribio Rodríguez de Mendoza de Amazonas. <https://hdl.handle.net/20.500.14077/4646>
- Santacreo Ponce, R. (2012). *Mejoramiento genético de café*. Instituto Hondureño del Café [IHCAFE]. <https://ihcafe.hn/mejoramiento-genetico/>
- Silva, L. O. E., Schmidt, R., Valani, G. P., Ferreira, A., Ribeiro-Barros, A. I., & Partelli, F. L. (2020). Root trait variability in *Coffea canephora* genotypes and its relation to plant height and crop yield. *Agronomy*, 10(9), 1394. <https://doi.org/10.3390/agronomy10091394>
- Silva Rincon, C. I., Alarcón Gutiérrez, E., García Pérez, J. A., Sánchez-Velásquez, L. R., & Iglesias Andreu, L. G. (2024). La variedad de café Geisha y su estatus en el mundo y en México. *Revista Mexicana de Ciencias Agrícolas*, 15(7), e3403. <https://doi.org/10.29312/remexca.v15i7.3403>
- Soares Ferreira, D., Eduardo da Silva Oliveira, M., Rodrigues Ribeiro, W., Altoé Filete, C., Toledo Castanheira, D., Cesar Pereira Rocha, B., Polonini Moreli, A., Catarina da Silva Oliveira, E., Carvalho Guarçoni, R., Partelli, F. L., & Louzada Pereira, L. (2022). Association of Altitude and Solar Radiation to Understand Coffee Quality. *Agronomy*, 12(8), 1885. <https://doi.org/10.3390/agronomy12081885>
- Valarezo Rivera, N. Y., Quevedo Guerrero, J. N., Ajila Gia, L. G., García Batista, R. M., & Chabla Carrillo, J. E. (2021). Evaluación del porcentaje de germinación de cinco cultivares de café (*Coffea arabica* L.) empleando cuatro tratamientos en vivero. *Revista Científica Agroecosistemas*, 9(1), 69–76. <https://aes.ucf.edu.cu/index.php/aes/article/view/446>
- Vidal-Tejeda, C. A. (2023). Atributos físicos y fisiológicos de las semillas de café (*Coffea arabica* L.). *Siembra*, 10(2), e4523. <https://doi.org/10.29166/siembra.v10i2.4523>
- Villafuerte Soledispa, D. E. (2023). *Comportamiento morfológico de dos genotipos de café arábigo (Coffea arabica L.) en etapa semillero, a la aplicación de dos sustratos con dos enraizadores*. Universidad Estatal del Sur de Manabí. <https://repositorio.unesum.edu.ec/handle/53000/5802>
- Wibowo, A., Aprillia Wijaya, S., & Suharjono. (2023). Germination and early seedling growth of three Arabica coffee varieties at four seed soaking water temperatures. *Pelita Perkebunan*, 39(1), 1–10. <https://doi.org/10.22302/icri.jur.pelitaaperkebunan.v39i1.540>

-
- Wintgens, J. N. (2004). *Coffee: Growing, Processing, Sustainable Production*. Wiley. <https://doi.org/10.1002/9783527619627>
- World Coffee Research. (2021). *Guía de buenas prácticas en el manejo de vivero de café*. <https://worldcoffeeresearch.org/es/download/296c6e39-092b-43ce-b18c-5a3fc76cc-fc2>
- Zhirvi Ordóñez, C. M. (2017). Evaluación de dos (2) especies nativas y una comercial de *Trichoderma* sp. como agente de control de los hongos que ocasionan el damping off (*Rhizoctonia* spp.) en semilleros de café (*Coffea arabica* L.) variedad bourbón. Universidad de Cuenca. <http://dspace.ucuenca.edu.ec/handle/123456789/26240>