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Article

Effect of the endocarp on the emergence kinetics and uniformity of coffee trees

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Abstract

The physical quality of coffee seeds is key to producing seedlings, especially under uncontrolled edaphoclimatic conditions, where the endocarp acts as a barrier that delays emergence and makes it irregular. This study aimed to evaluate the effect of the endocarp on the emergence kinetics and uniformity of seedlings of six coffee genotypes under seedbed conditions in Oxapampa, Pasco, Peru, between May and August 2025. Six coffee genotypes and two conditions (with and without endocarp) were evaluated. The design was completely randomized with a 6 × 2 factorial arrangement and two blocks. Seedling emergence percentage, time, speed and index were evaluated. Data were analyzed with analysis of variance, simple effects and Tukey's test ($p \leq 0.05$). The genotype × endocarp interaction was significant for PE, MET, MES and ESI. Endocarp removal increased the percentage and speed of emergence and reduced the mean emergence time in all genotypes. Obata Amarillo, Marsellesa, Cuscatleco and Catigua recorded the highest percentages of emergence (92.19-96.88%), while Marsellesa exhibited the fastest emergence (87.2 days) and the highest speed of emergence (1.29 seedlings day^{-1}). ESI showed a differential response according to genotype. The research revealed that removing the endocarp improves kinetics by reducing emergence time and enhances seedling emergence uniformity.

Keywords:

genotype, germination, parchment, seed, seedling.

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Introduction

The coffee tree (*Coffea arabica* L.) is the main species cultivated in Oxapampa, a district located in the central rainforest of Peru (Acosta and Acosta, 2025). Its cultivation is the livelihood of small farmers (Acosta *et al*., 2022). However, there is a context of limited information on varietal identity (Acosta *et al*., 2022) and on the specific emergence kinetics of each nanobasin.

The renovation and establishment of new coffee plantations face limitations in obtaining quality seedlings, given that germination is slow and uneven under conventional management (Nápoles-Vinent *et al*., 2022), which prolongs the time spent in the seedbed, extends associated cultural management, and increases heterogeneity among seedling batches. In addition, commercial coffee cultivars are self-pollinated and seed-propagated (Gebreselassie *et al*., 2010).

Coffee seeds can germinate after harvest, but they lose viability quickly (Coste, 1992). In addition, the endocarp acts as a physical barrier that limits germination by hindering radicle protrusion; therefore, the need to evaluate seeds without the endocarp arises (Eira *et al*., 2006).

Seed analysis provides fundamental information and allows us to establish standards for determining seed quality (Morejón and Díaz, 2023), and that genotype and the absence of endocarps influence seedling emergence and growth (Acosta *et al*., 2022). In contrast, removing the endocarp tends to accelerate emergence and improve uniformity (Gebreselassie *et al*., 2010; Coa *et al*., 2014).

Given this background, the objective of this research was to evaluate the effect of the endocarp on the emergence kinetics and uniformity of seedlings of six genotypes of coffee (*Coffea arabica* L.) under seedbed conditions in Oxapampa, Pasco, Peru, in order to contribute to the selection of genotypes with seedling uniformity and to generate knowledge about the efficiency of their emergence.

Materials and methods

The research was conducted from May to August 2025 at the Miraflores III Experimental Field of the Daniel Alcides Carrión National University, Oxapampa, Pasco, Peru, located in zone 18 L, at 45.7615° east and 88.29303° north, at an altitude of 1 835 m (Figure 1).

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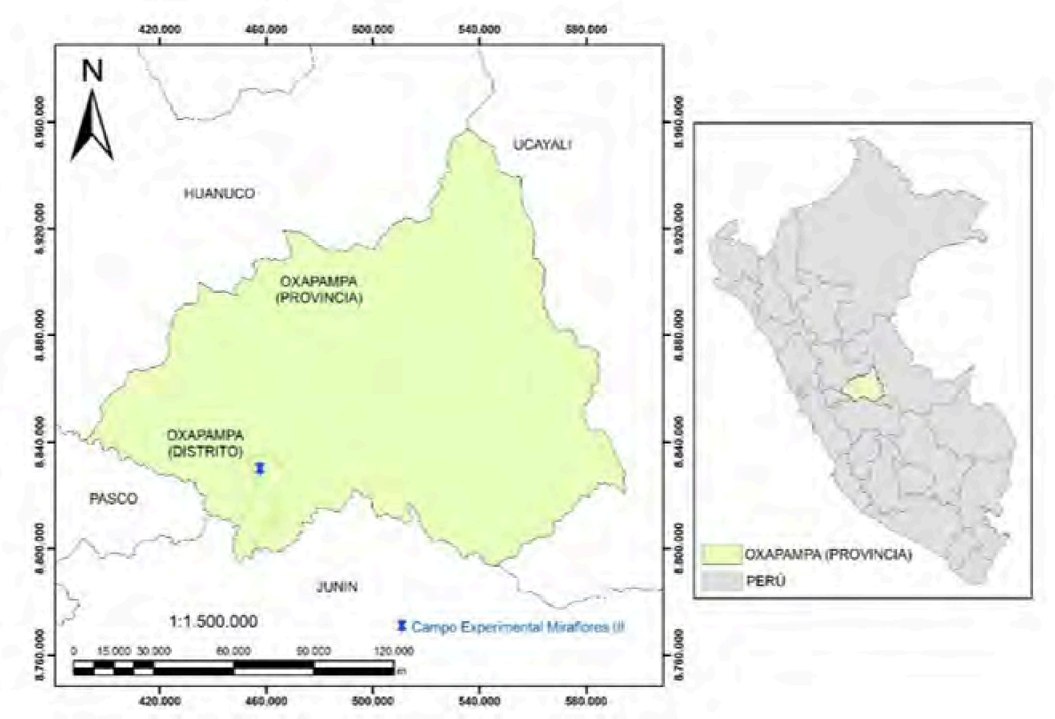
Figure 1. Location of the study site.



During the experimental period, the average environmental temperature was 17.37 °C, the relative humidity was 84.5%, and the accumulated rainfall was 312.3 mm (SENAMHI, 2025).

The coffee seeds came from non-certified seed multiplication plots of the Aroma de Montaña farm in the district of Villa Rica.

The design used was a completely randomized block design with a 6 × 2 factorial arrangements, for genotype (Obata Rojo, Obata Amarillo, Cuscatleco, Castillo, Marsellesa and Catigua) and endocarp [with endocarp (WE) and without endocarp (NE)], distributed across 12 treatments, with two blocks and experimental units (EUs) consisting of 32 seeds.

The substrate used was river sand, previously sifted through a 0.5 cm mesh sieve and disinfected (Julca *et al*., 2015; Caballero-Salas *et al*., 2021). The seedbed measured 2.22 m long (4 rows of EUs), 1.94 m wide (6 rows of EUs), and 0.3 m deep (Valarezo *et al*., 2021) and had wooden edges. Endocarp removal was performed manually (Escobedo *et al*., 2025).

To select the seeds, they were placed in a 500 ml beaker with distilled water and separated by flotation and decantation, discarding impurities and floating seeds (Carrasco *et al*., 2025). The planting frame was 6 x 6 cm and each experimental unit was kept 10 cm apart from the next. The seeds were buried at a depth of 1.5 cm (Coa *et al*., 2014). An irrigation regime was maintained with a frequency of two days, and the experimental units were kept under nursery conditions.

The percentage of emergence (equation 1), the mean emergence time (equation 2), the mean emergence speed (equation 3) and the emergence synchrony index (equations 4 and 5) were evaluated.

1

$$PE = \left(\frac{\text{Emerged seedlings}}{\text{N° of seeds sown}}\right) \times 100$$

(equation 1, Morejón and Díaz, 2023);

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2

$$MET = \frac{\sum_{t=1}^{6} n_i t_i}{\sum_{t=1}^{6} n_i}$$

(equation 2, Maqueira *et al*., 2023);

3

$$\mathrm{MES} = \sum_{i=1}^{6} \frac{n_i}{t_i}$$

(equation 3, Vieira *et al*., 2016);

4

$$\mathrm{ESI} = -\sum_{i=1}^{6} f_i \log_2\left(f_i\right)$$

(equation 4, Ranal and García, 2006);

5

$$f_i = \frac{n_i}{\sum_{i=1}^{6} n_i}$$

(equation 5, Ranal and García, 2006). Where: n_i is the number of seedlings that emerged at the i-th data collection; n_i is the day of the i-th data collection.

Data were collected at 70, 75, 80, 85, 90 and 95 days after sowing (das). Percentage values were transformed using the arcsine function (Martínez *et al*., 2012). Data were subjected to an analysis of variance (Anova) at a 95% confidence level, followed by analysis of simple effects (95% confidence level) and Tukey's test; means with equal letters do not differ statistically (p# 0.05). For this purpose, the InfoStat program (version 2020e) was used.

Results and discussion

The emergence of seedlings of the six coffee genotypes was affected by the presence or absence of the endocarp. It was observed that in seeds sown with endocarp, emergence was late, starting at 75 das, confirming the endocarp's retarding effect; in this group, Cuscatleco was the earliest and had the highest average number of seedlings emerged (24.5 ±0.5), reaching the highest value at 95 das, followed by Castillo (12.5 ±2.5) and Obata Amarillo (9 ±1), whereas Marsellesa showed the lowest (3.5 ±0.5) and late emergence (Figure 2A).

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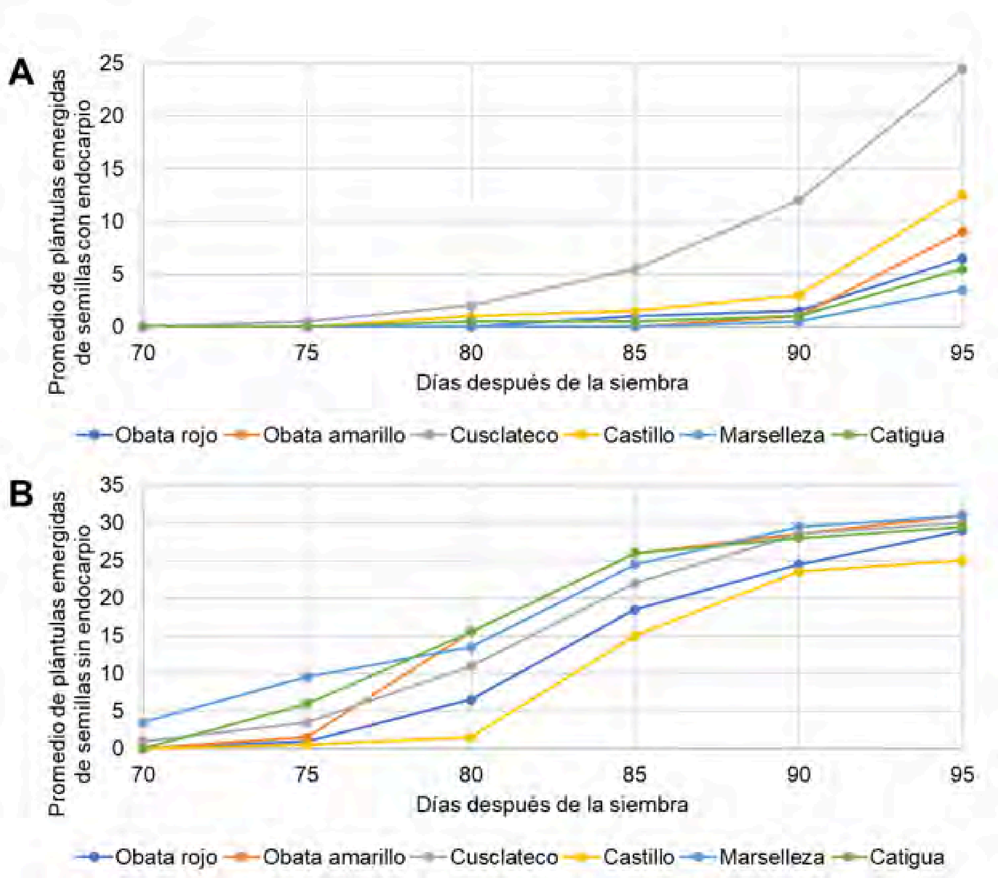
Figure 2. Curve of seedling emergence of six coffee genotypes under two endocarp conditions (A and B) in Oxapampa.



In contrast, in seeds without endocarp, emergence began earlier and increased rapidly in all genotypes, indicating that its absence leads to a faster and more uniform emergence; under this condition, Obata Amarillo and Marsellesa recorded the highest number of emerged seedlings, averaging 31 seedlings at the end of the evaluation period, while Castillo presented the least emergence level, with 25 ±1 seedlings (Figure 2B).

The results confirm genetic differences in both speed and emergence, as well as a clear influence of the endocarp on this process. Considering the emergence period in this research, Diaz *et al*. (2023) report that seedling emergence can occur within an interval of 50 to 90 das at an approximate altitude of 10 m.

For PE, the ANOVASE determined that the genotype factor presented highly significant statistical differences ($p< 0.01$) both in the presence and absence of the endocarp; likewise, the endocarp factor showed highly significant statistical differences ($p< 0.01$) among the genotypes evaluated (Table 1).

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Table 1. Analysis of variance and analysis of simple effects for four vigor indicators of coffee seedlings, at 95 das.

Source of variation	Degrees of freedom	PE[1]	MET	MES	ESI
Anova					
Block	1	0.00094^{ns}	1.55^{ns}	0.02^{ns}	0.01^{ns}
Genotype (G)	5	0.07**	1.47^{ns}	0.06**	0.19^{ns}
Endocarp (E)	1	2.98**	117.93**	4.77**	6.81**
G x E	5	0.09**	4.01**	0.09**	0.41*
Error	11	0.0037	0.59	0.01	0.08
Total	23				
Analysis of variance of simple effects (Anovase)					
Endocarp on Obata Rojo	1	0.638**	10.793**	0.629**	0.606*
Endocarp on Obata Amarillo	1	0.697**	36.649**	1.117**	2.923**
Endocarp on Cuscatleco	1	0.064**	8.39**	0.363**	0.245^{ns}
Endocarp on Castillo	1	0.169**	4.16*	0.282**	0.141^{ns}
Endocarp on Marsellesa	1	1.117**	51.517**	1.551**	3.661**
Endocarp on Catigua	1	0.748**	26.549**	1.255**	1.257**
Genotype with endocarp	5	0.137**	2.661*	0.054**	0.508**
Genotype without endocarp	5	0.026**	2.823*	0.089**	0.092^{ns}
Coefficient of variation (%)		6.49	0.84	13.81	19.34

[1]= variable transformed before statistical analysis with arcsine (root(PE/100)); *= significant ($p \leq 0.05$); **= highly significant ($p \leq 0.01$), ns: not significant.

For MET, the Anovase determined that the genotype factor showed statistically significant differences ($p< 0.05$) in the presence and absence of the endocarp; the endocarp factor also showed statistically significant differences ($p< 0.05$) among the genotypes evaluated (Table 1).

For MES, the Anovase determined that the genotype factor presented highly significant statistical differences ($p< 0.01$) both in the presence and absence of the endocarp; likewise, the endocarp factor showed highly significant statistical differences ($p< 0.01$) among the genotypes evaluated (Table 1).

For ESI, the Anovase indicated that the genotype factor presented highly significant statistical differences ($p< 0.01$) in the presence of the endocarp, whereas no statistically significant differences ($p> 0.05$) were observed in its absence (Table 1).

The findings of González *et al*. (2015) highlight that seedling emergence is directly related to seed vigor, which depends on seed quality and the efficiency of the metabolic processes that occur during germination. Initial vigor is essential because it determines seedling growth (Moreno-Peña *et al*., 2025) and development before transplantation.

In the presence of the endocarp, the Cuscatleco genotype registered the highest PE (76.56%), significantly exceeding the other genotypes, whose value ranged from 10.94 to 39.06%. In the absence of the endocarp, Obata Amarillo, Marsellesa, Cuscatleco, and Catigua formed the statistically superior group, with percentages of emergence ranging from 92.19 to 96.88% and no significant differences among them. Obata Rojo presented intermediate behavior (90.63%), while Castillo exhibited the lowest PE (78.13%) (Table 2).

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Table 2. Average percentage of emergence (PE) for genotype (endocarp), simple effects of genotype on endocarp, at 95 das.

Genotype (CE)	PE (%)	Genotype (SE)	PE (%)
Cuscatleco	76.56^{a}	Obata Amarillo	96.88^{a}
Castillo	39.06^{b}	Marsellesa	96.88^{a}
Obata Amarillo	28.13^{b}	Cuscatleco	93.75^{a}
Obata Rojo	20.31^{b}	Catigua	92.19^{a}
Catigua	17.19^{b}	Obata Rojo	90.63^{ab}
Marsellesa	10.94^{b}	Castillo	78.13^{b}

Means with the same letter do not differ significantly (Tukey, p≤ 0.05)

The endocarp constitutes a physical barrier that limits imbibition and gas exchange, thereby delaying the activation of metabolic processes associated with germination (Bewley *et al*., 2013). Accordingly, Gebreselassie *et al*. (2010); Carvalho and Nakagawa (2012) reported that endocarp removal favors seedling emergence by reducing the physical restrictions imposed on the embryo.

This effect may be due to greater ease of imbibition, which favors the reactivation of cell metabolism and consequently, the processes of germination and seedling emergence (González *et al*., 2015).

Tukey's mean comparison test (α= 0.05) for the simple effects of the genotype × endocarp condition interaction showed that, in the presence of the endocarp, there were no significant differences in MET between the genotypes evaluated, whose values ranged from 91.54 to 94.58 days.

In the absence of the endocarp, significant differences were observed among genotypes, with Castillo showing the highest MET (90.44 days) and not differing statistically from Obata Rojo, Cuscatleco, Obata Amarillo, and Catigua. By contrast, Marsellesa exhibited the lowest MET (87.2 days) and differed significantly from Castillo (Table 3), showing a faster emergence.

Table 3. Average of the mean emergence time (MET) for genotype (endocarp), simple effects of genotype on endocarp, at 95 das.

Genotype (WE)	MET (days)	Genotype (NE)	MET (days)
Obata Amarillo	94.58^{a}	Castillo	90.44^{a}
Marsellesa	94.38^{a}	Obata Rojo	89.71^{ab}
Obata Rojo	93^{a}	Cuscatleco	88.64^{ab}
Catigua	93^{a}	Obata Amarillo	88.53^{ab}
Castillo	92.48^{a}	Catigua	87.85^{ab}
Cuscatleco	91.54^{a}	Marsellesa	87.2^{b}

Means with the same letter do not differ statistically (Tukey, p≤ 0.05)

The high MET values observed reflect a slow emergence process of coffee seeds, which may potentially be associated with genetic traits related to seed vigor (Filho, 2015). Nonetheless, the reduction in MET in the absence of the endocarp shows the restrictive effect of this physical structure on emergence. These results align with Acosta *et al*. (2022), who reported improved seedling emergence after endocarp removal.

In the presence of the endocarp, Cuscatleco had the highest MES (0.49 seedlings day^{-1}), significantly outperforming the other genotypes, whose values ranged from 0.04 to 0.2 seedlings day^{-1}. In the absence of the endocarp, Marsellesa, Catigua and Obata Amarillo formed the statistically superior group, with emergence speeds of 1.29, 1.2 and 1.16 seedlings day^{-1}, respectively, with no significant differences among them. Cuscatleco and Obata Rojo showed intermediate values (1.09 and 0.89 seedlings day^{-1}), while Castillo recorded the lowest MES (0.73 seedlings day^{-1}) (Table 4).

Table 4. Average of mean emergence speed (MES) for genotype (endocarp), simple effects of genotype on endocarp, at 95 das.

Genotype (WE)	MES (seedlings day^{-1})	Genotype (NE)	MES (seedlings day^{-1})
Cuscatleco	0.49^{a}	Marsellesa	1.29^{a}
Castillo	0.2^{b}	Catigua	1.2^{a}
Obata Amarillo	0.11^{b}	Obata Amarillo	1.16^{a}
Obata Rojo	0.1^{b}	Cuscatleco	1.09^{ab}
Catigua	0.08^{b}	Obata Rojo	0.89^{ab}
Marsellesa	0.04^{b}	Castillo	0.73^{b}

Means with the same letter do not differ significantly (Tukey, p≤ 0.05)

The endocarp factor significantly affected the ESI of Obata rojo ($p < 0.05$) and had a highly significant effect on the ESI of Obata Amarillo, Marsellesa and Catigua ($p < 0.01$). However, in the presence of the endocarp, Tukey's test ($\alpha = 0.05$) did not show significant differences among the evaluated genotypes, whose ESI values ranged from 0.33 to 1.11 (Table 5).

Table 5. Average of emergence synchrony index (ESI) for genotype (endocarp), simple effects of genotype on endocarp, at 95 das.

Genotype (WE)	ESI
Obata Amarillo	0.33^{a}
Marsellesa	0.41^{a}
Catigua	1.04^{a}
Obata Rojo	1.11^{a}

Means with the same letter do not differ significantly (Tukey, p≤ 0.05)

The absence of significant differences in ESI among genotypes indicates a similar temporal distribution of emergence under the endocarp condition. Likewise, the values obtained suggest a comparable behavior in the uniformity of seedling emergence, considering that lower ESI values reflect greater synchrony in the emergence process (Narváez *et al*., 2022).

Conclusions

Removing the endocarp significantly improved coffee seedling emergence by increasing both the percentage and speed of emergence and reducing the mean emergence time.

The magnitude of this response depended on the genotype, with Obata Amarillo, Marsellesa, Cuscatleco and Catigua standing out for their high performance.

Overall, the results demonstrate that removing the endocarp leads to faster, more efficient emergence of coffee seedlings.

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