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REVIEW ARTICLE

Mechanical Scarification and Sucrose Priming Overcome Physical Dormancy in Caesalpinia spinosa (Tara) Seeds from the Peruvian Highlands

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Abstract: Caesalpinia spinose (tara) is a leguminous tree native to the Peruvian Andes-Amazon region, valued for soil restoration and high tannin content. However, its large-scale propagation is constrained by physical seed dormancy caused by a hard and impermeable seed coat. This study evaluated six pre-germination treatments to break dormancy and enhance early seedling development under local agroclimatic conditions in Magdalena District, Chachapoyas, Peru. A completely randomized block design with three replicates was used. Treatments included mechanical scarification (seed coat incision with nail clippers) followed by soaking in a 10% sucrose solution for 2, 4, or 6 days (T1, T2, T3); mechanical dehulling with a mill followed by sucrose soaking (T4); hot water shock (T5); and an untreated control soaked in cold water (T6). Germination percentage, plant height, leaf number, and root length were recorded over approximately 8 weeks. Treatments T2 and T3 achieved the highest germination rates (90.7-92.5%), significantly outperforming all other treatments ($p<0.001$). These treatments also produced the tallest seedlings (up to 8.2 cm), the highest number of true leaves (nearly four per plant), and the longest roots (>15 cm). In contrast, hot water shock (T5) and mechanical dehulling (T4) resulted in low germination (~20%), while the control (T6) had only 5.15% germination. The combination of controlled seed coat incision and osmotic priming with 10% sucrose effectively overcomes physical dormancy, promotes vigorous seedling growth, and offers a simple, low-cost method suitable for nursery propagation and reforestation programs in the Peruvian Andes.

Keywords: *Caesalpinia spinose*, Tara, Seed Dormancy, Pre-Germination Treatments, Mechanical Scarification, Sucrose Priming, Osmotic Conditioning, Germination Percentage, Seedling Vigor, Reforestation, Peruvian Andes

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Introduction

Caesalpinia spinosa (tara) is a leguminous tree native to the Andean-Amazonian region of Peru and plays a dual ecological and economic role. It is highly valued by local communities for its ability to restore degraded soils and for its high tannin content, which supports industries such as leather processing, pharmaceuticals, and natural dyes. Despite its importance, the spread of tara is limited by the physical dormancy of its seeds. These have a hard, impermeable coat that can delay germination for months or even years until favorable conditions arise [1].

Although dormancy is a natural adaptation mechanism, it poses a challenge for nursery production and reforestation programs. Several pre-germination techniques have been tested to overcome this limitation, including mechanical scarification, thermal shock, and chemical treatment. Traditional methods, such as scraping or making a small cut in the seed coat, help water to enter more easily, promoting the imbibition process. In recent years, more innovative alternatives have also been explored, such as immersing seeds in sugar solutions, which can stimulate their metabolic activity from the early stages of germination [2, 3].

However, the effectiveness of pre-germination treatments may vary depending on seed characteristics and local environmental conditions. Methods that produce satisfactory results in controlled environments or other regions may not work as well in the agroclimatic conditions of Magdalena, a high-altitude district in Chachapoyas where temperature, soil type, and moisture patterns influence germination success [4].

In this context, the present study aims to compare six pre-germination methods to determine which are most effective in breaking dormancy and promoting early seedling development of C. spinosa under local conditions. This evaluation combines established scientific techniques with practical considerations relevant to community nurseries [5-8].

The results are expected to generate practical, accessible, and low-cost recommendations for seed propagation, providing tools to drive the restoration of Andean ecosystems and promote the sustainable use of tara. The aim is to contribute not only to biodiversity conservation but also to the strengthening of communities that coexist with and depend on this valuable resource in the Peruvian Andes.

Materials and Methods

Study Area

The study was conducted in the district of Magdalena, province of Chachapoyas (Amazonas, Peru), an area with favorable agroclimatic characteristics for *Caesalpinia spinosa* (tara) cultivation [8].

This region has a subtropical climate with an average altitude of 2,200 m above sea level, average annual temperatures of 16-20 °C and rainfall between 800-1,200 mm per year, conditions that influence the germination and growth of the species [9, 10]. Magdalena is part of the high forest ecosystem, where tara grows wild and in traditional agroforestry systems [11].

The soils of Magdalena are predominantly clay loam, with good drainage and moderate organic matter content (2.5-3.5%), characteristics suitable for experimentation with forest seeds [4]. In addition, recent research highlights the potential of tara in agroforestry systems resilient to climate change in the Peruvian Amazon [12].

The selection of the area responds to the need to optimize pre-germinative techniques for the propagation of tara, a species valued for its use in the tannin industry and its role in the recovery of degraded soils [13].

Experimental Design

A completely randomized block design was used in an experimental area of 76 m² (9.5×8.0 m), with 6 scarification treatments, 3 replicates, and 18 experimental units measuring 2.0×1.0 m each. A total of 1,800 seeds were sown (100 per unit; 300 per treatment). For the morphometric assessments (seedling height, number of leaves, and root length), 5 seedlings were selected from the central area of each unit to avoid edge effects. Seedling emergence percentage was determined for each experimental unit based on the total number of seeds sown (100 per plot). To ensure statistical validity and avoid pseudo-replication, the values of these 5 subsampled seedlings per plot were averaged. Consequently, the statistical analysis was conducted strictly using the plot mean as the experimental unit, resulting in an effective replication of $n=3$ per treatment.

Substrate Preparation and Seedbed Conditioning

Sifted river sand was used, disinfected with formaldehyde (1 L in 20 L of water) and covered with polyethylene for 4 days. A seedbed was installed 1.50 m above the ground (2.0×1.0×0.30 m), covered with Raschel mesh to mitigate external environmental conditions.

Seed Collection and Pre-Germination Treatments

The seeds were collected at the Huillín farm from 10-20 vigorous and phytosanitary healthy trees. They were extracted from mature pods, selecting those of uniform size and discarding those at the extremes. Physical scarification treatments (soaking in cold and hot water) and mechanical scarification treatments (cutting the testa) were applied, according to the experimental distribution described in Table 1.

For treatments T1-T4, the sucrose solution was prepared by dissolving 100 g of commercial white sugar in 900 mL of tap water and then bringing the volume to 1 L (10% w/v). The solution was replaced every 24 hours to prevent microbial fermentation. Soaking was carried out at room temperature (20±2°C). For the hot water treatment (T5), 3 L of tap water was brought to a rolling boil for 10 minutes, removed from heat, and left uncovered for exactly 5 minutes. At that moment, the water temperature was measured as 85 ± 2 °C using a calibrated thermometer. Seeds were then added and left to cool to room temperature (approximately 4 hours). The control (T6) consisted of unscarified seeds soaked in cold tap water (20±2°C) for 24 hours.

Table 1: Pre-germination treatments applied to *Caesalpinia spinosa* seeds

Treatment	Scarification method	Soaking solution	Concentration (% w/v)	Soaking duration	Solution renewal	Temperature (°C)
T1	Seed coat incision with nail clippers	Sucrose (table sugar) in tap water	10%	2 days	Every 24 h	20 ± 2
T2	Seed coat incision with nail clippers	Sucrose in tap water	10%	4 days	Every 24 h	20 ± 2
T3	Seed coat incision with nail clippers	Sucrose in tap water	10%	6 days	Every 24 h	20 ± 2
T4	Mechanical dehulling (manual grain mill, gap ~1 mm)	Sucrose in tap water	10%	2 days	Every 24 h	20 ± 2
T5	None (hot water shock)	Tap water	-	Seeds added 5 min after boiling; left until room temp (~4 h)	N/A	85 ± 2 at seed addition
T6 (control)	None	Tap water	-	1 day	N/A	20 ± 2

Note: For T5, 3 L of water was boiled for 10 minutes, then left uncovered for 5 minutes before adding seeds. Temperature was measured with a calibrated thermometer. For all sucrose treatments, the solution was prepared by dissolving 100 g of sugar in 900 mL of tap water and then bringing the volume to 1 L (10% w/v). Solutions were replaced every 24 hours to prevent fermentation

Sowing and Agronomic Management

Sowing took place between August and November 2023 at a depth equivalent to twice the thickness of the seed, covered with sterile sand. Initial irrigation was applied, followed by 2-3 irrigations per week depending on environmental conditions. No fertilizers were used during the evaluation period.

Variables Evaluated

Evaluations were carried out until the seedlings reached 6-9 cm in height (optimal phase for transplanting, ~8 weeks):

- Seedling emergence (%): recorded daily as the proportion of seeds showing radicle emergence (≥2 mm) or shoot emergence above the substrate, until no new seedlings appeared for three consecutive days
- Height (cm): measured from the base of the stem to the apex with a millimeter ruler
- Number of leaves: count of true (compound) leaves
- Root length (cm): direct measurement after careful removal of the substrate. Materials, equipment, and accessories

The materials included *Caesalpinia spinosa* seeds, drinking water, disinfected sand, and pre-germination substances, depending on the treatment. The equipment used included germination trays, digital scales, rulers or calipers, timers, water baths, and mechanical scarification tools (nail clippers or small grinders). Accessories included soaking containers, watering cans or sprinklers, labels, gloves, masks, protective goggles, and notebooks or digital recording devices.

Statistical Analysis

The data were processed using R software. Prior to the analysis of variance (ANOVA), the data from the 5 subsamples per plot were averaged to obtain a single representative value per experimental unit (n = 3 per treatment, total N = 18). Once the statistical assumptions of normality and homoscedasticity were met, a conventional ANOVA was applied for a completely randomized block design. Duncan's multiple range test (α = 0.05) was used to determine significant differences between treatment means.

Results

Percentage (%) of Germination

Analysis of variance (ANOVA) showed that the treatments evaluated had a significant impact on the germination percentage ($F = 22.83$; $p<0.001$), confirming that the differences observed respond to the actual effect of the treatments and not to chance (Table 2). The low experimental error supports the accuracy of the measurements and the reliability of the results.

Table 2: Analysis of variance (ANOVA) in a completely randomized block design for the percentage of tara germination in Magdalena, Chachapoyas, Amazonas, Peru

Source	gl	Sum of Squares (SS)	Mean Square (MS)	F-value	p-value
Blocks	2	0.33	0.16	0.71	> 0.05 (ns)
Treatments	5	2605.59	521.12	22.83	< 0.001 ***
Error	10	228.20	22.82		
Total	17	2834.12			

Duncan's test (α = 0.05) identified three statistically distinct groups (Table 3; Fig. 1). Treatments T1, T2, and T3 achieved the highest germination rates (88.30-92.50%) with no significant differences between them, demonstrating a homogeneous and superior response compared to the other treatments. T4 and T5 formed a second group with values close to 20%, while T6 recorded the lowest germination (5.15%), remaining as an independent group, confirming the marked influence of the type of treatment applied on the germination response.

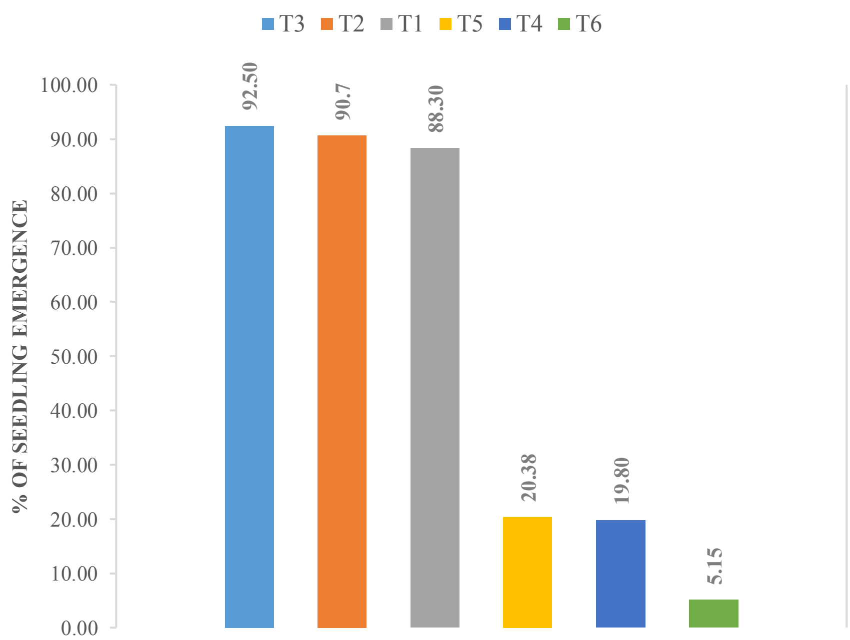

Fig. 1: Percentage of emergence of *Caesalpinia spinosa* seedlings under different pre-germination treatments. Error bars represent standard deviation (n = 3). Different letters indicate significant differences according to Duncan's test (α = 0.05)

Table 3: Comparison of mean germination percentages according to Duncan's test (α = 0.05)

Treatment	Mean (% germination)	Group (Duncan)
T3	92.50	A
T2	90.70	A
T1	88.30	A
T5	20.38	B
T4	19.80	B
T6	5.15	C

Note: Means with the same letter do not differ statistically from each other

The high performance of T1-T3 is attributed to the combination of controlled mechanical scarification and soaking in 10% sucrose, factors that favored more efficient imbibition and early metabolic activation of the embryo. In particular, the longer soaking time applied in T3 enhanced physiological recovery and mobilization of reserves, which would explain its relatively better performance. In contrast, T4 showed a lower response, possibly due to damage or irregularities in mechanical scarification, while T5, based solely on thermal shock, promoted partial activation that was not sufficient to overcome physical dormancy. The control (T6), without physical or osmotic stimulation, maintained the impermeability of the seed coat, drastically limiting germination. Overall, the results show that, in tara seeds, controlled tegument rupture, accompanied by an osmotic stimulus such as sucrose, is decisive in activating the physiological processes that drive germination, improving emergence uniformity, and optimizing seedling production in nurseries.

Plant Height

The analysis of variance showed significant differences in plant height between the treatments applied ($F = 17.68$; $p<0.001$), indicating a consistent effect of the interventions evaluated (Table 4). Block variation was not significant in this analysis ($F = 2.09$; $p>0.05$), but the overall model still supported the use of a randomized block design.

Table 4: Analysis of variance (ANOVA) for plant height (cm) of tara

Source	gl	Sum of Squares (SS)	Mean Square (MS)	F-value	p-value
Blocks	2	0.21	0.103	2.09	> 0.05 (ns)
Treatments	5	43.47	8.694	17.68	< 0.001 ***
Error	10	4.92	0.492		
Total	17	48.60			

Duncan's test (α = 0.05) showed marked differences between the treatments for plant height, organizing them into four well-defined groups (Table 5; Fig. 2). The first response level included treatments T3 (8.20 cm) and T2 (7.95 cm), both within group A. These treatments showed the best results and did not present statistical differences between them, which highlights them as the most favorable alternatives. A second set of yields corresponded to group B, consisting of T1 (5.30 cm) and T5 (5.10 cm). Although their values were lower than those of group A, they maintained a consistent advantage over the other treatments. Treatment T4 (4.70 cm) was grouped individually in group C, showing intermediate performance. Finally, T6 (4.30 cm) was placed in group D, recording the lowest height and differing significantly from the other treatments. Thus, the results establish a clear hierarchy among the treatments, with T3 and T2 consolidating their position as the most effective options for promoting height growth.

Treatments T2 and T3 promoted greater height in tara plants because scarification and soaking in sucrose efficiently activated the embryo and mobilized reserves, favoring cell elongation. T1 and T4 showed intermediate heights, while T5 and the control T6 recorded the lowest heights, associated with limited physiological activation due to partial scarification or absence of treatment. These results indicate that plant height is directly related to the efficiency of the initial physiological processes of the seed.

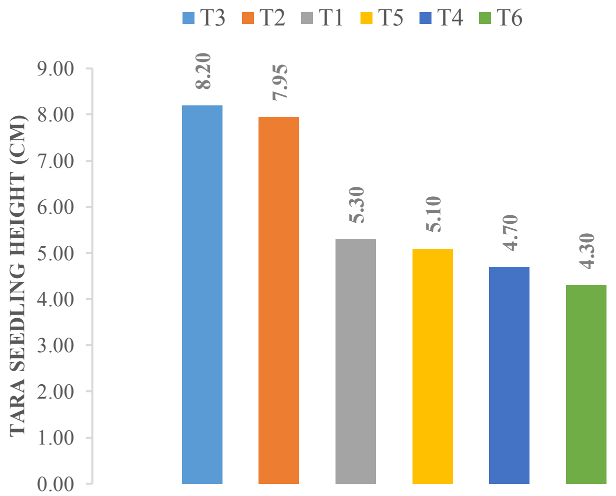

Fig. 2: Mean height (cm) of *Caesalpinia spinosa* seedlings at eight weeks after sowing. Error bars represent standard deviation (n = 3). Different letters indicate significant differences according to Duncan's test (α = 0.05)

Table 5: Comparison of mean plant heights (cm) according to Duncan's test (α = 0.05)

Treatment	Mean (cm)	Group (Duncan)
T3	8.20	A
T2	7.95	A
T1	5.30	B
T5	5.10	B
T4	4.70	B
T6	4.30	

Note: Means with the same letter do not differ statistically from each other.

Number of Leaves

Efficient germination is a critical factor for early and vigorous seedling establishment. The different pre-germination treatments significantly affected the number of leaves per seedling ($F = 9.05$; $p < 0.01$), with those combining mechanical scarification and soaking in a sugar solution promoting higher leaf development (Table 6). Variation between blocks was not significant, and experimental error contributed minimally. These findings highlight that the pre-germination practices applied not only increase the number of leaves but also enhance the initial vigor of the seedlings, offering an effective strategy for improving early production.

Table 6: Analysis of variance (ANOVA) in a completely randomized block design for the number of tare leaves in Magdalena, Chachapoyas, Amazonas, Peru

Source	gl	Sum of Squares (SS)	Mean Square (MS)	F-value	p-value
Blocks	2	0.048	0.024	1.34	> 0.05 (ns)
Treatments	5	8.112	1.622	9.05	< 0.01 **
Error	10	1.792	0.179		
Total	17	9.952			

The combination of mechanical scarification and soaking in sugar solution significantly increased the number of tara seedling leaves, with T3 and T2 standing out as the most effective treatments according to Duncan's test (Table 7; Fig. 3). These results show that specific pre-germination practices enhance initial vigor and promote more efficient early establishment, offering clear strategies for improving leaf production and the potential yield of this strategic crop in high Andean regions.

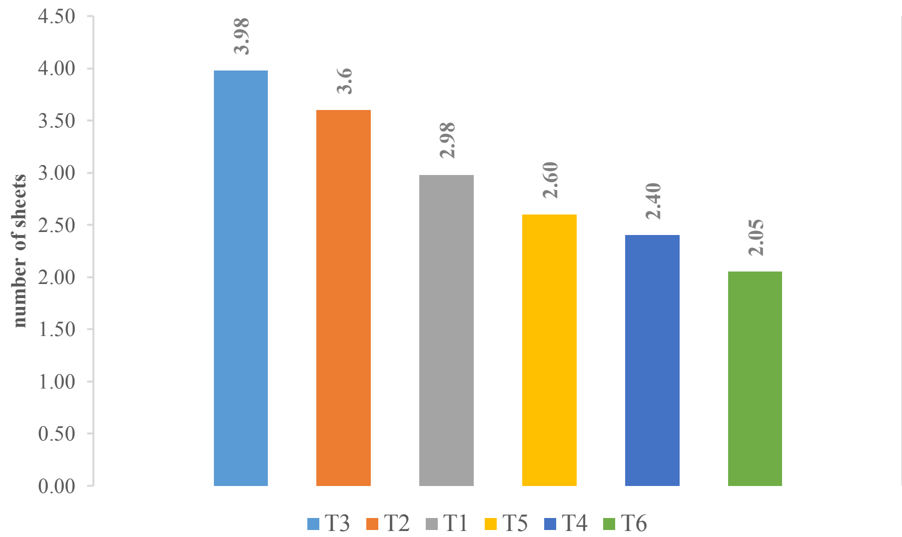

Fig. 3: Number of true leaves per seedling of *Caesalpinia spinosa* under different pre-germination treatments. Error bars represent standard deviation (n = 3). Different letters indicate significant differences according to Duncan's test (α = 0.05)

Table 7: Comparison of mean number of leaves according to Duncan's test (α = 0.05)

Treatments	Mean (number of leaves)	Group (Duncan)
T3	3.98	A
T2	3.60	A
T1	2.98	B
T5	2.60	B
T4	2.40	C
T6	2.05	C

Note: Means with the same letter do not differ statistically from each other

Root Length

The analysis of variance showed that the treatments had a significant effect on root length ($F = 3.22$; $p<0.05$), while blocks did not contribute significantly (Table 8). The low experimental variability reflects the accuracy of the measurements and allows us to conclude that the differences observed are mainly due to the treatments applied.

Table 8: Analysis of variance (ANOVA) for root length (cm) of tara

Source	gl	Sum of Squares (SS)	Mean Square (MS)	F-value	p-value
Blocks	2	0.298	0.149	1.17	> 0.05 (ns)
Treatments	5	20.520	4.104	3.22	< 0.05 *
Error	10	12.750	1.275		
Total	17	33.568			

Treatments T3 and T2, which promoted the longest roots (group A, Table 9; Fig. 4), likely favored key physiological processes such as root meristem activation, efficient nutrient absorption, and stimulation of growth hormones such as auxins and cytokinins. These effects could be related to scarification techniques, soaking, or the application of specific nutrient solutions, which facilitate vigorous germination and root elongation. T1 showed an intermediate effect, while T5 and T4 induced moderate growth, possibly due to limitations in the availability of factors that stimulate cell division and root elongation. Finally, T6, the least effective, reflects the absence of treatments that activate these physiological mechanisms, limiting root development capacity.

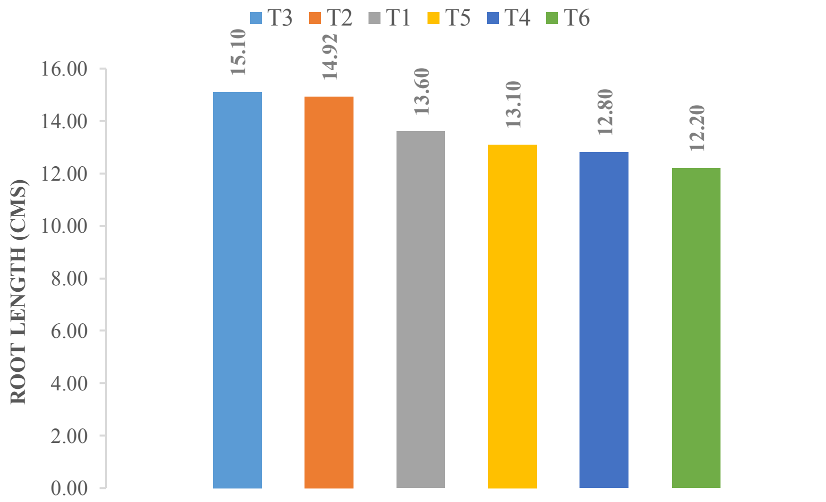

Fig. 4: Root length (cm) of *Caesalpinia spinosa* seedlings at eight weeks after sowing. Error bars represent standard deviation (n = 3). Different letters indicate significant differences according to Duncan's test (α = 0.05)

Table 9: Comparison of mean root length (cm) according to Duncan's test (α = 0.05)

Treatments	Mean (cm)	Group (Duncan)
T3	15.10	A
T2	14.92	A
T1	13.60	B
T5	13.10	B
T4	12.80	B
T6	12.20	B

Note: Means with the same letter do not differ statistically from each other

Discussion

The results obtained show that pre-germination treatments combining mechanical scarification with soaking in a 10% sucrose solution for 4 to 6 days (T2 and T3) were the most effective in stimulating germination and initial growth of *Caesalpinia spinosa*. This response occurs because scarification breaks the hardness of the testa, allowing water to enter, while soaking in sucrose acts as an osmotic conditioner that gradually activates the embryo's metabolic processes [14, 15].

Through this interaction, the seeds achieve an internal balance that favors faster, more uniform, and more vigorous germination. The high germination rate (88-92%) achieved by these treatments can be explained by the fact that sucrose allows slow, controlled hydration, preventing damage from excess water and promoting the orderly activation of enzymes that mobilize endosperm reserves. At the same time, the resulting osmotic environment stimulates antioxidant mechanisms that protect the embryo, resulting in stronger seedlings with improved initial development [15].

Seedlings from T2 and T3 showed greater height, more leaves, and longer roots - indicators of more vigorous growth. This behavior is associated with early metabolic activation, which increases the availability of energy and sugars necessary for cell division and elongation. Soaking in sucrose acts as a "physiological alarm clock," preparing the seed for a more efficient transition to the autonomous growth phase, a phenomenon also observed in other plant species [16]. Similarly, the longer and more branched roots recorded in these treatments result from the combination of eliminating physical barriers in the testa and the hormonal effect induced by sucrose on root elongation pathways [15].

This improvement in the root system not only facilitates water and nutrient absorption but also strengthens the seedlings' ability to adapt and survive after transplanting. These findings are consistent with reports by [17, 18], showing that physiological and nutritional management practices directly impact metabolic efficiency and crop productivity. In Valencia oranges, balanced fertilization improved fruit physiology and quality [17], while agroecological conditions and agronomic management determined plant physiological responses [17, 18]. Likewise, the application of Gibberellic Acid (GA_3) to potatoes accelerated RNA and protein synthesis, stimulating sprouting [19] - a process analogous to that occurring in tara seeds during osmotic soaking.

In summary, these results confirm that the combination of mechanical scarification and soaking in 10% sucrose is a simple, economical, and environmentally friendly technique for overcoming dormancy in Caesalpinia spinosa seeds. This procedure not only improves germination and initial vigor but also contributes to obtaining healthier, more uniform, and more adaptable seedlings, ideal for nursery and reforestation programs under variable conditions.

Conclusion

Treatments T2 and T3 (mechanical scarification with nail clippers followed by soaking in 10% sucrose solution for 4 to 6 days) showed the highest emergence percentages in Caesalpinia spinosa seedlings, with values of 92.50% and 90.70%, respectively. These methods effectively eliminated physical dormancy, facilitating embryo emergence and confirming their practical usefulness for propagating this species.

In addition, morphological variables (seedling height, number of leaves, and root length) were significantly influenced by these treatments, showing that seeds with intact internal structures have a better germination response and initial development. In contrast, physical scarification with boiled water (T5) was less effective, likely due to thermal damage to the seeds and insufficient soaking time. To optimize this method, we recommend reducing exposure to boiling water to less than one minute and extending the soaking period beyond one week, which could improve efficacy without compromising seed viability.

Overall, controlled mechanical scarification combined with osmotic priming using a 10% sucrose solution offers a simple, low-cost, and practical technique for enhancing tara seed germination and seedling establishment. This approach provides valuable support for nursery production, reforestation programs, and sustainable land management initiatives in the Peruvian Andes.

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Author Contributions

Wilfredo Ruiz Camacho, Ítalo Maldonado Ramirez and Juan Eduardo Suarez Rivadeneira: Designed the research plan and organized the study, participated in all experiments, coordinated data analysis, and contributed to the writing of the manuscript.

Juan Alberto Rojas Castillo: Coordinated the research work and data analysis, participated in all experiments, and contributed to the writing of the manuscript.

Edilbrando Vega Calderón and Mayra Pamela Musayón Diaz: Coordinated the research work, participated in all experiments, and contributed to the writing of the manuscript.

Ethics

All references related to the enrichment of this scientific knowledge have been included in the bibliography of the journal.

References

1. Agro Rural. (n.d.). *CULTIVO DE TARA (Caesalpinia spinosa)*. Manual de Abonamiento con Guano de las Islas. Retrieved July 30, 2025, from https://repositorio.midagri.gob.pe/bitstream/20.500.13036/320/1/ficha%20tecnica%20tara.pdf
2. Bravo-Jaico, J., Serquén, O., Alarcón, R., Suarez-Rivadeneira, J. E., Ruiz-Camacho, W., & Manayay, F. A. (2026). Artificial intelligence for biodiversity and tourism governance: predictive insights from multilayer perceptron models in Amazonia. *Frontiers in Artificial Intelligence*, *9*, 1–13. https://doi.org/10.3389/frai.2026.1702544
3. Camacho, W. R., Villegas-Rivas, D., Sánchez, J. M. P., Ordoñez, F. R. R., Carranza, J. C. P., Sanchez, G. N., Santamaría, R. Y. L., Guerrero, A. W. P., Aldana, M. F. O., Cueva, L. R., Valdivia, J. C., Rodriguez, E. B. B., Rios-Campos, C., Ramirez, I. M., Rodriguez-Barboza, J. R., Rojas, J. V., Aparcana, N. M. H., Guerrero, M. I. M., Osorio-Carrera, C., … Terry-Ponte, O. (2024). Evaluation of the Optimal Dose of Gibberellic Acid (Full Gib) in the Induction of Sprouting of Yungay Potato Variety Tuber (Solanum tuberosum L.). *OnLine Journal of Biological Sciences*, *24*(4), 758–764. https://doi.org/10.3844/ojbsci.2024.758.764
4. Dos Santos, V. A., Graziele Silva, L., Coelho de Moura, C., & Mendonca Machado, E. L. (2018). MÉTODOS PARA QUEBRA DE DORMÊNCIA EM SEMENTES DE Tara Spinosa. *TreeDimensional*, *3*(6), 24–34. https://doi.org/10.18677/treedimensional_2016b3
5. Enciso Altamirano, M., Nuñez Delgado, J., Sotelo Méndez, A., Ruiz Camacho, W., Maldonado Ramirez, Í., & Suarez Rivadeneira, J. E. (2025). Yield and Nutritional Value of Oats Associated With Vicia in High Andean Conditions of Puno, Peru. *OnLine Journal of Biological Sciences*, *25*(3), 627–632. https://doi.org/10.3844/ojbsci.2025.627.632
6. Enciso Altamirano, M., Nuñez Delgado, J., Sotelo-Méndez, A., Ruiz-Camacho, W., Maldonado Ramirez, Í., & Suarez Rivadeneira, J. E. (2025). Oat Pellets and Hay in Alpacas of Pastures of the Andean Zone, Perú. *American Journal of Animal and Veterinary Sciences*, *19*(4), 444–449. https://doi.org/10.3844/ajavsp.2024.444.449
7. Epquin Rojas, M. L. (2018). *Evaluación de carbono total en bosque de Tara (Caesalpinia spinosa Molina Kuntze): Centro Poblado Señor de los Milagros, distrito Magdalena, provincia Chachapoyas – Amazonas, 2017* [Universidad Nacional Toribio Rodriguez de Mendoza Amazonas]. https://repositorio.untrm.edu.pe/bitstream/handle/20.500.14077/1362/Epquin%20Rojas%20Melissa%20Lucerito.pdf?sequence=1
8. Jeya Rathi, J., Sasirekha, R., & Ranjith Kumar, R. (2021). Effect of physical and chemical treatments on breaking the seed dormancy of Caesalpinia bonduc (L.) Roxb. *Plant Science Today*, *8*(3), 572–577. https://doi.org/10.14719/PST.2021.8.3.1049
9. J.Mantilla, Á. (2008). Desarrollo y germinación de las semillas. In J. Azcón-Bieto & M. Talón (Eds.), *Fundamentos de Fisiología Vegetal* (2da ed., pp. 1–23). https://www.researchgate.net/publication/271512205_Desarrollo_y_germinacion_de_las_semillas
10. Lei, C., Bagavathiannan, M., Wang, H., Sharpe, S. M., Meng, W., & Yu, J. (2021). Osmopriming with polyethylene glycol (Peg) for abiotic stress tolerance in germinating crop seeds: A review. *Agronomy*, *11*(11), 1–12. https://doi.org/10.3390/agronomy11112194
11. Lindo-Angulo, T., La Torre-Acuy, M. I., & Luján-Roca, D. Á. (2017). GERMINATION OF CAESALPINIA SPINOSA (TARA) AS AFFECTED BY TEMPERATURE AND GIBBERELLIC ACID. *The Biologist (Lima)*, *15*(1), 59–64. https://www.researchgate.net/publication/318489230_EFECTO_DE_LA_TEMPERATURA_Y_EL_ACIDO_GIBERELICO_EN_LA_GERMINACION_DE_SEMILLAS_DE_CAESALPINIA_SPINOSA_TARA
12. Ma, L., Wei, J., Han, G., Sun, X., & Yang, X. (2024). Seed osmopriming with polyethylene glycol (PEG) enhances seed germination and seedling physiological traits of Coronilla varia L. under water stress. *PLoS ONE*, *19*(5 May), 1–21. https://doi.org/10.1371/journal.pone.0303145
13. Manayay, F. A., Suarez-Rivadeneira, J. E., Chavez-Pasco, G. S., Perez-Medina, L. F., & Lecca-González, M. (2026). Sustainability indicators for municipal solid waste management in an Amazonian riverine city: A baseline assessment and circular economy policy gaps in Bagua, Peru. *Environmental Challenges*, *24*, 1–12. https://doi.org/10.1016/j.envc.2026.101528
14. Mancero, L. (2008). *LA TARA (Caesalpinia spinosa) En Perú, Bolivia y Ecuador: Analisis de la Cadena Productiva en la Región*. Programa Regional ECOBONA - INTERCOOPERATION, Quito. Quito, febrero 2009. https://sinia.minam.gob.pe/sites/default/files/siar-apurimac/archivos/public/docs/376.pdf
15. Ministerio del Ambiente. (2021, February 8). *Lineamientos para la valoración Económica de la Diversidad Forestal y Fauna Silvestre*. Resolución Ministerial N° 023-2021-MINAM. www.gob.pe/minam
16. Murga-Orrillo, H., Lobo, F. D. A., Silva Amorim, R. S., Silva Dionisio, L. F., Nuñez Bustamante, E., Chu-Koo, F. W., Arévalo López, L. A., Arévalo-Hernández, C. O., & Abanto-Rodriguez, C. (2023). Increased Production of Tara (Caesalpinia spinosa) by Edaphoclimatic Variation in the Altitudinal Gradient of the Peruvian Andes. *Agronomy*, *13*(3), 1–17. https://doi.org/10.3390/agronomy13030646
17. Neri Chávez, J. C., Collazos Silva, R., Oliva, M., Huamán Huaman, E., & Vásquez García, J. (2018). Aplicación de la escarificación física y mecánica en la emergencia y crecimiento de semillas de tara (Caesalpinia espinosa). *Revista de Investigación de Agroproducción Sustentable*, *2*(2), 45–53. https://doi.org/10.25127/aps.20182.392
18. Okello, D., Komakech, R., Gang, R., Rahmat, E., Chung, Y., Omujal, F., & Kang, Y. (2022). Influence of various temperatures, seed priming treatments and durations on germination and growth of the medicinal plant Aspilia africana. *Scientific Reports*, *12*(1), 1–11. https://doi.org/10.1038/s41598-022-18236-2
19. Pomachari Bonilla, A. (2023). *Efecto de la fertilización foliar en el crecimiento y desarrollo de plantas de tara(Caesalpinia spinosa Mol. O. Kuntz.) bajo condiciones de vivero en la parte media del Valle Chancay - Lambayeque.* [Universidad Nacional Pedro Ruiz Gallo]. https://repositorio.unprg.edu.pe/handle/20.500.12893/13498

20. Reyes-Ramírez, S., Chalco-Sandoval, W., Valarezo-Aguilar, K., & Ordóñez Gutiérrez, O. (2023). Tratamientos pre-germinativo de semillas de Caesalpinia spinosa (Mol) O. Kuntze con distintos sustratos en el vivero de la Universidad Nacional de Loja. *Bosques Latitud Cero*, *13*(2), 43–55. https://doi.org/10.54753/blc.v13i2.1868
21. Ruiz Camacho, W., Julca Otidiano, A., & Colmenares Mayanga, W. (2022). Efecto de la fertilización sobre la naranja variedad Valencia en tres zonas agroecológicas en la Provincia de Chanchamayo, Junín, Perú. *IDESIA*, *4*(40). https://idesia.uta.cl/?v=vm&manid=1363
22. Ruiz-Camacho, W., Villegas-Rivas, D., Borjas-Ventura, R., Alvarado-Huamán, L., Bello-Amez, S., Arias-Heredia, G., Sernaque-Auccahuasi, F., Palacios-Sánchez, J. M., Alzamora-Rivero, C. A., Franco-Del Carpio, C. M., Castro-Cepero, V., Julca-Otiniano, A., Paredes-Guerrero, Á., Colmenares-Mayanga, W., Damián-Sandoval, J., Damián-Sandoval, L., Rodriguez-Ordoñez, F. R., Roman-Castillo, E., Rubio-Cueva, L., … Cruz-Salinas, L. E. (2023). The Behavior of Valencia Orange Cultivation (Citrus x sinensis (L) Osbeck cv. Valencia) in “Type Farms” in a Province in Central Jungle of Peru. *OnLine Journal of Biological Sciences*, *23*(3), 307–312. https://doi.org/10.3844/ojbsci.2023.307.312
23. Silvertown, J. (1999). Seed ecology, dormancy, and germination: a modern synthesis from Baskin and Baskin. *American Journal of Botany*, *86*(6), 903–905. https://doi.org/10.2307/2656711
24. Suarez Rivadeneira, J. E., Manayay, F. A., Campos Mego, J. D., Ruiz Camacho, W., Maldonado Ramirez, I., & Perez Londoño, G. A. (2026). Hydrological asymmetry and water stress in Peru: An integrated assessment of resource distribution, anthropogenic pressure, and governance gaps across three drainage basins. *F1000Research*, *15*, 456. https://doi.org/10.12688/f1000research.176208.1
25. Villena, J. J., & Seminario, J. F. (2021). Origin and domestication of Tara spinosa (Leguminosae, Caesalpinioideae). *Lilloa*, *58*(2), 131–159. https://doi.org/10.30550/j.lil/2021.58.2/2021.11.14