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Effect of ultrasound on emergence and development of *Schizolobium Amazonicum* herb

Efeito do ultrassom na emergência e desenvolvimento de *Schizolobium Amazonicum* herb

Efecto de la ultrasonido en la germinación y el desarrollo de la hierba *Schizolobium Amazonicum*

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ABSTRACT
The paricá (*Schizolobium amazonicum* Herb) is a species with great potential for economic use and reforestation. However, its seeds exhibit a dormancy period. This study aimed to analyze the effect of ultrasound treatment on paricá seeds. A total of fifty seeds per group were used, with four replications for each treatment, including the Control Group, totaling two hundred seeds per group. The experimental design included one Control Group (CG) and three test groups subjected to an ultrasound frequency of 3 MHz, an intensity of 2.0 W/cm², and exposure times of 4, 5, and 6 minutes. After ultrasound application, the seeds from each group were transferred to a greenhouse and irrigated daily. A Completely Randomized Design (CRD) was employed. Following sowing, the percentage of Emergence (E), Mean Emergence Time (MET), and Emergence Speed Index (ESI) were evaluated. The 6-minute group showed superior performance in terms of E, ESI, and both fresh and dry shoot mass. However, according to the M-value, the optimal treatment was 5 minutes, which promoted nearly three times greater improvement compared to the Control Group when considering all analyzed variables. Regarding the fresh and dry mass of shoots and roots, ultrasound application did not show a beneficial effect.

Keywords: Emergence, Reforestation, Dormancy, Parica.

RESUMO
O paricá (*Schizolobium amazonicum* Herb) é uma espécie com grande potencial para a economia e o reflorestamento. Entretanto, as sementes dessa espécie apresentam um período de dormência. Esta pesquisa teve como objetivo analisar o efeito do ultrassom em sementes de paricá. Foram utilizadas 50 sementes por grupo, no total foram realizadas 4 repetições para cada tratamento, incluindo o grupo controle, totalizando 200 sementes

por grupo. Na Experimentação foram utilizados um grupo controle (GC) e três grupos teste com aplicação de frequência a 3 MHz e intensidade de 2,0 W/cm² e com tempo de aplicação de 4, 5 e 6 minutos. Após a aplicação do ultrassom, as sementes de cada grupo foram transportadas para casa de vegetação, sendo irrigadas todos os dias. Utilizou-se o modelo de Delineamento Inteiramente Randomizado – DIC. Após o plantio, foram observados a porcentagem de emergência (E), o tempo médio de emergência (TME) e o índice de velocidade de emergência (IVE). O grupo 6-min destacou-se dos demais em relação a E, IVE e às massas fresca e seca da parte aérea. Porém, de acordo com o M-value, a melhor dose foi 5 min que favoreceu quase 3 vezes mais em relação ao grupo controle, quando se considera todas as variáveis analisadas. Em relação à massa fresca e seca da parte aérea e da raiz, a aplicação de ultrassom não favoreceu.

Palavras-chave: Emergência, Reflorestamento, Dormência, Paricá.

RESUMEN

El paricá (*Schizolobium amazonicum* Herb) es una especie con gran potencial para la economía y la reforestación. Sin embargo, las semillas de esta especie presentan un período de dormancia. Esta investigación tuvo como objetivo analizar el efecto del ultrasonido en semillas de paricá. Se utilizaron 50 semillas por grupo, con un total de 4 repeticiones para cada tratamiento, incluyendo el Grupo Control, totalizando 200 semillas por grupo. En la experimentación se empleó un Grupo Control (GC) y tres grupos de prueba con aplicación de frecuencia de 3 MHz, intensidad de 2,0 W/cm² y tiempos de exposición de 4, 5 y 6 minutos. Después de la aplicación del ultrasonido, las semillas de cada grupo fueron trasladadas al invernadero, siendo irrigadas diariamente. Se utilizó el modelo de Diseño Completamente Aleatorizado (DCA). Después de la siembra, se evaluaron el porcentaje de Emergencia (E), el Tiempo Medio de Emergencia (TME) y el Índice de Velocidad de Emergencia (IVE). El grupo de 6 minutos se destacó de los demás en relación con E, IVE y las masas fresca y seca de la parte aérea. No obstante, de acuerdo con el valor M, la mejor dosis fue de 5 minutos, la cual favoreció casi tres veces más en comparación con el grupo control, considerando todas las variables analizadas. En cuanto a la masa fresca y seca de la parte aérea y de la raíz, la aplicación de ultrasonido no presentó efecto favorable.

Palabras clave: Emergencia, Reforestación, Latencia, Paricá.

1 INTRODUCTION

Reforestation represents a fundamental strategy for the restoration of degraded ecosystems. To ensure the effectiveness of this process, advances in biotechnology are essential, particularly regarding the development and propagation of high-quality seeds and seedlings of forest species. The search for efficient and sustainable alternatives has intensified in response to the growing demand for seedlings suitable for forest restoration, reforestation, and urban afforestation programs (De Oliveira et al., 2024).

Nevertheless, many forest species exhibit natural seed dormancy, as observed in *Schizolobium amazonicum*, whose dormancy is primarily physical and caused by the impermeability of the seed coat. This characteristic limit germination and seedling uniformity, often resulting in germination rates below 30% when no specific pre-germination treatments are employed (De Aquino et al., 2025; Rosa, 2006). Several methods have been proposed to overcome this constraint, including the use of chemical scarification, hormonal treatments, and hydration-promoting techniques (Labbaf; Rohollahi; Naji, 2023; Weerasekara et al., 2021). Although these approaches may be effective, many are labor-intensive, costly, and may lead to undesirable environmental impacts.

In this context, ultrasonic treatment has emerged as a promising and eco-friendly alternative. The technique involves the application of high-frequency sound waves in a liquid medium, inducing cavitation and the formation of microfissures in the seed coat, which facilitates water absorption and promotes dormancy release (Torsian, 2020). In addition to accelerating germination, ultrasound enhances oxygen uptake, induces beneficial physiological modifications in seeds, and eliminates the need for chemical agents. It is therefore regarded as a green technology (López-Ribera; Vicient, 2017; Nogueira et al., 2024). Previous studies involving different crop and forest species, such as soybean and pea, have demonstrated that ultrasonic treatment can significantly increase germination rates and seedling vigor (Alfalahi et al., 2022; Chiu; Sung, 2014; Melo et al., 2024).

Schizolobium amazonicum—a fast-growing leguminous tree—is extensively used in the timber industry, particularly in furniture manufacturing, owing to the lightness and workability of its wood. In recent years, the cultivation of this species has expanded substantially; however, its production systems still lack technological innovations and more efficient silvicultural practices (De Oliveira et al., 2024; Rabelo et al., 2023; Sales et al., 2024).

Given the challenges associated with the physical dormancy of *S. amazonicum* seeds and the limitations of conventional dormancy-breaking techniques, this study aimed to assess the effectiveness of ultrasonic treatment in overcoming seed dormancy and improving the germinative performance of the species. The goal was to contribute to the advancement of sustainable methodologies applicable to reforestation programs and commercial seedling production.

2 METHODOLOGY

The experiment was conducted using *Schizolobium amazonicum* Herb. seeds at the Biophysics Laboratory of the Federal University of Acre (UFAC), located in the municipality of Rio Branco, state of Acre, Brazil. The experimental period extended from February to July 2024.

Initially, the seeds were washed with running water to remove surface impurities. Subsequently, a stereoscopic magnifier was employed for visual inspection to identify and discard seeds exhibiting visible physical damage. After this screening process, the selected seeds were placed on paper towels and allowed to dry at room temperature (approximately 25 °C) for 24 hours.

2.1 VIABILITY TEST

To assess seed viability, an analysis was performed using the exudate pH test, using 100 seeds. The seeds were placed in 50 mL containers and immersed in distilled water containing an electrochemical electrode (neutral pH) in a solution composed of one drop of phenolphthalein and one drop of sodium carbonate. The exudate pH test is a low-cost method that allows for rapid results in assessing seed viability (Pelissari; Coimbra, 2023; Ramos et al., 2012). Seeds that presented a pink coloration were considered viable for planting.

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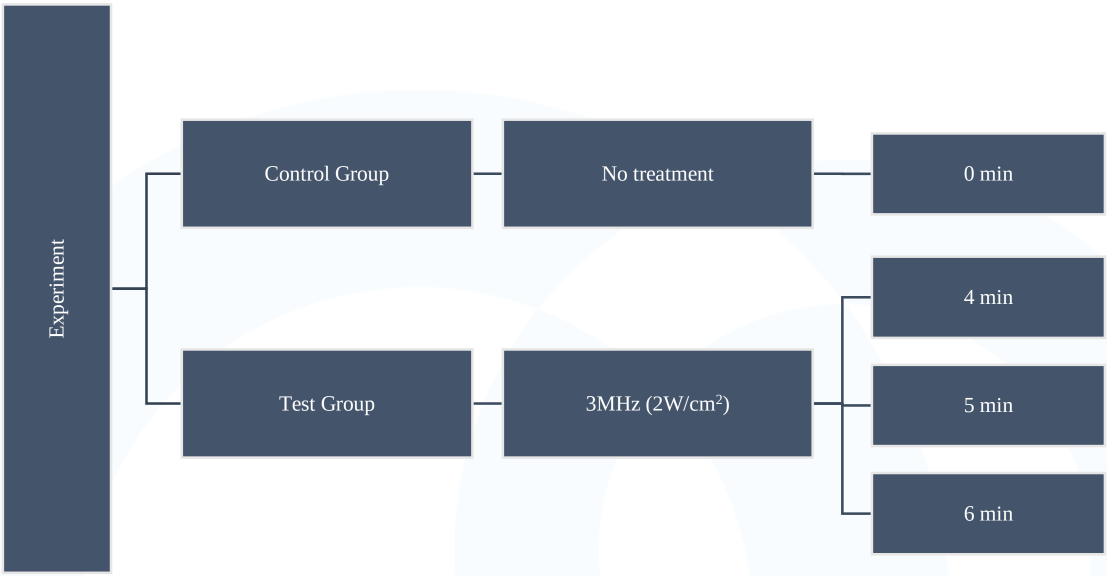
2.2 ULTRASOUND APPLICATONS

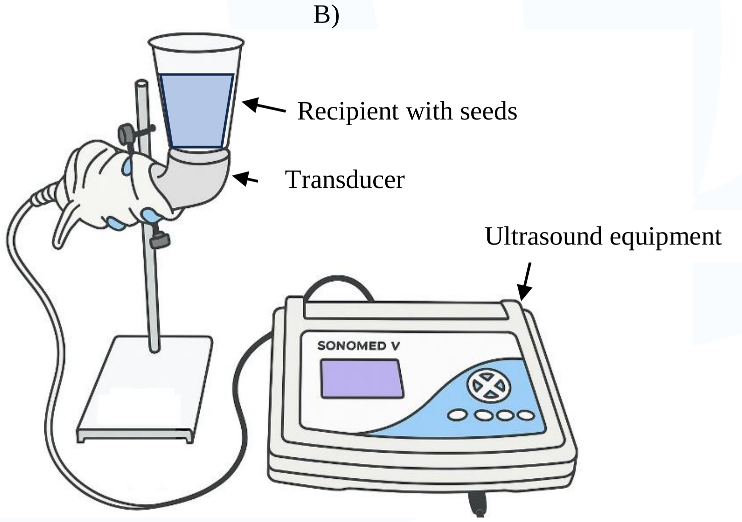
During the ultrasound treatment, three experimental groups were established, each exposed to a frequency of 3 MHz and an intensity of 2.0 W/cm². The exposure durations were 4, 5, and 6 minutes, respectively. For each treatment, including the control group, 50 seeds were used per replicate, totaling four replicates and 200 seeds per group. Throughout the ultrasound application, the seeds were immersed in 15 mL of distilled water contained in a 200 mL plastic beaker, with exposure times corresponding to their respective treatment groups. The beaker was positioned directly over the surface of the ultrasonic transducer, which was connected to the ultrasound device (Sonomed V, Carci®) and coupled with conductive gel (Figure 1). A control group (CG), not subjected to ultrasound, was included for comparative analysis.

Figure 1. A) Diagram showing the application of ultrasound at a frequency of 3 MHz (intensity of 2.0 W/cm²) at different times. B) Design of the experiment.

A)



B)



Source: Prepared by the authors themselves.

2.3 EMERGENCE MEASUREMENT

After ultrasound treatment, the seeds from each group were transported to the greenhouse and sowing 1 cm of depth in substrate (sand), being irrigated daily. A Completely Randomized Design (CRD) model was used. The following parameters were evaluated: Emergence Percentage (E) (Equation 1), Emergence Velocity Index (EVI)

(Equation 2) and Mean Emergence Time (MET) (Equation 3), following the methodology proposed by Maguire and De Paiva (De Paiva et al., 2016; Maguire, 1962).

$$E\ (\%) = (N/n_i) \times 100 \qquad (1)$$

Where:

N = represents the total number of seeds sown.
ni = number of seedlings emerged at the end of the experiment

$$EVI\ (seeds/day) = \sum (n_i/t_i) \qquad (2)$$

Where:

ni = number of seedlings emerged at time *i*,
ti = time elapsed after the start of the test.

$$MET\ (days) = \sum (n_i.t_i) / \sum n_i \qquad (3)$$

where:

ni = number of seeds emerged per day,
ti = incubation time.

2.4 BIOMETRIC MEASUREMENT

Biometric analyses of the seedlings were performed after a period of 4 months. Ten plants were collected from each replicate, totaling 40 plants for each experimental group. The Fresh Weight of Shoot (FWS), Dry Weight of Shoot (DWS), Fresh Weight of the Root (FWR), and Dry Weight of the Root (DWR) of each plant were evaluated using an analytical balance.

Since the ultrasound application time influences the values of the parameters, an equation involving all normalized values was developed to find the best overall application time. To calculate the normalized values from all parameters, each mean value was divided by the mean value of the Control Group. Then, the M-value was stipulated using Equation 4. The higher the M-value, the better the performance of the treatment.

$$M_{-VALUE} = \frac{E \times EVI \times FWS \times DWS \times FWR \times DWR}{MET} \qquad (4)$$

2.5 STATISTICAL ANALYSES

For the statistical analyses, analyses of variance (ANOVA) were performed using the F-test. Treatment means were compared using Tukey's test ($p \leq 0.05$). The normality of the residuals was verified using the Shapiro-Wilk test, and the homogeneity of variances was assessed using Bartlett's test (1937), with the aid of the free software Jamovi (version 2.6.26).

3 RESULTS AND DISCUSSIONS

The viability test indicated that 84% of the seeds were viable (Ramos et al., 2012). Table 1 presents the mean values and respective standard deviations of the Emergence Percentage (E), Emergence Velocity Index (EVI), Mean Emergence Time (MET), Fresh Weight of Shoot (FWS), Dry Weight of Shoot (DWS), Fresh Weight of Root (FWR), and Dry Weight of Root (DWR) of the different seed groups. The emergence percentage (E) was higher for all groups compared to the control group; however, only the 6-minute group showed a statistically significant difference from the control group (Tukey test, p-value = 0.026). This group had the longest ultrasound exposure time and showed the highest emergence rate (37 ± 7%) compared to the other groups, including the control.

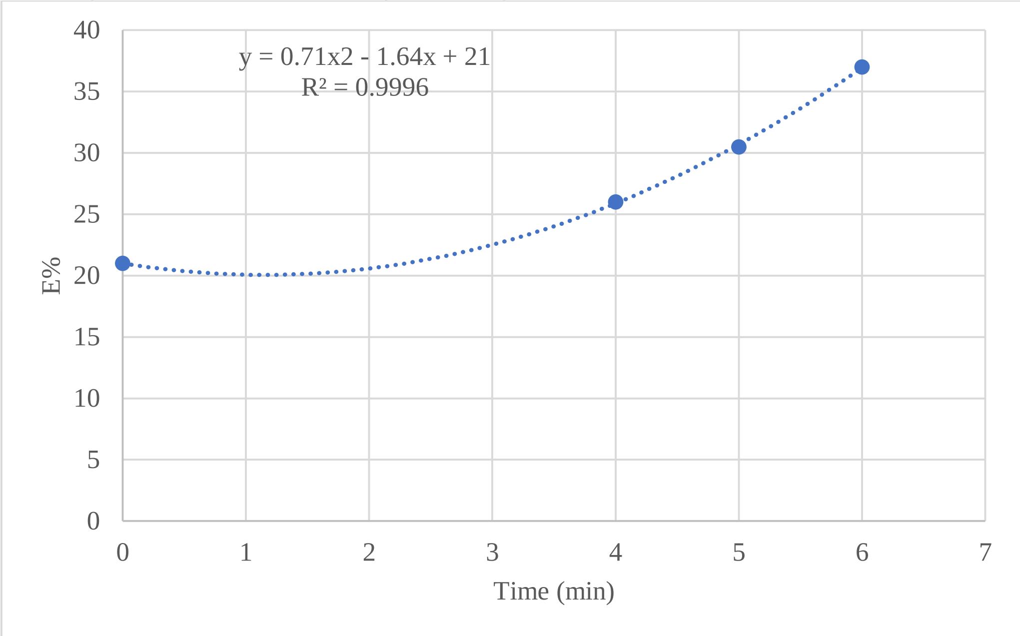
Table 1. Emergence Percentage (E), Emergence Velocity Index (EVI) and Mean Emergence Time (MET), Fresh Weight of Shoot (FWS), Dry Weight of Shoot (DWS), Fresh Weight of the Root (FWR), and Dry Weight of the Root (DWR) of the different groups of seeds.

Group		E (%)	EVI (seeds/day)	MET (days)	FWS (g)	DWS (g)	FWR (g)	DWR (g)
Control		21±3	0.36±0.17	49.6±4.0	3.86±0.26	1.46±0.08	3.43±0.71	0.70±0.15
Test	**4min**	26±9	0.47±0.20	42.8±9.8	4.50±0.84	1.76±0.33	3.11±0.81	0.59±0.08
	5min	30±9	0.50±0.13	42.4±5.8	4.55±0.42	1.83±0.20	1.99±0.19*	0.63±0.04
	6min	37±7*	0.61±0.13	47.5±1.4	5.16±1.06	2.00±0.37*	2.10±0.36*	0.57±0.04

*Significant difference compared to the control group. Tukey's post hoc test ($p < 0.05$)
Source: Authors

The Figure 2 shows the graph of variation of emergence percentage (E%) of paricá seeds as a function of the time of exposure to therapeutic ultrasound. Note that the emergence percentage was directly proportional to the exposure time. The trend curve fitted to the data follows a second-degree polynomial regression, expressed by the equation: $y = 0.71x^2 - 1.64x + 21$ with a coefficient of determination $R^2 = 0.9996$, indicating an excellent fit between the experimental data and the proposed mathematical model. The quadratic equation indicates that the rate of emergence increases rapidly after a certain point, which may be related to the intensification of the mechanical and thermal effects of ultrasound on the external structures of the seed.

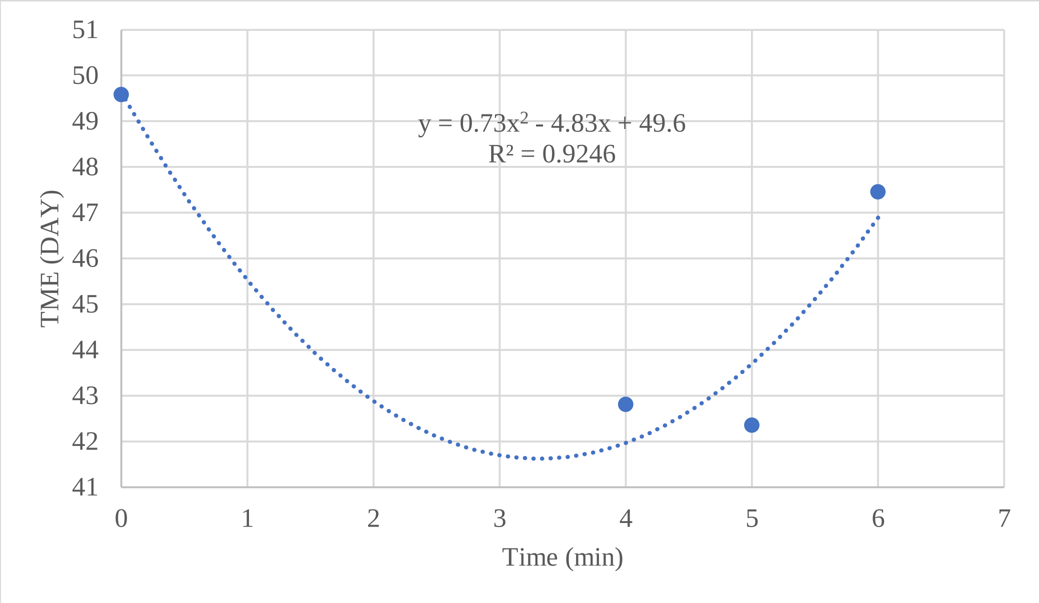
Figure 2. Graphic of Percentage of Emergence E(%) with time of application (min).



Source: The authors, 2025

Regarding the Emergency Velocity Index (EVI), there was no statistically significant difference between the treatments and the control group (ANOVA test, α = 0.05, p-value = 0.301). The group with the highest EVI value was the 6-minute group (0.613 seeds/day), while the control group showed the lowest value (0.362 seeds/day). Note that the EVI value was also directly proportional to the exposure time. In general, the Mean Emergence Time (MET) was statistically similar among all groups (ANOVA test, p-value = 0.343). The group with the highest MET was the control group, with 49.6 days for emergence, while the 5-minute group presented the lowest MET, with 42.4 days, representing a reduction of 7 days. This reflects a tendency to decrease the Mean Emergence Time with the application of ultrasound. The graph represents the variation in the MET of paricá seeds as a function of the time of exposure to therapeutic ultrasound. The data behavior fit a second-degree polynomial regression, described by the equation: $y = 0.73x^2 - 4.83x + 49.6$ with coefficient of determination $R^2 = 0.9246$. The characteristic curve of a quadratic relationship, in which there is an initial reduction in the mean emergence time to a minimum point, followed by a gradual increase at longer exposure times. This indicates that the best mean emergence time was achieved when the seeds were exposed to ultrasound for approximately 3 to 3.5 minutes, i.e., this interval corresponds to the optimal treatment time to promote faster emergence (Figure 3).

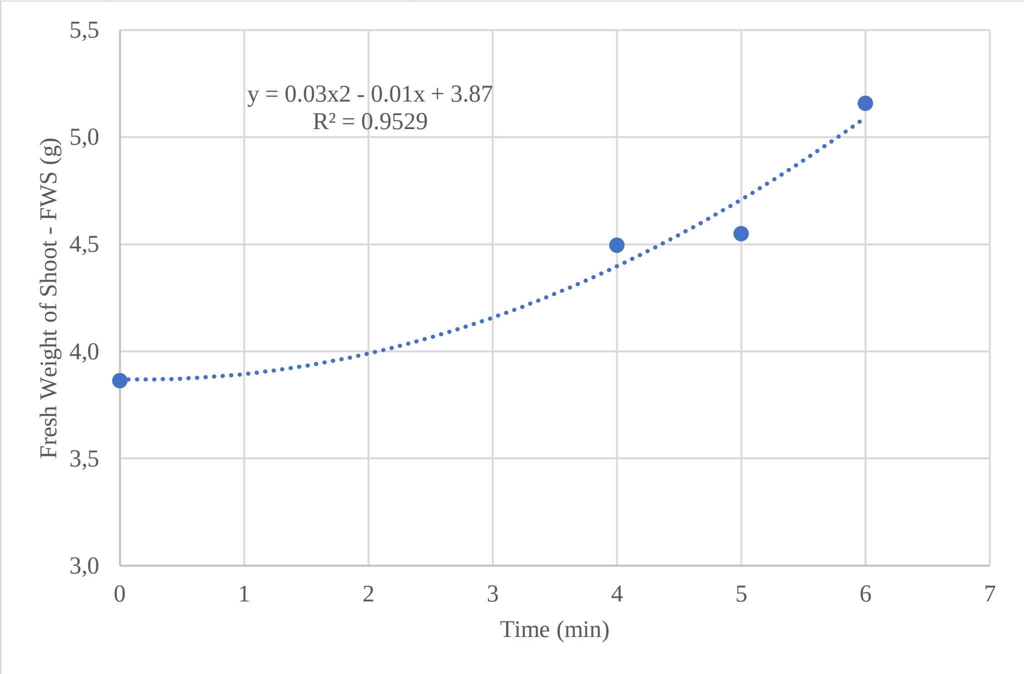
Figure 3. Graphic of Mean Emergence Time (MET) with time of ultrasound application (min).



Source: The authors, 2025

The mass values, in grams, for the Fresh Above-Ground Biomass (FMA) and Dry Above-Ground Biomass (DMA) showed the same trend of increasing value with increasing exposure time. The 6-minute ultrasound treatment showed the highest averages (5.16 ± 1.06 g and 2.00 ± 0.372 g, respectively). Dry above-ground biomass was the only parameter that showed a statistically significant difference compared to the control group (ANOVA, p-value = 0.04). The group with the lowest FMA was the control (3.86 ± 0.26 g), which also presented the lowest average for DMA (1.46 ± 0.08 g). The Figure 4 shows the graph between fresh weight of shoot (FWS) of paricá seedlings and vthe time of exposure to therapeutic ultrasound (min). The experimental data fit a second-degree polynomial regression, described by the equation: $y = 0.03x^2 - 0.01x + 3.87$ with a coefficient of determination (R^2) = 0.9529. The resulting curve presents an upward trend, showing that the increase in exposure time is positively correlated with the increase in fresh biomass of the aerial part (Figure 4 and Figure 5).

Figure 4. Graphic of Fesh Weight of Shoot (FWS) with time of application (min).



Source: The authors, 2025

The values for Fresh Weight Root (FWR) and Dry Weight Root (DWR) presented in Table 1 indicate that the control group had the highest averages (3.43 ± 0.71 g and 0.70 ± 0.15 g, respectively). The lowest average FWR was observed in the 5-minute group (1.99 ± 0.19 g) and the 6-minute group (2.00 ± 0.37 g), both statistically different from the control group (p-value = 0.019 and p-value = 0.03, respectively). Regarding dry root mass, all groups were statistically similar (ANOVA, p-value = 0.277). Which means that ultrasound increased the weight of the shoot but reduced the weight of the root.

Figure 5. Picture of seedling of *Schizolobium amazonicum*, control group compared with ultrasound time application (min).

Source: Prepared by the authors (2025).

Since one ultrasound application time was better for some parameters but not for others (e.g., 6 minutes was better for E, IVE, FWS, and DWS, but not for MET and FWR), Equation 4 was created using all measured values normalized by their respective control group values in order to determine the best overall dose. A higher M-value indicates better treatment performance. Table 2 shows that the best M-values were for 5 minutes (2.97), followed by 6 minutes (2.85), meaning that, when summing all analyzed parameters, these ultrasound application times increased growth by almost three times compared to the control group.

The pursuit of alternative and efficient approaches to overcome seed dormancy and enhance germination has generated growing interest in physical methods, particularly the use of ultrasound. The application of this technique has been explored as a promising strategy to accelerate seedling emergence and improve vigor across various forest and agricultural species (Nogueira et al., 2024).

Table 2. Normalized values of Emergence Percentage (E), Emergence Velocity Index (EVI) and Mean Emergence Time (MET), Fresh Weight of Shoot (FWS), Dry Weight of Shoot (DWS), Fresh Weight of Root (FWR), Dry Weight of Root (DWR) of different groups of paricá seeds and M-value.

Groups		**E %**	**IVE (seeds/day)**	**TME (days)**	**MFA (g)**	**MSA (g)**	**MFR (g)**	**MSR (g)**	**M-value**
Control		1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Test	4-min	1.24	1.29	0.86	1.16	1.20	0.91	0.84	1.99
	5-min	1.45	1.38	0.85	1.18	1.25	0.95	0.90	2.97
	6-min	1.76	1.69	0.96	1.34	1.37	0.61	0.82	2.85

Source: Authors

Various biological approaches have been developed to enhance seed germination or overcome dormancy, including the use of regulatory hormones, scarification, and genetic engineering. Although effective, many of these methods are time-consuming, costly, or environmentally detrimental. Recent studies have identified ultrasound as a promising alternative, capable of promoting seed germination and seedling development across different species by enhancing water and oxygen uptake and stimulating metabolic activity. In *Sterculia amazonicum*, several treatments can improve germination, as the species exhibits prolonged germination under natural conditions. However, most conventional chemical or hormonal treatments are expensive, labor-intensive, and may cause structural or genetic damage. In contrast, ultrasound application is a rapid and residue-free technique that effectively promotes seedling emergence, highlighting its potential as a sustainable method for dormancy breaking (Nogueira et al., 2024; Weerasekara et al., 2021).

When low-frequency ultrasound was applied to *Hymenaea courbaril* L. seeds, the treatment resulted in higher germination rates compared with the control group (Dávila et al., 2021). Conversely, in *Arachis pintoi* (forage peanut) seeds, the emergence rate did not differ significantly from the control group (Melo et al., 2024). These findings suggest that the effectiveness of ultrasound treatment is directly dependent on the precise adjustment of both dosage and exposure time. Improper application—whether due to excessive or insufficient intensity or time—may compromise the potential benefits of the technique. Therefore, careful optimization of parameters, considering the specific characteristics of the species, seed lot and characterises, and environmental conditions, is essential to achieve maximum performance and reproducible results

According to Alfalahi et al. (2022), exposing soybean seeds (*Glycine max* L. Merr.) to ultrasound treatment promoted the formation of microcracks and pores in the seed coat structure, facilitating water penetration during the imbibition process (Alfalahi et al., 2022). This increased water absorption favors more efficient hydration of the internal tissues, accelerating the initial metabolism of germination. Furthermore, positive effects were observed on the expression of genes related to the antioxidant response, resulting in increased enzymatic activity, especially of enzymes involved in neutralizing reactive oxygen species (ROS) and promoting the hydrolysis of energy reserves. These factors, together, indicate that the use of these waves may represent a promising technology to improve the physiological performance of seeds, contributing to faster, more uniform, and vigorous germination, which are essential aspects for the initial success of agricultural cultivation.

In a mini-review, Nazari (2017) evaluated the effects of ultrasonic waves on seed germination percentage and rate, as well as the underlying mechanisms by which ultrasound influences seeds across different species (Nazari, 2017). The author reported that ultrasound generally enhances germination percentage in most of the tested seeds and accelerates germination rate in all species analyzed. Concerning the mechanism of action, it was proposed that ultrasound exerts mechanical pressure on the seed cell wall, increasing its porosity and, consequently, its permeability to oxygen and water. This enhanced permeability promotes greater metabolic activity, particularly by stimulating α-amylase activity within the seed, which in turn intensifies starch hydrolysis. As a result, both germination percentage and rate are improved.

The application of low-frequency ultrasound in liquid media facilitates water uptake by seeds, thereby increasing germination and growth rates. Ultrasonic vibrations in such media generate cavitation bubbles that release substantial amounts of energy, contributing to the disruption of seed dormancy. However, both the applied dosage and the duration of exposure to ultrasonic waves exert varying degrees of influence on the germination process (Venâncio; Martins, 2019).

In this study with *Schizolobium amazonicum*, the 6-minute treatment favored higher germination (37%) when compared to the control group (21%). A study conducted by Rosa (2006) in different seasons found average germination rates between 4% and 26% (Rosa, 2006), shown that ultrasound present better results when compared with traditional techniques of sowing. Ultrasound technology has already been used in several plant species, showing various benefits (Nikbakht Nasrabadi; Sedaghat Doost; Mezzenga, 2021; Rawat; Saini, 2023; Romanini et al., 2021; Zhang et al., 2023) and seems easier to apply compared to other methods such as sand scarification, acid scarification, and other available techniques. Furthermore, the ultrasound technique does not contaminate the seeds with chemical products (Nazari, 2017).

4 CONCLUSION

This study evaluated the application of 3 MHz ultrasound, at an intensity of 2 W/cm^2, for 4, 5, and 6 minutes on *Schizolobium amazonicum* seeds. A new index (M-value) was proposed that integrates all parameters to evaluate the overall effect of the ultrasound. The group that obtained the best result in terms of emergence rate was the 5-minute group, followed by the 6-minute group. Regarding the Emergence Velocity Index and Mean Emergence Time, all results were similar to the control group. The 6-minute group also showed the highest average compared to the control for the fresh and dry weight of shoot. However, for the dry and fresh weight of the root, the control group obtained the highest averages, although their averages were statistically similar. When analyzing the M-value index, it became evident that the 5-minute application achieved an overall performance approximately 3 times greater than the control group. Given the positive results presented here, the application of ultrasound as an auxiliary technique in germination proves to be a viable and low-cost strategy, with the potential to be incorporated into forest seedling production programs. Future studies exploring different parameters of exposure time, frequency, and intensity may further highlight the beneficial effects of the technique. Another proposal would be to conduct biochemical evaluations to verify whether ultrasound may be influencing the molecular structure.

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