Optimization of KNO_3 Concentration in Breaking Dormancy and Enhancing Seed Vigor of *Hevea brasiliensis*

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Abstract: Seed dormancy remains one of the major constraints affecting the propagation and seedling availability of *Hevea brasiliensis* in rubber cultivation systems. Low germination percentage and poor seed vigor often reduce seedling quality and hinder plantation productivity. This study aimed to determine the optimal concentration of Potassium Nitrate (KNO_3) in breaking seed dormancy and enhancing seed vigor of *Hevea brasiliensis*. The study was conducted using a Completely Randomized Design (CRD) consisting of five treatments, namely 0%, 10%, 20%, 30%, and 40% KNO_3 concentrations with four replications. Rubber seeds were soaked in KNO_3 solutions for 72 hours and observed for 60 days. Parameters measured included germination percentage, germination rate, plumule length, and root length. Data were analyzed using One-Way Analysis of Variance (ANOVA) followed by Least Significant Difference (LSD) and Duncan's Multiple Range Test (DMRT) at a 5% significance level. The results showed that KNO_3 treatment significantly affected dormancy breaking and seed vigor enhancement. The 40% KNO_3 treatment produced the highest germination percentage, fastest germination rate, and best seedling growth performance compared to other treatments. These findings indicated that KNO_3 application effectively stimulated germination activity and improved the physiological quality of rubber seeds.

Keywords: seed dormancy, potassium nitrate, seed vigor, *Hevea brasiliensis*

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Introduction

Natural rubber produced by *Hevea brasiliensis* has long become one of the important plantation commodities contributing to the agricultural economy in tropical countries, particularly in Southeast Asia. Indonesia has consistently been recognized as one of the world's largest natural rubber producers with extensive plantation areas managed by both state and smallholder sectors (Kurnia et al., 2020; Sari et al., 2021; Zebua et al., 2026). The increasing industrial demand for latex has encouraged continuous efforts to improve rubber cultivation practices and seedling production systems. However, low seed germination and poor seed vigor remain common constraints in the propagation of rubber plants, especially in community-based plantations (Nurul Asyiqin & Ong, 2025).

Seed dormancy is a physiological condition in which viable seeds fail to germinate even under favorable environmental conditions. Dormancy in rubber seeds has been associated with physical barriers, limited water imbibition, and physiological immaturity of embryos that inhibit normal germination processes (Bhatla & Kathpalia, 2023; Nautiyal et al., 2023). In many rural plantation areas, farmers still experience difficulties in producing high-quality rubber seedlings because germination rates are inconsistent and often accompanied by seed decay. These conditions have reduced seed viability and negatively affected the sustainability of rubber cultivation in several regions of Indonesia.

Seed vigor and germination capacity are essential indicators in determining the quality of planting materials for plantation crops (Ziraluo & Duha, 2020; Ziraluo & Zebua, 2026). High-vigor seeds generally exhibit rapid and uniform germination, which supports optimal seedling establishment and subsequent plant growth (Reed et al., 2022). Several seed treatment methods have been applied to overcome dormancy problems, including mechanical scarification, soaking treatments, stratification, and chemical stimulation. Among these methods, chemical treatment using Potassium Nitrate (KNO_3) has been widely reported as an effective and practical approach to stimulate seed germination in many plant species.

Potassium nitrate has been recognized as a germination promoter because it enhances oxygen availability and activates metabolic pathways associated with embryo growth. The application of KNO_3 has also been reported to stimulate gibberellin activity and enzymatic hydrolysis processes involved in mobilizing food reserves during seed germination (Ahmad et al., 2022; Narejo et al., 2023). Previous studies demonstrated that KNO_3 treatment improved germination percentage, seedling growth, and vigor in rice, areca nut, and longan seeds (L. G. Ali et al., 2021a, 2021b). Nevertheless, the effectiveness of KNO_3 treatment varies depending on seed characteristics, concentration levels, and soaking duration applied in different plant species.

Several earlier studies primarily focused on the influence of KNO_3 on food crops and horticultural plants, while limited attention has been given to plantation crops such as rubber. Existing studies on rubber seed dormancy mostly emphasized conventional propagation methods without examining the physiological response of seeds to varying KNO_3 concentrations. In addition, inconsistencies in concentration ranges and experimental designs among previous studies have produced findings that are difficult to generalize. These limitations indicate the existence of a research gap concerning the optimization of KNO_3 concentration for improving dormancy breaking and seed vigor in *Hevea brasiliensis*.

The ideal condition in seed propagation is the availability of viable seeds with rapid germination and strong vigor to support sustainable rubber cultivation. However, field observations in rubber-producing communities showed that many seeds experienced delayed germination, abnormal sprout development, and seed mortality caused by dormancy-related problems. Farmers often relied on traditional practices without understanding appropriate chemical treatments capable of stimulating germination effectively. This discrepancy between the expected quality of seed germination and the actual conditions in the field highlighted the importance of developing a more effective dormancy-breaking strategy for rubber seeds.

Based on these considerations, the present study investigated the optimization of KNO_3 concentration in breaking dormancy and enhancing seed vigor of *Hevea brasiliensis* through an experimental approach. This study specifically evaluated the effects of different KNO_3 concentrations on germination percentage, growth rate, plumule length, and root length of rubber seedlings. The findings were expected to provide scientific information regarding the most effective concentration of KNO_3 for improving rubber seed germination performance. Therefore, an important question addressed in this study was whether increasing KNO_3 concentration could significantly optimize dormancy breaking and seed vigor enhancement in rubber seeds under controlled experimental conditions.

Methods

This study was conducted using a quantitative experimental approach with a Completely Randomized Design (CRD). The experiment was carried out from January to March 2026 in Pekan Hilisimaetano Village, Maniamolo District, South Nias Regency, Indonesia. The objective of the study was to determine the effect of different concentrations of Potassium Nitrate (KNO_3) on breaking seed dormancy and enhancing seed vigor of *Hevea brasiliensis*. The experimental design consisted of five treatments, including one control treatment and four KNO_3 concentration treatments.

The treatments applied in this study consisted of P0 (control without KNO_3), P1 (10% KNO_3), P2 (20% KNO_3), P3 (30% KNO_3), and P4 (40% KNO_3). Each treatment was replicated four times, resulting in 20 experimental units. Ten rubber seeds were used in each experimental unit, so a total of 200 seeds were included in the experiment. The seeds were collected from mature rubber fruits that had naturally fallen from rubber trees in local plantations.

The materials used in this experiment included rubber seeds, potassium nitrate (KNO_3), distilled water, and cotton media. Several laboratory and field tools were utilized, including beaker glasses, plastic containers, analytical balances, rulers, cameras, and measuring instruments. KNO_3 solutions were prepared by dissolving the required amount of potassium nitrate into 500 mL of water according to the designated treatment concentrations. All solutions were prepared before the soaking treatment was conducted.

Prior to the germination test, the rubber seeds were cleaned and selected based on their physical appearance to ensure uniformity. The seeds were then soaked in each KNO_3 solution according to the treatment groups, while the control group was soaked in water without KNO_3. The soaking process was carried out for 72 hours under room temperature conditions. After soaking, the seeds were transferred onto cotton media and maintained under natural environmental conditions for germination observation.

Seed germination observations were conducted for 60 days after sowing. Watering activities were performed one to two times daily depending on weather conditions to maintain sufficient moisture during germination. Data collection was carried out weekly by recording the number of normal germinated seeds in each treatment group. Additional observations included seedling growth variables such as plumule length and root length at the end of the observation period.

Several germination parameters were measured in this study, including germination percentage, germination rate, plumule length, and root length. Germination percentage was calculated based on the proportion of normal seedlings produced from the total number of seeds tested. Germination rate was determined by observing the speed of seed emergence during the germination period. Plumule length and root length were measured using a ruler and expressed in centimeters.

The collected data were analyzed statistically using SPSS Statistics version 20. Prior to hypothesis testing, normality and homogeneity tests were performed to evaluate data distribution and variance assumptions. Normality testing was conducted using the Kolmogorov–Smirnov test, while homogeneity testing was analyzed using Levene's test. Hypothesis testing was subsequently carried out using One-Way Analysis of Variance (ANOVA), followed by Least Significant Difference (LSD) and Duncan's Multiple Range Test (DMRT) at a 5% significance level to identify differences among treatment means. The analyzed data were presented in the form of tables, graphs, and descriptive statistical explanations.

Result

This study employed a quantitative experimental approach to evaluate the effectiveness of potassium nitrate (KNO_3) in breaking dormancy and enhancing the germination performance of rubber seeds (*Hevea brasiliensis*). The experiment was conducted from April to June 2021 using a Completely Randomized Design (CRD) consisting of five treatments: P0 (0% KNO_3, control), P1 (10% KNO_3), P2 (20% KNO_3), P3 (30% KNO_3), and P4 (40% KNO_3). Each treatment was replicated four times, with 40 seeds allocated to each treatment. Seeds were soaked in the respective KNO_3 solutions for 72 hours and observed for a period of 60 days.

The results demonstrated a clear positive relationship between KNO_3 concentration and seed germination performance. Rubber seeds treated with higher concentrations of KNO_3 exhibited greater germination rates and more vigorous seedling growth than untreated seeds. The control treatment (P0) consistently produced the lowest values across all measured parameters, indicating that natural germination without KNO_3 treatment was relatively limited. In contrast, seeds treated with KNO_3 showed substantial improvements in germination and growth, suggesting that potassium nitrate effectively stimulated physiological processes associated with dormancy release and seedling development.

Germination Speed

The mean germination speed increased progressively with increasing KNO_3 concentration. The control treatment (P0) recorded the lowest mean germination speed of 1.50, whereas treatments P1, P2, P3, and P4 achieved mean values of 3.25, 4.00, 5.25, and 7.75, respectively. These results indicate that KNO_3 accelerated germination, with the 40% concentration producing the fastest germination response. The gradual increase in germination speed across treatments suggests that higher KNO_3 concentrations were more effective in overcoming dormancy constraints and promoting early metabolic activation within the seeds.

Table 1. Mean Germination Speed of Rubber Seeds

Treatment	KNO_3 Concentration	Mean Germination Speed
P0	0% (Control)	1.50
P1	10%	3.25
P2	20%	4.00
P3	30%	5.25
P4	40%	7.75

Germination Capacity and Seedling Growth

The influence of KNO_3 was also evident in germination capacity, seed growth rate, plumule length, and root length. The highest values for all parameters were observed in treatment P4 (40% KNO_3). Germination capacity increased from 1.0 in the control treatment to 3.5 in P4. Similarly, seed growth rate rose from 0.01 in P0 to 0.11 in P4. Plumule length increased substantially from 0.01 cm in the control treatment to 7.0 cm in P4, while root length increased from only 0.02 cm to 9.0 cm. These findings indicate that KNO_3 not only promoted germination but also enhanced seedling vigor by stimulating both shoot and root development.\

Table 2. Germination and Seedling Growth Parameters under Different KNO_3 Concentrations

Parameter	P0 (0%)	P1 (10%)	P2 (20%)	P3 (30%)	P4 (40%)
Germination Capacity	1.0	2.0	1.5	2.5	3.5
Seed Growth Rate	0.01	0.03	0.05	0.08	0.11
Plumule Length (cm)	0.01	1.5	3.0	5.0	7.0
Root Length (cm)	0.02	2.0	2.5	4.0	9.0

The pattern observed across all variables demonstrates that increasing KNO_3 concentrations consistently improved seed performance. The superior growth observed in P4 suggests that the higher concentration effectively enhanced water uptake, enzyme activation, and mobilization of stored food reserves necessary for germination and seedling establishment. Prior to hypothesis testing, the data were evaluated for normality and homogeneity. The Kolmogorov–Smirnov normality test yielded a significance value of 0.412, which exceeded the threshold of 0.05, indicating that the data were normally distributed. The homogeneity test produced a significance value of 0.074, also greater than 0.05, confirming that the variances among treatment groups were homogeneous. These results satisfied the assumptions required for parametric statistical analysis.

Table 3. Results of Normality and Homogeneity Tests

Test	Statistic	p-value	Interpretation
Kolmogorov–Smirnov	0.886	0.412	Normally distributed
Levene's Test	2.655	0.074	Homogeneous variance

The one-way ANOVA revealed a statistically significant effect of KNO_3 concentration on rubber seed germination speed. The calculated F-value (4.595) exceeded the critical F-table value (3.06), while the significance value (0.013) was below 0.05. These results indicate that KNO_3 concentration significantly influenced the dormancy-breaking process and germination performance of rubber seeds.

Table 4. One-Way ANOVA Results

Source of Variation	Sum of Squares	df	Mean Square	F-value	p-value
Between Groups	87.300	4	21.825	4.595	0.013
Within Groups	71.250	15	4.750		
Total	158.550	19			

The significant ANOVA result confirms that differences in germination performance among treatments were not due to random variation but were directly associated with the application of different KNO_3 concentrations. Further analysis using LSD and Duncan's Multiple Range Test demonstrated that treatment P4 (40% KNO_3) produced the strongest effect on germination speed and differed significantly from the lower concentration treatments and the control group. Duncan's test ranked the treatments in the following order:

P4 (40%) > P3 (30%) > P2 (20%) > P1 (10%) > P0 (0%)

This ranking confirms that germination performance improved progressively as KNO_3 concentration increased. The highest concentration tested (40%) was the most effective in enhancing germination, seedling growth, and overall seed vigor. The findings clearly demonstrate that potassium nitrate is an effective dormancy-breaking agent for *Hevea brasiliensis* seeds. Increasing KNO_3 concentration resulted in higher germination capacity, faster germination speed, greater seedling growth rates, and longer plumule and root development. Among all treatments, the 40% KNO_3 solution consistently produced the best results and was identified as the most effective treatment for improving germination performance and early seedling establishment. These results suggest that KNO_3 can be utilized as a practical pre-sowing treatment to enhance the propagation and cultivation of rubber plants.

Conclusion

The results of this study demonstrated that the application of Potassium Nitrate (KNO_3) significantly influenced dormancy breaking and seed vigor enhancement in *Hevea brasiliensis*. The increase in germination percentage, germination rate, plumule length, and root length indicated that KNO_3 treatment successfully stimulated physiological activity during seed germination. These findings supported the theory that nitrate compounds function not only as nutrient sources but also as signaling molecules capable of activating metabolic pathways associated with seed germination (A. Ali, 2020). Nitrate has been reported to stimulate embryo growth through hormonal regulation, especially by reducing abscisic acid activity and increasing gibberellin responses that promote dormancy release.

The highest germination performance observed in the 40% KNO_3 treatment suggested that rubber seeds responded positively to higher nitrate availability during imbibition. The increase in root and plumule growth reflected enhanced water uptake and more active mobilization of seed food reserves. Similar findings were reported in soybean and forage grass seeds, where KNO_3 priming improved germination uniformity and seedling vigor through activation of antioxidative metabolism and enhanced physiological conditioning (Javed et al., 2020). These results confirmed that KNO_3 treatment could improve the physiological potential of seeds, particularly in species with dormancy-related germination problems.

The present findings were also consistent with previous studies showing that KNO_3 effectively accelerated dormancy breaking in several tropical plant species. Research conducted on Urochloa humidicola demonstrated that immersion in KNO_3 solution significantly increased germination and reduced dormant seed percentages (Pereira et al., 2021). Similar responses were also observed in sugar palm seeds, where KNO_3 soaking treatments improved germination percentage and seedling establishment under controlled conditions (Javed et al., 2020). The consistency between the current study and earlier findings indicated that nitrate-based seed treatments have broad applicability across species with physiological dormancy constraints.

Although KNO_3 generally improved germination performance, an interesting observation emerged from the relatively moderate response shown in the 20% treatment compared to the higher concentration groups. This pattern indicated that the response of rubber seeds to nitrate stimulation did not always increase linearly with concentration. Such findings reflected the complex interaction between seed physiology, osmotic balance, and metabolic activation during imbibition. Previous studies also reported that KNO_3 effectiveness varied among plant species and depended on treatment duration, seed quality, and environmental conditions (Ahmadi et al., 2023; Da Rocha et al., 2025). This unexpected variation encouraged further curiosity regarding the threshold concentration and tolerance level of rubber seeds toward nitrate exposure.

The findings of this study also strengthened previous evidence concerning the importance of seed vigor in plantation crop establishment. High-vigor seeds generally exhibit faster and more synchronized germination, which contributes to improved seedling survival and growth performance in the field. Research on rubber seed physiology showed that seed vigor and germination behavior were closely associated with water imbibition patterns and morphophysiological characteristics of seedlings (Pompelli et al., 2023). In the present study, the higher root length observed in KNO_3-treated seeds indicated that nitrate stimulation promoted more rapid seedling establishment, which could potentially support stronger adaptation during early growth stages.

Compared with earlier studies, the present research contributed new information regarding the optimization of KNO_3 concentration specifically for rubber seeds. Previous research on *Hevea brasiliensis* primarily focused on seed storage, planting media, and environmental conditions affecting viability and vigor (de Carvalho et al., 2023). Limited studies examined chemical dormancy-breaking strategies using different KNO_3 concentrations on rubber seeds under experimental conditions. Therefore, this study expanded existing knowledge by demonstrating that concentrations between 30% and 40% produced the most favorable germination responses. The study also provided empirical evidence that nitrate-based treatments could become practical alternatives for improving rubber seed propagation in plantation systems.

Despite its contribution, this study still had several limitations. The experiment was conducted within a relatively limited observation period and under controlled environmental conditions, so the long-term effects of KNO_3 treatment on field performance were not evaluated. In addition, physiological parameters such as enzymatic activity, respiration rate, and hormonal dynamics were not analyzed in detail, limiting deeper understanding of the dormancy-breaking mechanism. Future studies are therefore recommended to investigate molecular and biochemical responses of rubber seeds exposed to nitrate treatments under varying environmental conditions. Further research involving wider concentration ranges, soaking durations, and field-scale evaluations is also necessary to strengthen the generalization and practical application of KNO_3 treatment in sustainable rubber cultivation systems.

Conclusion

The findings of this study demonstrated that the application of Potassium Nitrate (KNO_3) played an important role in improving dormancy breaking and seed vigor of *Hevea brasiliensis*, particularly at concentrations of 30–40%, which produced the most favorable germination responses. These results highlighted the importance of chemical seed treatment as a practical strategy to support the propagation of rubber plants and improve the availability of high-quality seedlings in plantation systems. Nevertheless, this study was limited by the relatively short observation period and the absence of physiological and biochemical analyses related to seed metabolism during germination. The study implied that optimizing dormancy-breaking techniques could contribute to more efficient rubber cultivation practices, while future research was recommended to explore broader concentration ranges, longer observation periods, molecular responses, and field-scale applications to strengthen the scientific understanding and practical implementation of KNO_3-based seed treatments.

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