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Effect of H_2SO_4 Concentration and Seed Soaking Time on Breaking Dormancy of Rubber Seeds (Hevea Brasiliensis Muell. Arg.)

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A B S T R A C T

Rubber seed dormancy limits uniform germination due to a hard seed coat. This study aimed to evaluate the effect of H_2SO_4 concentration and soaking time on germination performance of Hevea brasiliensis. A factorial Completely Randomized Design was used with three concentrations of H_2SO_4 (1%, 2%, 3%) and three soaking durations (10, 15, 20 minutes). Observed parameters were germination percentage, germination time, and number of normal seedlings. Results showed that both factors and their interaction significantly affected all parameters. The 3% H_2SO_4 combined with 20-minute soaking produced the highest germination and normal seedlings and the fastest germination time. In conclusion, chemical scarification using 3% H_2SO_4 for 20 minutes is the most effective treatment to break dormancy and improve rubber seed germination

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INTRODUCTION

Indonesia is a country rich in natural resources. One of the natural resources developed by the community for agricultural purposes is rubber (*Hevea brasiliensis* Muell. Arg.). Indonesia has one of the largest rubber plantation areas in the world. In 2022, the area of rubber plantations in Indonesia was 3,557,091 hectares, comprising 3,263,127 hectares of smallholder plantations, 165,200 hectares of large private plantations, and 129,254 hectares of large state-owned plantations, with a production of 2,717,081 tons (BPS, 2023)

The rubber plant is a fairly tall tree with a large, generally straight trunk. Its trunk contains a sap called latex, which is currently used as a raw material in various industries, such as the automotive industry, which produces vehicle tires, and the manufacturing industry, which produces components such as hoses, rubber cords, and solid rubber for vibration damping. This plant produces fruit, each with three chambers containing rubber seeds. Each chamber usually contains one seed, but can contain more depending on the number of chambers in the fruit (Adhikari et al., 2023; Wei & Abd Razak, 2021).

Pratama stated that germination is a series of important processes that occur from the dormant state of seeds to the emergence of young plants, which then begin to grow depending on seed viability, suitable environmental conditions, and dormancy-breaking efforts (Pratama, 2021). Seed requirements for rubber plant seeds include: uniform seed size, seeds must bounce when dropped on a hard surface, clean and shiny seed coats, minimum seed freshness of 80%, germination power of at least 80% within 21 days, seed moisture content between 32-45%, minimum seed purity of 98%, and the age of the parent tree as the seed source must have reached 8 years or more (Charloq et al., 2017; A. Lestari et al., 2023).

The purpose of this research is to accelerate the germination period of seeds from a germination period of 21 days after sowing. Due to the still-high demand for seeds for rubber plantations in Indonesia, this research was conducted to accelerate seed germination. One objective of this seed dormancy-breaking research is to obtain seedlings with strong, well-developed roots, thereby enabling optimal nutrient absorption and reducing the risk of falling. Therefore, thorough preparation is required, including nursery media, seed handling, germination, seedling planting, and plant maintenance in the nursery (S. U. Lestari, 2021).

Soaking is a method to increase the water content of seeds, which can affect their germination process. Seeds soaked and germinated under favorable conditions will germinate faster than those that are not. Seeds soaked for 5 days with the water changed every 24 hours have a longer shelf life, up to 10 weeks, with a consistently high germination rate. Farmers have other methods to accelerate rubber seed germination, namely by removing the microphylls and soaking them in water overnight, or by placing the seeds in a burlap sack and soaking them in running water for two nights. This process, called scarification, increases the seeds' permeability to water and gases, thereby accelerating germination.

Rubber plant seeds are included in the recalcitrant seed category with several characteristics, namely: never dry while still on the tree (water content around 35%), not resistant to drought, do not have a dormancy period, germination or viability decreases quickly, have a short shelf life, and can experience cell freezing if stored at temperatures below 0°C (Pujiono, 2018; Wagner et al., 2018).

Dormancy in rubber seeds is caused by the hard seed coat, which prevents the air and water needed for germination from entering the seed. Germination takes a long time, which can impact seed availability. To optimize germination, rubber seeds require pre-planting treatment. One effective method for breaking seed dormancy is the use of chemical solutions(A. Lestari et al., 2023). Sulfuric acid (H_2SO_4) is a strong acid commonly used in this process because it softens the seed coat. This research draws on a study of candlenut seed dormancy with H_2SO_4. Candlenut seeds, which have a hardness similar to rubber seeds, are 5-7 mm thick, while rubber seeds are 4-5 mm thick. H_2SO_4 can loosen the hard seed coat, allowing water to enter the seed embryo more easily during imbibition. This is because H_2SO_4 can dissolve the lignin in the seed coats of candlenut and rubber, which are impermeable compounds that prevent water from entering. In Ismail's (2018) research, the use of H_2SO_4 with a concentration of 20% on candlenut with a soaking time of 10, 20 and 30 minutes was not effective in breaking dormancy, resulting in a decrease in the percentage of germinated seeds, the average number of germinated seeds per day and the germination value as well as an increase in the average number of days the seeds germinated (Ismail, 2018).

THEORETICAL REVIEW

Rubber trees originally grew only in Brazil, South America. The plant that produces this latex has been known for centuries and traditionally used by indigenous people in Brazil. Hevea brasiliensis Muell.Arg. grows wild in the Amazon River valleys, and locals often collect its latex for various purposes, such as lighting fires and making balls for games. Although Europeans already knew of its use during their voyage to South America in 1473 and by early 16th-century explorers, rubber was not of interest to them at that time because its benefits were not very useful for their daily needs(Gent, 2020).

The rubber plant, known scientifically as Hevea brasiliensis Muell.Arg., has been successfully cultivated in Southeast Asia and is currently widely planted there as a source of natural rubber. Rubber plants are an important commodity in the global rubber industry. The latex produced is used in various industrial products, including tires, medical devices, and household goods. Furthermore, rubber cultivation also contributes to the local economy by creating jobs and increasing farmers' incomes.

Sulfuric acid (H_2SO_4) is a strong acid and is soluble in water in various proportions. This substance has various applications in the chemical industry, including mineral ore processing, chemical synthesis, wastewater treatment, and oil processing (Rahman, 2021). Sulfuric acid, or Sulfuric Acid, is a compound consisting of the elements sulfur, oxygen, and hydrogen with the formula H_2SO_4.

This compound is highly acidic and corrosive. Sulfuric acid at 98% concentration is commonly called concentrated sulfuric acid. There are various concentrations of sulfuric acid used for various purposes, including laboratory use, battery acid, fertilizer acid, and chamber/tower acid.

Chemically, breaking physical dormancy (hard seed coat) is done by soaking the seeds in a diluted strong acid solution (chemical scarification process) (Almanda et al., 2023). Pratama stated that H_2SO_4 solution is often used to overcome seed dormancy, with varying concentrations adjusted to the conditions of the seeds to be grown. In addition, the duration of soaking must also take into account the condition of the seed coat or pericarp, so that the combination of concentration and soaking time can produce optimal results without damaging the embryo, which can inhibit its growth (Pratama, 2021).

METHODOLOGY

This research was conducted at the Seed Technology Laboratory of the Indonesian Methodist University, Tanjung Sari, Medan Selayang District, Medan City, with an altitude of approximately ±32 meters above sea level. The materials used in this study were rubber seeds (Hevea brasiliensis Muell. Arg.), H_2SO_4 solution, cotton, and water. The tools used included germination tanks, dropper pipettes, tweezers, beakers, and other supporting tools needed during the research. This study used a factorial Completely Randomized Design (CRD) with two treatment factors. The first factor was the concentration of H_2SO_4 which consisted of three levels, namely H1 = H_2SO_4 1%, H2 = H_2SO_4 2%, and H3 = H_2SO_4 3%. The second factor was the soaking time, with three levels: L1 = 10 minutes, L2 = 15 minutes, and L3 = 20 minutes. Thus, there are 9 treatment combinations, namely H1L1, H1L2, H1L3, H2L1, H2L2, H2L3, H3L1, H3L2, and H3L3. Each treatment was repeated 10 times, resulting in 90 experimental units. Each experimental unit used 5 seeds, for a total of 450 in this study. The rubber seeds used were selected for uniformity in size and physical condition. The seeds used were intact, unbroken, unwrinkled, and free of mold. The seeds were then cleaned of any dirt before being treated.

The treatment was carried out by soaking the seeds in H_2SO_4 solutions at 1%, 2%, and 3% concentrations, with soaking times of 10, 15, and 20 minutes, respectively. The soaking was carried out in a beaker. After the soaking process was complete, the seeds were rinsed and air-dried before being germinated. The treated seeds were then germinated in a prepared germination tank. During germination, media humidity was maintained by watering or adding sufficient water to keep environmental conditions conducive to imbibition and seedling growth. The parameters observed in this study included germination power, germination time, and the number of normal seedlings. Germination power was calculated as the percentage of seeds that produced normal seedlings among the total number of seeds germinated. Observations were made from the beginning of germination until the 10th day after germination. Germination power was calculated using the formula:

Germination rate (%) = (Number of normal sprouts / Number of seeds germinated) × 100%

Germination Time

Germination time was monitored to determine the average time to germination for rubber seeds. Observations were conducted at 10-day intervals until the 10th day after germination. Germination time was calculated using the formula:

$$\mathbf{LB = \Sigma(ni \times hi) / \Sigma ni}$$

Description: LB = germination time
ni = number of seeds that germinate on day i
hi = time or day of observation i

Normal sprouts were defined as those that showed normal growth and had the potential to develop into perfect plants under optimal environmental conditions. The criteria for normal sprouts were based on the growth of the main organs, which were good, undamaged, and showed healthy development. The observation data were analyzed using analysis of variance (ANOVA) in accordance with a factorial Completely Randomized Design. The mathematical model used is as follows:

$$\mathbf{Yijk = \mu + Hi + Lj + (HL)ij + \varepsilon ijk}$$

Description: Yijk = observation value for the treatment of H_2SO_4 concentration at level i, soaking time at level j, and repetition k
μ = general mean value
Hi = influence of H_2SO_4 concentration at level i
Lj = influence of immersion time on level j
(HL)ij = the effect of the interaction between the concentration of H_2SO_4 at the i-th level and the soaking time at the j-th level
εijk = experimental error

If the analysis of variance indicates a real or very real effect, the analysis continues with Duncan's Multiple Range Test (DMRT) at the 5% level to determine differences between treatments.

RESEARCH RESULTS

Germination Power (%)

The analysis of variance showed that the treatments of H_2SO_4 concentration and soaking time, as well as their interaction, significantly affected the germination power of rubber seeds. Table 2 presents the average germination rate of rubber seeds under different H_2SO_4 concentration treatments and soaking times.

Table 1. Average Germination Power (%) of Rubber Seeds Due to H_2SO_4 Concentration Treatment and Soaking Time

Treatment (%)	Germination Power
H1	9.46b
H2	9.78a
H3	9.88a
L1	9.36c
L2	9.74b
L3	10.02a

H1L1	9.08c
H1L2	9.29bc
H1L3	10.02a
H2L1	9.39bc
H2L2	9.92a
H2L3	10.02a
H3L1	9.60ab
H3L2	10.02a
H3L3	10.02a

Description: Numbers followed by the same letter in the same column mean that they are not significantly different in the DMRT test at the 5% test level.

Table 1 shows that in the H2SO4 concentration treatment, the highest germination rate of rubber seeds was observed in the H3 treatment, which was significantly different from H1 but not significantly different from H2. The germination rate of rubber seeds in the H2 treatment was not significantly different from that in the H1 treatment. In the soaking time treatment, the highest germination rate of rubber seeds was observed in the L3 treatment, which was significantly higher than in the L1 and L2 treatments. The germination rate of rubber seeds in the L2 treatment was significantly higher than in the L1 treatment. In the interaction treatment, H2SO4 concentration and soaking time had significantly different effects on rubber seed germination rate. The highest germination rate of rubber seeds in the combination of H1L3, H2L3, H3L2, and H3L3 treatments was significantly higher than in H1L1, H1L2, and H2L1, but not significantly different from H2L2 and H3L1. The highest germination power of rubber seeds was found in the combination of H1L3, H2L3, H3L2, and H3L3 treatments at 100%, while the lowest germination power was found in the H1L1 treatment at 82%. The effect of the interaction between H2SO4 concentration and soaking time on the germination rate of rubber seeds is shown in Figure 1.

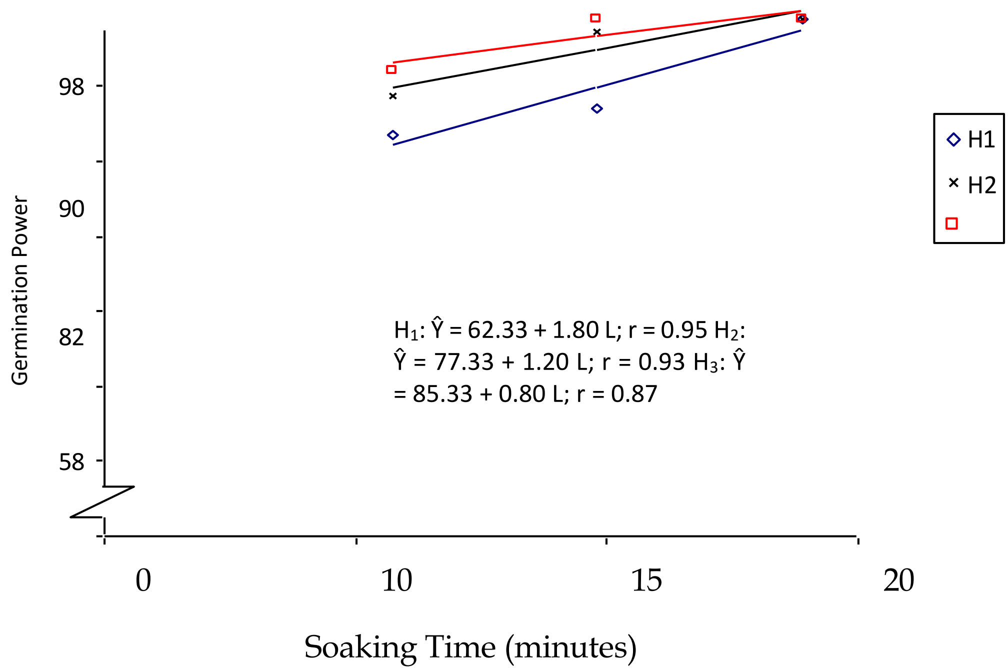

Figure 1. Effect of Soaking Time on the Germination Power of Rubber Seeds at Various H2SO4 Concentrations

Figure 1 shows that soaking seeds in a 3% H2SO4 solution for 15 minutes resulted in 100% germination, whereas soaking in 1% or 2% H2SO4 solutions yielded germination rates below 98%.

Germination Time (%)

The analysis of variance showed that the treatments of H2SO4 concentration and soaking time, as well as their interaction, significantly affected the germination time of rubber seeds. Table 3 presents the average germination time of rubber seeds due to different H2SO4 concentration and soaking time treatments.

Table 2. Average Germination Time (days) of Rubber Seeds Due to H2SO4 Concentration Treatment and Soaking Time

Treatment	Germination Time (days)
H1	18.71a
H2	17.89b
H3	17.38b
L1	18.93a
L2	18.06b
L3	16.99c
H1L1	20.00a
H1L2	19.06ab
H1L3	17.08de
H2L1	18.64bc
H2L2	17.77cde
H2L3	17.26de
H3L1	18.16bcd
H3L2	17.36cde
H3L3	16.62e

Description: Numbers followed by the same letter in the same column mean that they are not significantly different in the DMRT test at the 5% test level.

Table 2 shows that in the H2SO4 concentration treatment, the fastest germination time was in the H3 treatment, which was significantly different from H1, but not significantly different from H2. In the soaking time treatment, the fastest germination time of rubber seeds was in the L3 treatment, which was significantly different from the L1 and L2 treatments. The germination time of rubber seeds in the L2 treatment was significantly different from that in the L1 treatment. In the interaction treatment, the H2SO4 concentration and soaking time had a significantly different effect on the germination time of rubber seeds. The fastest germination of rubber seeds in the H3L3 treatment combination was significantly different from H1L1, H1L2, H2L1 and H3L1, but not significantly different from H1L3, H2L2, H2L3 and H3L2. The effect of the interaction between H2SO4 concentration and soaking time on germination time of rubber seeds is shown in Figure 2.

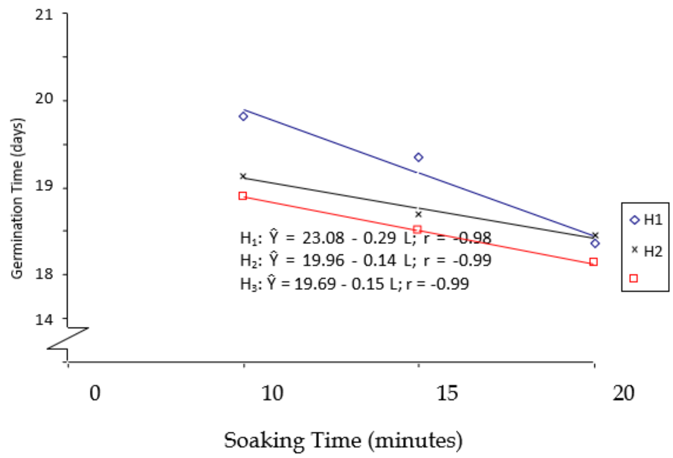

Figure 2. Effect of Soaking Time on Germination Time of Rubber Seeds at Various H2SO4 Concentrations

Figure 2 shows that soaking seeds in a 3% H2SO4 solution for 10 minutes can accelerate rubber seed germination by 2 days compared to soaking in a 1% H2SO4 solution for 15 minutes. Using higher H2SO4 concentrations, combined with longer soaking time, will further accelerate seed germination.

Normal Number of Sprouts (seeds)

The analysis of variance showed that the treatments of H2SO4 concentration and soaking time, as well as their interaction, significantly affected the number of normal rubber seed sprouts. Table 3 presents the average number of normal rubber seed sprouts due to different H2SO4 concentration and soaking time treatments.

Table 3. Average Number of Normal Sprouts (Seeds) of Rubber Seeds Due to H2SO4 Concentration Treatment and Soaking Time

Treatment	Normal Number of Sprouts (%)
H1	4.47b
H2	4.77a
H3	4.80a
L1	4.27b
L2	4.77a
L3	5.00a
H1L1	4.00c
H1L2	4.40bc
H1L3	5.00a
H2L1	4.30bc
H2L2	5.00a

H2L3	5.00a
H3L1	4.50b
H3L2	4.90a
H3L3	5.00a

Description: Numbers followed by the same letter in the same column mean that they are not significantly different in the DMRT test at the 5% test level.

Table 3 shows that in the H2SO4 concentration treatment, the highest number of normal rubber seed sprouts was observed in the H3 treatment, which was significantly different from H1 but not significantly different from H2. The number of normal rubber seed sprouts in the H2 treatment was significantly different from that in the H1 treatment. In the soaking time treatment, the highest number of normal rubber seed sprouts was observed in the L3 treatment, which was significantly different from the L1 treatment but not significantly different from the L2 treatment. The number of normal rubber seed sprouts in the L2 treatment was significantly different from L1. In the interaction treatment, the H2SO4 concentration and soaking time had a significantly different effect on the number of normal rubber seed sprouts. The highest number of normal rubber seed sprouts was observed in the combination of H1L3, H2L2, H2L3, and H3L3 treatments, which was significantly higher than in H1L1, H1L2, H2L1, and H3L1, but not significantly different from H3L2. The highest number of normal rubber seed sprouts was observed in the treatment combinations H1L3, H2L2, H2L3, and H3L3, with 5 sprouts each, while the lowest number was observed in the H1L1 treatment, with 4 sprouts. The interaction between H2SO4 concentration and soaking time on the number of normal rubber seed sprouts is shown in Figure 3.

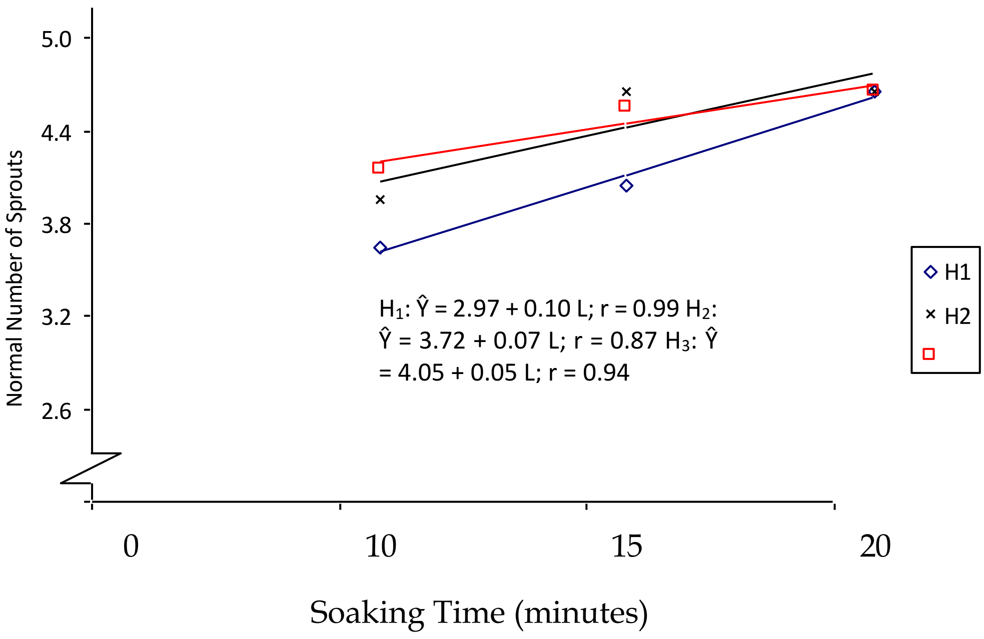

Figure 3. Effect of Soaking Time on the Number of Normal Rubber Seed Sprouts at Various H2SO4 Concentrations

Figure 11 shows the effect of soaking time on the number of normal sprouts. Higher concentrations of H2SO4, followed by longer soaking times, will increase the number of normal sprouts. Using H_2SO_4 concentrations of 2% and 3% with a 15-minute soaking time has resulted in a total number of normal sprouts.

DISCUSSION

Effect of H Concentration2SO4on Breaking Seed DormancyRubber (Hevea brasiliensis Muell.Arg)

The results of the study showed that H_2SO_4 concentration significantly affects germination rate, germination time, and the number of normal sprouts.

The higher the concentration of H_2SO_4, the higher the germination capacity of rubber seeds. The highest germination capacity was observed in the H3 (3%) treatment at 97.33%, and the lowest in the H1 (1%) treatment at 89.33%. Soaking the seeds in H_2SO_4 solution softens the seed coat, allowing water and gas to diffuse in, and dissolving germination inhibitor compounds such as fluoride and coumarin in the H_2SO_4 during the soaking process. After water absorption, enzymes are activated and enter the endosperm, leading to the breakdown of food reserves. The amylase enzyme breaks down starch into glucose, the lipase enzyme breaks down fat into fatty acids and glycerol, and the protease enzyme breaks down protein into amino acids. These simple compounds will be transported to the embryo for growth. In addition, protease activity produces amino acids that are used to form new proteins, such as α-amylase. If the α-amylase enzyme increases, the process of hydrolyzing starch into simple sugars can occur more quickly. The first organ to emerge from a germinating seed is the radicle, the embryonic root. Next, the shoot tip must penetrate the soil surface. In field beans and many other dicotyledonous plants, the hypocotyl forms a hook-like structure, and growth pushes the hook above the soil surface. Research by (Imbiri et al., 2022) found that using 50% H_2SO_4 yielded the highest germination rate for cashew seeds, at 97.50%.

The higher the concentration of H_2SO_4, the shorter the germination time of rubber seeds. The fastest germination of rubber seeds was found in the H3 treatment (3%) of 17.38 days and the longest on H1 (1%) of 18.71 days. The germination process occurs if environmental conditions, such as temperature, humidity, and oxygen, are suitable for seed germination. Increasing the concentration of H_2SO_4 will raise the seed temperature, thereby increasing metabolic activity. Seed germination generally begins with the formation of radicles that will develop into roots. Initially, these radicles use food reserves in the cotyledons. However, as the seeds develop, these radicles will form roots that can absorb water and nutrients from the environment to support the growth of other plant organs. Research by (Puspita & Erawati, 2019) found that using a 20% H_2SO_4 solution can accelerate coffee seed germination by 28-29 days. Research by (Ismail, 2018) found that soaking candlenut seeds in a 20% H_2SO_4 solution accelerated germination by 36.50 days compared to the control treatment (39.67 days).

The higher the concentration of H_2SO_4, the number of normal sprouts increased. The highest number of normal sprouts was found in treatment H3 (3%) at 4.80 seeds and the longest in H1 (1%) at 4.47 seeds. The highest H_2SO_4 concentration used in this study was 3%, so it did not affect the level of seed damage. The higher the concentration and the longer the soaking time, the higher the seed damage. Research by Fitri et al. (2022) found that soaking seeds in a 20% H_2SO_4 solution resulted in a germination percentage of 84.56%, compared to the control treatment of 29.03%.

The Effect of Soaking Time on the Dormancy Breaking of Rubber Seeds (Hevea brasiliensis Muell.Arg)

The results of the study showed that the soaking time treatment had a significant effect on germination rate, germination time, and the number of normal sprouts.

The longer the soaking time, the greater the germination rate of rubber seeds. The highest germination rate was found in treatment L3 (20 minutes) at 100%, and the lowest in L1 (10 minutes) at 87.33%. The increase in germination percentage in rubber seeds is due to the longer soaking time, which allows more water and oxygen to enter the seeds, thereby enabling the imbibition and respiration processes to run smoothly and allowing the germination process to proceed properly. During germination, the need for oxygen increases as respiration increases, because respiration will continue as long as the seeds are alive. A limited amount of oxygen can inhibit germination. Oxygen is needed in the process of synthesizing fat into sugar, because fatty acid molecules contain less sugar than sugar molecules. Research by (Sitanggang & Rizal, 2019) found that soaking rubber seeds for 12 hours increased germination by 85% compared to non-soaking by 65%.

The longer the soaking time, the faster the germination time of rubber seeds. The fastest germination time was in treatment L3 (20 minutes) at 17.38 days and the longest in L1 (10 minutes) at 18.93 days. A longer soak will make it easier for water and oxygen to enter the seeds, so that the imbibition process that stimulates hydrolysis and activates enzymes involved in germination, namely amylase, is more quickly translocated to the embryo, causing the seeds to germinate faster. (S. U. Lestari, 2021)stated that soaking seeds for 12 hours can accelerate rubber seed germination with a germination rate of 1.96% KN/etmal.

The longer the soaking time, the higher the number of normal sprouts. The highest number of normal sprouts was found in the L3 treatment (20 minutes) with 5 seeds, and the longest in the L1 treatment (10 minutes) with 4.27 seeds. The longer the soaking time, the faster the induced sprouts. This is because the seeds given the soaking treatment have a higher water content, which can cause swelling in the cotyledons and rupture the testa, allowing water and oxygen to enter the seeds and enabling germination. Research by (Gusman et al., 2019) found that soaking for 1 hour is insufficient to break dormancy, whereas soaking for 12 hours or more can damage the seeds.

Influence Concentration H_2SO_4 and Soaking Time to Breaking dormancy of Rubber Seeds (Hevea brasiliensis Muell.Arg)

The study found that the interaction between H_2SO_4 concentration and soaking time significantly affected germination rate, germination time, and the number of normal sprouts.

The results of the study showed that the 3% H_2SO_4 (H3) treatment with a 20-minute soaking (L3) produced the highest seed germination rate compared to other treatment combinations. The use of 3% sulfuric acid softened the rubber seed coat. The H_2SO_4 chemical solution can also kill fungi or bacteria that can cause seed dormancy. Softening the seeds increases water penetration into them. This will then lead to the reactivation of enzymes and hormones, allowing germination metabolism to occur more quickly. Sulfuric acid not only functions to help accelerate imbibition but also increases protein decomposition activity in the cytoplasm. The rate of water absorption into the seeds will increase with longer soaking times. Longer soaking times will increase seed imbibition, resulting in differences in the time required for the radicle and plumule to grow. The ability of seeds to germinate also depends on the availability of energy sources and compounds.

Important compounds needed to build the components of cells that form parts of the sprout organs, such as roots and shoots. Research by Gunawan et al. (2024) found that soaking coffee seeds in a 10% H_2SO_4 solution for 10 minutes yielded the highest germination rate among treatments. Research by (Binarht et al., 2023) found that soaking in a 20% H_2SO_4 solution for 20 minutes produced the highest germination rate of 97.78%.

The results of the study showed that the 3% H_2SO_4 (H3) treatment with a 20-minute soak (L3) had the fastest seed germination time among the treatment combinations. This relates to the use of H_2SO_4 concentration, which can soften the seed coat; if followed by a longer soaking, it will increase the water entering the seeds. Increasing water imbibition in the seeds will speed up germination. Research by (Ismail & Duryat, 2018) found that soaking candlenut seeds in a 20% H2SO4 solution for 30 minutes resulted in the fastest germination time of 36.50 days.

The results of the study showed that the 3% H_2SO_4 (H3) treatment with 20 minutes of soaking (L3) produced the highest number of normal sprouts compared to other treatment combinations. Research by Puspita and Erawati (2019) found that soaking Arabica coffee seeds in a 20% H_2SO_4 solution for 30 minutes resulted in the highest percentage of normal sprouts (66.25%).

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the study, it can be concluded that the treatment of rubber seed (Hevea brasiliensis Muell. Arg.) dormancy breaking using sulfuric acid (H_2SO_4) with different concentrations and soaking durations significantly influences seed germination performance. The application of H_2SO_4 up to a concentration of 3%, combined with a soaking duration of up to 20 minutes, was found to improve germination percentage, accelerate germination time, and increase the number of normal seedlings. Overall, seeds treated with the optimal combination showed faster physiological responses compared to other treatments, as indicated by higher germination rates and more uniform seedling growth. This demonstrates that chemical scarification using sulfuric acid is effective in weakening the hard seed coat, thereby enhancing water imbibition and activating embryo metabolism. Consequently, the combination of H_2SO_4 concentration and soaking duration is a critical factor in optimizing rubber seed germination and improving nursery efficiency.

Recomendation : Based on the findings of this study, it is recommended that rubber seed propagation programs use seeds derived from physiologically mature parent trees and apply appropriate pre-sowing treatments to improve germination success. The use of diluted sulfuric acid at controlled concentrations and carefully regulated soaking times can serve as an effective method for breaking seed dormancy. However, caution must be taken to avoid excessive concentration or prolonged exposure, as this may damage the seed embryo and reduce germination quality. Furthermore, future research is recommended to explore a wider range of acid concentrations and soaking durations, as well as to combine chemical scarification with physical or biological treatments. Such studies could help identify more efficient, safer, and scalable methods for large-scale rubber seed propagation. In addition, further physiological and biochemical investigations are suggested to better understand the dormancy mechanisms in rubber seeds, which would support continuous improvement in nursery practices.

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