



Effect of Sulfuric Acid (H_2SO_4) Scarification on Seed Dormancy Breaking and Germination of Soursop (*Annona muricata* L.)

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Abstract. *Soursop (*Annona muricata* L.) is a tropical fruit plant with high economic value; however, its cultivation is limited by seed dormancy, which delays germination. This study aimed to determine the most effective sulfuric acid (H_2SO_4) concentration for breaking seed dormancy and improving seed viability of soursop. The experiment was conducted at the Greenhouse and Plant Breeding Laboratory, Faculty of Agriculture, Universitas Riau, and implemented using a completely randomized design with four treatments: 0% (control), 70%, 75%, and 80% H_2SO_4 concentration. Each treatment was repeated five times. A total of 20 experimental units were obtained, each consisting of 25 seeds, for a total of 500 seeds used in the experiment. The results indicated that sulfuric acid treatment significantly affected most germination parameters. Seeds soaked in a 75% sulfuric acid solution exhibited the fastest germination time (28.40 Day After Planting), the highest germination percentage (88.80 %), and the strongest seed vigor (5.55%). These findings suggest that chemical scarification with 75% H_2SO_4 for 30 minutes can serve as a practical and efficient pre-sowing treatment to improve seedling establishment in soursop propagation.*

Keywords: *seed viability seed coat permeability, tropical seed physiology, vigor index.*

1. Introduction

Soursop (*Annona muricata* L.) is a tropical fruit plant originating from the Caribbean, Central America, and South America, and is now widely cultivated in Southeast Asia due to its high nutritional and economic value. The fruit is rich in potassium, vitamin C, dietary fiber, and carbohydrates, which are beneficial to human health. These nutritional properties have contributed to its widespread consumption among communities. In addition to being consumed fresh, soursop is also processed into various products such as soursop juice, soursop jam, and soursop ice cream, making it a versatile ingredient in local food industries (Sanusi *et al.*, 2023).

Preparing seeds or seedlings is the first step in soursop growing. The ability to obtain seeds quickly and in large quantities facilitates the cultivation of soursop plants. Farmers and the general public utilize soursop seeds as planting material. There are two methods for soursop propagation:

generative and vegetative. To produce a high number of seedlings, farmers or the community typically propagate soursop plants generatively (Leal & Paull, 2023).

When soursop plants are propagated generatively, a common issue is that the seeds take a long time to sprout. This is because the soursop seed coat is stiff, making it difficult for gasses and water to pass through and preventing germination (Zutah *et al.*, 2024). It takes two to three months for the seeds to sprout when soursop plants are propagated generatively (Okoli *et al.*, 2020). According to (Mimi *et al.*, 2023), soursop seeds have thick, hardseed coats that prevent them from absorbing gases and water, a process known as seed dormancy that hinders germination. The physiological state of the embryo, the physical traits of the seed coat, or a combination of the two may be the cause of seed dormancy (Espitia-Flores *et al.*, 2023).

Soursop seeds exhibit physical dormancy due to structural constraints and a thick, hard seed coat that restricts the entry of water and oxygen, thereby inhibiting germination. Dormancy-breaking therapies, appropriate climatic conditions, and seed viability all affect soursop seed germination (Najorda *et al.*, 2019). Even under optimal development conditions, mature and viable seeds may fail to germinate due to seed dormancy (Reed *et al.*, 2022).

A sulfuric acid solution disrupts cellulose microfibril linkages and partially degrades the seed cell wall, thereby enhancing permeability and facilitating the imbibition process. The entry of water and oxygen into the seed is essential for supporting embryo respiration and maintaining proper metabolic activity (Lestari *et al.*, 2016). The goal of sulfuric acid treatment for seed dormancy is to harm the seed coat; if the concentration or soaking time is too high, it could harm the seed embryo (Hidayat & Ridhawati, 2020).

Soaking seeds in sulfuric acid is commonly used to break seed dormancy. Gardner *et al.* (2018) reported that sulfuric acid, a strong acid, can soften hard seed coats, thereby facilitating the entry of water and gases during the germination. Sulfuric acid solution is capable of dissolving portions of the seed cell wall by breaking cellulose microfibril bonds, resulting in increased cell wall permeability and enhanced imbibition. The entry of water and oxygen into the seed is essential for embryo respiration, allowing proper metabolic activity to occur within the seed (Lestari *et al.*, 2016). Soursop seeds were soaked for 30 minutes in solutions containing 70%, 75%, and 80% sulfuric acid as part of the study. According to Suyatmi *et al.* (2011), soaking teak seeds in 70% and 80% H₂SO₄ for 30 minutes produced vigor indices of 0.76 and 1.13, respectively, and germination percentages of 69.00% and 81.00%. Pomegranate seeds soaked in 75% sulfuric acid for 10 minutes produced a vigor rating of 2.31 and an 86.67% germination rate (Satya *et al.*, 2015).

Several studies on soursop seeds have also reported that soaking duration significantly affects germination percentage, although its effect on seedling growth parameters is often

inconsistent (Sitorus *et al.*, 2025). Despite these findings, most studies have focused primarily on soaking duration, while systematic evaluation of different sulfuric acid concentrations under uniform experimental conditions remains limited. In addition, a comprehensive assessment combining germination and seed vigor parameters is still lacking.

Therefore, determining the ideal sulfuric acid concentration to successfully break dormancy in soursop while preserving seed viability and vigor is clearly a research need. The systematic assessment of various H₂SO₄ concentrations on germination success and seedling vigor using a controlled experimental design is what makes this work new. It provides more comprehensive and useful information for enhancing soursop seed propagation.

According to research by Azahra *et al.* (2022), soaking in H₂SO₄ for 15 minutes produced the highest germination values and significantly increased germination percentage, germination power, and seedling height, compared with soaking for 5 minutes. These results are in line with Khalil and Suleman (2019), the treatment of soaking duration in sulfuric acid significantly affects the germination percentage of soursop seeds, which is 81.25%, but does not have a significant effect on seedling height (cm), number of leaves (pieces), and fresh weight of the plants (g). The optimal concentration of sulfuric acid to break soursop seed dormancy is still not well researched, so this study was conducted with the aim of determining the effect of soaking soursop seeds in various concentrations of sulfuric acid, and to find the best concentration to break soursop seed dormancy.

2. Materials and Methods

The study was conducted at the Plant Breeding Laboratory and the Experimental Garden Greenhouse, Faculty of Agriculture, Universitas Riau, Bina Widya Campus (KM 12.5, Simpang Baru Sub-district, Binawidya District, Pekanbaru, Indonesia). The research was carried out from December 2024 to February 2025.

2.1 Materials

A local type of soursop seeds from Kediri, East Java, sulfuric acid, distilled water, soil, manure, sand, label paper, and Furadan 3G were among the ingredients utilized in this study. Glass containers, measuring cylinders, plastic germination trays that were 38 cm by 31.5 cm by 12 cm, polybags 15x15 cm, wooden stakes, sticks, machetes, watering cans, rulers, soil sieves, digital scales, an oven, stationery, and a camera were among the tools that used.

2.2 Methods

A completely randomized design was used for the experiment (CRD). Soursop seeds were soaked in different sulfuric acid concentrations as part of the treatment, which included the following four treatments:

M0 = Seed soaking in purified water (control)

M1 = Immersing seeds at 70% sulfuric acid concentration

M2 = Immersing seeds in 75% sulfuric acid solution

M3 = Immersing seeds in 80% sulfuric acid solution

For half an hour, each treatment was soaked. A total of 20 experimental units were produced, with five replications per treatment. A total of 500 seeds were employed in this investigation, with 25 seeds per experimental unit.

The soursop seeds used in this study were obtained from local sources. Prior to planting, the seeds were carefully selected based on uniformity in size and shape, free from physical damage (such as shriveling or wrinkling), and absence of pest and disease symptoms. The selected seeds were then immersed in distilled water for approximately 1 minute to identify viable and high-quality seeds. Only seeds that sank were considered viable and subsequently used for the experiment.

The selection of sulfuric acid concentrations ranging from 70–80% was based on the principle that the solution must be sufficiently strong to soften the hard seed coat without causing damage to the embryo. Lower concentrations are generally ineffective at breaking dormancy, whereas excessively high concentrations may lead to seed injury. Previous studies, [Utami *et al.* \(2020\)](#) have indicated that concentrations between 60–80% represent an optimal range for chemical scarification of hard-coated seeds. Therefore, the use of three concentration levels within this range aimed to determine the optimal balance between dormancy-breaking effectiveness and embryo safety.

A soaking duration of 30 minutes was selected because it represents an optimal period for softening the seed coat without causing damage to the embryo. Shorter soaking durations are insufficient to break seed dormancy, whereas prolonged exposure may result in tissue damage and disrupt of seed metabolic processes. [Sipahutar *et al.* \(2023\)](#) also reported that soaking durations of 15–30 minutes effectively increase seed coat permeability without reducing seed viability.

The observed parameters in this study:

1. Germination Time (days after sowing, DAS)

which was recorded daily from sowing until 50% of the seeds had germinated

2. Germination Percentage (%)

calculated using the formula (1):

$$\text{Germination percentage} = \frac{\text{number of normally germinated seeds}}{\text{total number of seeds sown}} \times 100\% \quad (1)$$

3. Vigor Index (%)

Determined based on standard vigor index calculations (2):

$$I.V = \frac{G_1}{D_1} + \frac{G_2}{D_2} + \frac{G_3}{D_3} + \dots + \frac{G_n}{D_n} \quad (2)$$

Note:

I.V = Vigor Index

G = Number of normal seedlings at each observation

D = Time corresponding to the number of germinated seeds (days)

n = Total number of days at the final observation period

4. Plumule Length (cm)
5. Radicle Length (cm)
6. Plant Height (cm)
7. Leaf Number (leaves)
8. Shoot Fresh Weight (g)
9. Root Dry Weight (g)

The collected data were analyzed using SAS software through analysis of variance (ANOVA) at a 5% significance level. When significant differences were detected, further analysis was conducted using the Honestly Significant Difference (HSD) test at the 5% level to identify the best treatment.

3. Results and discussion

3.1 Germination Time

The germination period of soursop seeds is significantly affected by sulfuric acid soaking, as indicated by the analysis of variance.

Soaking of soursop seeds in a 75% sulfuric acid solution produced a germination time of 28.40 (DAP), according to [Table 1](#). Since soursop seeds take two to three months to sprout, bathing them in sulfuric acid successfully breaks seed dormancy and speeds up germination in just four weeks ([Okoli et al., 2020](#)).

Table 1. Shows the germination time after soaking in different sulfuric acid concentrations.

Sulfuric Acid Concentration (%)	Germination Time (DAP)
0	34.00±0.89 b
70	30.80±0.58 ab
75	28.40±0.50 a
80	31.80±0.73 b

Note: The Tukey's Honestly Significant Difference (HSD) test indicates that numbers in the same column that are followed by distinct lowercase letters differ substantially at the 5% level.

When compared to soaking in 0% aquades (control) and 80% sulfuric acid, soaking in 75% sulfuric acid accelerated germination; however, there was no discernible difference compared to soaking in 70% sulfuric acid. Since sulfuric acid is powerful enough to weaken the hard seed coat, including the waxy layer and suberin, without harming the seed's inside (the embryo). Therefore, soaking the seeds in a 75% sulfuric acid solution is thought to be the best way to hasten the

emergence of soursop seedlings. Our data is consistent with the research by [Tanjung *et al.* \(2017\)](#). They found that immersing pea seeds in a 75% sulfuric acid solution for 10 minutes produced a germination time of 32.47 DAP.

By weakening or eroding the thick outer layer, soaking seeds in sulfuric acid facilitates the breakdown of the hard seed coat and makes it easier for oxygen and water to enter the seed. By promoting the faster transport of oxygen and water into the embryo, the eroded seed coat speeds up the imbibition process, causing seed enlargement and a rise in internal pressure ([Nurhaliza *et al.*, 2023](#)). The improved entry of water into the seed accelerates the imbibition process, which is the initial phase of germination. During imbibition, seeds absorb water rapidly, leading to swelling and increased internal pressure within the embryo and surrounding tissues. This physical expansion helps to further weaken the seed coat and facilitating radicle emergence. In addition, oxygen availability supports aerobic respiration, which is essential for energy production during early germination ([Ranmeechai *et al.*, 2022](#)).

When the seed coat is damaged, water and oxygen may enter, which helps enzymes like lipase, amylase, and protease start working by converting the food stores in the seed—such as carbohydrates, proteins, and fats—into smaller, more usable molecules. Because seed's food stores—such as carbohydrates, proteins, and fats—into smaller, more usable molecules. Because seeds need energy to develop, this mechanism increases respiration, especially aerobic respiration, and generates energy ([Penfield, 2017](#)). In the process that follows, the seeds create new cell structures and proteins to aid in growth. Cells start to lengthen and divide, especially in the radicle, which is the root's precursor. An early indication of germination is the radicle's appearance from the seed coat ([Muñoz-Llandes *et al.*, 2023](#)).

3.2 Germination Percentage

Analysis of variance data shows that soaking soursop seeds in sulfuric acid at different concentrations significantly affects their germination rate.

[Table 2](#) demonstrates that soaking soursop seeds in 75% sulfuric acid considerably boosts germination power when compared to soaking in 80% sulfuric acid and 0% aquades, but there is no discernible difference when soaking in 70% sulfuric acid. [Hidayat and Ridhawati \(2020\)](#) study, The lowest germination rate, at 20%, was observed at a sulfuric acid concentration of 90%. Excessively high concentrations can damage the seeds and inhibit germination, even when seeds are soaked in a gibberellin solution for 12 hours and 24 hours, which was not able to enhance the germination capacity of the seeds. [Wang *et al.* \(2019\)](#) reported that a 75% concentration efficiently breaks down or softens the soursop's hard seed coat, thereby accelerating enzyme activation by allowing water and oxygen to enter the seed embryo. Thus, the seeds' food stores can support

embryo growth, increasing the speed and vigor of germination (Azahra *et al.*, 2022). Tanjung *et al.* (2017) found that the combination of seeds soaked in 75% sulfuric acid for 10 minutes produces the highest germination percentage, vigor indices, and axis embryo + radicle length, i.e., 100%, 0.31, and 10.42 cm, respectively.

Table 2. Germination power after soaking in different sulfuric acid concentrations

Sulfuric Acid Concentration (%)	Germination Power (%)
0	60.80±0.37 b
70	79.20±0.80 a
75	88.80±0.48 a
80	66.40±0.67 b

Note: The Tukey's Honestly Significant Difference (HSD) test indicates that numbers in the same column that are followed by distinct lowercase letters differ substantially at the 5% level.

The viability and vigor of castor bean (*Jatropha curcas* Linn.) seeds were studied by Indriana (2017) using sulfuric acid, with a 93.521% germination rate. According to Rahayu and Suharsi (2015), a germination power of $\geq 80\%$ is deemed high, and the germination power shown with the 75% concentration treatment is regarded as substantial. These results are supported by recent research showing that germination is a key indicator of seed physiological quality and reflects the ability of seeds to produce normal seedlings under optimal conditions, where seeds with high germination tend to show better metabolic efficiency and faster activation of growth processes, which ultimately improves seedling establishment and early plant development (Pompelli *et al.*, 2023).

Utilizing sulfuric acid at the appropriate concentration can optimize the water imbibition process. According to Dai *et al.* (2023), Sulfuric acid, as a strong acid, is highly effective at breaking dormancy in hard-seeded species; it can soften the seed coat, allowing water to penetrate more easily. This is consistent with study by Ramadhani *et al.* (2015), which found that soaking in sulfuric acid is the most effective chemical dormancy-breaking therapy for increasing germination and vigor index while accelerating up the germination rate.

It works better to soak seeds in sulfuric acid than in aquades (control). Soaking soursop seeds in distilled water does not effectively break dormancy, as the seeds possess a thick and rigid coat that restricts the penetration of water and gases. Aquades find it challenging to break through the seed coat and start the imbibition process, which is essential for germination, as a result. Without weakening or releasing the hard coating, Aquades only succeeds in moistens the seed coat's surface, which keeps the seeds from absorbing the water they need to start germination (Muhammad *et al.*, 2020).

According to Table 2, soaking seeds in an 80% sulfuric acid solution reduced germination power, indicating a decline in seed viability and physiological quality. Germination power reflects the ability of seeds to germinate rapidly and uniformly under favorable conditions and is closely

associated with seed vigor, metabolic activity, and structural integrity. Previous studies have shown that any damage to seed tissues or disruption of metabolic processes can reduce germination performance and delay seedling establishment (Nonogaki, 2019). Therefore, excessive chemical exposure may impair enzymatic activity and reduce the overall germination capacity of seeds. In addition, excessive exposure to strong acids can disrupt membrane integrity and impair cellular respiration, ultimately inhibiting embryo viability and reducing germination success (Wen *et al.*, 2023). Ribeiro *et al.* (2020) further reported that prolonged exposure to highly concentrated sulfuric acid can result in tissue degradation and irreversible embryo damage, ultimately reducing germination capacity.

When seed metabolism is disrupted, viability and germination power gradually drop rather than dying instantly. This decrease results in reduced respiratory capacity, enzyme activity, and the germination process's energy (ATP) and assimilate supply required for germination (Widajati *et al.*, 2013). Suyatmi *et al.* (2011) found that soaking aren seeds in 80% or 90% sulfuric acid did not result in high germination percentages due to the extreme concentration, which denatures enzyme proteins and interferes with cotyledon and embryo metabolic processes.

3.3 Vigor Index

According to the analysis of variance, soaking soursop seeds in a sulfuric acid solution significantly affects germination rate.

Table 3. Vigor index after soaking in different sulfuric acid concentrations

Sulfuric Acid Concentration (%)	Vigor Index (%)
0	3.71±0.17 b
70	5.02±0.27 a
75	5.55±0.25 a
80	4.05±0.14 b

Note: The Tukey's Honestly Significant Difference (HSD) test indicates that numbers in the same column that are followed by distinct lowercase letters differ substantially at the 5% level.

Table 3 indicates that soaking in a 75% sulfuric acid solution raises the vigor index when compared to soaking in 80% sulfuric acid and 0% aquades, but it is not substantially different from soaking in 70% sulfuric acid. This result is in line with studies by Tanjung *et al.* (2017), in which sulfuric acid in sugar palm seeds sulfuric acid has a significant effect on the vigor index observation variable, with the highest data recorded at a treatment combination of 75% sulfuric acid concentration soaked for 10 minutes, yielding 0.31 germinations/day. The lowest data was observed at a treatment combination with 0% sulfuric acid concentration soaked for 10 minutes, yielding 0.06 germinations/day.

In contrast to Tanjung *et al.* (2017), the percentage of vigor index for aren is shown in Table 3. The interaction between the concentration treatment and soaking duration of sulfuric acid has a significant effect on the vigor index observation variable, with the highest data produced at a

treatment combination of 75% sulfuric acid concentration soaked for 10 minutes, yielding 0.31 germinations/day. The lowest data was observed at a treatment combination with 0% sulfuric acid concentration soaked for 10 minutes, yielding 0.06 germinations/day. This correlates with the remark of [Firmansyah \(2022\)](#), which indicated that soaking in sulfuric acid for 1 to 10 minutes does not affect dormancy breaking in saga seeds (*Adenanthera pavonina* L.), however soaking seeds for 60 minutes or more may cause overall harm to the seeds.

Combining these two variables can yield the best outcomes without harming the embryo inside the seed since variations in sulfuric acid concentration and soaking time impact the state of the seed coat or pericarp. Seed vigor is reflected in the rate and consistency of seed germination; seeds that can grow rapidly and consistently are more likely to flourish under less-than-ideal field conditions ([Ebone et al., 2020](#)). A thick and hard seed coat that delays the time it takes for the roots to penetrate is the cause of low seed vigor ([Zutah et al., 2024](#)).

The fact that the seeds come from various trees and geographic areas may also have an impact on the vigor index of soursop seeds. The seeds utilized in this study were collected from diverse plants and settings due to the restricted availability of soursop seeds. According to research by [Latue \(2019\)](#), a seed's resilience to multiple limiting factors affecting growth and development indicates that it has a high vigor value.

Genetic characteristics, including seed type, play a significant role in influencing factors that limit germination. The vigor index is commonly calculated based on the number and rate of seeds that germinate early. Seeds with a high vigor index demonstrate greater developmental potential and are more likely to establish into healthy plants with sustained growth performance in field conditions. ([Reed et al., 2022](#)). The rate of seed growth (days to germination) within a set of seeds is directly correlated with the vigor index of seeds.

A high vigor index indicates that the seeds are more resistant to adverse environmental circumstances and have a high germination rate. This supports [Iswara et al. \(2024\)](#) assertion that seedling vigor increases with seedling germination speed. Germination speed is a variable used as a measure of seed vigor and growth strength. The measurement of germination speed is obtained from the germination rate test.

3.4 Plumule Length

According to the analysis of variance, plumule length is not significantly affected by soaking soursop seeds in sulfuric acid.

In this study, the seeds used were uniform in size, meaning that the endosperm and food reserves inside the seeds were also relatively similar. The growth of plumule length primarily uses energy derived from the food reserves in the soursop seed endosperm itself ([Ilyas, 2012](#)). [Table 4](#)

demonstrates that soaking soursop seeds in sulfuric acid does not increase the plumule length of the seedlings. This suggests that the treatment of soaking soursop seeds in sulfuric acid solution has no effect on plumule length.

Table 4. Plumule length after soaking in different sulfuric acid concentrations

Sulfuric Acid Concentration (%)	Plumule length (cm)
0	5.88±0.09 a
70	6.91±0.06 a
75	7.87±0.03 a
80	6.74±0.04 a

Note: The Tukey's Honestly Significant Difference (HSD) test indicates that numbers in the same column that are followed by distinct lowercase letters differ substantially at the 5% level.

Water availability also affects plumule length, which is in line with [Setiawan *et al.* \(2021\)](#) assertion that plumule emergence is influenced by seed size and water availability. The process of water absorption is influenced by the seeds' initial water content and the amount of water that is available. Larger seeds tend to absorb water more quickly, so quickening the development of the radicle, followed by quicker expansion of the plumule, which also tends to grow longer. This is corroborated by [Zanzibars \(2017\)](#) assertion that nutrients, lipids, and carbohydrates in the endosperm are crucial for embryo development during the latter phases of germination.

[Tumpa *et al.* \(2021\)](#) discovered that tiny and big seeds display variances in plant development processes. Larger seeds are regarded preferable than smaller seeds, as they contain greater nutritional reserves. This study demonstrates that plumule lengths were consistent across all treatments.

3.5 Radicle Length

Radicle length is not significantly impacted by soaking soursop seeds in sulfuric acid solution, according to the analysis of variance data.

Table 5. Radicle length after soaking in different sulfuric acid concentrations

Sulfuric Acid Concentration (%)	Radicle Length (cm)
0	9.25±0.71 a
70	10.59±0.58 a
75	10.70±0.96 a
80	10.22±0.45 a

Note: The Tukey's Honestly Significant Difference (HSD) test indicates that numbers in the same column that are followed by distinct lowercase letters differ substantially at the 5% level.

[Table 5](#) demonstrates that the radicle length of the seedlings is unaffected by soaking soursop seeds in sulfuric acid. According to this study, the only way to break the dormancy of soursop seeds was to immerse them in a sulfuric acid solution. Since the soaking in sulfuric acid mainly helped the first phase (germination) by weakening the soursop seed coat, which is stiff and impermeable, without appreciably promoting or speeding radicle development, the soaking treatments did not show any discernible changes ([Elfianis *et al.*, 2023](#)). This is in line with the findings of [Satya *et*](#)

al. (2015), who found that soaking in sulfuric acid improved the germination rate of soursop seeds but had no discernible impact on radicle length.

It is thought that the growth media and water availability in this study affect radicle elongation rate. If the soil's water content and nutritional components remain present during the root development phase, roots will continue to grow. These findings are consistent with [Bachtiar \(2017\)](#) who reported that both external and internal factors influence the rate of root elongation. Under uniform treatments, growing media, and environmental conditions, plumule growth was observed to be relatively consistent across all treatments.

Soil temperature and moisture content are environmental factors that affect growth. A key component of plant growth is root volume, which indicates the plant's capacity to absorb nutrients and the metabolic activities within it. The growing medium or the state of the soil might also have an impact on the root system. According to [Cheraghi et al. \(2023\)](#) the main factor assisting seed germination is not the growth medium. Since irrigation was not used in this study's treatments, each plant received the same quantity of water. As a consequence, the soursop plants' root development was comparable in each treatment. The developing medium, an organ in charge of absorbing nutrients and water, is intimately associated with root development.

3.6 Plant Height

Plant height is not significantly affected by soaking soursop seeds in sulfuric acid solution, according to the analysis of variance.

Table 6. Plant height after soaking in different sulfuric acid concentrations.

Sulfuric Acid Concentration (%)	Plant Height (cm)
0	21.55±0.55 a
70	22.58±0.16 a
75	23.53±0.31 a
80	21.81±0.96 a

Note: The Tukey's Honestly Significant Difference (HSD) test indicates that numbers in the same column that are followed by distinct lowercase letters differ substantially at the 5% level.

Table 6 demonstrates that the height of the soursop plants is unaffected by soaking the seeds in a sulfuric acid solution. This is because soaking soursop seeds in sulfuric acid prevents vegetative development and solely affects the breakdown of seed dormancy. The soaking treatment with H₂SO₄ does not affect the length of the hypocotyl and radicle of the seedlings because the seeds that are able to germinate after the H₂SO₄ treatment are only affected in terms of softening the seed coat and do not reach the embryo, allowing the embryo to continue growing normally ([Suyatmi et al., 2011](#)).

Relatively uniform seedling development was observed across all treatments due to the consistent environmental conditions. Furthermore, plant height is strongly influenced by the availability of nutrients. Plants need certain amounts specific nutrients to support physiological

functions and growth, including photosynthesis, cell division, and cell creation. Insufficient nutrients in the polybags may prevent plants from growing to their full potential. This is consistent with [Namserna \(2023\)](#) Nutrient content has a significant effect on plant height. The more nutrients that are applied, the greater the increase in stem height. Plant height growth will improve if the plant's nutrient requirements are met. The increase in plant height will determine whether the number of leaves. Photosynthesis will occur optimally due to light absorption by chlorophyll present in the leaves, which is greatly influenced by the number of leaves formed.

[Namserna \(2023\)](#) claims that cell growth and development determine plant height increase. In plant growth and development, light intensity plays a crucial role in supporting the processes of photosynthesis, respiration, and transpiration. Plants that receive adequate sunlight tend to grow better because high light intensity can maximize the rate of photosynthesis. Additionally, light influences morphological characteristics of plants, such as leaf shape and number, stem thickness, and plant height. According to [Poorter *et al.* \(2019\)](#), light intensity plays a crucial role in determining photosynthetic rate. When light intensity is too low, plants do not obtain sufficient energy, resulting in a reduced photosynthetic rate. Conversely, excessive light intensity may disrupt photosynthesis due to surplus energy input. In the context of plant growth and development, light intensity is essential for supporting photosynthesis, respiration, and transpiration processes.

Particularly in low-light conditions, impaired hormone activity can interfere with the development of meristematic cells in the stem diameter ([Bachtiar, 2017](#)). In addition to improving cell elongation, division, and differentiation, nutrient availability during plant growth can enhance photosynthetic activity, thereby promoting overall plant growth and development ([Sari *et al.*, 2019](#)).

3.7 Leaf Number

The quantity of leaves (or leaflets), and the time of soaking soursop seeds in a sulfuric acid solution, significantly affected the number of leaves, according to the analysis of variance.

Table 7. Leaf number soaked in different sulfuric acid concentrations

Sulfuric Acid Concentration (%)	Leaf number (leaflets)
0	4.96±0.67 b
70	7.89±0.19 a
75	8.56±0.14 a
80	7.68±0.26 a

Note: The Tukey's Honestly Significant Difference (HSD) test indicates that numbers in the same column that are followed by distinct lowercase letters differ substantially at the 5% level.

According to [Table 7](#), soaking soursop seeds in a sulfuric acid solution might cause the plants to produce more leaves. There was no discernible difference between soaking soursop seeds in 70% and 80% sulfuric acid, however soaking them in 75% sulfuric acid produced a much greater

number of leaves than soaking them in 0% aquades. The pace of leaf emergence and other aspects of the plants' vegetative development can be accelerated by the speed at which seeds germinate.

Both the environment and genetic variables affect growth and leaf number. Leaves are essential organs in plants, as they function as the primary site for photosynthesis, enabling plants to convert light energy into chemical energy (Yudianto *et al.*, 2015). The growth and development of plants are influenced by leaf number; plants with more leaves have a greater capacity to capture light and produce energy compared to those with fewer leaves.

Environmental and genotypic variables affect the quantity and size of leaves. Temperature, air quality, water availability, and nutritional content are environmental elements that impact leaf size and quantity. Sufficient food stores (proteins and carbs) are necessary for leaf production; as the number of leaves rises, photosynthesis likewise accelerates, storing and using more food reserves for growth (Sari *et al.*, 2019).

The results of the study indicate that the number of leaves in *S. punicea* seedlings is significantly influenced by sulfuric acid concentration. The 98% H₂SO₄ concentration produced the maximum number of leaves per seedling (31.05), while the 50% concentration resulted in 29.31 leaves. An immersion time of 15 minutes yielded the highest number of leaves (32.08) compared to the control (27.72 leaves). Hot water treatment also increased the number of leaves, with seeds soaked in hot water producing 31.27 leaves. The interaction between the 98% H₂SO₄ concentration, a 15-minute immersion duration, and hot water soaking resulted in the highest number of leaves per seedling (36.66), significantly different from other treatments, while the control showed the minimum number (29.58). This indicates that soaking seeds in sulfuric acid and hot water can enhance leaf production in soursop plants (Al-Hadedy *et al.*, 2024).

3.8 Shoot fresh weight

The shoot fresh weight is significantly affected by soaking soursop seeds in sulfuric acid solution, according to the analysis of variance.

Table 8. Shoot fresh weight after soaking in different sulfuric acid concentrations

Sulfuric Acid Concentration (%)	Shoot Fresh Weight (g)
0	0.89±0.18 c
70	1.82±0.12 ab
75	2.14±0.11 a
80	1.54±0.15 b

Note: The Tukey's Honestly Significant Difference (HSD) test indicates that numbers in the same column that are followed by distinct lowercase letters differ substantially at the 5% level.

As seen in Table 8, soaking soursop seeds in sulfuric acid can increase the shoot fresh weight of seedlings. While soaking soursop seeds in 75% sulfuric acid is not very different from soaking them in 70% sulfuric acid, it is different from soaking them in 0% aquades and 80% sulfuric acid. According to Tanjung *et al.* (2017) and Satya *et al.* (2015), seed fresh weight indicates their

physiological status. High physiological grade seeds will grow vigorously and yield plants with a greater fresh weight.

The stem's diameter increases the amount of water it contains, which raises the canopy's new weight. According to [Al-Hadedy *et al.* \(2024\)](#), a plant's fresh weight is determined by the amount of water in its organs, such as the stem, leaves, and roots; a higher water content might result in a higher fresh weight for the plant's canopy. This is supported by previous studies indicating that plant water content is closely associated with biomass accumulation and tissue hydration status, which directly influence fresh weight measurements ([Ievinsh, 2023](#)).

By dissolving or damaging the hard outer layer, soaking soursop seeds in sulfuric acid can weaken the seed coat and make it easier for nutrients, oxygen, and water to reach the seeds. This improves the seedlings' capacity to take up nutrients and water. The water content of seeds increases with their capacity to absorb water, which can hasten germination, encourage plant development, and improve seed metabolism ([Carrera-Castaño *et al.*, 2020](#)). According to [Tambunsaribu *et al.* \(2017\)](#), the dry weight of the plants is closely related to germination capacity, with higher germination capacity resulting in faster seedling growth and, consequently, a heavier dry weight.

Strong root growth enables the plant's roots to seek out water and nutrients on their own, producing plants with comparatively high fresh weight values. Photosynthesis results in an increase in the fresh weight of plants due to the uptake of CO₂, while respiration leads to a decrease in fresh weight due to the release of CO₂ ([Zainal *et al.*, 2014](#)). If the plant's relative growth rate is higher, photosynthesis will be better, ultimately increasing the plant's fresh weight. A reduction in water volume decreases the plant's fresh weight. Insufficient water absorption by the plant hinders the increase in size and volume of the cells, preventing plant organs from growing properly.

It has been demonstrated that soaking seeds in a sulfuric acid solution can hasten the germination process and improve the early development of plants. By softening the outer layer (testa), this treatment helps to break the seeds' physical dormancy ([Azahra *et al.*, 2022](#)).

3.9 Root Dry Weight

Soaking soursop seeds in a sulfuric acid solution significantly affects root dry weight, as indicated by analysis of variance.

Table 9. Root dry weight after soaking in different sulfuric acid concentrations

Sulfuric Acid Concentration (%)	Root Dry Weight (g)
0	0.11±0.02 c
70	0.21±0.01 b
75	0.29±0.01 a
80	0.21±0.01 b

Note: The Tukey's Honestly Significant Difference (HSD) test indicates that numbers in the same column that are followed by distinct lowercase letters differ substantially at the 5% level.

Table 9 illustrates how the dry weight of the roots of soursop seedlings can be impacted by soaking them in a sulfuric acid solution. With a dry root weight of 0.29 g, soursop seeds soaked in 75% sulfuric acid produced the highest weight. All other therapies are very different from this one. Longer-rooted plants outperform those with shorter roots. Longer roots often have a larger dry weight, which is a sign of more root biomass, since their length represents their capacity to develop and obtain water and nutrients in the growth medium.

The buildup of organic compounds produced by the plant, which is influenced by the roots' capacity to absorb water and nutrients, is what gives the roots their dry weight. Because longer roots have more extensive and dense root networks, which result in increased root biomass and enable optimal plant growth, a longer radicle length suggests superior root development, which is typically followed by a rise in dry root weight (Sofi *et al.*, 2018).

The plant's capacity for photosynthetic activity also affects root development. In this process, leaves are essential; the more leaves there are, the better photosynthesis is, which in turn affects root growth and, eventually, dry weight (Yudianto *et al.*, 2015). In addition to meeting the plant's nutritional needs, optimal root growth can result in taller plants with a higher leaf index, enhancing the plant's capacity to absorb and utilize sunlight for photosynthesis. Consequently, the plant's photosynthetic activity increases, which raises dry weight, reflecting the amount of organic compounds produced, which in turn depends on the rate of photosynthesis and the rate of nutrient absorption by the roots. The nutrients that can be rapidly absorbed by the plant activate photosynthesis, further accelerating it (Giller *et al.*, 2021).

According Shara *et al.* (2014), plants with robust roots are better able to find and absorb nutrients and water from the soil. The roots' ability to absorb nutrients from the soil environment increases with length. The roots' ability to transfer water throughout the plant depends on how much of it they can absorb. Inadequate root absorption of water and nutrients is frequently the cause of low dry root weight. The increase in biomass is attributed to greater water and nutrient absorption. Nutrients stimulate the development of plant organs, such as roots, allowing the plant to absorb more nutrients and water, thereby enhancing photosynthesis, root fresh weight, and root dry weight (Pratiwi & Nafira, 2021).

Higher dry root weight indicates that seeds with high vigor often yield stronger seedlings and higher root development. The biomass produced, which best absorbs water and nutrients to support plant development, is indicated by the dry weight of the roots. In order to assist the plant's general growth and development, seeds with high vigor typically have strong roots and a high dry root weight (Hidayat & Ridhawati, 2020).

4. Conclusions

Soaking soursop (*Annona muricata* L.) seeds in different concentrations of sulfuric acid significantly affected several growth parameters, including germination duration, germination rate, vigor index, leaf number, shoot fresh weight, and root dry weight. Among the various treatments, soaking the seeds in 75% sulfuric acid produced the best results. This treatment yielded the highest germination rate (88.80%), the shortest germination time (28.40 days after sowing), the highest vigor index (5.55), the greatest number of leaves (eight leaflets), as well as the highest canopy fresh weight and root dry weight (2.14 g and 0.29 g, respectively), compared with other concentrations tested. Sulfuric acid concentration did not significantly affect plumule length, radicle length, or plant height, providing a complete and balanced summary of the findings. Future research should explore the combined application of acid scarification with other dormancy-breaking methods, such as hormonal treatments or mechanical scarification, to further optimize germination and early plant growth.

Abbreviations

HSD Honestly Significant Difference
DAP Days After Planting

Data Availability Statement

Data will be made available on request.

Credit Authorship Contribution Statement

Eko Wahyudi: conceptualisation, data analysis, research methodology, data collection, data analysis, **Melati Hutabarat:** Data collection. **Elza Zuhry:** methodology, conceptualisation, sumber daya, and pengawasan. **Elisa Apriliani:** understanding and conceptualisation. **Dian Rakhmad:** data analysis, conceptualisation, and observation. **Anthony Hamzah:** data validation and conceptualisation. **Chandra Gunawan:** verification of literary writing. **Yunandra:** understanding and conceptualisation, verification of data.

Declaration of Competing Interest

The author writes that there are no conflicts of interest or competing interests.

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