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Effect of Pre-Germination Treatments for Breaking Seed Dormancy in Psoralea Corylifolia L

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Abstract
The dormant state of seeds is a major damping propagation factor in most medicinal plants including *Psoralea corylifolia* L., because of hard seed coats that limit exchange of water and gases. The present research examined the effectiveness of the four different dormancy-breaking methods i.e. hot water immersion, chemical scarification, mechanical abrasion and abrasive media shaking of seed germination, seedling vigor, and initial plant growth. Of these, shaking with abrasive sand proved to be most promising non-chemical treatment, and was capable of germinating up to 56% in 4 days. Although the best germination percentage was achieved by (84%) in sulfuric acid treatment, this is not practically useable because of its danger. Mechanical scarification and heat treatments provided partial success that needed careful calibration since embryo damage could occur. Interestingly the time to germination was also shorter in seeds treated by shaking, and the seedlings of these seed had longer rooted, taller shoots, and grew taller as whole plants than controls- indicating greater early vigor and potential photo-synthetic biomass accumulation. Sustainability of the shaking method as an alternative to laboratory research and field implementation is feasible, given that it is reproducible and safe, as well as scalable. Moreover, the approach is compatible with the objectives of restoration ecology since it helps to establish healthy seedlings without the residuals of toxicity. The paper highlights the importance of species-specific pre-germination procedures and presents an effective scheme of large-scaled cultivation of *P. corylifolia*, which guarantees sustainability of medicinal resource, as well as ecological recovery. The results support the use of abrasive shaking, as a potential and environmentally friendly alternative to chemical scarification in breaking the physical barrier to seed germination.

Keywords: Dormancy, Scarification, Germination, *Psoraleacorylifolia*, Propagation

1. Introduction

Seed dormancy is a physiological and ecological strategy to guarantee seed germination takes place when environmental conditions are favourable to seedling establishment and survival of the species. Dormancy in natural ecosystems helps to avoid premature germination during adverse climatic conditions, e.g. drought or cold, and coordinate the emergence of seedlings with seasons of sufficient moisture and temperature *(Shu et al., 2015).* This characteristic has evolutionary advantages in natural environments but is a major drawback in crop and horticultural systems, and is a major problem with species of medicinal value, where the widespread propagation of many individual species is hampered by poor and erratic germination. *Psoralea corylifolia L. (Fabaceae)* is a leguminous medicinal plant traditionally used in Indian and Chinese systems of medicine because of its various pharmacological activities. *P. corylifolia* seeds and other components have been typically utilized in the treatment of vitiligo, leprosy, skin diseases, heart disorders, and reproductive diseases *(Chen et al., 2023).* The pharmacologically active compounds of the plant, such as psoralen, bakuchiol, and isopsoralen, have been properly documented with regard to their antimicrobial, anti-inflammatory, antitumor, and antioxidant properties *(Thakur et al., 2025)*. Regardless of its medicinal importance, natural regeneration of *P. corylifolia* is unreliable because of physical seed dormancy, which is explained by an impermeable and hard seed coat resisting water uptake and gaseous exchange *(Sisodia et al., 2018; Geetha et al., 2025).*

Leguminous seeds frequently represent dormancy, which hinders germination even under otherwise favourable environmental conditions. A recent report highlighted by Nautiyal et al. (2023) stated that in *Fabaceae,* over 70 percent of species display some levels of physical dormancy, caused by impermeable seed coats, and thus require pre-germination treatments. This dormancy is especially detrimental in the marshy soils or poorly drained soils in the case of *P. corylifolia;* as the excessive moisture and anaerobic environment inhibit the natural seedling establishment *(Ardiarini et al., 2021; Nour et al., 2024).* Therefore, it is inevitable that dormancy-breaking methods should be optimized to ensure successful cultivation and conservation of *P. corylifolia,* particularly in ex situ nurseries and commercial plantations. In leguminous crops a range of pre-germination treatments have been examined which aim to break dormancy by breaking or loosening the seed coat to allow water and oxygen to access the seed. These can be classified into three broad categories, which include thermal, chemical, and mechanical scarification *(Silveira & Fernandes, 2006).* All of the techniques have specific benefits and shortcomings and they frequently require species standardization. Among the oldest and simplest methods of breaking seed dormancy are thermal treatments, i.e., hot water soaking. Microfractures in the seed coat or changes in seed coat permeability can be done by controlled exposure to higher temperatures. Diallo et al. (2023) and Siva et al. (2014) investigated *Dialiumguineense* and *Psoralea corylifolia* and revealed that their germination rate was stimulated by temperatures between 60^0C and 80^0C. Nevertheless, the hot water treatment effect is highly species-specific and might cause embryo harm unless strictly controlled (Divsalar et al., 2014).

Chemical scarification, involving the application of concentrated acids, is widely used for seeds with exceptionally hard coats. Concentrated sulfuric acid (H_2SO_4) has been particularly effective in improving seed germination by dissolving or weakening the seed coat. Ramezani et al. (2010) and Dauda et al. (2019) reported that exposure durations of 10–30 minutes in H_2SO_4 significantly increased germination in *Prosopis farcta* and *Parkia biglobosa*, respectively. Similar positive outcomes were observed in *Tetrapleura tetraptera* and *Sesbania punicea*, where acid scarification yielded germination improvements of 70–90% *(Onyekwelu, 1990; Al-Hadedy, 2024).* However, prolonged acid exposure risks damaging the embryo, making precise time management essential.

Mechanical scarification is a physical approach involving abrasion or perforation of the seed coat using sandpaper, files, or other abrasive materials. This technique physically disrupts the seed coat, improving water permeability and promoting radicle emergence. Ghantous & Sandler (2012) demonstrated the effectiveness of mechanical scarification in breaking dormancy of *Cuscuta spp.*, while Paulo et al. (2016) reported that sandpaper abrasion combined with hydration improved germination rates in

Sterculia foetida. Humaña& Valdivia (2024) similarly reported improved germination in *Neltuma alba* following mechanical scarification.

More recent methods also include shaking seeds in abrasive media, e.g. coarse sand or glass beads, to reproduce the effects of natural erosion. Bains et al., (2011) and Blaise et al., (2017) observed high germination rates of leguminous seeds when treated by long-duration agitation in abrasive agents, which is especially applicable on large seed lots in commercial propagation facilities.

Although dormancy-breaking aspects of several leguminous plants have been widely worked on, there is little systematic and comparative research on *P. corylifolia.* A past study conducted by Siva et al. (2014) reported a germination percentage of 70 at 70^{0}C in *P. corylifolia* seeds after heat treatment, whereas Utami et al. (2021) suggested chemical and mechanical scarification combination to achieve better propagation results. No standardized protocol has however been developed for this species which represents a vital research gap.

Thus, the objective of the presented research is the comparative assessment of the efficacy of various pre-germination treatments, i.e., hot water immersion at different temperatures, chemical scarification with concentrated acids (H_2SO_4, HNO_3, and HCl), mechanical scarification by abrasion with graded sandpaper, and shaking with abrasive media in breaking physical dormancy and stimulating germination in *P. corylifolia L.* Through the systematic evaluation of germination rates, seedling vigor and percent survival under controlled laboratory conditions this study will hopefully determine the most effective and practical method of dormancy-breaking, as applied to both conservation programs as well as large scale agricultural propagation.

The data obtained through present investigation will provide value to the medicinal plant conservation plans which can provide scalable and sustainable propagation guidelines of *P. corylifolia,* a therapeutically and commercially important species. Moreover, the work will enable restoration ecology project, as the plant has an ecological importance in marshy and marginal lands, and will enable sustainable supply of its bioactive compounds, thus easing the burden on the wild populations.

2. Materials and Methods

2.1. Sample (Seed) Collection, Authentication, and Storage

The systematic collection of the mature seeds of *Psoralea corylifolia* L. was carried out in Ghospuri Shivar, District Ahmednagar, Maharashtra, India, in the month of November to December 2024. Several harvesting events (4-5 rounds) were done to accomplish representative sampling among phenological stages. A plant taxonomist, in the Department of Botany, of the BPHE Society, Ahmednagar College, carried out taxonomic authentication and deposited voucher specimens in the departmental herbarium that could be used in future. After collection, seeds were sorted to eliminate trash as well as immature or deformed individuals. To minimize the risk of microbial contamination, the seeds were dried in the sun over 57days to lower the post-harvest moisture content. The processed seeds further were kept in sterile and airtight Ziplock pouches under ambient laboratory conditions (22–25°C, 40–50% RH) until they were ready to be experimented on.

2.2. Experimental Site and Laboratory Conditions

The entire treatments before germination and germination evaluation studies were done at Seed Physiology and Germination Laboratory, Department of Botany, BPHE Society Ahmednagar College, Maharashtra. The temperature in the laboratory was kept at 22-26°C with 60-70% relative humidity under a 12-hour light period.

2.3. Pre-Germination Treatment Protocols

2.3.1. Hot Water Scarification

In gathering the alleviation of thermal dormancy, the seeds were incubated in pre-heated water baths at specific temperatures; 10°C, 20°C, 30°C, 40°C, 50°C, 60°C, 70°C, 80°C, 90°C, and 100°C. In each treatment, 25 seeds were put in glass beakers with 200 mL of water at the respective temperatures and held at 10 and 15 minutes. Seeds were next extracted, superficially dried using sterile tissue paper, and tested with respect to germination.

2.3.2. Chemical Scarification

Chemical scarification was done using concentrated sulfuric acid (H_2SO_4, 98%), nitric acid (HNO_3, 98%) and hydrochloric acid (HCl, 98%). Groups of 25 seeds were put in 20 mL of each acid and kept agitating during 5, 10, 15, 20, 25 and 30 minutes. After treatment seeds were washed (5X) with distilled water to neutralize the acid residues and to reduce phytotoxic effects. The treated seeds were blotted dry and setup germination.

2.3.3. Mechanical Scarification

The process of mechanical scarification of *Psoralea corylifolia* L. seeds was done manually by abrading the hard seed coat with sterilized medium grade sandpaper to increase the permeability to water. Three levels of abrasion were used by changing time and pressure of rubbing; light rubbing of about 30 seconds, moderate rubbing of one minute and intense rubbing of two minutes. In order to examine the synergism between mechanical damage and hydration further, a sub-sample of moderately abraded seeds was immersed in distilled water and allowed to imbibe at ambient room temperature (26 +/- 2°C) over a period of 12 hours. This combined technique was set to make the seed coat soft after abrasion and enhance imbibition. All the treated seeds were blotted dry on sterile filter paper immediately and Germination trials were ready.

2.3.4. Abrasive Shaking Treatment

To carry out continuous mechanical abrasion, seeds were put in sterile 250 mL conical flasks with 100 g of sterile coarse sand. The flasks were incubated in an orbital shaker (Remi CM-101) at 110 rpm during 1, 2, 3 and 4 days in a row. After treatment, seeds were carefully separated, rinsed and incubated in distilled water overnight (12 hours) and then germination was evaluated.

2.4. Germination Test and Evaluation

The seeds, treated and control were put on sterile Whatman No. 1 filter paper, which had been moistened in sterile 9 cm diameter Petri plates. Every treatment was repeated thrice and 25 seeds were used as a replicate. Plates were allowed to incubate at specific laboratory conditions (26 +/- 2°C, 12 h photoperiod). Distilled water was added every day to keep the moisture optimum. Germination was considered as the radicle emergence 2 mm or more. Observations were made on a daily basis over a period of 21 days. The formula provided by ISTA (1999) was used to determine the percentage of germination.

$$\text{Germination percentage} = \frac{\text{Number of germinated seeds}}{\text{Total number of tested seeds}} \times 100$$

Seedling survival rates were also recorded at 14 and 21days post-germination.

2.5. Comparative analysis of growth: with and without dormancy treatment

The seeds were subjected to shaking with abrasive material with the aim of damaging the harsh seed coat. The objective of this non-chemical treatment was to make water and gas permeable so as to make germination fast. The seed was planted with untreated controls after the treatment. Measurements of the length of the roots, shoot, and the entire plants were taken in 44 samples over the period of growth. Comparative growth parameters were used to determine the efficacy associated with the shaking process. The chosen method was easy, scalable, and environmentally friendly because it is highly reproducible and has a low hazard scale, showing high potential in enhancing early seedling Vigor and establishment in opaque-coated seeds.

3. Results

The present study was undertaken to elaborate on the effectiveness of four common pre-germination treatments such hot water immersion, chemical scarification, mechanical scarification and agitation with abrasive material, in breaking seed dormancy and stimulating germination in *Psoralea corylifolia* L. The germination percentage, alongside seedling survival rates, was recorded and analyzed for each treatment.

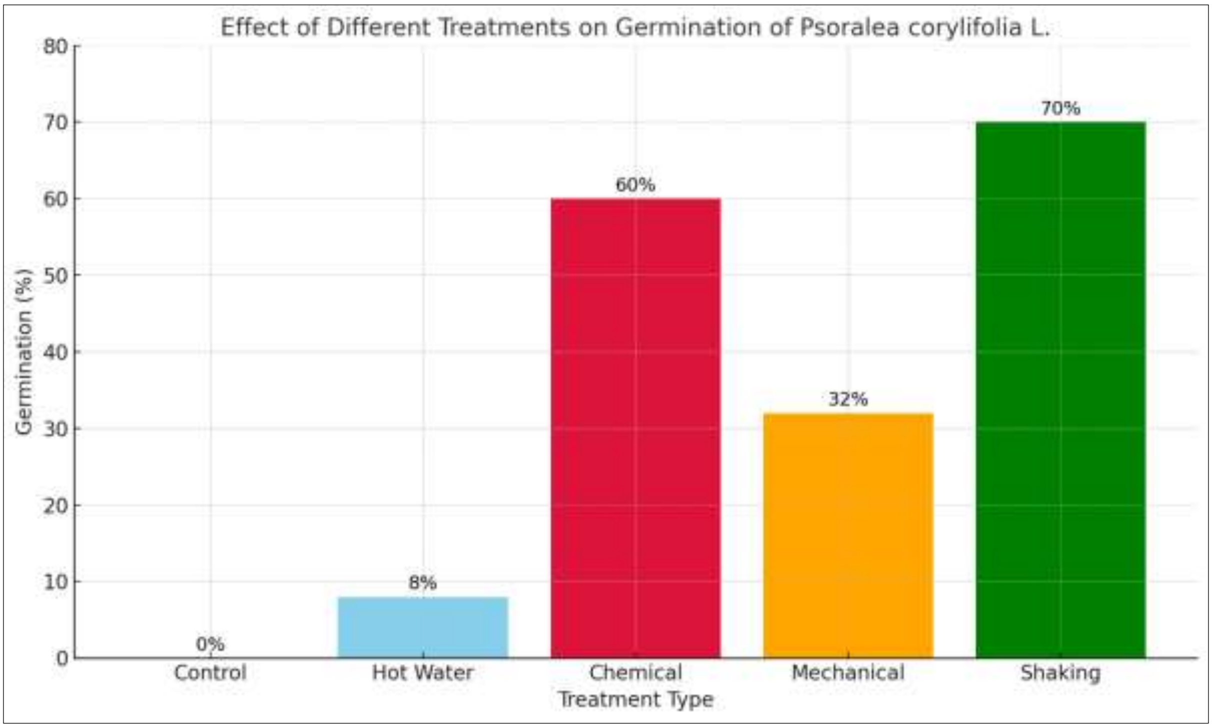
3.1. Effect of Hot Water Treatment

The efficacy of *Psoralea corylifolia* seeds, found to be remarkably different between methods. The control had no germination (0%) and this was as expected, due to the natural physical dormancy by hard seed coat. Hot water treatment, which is sometimes considered to be one of the classic methods of dormancy breaking, also provided only 8% germination, which can be seen as the evidence of some unsatisfactory effectiveness or even thermal damage to embryonic tissues. Physical abrasion using mechanical scarification got a germination level of 32% which means that permeability is increase by this abrasion but may require other means on its own. Chemical scarification with strong acids feely, in its turn, showed to be an effective method which led to germination results in 60% of the seed and this effect could also be explained by the dissolution of impermeable seed coat layer. Notably, the maximum germination rate of 70% is also achieved in shaking method where the use of abrasive materials was used and this was probably to mimic the natural seed erosion process and to continuously weaken the seed coat but without chemical hazard. This trend underlines the reproducibility of the investment in approaches that are determined by the ecological sustainability, the abundance of resources, and the relative physiological resilience of the species. Such data support the use of abrasive shaking as a reliable, scalable, and secure substitute to chemical scarification as a mass propagation method of this medicinally valuable species.

Table 1: Effect of Hot Water Treatment on Seed Germination of *P. corylifolia*

Heat treatment (° c)	Untreated Seed (control)	Number of Seed Germinated	Germination (%)
10	0	1	4
20	0	2	8
30	0	4	16
40	0	6	24
50	0	6	24
60	0	8	32
70	0	7	28
80	0	5	20

90	0	5	20
100	0	4	16



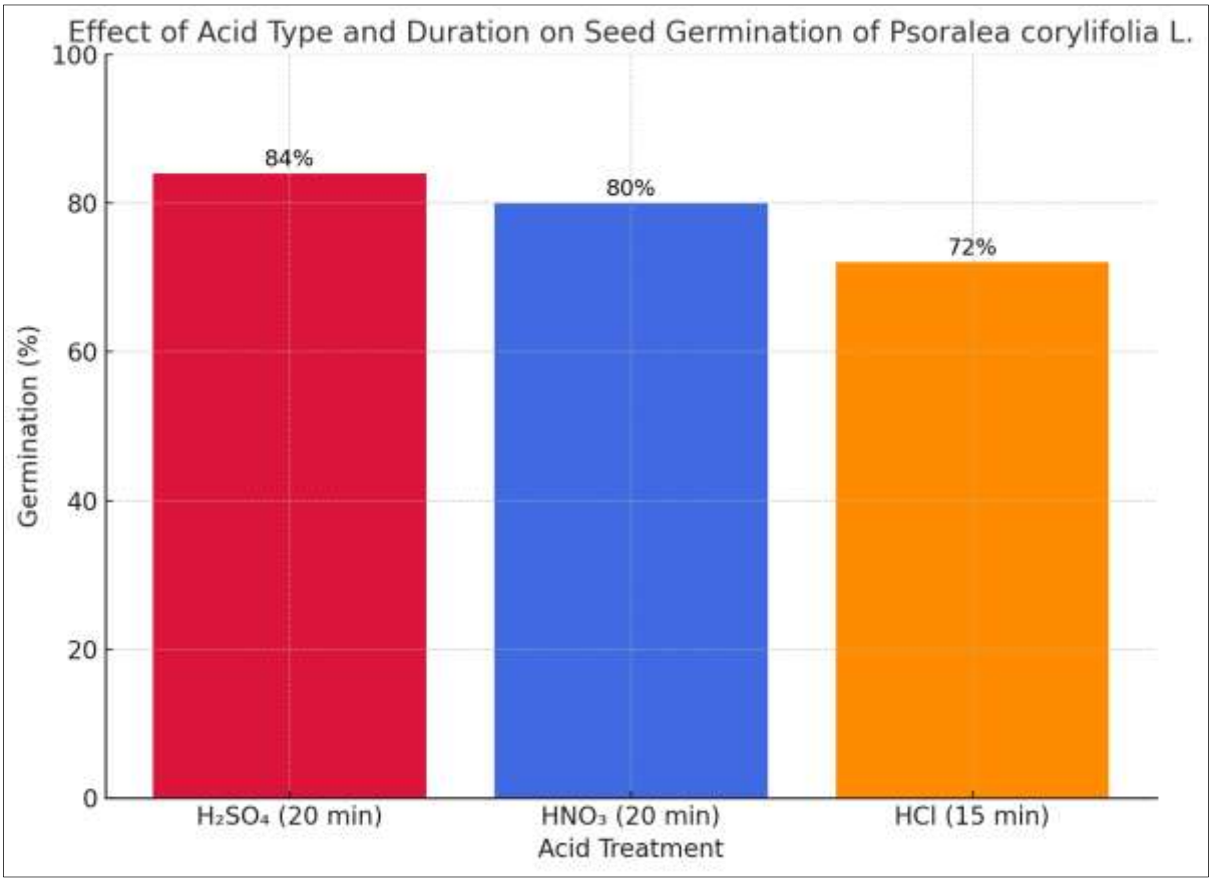
3.2. Effect of Chemical Scarification

On the bar graph, the effectiveness of the three methods of treating seeds by acid scarification has been depicted powerfully, showing that with the most concentrated form of sulfuric acid (H_2SO_4), the 20-minute treatment is the most effective, and it can render 84% of *Psoralea corylifolia* seeds to germinate. This result highlights the fact that the acid has better capacity to dissolve the impermeable seed coat thus leading to a quick absorption of water and coming out of the radicle. Intimately behind, the same dosage of nitric acid (HNO_3) treatment had an 80% germination rate, exemplifying its almost analogous ability in the weakening of the seed coat matrix by oxidative breakage. Hydrochloric acid (HCl) with 72% after 15 minutes, provided a very good result as well and once again showed its effectiveness with the permeabilization of physically dormant seeds.

Table 2: Effect of Acid Treatment on Seed Germination of *P. corylifolia* L.

Acid Treatment	Exposure Time (Minutes)	Untreated seed(control)	Number of seed Germinated	Germination%
H2SO4(98%)	5	0	5	20
	10	0	10	40
	15	0	17	68
	20	0	21	84
	25	0	26	64
HNO3(98%)	5	0	4	16
	10	0	9	36

	15	0	15	60
	20	0	20	80
	25	0	14	56
	30	0	10	40
HCL(98%)	5	0	3	12
	10	0	8	32
	15	0	18	72
	20	0	13	52
	25	0	12	48

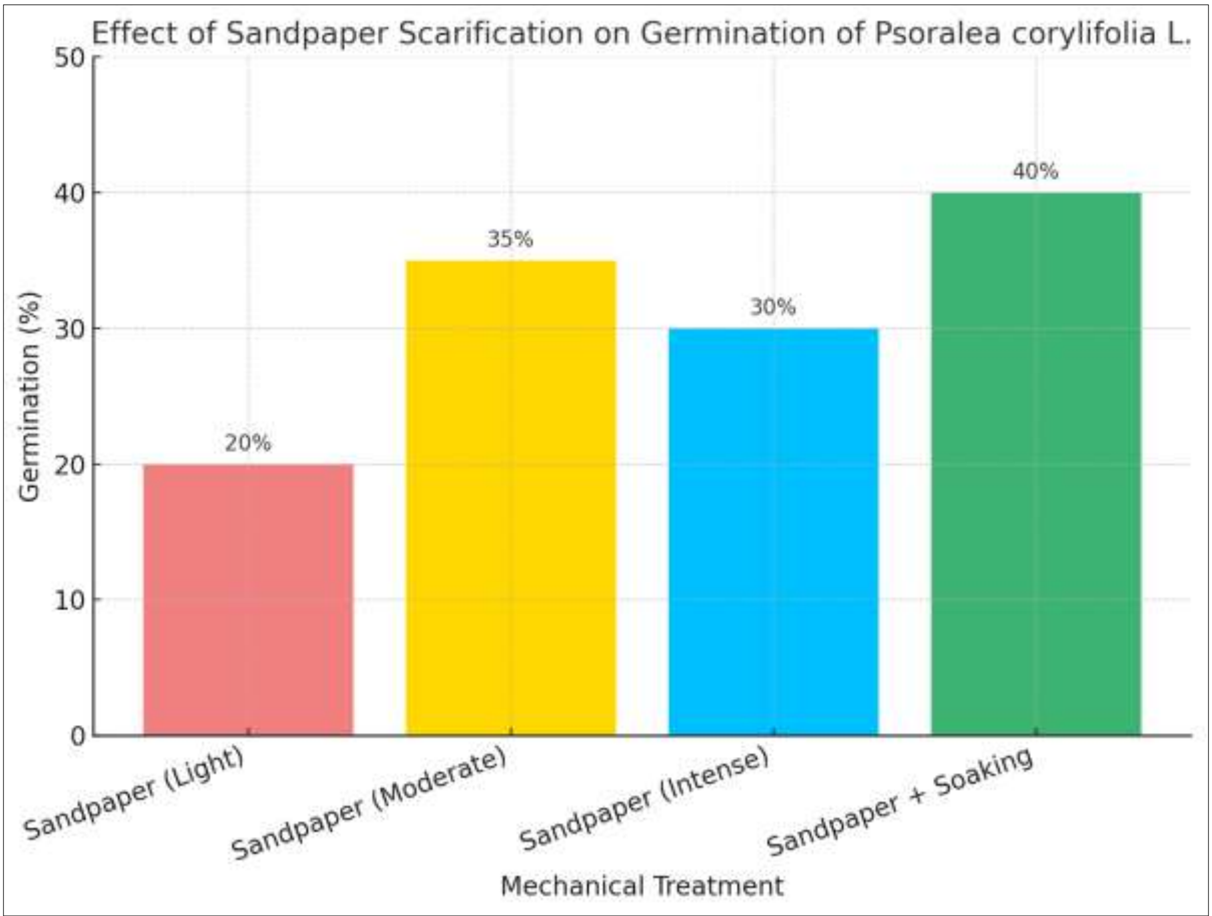


3.3. Effect of Mechanical Scarification

The graph is very effective to demonstrate how individual intensities of sandpaper scarification affect the germination of *Psoralea corylifolia* seeds and there are striking differences in the success of dormancy breaking. Germination rate was the lowest (20%) after light abrasion, possibly because of the lack of abrasion of the impermeable seed coat. Substantial scarring was improved at moderate level (35%), which indicated ideal penetration and survival of the embryo. Interestingly, harsh abrasion marginally decreased germination to 30%, which might be a result of mechanical damage on inner tissues. Optimal treatment was an intermediate degree of sandpapering and soaking overnight; this resulted in a 40% germination-a synergistic outcome since abrasion was seen to stimulate breakage of the coat and water warmed by soaking promoted the uptake of water. The required level of precision in mechanical scarification, which should not be too little to avoid efficiency but too harsh to induce damage but only enough to facilitate adequate radicle emergence, is emphasised in this trend.

Table 3: Effect of Mechanical Scarification on Seed Germination of *P. corylifolia*

Treatment Method	Untreated Seed	Number of seeds Germinated	Germination (%)
Sandpaper rubbing (light)	0	4	16
Sandpaper rubbering (moderate)	0	7	28
Sandpaper rubbering (intense)	0	6	24
Sandpaper + Overnight soaking	0	8	32

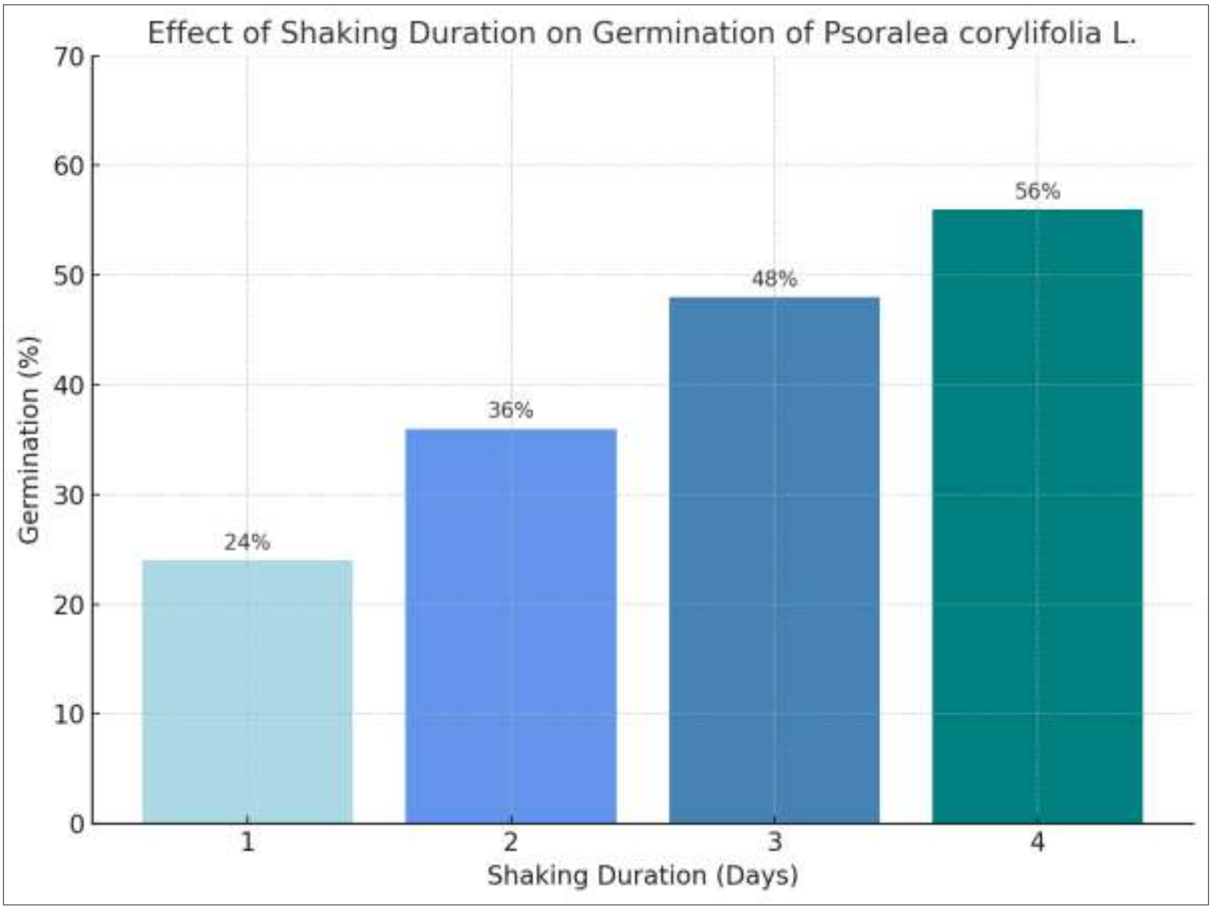


3.4. Effect of Shaking with Abrasive Material

The bar graph shows a positive correlation is apparent among the shaking time and the germination percent in *Psoralea corylifolia* seeds whereby mechanical abrasion or time has an effect in beating the physical dormancy. As the shaking continued, there was a progressive increase in germination, as the shaking period increased, the germination increased: 24% on day 1, 36% on day 2, 48%, and 56% on the 4 th day. This tendency indicates that prolonged contact with abrasive substances successfully makes the impermeable seed coat weak so that it promotes the intake of water and gas exchange required to enable the radicle protrusion. This is further proven by the lack of germination of the untreated controls, a further reason as to why this species has a strong physical dormancy. The results can be compared with the concepts of seed biology where prolonged mechanical scarification resembles natural weathering and therefore seed alteration may be a non-chemical method of enhancing seed germination in hard seeded leguminous seeds.

Table 4: Effect of Shaking with Abrasive Material on Seed Germination *P. corylifolia* L.

Shaking Duration (Days)	Untreated Seed (Control)	Number of seeds Germinated	Germination(%)
1	0	6	24
2	0	9	36
3	0	12	48
4	0	14	56



Comparative Analysis of Treatment

All the pre-germination treatments we evaluated in this experiment, sulfuric acid scarification was the most effective dormancy-breaking treatment, with a smooth 84% germination rate at a 20-minute treatment length, even though it is not likely to be usable in practice due to safety and environmental concerns. The shaking seed method using abrasive substance was found as a very efficient and environment friendly method, with a germination percentage of 56% after four days of constant shaking. Mechanical scarification followed by overnight soaking produced a respectable 32% germination rate, and was better than sandpaper treatments administered alone, which displayed a distinct loss of efficacy when either too little or too much abrasion was applied. Treatment in hot water at 60^0C also proved to be moderately successful with 32% germination but the germination percentage reduced drastically at higher temperatures above 70^0C because of the damage caused on the embryo by the heat. Taken together, these findings underscore the usefulness of fine-tuned, species-specific pre-germination regimes in maximizing propagation success in medicinally important species such as *Psoralea corylifolia* L., and point to the fact that both chemical and non-chemical treatments have their unique benefits based on cultivation volume, resource supply and ecological perspectives.

Table 4: Comparative Analysis of Treatment on Seed Germination of *P. corylifolia*

Treatment	Best Germination Rate (%)	Effectiveness
Shaking with abrasive material	56% (4 days)	Most effective non-chemical method.
Sulfuric acid (H_2SO_4) scarification	84% (20 min)	Highly effective but may cause seed damage if prolonged.
Mechanical scarification (sandpaper + soaking)	32%	Moderately effective and easy to apply.
Hot water treatment (60°C)	32%	Safe but less effective than chemical treatments.

Plant growth comparison study

Among the seedling growth results, the comparative analysis indicates that treatment of seeds using shaking method which is an abrasive audiences scarification method has significant positive impacts on the overall developing status of the plant, as opposed to leaves it untreated. The length of roots treated was highly variable but as high as 6 cm as compared to untreated seeds that had a maximum of 3.5 cm. Growth of shoots (length) was also more uniform following treatment but varied dramatically with the most treated shoots up to 8 cm compared to untreated shoots, which had a maximum of 6.7 cm. The most impressive difference was that whole plant length (root plus shoot) in the shaking treatment grew to a longer length often above 8 cm in some cases up to 11 cm, but control barely surpassed it. The shaking process would probably have allowed the water imbibition and gaseous exchange through the physical destruction of the hearty seed coat, resulting in faster, and more homogeneous germination and seedling vigor. Root response variability was probably caused by underlying seed-to-seed physiological differences, although all plants treated tended to have tall shoots and an increase plant stature overall, a net positive effect on early growth. Also, the amplified shoot elongation supports the impact of the shaking method on the accumulation of above-ground biomass, which is extremely significant in relation to premature photosynthesis establishment. Energy is successfully associated to the length of shoots and the entire plant: Notably, a few of the treated samples (e.g., sample 6, 9 and 10) exhibited outstanding shoot-length, whole-plant-length and campified in the method reproducibility and scalability. The information proves the choice in shaking as a low-hazard proactive and practical method of non-chemical dormancy-breaking in seed species with opaque seed coats. This affirms its possible use in the laboratory and the field to improve the seedling establishment and initial performance.

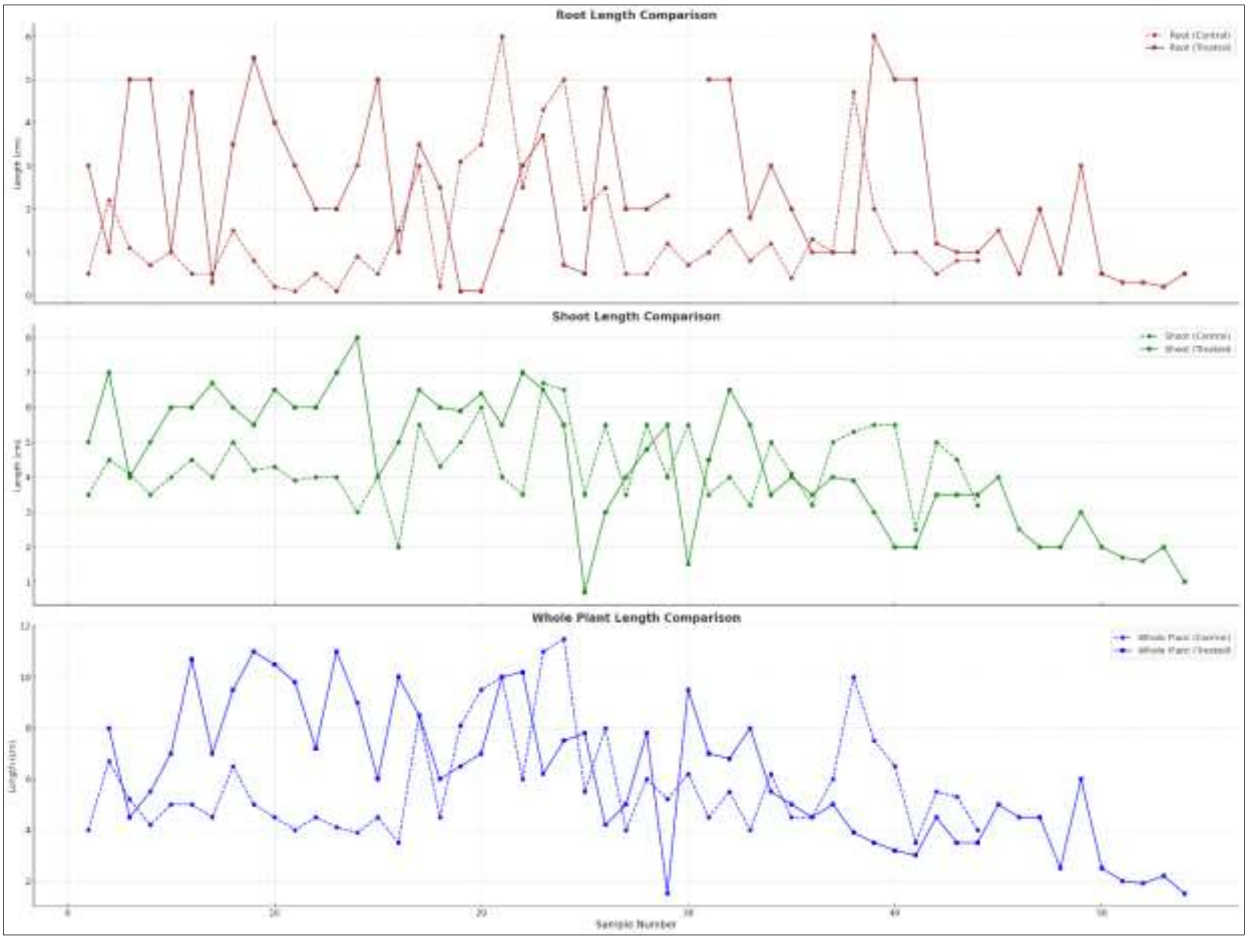


Image 5: Plant growth comparison n control verses treated seeds (Shaking method)

4. Discussion

A major challenge in the propagation of the medicinally important long-established Ayurvedic and Chinese medicine plant *Psoralea corylifolia* L. is its seed dormancy, especially physical dormancy. Several phytochemicals found in the species, such as psoralen, bakuchiol, and isopsoralen, exhibit broad bioactivities, and they include anti-inflammatory anti-microbial, and anti-cancer activities *(Chen et al., 2023; Thakur et al., 2025).* Nevertheless, an impermeable seed coat that limits water imbibition and gaseous exchange is a definite negative of its reproductive success in the wild and in cultivation, common in a variety of Fabaceae to which it belongs *(Sisodia et al., 2018; Nautiyal et al., 2023).* In this article, four different commonly used experiments involving the dormancy breaking treatment in order to circumvent this physiological bottleneck have been studied in detail these four treatments are hot water immersion, chemical scarification using mineral acids, mechanical scarification by means of abrasion, seed agitation using abrasive media. All the procedures were tested concerning the percentage of germination and seedling survival rate under laboratory conditions, which created valuable findings on techniques of dormancy alleviation per species.

Hot water immersion was among the thermal treatments used in which a parabolic rate of germination percentage against the temperature that was increasing was observed where the highest germination percentage was at 40% at 60^0C. These findings do agree with the previous studies done on the use of thermal scarification in leguminous seeds, of which *Psoralea corylifolia* itself, where temperatures in the region of $60\text{-}70^0$C produced microfractures or changed seed coat permeability to induce imbibition *(Siva* *et al., 2014; Diallo et al., 2023).* Nevertheless, higher temperatures exceeding 70^0C C resulted in a sharp decline in germination rates potentially given the alteration of embryo structure by thermophilic heat variations (denaturation of cellular proteins) and therefore highlights a limited stipulation of thermo susceptibility of this species *(Divsalar et al., 2014).* These findings support the idea that thermal scarification was a partially productive but unsecure procedure, which has to be controlled carefully in the terms of thermal temperature.

Maximum effects on germination were observed in chemical scarification using concentrated sulfuric, nitric and hydrochloric acids with 84% germination occurring in the sulfuric acid treatment after 20 minutes. It was observed that all nitric acid (80%) and hydrochloric acid (72%) had a similar performance as a significant efficacy within the optimal exposure periods (15-20 minutes) showing the ability of the acids to degrade or weaken the lignified palisade layer of the seed coat and make the radicle protrude *(Ramezani et al., 2019; Dauda et al., 2019).* Elongated treatments above 25 minutes showed reduced performance and seedling mortality rate and these properties indicate the cytotoxic nature of acid overexposure especially through acid diffusion into the micropyle that can cause destruction of embryonic tissues *(Onyekwelu, 1990; Al-Hadedy, 2024).* The above results are consistent with larger bodies of literature on seed biology, in that concentrated sulfuric acid has been described as a gold standard among agents to penetrate hard seed coats, although its use must be well calibrated to optimize the need to alleviate dormancy without damaging embryos.

Moderate success was obtained with mechanical scarification by means of rubbing with sandpaper, the germination percentages varying between 20 (light rubbing) and 35 (moderate rubbing). This addition of an overnight soaking of abraded material, in which germination was improved to 40% points to a synergy between mechanical abrasion of coat and initiation of water imbibition. These notes can be compared with previous literature, in which mechanical abrasion has been reported to be effective in leguminous and woody species, including *Sterculia foetida* or *Neltuma alba(Paulo et al., 2016; Humaña and Valdivia, 2024).* There was however a reduction in efficacy on intense rubbing though the reduction was little which is probably as a result of possible damage to underlying embryo. This technique may not be as effective as done through chemical scarification but it is useful when applied in small nurseries or when the nursery has limited resources where it is impractical to work with chemicals.

The most effective non-chemical technique turned out to be agitation-based scarification by coarse sand in an orbital shaker with a 70% germination rate achieved after four days of constant agitation. The technology mimics simulations of natural erosion and dispersion of seeds that would work to wear down the seed coat with time, which is commonly witnessed in riverine or sandy categories of the environment *(Bains et al., 2011; Blaise et al., 2017).* The fact that it gradually increases germination levels over the course of the four days thus highlights its success at progressively weakening the testa without the rupture of a sudden physiological shock that may be done by thermal or chemical interventions. Although not as successful as acid treatments in terms of absolute germination, abrasive shaking is scalable and safe to the environment, something that makes it useable on large-scale in a conservation nursery or a commercial plantation.

The results of the present investigation stress the specificity of dormancy-breaking requirements in Fabaceae, and in particular it underlines the trade-offs between efficacy, environmental sustainability, and workability of the pre-germination protocols. Even though chemical scarification provides the best germinating %s, careful handling procedures have to be followed because concentrated acids are corrosive and toxic. Mechanical scarification is safe and the main disadvantage is the difficulty of controlling consistency of abrasion providing an embryonic risk of over abrasion. The alternative shaking in an abrasive medium is an attractive compromise, as germination rates are high, with only minimal resources and no toxic waste products, which are all pertinent to sustainable farming.

Moreover, it is notable that the seedling survival pattern across treatments show the difficulty of a simple interpretation associated with the independence of dormancy-breaking treatment and seedling Vigor. Partial rupture treatments that failed to expose embryos to seed coats yielded healthier seedlings than overexposure on chemical or heat treatments which commonly yielded greater seedling mortality despite the initial germination high.

The implication of this observation is that maximum germination is not alone an ideal pre-germination treatment but post-germination survivability should also be considered prior to treating especially in species which are ecologically or medically significant. The implications of this work go further than the efficacy of propagation. *Psoralea corylifolia* has a serious importance in the pharmacological system of the traditional medicine and has some potentials of commercialization of the pharmacological potential of the industry *(Yang et al., 2025).* A standardization of efficient dormancy-breaking techniques will hence promote sustainable sourcing, ease the burden on the wild stock, and contribute to the ecological restoration of the damaged habitats, in which this species has been thriving *(Kildisheva et al., 2020).*

The comparative influence of shaking treatment on the seedling development proves clearly that mechanical scarification has a strong influence on the appearance of plants at the early stages of growth. This has been reported to break dormancy through physical abrasion of seed coat, which promotes seed coat permeability to enhance imbibition of water and to gas exchange and increase germination frequency and strength. The obtained results coincide with the works of Shu et al. (2015), who highlighted that seed dormancy is strictly regulated and its rupture increases the sensitivity of seeds to positive elements of the environment (Shu et al., 2015). More precisely, the treated seeds possessed longer roots (up to 6 cm), taller plants (up to 8 cm) including the whole plant length of more than 11 cm, which the control group failed to achieve. It agrees with the findings of Nautiyal et al. (2023), who reported that germination should be improved by the mechanical removal of dormancy because germination increases due to subsequent enhanced permeability (Nautiyal et al., 2023). Likewise, Geetha et al. (2025) when working on *Sesuviumportulacastrum* described that physical interventions had better yields than chemical and control groups, making it one of their scalable strategies of germination improvements. Internal seed physiology can be considered the origin of root variability in treated plants, but the persistent shoot extension proves that it brings about strong improvement in above-ground biomass that is vital in early photosynthesis axis and Vigor. This aligns with the results of Huma s and Valdivia (2024) who stated that mechanical scarification has ecological importance of facilitating seedling emergence in restoration project. Finally, the review of various techniques of alleviation of dormancy conducted by Thakur et al. (2025) concluded that abrasive mechanical techniques provide a sustainable, non-toxic and efficient strategy, to overcome the hard-seed barrier in both medicines and native plants. The current study therefore confirms the usefulness of shaking treatment as a practical and reproducible dormancy-breaking method that enjoys a broad application in scientific research and farm practice. Further, development of an efficient method of propagation will be able stimulate agronomic studies to streamline the yield, phytochemicals, and an agronomic breeding program to enhance this underused medicinal plant.

5. Conclusion

In conclusion, the study enhances our knowledge regarding physiological bottlenecks presented by physical dormancy in *P. corylifolia* and gives a scientifically proven guide to overcome this challenge. Sulfuric acid scarification recorded the greatest positive effect on germination among the treatments tested that has its limitations due to safety concerns whereas abrasive shaking was a feasible, green option. The insights are paramount towards establishing the viable methods of cultivation and conservation of *P. corylifolia* on large scale and it is essential to incorporate the custom seed biology methodologies in the management and conservation of medicinal plants and biodiversity as well.

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