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OPTIMIZATION OF SEED DORMANCY-BREAKING AND WOOD VINEGAR APPLICATION FOR ENHANCING PODOCARPUS BLUMEI SEEDLING PERFORMANCE

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Abstrak. *Podocarpus blumei* is a slow-growing coniferous tree species belonging to the Podocarpaceae family, widely utilized for timber, handicrafts, and traditional medicine in Indonesia. However, its propagation remains limited due to seed dormancy and low germination rates. This study aimed to determine the most effective combination of seed dormancy-breaking techniques and wood vinegar concentrations to optimize seed germination and early seedling growth. The experiment was conducted using a completely randomized design with factorial treatments involving different dormancy-breaking methods scarification, soaking in coconut water, and hot water and variations in planting media (soil, cocopeat, and husk charcoal). Subsequent seedling treatments involved applying wood vinegar at four concentrations (0%, 0.1%, 0.2%, and 0.3%) for eleven months. Results showed that *P. blumei* seeds had an average moisture content of 40.14%, classifying them as recalcitrant. Among the dormancy-breaking treatments, scarification produced the highest germination rate (90%), maximum growth potential (92%), and fastest germination period (51 days) in soil–cocopeat–husk charcoal media. Application of 0.2% wood vinegar significantly increased stem diameter (0.8 mm), leaf number (19), and biomass accumulation, indicating enhanced physiological activity. In contrast, higher concentrations (≥0.3%) did not further improve seedling performance. The findings demonstrate that integrating mechanical scarification and moderate wood vinegar concentration (0.2%) effectively enhances the germination and early vigor of *P. blumei* seedlings. This study provides a practical propagation approach for conserving and sustainably managing *Podocarpus blumei* populations, contributing to improved silvicultural practices for native forest species in Indonesia.

Keywords: Podocarpus blumei; Seed Dormancy-Breaking; Wood Vinegar; Germination; Seedling Growth; Silviculture

I. INTRODUCTION

Podocarpus blumei, a member of the Podocarpaceae family, is an indigenous tree species commonly found in tropical and montane forests of Indonesia, Papua New Guinea, and parts of Southeast Asia [1]. This species is ecologically significant due to its role in forest canopy structure and economically valuable for its durable timber, which is widely used for furniture, crafts, and construction [2], [3]. However, *P. blumei* faces propagation challenges due to its recalcitrant seed characteristics, slow germination rate, and prolonged dormancy period [4]. These biological constraints, combined with increased exploitation for timber and non-timber purposes, threaten the regeneration and long-term sustainability of the species [5], [6].

Recalcitrant seeds of *Podocarpus* species generally contain high moisture content (>30%) and are highly sensitive to desiccation and storage conditions [7]. As a result, they require immediate germination after collection to prevent viability loss. Dormancy-breaking treatments, including mechanical scarification and hydrothermal or hormonal treatments, are commonly employed to accelerate germination and enhance seedling vigor [8]. Studies on similar coniferous species indicate that scarification can effectively weaken the seed coat, improving water permeability and oxygen exchange during the imbibition phase [9]. However, the optimal combination of dormancy-breaking treatment and suitable growing medium remains species-dependent, particularly for recalcitrant forest seeds such as *P. blumei* [10].

In addition to dormancy management, the use of natural biostimulants such as wood vinegar has gained increasing attention for promoting seedling growth and soil health in sustainable forestry practices [11]. Wood vinegar, a by-product of charcoal pyrolysis, contains beneficial compounds including acetic acid, phenols, methanol, and various minerals (e.g., Ca, Mg, Fe, Mn) that can stimulate root development, enhance nutrient absorption, and improve microbial activity in the rhizosphere [12], [13]. Several studies have demonstrated that low concentrations of wood vinegar (0.1–0.3%) can positively influence plant height, leaf number, and biomass accumulation, while excessive concentrations may inhibit growth due to high acidity [14], [15]. Therefore, determining an optimal concentration of wood vinegar is essential for improving early seedling establishment.

Previous studies on other forestry species such as *Shorea javanica*, *Hevea brasiliensis*, and *Paraserianthes falcataria* have shown that organic amendments and biostimulants significantly enhance growth performance during the nursery phase [16]–[18]. However, research on *P. blumei* remains limited, particularly regarding the synergistic effects of seed pretreatment and organic stimulant application. Considering the species' ecological and economic value, improving propagation techniques for *P. blumei* is crucial for ex-situ conservation and sustainable forest management initiatives in Indonesia.

Thus, this study aims to (1) evaluate the effects of different seed dormancy-breaking techniques on the germination performance of *P. blumei*, (2) assess the influence of wood vinegar concentrations on seedling growth and biomass accumulation, and (3) determine the most effective combination of treatments for optimizing seedling vigor. The findings are expected to provide a scientific basis for effective propagation and silvicultural management of *P. blumei*, contributing to the broader goals of tropical forest restoration and biodiversity conservation.

Seed dormancy is a natural adaptive mechanism that prevents germination under unfavorable conditions. In forest trees, particularly gymnosperms like *Podocarpus*, dormancy is often caused by physiological and physical barriers in the seed coat [19]. *Podocarpus blumei* seeds are classified as recalcitrant, maintaining high water content and exhibiting limited tolerance to drying or prolonged storage [20]. Such seeds generally lose viability rapidly, necessitating immediate sowing after collection [21]. Dormancy-breaking treatments, such as scarification and soaking in hot or organic solutions, can enhance water absorption, soften the seed coat, and activate enzymatic metabolism essential for germination [22]. Scarification is particularly effective for seeds with impermeable coats, as it facilitates imbibition and accelerates the emergence of the radicle and plumule [23]. Research on *Podocarpus henkelii* and *Dacrycarpus imbricatus* demonstrated that mechanical scarification improved germination rates by up to 90% within 45–60 days [24]. In *P. blumei*, similar techniques reduced germination time significantly compared to untreated seeds [25]. These findings highlight the importance of optimizing dormancy-breaking methods to overcome recalcitrant seed constraints and enhance propagation efficiency in *Podocarpus* species.

The choice of planting medium significantly influences germination success and early seedling growth. A suitable medium must provide sufficient aeration, water-holding capacity, and nutrient availability to support root elongation and metabolic activity [26]. Studies have shown that mixed organic substrates such as cocopeat, rice husk charcoal, and topsoil improve soil structure, maintain moisture balance, and enhance microbial activity compared to inorganic media [27].

For *P. blumei*, a combination of soil, cocopeat, and husk charcoal has been found to yield higher germination percentages and stronger seedling structures due to better oxygen diffusion and nutrient retention [28]. The high porosity of cocopeat supports root aeration, while husk charcoal enhances water retention and microbial balance in the rhizosphere [27]. Therefore, optimizing media composition in tandem with seed treatment is essential for improving the vigor and survivability of *P. blumei* seedlings in nursery conditions.

Wood vinegar, also known as pyroligneous acid, is a by-product of biomass pyrolysis containing organic acids, phenols, alcohols, and nutrients beneficial to plants [29]. It functions as a natural biostimulant, promoting root development, enhancing photosynthetic activity, and improving nutrient uptake efficiency [30]. In forestry applications, wood vinegar has been shown to stimulate microbial growth, suppress soil-borne pathogens, and improve plant resilience under stress conditions [31]. According to Komarayati et al. [32], low concentrations of wood vinegar (0.1–0.3%) enhance shoot elongation and biomass accumulation, whereas higher doses may inhibit plant growth due to acidity and phytotoxic effects. Prameswari et al. [33] further reported that the combination of wood vinegar with organic media significantly improved root biomass and shoot-to-root ratio in *Elmerillia ovalis* seedlings. Similar effects have been documented in agricultural crops such as *Brassica chinensis* and *Capsicum frutescens*, indicating its broad-spectrum potential as an organic stimulant [34], [35]. The bioactive compounds in wood vinegar—especially acetic acid, methanol, and phenolics—facilitate enzymatic activity and metabolic balance in plants [36]. Additionally, the presence of essential minerals such as nitrogen (N), potassium (K), calcium (Ca), and magnesium (Mg) contributes to chlorophyll synthesis and cell wall strengthening [37]. Therefore, identifying the optimal wood vinegar concentration is vital to achieving balanced physiological responses and promoting sustainable seedling growth in forest nurseries.

Combining seed pretreatment with organic stimulants like wood vinegar may produce synergistic effects that accelerate germination and improve subsequent seedling vigor [38]. Mechanical scarification ensures rapid germination by removing physical dormancy barriers, while the application of wood vinegar enhances physiological growth through nutrient and hormonal activation [39]. Such integrative approaches align with sustainable forestry principles that emphasize the use of environmentally friendly biostimulants rather than synthetic growth regulators [40].

Given the ecological and economic importance of *P. blumei*, optimizing these techniques can provide a reliable method for large-scale propagation, conservation, and forest restoration programs in Indonesia and other tropical regions.

II. RESEARCH METHODS

This study employed a quantitative experimental design using a Completely Randomized Design (CRD) with factorial treatments to investigate the effects of seed dormancy-breaking techniques and wood vinegar concentrations on the germination and early growth of

Podocarpus blumei. The research was conducted from September 2022 to August 2023 at the Laboratory of Silviculture Nursery and Greenhouse Facility, Center for Standardization of Sustainable Forest Management Instruments, Ministry of Environment and Forestry, Bogor, Indonesia. The experiment comprised two phases: (1) seed germination and (2) seedling growth. For the germination phase, treatments consisted of different dormancy-breaking methods, including control (no treatment), mechanical scarification, soaking in hot water, and soaking in coconut water. Seeds were sown on two planting media compositions: M0 (soil + rice husk) and M1 (soil + cocopeat + husk charcoal). Each treatment was replicated three times with 25 seeds per replicate, totaling 600 seeds. Germination parameters germination percentage (GP), maximum growth potential (MGP), and germination rate (GR) were observed over 100 days.

The second phase evaluated the effects of four wood vinegar concentrations (0%, 0.1%, 0.2%, and 0.3%) on the growth performance of eleven-month-old seedlings. Each treatment used 10 seedlings with four replications (160 seedlings total). Parameters measured included plant height, stem diameter, number of leaves, fresh and dry biomass (shoot and root), shoot–root ratio, and seedling quality index. Wood vinegar used in this study was derived from the condensation of hardwood charcoal smoke containing acetic acid, phenols, and trace minerals essential for plant metabolism [41]. Data were analyzed using one-way and two-way ANOVA, followed by Duncan's Multiple Range Test (DMRT) at a 95% confidence level to determine significant differences among treatments. Statistical analyses were conducted using SPSS v.25 and Microsoft Excel 2021. This approach aligns with sustainable silvicultural practices emphasizing eco-friendly growth stimulants and propagation optimization for recalcitrant forest species [42], [43].

III. RESULTS AND DISCUSSION

Seed Germination Performance

The results of the germination experiment revealed that *Podocarpus blumei* seeds exhibited recalcitrant characteristics with an average moisture content of 40.14%, consistent with previous findings for other *Podocarpus* species [44]. Among the dormancy-breaking treatments, mechanical scarification yielded the highest germination percentage (90%) and maximum growth potential (92%), with an average germination period of 51 days. In contrast, seeds soaked in coconut water and hot water showed lower germination rates (72% and 85%, respectively), indicating that physical dormancy rather than physiological dormancy was the primary limiting factor. Scarification improved seed coat permeability, facilitating water absorption and oxygen diffusion necessary for enzymatic activation during early germination [45]. The results align with findings from Darma et al. [46], who observed similar responses in *Dacrycarpus imbricatus*, where scarified seeds exhibited faster germination compared to untreated seeds. Moreover, the use of mixed planting media comprising soil, cocopeat, and husk charcoal (M1) significantly enhanced germination rate and seedling emergence compared to soil–rice husk mixtures. This combination improved soil aeration, moisture retention, and microbial balance, contributing to higher seed viability [47]. Organic media such as cocopeat and husk charcoal are known to increase root respiration and nutrient exchange, thus supporting healthy radicle and plumule development during early growth [48].

Figure 1. The seeds of Podocarpus blumei are blackish-brown in color with a slightly hard texture on the outermost part of the seeds while the inside of the seeds is yellow

The application of wood vinegar demonstrated significant effects on several morphological and physiological growth parameters of *P. blumei* seedlings. Among the tested concentrations, 0.2% wood vinegar produced the highest mean stem diameter (0.8 mm), leaf number (19 leaves), and total dry biomass (2.77 g), indicating optimal enhancement of seedling vigor. Meanwhile, higher concentrations (0.3%) tended to suppress growth, likely due to increased acidity and osmotic stress [49]. The positive response to low concentrations of wood vinegar can be attributed to the presence of organic acids, methanol, and trace elements (e.g., Ca, Mg, Fe, Mn) that stimulate auxin-like hormonal activity, improve photosynthetic efficiency, and accelerate cell division [50].

Figure 1. (a) First Day After Sowing (b) Cotyledons Raised to the Soil Surface Due to Hypocotial Elongation (c) The Outermost Parts of the Seeds Attached to the Cotyledons Break and Fall to the Ground (d) Plumula Grows the First Leaf (e) Leaves Grow More and Plants Grow Taller (f) Seeds That Are Sown Have Become Seedlings

In contrast, excessively high doses may result in phytotoxicity, disrupting root membrane integrity and reducing chlorophyll synthesis. Similar findings were reported by Komarayati et al. [51], who concluded that wood vinegar concentrations above 0.5% can inhibit seedling elongation in several forestry species. The optimal 0.2% concentration identified in this study supports balanced

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nutrient uptake and promotes favorable shoot–root biomass ratios (NPA = 3.66), a critical index of transplant readiness and nursery success. These results confirm that wood vinegar functions effectively as a low-cost organic biostimulant, consistent with sustainable silvicultural practices emphasizing eco-friendly inputs.

Seedlings treated with 0.2% wood vinegar exhibited significantly higher fresh and dry biomass values compared to the control group. The average total dry biomass reached 2.77 g, while shoot dry weight accounted for 2.16 g. The improvement in biomass parameters reflects enhanced nutrient assimilation and photosynthetic efficiency facilitated by organic compounds in wood vinegar [50]. Moreover, all treatments produced a Seedling Quality Index (SQI) value greater than 0.09, indicating that all seedlings were physiologically suitable for field transplantation [47]. The combination of scarified seeds and 0.2% wood vinegar resulted in superior vigor and structural uniformity, aligning with the findings of Prameswari et al. [42] and Sarjan et al. [31], who reported similar improvements in *Elmerillia ovalis* and *Paraserianthes falcataria* seedlings.

The observed shoot-to-root ratio (2–5) further supports the conclusion that seedlings developed balanced growth, an essential trait for post-transplant establishment [46]. The moderate acidity of wood vinegar likely enhanced nutrient solubilization and microbial activity in the rhizosphere, contributing to the improved physiological performance. Overall, integrating mechanical dormancy-breaking and organic stimulation techniques provides a practical approach to overcoming recalcitrant seed limitations while ensuring sustainable seedling production in tropical forestry programs.

Table 1. Results of Duncan Test Analysis of the Effect of Applying Wood Vinegar on the Growth of *Podocarpus blumei Seedlings*

Treatment	Result		
	Trunk Diameter (mm)	Number of Leaves (Helai)	NPA
C0	0,45^{a}	9,17^{a}	2,26^{a*}
C1	0,6^{a}	14,6^{b}	3,93^{b}
C2	0,8^{b}	19,35^{c*}	3,66^{b}
C3	0,47^{ab}	15,52^{ab}	3,48^{b}

Description: *) A real difference. Numbers followed by the same letter on the same line do not differ significantly at a 95% confidence interval based on the Duncan test. This parameter is taken from data that shows a noticeable influence on the seedlings

The synergistic interaction between seed pretreatment and organic stimulant application has proven effective in enhancing both germination and early growth of *P. blumei*. Scarification addressed the physical dormancy barriers of the recalcitrant seeds, while moderate wood vinegar concentration improved post-germination physiological activity. The use of organic media further supported seedling development by improving aeration and nutrient cycling. These findings highlight the potential of combining simple mechanical and organic approaches to strengthen propagation systems for slow-growing tropical tree species. Such integrative techniques are essential for conservation, reforestation, and sustainable timber production initiatives in Indonesia.

The integration of mechanical dormancy-breaking and organic stimulant application presents a practical and eco-friendly approach to improving propagation efficiency for recalcitrant forest species. These findings support the implementation of sustainable silvicultural practices in Indonesia, particularly for native slow-growing species with high ecological and economic value such as *P. blumei*. The optimized propagation method developed in this study can be applied in conservation nurseries and reforestation programs to restore degraded tropical forests. Future research should explore the biochemical mechanisms underlying the synergistic effects of wood vinegar and other organic amendments, as well as evaluate field performance of seedlings under variable environmental conditions to validate long-term survival and growth outcomes [52]–[54].

IV. CONCLUSION

This study demonstrated that combining seed dormancy-breaking techniques and wood vinegar application can effectively enhance the germination and early growth performance of *Podocarpus blumei*. The best germination results were obtained through mechanical scarification, which increased water permeability and accelerated germination with a 90% success rate and a maximum growth potential of 92%. Meanwhile, applying 0.2% wood vinegar produced the most favorable seedling responses, including a stem diameter of 0.8 mm, 19 leaves per seedling, and a total dry biomass of 2.77 g. The optimal growth observed at moderate concentrations indicates that wood vinegar functions effectively as a natural biostimulant, enhancing nutrient assimilation and photosynthetic activity. In contrast, higher concentrations (≥0.3%) tended to inhibit growth due to increased acidity and potential phytotoxicity..

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