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The potential for the cultivation of *Styrax benzoin* based on land suitability evaluation in Pakpak Bharat District, Indonesia

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Abstract. *Rahmawaty, Ginting YA, Batubara R, Rauf A. 2024. The potential for the cultivation of* Styrax benzoin *based on land suitability evaluation in Pakpak Bharat District, Indonesia. Biodiversitas 25: 1071-1080. Styrax benzoin* (*kemenyan*), a latex-producing plant native to North Sumatra Province, Indonesia requires development and sustainable cultivation. Currently, it is increasingly common to cultivate *S. benzoin* in conjunction with other crops, including *gambir* (*Uncaria gambir*). This research focused on assessing the suitability of land in Pakpak Bharat District for cultivating *S. benzoin* on land previously used for *U. gambir* cultivation. In this research, a survey methodology was employed, involving purposive soil sample collection from areas previously used for *U. gambir* cultivation. These specific locations were Aornakan I Village in Pergetteng Getteng Sengkut Sub-district and Kuta Tinggi Village in Salak Sub-district, both within Pakpak Bharat District, North Sumatra Province. The suitability assessment of cultivating *S. benzoin* on land previously used for *U. gambir* cultivation employed the matching method. The results revealed that the actual land suitability for *S. benzoin* was classified as moderately suitable (S2). Land Unit 1 is constrained by factors such as water availability (wa), root media (rc), and erosion hazards (eh), while Land Units 2, 3, and 4 with limitations primarily related to water availability (wa) and root media (rc). The findings also suggest that the potential land suitability class for *S. benzoin* remains at S2 for growth in areas where *U. gambir* was cultivated, with notable restrictions related to water availability and root media across all land units.

Keywords: Erosion hazard, evaluate, root zone, water availability

INTRODUCTION

Styrax benzoin, known as "*kemenyan*," is native plants in North Sumatra Province (Jayusman 2014; Silalahi and Sunandar 2017; Harada et al. 2021; Wulandari et al. 2023). *S. benzoin* can be commonly found in various regencies within North Sumatra Province, including Tapanuli Utara, Humbang Hasundutan, Tapanuli Tengah, and Toba Regencies. In the Batak language, the *S. benzoin* plant is referred to as "*haminjon*" (Jayusman 2014; Silalahi and Sunandar 2017). It is considered one of highly valued non-wood forest products and serves as a resin-producing plant (Anas and Kholibrina 2017). The sap from *S. benzoin* plays a significant role in the local economy and contributes to the export industry, particularly in the cosmetic and perfume sectors (Pasaribu et al. 2013). Additionally, it is considered a key agricultural commodity in Pakpak Bharat District (Rahmawaty et al. 2021a).

One of the efforts that need to be considered to increase the production of *S. benzoin* is to carry out a land suitability evaluation. This activity is carried out to determine the potential of a plot of land through an assessment of the land characteristics. It is intended to maximize land use (Ritung et al. 2011). Land use that does not match the land capabilities can damage the land. Therefore, it is crucial to carry out a land evaluation so that the land's capabilities become known and harnessed according to the land's designation (Ritung et al. 2011: Rahmawaty et al. 2019a, 2019b, 2019c). Land characteristics related to land quality are generally interrelated, which affects the use and growth of crops and land-based commodities. The purpose of a land evaluation is to determine the potential or value of a plot of land according to its designation. It enables finding out the relationship between land conditions and land use (Ritung et al. 2011). Another effort is to optimize land use, such as by growing crops using an agroforestry system.

Numerous studies have been conducted on *S. benzoin*, including those on such topics as the impact of cutting material age and growth regulators on cutting success (Putri and Danu 2014), estimation models for its resin productivity (Anas and Kholibrina 2017), growth and yield models for its non-timber forest product in Tapanuli, (Aswandi and Kholibrina 2018), profitability and market chain analysis in Humbang Hasundutan (Gaol and Simangunsong 2012), its flowering and fruiting phenology (Kholibrina et al. 2018), land suitability for its cultivation (Sunandar 2012), land characteristics and land suitability assessment for *Styrax* sp. in Humbang Hasundutan (Rahmawaty et al. 2023a). Research conducted by Rahmawaty et al. (2021b; 2023a) regarding *kemenyan* and research conducted by et Rauf et al. (2015); Rahmawaty et al. (2021a; 2023b) regarding *gambir* has indicated that *kemenyan* and *gambir* share similar land characteristics across various parameters. These criteria include factors,

such as: temperature (tc), water availability (wa), root media (rc), nutrient retention (nr), and the erosion hazard (eh). Research related to land evaluation (Rahmawaty et al. 2011, 2020a-2020g; Harahap et al. 2019; Purba et al. 2019), also have been carried out in various regions of North Sumatra. However, there is a notable absence of research aimed at evaluating the suitability of land for cultivating *S. benzoin* in Pakpak Bharat District. Consequently, there is a need for such research to be undertaken. The objective of this study is to assess the feasibility of cultivating *S. benzoin* on land previously used for *Uncaria gambir* cultivation in Pakpak Bharat District. This research is expected to enable local farmers to harness the land's potential to increase the production of this commodity. The study also aims to evaluate land suitability (both actual and potential) for *S. benzoin*. Understanding the suitability of land for cultivating *S. benzoin* provides valuable insights into the potential economic opportunities for farmers and agricultural stakeholders in Pakpak Bharat District. If the land is found to be suitable for *S. benzoin* cultivation, it could open up new avenues for income generation and economic development in the region.

MATERIALS AND METHODS

Research location

The study was conducted in Aornakan I Village in Pergetteng Getteng Sungkut (PGGS) Sub-district and Kuta Tinggi Village in Salak Sub-district, Pakpak Bharat District, North Sumatra, Indonesia. Salak serves as the administrative center of Pakpak Bharat District. These specific villages were deliberately selected due to the frequent presence of *U. gambir* plants within these villages. Aornakan I Village and Kuta Tinggi Village were selected intentionally for this research due to their reputation as areas where *U. gambir* plants are extensively grown within Pakpak Bharat District. This deliberate choice was made because these villages offered an ideal environment for studying the land suitability of *S. benzoin* when cultivated alongside *U. gambir*, as both crops share presence in these locations. By focusing on these villages, researchers could gain valuable insights into the potential challenges and opportunities of co-cultivating *S. benzoin* and *U. gambir* in these specific regions. The research spanned approximately eight months, from October 2020 to June 2021. Aornakan I Village is approximately situated at 2°31'45"N and 98°25'E, while Kuta Tinggi Village is situated at around 2°30'14”N and 98°19'49"E, as indicated by Rahmawaty et al. in (2021). Salak Sub-district has an elevation of 922 meters above sea level (asl), while Pergetteng Getteng Sungkut Sub-district is situated at 1032 meters asl. In terms of distance from Medan City, Aornakan I Village is approximately 179 km away, while Kuta Tinggi Village is roughly 190 km away. This translates to a journey of about six hours by car, as illustrated in Figure 1. The two research sites are in close proximity, Pergetteng Getteng Sungkut Sub-istrict to the north and Salak Sub-district to the south. Geographically, both Aornakan I Village and Kuta Tinggi Village are directly adjacent to protected forest regions. The terrain in these settlements ranges from flat areas to gradually sloping and eventually steep hills. The residents of these two villages primarily engage in farming activities.

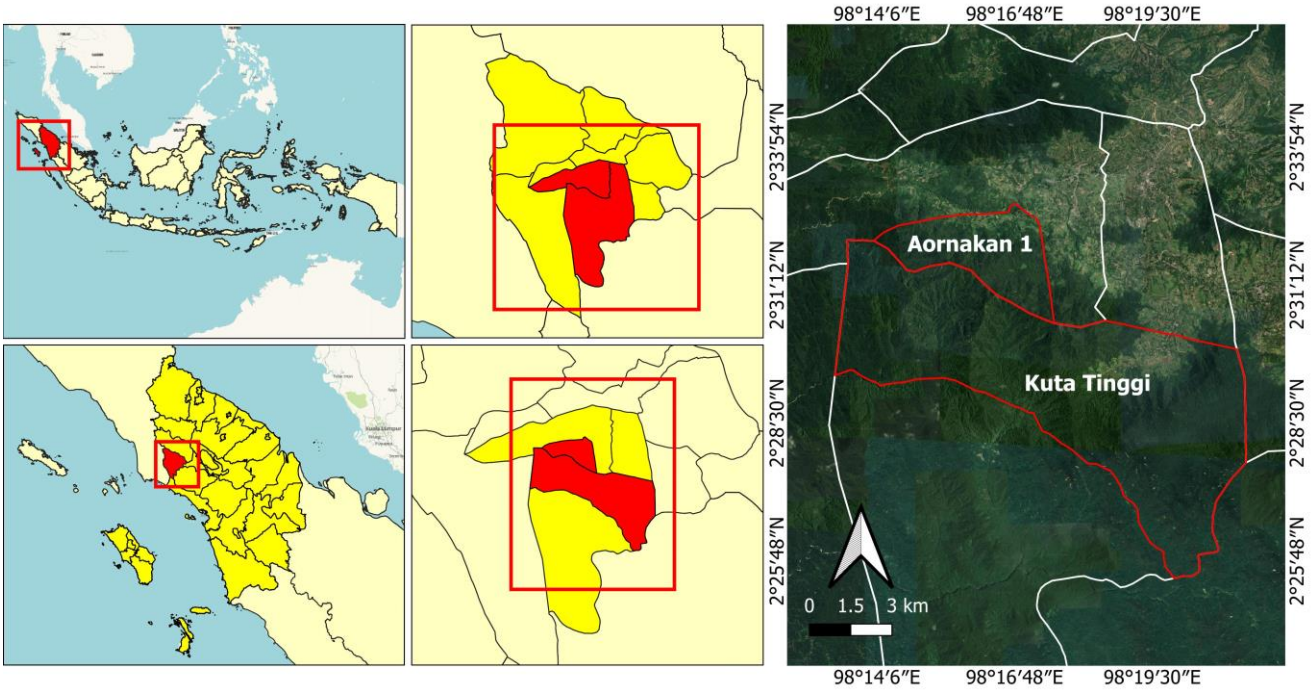

Figure 1. Map of research location in Aornakan I Village, Pergetteng Getteng Sungkut Sub-district and Kuta Tinggi Village, Salak Sub-district, Pakpak Bharat District, North Sumatra Province, Indonesia

Soil sample collection

The primary data collection process is through field surveys. Soil sampling was carried out in each village (Aornakan I and Kuta Tinggi) in a representative manner based on land units. A land unit refers to a particular area of land identified and described based on characteristics, such as soil type, topography, and land use (Rahmawaty et al. 2011; 2023a). This land unit helps ensure that soil samples collected from different locations within the same land unit have relatively uniform soil properties, helping obtain representative data for analysis. There are three land units in Aornakan I Village, namely: Land Units 1,2,3 and one land unit in Kuta Tinggi Village, namely: Land Unit 4. The total number of land units in this research area is four. For each land unit, three soil samples were taken, for a total of 12 samples, which can represent the area that was evaluated as a whole. The soil samples taken were placed in a clean container and labeled (sample number, sampling location, and sampling date). The soil samples are then analyzed in the laboratory.

Laboratory analysis

The physical and chemical properties of the soil, crucial for the land suitability assessment, were analyzed in the central laboratory of the Faculty of Agriculture at Universitas Sumatera Utara, Medan, North Sumatra Province, Indonesia. The assessment considered various criteria indicative of land quality, including such factors as temperature (tc), water availability (wa), oxygen availability (oa), nutrient retention (nr), erosion hazard (eh), and flood hazard (fh). The determination of land characteristics related to nutrient retention, such as soil texture, Cation Exchange Capacity (CEC), pH level, organic carbon content, and base saturation, was adjusted according to the root zone depth of the intended plant. These characteristics were categorized into specific land suitability classes based on interval values in accordance with the guidelines outlined in the FAO (1976) standards.

Land suitability analysis

The suitability class was determined using the matching method, as described in studies by Ritung et al. (2011) and Rahmawaty et al. (2021). This involved comparing the field observation and laboratory analysis results with the criteria and conditions necessary for the cultivation of *S. benzoin*. A land suitability assessment was performed, and the land was categorized into different suitability classes. The criteria for determining the suitability of growing *S. benzoin* were based on prior research findings, which are compiled and presented in a table (the land suitability characteristics of *S. benzoin* were derived from the "Valuable Sap of *S. benzoin* Booklet" published by the Ministry of Forestry, Forestry Research, and Development Agency, Aek Nauli Forestry Research Institute, Simalungun District, North Sumatra (Jayusman 2014; Silalahi and Sunandar 2017; Rahmawaty et al. 2021a, 2023a) (Tabel 1). Based on land evaluation process results, four distinct land suitability classes are established: highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N). Class S1 represents land with minimal obstacles for implementing required management practices, or land with minor constraints that do not significantly impact its productivity. Class S2 indicates that the land has relatively significant limitations that must be addressed when applying necessary management practices. Class S3 signifies that the land has substantial restrictions that must be considered to maintain the required management level. Finally, class N denotes land with permanent and irreversible limiting factors (FAO 1976; Ritung et al. 2011; Rahmawaty et al. 2021b, 2023a). Land suitability maps for *S. benzoin* in both of the villages were developed and described to provide visual representations of the land's suitability for this crop.

Table 1. The criteria for determining the land suitability for *Styrax benzoin*

Land characteristic	Land suitability class			
	Highly suitable (S1)	Moderately suitable (S2)	Marginally suitable (S3)	Not suitable (N)
Temperature (tc) (°C)	17-29	30-33	-	-
Water availability (wa):				
Rainfall (mm)	2,000-2,500	2,500-3,000	1,500-2,000	<1,500
Oxygen availability (oa):				
Drainage	well-drained, good	rather fast, moderately suitable	fast	very fast
Root media (rc):				
Texture	moderately suitable	slightly coarse	coarse	-
Soil depth (cm)	>150	100-150	75-100	<75
Nutrient retention (nr):				
CEC (me.100g $^{-1}$)	>12	5-12	<5	-
Base saturation (%)	1.05-1.80	-	-	-
pH H_2O	5.5-7.0	4.0-5.5	<4.0	-
C-organic (%)	>0.4	≤0.4		
Erosion hazards (eh):				
Slope (%)	0-8, 8-15	15-25	25-40	>40
Erosion hazard level	very low-low	moderately suitable	steep	very steep

Sources: Jayusman (2014); Silalahi and Sunandar (2017); Rahmawaty et al. (2021a); Rahmawaty et al. (2023a)

RESULTS AND DISCUSSION

The land suitability evaluation using the matching method

The results of matching data from the field and laboratory analysis results with land characteristics for *S. benzoin* are presented in Table 2-5. Likewise, the process of assessing actual land suitability to potential land suitability for *S. benzoin* in Land Units 1-4 is presented in Tables 2-5.

In land Unit 1, the actual land suitability is moderately suitable (S2), with limiting factors being water availability (wa), root media (rc), and erosion hazards (eh). For erosion hazards (eh), the slope can be Improve by make terrace construction and erosion hazard levels can be improve with planting ground cover crops (Table 2). Water availability (wa), improvement cannot be made because it is a natural factor. In term of root media (texture and soil depth were also limiting factors that farmers cannot improve because they are natural factors that are very difficult to overcome (Rahmawaty et al. 2011, 2019a-c; Ritung et al. 2011). Therefore, the potential land suitability in Land Unit 1 is still S2, with the limiting factors being wa and rc.

In land Unit 2, the actual land suitability is moderately suitable (S2), with limiting factors being water availability (wa) and root media (rc) (Table 3). As previously explained that water availability (wa), improvement cannot be made because it is a natural factor, as well as root media (rc) (texture and soil depth were also limiting factors that farmers cannot improve because they are natural factors that are very difficult to overcome (Rahmawaty et al. 2011, 2019a-c; Ritung et al. 2011). Therefore, the potential land suitability in Land Unit 2 is S2, with the limiting factors being wa and rc.

In Land Unit 3, the land suitability is assessed as moderately suitable (S2), with water availability (wa) and root media (rc) identified as limiting factors (refer to Table 4). It has been previously noted that improving water availability (wa) is impractical due to its natural limitations, as is enhancing root media (rc) since factors like texture and soil depth are challenging for farmers to modify, being inherent natural constraints (Rahmawaty et al. 2011, 2019a-c; Ritung et al. 2011). Consequently, the potential land suitability in Land Unit 2 remains at S2, with water availability (wa) and root media (rc) as the constraining factors.

In Land Unit 4, the land suitability is assessed as moderately suitable (S2). Same with Land Unit 2 dan 3, with water availability (wa) and root media (rc) identified as limiting factors (refer to Table 5).

The actual and potential land suitability for cultivating *Styrax benzoin*

The assessment of land suitability that takes into account the biophysical characteristics of the soil or land resources without any intervention to address limitations is referred to as actual land suitability assessment. The actual and potential land suitability for cultivating *S. benzoin* across all land units is detailed in Table 1. Potential land suitability indicates the level of suitability that can be attained with improvements in all land units and is also presented in Table 6.

Table 2. The land evaluation process for *Styrax benzoin* in Land Unit 1 using the matching method

Land characteristic	Data form the Field and Laboratory (DFL)	Actual Land Suitability (ALS)	Improvement effort	Potential Land Suitability (PLS)
Temperature (tc) (°C)	22.07	S1 (17-29)	(v)	S1
Water availability (wa):				
Rainfall (mm)	2,524	S2 (2,500-3,000)	(-)	S2
Oxygen availability (oa):				
Drainage	well drained	S1 (well drained)	(v)	S1
Root media (rc):				
Texture	slightly coarse	S2 (slightly coarse)	(-)	S2
Soil depth (cm)	100	S2 (100-150)	(-)	S2
Nutrient retention (nr):				
CEC (me.100g^{-1})	18.54	S1 (>12)	(v)	S1
Base saturation (%)	12.33	-	-	-
pH H_2O	5.69	S1 (5.5-7.0)	(v)	S1
C-Organic	3.44	S1 (>0.4)	(v)	S1
Erosion hazards (eh):				
Slope (%)	13-16	S2 (15-25)	(+) (a)	S1
Erosion hazard level	moderate	S2 (moderate)	(+) (b)	S1
Land suitability classification		ALS = S2 wa, rc, eh		PLS = S2 wa, rc

Note: S1: Highly suitable, S2: Moderately suitable, eh: Erosion hazard, wa: Water availability, rc: Root media, (v): There is no need improvement effort because it is suitable, (-): Improvement cannot be done because it is a natural factor, (+) (a): Improvements can be done, such as: terrace construction, (+) (b): Improvements can be done, such as: planting ground cover crops, ■: There is a change land suitability class, ■: There is a change limiting factors

Table 3. The land evaluation process for *Styrax benzoin* in Land Unit 2 using the matching method

Land characteristic	Data form the Field and Laboratory (DFL)	Actual Land Suitability (ALS)	Improvement effort	Potential Land Suitability (PLS)
Temperature (tc) (°C)	21.31	S1 (17-29)	(v)	S1
Water availability (wa):				
Rainfall (mm)	2,524	S2 (2,500-3,000)	(-)	S2
Oxygen availability (oa):	well drained	S1	(v)	S1
Drainage		(well drained)		
Root media (rc):				
Texture	slightly coarse	S2 (slightly coarse)	(-)	S2
Soil depth (cm)	100	S2 (100-150)	(-)	S2
Nutrient retention (nr):				
CEC (me.100g^{-1})	12.67	S1 (>12)	(v)	S1
Base saturation (%)	17.95	-	-	-
pH H_2O	6.20	S1 (5.5-7.0)	(v)	S1
C-Organic	4.48	S1>0.4	(v)	S1
Erosion hazards (eh):				
Slope (%)	10-15	S1 (8-15)	(v)	S1
Erosion hazard level	low	S1 (low)	(v)	S1
Land suitability classification		ALS = S2 wa, rc		PLS = S2 wa, rc

Note: S1: Highly suitable, S2: Moderately suitable, wa: Water availability, rc: Root media, (v): There is no need improvement effort because it is suitable, (-): Improvement cannot be done because it is a natural factor

Table 4. The land evaluation process for *Styrax benzoin* in Land Unit 3 using the matching method

Land characteristic	Data form the Field and Laboratory (DFL)	Actual Land Suitability (ALS)	Improvement effort	Potential Land Suitability (PLS)
Temperature (tc) (°C)	19.20	S1 (17-29)	(v)	S1
Water availability (wa):				
Rainfall (mm)	2,524	S2 (2,500-3,000)	(-)	S2
Oxygen availability (oa):				
Drainage	well drained	S1 (well drained)	(v)	S1
Root media (rc):				
Texture	slightly coarse	S2 (slightly coarse)	(-)	S2
Soil depth (cm)	100	S2 (100-150)	(-)	S2
Nutrient retention (nr):				
CEC (me.100g^{-1})	22.58	S1 (>12)	(v)	S1
Base saturation (%)	10.82	-	-	-
pH H_2O	6.55	S1 (5.5-7.0)	(v)	S1
C-Organic	4.50	S1 (>0.4)	(v)	S1
Erosion hazards (eh):				
Slope (%)	10-15	S1 (8-15)	(v)	S1
Erosion hazard level	low	S1 (low)	(v)	S1
Land suitability classification		ALS = S2 wa, rc		PLS = S2 wa, rc

Note: S1: Highly suitable, S2: Moderately suitable, wa: Water availability, rc: Root media, (v): There is no need improvement effort because it is suitable, (-): Improvement cannot be done because it is a natural factor

For Land Unit 1, the analysis of land characteristics, including temperature, drainage, Cation Exchange Capacity (CEC), water pH, and organic carbon content (C-organic), reveals that the land is highly suitable class (S1) (Table 2 and Table 6). However, when water availability (wa) (rainfall), rooting media (re) (soil texture and depth), and erosion hazard (eh) (slope and susceptibility to erosion) are taken into consideration, the land suitability falls to moderately suitable class (S2). Soil texture and rainfall represent constraining factors that pose challenges, although they can be addressed to some extent. Consequently, the potential land suitability class for Land Unit 1 is determined to be S2 wa, rc. Hence, the actual land suitability class for Land Unit 1 is S2, with the limiting factors being wa, rc, and eh.

For Land Unit 2, when data related to land characteristics such as temperature, drainage, water pH, organic carbon content, and erosion hazard (eh) are considered, the land suitability analysis results indicate highly suitable (S1) (Table 3 and Table 6). However, when factors like water availability (wa) (rainfall) and root media (rc) (texture, CEC, and soil depth) are considered, the suitability becomes moderately suitable (S2). Consequently, the actual land suitability class for Land Unit 2 is S2, with the limiting factors being wa and rc. Texture and rainfall are factors that present significant challenges and are difficult to overcome. The potential land suitability class of Land Unit 2 is the same as the actual land suitability class, i.e., S2 wa, rc.

Table 5. The land evaluation process for *Styrax benzoin* in Land Unit 4 using the matching method

Land characteristic	Data form the field and laboratory (DFL)	Actual land suitability (ALS)	Improvement effort	Potential land suitability (PLS)
Temperature (tc) (°C)	18.34	S1 (17-29)	(v)	S1
Water availability (wa):				
Rainfall (mm)	2,524	S2 (2,500-3,000)	(-)	S2
Oxygen availability (oa):				
Drainage	well drained	S1 (well drained)	(v)	S1
Root media (rc):				
Texture	slightly coarse	S2 (slightly coarse)	(-)	S2
Soil depth (cm)	100	S2 (100-150)	(-)	S2
Nutrient retention (nr):				
CEC (me.100g^{-1})	12.94	S1(>12)	(v)	S1
Base saturation (%)	21.35	-	-	-
pH H_2O	6.36	S1 (5.5-7,0)	(v)	S1
C-Organic	4.49	S1 (>0.4)	(v)	S1
Erosion hazards (eh):				
Slope (%)	8-13	S1 (8-15)	(v)	S1
Erosion hazard level	low	S1 (low)	(v)	S1
Land suitability classification		ALS = S2 wa, rc		PLS = S2 wa, rc

Note: S1: Highly suitable, S2: Moderately suitable, wa: Water availability, rc: Root media, (v): There is no need improvement effort because it is suitable, (-): Improvement cannot be done because it is a natural factor

Table 6. Actual and potential land suitability of Land Units 1-4

Land characteristic	Land Unit 1 (Aornakan 1)			Land Unit 2 (Aornakan 1)			Land Unit 3 (Aornakan 1)			Land Unit 4 (Kuta Tinggi)		
	DFL	ALS	PLS	DFL	ALS	PLS	DFL	ALS	PLS	DFL	ALS	PLS
Temperature (tc) (°C)	22.07	S1	S1	21.31	S1	S1	19.20	S1	S1	18.34	S1	S1
Water availability (wa):												
Rainfall (mm)	2,524	S2	S2	2,524	S2	S2	2,524	S2	S2	2,524	S2	S2
Oxygen availability (oa):												
Drainage	well drained	S1	S1	well drained	S1	S1	well drained	S1	S1	well drained	S1	S1
Root media (rc):												
Texture	slightly coarse	S2	S2	slightly coarse	S2	S2	slightly coarse	S2	S2	slightly coarse	S2	S2
Soil depth (cm)	100	S2	S2	100	S2	S2	100	S2	S2	100	S2	S2
Nutrient retention (nr):												
CEC (me.100g^{-1})	18.54	S1	S1	12.67	S1	S1	22.58	S1	S1	12.94	S1	S1
Base saturation (%)	12.33	-	-	17.95	-	-	10.82	-	-	21.35	-	-
pH H_2O	5.69	S1	S1	6.20	S1	S1	6.55	S1	S1	6.36	S1	S1
C-Organic	3.44	S1	S1	4.48	S1	S1	4.50	S1	S1	4.49	S1	S1
Erosion hazards (eh):												
Slope (%)	13-16	S2	S1	10-15	S1	S1	0-7	S1	S1	8-13	S1	S1
Erosion hazard level	moderately suitable	S2	S1	low	S1	S1	very low	S1	S1	low	S1	S1
Land suitability classification		S2 wa, rc, eh	S2 wa, rc		S2 wa, rc	S2 wa, rc		S2 wa, rc	S2 wa, rc		S2 wa, rc	S2 wa, rc

Note: DFL: Data form the Field and Laboratory, ALS: Actual Land Suitability, PLS: Potential Land Suitability, S1: Highly suitable, S2: Moderately suitable, eh: Erosion hazard, wa: Water availability, rc: Root media, : There is a change land suitability class, : There is a change limiting factors

Similarly, for Land Unit 3, based on the data concerning land characteristics that include temperature, drainage, CEC, water pH, organic carbon content, and erosion hazard (eh), the land suitability assessment results indicate a highly suitable (S1) classification (Table 4 and Table 6). However, when water availability (wa) (rainfall) and root media (rc) (soil texture and depth) are considered, the suitability becomes moderately suitable (S2). Texture and rainfall are limiting factors that pose significant challenges and are difficult to overcome. Therefore, the potential land suitability class of Land Unit 3 is the same as the actual suitability class, i.e., S2 wa, rc. As a result, the actual land suitability class for Land Unit 3 is moderately suitable (S2), with the limiting factors being wa and rc.

Table 7. Recapitulation of actual and potential land suitability for cultivating *Styrax benzoin*

Village	Land unit	ALS	PLS
Aornakan 1	1	S2 wa, rc, eh	S2 wa,rc
Aornakan 1	2	S2 wa,rc	S2 wa,rc
Aornakan 1	3	S2 wa, rc	S2 wa, rc
Kuta Tinggi	4	S2 wa, rc	S2 wa, rc

Note: ALS: Actual Land Suitability, PLS: Potential Land Suitability, S1: Highly suitable, S2: Moderately suitable, eh: Erosion hazard, wa: Water availability, rc: Root media, : There is a change limiting factors

For Land Unit 4, the assessment of the data concerning such land characteristics as temperature, drainage, water pH, organic carbon content, and erosion hazard (eh) indicate that the land suitability is high (S1) (Table 5 and Table 6). However, when water availability (wa) (rainfall) and root media (rc) (texture, CEC, and soil depth) are considered, the suitability falls into the moderately suitable category (S2). Consequently, the actual land suitability class for Land Unit 4 is S2, with the limiting factors being wa and rc. Similar to Land Unit 3, texture and rainfall pose significant challenges and represent limiting factors that are challenging to address. Land Units 1, 2, and 3 are situated within Aornakan 1 Village, while Land Unit 4 is positioned in Kuta Tinggi Village. The potential land suitability class of Land Unit 4 is the same as the actual land suitability class, i.e., S2 wa, rc. A summary of potential land suitability classes for cultivating *S. benzoin* is presented in Table 7.

In Table 7, it is evident that all land units share an actual land suitability class of S2 (moderately suitable). Land Unit 1 has limiting factors including wa, re, and eh, while Land Units 2, 3, and 4 have limiting factors including wa and rc. This signifies that the land faces constraints that impact its productivity and necessitate additional inputs. However, it is worth noting that erosion hazard (eh) can be mitigated, which leads to the potential land suitability for all four units being categorized as moderately suitable (S2), with limiting factors including wa and rc. Erosion hazard refers to the risk of soil erosion, which can lead to the loss of topsoil and degradation of land quality. In the context of *S. benzoin* cultivation, mitigating erosion hazard is a crucial step in land management. Mitigation of erosion hazard often involves implementing practices such as terracing and erosion control measures. Terracing helps to create level platforms or steps on sloping land, reducing the speed of runoff water and allowing the runoff water to infiltrate the soil rather than causing erosion. Erosion control measures can include planting cover crops, building check dams, and using mulch to protect the soil from erosion. Enhancing soil structure through organic matter amendments and appropriate tillage practices can also contribute to erosion mitigation. Soils with improved structure are less prone to erosion because they can better hold water and resist runoff. Managing sedimentation in waterways and drainage channels can prevent the transport of eroded soil particles downstream. This is important not only for preserving the land but also for preventing environmental impacts downstream.

Several previous studies conducted in North Sumatra Province, as documented by Harahap et al. (2019) and Rahmawaty et al. (2019c, 2020b, 2020e, 2020g), have consistently identified wa and re as common limiting factors in various areas of North Sumatra. Some of these studies, such as those on the land suitability for *Durio zibethinus* (Rahmawaty et al. 2020b) and *Persea americana* (Rahmawaty et al. 2020b), indicated that the limiting factor was related to the root media (rc). Similarly, land suitability studies for *Hevea brasiliensis* and *Aquilaria malaccensis* in North Sumatra (Rahmawaty et al. 2020e) revealed water availability (wa) as a limiting factor. Conversely, for *Elaeis guineensis*, the limiting factor was identified to be wa in land evaluation studies (Harahap et al. 2019; Rahmawaty et al. 2019c). The relationship between the suitability of the *S. benzoin* and the criteria of the land unit is that the *S. benzoin* will thrive if all these factors align with its growth requirements. If the land unit criteria meet all these requirements, then the *S. benzoin* will have a highly suitable in that area or land unit. It is worth noting that different plant species have distinct criteria and requirements for optimal growth, as demonstrated by the variations in limiting factors, such as temperature (tc) and erosion hazard (eh) for species like *Pinus merkusii* (Rahmawaty et al. 2019a). These differences underscore the unique needs and conditions specific to each plant species.

Mapping of actual and potential land suitability for *Styrax benzoin*

Figures 2 and 3 display the maps of the actual and potential land suitability for *S. benzoin*.

Figure 2 illustrates that Aornakan 1 Village currently has land suitability for *S. benzoin* of class S2, with limiting factors including wa, tc, and eh. Both Aornakan 1 Village and Kuta Tinggi Village are of class S2 with shared limiting factors including wa and tc, as depicted in Figure 2. Land Unit 1 in Aornakan 1 Village faces challenges related to erosion hazard (eh) in addition to water availability (wa) and root media (rc) issues. Meanwhile, Land Units 2, 3, and 4, spanning Aornakan 1 Village and Kuta Tinggi Village, share common limiting factors of water availability (wa) and root media (rc) that impact the suitability for *S. benzoin* cultivation. Addressing these limiting factors through appropriate land management strategies is crucial for successful cultivation in these areas. Land Unit 1, located in Aornakan 1 Village, exhibits several limiting factors for the cultivation of *S. benzoin*. These factors are water availability (wa), root media (rc), and erosion hazard (eh). This land unit faces challenges in terms of water availability. There may not be a consistent and sufficient water supply, which can affect the crop's growth and development. The root media, encompassing aspects like soil texture, Cation Exchange Capacity (CEC), and soil depth, is not entirely suitable for *S. benzoin* cultivation in this unit. This can impact the plant's root development and nutrient uptake. There is also an issue with erosion hazard in Land Unit 1. This means that the soil may be prone to erosion, which can lead to loss of topsoil and degradation

of the land's quality. Land Units 2, 3, and 4, situated in both Aornakan 1 Village and Kuta Tinggi Village, share common limiting factors: water availability (wa) and root media (rc). These land units face challenges related to water availability, similar to Land Unit 1. Adequate and consistent moisture levels are essential for crop growth, and this factor needs to be addressed in all three units. The root media, encompassing soil texture, CEC, and soil depth, is another common limiting factor in Land Units 2, 3, and 4. This suggests that the soil characteristics in these units are not entirely suitable for *S. benzoin* cultivation. Meanwhile, Figure 3 reveals that both Aornakan 1 Village and Kuta Tinggi Village have potential land suitability for *S. benzoin* of class S2, with the limiting factors being wa and rc. Notably, the average temperature and altitude in these two villages are categorized as S2 (moderately suitable) (Rahmawaty et al. 2021c).

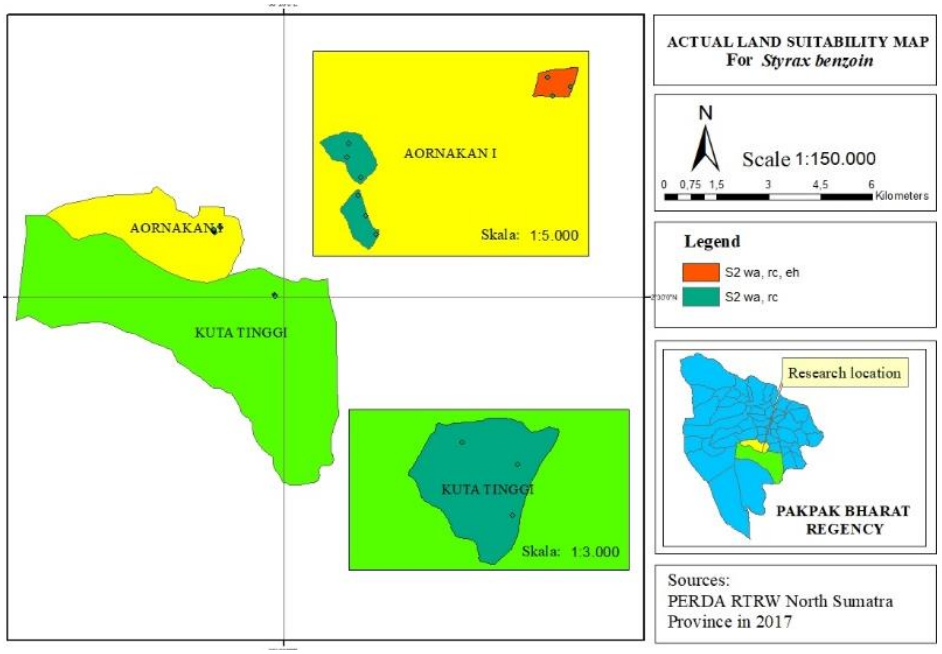

Figure 2. Map illustrating the actual land suitability for *Styrax benzoin* across the four land units

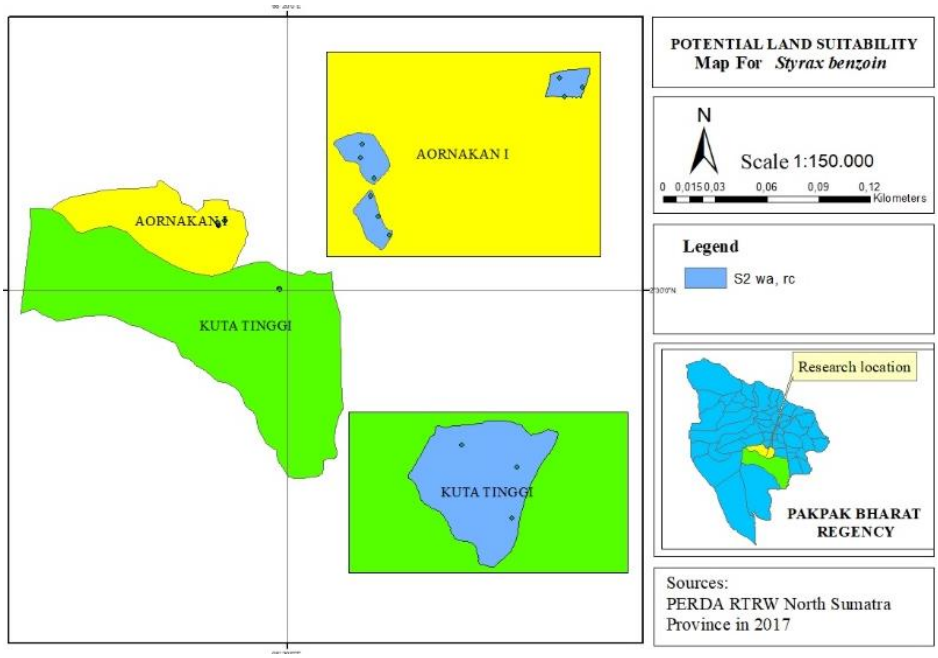

Figure 3. Map illustrating the potential land suitability for *Styrax benzoin* across the four land units

Previous research in the same villages, Aornakan I Village and Kuta Tinggi Village, indicated that the land was marginally suitable for *Coffee arabica* cultivation (S3), with the limiting factor being the root medium (rc), particularly soil texture. To summarize, the land suitability for *S. benzoin* cultivation across all land units in Aornakan 1 Village and Kuta Tinggi Village is of the moderately suitable class (S2). This implies that *S. benzoin* cultivation can be pursued alongside *U. gambir* cultivation in these locations. However, it is important to consider limiting factors, particularly water availability (wa) and root media (rc), when developing *S. benzoin* in these areas. To address the limiting factors of water availability (wa) and root media (rc) for the successful cultivation of *S. benzoin* in Aornakan I Village and Kuta Tinggi Village, land management interventions such as irrigation systems, soil improvement, soil texture modification, terracing and erosion control, root zone management, monitoring and data collection, crop rotation, and research and adaptation can be implemented. To ensure an adequate water supply, especially during dry periods, installing irrigation systems such as drip or sprinkler irrigation can help maintain consistent moisture levels in the soil. Amending the soil with organic matter and mulch can improve its water-holding capacity and overall quality. This can enhance root development and provide a suitable growing medium for *S. benzoin.* If the soil texture is a limiting factor, it may be necessary to modify it. This can involve soil replacement or the addition of materials to improve texture, ensuring that the soil meets the specific requirements of *S. benzoin*. Given that erosion hazard (eh) is one of the limiting factors, implementing terracing techniques and erosion control measures, such as contour farming and planting cover crops, can help mitigate soil erosion and maintain soil structure. Managing the root media is critical. This may involve adjusting the depth of planting or using raised beds with well-draining media to ensure optimal root conditions for *S. benzoin*. Regularly monitoring soil moisture, nutrient levels, and other relevant factors can help fine-tune land management practices to suit the specific needs of *S. benzoin*. Implementing crop rotation practices with complementary plants that have different water and nutrient requirements can help improve overall land suitability and reduce stress on limited resources. Continuously researching and adapting land management techniques based on local conditions and ongoing research findings can lead to more effective solutions for overcoming limiting factors. It is important to note that the choice of intervention will depend on the specific characteristics of the land, local climate, and available resources.

Research about *kemenyan* was conducted by Rahmawaty et al. (2021b; 2023a) and *gambir* (Rauf et al. 2015; Rahmawaty et al. 2021a; 2023b) have demonstrated that both *kemenyan* and *gambir* share similar land characteristics across various criteria. These findings suggest that both plants have the potential to thrive in the same land units. The research results indicate that the environmental conditions in the surveyed area are suitable for the cultivation of both *kemenyan* and *gambir*. However, it is important to note that the successful cultivation of these plants would also depend on other crucial factors, such as effective pest and disease management, as well as employing appropriate agronomic practices. These considerations should be taken into account when planning for their simultaneous cultivation.

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