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RESEARCH ARTICLE

The assessment of essential oil potential from waste logging of different eucalyptus clones in PT Toba Pulp Lestari Tbk's industrial plantation forests, Indonesia

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Abstract

PT. Toba Pulp Lestari Tbk's Industrial Plantation Forest is the largest forest company in North Sumatra Province, with a total area of 188055 ha. Eucalyptus leaves in this company have not been optimally utilized and processed, commonly left as waste. This study aims to calculate the potential of leaves and the potential production of essential oils from eucalyptus leaves which are waste from logging. The method used to calculate the potential of eucalyptus leaves from logging waste is to measure the weight of the leaves from the sample tree. The yield of essential oils produced from eucalyptus leaves is obtained through distillation techniques in the laboratory. The annual production potential of essential oils is calculated using annual logging area data for each clone. The study produced average data on eucalyptus leaf potential from logging waste for each clone and the entire logging area per year. Distillation was performed on all clones to produce eucalyptus oil's average yield and density. Conversion of yield with leaf potential and area of felling results in the amount of oil produced from felled logging waste leaf per year. The potential for eucalyptus production is very significant and related to efforts to increase the economy of non-timber forest products.

Keywords

clones; essential oils; eucalyptus; industrial plantation forest; logging waste; Toba Pulp Lestari

Introduction

The Industrial Plantation Forest (IPF) Management Company, PT Toba Pulp Lestari Tbk, is located in Indonesia, especially in 12 regencies/cities in North Sumatra Province, with a total concession area of 188,055 ha (1). The research location is in the altitude range of 1154-1365 meters above sea level (2). The main plant species developed in this company is Eucalyptus (*Eucalyptus spp*), which is further developed as paper raw materials, producing superior clones. The superior clones referred to here are the clones resulting from crosses of various eucalyptus species to produce clones that have the best characteristics in the context of producing wood for the pulp industry raw materials. However, the use of Eucalyptus trees is still limited to wood (stems and branches). Even though eucalyptus leaves are widely known as producers of essential oils of high economic value they have not been utilized to their potential and only are expected to be decomposed into compost as a source of natural nutrients (3).

Eucalyptus is native to Australia and has about 700 species, it is a genus of tall, evergreen, and lush trees cultivated worldwide for raw materials, oils, gums, pulp, wood, medicine, and aesthetic value. The essential oil in the leaves is very important and is widely used in the food, perfumery, and pharmaceutical industries (4). As mentioned by authors in previous literature (5), the most important product of eucalyptus is the essential oil. The oil has a broad spectrum of biological activities, including anti-microbial, fungicidal, insecticide/insect repellent, herbicide, acaricide and nematicide.

The Indonesian government is focusing on efforts to increase the economic benefits of forests by exploring sources of benefit from non-timber forest products (NTFPs) and forest services. One approach is the issuance of Regulation of the Minister of Environment and Forestry Number 8 of 2021 concerning the obligation of forest managers to implement multi-business forestry as a mandatory approach in managing their business. Multi-business forestry is the application of several forestry business activities in the form of area utilization businesses, timber and non-timber forest product utilization businesses, and/or environmental service utilization efforts to optimize forest areas in protected forests and production forests. This is done by learning from the experiences of various countries that are more advanced in forest resource management. For example, in England, eucalyptus is used to generate heat and electricity. From the aspect of forest services, the main benefit of forest ecosystems for the environment is their potential as an alternative to fossil fuels and trapping carbon emissions produced in industrial activities. High eucalyptus productivity can produce significant biomass, reduce greenhouse gas emissions from fossil fuel consumption, and can also reduce the use of fossil fuels with more renewable biomass-based fuels (6). Eucalyptus plantation forest stands also contribute greatly to the availability of nitrogen from the leaves (7). The above practices are forms of inspiration from the multi-business forestry model that can be indented in eucalyptus industrial plantations in Indonesia, especially by producing essential oils from eucalyptus leaves.

The current global Covid-19 pandemic is happening, including in Indonesia. Therefore, natural resources should be maximized to comprehensively overcome the pandemic (8). Therefore, serious efforts are needed to explore the potential of eucalyptus oil production as one of the natural ingredients that are useful in overcoming the COVID-19 pandemic (9-11). Eucalyptus oil is important in efforts to overcome the COVID-19 pandemic because there are quite a lot of reports stating that eucalyptus oil is one of the natural remedies for the prevention and control of COVID-19 (9, 11 -14).

Eucalyptus is a unique species in terms of growth and wood quality properties (15, 16). It is a competitive species even though it suffers from the disease (17). The quality of charcoal from eucalyptus wood also shows satisfactory gravimetric results (18). However, as a tropical country with high humidity, Indonesia also has weaknesses, where relatively high humidity supports the emergence of diseases in eucalyptus leaves (19). The problem is the untapped potential of essential oil from IPF logged waste leaves, which is used only as wood as raw material for fiber, while the Indonesian government places great emphasis on the use of forest products in each forest area and requires forest management companies to implement a multi-business forestry model. Forest management companies must be able to explore various forms of alternative business potential from their forest concessions, including essential oil business potential. Therefore, this study was conducted to examine the potential of logging waste leaves, rendement, and essential oils that can be produced from various eucalyptus clones in PT Toba Pulp Lestari Tbk's industrial plantation forests. Research on eucalyptus is also necessary because it will be instrumental in planning the management of industrial forest plantations. The dominant compounds in Eucalyptus oil include 1, 8-cineole, limonene, p-cymene, γ-terpinene, α-pinene, α-terpineol, camphene, linalool, and ocimene which are already known to be antimicrobial (20). Many previous studies have proven that eucalyptus essential oil has proven to have the potential to inhibit viral infections and reduce post-COVID syndrome, so it has the potential to be used to protect the world from the COVID-19 pandemic (12, 15, 21, 22). The potential utilization of essential oils is the key to develop industrial plantations sustainable in the future, considering that the source of pulp raw materials is still very dependent on wood fibers (12).

Materials and Methods

Time and research location

The research location is in the logging area of PT Toba Pulp Lestari Tbk in the Aek Nauli sector. The research map is illustrated in Figure 1. The Aek Nauli sector was chosen as the research location because the characteristics of this sector are the most representative of all existing concession areas. This research was conducted from 2020 to 2021. Primary data collection was carried out in August - September 2020.

Research data

The primary data studied were the potential and rendement of oil from eucalyptus leaves in each variety cut in the area of PT. Toba Pulp Lestari, Tbk. The secondary data needed are concession maps, annual harvest area, number of trees felled, and Eucalyptus plant varieties in PT Toba Pulp Lestari, Tbk's Industrial Plantation Forest.

Sampling and measurement methods

This study used five clones according to the number of clones cut down in the area of PT Toba Pulp Lestari Tbk at the time of the study. A sample of 20 trees was taken for each clone, and the tree selection was conducted randomly. This amount is determined by considering the condition of the population, which tends to be

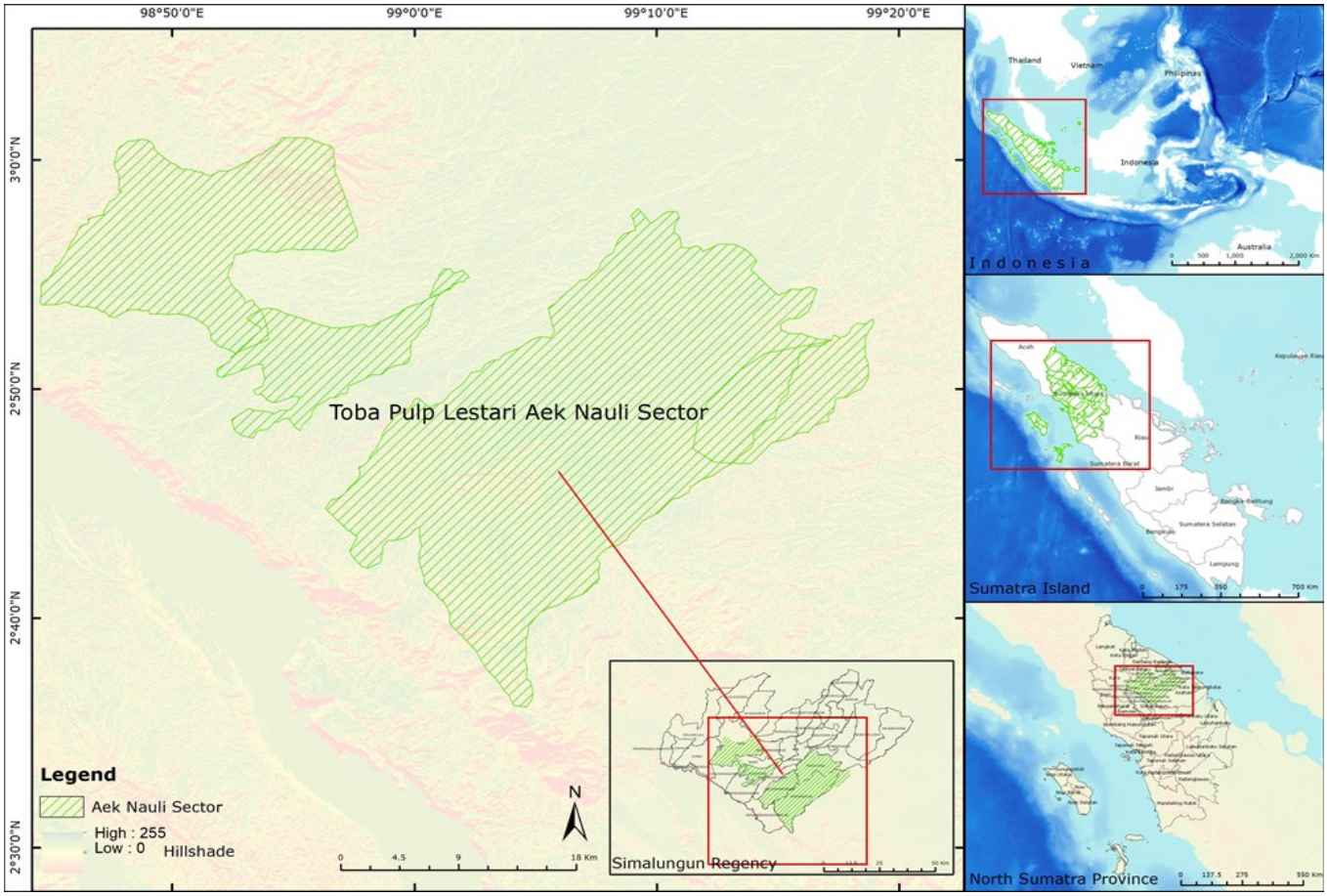

Fig 1. Map of Research Location

homogeneous. Subsequently, the following steps are conducted:

Weighing of leaves on each tree in each eucalyptus variety.

Calculate the average of 20 trees in each eucalyptus variety.

Analysis of data using the formula (i-iv).

Data analysis

Data analysis using quantitative descriptive method. Quantitative analysis is performed using the following formulas:

Eucalyptus leaf potency in each variety

$$\mathbf{PBV} = S\ x\ i\ x\ L$$

v (i)

Where PBV = Eucalyptus leaf potency in each variety/clone (kg), S = Average weight of sample for each variety (kg/ind), i = Crop intensity in each variety (ind/ha), and Lv = Area planted in one variety (ha).

Eucalyptus leaf potential for each sector (ii

$$\mathbf{PPBS} = \sum (S\ x\ Lvi)$$

Where PBS = Eucalyptus leaf potential in sector with (kg), S = Average weight of sample for each variety (kg), and Lvi = Total annual harvested area of each variety in sector I[th] (ha).

Eucalyptus leaf potency, (iii

$$\mathbf{PB} = \sum\ S\ x\ i\ x\ Lvt$$

Where PB = Eucalyptus leaf potential in the entire area (kg), S = Average weight of sample for each variety (kg/ind), i = Crop intensity in each variety (ind/ha), and Lvt = Total area of annual harvested area of each variety (ha).

Eucalyptus leaf oil potency (iv

$$\mathbf{PBM} = M\ x\ PB$$

Where PBM = Potential Eucalyptus Leaf Oil (L), M = Yield of essential oil distillate from Eucalyptus leaves (Ml), and PB = Eucalyptus leaf potential (kg). Eucalyptus oil yield is produced by mixing proportionally eucalyptus leaves from all clones, and distilling with 3 repetitions to get better results. The conversion of the production potential of eucalyptus oil from units of volume to units of weight is used for the measurement of the specific gravity of eucalyptus oil (23, 24).

Results

Eucalyptus clone

There were 6 eucalyptus clones with 16 hybrids and 40 clones from crosses in the PT Toba Pulp Lestari area. In

Table 1. Eucalyptus Sample Clone

Nu	Clone	Seed ID
1	IND 33	*E. grandis* dan *E. pellita* (GP2)
2	IND 38	*E. grandis* dan *E. urophylla* (GU3)
3	IND 46	*E. grandis* dan *E. pellita* (GP1)
4	IND 47	*E. grandis* dan *E. urophylla* (GU1)
5	IND 65	*E. grandis* dan *E. urophylla* (GU2)

this study, 5 clones were selected because the five clones were clones that at the time of the research were being widely developed and there were logging activities. Eucalyptus Sample Clone and Eucalyptus clones are presented in Table 1 and Table 2.

hybrid technique is the result of crossing two or more clones that produce plant varieties with different genetic compositions (13). For example, in the PT Toba Pulp Lestari area, clones EG1, EG2, and EG3 were the parent plant of *Eucalyptus grandis*, and clone ES was the parent *Eucalyptus saligna*, clone EP was the parent *Eucalyptus pellita,* and clone EU was the parent *Eucalyptus urophylla*. The clones GP1, GP2, and GP3 were the parent plants of a cross between *E. grandis* and *E. pellita*. Furthermore, the clones GU1, GU2, GU3, GU4, and GU5 resulted from a cross-breed of *E. grandis* and *E. urophylla* (Table 3).

The space used at PT Toba Pulp Lestari was 2 x 3 m^2, and no thinning was conducted from planting to harvesting. Until harvest, the cutting distance remained 2 x 3 m^2. This was used as a basis for determining the amount and potential of essential oil production from eucalyptus leaves under-researched.

Logging was carried out on 5 types of clones. Harvesting/logging of IND 33 eucalyptus clones was found in the Aek Nauli, Habinsaran, and Tele sectors. The IND 46 clone was logged in the Aek Nauli and Outrageous sectors. IND 38 eucalyptus clones were only carried out in the Aek Nauli sector. IND 47 and 65 were the most collected of the five clones in eucalyptus clones felling occurred. This was

Table 2. Eucalyptus Clones used in the study.

Nu	Group	Clone ID/ Seed ID
1.	EG1	*E. grandis* Seedling
2.	EG2	IND35, IND 53
3.	EG3	IND 37, IND 57
4.	ES	IND 50
5.	EP	*E. pelita* Seedling
6.	EU1	405/15
7.	EU2	IND 51
8.	EU3	IND 06, IND 49
9.	GP1	IND 45, IND 46
10.	GP2	IND 48, IND 33, TPL 10, TPL 20
11.	GP3	IND 34, TPL 14, TPL 12
12.	GU1	IND 47
13.	GU2	IND 32. IND 60, IND 61, IND 63, IND 64, IND 65
14.	GU3	IND 01, IND 31, IND 38, IND 40, IND 41, IND 42, IND 52, IND 54, IND 59, IND 62
15.	GU4	IND 03, IND 05
16.	GU5	MIX

because these clones produced good fiber quality according to the needs of pulp raw materials. This is also consistent with other similar experiments (25) that *E. grandis, E pelita,*and *E. urophylla* are superior species that have been developed in Industrial Plantation Forests (HTI). *E. urophylla* has several advantages: fast growth, high regeneration power, relatively fire resistance, and can grow in various soil conditions, ranging from fertile to low fertility. Eucalyptus has high productivity; hence it can provide substantial biomass yields, reduce greenhouse gas emissions from fossil fuel consumption, and reduce the use of fossil fuels (6).

Eucalyptus has a relatively high overall stand volume productivity, reaching 15 m^3/ha (26). It also has excellent adaptability, although based on the results of

Table 3. Leaf Weight Measurement Data for Each Clone

Tree	IND 33 (kg)	IND 38 (kg)	IND 46 (kg)	IND 47 (kg)	IND 65 (kg)
1.	11.43	4.31	17.52	11.50	5.90
2.	7.46	8.66	6.50	10.32	3.20
3.	4.91	5.17	6.44	5.95	2.18
4.	5.17	5.32	9.43	4.21	6.74
5.	8.49	5.42	8.22	5.86	8.40
6.	5.62	8.36	7.53	2.79	3.83
7.	3.11	3.67	10.20	5.27	11.85
8.	5.68	6.70	11.46	6.43	14.58
9.	4.44	5.95	12.11	9.32	8.25
10.	6.02	6.03	8.65	7.15	9.17
11.	5.72	3.87	8.01	7.04	5.45
12.	8.21	4.21	9.24	8.09	6.13
13.	3.31	6.32	7.15	5.06	11.21
14.	7.21	5.12	11.56	4.12	7.14
15.	7.01	7.21	8.77	6.02	8.15
16.	4.56	4.13	9.50	7.23	7.16
17.	8.21	7.48	8.32	5.11	6.11
18.	8.54	5.06	14.11	6.23	5.23
19.	5.62	8.15	9.40	8.03	5.75
20.	8.97	7.89	9.10	5.42	5.27
Average	6.48	5.95	9.66	6.56	7.08

research, the response to environmental factors varies between clones, especially for aspects of altitude, rainfall, boron, and zinc content (27).

Leaf weight measurement results

The results of leaf weight measurements for each clone are presented in Table 3 below:

From the data in Table 3, the highest ND and lowest average leaf weight were found in the IND 46 and 38 clones, which were 9.66 kg/clone and 5.95 kg/clone. This difference was caused by each eucalyptus clone's crown density and branch-free stem height. A higher header density indicates that the intensity of branches, twigs, and leaves in the clone is higher, resulting in heavier overall leaves. Clones with higher branch-free stems have fewer twigs and leaves, and vice versa. Based on field observations, eucalyptus clones of IND 46 appeared to be the most dominant among others. These clones have a high crown density and a lower branch-free stem.

Leaf weight on the five eucalyptus varieties

The potential average leaf weight produced for the entire area of PT Toba Pulp Lestari was obtained from the average production of each clone, weighted by the number of plants in each clone in the entire planting area. The average weight of eucalyptus logging waste leaf for the entire area was obtained by dividing the total weight of potential leaves by the number of individual trees in PT Toba Pulp Lestari (Table 4). In Table 4, the average weight of the total logging waste leaf is 6.85 kg/tree.

The potential leaf weights produced from 5 varieties of eucalyptus are shown in Tables 4, 5, and 6. In Table 4, the heaviest eucalyptus leaves were found in the IND 46 clone, which weighed 9.66 kg. The clone with the lowest weight was IND 38, which was 5.95 kg. The total potential of eucalyptus leaves from IND 38 clones is the least, which is 278.21 tons in the entire area. IND 38 is the least-produced clone and is only found in the Aek Nauli Sector. The highest potential of eucalyptus leaves was found in the IND 47 clone, which was 22,343.94 tons. Furthermore, the IND 47 clone is the most widely planted eucalyptus clone and is spread throughout the PT Toba Pulp Lestari area.

Based on the data in Table 5, the total potential of eucalyptus leaves produced by PT Toba Pulp Lestari Tbk amounted to 125,515.8 tons per year. This total comes from the harvested area of 10,994 ha multiplied by the average weight of logging waste leaf from each tree.

The potential of eucalyptus oil from logging waste

In general, the potential of eucalyptus oil from the PT TPL area in North Sumatra Province, Indonesia, is more significant compared to other regions in Indonesia. This is because North Sumatra has an almost wet climate throughout the year. This explanation refers to various papers stating that water availability and the rainy season significantly affect eucalyptus production (28-30). The rainy season dramatically affects the annual yield compared to the dry months (31).

The potential essential oil produced from eucalyptus leaf waste in the logged area is calculated by multiplying the yield produced from the refining process by the total potential of the raw material (eucalyptus leaves). The result is changed according to the specific gravity in liters. From the distillation conducted on various eucalyptus clones, an average yield of 0.16 percent was obtained with an oil density per liter of 0.915 kilograms. Obtained almost similar results at the exact location, namely 0.161% for *E. grandis*, 0.142% for *E. urophylla*, and 0.045% for *E. pelita*. This is slightly higher, which produces 0.15% *E. urophylla* oil (32).

The potential of eucalyptus oil produced is obtained by multiplying the yield (0.16%) by the total potential of logging waste leaf, which is 125,515.8 tons per year. Thus, the total potential of eucalyptus oil that can be produced by PT Toba Pulp Lestari is 196,242.9 kg/year. By using the specific gravity measurement figure (0.915 kg/l), the potential volume of eucalyptus oil is 214,473.11 l/ year. This potential eucalyptus oil production can play a

Table 4. The Potency of Eucalyptus Leaves from five Harvested Varieties

Nu	Klon	Total Area (Ha)	Average Leaf/Tree Weight (Kg)	Total of Trees (trees/ Ha)	Σ Leaf Weight (Tons)
1	IND 33	500.22	6.48	833,700.00	5,469.07
2	IND 38	17.28	5.95	28,800.00	278.21
3	IND 46	152.86	9.66	254,766.66	1,650.89
4	IND 47	2,253.17	6.56	3,755,283.33	22,343.94
5	IND 65	1,776.70	7.08	2,961,166.66	20,965.06
Total		4,700.23	-	7,833,716.66	50,707.16
Weighted Average			6.85	-	-

Table 5. The Potential of Eucalyptus Leaves in Each Sector of Forest Plantation

Nu	Sector	Production Area (Ha/ Year)	Leaf Weight (Kg/Tree)	Total of Trees (Tree/Ha)	Σ Leaf Weight (Tons/Year)	Oil Production (Kg/Year)	Production (L/ Year)
1	Aek Nauli	1,177	6.85	1,961,667	13,437.40	21,499.84	23,497.09
2	Aek Raja	543	6.85	905,000	6,199.30	9,918.88	10,840.31
3	Habinsaran	1,294	6.85	2,156,667	14,773.30	23,637.28	25,833.09
4	Tele	7,162	6.85	11,936,667	81,766.20	130,825.92	142,979.15
5	Padang Sidempuan	818	6.85	1,363,333	9,339.80	14,943.68	16,331.89
	Total	10,994			125,516.00	200,825.60	219,481.53

significant role in increasing economic benefits through the use of non-timber forest products (32). In addition, the multi-product concept in forest management is becoming increasingly popular as it is possible to obtain different product combinations from agricultural and forestry products (18).

Various studies have proven eucalyptus oil to be an alternative material for natural treatment in preventing and controlling the Covid-19 virus outbreak, which is currently a strategic problem for the Indonesian people (33). The efforts above are significant because, the impact of the pandemic has dramatically affected the economy in Indonesia, especially the household sector (6). Therefore, the addition of eucalyptus oil supply is expected to contribute to efforts to overcome the Covid-19 situation significantly (9-13).

Eucalyptus essential oil has a broad spectrum of biological activity against fungi, bacteria, insects, mites, and weeds and provides a simple solution (34, 35). These essential oils are cheaper and environmentally friendly. Moreover, they are non-polluting and have little or no toxicological problems. According to literature (5), eucalyptus oil has substantial toxicity in vapor form against various microbes and insects; therefore, it can be used commercially as a fumigant for applied and impregnated products to prevent infestation. Eucalyptus leaves play a role in inhibiting candidiasis. This validates the traditional use of this plant to control fungal infections in diabetic patients.

The potential production of eucalyptus oil of 214,473.11 l/year is equivalent to a value of 200 – 300 billion rupiah when referring to the current selling price of around IDR 100,000 to 150,000 / 100 ml in the local market. The potential economic value is very likely to become one of the alternatives to the development of a multi-business forestry model in the concession area of PT, TPL. The company should develop an alternative business model through the use of eucalyptus oil in the industrial plantation forest concession area. Alternative business models that can be further studied for development include a form of business diversification, partnership efforts with business partners, and an effort to partner with community groups around the work area as a form of CSR. Further research is needed to calculate the level of business feasibility and models of the most efficient utilization business approach.

Conclusion

The total potential of eucalyptus leaf waste generated from logging firewood of PT Toba Pulp Lestari, Tbk. is 125,516.0 tons/year. The potential is obtained from a harvest area of 10,994 ha, with details of cloning IND 33 of 5,469.07 tons, IND 38 of 278.21 tons, IND 46 of 1,650.89 tons, IND 47 of 22,343.94 tons, and IND 65 of 20,965.06 tons. Furthermore, from distillation tests carried out on various eucalyptus clones, an average yield of eucalyptus oil yield was obtained by 0.16 % with an oil density per litre of 0.915 kilograms. The total potential of eucalyptus oil that can be produced from all clones in the logging area is 219,481.53 l/year. Given the importance of eucalyptus oil as a biomedical source, this potential production data is invaluable. Therefore, it is advisable to further examine the feasibility and production model economically so that eucalyptus oil can be produced on an economic scale and can be an alternative business model for forest management companies.

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Authors' contributions

AP, M, and IA conceptualized; AP, RKS, and IA have designed methods; AP, YRUS, and HS have conducted data collection; AP, YRUS, and HS have drafted the manuscript; AP and RKS have supervised; AP and M have managed the administration of the project. All authors read and approved the final manuscript.

Compliance with ethical standards

Declaration : The authors declare no conflict of interest.

Ethical issues: None.

References

1. Indonesian Forest Entrepreneurs Association (APHI). APHI's Contribution of Thoughts to the Nation: List of HTI Areas in Indonesia. Jakarta; 2015.
2. Latifah S. Distribusi Spasial Produktivitas Biomassa untuk Penentuan Daur Optimal Hutan Tanaman *Eucalyptus hibrida* dalam Upaya Mitigasi dan Adaptasi terhadap Pemanasan Global di Sumatera Utara.
3. Puig CG, Álvarez-Iglesias L, Reigosa MJ, Pedrol N. *Eucalyptus globulus* leaves incorporated as green manure for weed control in maize. Weed Sci. 2013 Jan;61(1):154-61. https://doi.org/10.1614/WS-D-12-00056.1
4. Batish DR, Singh HP, Kohli RK, Kaur S. Eucalyptus essential oil as a natural pesticide. For Ecol Manag. 2008 Dec;256(12):2166-74. https://doi.org/10.1016/j.foreco.2008.08.008
5. Boukhatem MN, Amine FM, Kameli A, Saidi F, Walid K, Mohamed SB. Quality assessment of the essential oil from *Eucalyptus globulus* Labill of Blida (Algeria) origin. *Int. lett. chem. phys. astron*. 2014 May;17(3):303-15. https://doi.org/10.56431/p-68q125
6. Leslie AD, Mencuccini M, Perks M. The potential for eucalyptus as a wood fuel in the UK. Appl Energy. 2012 Aug;89(1):176-82. https://doi.org/10.1016/j.apenergy.2011.07.037P. L.
7. Valverde JC. Estimation of leaf nitrogen content from non-destructive methods in *Eucalyptus tereticornis* and *Eucalyptus saligna* plantations. Rev. Fac. Nac. Agron. Medellin. 2012 Dec;74 (3):9655-66. https://doi.org/10.15446/rfnam.v74n3.93619
8. Susilawati S, Falefi R, Purwoko A. Impact of COVID-19 pandemic on the economy of Indonesia. Budapest International Research and Critics Institute (BIRCI-Journal): Humanities and Social Sciences. 2020 May;3(2):1147-56. https://doi.org/10.33258/birci.v3i2.954

9. Sharma AD, Kaur I. Jensenone from eucalyptus essential oil as a potential inhibitor of COVID 19 corona virus infection. Res Rev Biotechnol Biosci. 2020Jan;7(1):59-66. http://doi.org/10.5281/zenodo.3748477

10. Panyod S, Ho CT, Sheen LY. Dietary therapy and herbal medicine for COVID-19 prevention: A review and perspective. J Tradit Complement Med. 2020 Jul;10(4):420-27. https://doi.org/10.1016/j.jtcme.2020.05.004

11. Chaachouay N, Douira A, Zidane L. COVID-19, prevention and treatment with herbal medicine in the herbal markets of salé prefecture, North-Western Morocco. Eur J Integr Med. 2021 Feb;42:101285. https://doi.org/10.1016/j.eujim.2021.101285

12. Abbass HS. Eucalyptus essential oil; an off-label use to protect the world from COVID-19 pandemic: Review-based hypotheses. Univers J Pharm Res. 2020;5:57-60. https://doi.org/10.22270/ujpr.v5i4.440

13. Sharma AD. Eucalyptol (1, 8 cineole) from eucalyptus essential oil a potential inhibitor of COVID 19 corona virus infection by molecular docking studies. 2020. https://doi.org/10.20944/preprints202003.0455.v1

14. Mindawati N, Indrawan A, Mansur I, Rusdiana O. Growth of *Eucalyptus urograndis* hybrid in North Sumatera. Jurnal Penelitian Hutan Tanaman. 2010 Feb;7(1):39-50. https://doi.org/10.20886/jpht.2010.7.1.39-50

15. Gallo R, Pantuza IB, dos Santos GA, de Resende MDV, Xavier A, Simiqueli GF, Valente BMDRT. Growth and wood quality traits in the genetic selection of potential *Eucalyptus dunnii* Maiden clones for pulp production. Ind. Crops Prod.. 2018;123: 434-41. https://doi.org/10.1016/j.indcrop.2018.07.016

16. Grattapaglia D, Vaillancourt RE, Shepherd M, Thumma BR, Foley W, Külheim C, Myburg AA. Progress in Myrtaceae genetics and genomics: Eucalyptus as the pivotal genus. Tree Genetics and Genomes. 2012;8(3):463-508. https://doi.org/10.1007/s11295-012-0491-x.

17. Pérez S, Renedo CJ, Ortiz A, Ortiz F, Santisteban A. Biomass losses caused by Teratosphaeria leaf disease in *Eucalyptus globulus* short rotation forestry. Forests. 2017Nov;8(11):447. https://doi.org/10.3390/f8110447

18. Castro AFNM, Castro RVO, Carneiro ADCO, Santos RCD, Carvalho AMML, Trugilho PF, Melo ICN. AD Correlations between age, wood quality and charcoal quality of eucalyptus clones. Revista Árvore. 2016 Jun;40:551-60. https://doi.org/10.1590/0100-67622016000300019

19. Oliveira de MES, Silva Fernandes F, Glória Junior MA, Soares de Oliveira A, Mafia RG, Alves Ferreira M. Temporal analysis of bacterial leaf blight in clonal eucalyptus plantations in Brazil. Forests. 2019 Sep;10(10):839. https://doi.org/10.3390/f10100839

20. Zhou L-J, Li F-R, Huang L-J, Yang Z-R, Yuan S, Bai L-H. Antifungal activity of *eucalyptus* oil against rice blast fungi and the possible mechanism of gene expression pattern. *Molecules.* 2016;21 (5):621. https://doi.org/10.3390/molecules21050621

21. Sharma AD, Kaur I. Molecular docking studies on Jensenone from eucalyptus essential oil as a potential inhibitor of COVID 19 corona virus infection. arXiv Preprint arXiv. 2020; 2004.00217. https://doi.org/10.48550/arXiv.2004.00217

22. Öztürk GY, Safçi SB. Effects of eucalyptus essential oil in post-COVID syndrome: A pilot study. J Immunol Clin Microbiol. 2022;7 (4):82-87. https://doi.org/10.58854/jicm.1223171

23. Patty DJ, Loupatty G. Analysis of eucalyptus oil distillates traditionally. Biol Chem Res. 2016;295-302.

24. Pidtasang B, Sukkas S, Pattiya A. Effect of *in-situ* addition of alcohol on yields and properties of bio-oil derived from fast pyrolysis of eucalyptus bark. *J. Anal. Appl. Pyrolysis*. 2016;120:82-93. https://doi.org/10.1016/j.jaap.2016.04.012

25. Mindawati N. Site quality study of hybrid industrial plantation forest *Eucalyptus urograndis* as raw material for pulp industry in sustainable forest management. Case Study at PT. Toba Pulp Lestari, Simalungun, North Sumatra (Dissertation). Graduate School. Bogor Agricultural Institute;2011.

26. Setyaji T, Sunarti S, Nirsatmanto A. Early growth and stand volume productivity of selected clones of *Eucalyptus pellita*. Indones. J. For. Res.. 2016 Apr;3(1):27-32. https://doi.org/10.20886/ijfr.2016.3.1.27-32

27. Souza TDS, Ramalho MAP, de Lima BM, Rezende GDSP. Performance of eucalyptus clones according to environmental conditions. Scientia Forestalis. 2017 Jan;45(116):601-10. dx.doi.org/10.18671/scifor.v45n116.01.

28. Binkley D, Campoe OC, Alvares CA, Carneiro RL, Stape JL. Variation in whole-rotation yield among eucalyptus genotypes in response to water and heat stresses The TECHS project. For Ecol Manag. 2020 Apr;462:117953. https://doi.org/10.1016/j.foreco.2020.117953

29. Medeiros PL, Silva GGC, Oliveira EMM, Ribeiro CO, Silva JMS, Pimenta AS. Efficiency of nutrient use for biomass production of a eucalyptus clone as a function of planting density in short-rotation cropping. Aust Forestry. 2020 Jun;83(2):66-74. https://doi.org/10.1080/00049158.2020.1774958

30. Costa d LSE, do Santos RC, Vidaurre GB, Castro RVO, Rocha SMG, Carneiro RL, Trugilho PF. The effects of contrasting environments on the basic density and mean annual increment of wood from eucalyptus clones. For Ecol Manag. 2020 Feb;458:117807. https://doi.org/10.1016/j.foreco.2019.117807

31. Silva LG, Santana RC, Oliveira MLRD, Gomes FS. Evaluation of different silvicultural management techniques and water seasonality on yield of eucalyptus stands. Scientia Agricola. 2021 May;79(2). https://doi.org/10.1590/1678-992X-2020-0064

32. Simanjuntak DJ. Comparison of characteristics of eucalyptus oil (*Eucalyptus* spp). (thesis) Student of Forest Products Technology Study Program. Forestry Department. Faculty of Agriculture. University of Northern Sumatra. Field;1996.

33. Arnold JEM, Perez MR. Income from forest; methods for the development and conservation of forest product for local communities. Chapter 2; The Role of Non-Timber Forest Product Development and Conservation. Center for International Forestry Research (CIFOR). SMT Grafika Desa Putra. Indonesia;1998.

34. Soares AA, Scolforo HF, Forrester DI, Carneiro RL, Campoe OC. Exploring the relationship between stand growth, structure and growth dominance in eucalyptus monoclonal plantations across a continent-wide environmental gradient in Brazil. For Ecol Manag. 2020 Oct;474:118340. https://doi.org/10.1016/j.foreco.2020.118340

35. Abdul-Rahaman AV, Irtwange SP, Kortse A, Makinta U. Anti-fungal potential of biobased oils from *Citrus sinensis* peels and *Eucalyptus globulus* leaves *in vitro* against fungal isolates. Plant Sci Today. 2023;10(2):106-13. https://doi.org/10.14719/pst.