# Preliminary Design of High-Yield Patchouli (*Pogostemon cablin* Benth.) Oil Production System with Phosphate Fertilizer Treatment and Nutrient Rich Biomass Production from Black Soldier Flies (*Hermetia illucens*) Larvae by Applying a Biorefinery Concept

Hafez Habiburrohman*, Harryyanto Ishaq Agasi, Levana Bernadetta

Bioengineering, School of Life Science and Technology, Bandung Institute of Technology, Jl. Let. Jend. Purn. Dr. (HC) Mashudi No.1, Jatinangor, 45363, Indonesia

*e-mail: hafezhabiburrohman@gmail.com

***Abstract—*** Patchouli oil is an essential oil extracted from patchouli (*Pogostemon cablin* Benth.) leaves. It is an important raw material used in the perfume, fragrance, and cosmetics industries**.** As the extraction process generates more waste compared with the extract, a waste treatment process is needed. In the conventional process, the waste is not treated and just thrown away. Biorefinery is a concept that can be applied to convert biomass waste into a variety of chemicals, biomaterials, and energy. This concept aims to increase the value of the biomass and minimize waste. The feasibility of the production system was determined in this study by mass balance and gross profit margin (GPM) analysis. Patchouli oil production system with biorefinery concept produced more varied products with GPM value of 2.442, 1.5 times higher than that of the conventional system. On the basis of mass balance and GPM analysis, it can be concluded that this patchouli oil production system is economically and technically feasible. Thus, it must be further developed and applied during the process of patchouli oil production.

***Keywords— Pogostemon cablin oil; Phosphate fertilizer; Black Soldier Fly Larvae; Biorefinery; Gross Profit Margin***

## I. INTRODUCTION

Patchouli oil is an essential oil produced by patchouli (*Pogostemon cablin* Benth.) It is an important raw material used in the perfume, fragrance, and cosmetics industries. Indonesia is the largest supplier of patchouli oil in the world market, exporting 90% of the global patchouli oil requirement or 1,400 MT of the 1,500 MT/year world consumption with acceptable quality. In 2017, the amount of patchouli productivity in Indonesia reached 1991 tons [1]. The high demand for patchouli oil requires the development of its production system in order to achieve a cheaper and more efficient production. In the previous study, patchouli oil extraction carried out with the combination of microwave water (5 L/min) and hydro-distillation for 20 minutes produced 2.76% of yield [2,3]. Another study showed the production process using pulsed electric field (PEF) of 2,000 V and 1,874 Hz for 8 hours, generating 2.7% of yield [4]. However, these methods are not suitable for application in the industrial scale because of the small amount of yield and high production cost. By increasing the patchouli oil yield production, production profit can improve. In the current research, the author found that patchouli oil yield can be increased until 5.28% w/w dry weight by planting patchouli plants on a medium containing phosphate fertilizer.

This paper offers an alternative patchouli oil preliminary production process by applying biorefinery concept and phosphate fertilizer pretreatment. Biorefinery is a concept that can be applied to convert biomass waste into a variety of chemicals, biomaterials, and energy, thereby increasing the value of the biomass and minimizing production waste [5].

In the patchouli oil extraction process, more waste is generated compared to the extract; thus, a waste treatment process is needed. The biomass waste is used as the feed in the black soldier fly larvae (BSFL) or *Hermetia illucens* L. cultivation, with the addition of aquadest and tofu waste. The BSFL is a noninfectious larvae that can be used as a nutrient-rich biomass; it can accumulate high amounts of protein (40-45%) and contains 25%–45% lipid of dry weight [6,7]. BSFL is often used as an organic waste conversion agent. In this proposed cultivation, BSF is grown from the BSF eggs in the feed medium, after which the eggs will hatch and grow until they transform into pupae and then fly [8]. The BSFL is harvested at the prepupa stage to produce BSFL biomass, liquid fertilizer, and organic fertilizer. Meanwhile, the hydrosol can be sold at high prices because it still contains polar metabolites from patchouli plant. This preliminary design is based on a research on the effect of phosphate fertilizer on patchouli oil production [9].

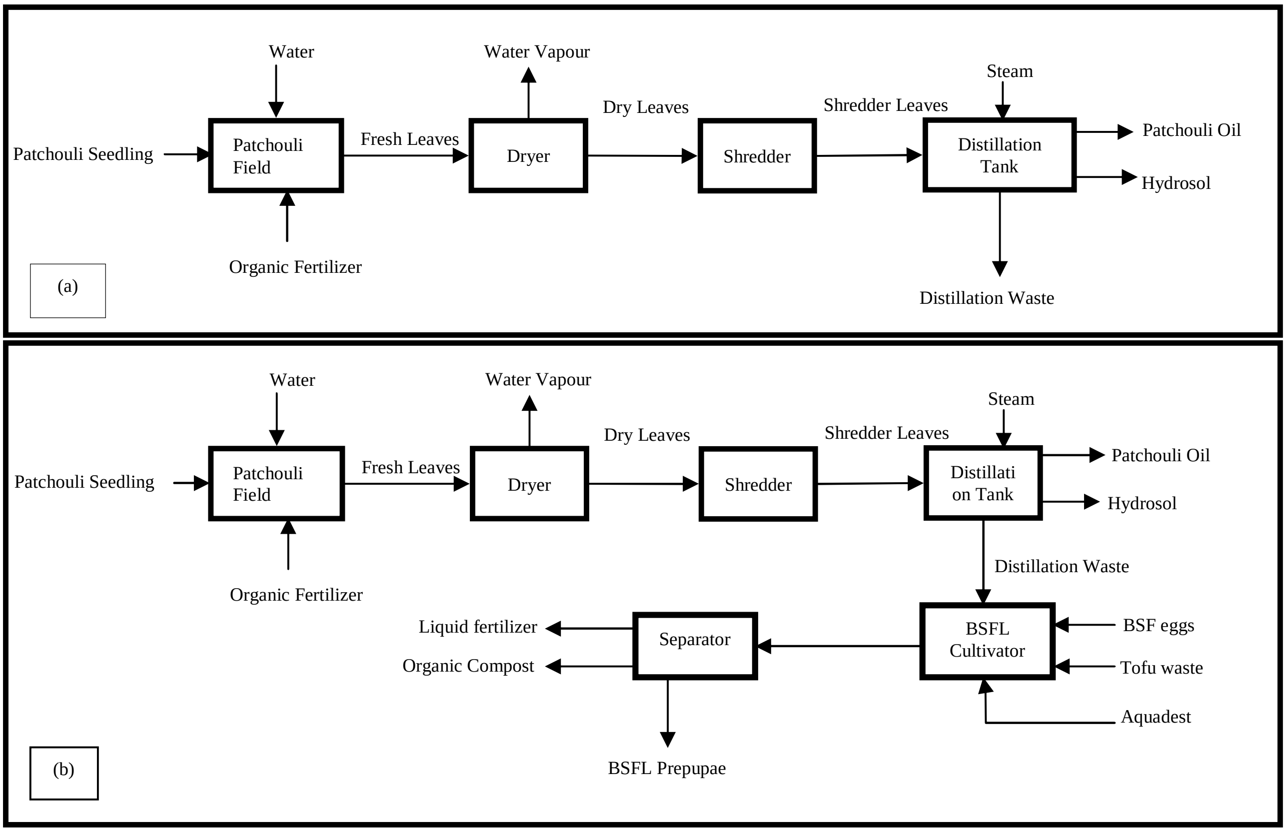


Fig. 1. Production scheme by using (a) Conventional process and (b) Biorefinery concept

## II. MATERIALS AND METHODS

### A. *Patchouli Cultivation*

The one-week-old Acehnese patchouli seedlings (*Pogostemon cablin* Benth.) of the Sidikalang variety are planted in Cipayung, Bogor. The seedlings were acclimatized for 8 weeks, after which they were planted on a mixture of soil, organic fertilizer, and sand with a ratio of 2:2:1 [10]. The variations of phosphate fertilizer treatment used were 0, 0.2, 0.4, and 0.6 g with four repetitions. Then, the patchouli plants were cultivated for 12 weeks. The 12-week-old patchouli plants were then harvested, and the oil was extracted by steam distillation.

### B. *Design of the Process Flow Diagram*

In this paper, the authors compared the production schemes using the conventional process and the biorefinery as shown in Fig. 1.

### C. *Mass Balance Analysis*

Mass balance analysis is used to identify each material flow that is needed at the selected process and the total amount of the product generated. The analysis is divided into three stations: cultivation, extraction, and waste treatment stations. The cultivation station provides preliminary patchouli treatment using phosphate fertilizer, which can increase the oil production. The extraction station simulates the patchouli oil extraction stages from the plant, which also produces hydrosol and biomass waste. The biomass waste is converted to the BSFL biomass, organic compost, and liquid fertilizer in the waste treatment station with the addition of BSF eggs, aquadest, and tofu waste.

TABLE I. THE ASSUMPTIONS FOR GPM ANALYSIS

| Raw Materials | | | | |
|---|---|---|---|---|
| Materials | Amount | Unit | Price (Rp/kg) | Total Price (Rp) |
| Patchouli seedlings | 250,000 | seedlings | 1,000 | 250,000,000 |
| Phosphate fertilizer | 3,675 | kg | 5,000 | 18,375,000 |
| Urea fertilizer | 4,725 | kg | 5,000 | 23,625,000 |
| KCl fertilizer | 3,937.5 | kg | 6,000 | 23,625,000 |
| ZA fertilizer | 4,725 | kg | 3,000 | 14,175,000 |
| Compost fertilizer | 210,000 | kg | 3,000 | 630,000,000 |
| BSF eggs | 14.37 | kg | 15,000,000 | 215,550,000 |
| Aquadest | 186,800 | kg | 1,500 | 280,200,000 |
| Tofu waste | 17,965 | kg | 1,000 | 17,695,000 |
| Product | | | | |
| Patchouli oil | 2,640 | kg | 950,000 | 2,508,000,000 |
| BSFL prepupae | 7,186 | kg | 100,000 | 718,600,000 |
| Organic Compost | 35,930 | kg | 2,000 | 71,860,000 |
| Liquid fertilizer | 28,744 | kg | 56,000 | 1,609,664,000 |
| Hydrosol | 19,600 | kg | 8,300 | 162,680,000 |

*D. Preliminary Economic Analysis Using Gross Profit Margin Comparison*

Gross profit margin (GPM) is a simple and basic tool that can be used to analyze the economic feasibility of a production process system. This analysis compares the profit of the product to the cost of raw material used. Determination of GPM is shown in Equation 1, where PP = product price, P = the amount of product produced, RP = raw material price, and R = the amount of raw material needed. Some assumptions used for GPM calculation are listed in Table I.

$$GPM = (\Sigma (PP*P) - \Sigma (RP*R))/ \Sigma (RP*P) \quad (1)$$

## III. Result and Discussion

*A. Effect of Phosphate Fertilizer Treatment on Plant Growth and Patchouli Oil*

The analysis of patchouli plant growth is based on plant height parameters. The growth curves of patchouli plants with plant height parameters are shown in Fig. 2 in which P0, P1, P2, and P3 represent 0, 0.2, 0.4, and 0.6 g of phosphate fertilizer treatments, respectively. Specific growth rate, doubling time, and patchouli oil yield are shown in Table II. The largest specific growth rate can be seen in the patchouli with the treatment of 0.2 g of phosphate fertilizer. The highest yield of patchouli oil was obtained from patchouli with phosphate fertilizer treatment of 0.4 g. Therefore, in this preliminary design, we used 0.4 g phosphate fertilizer per plant, which is equal to 100 kg/ha. Phosphate fertilizer of as much as 75 kg/ha was also added after harvest.

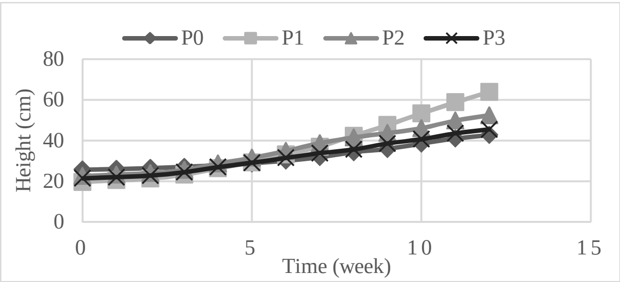


Fig. 2. Patchouli growth curves with phosphate fertilizer treatment (P0 = 0 g; P1=0.2 g; P2=0.4 g; P3=0.6 g)

TABLE II. Patchouli Specific Growth Rate and Oil Yield

| Phosphate fertilizer (g/polybag) | Average specific growth rate ($week^{-1}$) | Average doubling time (week) | Patchouli oil yield (% w/w) |
|---|---|---|---|
| 0 | 0.06 ± 0.021 | 12.36 ± 4.205 | 3.30 ± 0.47 |
| 0.2 | 0.12 ± 0.007 | 6.01 ± 0.327 | 3.40 ± 0.23 |
| 0.4 | 0.10 ± 0.006 | 7.03 ± 0.432 | 5.28 ± 0.86 |
| 0.6 | 0.07 ± 0.027 | 10.43 ± 4.303 | 4.12 ± 0.36 |

*B. Process Alternatives and Gross Profit Margin Analysis*

We evaluated the economic feasibility of the two patchouli oil production systems by comparing their GPM values. The conventional patchouli oil production system only produces patchouli oil, whereas the biorefinery alternative produced four more products aside from patchouli oil: BSFL protein-rich biomass, organic compost, liquid fertilizer, and hydrosol. The GPM value of the conventional production system is 1.613, whereas that of the biorefinery production system is 2.442 GPM as shown in Table III. In general, both alternatives are economically feasible, but by applying the biorefinery concept, the economic feasibility or GPM can be increased by 0.829.

TABLE III. GPM Comparison between the Conventional and the Biorefinery Concept Production Systems

| Parameter | Conventional Production System | Biorefinery Concept Production System |
|---|---|---|
| Total Revenue | 2,508,000,000 | 5,070,804,000 |
| Total cost | 959,800,000 | 1,473,245,000 |
| GPM | 1.613 | 2.442 |

*C. Production System*

The proposed production system consists of three subsystems, namely, patchouli cultivation, oil extraction, and biomass waste treatment subsystem. The overall process flow diagram is shown in Fig. 3. The cultivation subsystem consists of patchouli cultivation in 21 ha of plantation area, with fresh patchouli leaves as the product. Patchouli plants were cultivated for 6 months with the addition of phosphate fertilizer (as much as 25 kg/ha) apart from the usual fertilizer used. After 6 months of cultivation, patchouli leaves were harvested and dried for 3 days. The dried leaves were ground to 0.5–1.5 cm sizes and then distilled via the steam distillation method using water at 10 $0^{o}$C and 1 atm pressure for 7 hours. This subsystem produced patchouli oil, hydrosol, and distillation waste.

The third subsystem, the biomass waste treatment subsystem, consists of the BSFL cultivation and separation units. The BSFL cultivation unit is a tank filled with BSFL fed with mixed feed consisting of distillation waste, aquadest, and tofu waste. After the process is carried out, the mixture of BSFL and feed are separated in the separation unit. This subsystem produces protein-rich biomass, organic compost, and liquid fertilizer.

*D. Mass Balance Analysis*

The assumptions used for the mass balance analysis are as follows:

1. Steam distillation process is done at 100°C and 1 atm pressure for 7 hours.
2. The flow rate of the steam is 0.35 kg steam/hour/kg leaf DW.
3. There are no leakage in the separation unit so the pressure is constant.
4. The distillate consists of hydrosol and essential oil and then separated in the next process.
5. Oil yield is 5.28% kg oil/kg of dry leaves.
6. As much as 20% of total hydrosol produced in the steam distillation unit is sold.

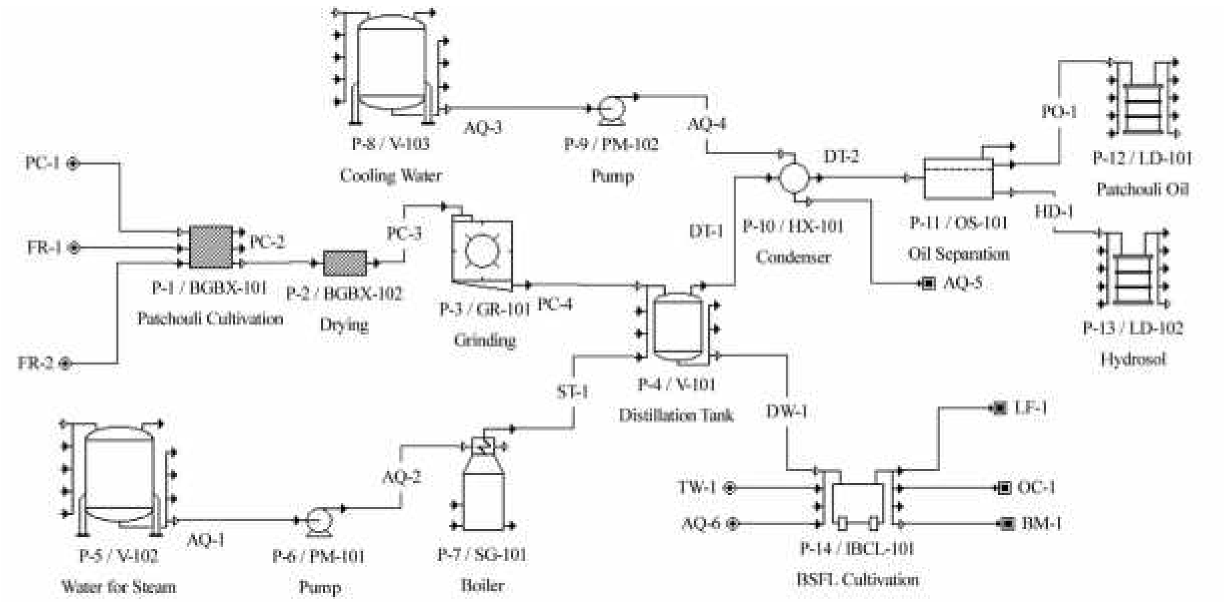


Fig. 3. Process flow diagram of the production system

Planting 250,000 patchouli seedlings on a 21 ha field needs 4,725 urea fertilizer, 3,938 KCl fertilizer, 4,725 ZA fertilizer, and 210,000 compost fertilizer with the addition of 3,675 phosphate fertilizer. After 6 months of cultivation, 250,000 kg of fresh patchouli leaves can be harvested. These are then dried at the dryer unit, eventually producing 50,000 kg of dried leaves. The dried leaves are ground using a grinding unit before being distilled in the distillation tank with 122,500 kg steam. The distillation unit produces 2,640 kg patchouli oil, 71,860 kg distillation waste, and 98,000 hydrosol. The patchouli oil and 20% hydrosol (19,600 kg) can be sold to other companies. Meanwhile, the distillation waste is used as BSFL cultivation feed by enrichment of nutrient and moisture. The aquadest is used to moisture the feed to achieve a 60% moisture content, which needs 1,500 kg of aquadest; the other 40% is the biomass consisting of tofu and distillation waste comprising 8% (17,965 kg) and 32% (71,860 kg) of the total feed, respectively [11]. The BSFL may be harvested around 21 days before it transforms to pupae. The feed shall then be consumed by 14,37 kg BSF eggs to produce 7,186 protein-rich biomass (10% of feed), 35,930 kg organic compost (50% of feed), and 28,744 kg liquid fertilizer (40% of feed).

## IV. CONCLUSION

The preliminary design of the patchouli oil production system with phosphate fertilizer pretreatment following the biorefinery concept is economically feasible as demonstrated by the GPM value of 2.442. This production system needs to be developed in advance so that it can be applied to the manufacturing level. The biorefinery concept also minimizes waste disposal, thus generating environment-friendly added value to the products.

## ACKNOWLEDGMENT

The authors would like to thank Dr. Rizkita Rachmi Esyanti for her input and help during the process of research. The authors also wish to thank Juang Arwafa Cita for his comments and suggestions in completing this paper.

## REFERENCES

[1] Direktorat Jendral Perkebunan dan Kementerian Pertanian. (2017). *Statistik Perkebunan Indonesia 2015-2017*. Jakarta: Sekretariat Direktorat Jendral Perkebunan.

[2] Kusuma, H. S., & Mahfud, M. (2017). The extraction of essential oils from patchouli leaves (*Pogostemon cablin* Benth) using a microwave air-hydrodistillation method as a new green technique. *RSC Advances*, *7*(3), 1336-1347.

[3] Franco-Vega, A., Ramírez-Corona, N., Palou, E., & López-Malo, A. (2016). Estimation of mass transfer coefficients of the extraction process of essential oil from orange peel using microwave assisted extraction. *Journal of Food Engineering*, *170*, 136-143.

[4] Irawan, Y. S. (2017). Optimization of patchouli oil (Pogostemon cablin, Benth) with steam distillation assisted by pulsed electric field via response surface methodology. *Journal of Engineering Science and Technology*, *12*(8), 2106-2119.

[5] Clark, J. H., & Deswarte, F. (Eds.). (2015). *Introduction to chemicals from biomass*. John Wiley & Sons.

[6] Abduh, M. Y., Manurung, R., Faustina, A., Affanda, E., & Siregar, I. R. H. (2017). Bioconversion of Pandanus tectorius using black soldier fly larvae for the production of edible oil and protein-rich biomass. *J Entomol Zool Stud*, *5*, 803-9.

[7] Sheppard, D. C., Newton, G. L., Thompson, S. A., & Savage, S.
A. (1994). Value added manure management system using the blacksoldier fly. *Bioresource Technology*, 275-279.

[8] Manurung, R., Supriatna, A., Esyanthi, R. R., & Putra, R. E. (2016). Bioconversion of rice straw waste by black soldier fly larvae (*Hermetia illucens* L.): Optimal feed rate for biomass production. *Journal of Entomology and Zoolgy Studies*, 1036-1041.

[9] Habiburrohman, H. (2018). *Pengaruh Pupuk Fosfat terhadap Perolehan dan Kandungan Patchouli Alcohol Minyak Atsiri Nilam Aceh (Pogostemon cablin Benth.) Varietas Sidikalang.* Bachelor Thesis, Bandung Institute of Technology.

[10] Sahwalita, & Herdiana, N. (2015). *Panduan Pelatihan Budidaya Nilam dan Produksi Minyak Atsiri Kelompok Citra Lestari Desa Napallicin Kecamatan Ulu Rawas Musi Rawas Utara*. Palembang: Deutsche Gesellschaft für Internationale Zusammenarbeit GmbH.

[11] Wardhana, A. H. (2016). Black Soldier Fly (*Hermetia illucens*) sebagai Sumber Protein Alternatif untuk Pakan Ternak. *Wartazoa, 26*, 069-078.