The potency of Myrtaceae Family from Cibodas Botanic Gardens (Cianjur, Indonesia) as botanical pesticide

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Manuscript received: 2 September 2021. Revision accepted: 29 September 2021.

Abstract. Pratiwi RA, Nurlaeni Y. 2021. The potency of Myrtaceae Family from Cibodas Botanic Gardens (Cianjur, Indonesia) as botanical pesticide. Biodiversitas 22: 4648-4664. Cibodas Botanic Gardens (CBG) is a biodiversity reservoir that can be explored for the discovery of new candidates for botanical pesticides. Myrtaceae has been reported to provide biological activity against pests or pathogens due to their essential oil contents. This research was conducted to inventory and categorize Myrtaceae collection in CBG that had the potency to be botanical pesticide. The list of Myrtaceae collection of CBG obtained from Unit Registration and Collection CBG per 2021. Database fulfilling regarding the bactericide/fungicide/herbicide/insecticide potency of the Myrtaceae of CBG’s collection was carried out through digital references search. Our result showed that there were 73 species of Myrtaceae (from 18 genera) that are potential to be botanical pesticide sources. There were 17 species that are considerably had a high potency. Most of them belong to the Eucalyptus and Melaleuca, followed by Backhousia, Leptospermum, Psidium, and Syzygium. The data resulted from this study is expected to serve as baseline information for further research about the formulation, efficacy, and conservation management of botanical pesticides from Myrtaceae for sustainable use. Furthermore, the development of biological pesticides is a step to improve the quality of Indonesian export products so as to increase national competitiveness in the globalization era nowadays.

Keywords: Botanical pesticide, Cibodas Botanic Gardens's collection, essential oil, inventory, Myrtaceae

INTRODUCTION

The infestation of pests, weeds, and pathogens is responsible for the annual global food crop losses approximated at 45% (Sharma et al. 2019). Pesticides are extensively served as crop protection in agriculture to ensure food security. Pesticides are defined as chemical substances and other materials as well as microorganisms and viruses that are used to prevent or against pests, weeds, and pathogens exposing plants, pets, and humans; to minimalize or eliminate their presence in households, buildings, and transportation. Pesticides comprise herbicides, insecticides, nematicides, molluscicides, acaricides, rodenticides, bactericides, antimicrobials, fungicides, avicides, and larvicides; no matter if it is a synthesis or natural-based products (President of The Republic of Indonesia 1973).

Synthetic pesticide is preferred the most compared to other control methods because it is technically practical, rapid in controlling pests, and effective economically. Unfortunately, over time the massive exposure of high pesticide doses has been associated with the development of resistance mechanisms for pests and pathogens over these compounds. The synthetic pesticides also gets accumulated in the plant, soil, water, air, and non-target biota, enters the food chain, and finally has adverse risks on human beings (Sharma et al. 2019).

The exposure of synthetic pesticides to the ecosystem must be limited by switching them to other environmentally friendly alternatives. The Indonesian government has issued a national policy as outlined in Government Regulation Number 6 of 1995 concerning plant protection by promoting the use of biological control agents or natural pesticides in the integrated pest management system (President of The Republic of Indonesia 1995).

Plants have acquired natural defense mechanisms related to their various secondary metabolites derived from root, leaf, fruit, and seed that repel, inhibit growth or kill pests and pathogens (Kardinan 2011). The plant-based pesticide has been used as local wisdom by earlier farmers with notable success. Botanical pesticides are considered renewable and non-harmful compared with their synthetic counterparts due to their existence as plants in nature for millions of years without any undesirable effect on the ecosystem, especially on non-target organisms. Their phytochemical contents degraded quickly and did not leave hazardous residues (Ebadollahi 2013). However, the commercialization of botanical pesticides depends on the availability of plant sources, which often conflict with other needs, such as food and medicine (Lengai et al. 2020). So, the current screening that emphasizes the botanical pesticide alternatives is being a necessity.

One of the biodiversity reservoirs that can be relied on as botanical pesticide candidates is botanical garden. A total of 50 families (127 species) of Bogor Botanic Gardens were recorded as botanical pesticide candidates (Wardani and Yudaputra 2015). On the other hand, there are 116 species belong to 46 families of Cibodas Botanic Gardens (CBG) plant collections that were confirmed to harbor the...
pesticide features. Myrtaceae, the family with the largest number of potential species as botanical pesticides at CBG (Nurlaeni 2016) has not been an investigation in depth. The Myrtaceae in CBG consists of the genera of Acca, Agonis, Backhousia, Callistemon, Corymbia, Decaspernum, Eucalyptus, Eugenia, Jambosa, Kunzea, Leptospermum, Lophostemon, Melaleuca, Myrcia, Myriciaria, Plinia, Psidium, Rhodaninia, Rhodomurus, Syzygium, Tristanioptis, and Xanthostemon. Meanwhile, the inventoried genera as a natural pesticide are limited to Eucalyptus, Melaleuca, and Leptospermum (Nurlaeni 2016).

This research was conducted to inventory and categorize Myrtaceae collection in CBG that potential to become a source of botanical pesticides in a detailed and comprehensive manner. The data resulted from this study is expected to serve as baseline information for further research about the formulation, efficacy, and conservation management for sustainable use. Furthermore, the development of biological pesticides is a step to improving the quality of Indonesian export products to increase national competitiveness in the globalization era nowadays.

MATERIALS AND METHODS

Study area

This research was conducted in Cibodas Botanical Garden (CBG) that located at Cianjur, West Java, Indonesia. CBG is a botanical garden managed by the National Research and Innovation Agency (BRIN), formerly the Indonesian Institute of Sciences (LIPI), that plays a role in ex-situ conservation, research, and utilization of plant collection.

Procedures

The investigation of pesticide potency on this research is limited to bactericide, fungicide, herbicide, and insecticide. The list of Myrtaceae collection of CBG obtained from Unit Registration and Collection CBG per 2021. Database fulfilling regarding the botanical pesticidal potency of the Myrtaceae of CBG’s collection was carried out through digital references search. The keywords were tailored for collecting information such as “the potential of Myrtaceae (name of species mentioned) as bactericide/fungicide/insecticide/herbicide, essential oils (EOs) of Myrtaceae, chemical compound of Myrtaceae” to retrieve the relevant articles in digital international journal repositories and publishers, such ScienceDirect (www.sciencedirect.com), Google Scholar (www.scholar.google.com), Pubmed (www.pubmed.ncbi.nlm.nih.gov), JSTOR (www.jstor.org), SciELO (www.scielo.org), BioOne Complete (www.bioone.org), Wiley Online Library (www.onlinelibrary.wiley.com), Springer (www.link.springer.com), MDPI (www.mdpi.com), Academic Journals (www.academicjournals.org), SAGE Journals (www.journals.sagepub.com), Taylor & Francis Online (www.tandfonline.com), Cambridge Journals (www.cambridge.org), Smujo (www.smujo.id), also national journal libraries indexed on Sinta Indonesia (www.sinta.ristekbrin.go.id) until June 2021. The language was limited to English and Indonesian. The data about Myrtaceae potency was retrieved manually from collected articles.

The scientific name of the plant species mentioned as a botanical pesticide was verified based on a digital database from Royal Botanic Garden Kew; Plants of The World Online (www.plantsoftheworldonline.org). The conservation status of the plant was determined based on the IUCN Red List of Threatened Species37 (www.iucnredlist.org). The compilation data served as a table that contained followed information: number, scientific name, biological activity against pest or pathogen (as bactericide/fungicide/herbicide/insecticide), score, major chemical compound, the part of the plant used, and references. For high potential Myrtaceae species, additional data are compiled, such as conservation status and origin. In addition, we inventoried the species of Myrtaceae that are not yet mentioned as botanical pesticides for further researches recommendations.

Data analysis

The potential plant as botanical pesticides were classified into four categories: bactericide, fungicide, herbicide, and insecticide. Each plant was assigned a score. Each type of potency (bactericide, fungicide, herbicide, or insecticide) has a score of 1. Thus, plants that have all four potencies have a score of 4 and are stated as high potential sources of botanical pesticide.

RESULTS AND DISCUSSION

The genera distribution of Myrtaceae with botanical pesticide properties

We found that CBG has 124 species of Myrtaceae. A number of 18 genera that consisted of 73 species of Myrtaceae collection of CBG are potential as botanical pesticides according to the literature research we conducted. The genus with the largest number of botanical pesticides is Eucalyptus (18 species), Melaleuca (15 species), and Syzygium (13 species). The distribution of genera that have botanical pesticide properties from CBG is shown in Figure 1.

The list of Myrtaceae from CBG that have a high potentially botanical pesticides

We summarize 73 species of Myrtaceae collection of CBG that have potency as biopesticides. For detailed information about its pesticide attributes, see Table 1. As many as 17 species are classified as high potential sources of botanical pesticide. Most of them belong to the Eucalyptus and Melaleuca, followed by Backhousia, Leptospermum, Psidium, and Syzygium (Table 2).
| Accepted name | Biological activity against pest/pathogen | Score | Major chemical constituent | Part | References |
|---------------|------------------------------------------|-------|----------------------------|------|------------|
| *Agonisia flexuosa* (Willd.) Sweet | Bactericide: Bacillus subtilis, Staphylococcus aureus  Fungicide: Aspergillus niger, Rhizopus oryzae. | 2 | Myrcene, α-thujene, limonene | Ae | (Saj and Thoppil 2011) |
| *Backhousia citriodora* F.Muell. | Bactericide: *S. aureus*, Escherichia coli, *Salmonella typhimurium*, *Mycobacterium phlei*, *Clostridium perfringens*. Fungicide: *Candida albicans*, *A. niger*. Herbicide: cytogenotoxic effect on meristematic cells of *Lactuca sativa*. Insecticide: *Crocidoloma binotalis*. | 4 | Epoxylinalool oxide, isopropyl 4-methyl-3-methylene-4-pentenoate, citral, geraniol, neral | L (EO) | (Wilkinson et al. 2003; Garba 2016; de Andrade Santiago et al. 2017) |
| *Corymbia calophylla* (Lindl.) K.D.Hill & L.A.S.Johnson | Bacitriacid: *S. aureus*, *B. subtilis*, *Kocuria rhizophila*. | 1 | Flavonol | K (Ex) | (Nobakht et al. 2017) |
| *Corymbia citriodora* (Hook.) K.D.Hill & L.A.S.Johnson | Bactericide: *Streptococcus pneumoniae*, *Haemophilus influenzae*. Fungicide: *Pyricularia grisea*, *Aspergillus spp.*, *Colletotrichum musae*. Insecticide: adulticide (*Bemisia tabaci*). | 3 | Citronellal, isopulegol, citronellol, 1,8-cineole | L (EO) | (Aguir et al. 2014; Hussein et al. 2017; Miguel et al. 2018) |
| *Corymbia maculata* (Hook.) K.D.Hill & L.A.S.Johnson | Bactericide: *S. aureus*, *Strepptococcus agalactiae*, *E. coli*, *Klebsiella pneumoniae*, *Proteus mirabilis*, *Pseudomonas aeruginosa*, *Staphylococcus typhimurium*. Fungicide: *Trichophytion mentagrophytes*. | 2 | β-citronellol, β-pinene, 2,6-dimethyl-2,6-octadiene, α-pinene | L (EO) | (Takahashi et al. 2004; Ololade et al. 2017) |
| *Corymbia torelliana* (F.Muell.) K.D.Hill & L.A.S.Johnson | Bacitriacid: *P. aeruginosa*, *S. aureus*. Fungicide: *C. albigicans*. | 2 | 3,4',5,7-Tetrahydroxyflavanone | K (Ex) | (Nobakht et al. 2017) |
| *Decaspermum fruticosum* J.R.Forst. & G.Forst. | Bacitriacid: *S. aureus*. | 1 | n.a. | B, L | (Chung et al. 2004) |
| *Decaspermum parviflorum* (Lam.) A.J.Scott | Bacitriacid: *Enterococcus faecalis*, *S. aureus*, *Acinetobacter baumannii*, *E. coli*, *K. pneumoniae*, *P. aeruginosa*. | 1 | n.a. | L (Ec) | (Paosen et al. 2017) |
| *Eucalyptus alba* Rehn. ex Blume | Bactericide: *S. aureus*, *E. coli*, *E. faecalis*. Fungicide: *C. albicans*, *Candida tropicalis*, *A. niger*, *T. mentagrophytes*, *Microsporum canis*. Insecticide: mosquito repellent. | 3 | 1,8-cineole, limonene, α-terpineol, globulol, α-pinene | L (EO) | (Cimanga et al. 2002a; Tine et al. 2020) |
| *Eucalyptus botryoides* Sm. | Bactericide: *S. aureus*, *MRSA*, *Bacillus cereus*, *E. faecalis*, *Pseudomonas putida*, *Catabacterium acnes*. | 2 | 1,8-cineole, α-pinene | L (EO) | (Takahashi et al. 2004) |
| *Eucalyptus camaldulensis* Dehn. | Bactericide: *S. aureus*, *C. acnes*, *B. cereus*, *E. faecalis*, *P. putida*, *MRSA*. Fungicide: *T. mentagrophytes*. Herbicide: inhibitory effect of growth and chlorophyll content of *Vigna radiata*. Insecticide: *Oryzaephilus surinamensis*, *Sitophilus oryzae*. | 4 | 1,8-cineole, α-pinene | L (EO) | (Takahashi et al. 2004; Ibrahim, 2011; Ebadollahi and Setzer 2020) |
| *Eucalyptus cinerea* F.Muell. ex Benth. | Bactericide: *S. aureus*, *Strepptococcus pyogenes*, *P. aeruginosa*. Fungicide: *C. albigicans*. Herbicide: inhibitory effect of germination, seedling growth, net photosynthetic rates of *Sinapis arvensis*, *Eraca vesticularia*, *Scorpius muricatus*, *Triticum durum*, *Vicia faba*, *Phaseolus vulgaris*. Insecticide: *Musca domestica*. | 4 | 1,8-cineole, α-pinene, limonene, α-terpineol, α-terpinyl acetate | L, F, Fr | (Silva et al. 2011; Rossi and Palacios 2015; Grichi et al. 2016) |
| Species                        | Activities                                                                 | Compounds                                                                 | Reference                                                                 |
|-------------------------------|-----------------------------------------------------------------------------|---------------------------------------------------------------------------|---------------------------------------------------------------------------|
| *Eucalyptus deglupta* Blume   | Bactericide: *B. subtilis*, *Citrobacter diversus*, *E. coli*, *Klebsiella oxysoca*, *K. pneumoniae*, *P. mirabilis*, *Proteus vulgaris*, *S. aureus*, *P. aeruginosa*, *S. typhimurium*, *Shigella flexneri*. Fungicide: *C. albicans*, *C. tropicalis*, *A. niger*, *M. canis*. Insecticide: strong repellent activities against *Culex quinquefasciatus*. | 1,8-cineole, cryptone, myrtenol                                            | (Cimanga et al. 2002a; Liu et al. 2013; Pujiarti and Fentiyanti 2017)     |
| *Eucalyptus diversifolia* Bonpl. | Bactericide: *E. faecalis*, *E. coli*, *S. aureus*, *P. aeruginosa*.          | L (EO)                                                                    | (Elaiissi et al. 2012)                                                   |
| *Eucalyptus dunnii* Maiden     | Insecticide: Adulticide on *Sitophilus zeamais*.                            | L (EO)                                                                    | (Mossi et al. 2011)                                                     |
| *Eucalyptus exserta* F.Muell.  | Bactericide: *Salmonella enteritidis*, *E. faecalis*, *E. coli*, *Lactobacillus plantarum*, *S. aureus*, *Listeria innocua*, *B. subtilis*, *Lactobacillus rhamnosus*. Fungicide: *A. niger*, *A. flavus*. Herbicide: inhibitory effect of *Raphanus sativus* and *L. sativa*. | 1,8-cineole, transpinocarveol, globulol, viridiflorol α-pinene, 1,8-cineole, aromadendrene, α-terpinol, globulol, viridiflorol | (Rensen and Pengwei 1997; Li and Xu 2012; Ambrosio et al. 2017; Oanh and Giang 2017) |
| *Eucalyptus globulus* subsp. Maidenii (F.Muell.) J.B.Kirkp. | Insecticide: cytotoxic on *Spodoptera litura* cell. Fungicide: *T. mentagrophytes*. Herbicide: inhibitory effect of germination and radicle growth of *L. sativa* and *Agrostis stolonifera*. Insecticide: adulticide on *S. zeamais*. | 1,8-cineole, α-pinene                                                    | (Takahashi et al. 2004; Mossi et al. 2011; Puig et al. 2013; Ambrosio et al. 2017) |
| *Eucalyptus gr&is* W. Hill ex Maiden | Bactericide: *S. aureus*, MRSA, *B. cereus*, *E. faecalis*, *Alicyclobacillus acidoterrestris*, *P. putida*, *C. acnes*. Fungicide: *T. mentagrophytes*. | 1,8-cineole, α-pinene                                                   | (Takahashi et al. 2004; Tian et al. 2011)                                   |
| *Eucalyptus haemastoma* Sm.   | Bactericide: *S. aureus*.                                                   | Alkaloids, flavonoids, steroids, Sap terpenoids, tannin                  | (Akter et al. 2016)                                                     |
| *Eucalyptus microcorys* F.Muell. | Bactericide: *E. coli*, *Enterobacter aerogenes*, *Staphylococcus lugdunensis*. Fungicide: *Geotrichum candidum*, *Aspergillus brasiliensis*, *C. albicans*. | 2 Phenolic, flavonoid, proanthocyanidins, saponins                       | (Bhuyan et al. 2017)                                                   |
| *Eucalyptus puncata* DC.      | Bactericide: *S. aureus*, *E. faecalis*, *A. acidoterrestris*, MRSA, *B. cereus*, *C. acnes*. Fungicide: *T. mentagrophytes*. | 1,8-cineole, α-pinene                                                   | (Takahashi et al. 2004; Ribeiro et al. 2018)                               |
| *Eucalyptus robusta* Sm.      | Bactericide: *S. aureus*, *E. faecalis*, *A. acidoterrestris*, MRSA, *B. cereus*, *C. acnes*. Fungicide: *T. mentagrophytes*. | 1,8-cineole, α-pinene                                                   | (Takahashi et al. 2004; Liu et al. 2014)                                   |
| *Eucalyptus saligna* Sm.      | Bactericide: *S. aureus*, *E. faecalis*, *A. acidoterrestris*, MRSA, *B. cereus*, *C. acnes*. Fungicide: *T. mentagrophytes*. Herbicide: inhibitory effect of germination, shoot, and root growth of *L. sativa*, *Amaranthus viridis*, *Ergrostis plana*, *Paspalum notatum*. Insecticide: Adulticide on *S. zeamais*. | 1,8-cineole, α-pinene                                                   | (Takahashi et al. 2004; Mossi et al. 2011)                               |
| Species                                               | Activity                          | Compound(s)                                      | Source(s)                                                                 |
|-------------------------------------------------------|-----------------------------------|--------------------------------------------------|---------------------------------------------------------------------------|
| *Eucalyptus tereticornis* Sm.                         | Bactericide: *S. aureus*, *E. faecalis*, *A. acidotherrestris*, MRSA, *B. cereus*, *C. acnes*, Fungicide: *C. albicans*, *C. tropicalis*, *A. niger*, *T. mentagrophytes*, *M. canis*. | 4 p-cymene, cryptone, cuminaldehyde, α-terpineol                           | (Cimanga et al. 2002a; Takahashi et al. 2004; Vishwakarma and Mittal 2014; Pujiarti and Fentyanti 2017) |
| *Eucalyptus urophylla* S.T.Blake                     | Insecticide: *C. quinquefasciatus*                                          | 4 1.8-cineole, α-pinene, globulol                 | (Cimanga et al. 2002a; Fang et al. 2009; Pujiarti and Kasmadjo 2016; Pujiarti et al. 2018) |
| *Eucalyptus viminalis* Labill.                        | Bactericide: *B. subtilis*, *C. diversus*, *S. aureus*, *E. coli*, *K. oxytoca*, *K. pneumoniae*, *P. aeruginosa*, *P. mirabilis*, *P. vulgaris*, *S. typhimurium*, *S. flexneri*, Fungicide: *A. niger*, *Fusarium oxysporum*. | 3 1.8-cineole, α-pinene                                              | (Takahashi et al. 2004) |
| *Eugenia uniflora* L.                                 | Bactericide: *S. aureus*, *Listeria monocytogenes*.                          | 3 Germacrenes, seline-1,3,7-(11)-trien-8-one oxide, curzerene, γ-elemene, atractylone, trans-β-lemonene | (Victoria et al. 2012; da Cunha et al. 2014) |
| *Feljoa sellowiana* (O.Berg) O.Berg                  | Insecticide: *Rhizoctonia solani*, *Botrytis cinerea*, *C. albicans*.         | 3 4-cyclopentene-1,3-dione                        | (Basile et al. 2010; Mokhtari et al. 2018) |
| *Kunzea ericoides* (A.Rich.) Joy Thomps.             | Bactericide: *C. tropicalis*, *S. aureus*, *Streptococcus mutans*, *Streptococcus sobrinus*, *E. coli*.  | 3 α-pinene, p-cymene                                           | (Van Vuuren et al. 2014; Chen et al. 2016; Park et al. 2017) |
| *Leptospermum brachyrum* (F.Muell.) Druce            | Fungicide: *Fusarium spp.*                                                   | 1 α-pinene, b-caryophyllene, terpinen-4-ol           | (Brophy et al. 1998) |
| *Leptospermum madidum* A.R.Bean                      | Bactericide: *B. cereus*, *S. aureus*, *E. coli*                              | 1 α-pinene, β-pinene, α-humulene, 1,8-cineole       | (Demuner et al. 2011) |
| *Leptospermum petersonii* F.M.Bailey                 | Bactericide: *S. aureus*, *Staphylococcus epidermidis*, *Mycobacterium smegmatis*, *E. faecalis*, *S. pyogenes*, *Streptococcus agalactiae*, *S. pneumonia*, *C. acnes*, *Brevibacillus brevis*, *Bacillus agri*, *Bacillus laterosporum*, *Moraxella catarrhalis*, *P. aeruginosa*, *K. pneumoniae*.  | 3 Citronellal, citronellol, neral, geranial           | (Van Vuuren et al. 2014; Park et al. 2017) |
| *Leptospermum polygalifolium* Salisb.                | Insecticide: *Platela xyllostella*                                            | 1 α-pinene, β-pinene, limonene, 1,8-cineole, γ-terpine, p-cymene, terpinen-4-ol | (Brophy et al. 1998; Windsor and Brooks 2012) |
| Plant Species | Bactericide | Fungicide | Herbicide | Insecticide |
|---------------|-------------|-----------|-----------|-------------|
| Leptospermum scoparium J.R.Forst. & G.Forst. | Bactericide: *S. aureus, S. mutans, S. sobrinus, E. coli*. Fungicide: *M. furfur, T. mucoides, C. albicans, C. tropicalis*. Herbicide: inhibitory effect of growth and pigment content of *Amaranthus retroflexus, Abutilon theophrasti, Calendula arvensis, Sesbania exalata, E. crus-galli*, and large crabgrass. | 4 Leptospormone, calamenene, flavesone | L (EO) (Dayan et al. 2011; Chen et al. 2016; Park et al. 2017) |
| Lophostemon confertus (R.Br.) Peter G.Wilson & J.T.Waterh. | Insecticide: larvicial against *Aedes aegypti* larvae. | 1 α-pinene, α-thujene | L (EO) (Siani et al. 2016) |
| Lophostemon suaveolens (Sol. ex Gaertn.) Peter G. Wilson & J.T.Waterh. | Bactericide: contains potentially antibacterial compounds. | 2 Aromadendrene, spathulenol, β-caryophyllene, α-humulene, α-pinene | L (Ec) (Packer et al. 2015; Naz et al. 2016) |
| Melaleuca alternifolia (Maiden & Betche) Cheel | Bactericide: *S. aureus*. Fungicide: *C. albicans*. | 3 Terpinene-4-ol, γ-terpinene, α-terpinene | L (EO) (Carson et al. 2006; Liao et al. 2016) |
| Melaleuca armillaris (Sol. ex Gaertn.) Sm. | Bactericide: *Acinetobacter baumannii, Micrococcus luteus, Actinomyces viscosus, B. cereus, E. faealis, Porphyromonas gingivalis, Enterococcus faecium, E. coli, K. pneumonia, MRSA, P. vulgaris, S. epidermidis, P. aeruginosa*. Fungicide: *A. flavus, Aspergillus fumigatus, A. niger, C. albicans, Saccharomyces cerevisiae*. Insecticide: Inhibitor of detoxifying enzymes, glutathione S-transferase (GST), carboxylesterase (CarE), and nerve conduction enzyme, acetylcholinesterase (AChE) of *S. zeamais*. | 2 Eugenol methyl ether, p-cymene, α-terpineol | L (EO) (Siddique et al. 2017) |
| Melaleuca bracteata F.Muell. | Bactericide: *B. subtilis subsp. spizizenii, S. aureus, E. aerogenes, E. coli, Salmonella enterica, K. pneumonia, P. aeruginosa*. Fungicide: *A. niger, A. flavus, F. oxysporum, Fusarium solani, Penicillium digitatum*. | 4 Methyl eugenol, (E)-methyl cinnamate, methyl chavicol, elemicin | L (EO) (Almarie et al. 2016; Goswami et al. 2017; Siddique et al. 2017; Yasin et al. 2021) |
| Melaleuca cajuputi Maton & Sm. ex R.Powell | Bactericide: *B. cereus, S. aureus, S. epidermidis*. Fungicide: *A. niger*. Herbicide: trigger the chlorosis to necrosis, inhibit the height of *E. crus-galli*. Insecticide: repellent effect, lethal effect on *Camponotus* sp. | 4 1,4-naphthalenedione, 4H-1-benzopyran-4-one, ethanone, 1,8-cineole, α-pinene | L (EO) (Al-Abd et al. 2015; Visheenta et al. 2018; Kueh et al. 2019; Wińska et al. 2019) |
| Species | Description | Effect | Compound(s) |
|---------|-------------|--------|-------------|
| *Melaleuca citrina* (Curtis) Dum. Cours. | Herbicide: inhibitory effect of growth of *LM. aequinoctialis*. | 4 | 1,8-cineole, α-pinene, β-pinene, terpinolene, limonene, hydroxylated sesquiterpenoids, viridiflorol |
| *Melaleuca decora* (Salish.) Britten | Insecticide: larvicidal against *Ae. aegypti*, *Cx. quinquefasciatus*. | 2 | n.a. |
| *Melaleuca leucadendra* (L.) L. | Fungicide: *H. annosum*. | 4 | α-eudesmol, guaiol, 1,8-cineole, α-terpineol, (E)-methyl cinnamate, (Z)-nerolidol |
| *Melaleuca linearis* var. *linearis* | Herbicide: inhibitory effect of germination, growth, and chlorophyll content of *E. crass-galli*, *Cyperus rotundus*, *Leptochloa chinensis*. | 3 | 1,8-cineole, α-terpineol, terpinen-4-ol |
| *Melaleuca lophantha* (Vent.) Ined. | Herbicide: inhibitory effect of growth against *C. albicans*. | 1 | 1,8-cineole, α-pinene, (E)-β-terpineol |
| *Melaleuca nodosa* (Sol. ex Gaertn.) Sm. | Bactericide: contains potentially antibacterial compounds. | 1 | Leptospernone |
| *Melaleuca polii* (F.M. Bailey) Craven | Bactericide: *E. coli*, *S. aureus*, *B. cereus*. | 1 | Terpinen-4-ol |
| *Melaleuca styphelioides* Sm. | Fungicide: *C. albicans*. Herbicide: inhibitory effect of growth of *LM. aequinoctialis*. | 4 | 1,8 cineole, α-pinene, β-pinene, aterpineol, limonene, hydroxylated sesquiterpenoids, viridiflorol |
| *Melaleuca rugulosa* (Link) Craven | Fungicide: *C. albicans*, *Cryptococcus neoformans*, *A. flavus*, *A. niger*, *Sporothrix schenckii*, *Trichophyton rubrum*. | 2 | 1,8-cineole, α-pinene, (E)-β-terpineol |
| *Melaleuca styphelioides* Sm. | Herbicide: inhibitory effect of radicle growth of *R. sativus*, *Lepidium sativum*, *S. arvensis*, *T. durum*, *Phalaris canariensis*. Insecticide: lethal effect on adults and nymphs of *Aphis gossypii*, *Aphis spiraecola*, *Myzus persicae*. | 4 | Methyl eugenol, spathulenol, caryophyllene oxide |
| Plant Name                      | Biological Activity | Chemical Constituents                                                                 | Refs                                    |
|--------------------------------|---------------------|--------------------------------------------------------------------------------------|-----------------------------------------|
| Melaleuca trichostachya Lindl. | Bactericide: *B. cereus*, *Bacillus pumilus*, *S. aureus*, *S. faecalis*, *E. cloacae*, *E. coli*, *K. pneumonia*, *P. vulgaris*, *P. aeruginosa*, *S. marcescens*. | 1 Terpinen-4-ol, γ-terpinene, 1.8-cineole, psymene, α-terpineol, terpinolene, sabine | (Oyedeji et al. 2014)                   |
| Myrciaria floribunda (H.West ex Willd.) O.Berg | Bactericide: *S. aureus*, *E. coli*. Insecticide: inhibitor of developmental stages and lethal effect on *Rhodnius prolixus* nymphs, estimated LD₅₀ = 19.51 µg/insect | 2 1.8-cineole, linalool, α-terpineol, β-selinene, β-curcumene, (E)-nerolidol, Selin-11-em-4-α-ol, (2Z,6E)-farnesol | (de Azevedo et al. 2019; Tietbohl et al. 2020) |
| Plinia cauliflora (Mart.) Kausel | Bactericide: *S. aureus*, *S. epidermidis*, *B. subtilis*, *E. coli*. Fungicide: *C. albicans*, *C. parapsilosis*, *C. tropicalis*. Insecticide: larvicidal against *Spodoptera frugiperda* larvae, inhibitor larva and pupae developmental stages, reducing amount of female adult. | 3 Gallic acid, galloocatechin, catechin, epicatechin, ellagic acid, salicylic acid | (Souza-Moreira et al. 2010; Alves et al. 2014) |
| Psidium cattleanum Sabine | Bactericide: *K. pneumoniae*, *S. epidermidis*. Fungicide: *C. albicans*. Herbicide: inhibitory effect of the germination and root growth of *L. sativa*. | 3 α-copaene, eucalyptol, δ-cadinene, γ-selinene | (Scur et al. 2016; Antonelli et al. 2020) |
| Psidium guajava L. | Bactericide: *Bacillus stearothermophilus*, *Brochothrix thermosphaeta*, *E. coli*, *L. monocytogenes*, *Pseudomonas fluorescens*, *S. enterica*, *S. aureus*, *Vibrio cholerae*. Fungicide: *T. rubrum*, *Trichophyton tonsurans*, *S. schenckii*, *M. canis*, *C. neoformans*, *C. parapsilosis*, *C. albicans*. Herbicide: inhibitory effect of germination, seedling development, chlorophylls and carotenoids content of *Parthenium hysterophorus*. Insecticide: lethal effect, locomotor deficit, oxidative stress response signaling on *D. melanogaster*. | 4 Morin-3-O-lyxoside, morin-3-O-arabinoside, quercetin, quercetin-3-arabinoside | (Rattanakaikun-sopon and Phumkhachorn 2010; Beatriz et al. 2012; Pinho et al. 2014; Kapoor et al. 2019) |
| Psidium guineense Sw. | Bactericide: *Mycobacterium tuberculosis*, MRSA. Fungicide: *C. albicans*. Herbicide: repellent effect on *Anopheles arabiensis* adults. | 2 Spathulenol, 1.8-cineole | (Chalannavar et al. 2013; do Nascimento et al. 2018) |
| Psidium oligospermum Mart. ex DC. (synonym *Psidium sartorianum*) | Bactericide: *T. rubrum*, *Trichophyton schoenleinii*, *T. mentagrophytes*. Fungicide: *Colletotrichum capsici*. | 1 n.a. | (Camacho-Hernández et al. 2004) |
| Rhodamnia cinerea Jack | Bactericide: *B. cereus*, *S. typhi*, *C. acnes*. | 1 Flavonoid, triterpenoid, carbohydrate | (Diaguna et al. 2015) |
| Rhodomyrtus tomentosa (Aiton) Hassk. | Fungicide: *C. albicans*. | 3 Flavonoid, triterpenoid, carbohydrate | (Kusuma 2016; Kasinathan et al. 2018) |
| Syzygium anisatum (Vickery) Craven & Biffin. | Insecticide: ovicidal and adulticidal activity against *Ae. aegypti*. Bactericide: *A. faecalis*, *B. cereus*, *E. coli*, *K. pneumonia*, *P. mirabilis*, *P. fluorescens*, *S. aureus*, *S. epidermidis*, *Aeromonas hydrophila*, *S. pyogenes*. Fungicide: *Dekkera anomala*, *Schizosaccharomyces pombe*, *S. cerevisiae*, *C. albicans*, *Rhodotorula mucilaginosa*, *C. krusei*. Insecticide: contain potential insecticide compounds. | 3 Gallotannin, ellagittannin, p-rophenylisole, isoestragole | (Blenua et al. 2012; Bryant and Cock 2016; Alderees et al. 2018) |
| Syzygium antisepticum (Blume) Merr. & L.M.Perry | Bactericide: *S. aureus*, MRSA. | 1 β-caryophyllene | (Yuan and Yuk, 2018) |
| Syzygium aqueum (Burm.f.) Alston | Bactericide: *S. aureus, B. subtilis, E. coli, P. aeruginosa.* | 1 | Alkaloid, tannins, glycosides, formic acid, tartaric acid, flavonoids, steroids | Fr, L | (Mapatac and Mamaoag 2014) |
| Syzygium australe (J.C.Wendl. ex Link) B.Hyl | Bactericide: *A. hydrophila, A. feacalis, B. cereus, B. subtilis, C. freundii, E. aerogenes, E. coli, K. pneumoniae, P. aeruginosa, P. fluorescens, S. salford, S. marcescens, S. aureus, Y. enterocolititia.* Fungicide: *S. cerevisiae.* | 2 | 1-vinylethanol, 2-ethyl-1-hexanol, 2-heptyl-1,3-dioxolane, 1-methyloctyl butyrate | Fr, L | (Sautron and Cock 2014; Noé et al. 2019) |
| Syzygium cumini (L.) Skeels | Bactericide: *S. aureus, E. coli, P. aeruginosa, B. subtilis.* Fungicide: *C. albicans.* Herbicide: inhibitory effect of growth of canary grass and wheat. Insecticide: *P. xylostella.* | 4 | n.a. | L, B, Sd | (Yousaf et al. 2014; Elfadil et al. 2015; Minj et al. 2017) |
| Syzygium filiforme Chantaran. & J.Parn. | Bactericide: *E. coli, S. aureus, B. subtilis.* | 1 | Arjunolic acid, aliphatic acid, ursolic acid | Fr | (Ahmad, 2015) |
| Syzygium jambos (L.) Alston | Bactericide: *S. aureus, B. subtilis, E. coli, K. pneumoniae, P. vulgaris, P. aeruginosa, S. typhi, V. cholerae.* Fungicide: *C. albicans, Microsporum gypseum, T. rubrum, T. mentagrophytes.* | 2 | Tannin | B, L, Sd | (Murugan et al. 2011; Noé et al. 2019) |
| Syzygium malaccense (L.) Merr. & L.M. Perry | Bactericide: *S. aureus, B. subtilis, E. coli, P. aeruginosa* | 1 | Flavonoid, tannin, quinone, phenol, steroid | L (Ec) | (Yuniarni et al. 2020) |
| Syzygium myrtifolium Walp. | Bactericide: *S. aureus, E. coli.* | 1 | Alkaloids, triterpenoids, steroids, saponins. | L (Ec) | (Haryati and Saleh 2015) |
| Syzygium nervosum A. Cunn. ex DC. | Bactericide: *A. faecalis.* Fungicide: *C. albicans.* Insecticide: larvicultural against *Ae. Aegypti, Cx. Quinquefasciatus* larvae. | 3 | (Z)-ß-ocimene, caryophyllene oxide, (E)-caryophyllene, ß-pinene | L (EO) | (An et al. 2020) |
| Syzygium polyanthum (Wight) Walp. | Bactericide: *S. aureus, E. coli, P. aeruginosa, B. subtilis.* Fungicide: *C. albicans.* Insecticide: larvicultural against *Aedes* spp. instar III-IV. | 3 | Alkaloid, carbohydrate, tannin, L, Fr steroid, triterpenoid, flavonoid. | Fr, L (Ec) | (Kusuma et al. 2011; Ramadhania et al. 2018; Tri and Bham 2020) |
| Syzygium polycaphalum (Miq.) Merr. & L.M.Perry | Bactericide: *P. aeruginosa* | 1 | n.a. | L (Ec) | (Yuniarni et al. 2020) |
| Syzygium racemosum (Blume) DC. | Bactericide: *S. aureus, E. coli, S. typhi.* Fungicide: *Aspergillus ochraceus, P. digitatum.* Insecticide: synergistic effect with *Citrus sinensis*–chlorpyrifos caused mortality on *S. zeamais.* | 3 | Eugenol, myrcene, chavicol, limonene, 1,8-cineole | L (EO) | (Alitonou et al. 2012; Brito et al. 2020) |
| Xanthostemon chrysanthus (F.Muell.) Benth. | Bactericide: *B. cereus, P. aureus, S. pneumonia, P. aeruginosa, E. coli.* | 1 | n.a. | B (Ec) | (Setzer et al. 2001; Paesen et al. 2017) |
Table 2. List of species of Myrtaceae from CBG that have a high potentially botanical pesticides

| Genus     | Species                                                                                       | Conservation status | Origin                        |
|-----------|------------------------------------------------------------------------------------------------|---------------------|-------------------------------|
| Backhousia| Backhousia citriodora F. Muell.                                                               | -                   | Queensland                    |
| Eucalyptus| Eucalyptus camaldulensis Dehn.                                                               | NT                  | Australia                     |
|           | Eucalyptus cinerea F. Muell. ex Benth.                                                        | NT                  | New South Wales and Victoria  |
|           | Eucalyptus exserta F. Muell.                                                                 | LC                  | Queensland and New South Wales|
|           | Eucalyptus globulus subsp. Maidenii (F. Muell.) J. B. Kirkp.                                  | LC                  | Victoria and Tasmania         |
|           | Eucalyptus saligna Sm.                                                                       | LC                  | Queensland, New South Wales   |
|           | Eucalyptus tereticornis Sm.                                                                  | LC                  | New Guinea and Australia      |
|           | Eucalyptus urophylla S. T. Blake                                                             | EN                  | Lesser Sunda Island           |
| Leptospermum| Leptospermum scoparium J. R. Forst. & G. Forst.                                              | LC                  | Australia and New Zealand     |
| Melaleuca | Melaleuca bracteata F. Muell.                                                                 | -                   | Australia                     |
|           | Melaleuca caajupii Maton & Sm. ex R. Powell                                                  | LC                  | Indo-China to North Northern Territory |
|           | Melaleuca citrina (Curtis) Durn. Cours.                                                       | -                   | East and South East Australia |
|           | Melaleuca leucadendra (L.) L.                                                                | -                   | Maluku to North Australia     |
|           | Melaleuca quinqueverringa (Cav.) S. T. Blake                                                 | LC                  | New Guinea, New Caledonia and East Australia |
|           | Melaleuca styphelioides Sm.                                                                  | LC                  | South East Queensland to New South Wales |
| Psidium   | Psidium guajava L.                                                                           | LC                  | Tropical and Subtropical America |
| Syzygium | Syzygium cumini (L.) Skeels                                                                  | LC                  | Tropical and Subtropical Asia to North Queensland |

Note: NT (near threatened), LC (least concern), EN (endangered)

Figure 1. The distribution of genera of Myrtaceae from CBG that have botanical pesticide properties

Discussion

Myrtaceae can be distinguished from other families by scaly bark, scented leaves that contain oil gland dots, flat-leaf edges, inframarginal venation, numerous, brightly and conspicuous stamens, and inferior ovary position which is often fused with hypanthium (Singh 2010). Some of the valuable products from Myrtaceae include timber, EOs, spices, fruits, natural dyes, ornamental plants, animal feed, and folk medicines such as antibacterial, antidiabetic, anti diarrheal, and antioxidants (Mitra et al. 2012; Kuspradini et al. 2019). The research about ethnobotany at Sesao protected forest, West Nusa Tenggara, Indonesia revealed that Myrtaceae (represented by Syzygium; the highest important value’s index in the primary forest of Sesao) is the most widely family utilized by community as plant-based treatment for various diseases, source of food as edible fruits, drinks, or jelly, and building material (Hidayat 2017).

The promising biological activities of Myrtaceae attributed to its secondary metabolites contents in the form of EOs. Plants elicited a plentiful number of secondary metabolites as a strong defense response to counteract pest and pathogen attack, attractant of pollinators and symbionts, and plant-plant communication. An interesting study about Ocimum kilimandscharicum (Lamiaceae) found these plants increased the production of its secondary metabolites during Helicoverpa armigera infestation. Moreover, these metabolites have been studied able to retard larval growth and induce pupal deformities. However, many of the plant-related defense compounds are autotoxic to plant metabolism (Singh et al. 2014). Thus, Myrtaceae which have similar defense mechanisms, stored the secondary metabolites for long-term protection in separated cellular structures such as oil glands that avoid it contaminate the key physiological processes. Even in E. brevistylis; a novel finding was found that there are two
foliar oil gland types, translucent and golden-brown, with different abundances which may reflect the different herbivores present (Goodey et al. 2018).

From Figure 1 and Table 2, it can be noticed that the *Eucalyptus* is the one that has received more attention in terms of its pesticide potency. Knowledge about EOs from *Eucalyptus* has been mapped. The observations regarding the folk utilization of eucalyptus oil against pathogens for hundreds of years have become the basis for the development of pesticides, as well as systematic screening followed by biological tests in order to determine the active compounds (Regnault-Roger and Philogène 2008). Major phytochemical content of eucalyptus oil such as 1,8-cineole, citronellal, citronellol, citronellyl acetate, p-cymene, eucamal, limonene, linalool, a-pinene, g-terpinene, a-terpineol, alloocimene, and aromadendrene which act synergistically to bring a wide spectrum of fungicide, bactericide, insecticide, acaricide, and nematicide (Batish et al. 2008). EOs from *Eucalyptus* and Myrtaceae in general are relatively well-investigated experimentally and clinically as well as used extensively in modern pharmaceuticals and perfumery industries. Many studies evaluated their toxicity on mammals and put them on low-risk products (Eboddallahi 2013).

Eucalyptus oil, as well as *Melaleuca* and *Rhodamnia* extract can inhibit several types of pathogens such as bacteria and fungi that attack plant commodities, besides as inhibitors of microorganisms that cause disease in humans and animals. Some interesting examples include *Pectobacterium carotovorum* (formerly classified as *Erwinia carotopora*) which is a pathogen on cabbage, tomatoes, eggplant, and nepenthes (Lee et al. 2014), *Xanthomonasaxonopodis* on citrus (Petrocelli et al. 2012), *X. campestris* on cruciferous plants (Vincente and Holub 2013), *X. oryzae* on rice (Lang et al. 2019), *Fusarium oxysporum* on banana (Maymon et al. 2020), *F. solani* on guava (Ingle 2017), *Agrobacterium tumefaciens* causing crown galls and hairy roots of over 20 different fruit trees (Smith and Townsend 2019), *Ralstonia solanacearum* on potato (Alvarez et al. 2019), *Rhizoctonia solani* (teleomorph: *Thanatephorus cucumeris*) on sugar beet (Windels et al. 1997), and *Colletotrichum capsici* on chili (Saxena et al. 2016). Thus, it is also expected to protect the collection of nepenthes and another plant collection belonging to CBG.

EOs from *E. urophylla*, *E. saligna*, *L. scoparium*, and *M. bracteata* as bioherbicides caused an inhibitory effect of seed germination, shoot and root growth, as well as reducing the amount of pigment content of *Acacia confusa*, *Amaranthus retroflexus*, *Amaranthus viridis*, and *Stachyarthepha indica*. Several species related with these weeds are familiar as invasive alien species (IAS) in CBG, including *Acacia farnesiana* (Junaedi and Mutaqien 2018), *Amaranthus spinosus* (Handayani et al. 2021), and *Stachyarthepha jamaicensis* (Handayani and Hidayati 2020). The EOs probably had a similar prospective to control the IAS in the CBG.

EOs as a botanical pesticide is most probably used under controlled environmental conditions only. It is unlikely for field-scale application considering the rapid volatility and low persistence in the environment due to the easy degradation of ultraviolet light or elevated temperatures (Eboddallahi 2013). Regarding the low toxicity, botanical pesticides from EOs of Myrtaceae are suitable for urban areas, hospitals, hotels, and offices (Kardinan 2011), such as for controlling mosquitos (*Ae. aegypti*, *Ae. albopictus*, *A. gambiae*, *A. Arabiensis*, and *Cx. quinquefasciatus*), cockroach (*Blatella germanica*), and fruit flies (*D. melanogaster*, *D. suzuki*) although it requires a higher application rate and frequent reaplication (Ismam, 2016). The application of EOs is also appropriate as a repellent for stored product pests. The EOs from *M. bracteata* leaves, as *Glycosmis lucida* (*Rutaceae*) and *Juniperus formosana* (*Cupressaceae*) do, was reported to contain significant repellent agent against *T. castaneum* and *Liposcielis bostrychophila* (Guo et al., 2016; 2017).

EOs application for pesticides can be used as a fumigant, in addition to being a repellent (Nattudurai et al., 2017). Their volatility in the case of aerosols to be used in urban environments is a blessing, in terms of attaching the pesticide vapor to the pest while at the same time quickly disappearing from the environment and leaving no harmful residue on surrounding objects, either plants, food, or humans (Lucia et al., 2009). Especially for controlling *Ae. aegypti*, volatile oil vapor extracted from various *Eucalyptus* (*E. gunnii*, *E. tereticornis*, *E. grandis*, *E. camaldulensis*, *E. dunnii*, *E. cinerea*, *E. saligna*, *E. sideroxylon*, *E. globulus* ssp. *globulus*, *E. globulus* ssp. *maidenii*, *E. viminalis* and hybrids of *E. grandis* x *E. tereticornis* and *E. grandis* x *E. camaldulensis*) are toxic to adult of *Ae. aegypti*, with the fastest knockdown time due to *E. viminalis* exposure (4.2 minutes), as good as dichlorvos, the standard knockdown agent (Lucia et al., 2009).

Although there are many literatures that explore the potency of Myrtaceae as a botanical pesticide, the development of plant-based pesticides is actually a long and challenging journey. The flow includes the discovery of plants with pesticide potency (active extraction compounds), optimization (biological evaluation), development (standardized formulation, toxicological assessment, environmental fate and safety), registration and regulatory approval, and commercialization (Luiz de Oliveira et al., 2018). For limited use, local farmers in Sumedang, Indonesia have succeeded in processing attractants from *Melaleuca* with a simple distiller they have made themselves. The EO yield is still in the form of a cloudy, but it is quite effective at trapping flies fruit (Kardinan 2011).

Recently, nanoemulsion technology has been developed as an efficient vehicle to overcome the problem of EOs stability. Nanoemulsion is a liquid dispersion system of two different immiscible liquids with nanometric sizes from 20 to 200 nm. The extremely small size of particles provides a wider surface contact area and resistance against gravity, resulting in a higher degree of delivery and absorption of particles to the target than bulk pesticides. In addition, the physicochemical properties of the coating agents can provide greater affinity with the target tissue and protection against particle degradation. The success
stories of nano emulsified EOs in controlling pests included larvicides against *Cx. quinquefasciatus* from eucalyptus oil that emulsified by Tween® 80, as well as insecticides, repellents, acaricides, and anti parasites from EOs nanoemulsions derived from citronella, hairy basil, vetiver, cinnamonum, lavender, rosemary, and pepper tree (*Echeverria* and Albuquerque, 2019).

Registration and regulatory approval for EOs-based pesticides must follow the guidelines that have been developed in evaluating synthetic pesticides, even though they are considered as low-risk active substances. This includes data on product chemistry, environmental fate, and toxicity on laboratory animals and non-target organisms, including fish, wildlife, pollinator, crop, and ornamental plants. Even some regulatory agencies require efficacy data as well (Isman, 2016). Until the 1990s there was no successful commercialized repellent, let alone EOs-based pesticides, which were successfully commercialized, except for citronella (Isman, 2016). As technology advances, insecticides based on EOs from Myrtaceae along with rosemary oil, peppermint, cinnamon, thyme, and 2-phenethyl propionate have been developed into the commercial brand by EcoSMART® USA (https://ecosmart.com/). In China, eucalyptol has been registered as an insecticide and fungicide. 1,8-cineole from Eucalyptus has been approved as an insecticide in India. In Australia, EOs from tea tree (Melaleuca) are also approved as insecticides and miticides (Isman, 2016).

Even the EOs are harmless and effective, the price remains an important consideration while the EOs will be brought into the commercialization stage. The price of EOs varies and depends on quality, source, and geographic area (related to expenditure for land and labor) (Isman, 2016). In addition, the issue of EOs extraction which spent a huge amount of plant sources and cost should not be ignored (Ebadollahi 2013). In our research, several species of Myrtaceae have been tested from other parts, such as sap, keno exudate, or crude leaf extract. It is necessary to carefully calculate the cost of extracting these sources compared to EOs extraction to determine which method is the most efficient.

On the other hand, the attention of the high potency of the plant-derived pesticide risks the plant population’s existence in the wild for the long term. Meanwhile, sustainability of the botanical resource in large volumes is the main requirement in the commercialization of pesticides (Isman 2005). In general, the risk of utilized plants can be evaluated based on the followed categories: low risk (high potential for sustainable use), medium risk, and high risk. The plants that utilized by fruit and foliage harvesting are categorized as low-risk plants because it is not destroying the plants seriously. The plants utilized by fruit and foliage harvesting are categorized as low-risk plants because it does not seriously destroy the plants. Logging the plants for building material and firewood put them at a high-risk of extinction (Hidayat 2017). Myrtaceae parts used as a source of EOs are mostly leaves, some fruits and flowers. Based on the categories above, the usability of Myrtaceae generally as botanical pesticide will drive them on low to moderate risk. However, this assessment may be different for Myrtaceae that have been classified as threatened plants, such as *E. urophylla* which is assigned by The RedList IUCN as endangered species (Hills 2019), *E. camaldulensis* (Fensham et al. 2019a) and *E. cinerea* as near-threatened species (Fensham et al. 2019b).

We offer several recommendations in following up on the information from our study. First, optimizing the usability of the high potential plants involving conservation consideration to assure their sustainability. Various sets of conservation strategies for utilized plants are recommended, such as providing both in situ and ex situ conservation and formulating good agricultural practices. In situ conservation plays a great role because most of the particular biological properties of the plant mainly rely on secondary metabolites secretion as a response to natural environmental stimuli, which may not be expressed under culture conditions. As an ex-situ conservation institution, botanic gardens play important roles by developing the protocol for domestication, variety breeding, and cultivation, while the seed banks help store the genetic diversity of plants. Some implementation of good agricultural practices are organic farming and leaves and flower harvesting as a more sustainable resource instead of destructive root and whole-plant harvesting (Chen et al. 2016). Second, exploring many species listed here in order to avoid overexploitation of a particular species, such as *E. exsenta*, *E. globulus*, *E. saligna*, *E. tereticornis*, *L. scoparium*, *M. cajuputi*, *M. quinquenervia*, *M. styphelioides*, *P. guajava*, and *S. cumini* whose populations were estimated quite stable. Although it is important to emphasize that *E. globules* (CABI 2015), *L. scoparium* (CABI 2012), *M. quinquenervia* (CABI 2007, 2013a), *P. guajava* (CABI 2013b), and *S. cumini* (CABI 2008) are invasive alien plants, so the risk analysis in their cultivation must to be considered. Third, investigating the 51 species of Myrtaceae at CBG whose potency is still not revealed due to limited research report, including *E. argillaceae*, *E. capitellata*, *E. deanei*, *E. dvyeri*, *E. foeunda*, *E. johnstonii*, *E. macandra*, *E. nigra*, *E. obtusifora*, *E. pilularis*, *E. piperita*, *E. platyphyllo*, and *E. racemosa* (Eucalyptus), *M. formosa*, *M. glauca*, and *M. williamsii* (*Melaleuca*), *S. acuminatissimum*, *S. acutangulum*, *S. ampliflorum*, *S. cerasiforme*, *S. claviflorum*, *S. cymosum*, *S. discophorum*, *S. formosum*, *S. furfuraceum*, *S. garciniifolium*, *S. glabratum*, *S. glomeratum*, *S. hemilaeprum*, *S. laxiforum*, *S. macromyrtus*, *S. magnolifolium*, *S. microcyrum*, *S. nigricans*, *S. paupercutatun*, *S. polypehaidoisa*, *S. pseudomalacence*, *S. punctulatum*, *S. pycahedon*, *S. rostratum*, *S. syzygioides*, *S. uninilor*, and *S. verteegii* (*Syzygium*), *C. gumnifera*, *C. leichhardtii* (*Corymbia*), *L. wooroomooroon*, *L. javanicum* (*Leptospermum*), *Eugenia expansa*, *Jambosa anastomosans*, *Myrcia subcordata*, and *Tristaniopsis laurina*.

To conclude, CBG is a great source of germplasm for the development of botanical pesticides. Our result showed that 73 species of Myrtaceae (from 18 genera) from CBG are potential to be botanical pesticide sources. In addition, 17 species considerably have high potency. Most of them belong to the *Eucalyptus* and *Melaleuca*, followed by *Backhousia*, *Leptospermum*, *Psidium*, and *Syzygium*. The
data resulted from this study is expected to serve as baseline information for further research about the formulation, efficacy, and conservation management of botanical pesticides from Myrtaceae for sustainable use. Furthermore, the development of biological pesticides is a step to improve the quality of Indonesian export products to increase national competitiveness in the globalization era nowadays.

ACKNOWLEDGEMENTS

The authors thank to the all of researchers and staff of registration and collection unit of the Cibodas Botanic Gardens, Indonesia for their kindness and help during the research.

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