Research Status of Botanical Insecticide in Indonesia and Its Commercial Constraints

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Abstract. This article aims to review the status of botanical insecticide and its commercialization constraints in Indonesia. The method used was by tracking botanical insecticide papers published from 1993 to 2019. The collected data consisted of the plant source of botanical insecticide; intensively studied insect pests; and the number of commercial botanical insecticides and their active ingredients. The results found that *Annona muricata*, *Azadirachta indica*, *Nicotiana tabacum*, *Carica papaya*, and *Cymbopogon nardus* were the most common plants used for botanical insecticide. The most studied insect pests were: *Spodoptera litura*, *Crocidolomia pavonana*, *Plutella xylostella*, *Sitophilus oryzae*, and *Aedes aegypti*. Methyl eugenol was the most common commercialized active ingredient followed by azadirachtin. Citronella and geraniol were used only as mixtures. The constraint of commercializing botanical insecticide was from the companies. They are not interested in developing botanical insecticides since the prospect is not certain and the registration fee is more expensive than that of synthetic ones.

1 Introduction

Botanical pesticides are natural pesticides extracted from plants that could be used as repellents, growth inhibitors, or pest killers since they have several modes of action depending on the bioactive compounds, including (1) damaging the development of insect eggs, larvae, and pupae, (2) inhibiting moulting process, (3) disturbing insect communication, (4) feeding deterrent, (5) inhibits the reproduction of female insects, (6) reduces appetite, (7) blocks the ability to eat insects, and (8) repels insects [1]. Botanical pesticides also have several advantages, including safety for the environment, ease of degradation, and difficulty in causing resistance to pests, and are usually compatible with other control methods [2]. They have been used for centuries ago to control human, animal, and crop pests and diseases. However, along with the widespread use of chemical pesticides, the use of botanical pesticides is less popular. Research and development towards commercial botanical pesticides are very slow.

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There are a lot of plants that can be used as pesticides. In 1984, around 1800 plant species were used for pest control, and in 2011, 500.000 plant species were recorded to have potentially acted as biopesticides [4]. The most popular species used for insecticide were from the families of Asteraceae, Fabaceae, and Euphorbiaceae, such as pyrethrum (*Chrysanthemum cinerariaefolium)*, rotenone (*Derris eliptica)*, neem (*Azadirachta indica)*, riania (*Ryania* sp.), tobacco (*Nicotiana tabacum)*, and sabadilla (*Schoenocaulon* sp.) [1, 5]. In Indonesia, there were 2400 plant species from 235 families containing bioactive material used for botanical pesticides [6], and 174 plant species were found in Sumatra [7], with 59 species having potential as pesticides [8]. Information on the research status of botanical pesticides and their development in various countries has been intensively reported, but not in Indonesia. Therefore, we collected papers from several national journals and proceedings to reveal the status of research and development of botanical insecticides in Indonesia. This paper also attempts to discuss the development of the commercialization of botanical insecticides and its constraints. To accomplish the aims, this paper will discuss several topics, including 1). The dynamic of botanical insecticide publications in Indonesia from 1993-2019; 2). The plant species commonly used for botanical insecticide and the insect pests were tested against the insecticides; 3). The most popular active ingredients used for commercial botanical insecticides; 4). The constraints of the development and commercialization of botanical insecticides and policy advice to solve the problems.

2 Materials and methods

For this review, we did track published papers on botanical insecticides from 1993 to 2019. The information collected included the plant source of botanical insecticides, intensively studied insect pests, the number of commercial botanical insecticides and their active ingredients. Regarding that information, we could further elaborate on botanical insecticide paper dynamics, plant species generally used for botanical insecticides and tested insect pests, active ingredients used for commercial botanical insecticides, and problems that were faced to develop and commercialize botanical insecticides and the government's policy supported botanical insecticide development.

3 Result and discussion

3.1 The dynamic of botanical insecticide publications in Indonesia from 1993-2019

Since the public has been aware of environmental health and the negative effects of chemical pesticides, scientists have started looking for more environmentally friendly alternatives, such as the use of botanical insecticides. There were 289 botanical insecticide papers published in National Journals from 1993-2019, but from 1995-2004 there was no publication found. From 2005-2011 the number of publications ranged from 1-15, with the peak in 2010. Botanical insecticides regained scientists' interest after 2011, since from 2012 to 2019 the number of publications increased sharply, except in 2014, it slightly decreased (Fig. 1).

Unfortunately, the results of these studies were not followed by the development or commercialization at the industrial level. The situations are almost the same as the conditions abroad. Based on articles published in the Center for Agriculture and Biosciences International (CABI) from 1980 to 2015, the number of papers on botanical insecticides has increased significantly, particularly several essential oil plants and neem, but the development of botanical pesticide commercialization is also slow [1]. It, therefore, emphasized the importance of commercialized research results rather than the exploration bioactive of wild plants.

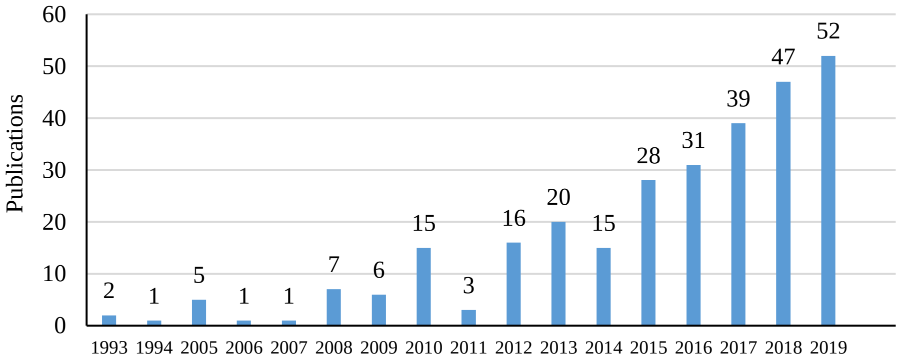

Fig. 1. Botanical insecticide publications from 1993-2019

3.2 The plant species commonly used for botanical insecticide and the insect pests tested against the insecticides

There were 94 plant species mentioned in 289 botanical insecticides publications, with the most frequently used was soursop (*Annona muricata*) (22 times), followed by neem (*Azadirachta indica*) (19 times), tobacco (*Nicotiana tabacum*) (17 times), papaya (*Carica papaya*) (11 times), lemongrass (*Cymbopogon nardus*) (10 times), and forest betel (*Piper aduncum*) (10 times), whilst other plant species were mentioned less than ten times (Table 1.). All the plants are tropical plants, some are known as medicinal plants. They are widespread throughout Indonesia. According to Isman [1, 5], the most popular species used for botanical insecticide were usually from the families of *Asteraceae*, *Fabaceae*, and *Euphorbiaceae*, particularly four species, i.e., pyrethrum (*Chrysanthemum cinerariaefolium)*, rotenone (*Derris eliptica)*, and neem (*Azadirachta indica*). However, according to the results from Indonesian journals and proceedings, *Anonna muricata* was the most frequent species tested against insect pests.

Table 1. Plant species, insect targets, and references

No.	Plant species used for botanical insecticides	Targets and references	Number of publications
1	*Acorus calamus*	*S. litura*; *M. domestica*	2
2	*Agathis borneensis*	*Artona flavipuncta*	1
3	*Ageratum conyzoides*	*S. litura; Helopeltis* sp.; *Aulocaphora* sp.; *Sitophilus oryzae*	4
4	*Alamanda cathartica*	*S. litura*.	1
5	*Allium sativum*	*Thrips*; *S. litura*; *Polyphagustarsonemus latus*; *Aphis gossypii*	4
6	*Alphitonia* sp.	*Callosobruchus chinensis*	1
7	*Alpinia galanga*	*Helopetis* sp.; *S. litura*	
8	*Anacardium occidentale*	*H. antonii*; *Sitophilus oryzae*	2
9	*Anonna glabra*	*Phaedonia inclusa; Nilaparwata lugens*	2
10	*Anonna muricata*	*S. litura*. *Boophilus* sp.; *Dermacentor* sp.; *A. aegypti*; *Callosobruchus analyst*; *Periplaneta americana*; *S. oryzae* ; *Myzus persicae*; *S. oryzae*; *A. aegypti*; *Maruca*	22

		testualis; *M. persicae*; *P. xylostella; C. analyst* ; *Setosia* nitens; *A. aegypti*; *A. glycines*;*Cylas formicarius*; *Pomaceae canaliculata* ; *R. linearis* ;*R. linearis*; *Aphis* sp.; *Setothosea asigna*	
11	*Anonna squamosa*	*N. lugens* ; *A. aegypti* ; *C. pavonana*; *A. aegypti* ; *S. oryzae*	5
12	*Antidesma bunius*	*P. latus*	1
13	*Apium graveolens*	*C. chinensis*	1
14	*Arcangelisia flava*	*P. xylostella*	
15	*Areca catechu*	*C. chinensis*; *P.canaliculata*; *C. pavonana*; *P. xylostella*	3
16	*Artocaspus altilis*	*S. oryzae*	1
17	*Azadirachta indica*	*Phaedonia inclusa* ; *N. Lugens*; *Ferrisia virgata* ; *S. litura; Helicoverpa armigera S. exigua*; *R. linearis* ; *Bemisia tabaci* ; *C. pavonana* ; *Cylas formicarius* ; *Pomaceae canaliculata Crocidolomia pavonana* ; *Doleschallia polybete*;*Conopomorpha cramerella* ;*Callosobruchus chinensis*	19
18	*Baringtonia asiatica*	*Plutella xylostella*	1
19	*Brucea javanica*	*C. pavonana*; *Heortia vitessoides*; S. *litura*	3
20	*Bruguiera gymnorrhiza*	*Aedes aegypti*	1
21	*Brugmansia soaveolens*	*S. litura* ; *Aspidomorpha milliaris*	2
22	*Calophylum inophyllum*	*Pteroma plagiophleps*	1
23	*Calotropis gigantea*	*P. latus*	1
24	*Capsicum spp.*	*C. binotalis*; *A. aegypti*; *S. exigua*	3
25	*Carica papaya*	*P. xylostella* ; *Setothosia asigna* ; *S. asigna*; *A. gossypii*; *Leptocorisa acuta*; *Etiella zinkenella*; *S. exigua* ; *Macrotermes*; *Anopheles; A. agyptii* ; *Thrips*	11
26	*Centella asiatica*	*P. xylostella*	1
27	*Cerbera odollam*	*Eurema* spp.; *S. litura*	2
28	*Cerbera manghas*	*S. litura*	1
29	*Chromolaena odorata*	*S. litura*; *Callosobruchus maculatus*; *P. latus*; *C. pavonana*; *P. xylostella*	5
30	*Chrysanthemum cinerariaefolium*	*Bemisia tabaci*	1
31	*Chrysopogon zizanioides*	*Sitophilus* spp.	1
32	*Cinnamomum verum*	*Ephestia cautella*; *Pachyzancla stultalis*	2
33	*Citrus aurantifolia*	*P. xylostella*; *S. oryzae*; *S. oryzae*; *L. oratorius*	4
34	*Citrus hystrix*	*S. oryzae*; *Periplaneta americana*; *P. xylostella; S .zeamays*	4
35	*Crescentia cujete*	*Empoasca flavescens*; *S. litura*	3
36	*Cromolaena odorata*	*Valanga* and *Gryllidae*	1
37	*Thigyllium croton*	*R. linearis*	1
38	*Cymbopogon nardus*	*M. domestica*; *Sitophilus* spp.; *Empoasca*; *Plusia calchitas* ; *S. oryzae*; *Helopeltis* sp.; *M. domestica*; *S. litura*; *Periplaneta americana*; *Pachyzancla stultalis*; *Pomacea canaliculata*	10
39	*Cymbopogon citratus*	*H. armigera*; *P. xylostella*; *A. aegypti*	3

40	*Datura metel*	*P. xylostella*	1
41	*Derris elliptica*	*L. acuta*; *P. latus*; *P. americana*; *L. Acuta*; *P. xylostela*	
42	*Dioscorea hispida*	*Pteroma plagiophleps*; *S. litura*; *L. Acuta*; *S. exigua*; *P.xylostela*	5
43	*Elephantopus sp.*	*P. xylostella*	1
44	*Euphorbia tirucalli*	*C. pavonana*	1
45	*Eurycoma longifolia*	*C. pavonana*	1
46	*Gliricidia maculata*	*Planococcus citri*; C. *pavonana*	2
47	*Gliricidia sepium*	*Pseudococcus*	1
48	*Jatropha curcas*	*S. oryzae*; *Bactrocera dorsalis*; *C. pavonana*	3
49	*Lansium domesticum*	*A. aegypti*; *A. aegypti*	2
50	*Lantana camara*	*Hyposidra talaca*; *B. tabaci*; *Aphis* sp.; *C. pavonana*; *P. xylostella*; *C. pavonana*; *P. xylostella*; *S. litura*	8
51	*Lavandula angustifolia*	*B. tabaci*	1
52	*Massoia aromatica*	*H.* antonii and *Chrysocoris javanus*	1
53	*Melaleuca cajuputi*	*C. pavonana*	1
54	*Melia azadirach*	*S. litura*	1
55	*Mentha arvensis*	*C. pavonana*	1
56	*Morinda citrifolia*	*S. litura* ; *S. oryzae*; *S. zeamays*; *A. aegyptii*; *C. binotalis*; *P. canaliculate*; *N.lugens*	
57	*Muntinga calabura*	*B.carambolae*	1
58	*Myristica fragrans*	*H. antonii*; *P. xylostella*	2
59	*Nicotiana tabacum*	*S. exigua*; *C. quinguefasciatus*; *P. xylostella*; *L. Acuta*; *L. oratorius*; *M. persicae*; *P. canaliculara*; *C. pavonana*; *Oryctes rhinoceros*; *P. xylostella*; *B. microplus*; *N. Lugensi*; *S. innotata; Drosophila melanogaster; L. acuta*, *C. cramerella*; *S. litura*	15
60	*Nocolaila artopurpurea*	*S. litura*	1
61	*Nothopanax scutellarium*	*Culex* sp.	1
62	*Ocimum basillicum*	*A. aconitus*; *M. domestica*; *M. domestica*	3
63	*Minimum ocimum,*	*Bactrocera* spp.	1
64	*Ocimum sanctum*	*Bactrocera* spp.	1
65	*Ocimum tenuiflorum*	*Bactrocera* spp.	1
66	*Pachyrhizus erosus*	*Crysomya bezziana*	11
67	*Pandanus amryllifolius*	*S. oryzae*	
68	*Pangium edule*	*P.xylostella*; *Hypothenemus hampei*	2
69	*Phaleria papuena*	*S. litura*	1
70	*Piper betle*	*P. xylostellai*; *S. asigna*	2
71	*Piper aduncum*	*S.incertulas*; *C. pavonana*; *S. zeamays*; *C. pavonana*; *S. litura*; *P. xylostella*; *O. rhinoceros; Diadegma semiclausum*	11
72	*Piper conoideus*	*C. pavonana*; *S. litura*	2
73	*Piper cubeba*	*C. pavonana*	1
74	*Piper retrofractum*	*C. pavonana*; *A. aegypti*; *H. antonii*	3
75	*Piper sarmentosum*	*S. litura*	1
76	*Pluchea indica*	*S. litura*	1
77	*Plumeria sp*	*S. litura*	1
78	*Pongamia pinata*	*Maruca testulalis*	1

79	*Pogostemon cablin*	*M. domestica*	1
80	*Sapindus rarak*	*C. pavonana*; *Callosobruchus maculatus*	4
81	*Swietenia mahagoni*	*S. litura*	2
82	*Syzygium polyanthum*	*P. americanai*; *C. chinesis*	2
83	*Syzygium aromaticum*	*Planococcus minor ; S. zeamays*	2
84	*Tagetes erecta*	*S. oryzae*	1
85	*Tagetes patula*	*Lamprosema indica*	1
86	*Tectona grandis*	*A. gossypii*	1
87	*Tephrosia vogelli*	*C. pavonana*; *P.xylostela*; *N. lugens*; *D. semicalusum*	4
88	*Terminalia catappa*	*P. latus*	1
89	*Thitonia diversifolia*	*B. tabaci*; *L. oratorius*; *C. pavonana*; *P.xylostella*; *E. flavescens*; *Scotinophora coarctata*; *Aleurodicus dugesii*	7
90	*Toona sinensis*	*C. pavonana*; *Hyposidra talaca*; *Eurema* spp.	3
91	*Vaccinium varingiefolium*	*P. xylostella*	1
92	*Vitex negundo*	*S. exigua*	1
93	*Vitex trifolia*	*Artona flavipuncta*	1
94	*Zingiber officinale*	*H. antonii*; Thrips	2

3.3 The dynamic of botanical insecticide publications in Indonesia from 1993-2019

There were five active ingredients listed in commercial botanical pesticides in Indonesia, i.e., eugenol (methyl eugenol), azadirachtin, citronella, and geraniol, with methyl eugenol as the first rank active ingredient registered in the Pesticide Registration Book [9]. Seven out of eight trade names for botanical insecticides contained methyl eugenol (ME) as their active ingredients, including Natural Pentana 220 SL (eugenol 188.4 g/L); Sainindo 10 VP (10% ME); Sainindo 800 SL (ME 800 g/L); Sainindo 200 EC (Eugenol 156 g/L, Citronella 26 g/L, and Geraniol 18 g/L); All-Net 100 EC (ME100 g/L); Petrogenol 800 SL (ME 800 g/L); and Methylate Glue 190 SL (ME 193.5 g/L). Only Bionano 0.13 SL contained azadirachtin 0.13 g/L). And sadly, all of the pesticides are now no longer registered due to their expired registration license.

The insect targets of ME were mainly fruit flies (*Bactrocera* spp.). Eugenol (ME) was mainly found in clove oil, approximately 15% [10], which is commonly used as an antibiotic for bacteria and fungi [11]. The function of eugenol (ME) in insecticides was more of an attractant, particularly for male fruit flies. Its application is usually added with a baited insecticide. Azadirachtin was for *S. litura, Lamprosema indicata, Etiela zinckenella*, and *Nezara viridula*. The extract of neem seed could kill several insect pests in several ways, such as (1) inhibiting egg hatching and moulting process (3) disrupting insect communication, (4) deter feeding an appetite, (5) inhibiting the development of female reproduction, (6) repels insect [12-14].

Based on the number of active ingredients of commercial botanical insecticides in several countries, Indonesia has fewer (only five) active ingredients [1]. The highest number was in Korea (38), followed by China (16); the United States (13); India (11); Chili (9); European Union, Australia, Canada, and France (6); Indonesia and Mexico (5), Kenya (3); and the least was Netherlands (2).

Although soursop (*A. muricata*) was the most frequent plant tested for its effectiveness against insect pests and was claimed by Isman [5] as the most prospective botanical insecticide in the Indonesian future, neem (*A. indica*) was the prosperous plant registered for commercial botanical pesticide. Soursop is an edible fruit, but the seeds contain several toxic alkaloids, one of them was *Annonaceous acetogenins* which have insecticidal and acaricidal activities [4]. The development of *A. muricata* as a source of bioactive botanical insecticide is limited by its continuous availability since the seeds are a by-product of the fruit. The situation is different, for neem (*A. indica*). The plant is usually purposely planted for fence and pesticide. Almost all parts of the plant contain several phytochemical bio-actives with pharmaceutical properties [15]. Azadirachtin was known to have antifeedant activity and its highest concentration was in the seed [16] with the concentration ranging from 0.2-0.6% [5].

3.4 Botanical insecticide: its future prospect and constraints

3.4.1 The reality of the development of botanical insecticide

The botanical insecticide has become popular and promises a good prospect in the future, particularly in tropical regions which have great plant materials sources. Globally, the demand for botanical insecticides increases because they are safe for agricultural products, increase organic farming, and export commodity farmers. There is lobbying from environmentalists and increasing pressure from new regulations on internationally traded food in Europe. This demand can only be fulfilled, among others, by providing leniency in the registration of botanical insecticides, efficient production methods, effective marketing and socialization of the use of botanical insecticide plants to farmers, and mass planting of plant-based insecticide crops associated with reforestation [1].

Each country has different obstacles to developing botanical insecticides. In the United States, Australia, and the European Union, commercialization of plant-based insecticides requires complicated conditions, while in China and South Korea is much easier [1]. In Indonesia, the commercialization of botanical insecticides should refer to the Minister of Agriculture Regulation Number 43 of 2019 concerning Pesticide Registration. The registration of botanical insecticides is slightly different from synthetic insecticides. Insecticide companies are mostly not interested in developing botanical insecticides because the prospect of plant-based insecticides is not certain, and the registration fee is more expensive than chemical insecticides.

Apart from non-technical constraints, there were also technical problems, including incomplete data on botanical insecticides' efficacy and safety. The efficacy of botanical insecticides is often inconsistent because the raw materials are of plant origin which is affected by the growing environment. Botanical insecticides work slowly to kill target pests, making most farmers less interested in using botanical insecticides. Farmers interested in using botanical insecticides are organic farmers or farmers who produce commodities for export purposes.

3.4.2 The need to simplify the circulation permit of botanical insecticide

Based on the manufacturing method, botanical insecticides are classified into three ways (1) merely soaking, cooking, pounding, crushing, and squeezing, (2) semi-industrial, including extraction with organic solvents and (3) industrially, among others, by isolating active ingredients and by adding a carrier. Is it possible that the classification of botanical insecticides is the same as drugs? Regulation of the Food and Drug Supervisory Agency, Number 32 of 2019 concerning Safety and Quality Requirements for Traditional Medicines, classifies drugs into three parts (1) traditional medicine or herbal medicine, (2) standardized herbal medicine, and (3) phytopharmaca.

Suppose botanical insecticides are analogous to the Regulation of the Food and Drug Supervisory Agency Number 32 of 2019, which regulates drug classification. In that case, botanical insecticides can be classified into three groups: (1) traditional botanical insecticides (equivalent to traditional medicines or herbal medicine), (2) standardized plant insecticides (on par with standardized herbal), and (3) modern botanical insecticides (phytopharmaca equivalent). The procedure for registering traditional botanical insecticides can be done by modifying the Regulation of the Minister of Health of the Republic of Indonesia Number 007 of 2012 concerning the Registration of Traditional Medicines. It regulates distribution permits, registration requirements, registration procedures, evaluation, and sanctions.

Based on the Republic of Indonesia Minister of Health Regulation Number 007 of 2012, registration of traditional medicines can be carried out by the Traditional Medicine Industry (TMI), Traditional Medicine Small Business (TMSB), or Traditional Medicine Micro-Business (TMMB), which has a license according to the provisions of the legislation. The Head of the Agency approves the form of a distribution permit or rejection of registration based on recommendations given by the Safety, Efficacy/Benefit, and Quality Assessment Team and the National Committee for Assessing Traditional Medicines. For registration of traditional plant-based insecticides and standardized plant-based insecticides, it is necessary to establish a business forum, for example, the Traditional Botanical Insecticide Industry (TBII), Traditional Botanical Insecticide Small Business (TBISB), or Traditional Botanical Insecticide Micro-Business (TBIMB) which has a license in accordance with the provisions of the legislation. The registration procedure of modern botanical insecticides has been regulated in the Regulation of the Minister of Agriculture of the Republic of Indonesia No. 43 of 2019 concerning Pesticide Registration.

Easing the license for traditional botanical insecticides and standardized plant insecticides is needed to provide botanical insecticide development opportunities at farms or small and medium enterprises. The high cost of registration is often an obstacle in developing or commercializing botanical insecticides. Simplifying the distribution permit for botanical insecticides means that it will allow farmers to use botanical insecticides, and the impact will reduce environmental pollution.

In addition to facilitating the distribution permit for botanical insecticides, the objective is to prevent the distribution or use of unregistered pesticides as regulated in Law No. 22 of 2019 concerning Sustainable Agricultural Cultivation System Article 77 [3]. Article 123, any person who circulates or uses unregistered pesticides, endangers public health and environmental sustainability, and is not labeled as intended in Article 77 paragraph (1) shall be punished with imprisonment of a maximum of seven years and a maximum fine of a lot of Rp. 5,000,000,000.00 (five billion rupiah).

4 Conclusion

Based on our literature review of the botanical insecticides-related published papers from 1993 to 2019, it can be highlighted that there were six plants that were widely studied as the source of botanical insecticides including *A. muricata*, *A. indica*, *N. tabacum*, *C. nardus*, *C. papaya*, and *P. aduncum*. In addition, fifty-six types of insect pests were studied or published, however, the most popular insects were *S. litura*, *C. pavonana*, *P. xylostela*, *S. oryzae*, and *A. aegypti*. It was recorded from 94 types of botanical insecticides published in Indonesia, only five active ingredients (eugenol, azadirachtin, methyl eugenol, citronella, and geraniol) have been successfully commercialized.

Our study also found that the high cost of registration is often an obstacle in developing or commercializing botanical insecticides. Therefore, easing the license for traditional botanical insecticides and standardized plant insecticides is needed by modifying the Republic Indonesia Minister of Health Number 007 of 2012 regulation concerning

Traditional Medicines' Registration to provide botanical insecticide development opportunities at the farm or small and medium enterprises.

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