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Overview of The Ethnobotany on The Use of Plants as Potential Botanical Pesticides in Indonesia

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Abstract: Ethnobotany of Indonesian communities utilizes plants as botanical pesticides. Recently, there has been no comprehensive data and information related to the ethnobotany of plants as potential botanical pesticides on a nationwide scale. This paper aimed to depict an overview of ethnobotany as botanical pesticides in Indonesia. The comprehensive literature was collected from the 29 published articles and theses (doctoral, master's, and bachelor's degrees) in English and Bahasa Indonesia. After the data was validated, only 27 papers were related to the study topic. Most literature data is from the western part of Indonesia (Oriental Realm): Java (n=10); followed by Kalimantan (n=7), and Sumatra (n=4). The results showed that 149 plant species were used as botanical pesticides. It consists of 130 species as an insecticide, 12 as a fungicide, 8 as a bactericide, 8 as a molluscicide, 3 as a rodenticide, and 2 as a nematicide. These species were dominated by the Compositae family (14 species) and plant parts used from leaf parts (38.9%). However, 11 species have two to four functions: *Archidendron pauciflorum, Areca catechu, Artocarpus heterophyllus, Caryota mitis, Cerbera manghas, Jatropha curcas, Melia azedarach, Morinda citrifolia, Pangium edule, Piper betle,* and *Piper ningrum*. The data of ethnobotany can be used as database information for further research regarding the bioprospecting, formulation, efficacy, and conservation for sustainable use. Furthermore, the development of botanical pesticides is also an alternative to reduce synthetic/chemical pesticides to provide sustainable agriculture.

Keywords: botanical pesticides, ethnobotany, family plant, plant parts used, plant species

Introduction

Several negative impacts of chemical pesticides use have been reported, namely (1) impacts on health that are short-term effects (i.e., skin eye and skin irritation, dizziness, headaches, as well as nausea) to long-term effects (i.e., asthma, cancer, and diabetes) (Bassil et al. 2007; Ntzani et al. 2013; Sarwar 2015; Kim et al. 2017); (2) impacts on the environment that lead of the biodiversity loss (Geiger et al. 2010; Beketov 2013; Park et al. 2015; Mingo et al. 2016; Dudley et al. 2017; Brühl and Zaller 2019), as well as water, air, and soil pollution (Anderson et al. 2013; Belenguer et al. 2014; Riah et al. 2014; Meftaul et al. 2020); (3) impact on the economy that in the USA, an estimated $9.6 billion of the economic damage was caused by the overuse of pesticides (Pimentel and Burgess 2014).

Based on the facts above, botanical pesticides can be an alternative to reduce synthetic/chemical pesticide use. The plant extracts contain insecticidal, antifungal, antibacterial, antivirus activity, antifeedant effects, insect growth regulation, repellence to pets, toxicity to nematodes, mites, and other pests (Seiber et al. 2014; Kumar and Singh 2015; Pavela and Benelli 2016). However, botanical pesticides still only reach a small number of pest control products globally. The shifting to botanical pesticides makes still slow progress because of the weakness of botanical pesticides, such as relatively quiet to kill, difficulty to kill the target pest directly, cost, not durable, challenges of production, less practical in application, lack of appropriate formulations, intolerant to sunlight now, and poor image based on previous low work of botanical pesticides (Glare et al. 2016).

Many local people use wild species (plants, fungus, and animals) nearby because they can harvest freely, and it is available so diverse (Mardiastuti et al. 2021 a,b). The study on the dynamic of the knowledge of the connection between local people, biota, and their environmental resources is called Ethnobiology (Clement 1998; Iskandar 2017). One of the branches of ethnobiology is ethnobotany, which is defined as the usability of plants by the ethnic people for their daily needs (Prance 1991; Gaoue et al. 2017; Pandey and Tripathi 2017). Most of the studies of ethnobotany are still focus on the utilization of plants as foods (Sukenti et al. 2016; Cita 2020; Navia et al. 2020; Waroy and Utami 2020; Afrianto et al. 2021), medicines (Putri et al. 2016; Nahdi et al. 2016; Supiandi et al. 2019; Jadid et al. 2020), or rituals/myths (Iskandar et al. 2017; Erawan et al. 2018; Ratnani et al. 2021). It is still rare to study the use of ethnobotany for botanical pesticides purposess.

There was no comprehensive data and information related to ethnobotany as botanical pesticides nationwide. Some studies have investigated in small-scale sites or specific species/families. For example, Pratiwi and Nurlaeni (2021) investigate the potency of botanical pesticides of the Myrtaceae family collected in the Cibodas Botanical Garden. The research of botanical pesticides must be done to collect and explore how to receive national data (Mardiastuti et al. 2021 a). This paper aimed to depict an overview of ethnobotany as botanical pesticides in Indonesia. Integrating ethnobotany, bioprospecting, and conservation will bring sustainable use of plant resources in the future (Afrianto et al. 2017; Afrianto et al. 2020).

Materials and Methods

Procedures

The comprehensive literature was collected from the 29 published papers and theses (doctoral, master's, and bachelor's degrees) in English and Bahasa Indonesia. After the data was validated, there were only 27 works related to the study topic. Literature data were from the western part of Indonesia (Oriental Realm): Java (n=10), followed by Kalimantan (n=7), and Sumatra (n=4). A small number of literature data were collected from Nusa Tenggara (n=4), Sulawesi (n=3), and Papua (n=1). Mainly, the paper published was in Indonesia Language.

Data analysis

The data was organized and analyzed based on plant species, local name, use category, the family of species, and part of plants used. The use category of botanical pesticides was grouped as insecticide, bactericide, rodenticide, nematicide, and molluscicide. Several data of plant parts used were not defined in the papers. Thus it was categorized as undefined.

Results and Discussion

Plant diversity

Based on the results of the identification and review conducted, in total, there were 149 species commonly used as botanical pesticides in Indonesia (Table 1). A total of 130 plant species used were dominated as insecticides, followed by fungicides (12), bactericides (8), molluscicides (8), rodenticides (3), and nematicides (2). These plants have potential as producers of botanical pesticides based on information on use, level of toxicity, and relevant literature information about the species concerned. On the other hand, 7 plant species were not identified until species level (taxonomically named as "*sp.*"). This is because ethnobotany research relies only on interview results, especially in plant identification. Generally, the respondents only know the local name of the plant species. Furthermore, based on the literature review, three species had not recorded the local name.

Botanical pesticides have several characteristics: repellence, anti-feeding, deterrent activity, growth regulator, ovipositional deterrence, and feed deterrence (Hikal et al. 2017; Tripathi et al. 2009). Application of the botanical pesticides has to be an hourly application at the pre-harvest interval, and degradation only needs to take a few days (Hans and Saxena 2021). According to Isman and Grieneisen (2014), more than 20.000 papers were published regarding botanical insecticides from 1980 to 2012.

Table 1. Diversity of plant used by the local people based on categories (black dots)

Local Name	Scientific Name	Family	Part of Plant Used	Insecticide	Bactericide	Rodenticide	Fungicide	Nematicide	Molluscicid
Brotowali/Akar Ali-ali	*Tinospora crispa* (L.) Hook. f. & Thomson	Menispermaceae	Stem	○	○	●	○	○	○
Cambai/sirih	*Piper betle* L.	Piperaceae	Leaf, stem	●	○	○	●	○	○
Jengkol	*Archidendron pauciflorum* (Benth.) I.C. Nielsen	Leguminosae	Fruit	○	○	●	○	○	●
Jeruk purut	*Citrus hystrix* DC.	Rutaceae	Leaf	●	○	○	○	○	○
Kapok	*Ceiba petandra* (L.) Gaertn.	Bombaceae	Leaf	●	○	○	○	○	○
Kemiri	*Aleurites moluccanus* (L.) Willd	Euphorbiaceae	Fruit, bark	●	○	○	○	○	○
Medang keladi	*Litsea crassinervia*	Lauraceae	Bark	●	○	○	○	○	○
Nangka	*Artocarpus heterophyllus* Lam.	Moraceae	Fruit, bark, root	●	○	○	○	●	○
Pinang	*Areca catechu* L.	Arecaceae	Leaf	●	○	○	○	●	○
Terong bulat hijau	*Solanum sp.*	Solanaceae	Leaf. seed	●	○	○	○	○	○
Jejer	*Derris sp.*	Leguminosae	Root	●	○	○	○	○	○
Kabau	*Pithecellobium bubalinum* (Jack) Benth.	Leguminosae	Peel	●	○	○	○	○	○
Durian	*Durio zibethinus* L.	Malvaceae	Bark	●	○	○	○	○	○
Puar kilat	*Globba sp.*	Zingiberaceae	Leaf	●	○	○	○	○	○
Sitawar	*Costus speciosus* (J.Koenig) Sm.	Zingiberaceae	Leaf	●	○	○	○	○	○
Legundi	*Vitex trifolia* L.	Lamiaceae	Leaf	●	○	○	○	○	○
Lengkonai	*Selaginella plana* (Desv. ex Poir.) Hieron.	Selaginellacea	Leaf, stem	●	○	○	○	○	○
Sirsak	*Annona muricata* L.	Annonaceae	Leaf, seed, root	●	○	○	○	○	○
Jior/johar	*Senna siamea* (Lam.) H. S. Irwin & Barneby	Leguminosae	Bark	●	○	○	○	○	○
Ingul/ungil	*Toona sureni* (Blume) Merr.	Meliaceae	Leaf	●	○	○	○	○	○
Gadung	*Dioscorea hispida* Dennst.	Dioscoreaceae	Tuber	●	○	○	○	○	○
Uwi alas	*Dioscorea alata* L.	Dioscoreaceae	Tuber	●	○	○	○	○	○
Lareng/tubak raong	*Derris elliptica* (Wall.) Benth.	Leguminosae	Root	●	○	○	○	○	○
Tuwa	*Croton tiglium* L.	Euphorbiaceae	Root	●	○	○	○	○	○
Sarang semut	*Myrmecodia armata* DC.	Rubiaceae	Undefined	●	○	○	○	○	○
Berkebo	*Tersntroemia toquin*	Theaceae	Undefined	●	○	○	○	○	○
Mengkudu	*Morinda citrifolia* L.	Rubiaceae	Leaf	●	○	○	○	○	●

Local Name	**Scientific Name**	**Family**	**Part of Plant Used**	**Insecticide**	**Bactericide**	**Rodenticide**	**Fungicide**	**Nematicide**	**Molluscicid**
Tomat	*Solanum lycopersicum* L.	Solanaceae	Fuit	●	○	○	○	○	○
Ketepeng	*Senna alata* (L.) Roxb.	Leguminosae	Leaf	●	○	○	○	○	○
Jarak	*Jatropha curcas* L.	Euphorbiaceae	Fruit	●	●	○	●	○	●
Karet	*Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg.	Euphorbiaceae	Seed	●	○	○	○	○	○
Daun katum	*Nephelium mangayi* Hiern	Rubiaceae	Leaf	○	●	○	○	○	○
Kase	*Pometia pinnata* J.R.Forst. & G.Forst.	Sapindaceae	Bark	○	○	○	○	○	●
Tembakau	*Nicotiana sp.*	Solanaceae	Leaf	●	○	○	○	○	○
Kecubung	*Datura metel* L.	Solanaceae	Leaf	●	○	○	○	○	○
Kalimonteng	*Homalomena cordata* Schott	Araceae	Leaf	●	○	○	○	○	○
Kepayang	*Pangium edule* Reinw.	Achariaceae	Leaf, fruit	●	○	○	○	○	●
Tuba goyeng	*Justicia gendarussa* Burm.f.	Acanthaceae	Leaf	●	○	○	○	○	○
Salumang	*Asimina triloba* (L.) Dunal	Annonaceae	Leaf	●	○	○	○	○	○
Risi/tukas	*Caryota mitis* Lour.	Arecaceae	Leaf	●	○	○	○	○	●
Bintaro	*Cerbera manghas* L.	Apocynaceae	Fruit	●	○	●	○	○	○
Buah sokma	*Crescentia cujete* L.	Bignoniaceae	Leaf, fruit	●	○	○	○	○	○
Pepaya	*Carica papaya* L.	Caricaceae	Leaf	●	○	○	○	○	○
Tegari	*Dianella sp.*	Liliaceae	Root	●	○	○	○	○	○
Mimba	*Azadirachta indica* A.Juss.	Meliaceae	Leaf, seed	●	○	○	○	○	○
Serai	*Cymbopogon citratus* (DC.) Stapf	Poaceae	Leaf	●	○	○	○	○	○
Pohon redan	*Nephelium maingayi*	Rubiaceae	Bark	○	○	○	○	○	●
Jelatang	*Urtica dioica* L.	Urticaceae	Leaf	○	○	○	○	○	●
Kecombrang	*Nicolaia speciosa* (Blume) Horan.	Zingiberaceae	Leaf	●	○	○	○	○	○
Adas	*Foeniculum vulgare* Mill.	Apiaceae	Stem, flower, leaf	●	○	○	○	○	○
Asam jawa	*Tamarindus indica* L.	Leguminosae	Fruit	○	○	○	●	○	○
Bandotan	*Ageratum conyzoides* (L.) L.	Compositae	Tuber	○	○	○	●	○	○
Bawang putih	*Allium sativum* L.	Amaryllidaceae	Tuber	○	○	○	●	○	○
Talas	*Colocasia esculenta* (L.) Schott	Araceae	Leaf, stem, root, fruit	●	○	○	○	○	○
Belimbing wuluh	*Averrhoa bilimbi* L.	Oxalidaceae	Leaf	○	○	○	●	○	○
Ceremei	*Phyllanthus acidus* (L.) Skeels	Phyllanthaceae	Fruit	●	○	○	○	○	○

Local Name	Scientific Name	Family	Part of Plant Used	Insecticide	Bactericide	Rodenticide	Fungicide	Nematicide	Molluscid
Dilem	*Pogostemon cablin* Benth.	Lamiaceae	Root, stem, leaf, flower	●	○	○	○	○	○
Langsep	*Lansium domesticum* Corrêa	Meliaceae	Fruit	●	○	○	○	○	○
Lidah buaya	*Aloe vera* (L.) Burm.f.	Xanthorrhoeaceae	Stem	○	○	○	●	○	○
Ganyong	*Canna edulis* Ker Gawl.	Cannaceae	Leaf, flower	●	○	○	○	○	○
Jambu biji	*Psidium guajava* L.	Myrtaceae	Leaf	○	○	○	●	○	○
Jambu monyet	*Anacardium occidentale* L.	Anacardiaceae	Flower	●	○	○	○	○	○
Dringu	*Acorus calamus* L.	Acoraceae	Root, stem, leaf, tuber	●	○	○	○	○	○
Kaliandra	*Calliandra haematocephala* Hassk.	Leguminosae	Leaf	●	○	○	○	○	○
Kamboja	*Plumeria acuminata* W.T.Aiton	Apocynaceae	Root	○	●	○	○	○	○
Kunyit	*Curcuma longa* L.	Zingiberaceae	Laef, rhizome, flower	●	○	○	○	○	○
Lada	*Piper ningrum* L.	Piperaceae	Fruit	●	●	○	○	○	○
Lerak	*Sapindus rarak* DC.	Sapindaceae	Laef, fruit	○	●	○	○	○	○
Mindi	*Melia azedarach* L.	Meliaceae	Fruit, leaf	●	●	○	●	○	○
Patah tulang	*Euphorbia tirucalli* L.	Euphorbiaceae	Root, stem	●	○	○	○	○	○
Mojo	*Aegle marmelos* (L.) Corrêa	Rutaceae	Fruit, leaf	●	○	○	○	○	○
Sambiloto	*Andrographis paniculata* (Burm.f.) Nees	Acanthaceae	Leaf, stem, root	●	○	○	○	○	○
Srikaya	*Annona squamosa* L.	Annonaceae	Leaf, seed, root	●	○	○	○	○	○
Tapak liman	*Elephantopus scaber* L.	Compositae	Leaf, stem	●	○	○	○	○	○
Tembelekan	*Lantana camara* L.	Verbenaceae	Leaf, flower	●	○	○	○	○	○
Kemangi	*Ocimum basilicum* L.	Lamiaceae	Leaf	●	○	○	○	○	○
Liak merah	*Zingiber officinale* Roscoe	Zingiberaceae	Undefined	●	○	○	○	○	○
Bambu tamiyang	*Schizostachyum iraten* Steud.	Poaceae	Leaf	●	○	○	○	○	○
Andong merah	*Cordyline terminalis* (L.) Kunth	Asparagaceae	Leaf	●	○	○	○	○	○
Pinang hutan	*Pinanga kuhlii* Blume	Arecaceae	Leaf	●	○	○	○	○	○
Alang-alang	*Cymbopogon nardus* (L.) Rendle	Poaceae	Undefined	●	○	○	○	○	○
Bamban	*Donax canniformis* (G.Forst.) K.Schum.	Marantaceae	Leaf, fruit, stem	●	○	○	○	○	○
Teureup	*Artocarpus elasticus* Reinw. ex Blume	Moraceae	Undefined	●	○	○	○	○	○

Local Name	Scientific Name	Family	Part of Plant Used	Insecticide	Bactericide	Rodenticide	Fungicide	Nematicide	Molluscicid
Aren	*Arenga porphyrocarpa* (Blume ex Mart.) H.E.Moore	Arecaceae	Undefined	●	○	○	○	○	○
Marigold	*Tagetes erecta* L.	Compositae	Undefined	●	○	○	○	○	○
Daun bangle	*Zingiber cassumunar* Roxb.	Zingiberaceae	Rhizome	●	○	○	○	○	○
Meniran	*Phyllanthus niruri* L.	Phyllanthaceae	Undefined	●	○	○	○	○	○
Paku rene	*Selaginella sp.*	Selaginellaceae	Leaf	●	○	○	○	○	○
Undefined	*Cyperus pilosus* Vahl	Cyperaceae	Undefined	●	○	○	○	○	○
Keboro	*Halopegia blumei* (Körn.) K.Schum.	Marantaceae	Undefined	●	○	○	○	○	○
Kencur	*Kaempferia galanga* L.	Zingiberaceae	Undefined	●	○	○	○	○	○
Bawang kucai	*Allium schoenoprasum* L.	Amaryllidaceae	Tuber	●	○	○	○	○	○
Laos hutan	*Alpinia malaccensis* (Burm.f.) Roscoe	Zingiberaceae	Rhizome	●	○	○	○	○	○
Salam	*Syzygium polianthum* (Wight) Walp.	Myrtaceae	Undefined	●	○	○	○	○	○
Jeruk purut	*Citrus maxima* (Burm.) Merr.	Rutaceae	Undefined	●	○	○	○	○	○
Lengkuas	*Alpinia galanga* (L.) Willd.	Zingiberaceae	Fruit	●	○	○	○	○	○
Senggani	*Melastoma candidum* D. Don	Melastomaceae	Undefined	●	○	○	○	○	○
Miana	*Plectranthus scutellarioides* (L.) R.Br.	Lamiaceae	Undefined	●	○	○	○	○	○
Ketumbar jawa	*Eryngium feotidum* L.	Apiaceae	Undefined	●	○	○	○	○	○
Pacing tawar	*Costus specious* (J.Koenig) Sm.	Costaceae	Undefined	●	○	○	○	○	○
Hoya	*Hoya diversifolia* Blume	Apocynaceae	Leaf	●	○	○	○	○	○
Bambu awi gede	*Gigantochloa pseudoarundinacea* (Steud.) Widjaja	Poaceae	Shoot	●	○	○	○	○	○
Kelor	*Moringa oleifera* Lam.	Moringaceae	Root	●	○	○	○	○	○
Kelor hutan	*Boenninghausenia albiflora* (Hook.) Rchb. ex Meisn.	Rutaceae	Leaf	●	○	○	○	○	○
Undefined	*Acanthospermum hispidum* DC.	Compositae	Undefined	○	●	○	○	○	○
Ajeran	*Bidens pilosa* L.	Compositae	Leaf	●	○	○	○	○	○
Kirinyu	*Chromolaena odorata* (L.) R.M.King & H.Rob.	Compositae	Leaf	●	○	○	○	○	○

Local Name	Scientific Name	Family	Part of Plant Used	Insecticide	Bactericide	Rodenticide	Fungicide	Nematicide	Molluscicid
Babadotan	*Eleutheranthera ruderalis* (Sw.) Sch.Bip.	Compositae	Undefined	●	○	○	○	○	○
Temu wiyang	*Emilia sonchifolia* (L.) DC. ex DC.	Compositae	Undefined	●	○	○	○	○	○
Undefined	*Grangea maderaspatana* (L.) Poir.	Compositae	Undefined	●	○	○	○	○	○
Undefined	*Sphaeranthus africanus* L.	Compositae	Undefined	●	○	○	○	○	○
Cagak langit	*Tridax procumbens* (L.) L.	Compositae	Undefined	●	○	○	○	○	○
Sawi langit	*Vernonia cinerea* (L.) Less.	Compositae	Leaf	○	○	○	●	○	○
Seruni laut	*Wedelia biflora* (L.) DC.	Compositae	Leaf	○	○	○	●	○	○
Pelawan	*Tristaniopsis merguensis* (Griff.) Peter G.Wilson & J.T.Waterh.	Myrtaceae	Leaf, bark	●	○	○	○	○	○
Pandan duri	*Pandanus tectorius* Parkinson ex Du Roi	Pandanaceae	Root, leaf	●	○	○	○	○	○
Rumbia	*Metroxylon sago* Rottb.	Arecaceae	Leaf	●	○	○	○	○	○
Bungur	*Lagerstroemia speciosa* (L.) Pers.	Lythraceae	Leaf, stem	●	○	○	○	○	○
Simpur	*Dillenia indica* L.	Dilleniaceae	Leaf, bark	●	○	○	○	○	○
Salak hutan	*Eleiodoxa conferta* (Griff.) Burret	Arecaceae	Shoot	○	●	○	○	○	○
Kelubuk	*Ficus sp.*	Moraceae	Leaf, fruit	○	○	○	●	○	○
Bijur laut	*Ipomoea pes-caprae* (L.) R. Br.	Convolvulaceae	Leaf. stem, root	●	○	○	○	○	○
Mensirak	*Ilex cymosa* Blume	Aquifoliaceae	Root, leaf	●	○	○	○	○	○
Api-api	*Avicennia marina* (Forssk.) Vierh.	Acanthaceae	Undefined	●	○	○	○	○	○
Bakung	*Crinum asiaticum* L.	Amaryllidaceae	Undefined	●	○	○	○	○	○
Tapak dara	*Catharanthus roseus* (L.) G. Don	Apocynaceae	Undefined	●	○	○	○	○	○
Biduri	*Calotropis gigantea* (L.) Dryand.	Apocynaceae	Undefined	●	○	○	○	○	○
Cemara	*Casuarina equisetifolia* L.	Casuarinaceae	Undefined	●	○	○	○	○	○
Nyamplung	*Calophyllum inophyllum* L.	Clusiaceae	Undefined	●	○	○	○	○	○
Ketepang	*Terminalia catappa* L.	Combretaceae	Undefined	●	○	○	○	○	○
Krasak	*Ficus superba* Miq.	Moraceae	Undefined	●	○	○	○	○	○
Cabe jawa	*Piper caninum* Blume	Piperaceae	Undefined	●	○	○	○	○	○
Cabai	*Capsicum annuum* L.	Solanaceae	Fruit	●	○	○	○	○	○

Local Name	Scientific Name	Family	Part of Plant Used	Insecticide	Bactericide	Rodenticide	Fungicide	Nematicide	Molluscicid
Tembakau rajangan	*Nicotiana tabacum* L.	Solanaceae	Leaf	●	○	○	○	○	○
Jagung	*Zea mays* L.	Poaceae	Seed	●	○	○	○	○	○
Jeruk pahit	*Citrus aurantium* L.	Rutaceae	Leaf	●	○	○	○	○	○
Sempuyung	*Hibiscus heterophyllus* Vent.	Malvaceae	Leaf	●	○	○	○	○	○
Krisan	*Chrysanthemum indicum* L.	Compositae	Leaf	●	○	○	○	○	○
Bandetan	*Clidemia hirta* (L.) D. Don	Melastomataceae	Leaf	●	○	○	○	○	○
Cempedak anyer	*Artocarpus dadah* Miq.	Moraceae	Leaf	●	○	○	○	○	○
Bayur	*Pterospermum javanicum* Jungh.	Malvaceae	Leaf	●	○	○	○	○	○
Marak besi	*Macaranga denticulata* (Blume) Müll.Arg.	Euphorbiaceae	Leaf	●	○	○	○	○	○
Tapak gajah	*Macaranga gigantea* (Rchb.f. & Zoll.) Müll.Arg.	Euphorbiaceae	Leaf	●	○	○	○	○	○
Marak Tiga Jari	*Macaranga hypoleuca* (Rchb.f. & Zoll.) Müll.Arg.	Euphorbiaceae	Leaf	●	○	○	○	○	○
Gamal	*Gliricidia sepium* (Jacq.) Walp.	Leguminosae	Leaf	●	○	○	○	○	○
Ngancar	*Planchonia valida* (Blume) Blume	Lechythidaceae	Stem	●	○	○	○	○	○
Ndarap	*Dysoxylum alliaceum* (Blume) Blume	Meliaceae	Stem	●	○	○	○	○	○
Muku mada	*Musa acuminata* Colla	Musaceae	Leaf	●	○	○	○	○	○
Peca merah	*Melia azedarach* L.	Meliaceae	Leaf	●	○	○	○	○	○

Family domination

There were 11 families dominated where these families consisted of at least five plant species. These species were Apocynaceae (5 species), Arecaceae (6 species), Compositae (14 species), Euphorbiaceae (8 species), Leguminosae (9 species), Meliaceae (6 species), Moraceae (5 species), Poaceae (5 species), Rutaceae (5 species), Solanaceae (6 species), Zingiberaceae (9 species) (Figure 1). Dadang (1999) reported that plants with great potential for insect pest control are from Meliaceae, Rutaceae, Asteraceae, Annonaceae, Labiatae, Aristolochiaceae, Malvaceae, Zingiberaceae, and Solanaceae. This indicates that these plant species found can be developed as botanical pesticides in this study.

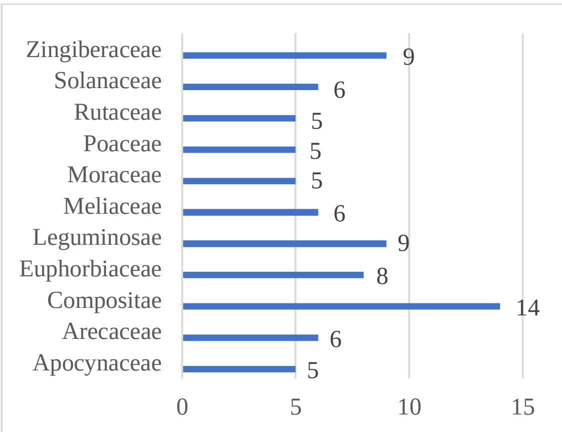

Figure 1. Plant family dominated as botanical pesticides in Indonesia

Plant parts used

For this analysis, plant part data were only available for ten categories: flower, rhizome, seed, stem, leaf, bark, tuber, root, fruit, and unidentified. A high percentage of unidentified classes (15.8%) was because many studies were not recorded part used in their studies. Available data showed that the majority of species used leaf (38.9%), followed fruit (10.5%), and root (8.9%) (Figure 2). Several plants can use more than one part for botanical pesticides, which were 20 plant species with two parts, 8 plant species with three parts, and 3 plant species with four parts.

Over the past few years, plant extracts and essential oils have emerged as alternatives to synthetic insecticides for insect pest control. They result from plants that contain a bioactive chemical (Magierowicz et al. 2020). All different portions of plants can be used as essential oils. Beneficials of the essential oils have been reported for antifungal (Cavanagh 2007), antibacterial (O'Bryan et al. 2015), insecticide (Jankowska et al. 2018), nematicidal (Andrés et al. 2012), acaricidal (Peixoto et al. 2015). The application of essential oils is used as the fumigant and repellent (Tripati et al. 2009).

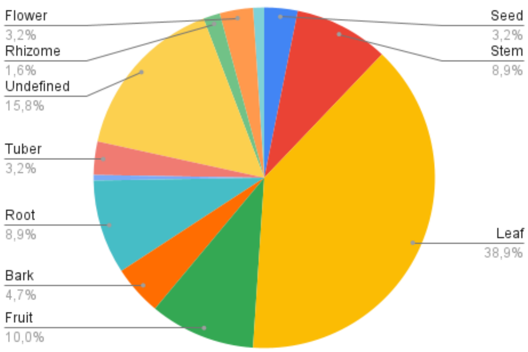

Figure 2. Plant parts used as botanical pesticides in Indonesia

Multiple uses

11 of 149 plant species had at least two to four functions: *Archidendron pauciflorum*, *Areca catechu*, *Artocarpus heterophyllus*, *Caryota mitis*, *Cerbera manghas*, *Jatropha curcas*, *Melia azedarach*, *Morinda citrifolia*, *Pangium edule*, *Piper betle*, and *Piper ningrum* (Tabel 2). Almost all plant species in this study were used for insecticide. Secondary metabolites that are essential oils of the plant can protect against herbivorous insect pests and pathogenic fungi (Apiaceae et al. 2011; Werrie et al. 2020).

Plant metabolites with diverse skeletons have been recorded to provide antimicrobial activities. Plant-derived that provide fungicidal and bactericidal compounds have relatively lower toxicity than insecticidal activity (Yoon et al. 2013). Moreover, plant-derived such as Cinnamaldehyde, l-Glutamic acid + gamma-aminobutyric acid, Jojoba oil, Laminarin, Milsana, Pink plume poppy powder extract, Essential oils, Fatty acids, Phenolic compounds, Alkaloids, and Glycosides can be used as antifungal activities. The botanical fungicides produce rapid biodegradation and high biocompatibility, lack of resistance, and structural diversity (Guo et al. 2021). For example, plant species, such as *Piper betle*, *Jatropha curca*, and *Melia azederach*, have been reported to have antifungal activity against *Ascochyta rabiei*, *Aspergillus flavus*, *Aspergillus niger*, *Botrytis cinerea*, *Colletotrichum fragariae*, *Colletotrichum gloeosporioides*, *Corynospora cassicola*, *Fusarium oxysporum f. sp. Lycopersici*, *Fusarium oxysporum*, *f. sp. Melonis*, *Fusarium sambucinum*, *Fusarium solani var. coeruleum*, *Geotrichum spp.*, *Pakospora pachyrhizi*, *Phytophthora sp.*, *Rhizoctonia solani*, *Rigidoporous sp.*, *Sclerotium spp.*, *and Trichoderma spp.* On the other hand, plant species *Piper ningrum* and *Melia azederach* have been reported to have antibacterial activity against *Alternaria alternata*, *Bacillus nealsonii*, *B. subtilis*, *B. thuringiensis*, *Citrobacter freundiiEnterococcus faecalis*, *Erwinia cacticida*, *Escherichia coli*, *Microbacterium oleivorans*, *Plesiomonas shigelloides*, *Proteus mirabilis*, *Pseudomonas aeruginosa*, *P. syringae pv. syringae*, *Rathayibacter tritici*, *Shigella dysenteriae*, *S. flexneri*, *Staphylococcus aureus*, and *Xanthomonas campestris pv. campestris*.

Not many studies have been conducted to examine the botanical pesticide for nematicide, molluciside, and rodenticide. Hurtada et al. (2012) conducted a study to examine the anthelmintic efficacy of *Artocarpus heterophyllus* on gastrointestinal nematodiasis on goats. Gastrointestinal nematodiasis cause a destructive impact on the productivity of goat farmings. This study has four genera of gastrointestinal nematodes to be tested, such as *Trichostrongylus spp.*, *Oesophagostomum spp.*, *Haemonchus spp.*, and *Bunostomum spp.* The result shows that *A. heterophyllus* decoctions have high efficacy against nematode larvae at high concentrations.

One of the pests that result from a high risk of crop failure in rice plants is Mollusca. This pest eats the stems and leaves of 15-day-old rice.

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According to Sulistianingsih et al. (2014) shows the extract of *Pangium edule* seed at 100 ppm can be used against various age levels. The concentration of 2.5% of seed *P. edule* extract with a hatching time of up to 28 days can inhibit hatching eggs of *Pomacea canaliculata* with average hatching of 63.84% (Noerfitryani 2017). The extract of *P. edule* fruit flesh has a more effect on mortality of *Bradybaena similaris* compared to the leaves and skin of the *P. edule* fruit (Noviyanti 2013). The peal of *Archidendron pauciflorum* with *Dieffenbachia seguine* leaf extract can be used against *P. canaliculata* at the optimum concentration of 15% (Mawardi et al. 2018). The old seed extract of *Jatropha curcas* contains more toxicity to kill Mollusca than the young seed extract (Banjarnahor et al. 2016). *Morinda citrifolia* fruit at a concentration of 100gr/L is the most significant concentration to kill mortality of *P. caniculata* (Chauhan et al. 2015). The extract of *Areca catechu* fruit at a concentration of 2.5% can kill young, preadult, and adult after 1, 4, and 5 days after application, respectively (Gassa 2011). The combination materials of *A. indica* and *A. catechu* are more effective because the mortality can reach 96.67% (Ma'wa and Hoesain 2020).

As pests, rats (*Rattus argentiventer*) can damage cultivated plants in a short time and cause considerable yield losses significant since the nursery, planting to the storage/warehouse, post-harvest. In the treatment, 600 g of *A. pauciflorum* seeds/liter of water and 800 g of *A. pauciflorum* seeds/liter of water can make *Rattus argentiventer* be abnormal growth where the effects are swelling of the stomach and neck (Pakki et al. 2009). Susanti et al. (2020) show that primary and secondary metabolites of *Cerbera manghas* can be used as a pest repellent.

Caryota mitis has not been proven as scientific as botanical pesticides. But, Community in Keranji uses *C. mitis* for insecticide and molluscicide. They take 10-20 *C. mitis* leaves to be dried and burned (Irtiawati et al. 2020).

Table 2. List of species that considered as multi-purpose species (i.e., has at least two out of six use categories) and scientific evidances

Scientific Name	Multiple uses	Targets	Sources
Archidendron pauciflorum	3	**Rodent:** *Rattus argentiventer*	Pakki et al. 2009
	6	**Mollusca:** *Pomecea canaliculata*	Mawardi et al. 2018
Piper betle	1	**Insect:** *Aedes aegypti, Musca domestica, Eudrilus eugeniae, Callosobruchus maculatus, Sitophilus zeamais, S. oryzae, Chrysomya megacephala (larvae), C. bezziana (larvae), Oxya serville*	Subaharan et al. 2021;Rahmawati 2020; Daswito et al. 2019; Anisah and Sukesi 2018; Vasantha-Srinivasan et al. 2018; Vasantha-Srinivasan et al. 2017; Arambewel et al. 2010; Mohottalage et al. 2007; Kumarasingha et al. 2002; Santhanam and Nagarajan 1990
	4	**Fungus:** *Colletotrichum sp., Fusarium oxysporium sp., Corynospora cassicola, Rigidoporous sp. and Phytophthora sp., Rhizoctonia sp., Fusarium solani var. coeruleum, Colletotrichum fragariae*	Subrata et al. 2019; Achmad and Suryana 2015; Wati et al. 2014; Subrata 2016; Ariyanti et al. 2012; Arambewela et al. 2010
Artocarpus heterophyllus	1	**Insect:** *Drosophila melanogaster, Sitophilus oryzae, Spodoptera litura, Scipophaga incertulas, Aedes aegypti, Scirpophage incercutlas, and Culex sp.*	Acero 2019; Firdaus and Kriswandana 2018; Sharon et al. 2018; Nair and Kavrekar 2017; Gupta et al. 2015; Upadhyay 2013; Shamim et al. 2011
	5	**Nematode:** *Trichostrongylus spp., Oesophagostomum spp., Haemonchus spp. and Bunostomum spp.*	Hurtada et al. 2014
Caryota mitis Lour.	1	**Insecticide:** Undefinied	
	6	**Mollusca:** Undefined	
Cerbera manghas L.	1	**Insect:** *Anua indiscriminate, Coptotermes Gestroi, Cryptotermes Cynocephalus Sitophilus oryzae,*	Haryanta and Joeniarti 2021; Salbiah 2020; Tuhadi et al. 2020; Susilo et al. 2019; Purwani et al. 2014; Setiawan and Supriyadi 2014; Guswenrivo et al. 2013; Tong et al. 2007

Scientific Name	Multiple uses	Targets	Sources
		Spodoptera litura. Helicoverpa armigera	
	3	**Rodent:** *Rattus argentiventer*	Fadhillah 2020; Zailani 2015
Areca catechu L.	1	**Insect:** *Callosbruchus analis, Rhyzopertha dominica, Sitophilus oryzae, Tribolium castaneum, Crocidolomia pavonana, Callosobruchus chinensis, Chrysodeixis chalcites, Spodoptera Liturra, Oryctes rhinoceros, Helicoverpa Armigera, Bactrocera carambolae, Nezara viridula, Lasioderma Serricorne, Plutella xylostellam, Nephotettix virescens, Macrotermes gilvus*	Eka 2021; Subekti 2020; Kewa 2019; Lorenza 2019; Salbiah et al. 2019; Suswando 2019; Abbas et al. 2018; Mading et al. 2018; Rikardo and Nuryasin 2018; Dewi et al. 2017; Hayata 2017; Gobai, et al. 2015; Fitriani et al. 2014; Eri et al. 2013;
	6	**Mollusca:** *Pomacea canaliculata*	Ma'wa and Hoesain 2020; Liunokas et al. 2019; Laoh et al. 2013; Gassa 2011
Morinda citrifolia L.	1	**Insecet**: *Spodoptera litura, Sitophilus oryzae, Helicoverpa armigera, Plutella xylostella, Sitophilus zeamais, Crocidolomia binotalis, Crocidolomia pavonana, Agrootis sp,, Anopheles stephensi, Culex quinquefasciatus, Aedes aegypti, Anopheles stephensi, Blattella germanica, Tuta absoluta, Callosobruchus maculatus, Cylas formicarius, Drosophila melanogaster*	Rahayu et al. 2021; Ardiana 2019; Armi et al. 2019; Rahmawati et al. 2019; de Barros et al. 2018; Rustam and Audina 2018; Warsa 2018; Nofia 2016; Saenong 2016; Isnaini et al. 2015; Kovendan et al. 2014; Owolabi et al. 2014; Chomsun and Muhfahroyin 2013; Fatmawati 2013; Leng and Reddy 2012; Hasna 2009; Kovendan et al. 2012; Legal et al. 1992
	6	**Mollusca**: *Pomacea caniculata*	Chauhan et al. 2015
Jatropha curcas L.	1	**Insect:** *Lepidoptera, Pyralidae, Musca domestica, Callosobruchus maculatus, Achaea Janata, Aphis fabae, Sitophilus zeamais, Rhyzorpertha dominica, Sitophilus zeamais, Plutella xylostella), Helicoverpa, Armigera, Rhipicephalus(Boophilus) annulatus, Spodoptera frugiperda, Homopteran sp., Lepidopteran sp., and Coleopteran sp., Aulacophora foveicoltes, Liphaphis erysium, Musca domestica*	Shaqi 2021; Sutriadi et al. 2019; Ingle et al. 2017; Jide-Ojo et al. 2013; Devappa et al. 2012; Juliet et al. 2012; Nabil and Yasser 2012; Silva et al. 2012; Abdoul Habou et al. 2011; Tukimin et al. 2010; Adebowale and Adedire 2006; Li et al. 2006
	4	**Fungus:** *Aspergillus niger, Aspergillus flavus, Colletotrichum gloeosporioides, Pakospora pachyrhizi,*	Rahman et al. 2011; Heriyanto 2015
	6	**Mollusca**: *Pomacea caniculata*	Banjarnahor et al. 2016
Pangium edule Reinw.	1	**Insect:** *Sitophylus oryzae, Crocidolomia Binotalis, Hypothenemus hampei, Spodoptera exigua, Plutella xylostella, Spodoptera litura, Aedes Aegypti. Coptotermes gestroi, Scotinophora coarctata, Plutella Xylostella, Blatella Germanica, Schedorhinotermes sp*	Kuntorini and Rusmiati 2021; Yulianti 2021; Hutasoit et al. 2020; Tampil et al. 2020; Manoppo et al. 2019; Haq and Desyanti 2018; Verawati 2018; Noerfitryani 2017; Sakul 2017; Hidayat 2016; Rusda 2014; Wiryadiputra et al. 2014; Sakul et al. 2012; Salaki et al. 2012; Yuningsih and Kartina 2007

Scientific Name	Multiple uses	Targets	Sources
	6	**Mollusca:** *Bradybaena similaris, Pomacea caniculata*	Noerfitryani 2014; Sulistianingsih et al. 2014; Noviyanti 2013
Piper ningrum L.	1	**Insect:** *Callosobruchus Chinensis, Sitophilus zeamais Motsch, Coptotermes sp, Spodoptera litura, Anopheles malaria, Bemisia tabaci, Aedes aegypti, Culex quinquefasciatus, Plutella xylostella, Rhizotrogus majalis, Sitophilus zeamais and Callosobruchus maculatus, Corcyra cephalonica*	Vite-Vallejo et al. 2018; Chaubey 2017; Rosmanto et al. 2017; Javed et al. 2016; Samuel et al. 2016; Mulyati et al. 2015; Lija-Escaline et al. 2015; Hasnah and Suryanti 2014; Khani et al. 2013; Bahri and Rinawati 2012; Fan et al. 2011; Vasudevan et al. 2009; Simas et al. 2007; Upadhyay and Jaiswal 2007; Woyinka et al. 2006; Hwang et al. 2005; Scott et al. 2005;
	2	**Bacteria:** *Citrobacter freundii, Erwinia cacticida*.	Paulkumar et al. 2014
Melia azedarach L.	1	**Insect:** *Phyllocnistis citrella (citrus leafminer), Sporodoptera frugiperda, Callosobruchus maculatus, Xanthogaleruca luteola, Drosophila melanogaster, Brevicoryne brassicae L.,Sitophilus granaries; Tribolium castaneum; Tribolium granarium*	Ali et al. 2021; Chiffelle et al. 2019; Shafiei et al. 2018; Kosma et al. 2014; Scapinello et al. 2014; Mckenna et al. 2013; Chiffelle et al. 2009
	2	**Bacteria:** *Pseudomonas syringae pv. syringae, Xanthomonas campestris pv. campestris, Rathayibacter tritici, Enterococcus faecalis, Bacillus subtilis (Bs), Escherichia coli, Alternaria alternata, Staphylococcus aureus; Bacillus thuringiensis, Microbacterium oleivorans, Bacillus nealsonii, Proteus mirabilis, Shigella flexneri, Pseudomonas aeruginosa, Shigella dysenteriae, Plesiomonas shigelloides*	Hadadi et al. 2020; Munir et al. 2017; Akacha et al. 2016; Al-Khafaji et al. 2016; Marino et al. 2015; Neycee et al. 2012 (a); Khan et al. 2011;
.	4	**Fungus**: *Ascochyta rabiei, Fusarium oxysporum, f. sp. Melonis, Fusarium sambucinum, Fusarium oxysporum f. sp. Lycopersici, Botrytis cinerea, Trichoderma spp., Sclerotium spp., Geotrichum spp.,Fusarium oxysporum, Rhizoctonia solani, Aspergillus flavus, Aspergillus niger*	Abbas et al. 2017: Akacha et al. 2016, Neycee et al. 2012 (b); Jabeen et al. 2011

NB: 1 = Insecticide, 2 = Bactericide, 3 = Rodenticide, 4 = Fungicide, 5 = Nematicide. 6 =Molluscicide

Regulation in Indonesia

In Indonesia, the registration and regulation of pesticides must follow the government regulations (PP) of the Minister of Agriculture of the Republic of Indonesia Number 43 of 2019 concerning pesticides. Botanical pesticides were categorized as natural pesticides because they have active ingredients derived from living things. Natural pesticides have to assess the same as synthetic pesticides, tested for quality, formula, environmental fate, efficacy, and toxicity.

Market potential

Recently, the global market of botanical pesticides is only 2% of the pesticide production or over 3,000 tons per year (Kumar and Singh 2015). However, according to Damalas and Koutroubas (2018), botanical pesticides' value has been estimated at $3 billion global, and it is predicted to increase significantly in the late 2040 and early 2050s (Olson 2015). The market is expanding because of the increasing demand for pesticide-free for growing organic food.

There are three factors to be considered to enlarge the market size. Firstly, the price should be regarded as an essential factor. This factor is influenced by the quality, geographic area, source (Isman 2016; Pratiwi and Nurlaeni 2021). Secondly, sustainability productivity for natural resources is one of the challenges (Hidayat et al. 2021). The productivity of biopesticides is still not optimal because of cultivation limited. Lastly, branding is also an essential factor, primarily the education for farmers because commonly, farmers are lack education and only focus on fast results.

Conclusions

In conclusion, based on the ethnobotany of the Indonesian community, 149 plant species can be used as insecticide, bactericide, rodenticide, fungicide, nematicide, and molluscicide and utilized as an alternative to synthetic/chemical pesticides for pest management. These species were dominated by the Compositae (14 species) and mainly used from the leaf part. The result of this study can be used as database information for further research regarding the efficacy, formulation, and conservation strategies for sustainable management. Furthermore, collecting the data can encourage citizens to be involved, so there is a bridge between people and nature and increasing community utilization (Afrianto and Najah 2017).

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