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MINI REVIEW

Essential oil from Piperaceae as a potential for biopesticide agents: a review

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Abstract

This review is aimed to present information on the properties of Piperaceae which can be potentially used as a biopesticide. The chemical compounds involved in were different as each species consist of different amount of secondary metabolites which then leads to different properties. In recent years, several reports have been published regarding the composition and the biological activities of the essential oils of *Piper* species. These studies have highlighted the existence of marked chemical differences among oils extracted from different species or varieties. Analysis of volatile constituents from Piperaceae species has revealed the presence of monoterpenes, sesquiterpenes and arylpropanoids that have shown interesting biological properties including cytotoxic, fungistatic, insecticide, molluscicidal, antioxidant and antimicrobial activities. Essential oils are natural complex secondary metabolites characterized by strong odour, volatility and have generally lower density than water. Due to their volatility, essential oils are environmentally non-persistent. On top of that, essential oils are 'generally recognized as safe' by the United States Food and Drug Administration (FDA). Since technology has become more advanced, people started to replace synthetic pesticide with bio-pesticide. The demand for EO has increased as it has biological properties that can be used to replace synthetic pesticide.

1. Introduction

Piperaceae or piper is famous and widely known around the world. Pepper was originated from Ghat Barat and Malabar in western India. It was brought to Malaya (Malaysia) through the port of Melaka by the Portuguese centuries ago. It then became the main product traded in the port of the states of Johor and Singapore. Later on, the cultivation for pepper crop expanded to Sarawak and it became Sarawak's main export product. This crop comes from a large family in flowering plants. The order Piperales represented the largest basal angiosperm that has been distributed worldwide. This order consists of three species, *Piper*, *Peperomica*, and *Aristolochia*. Piperaceae contains about 3,600 species roughly. These species are the ones that were currently accepted in the 13 genera. The pepper's vast majority can be found within the two main genera, *Piper* and *Peperomia*. The most known species is *Piper nigrum* or black pepper which produced peppercorns that are used as spices all over the world. In Malaysia, there were a few well-known species that are usually cultivated in places such as Kuching, Semenggok Perak, Semenggok Emas and many more. There were also many well-known species in other producing countries such as Belantung (Indonesia), Karimunda (India), Djambi (Indonesia) and Bangka (Indonesia) (Mah, 2017). Thus, the aim for this review was to reveal the properties of the Piperaceae species to be used as potential biopesticide along with its chemical compounds which have been proven to be responsible for each of the properties stated.

2. Ethnomedicinal uses of Piperaceae

Out of all the various species, *Piper nigrum L.* or known as black pepper has a prominent position and this species was acknowledged as the "King of Spices". It has many functional uses in traditional food formulations, perfumery, kitchen, and even beauty care. Besides that, pepper was also used for its medicinal properties. Black pepper has been used in the Asian folk

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medicine and the Indian Ayurvedic System of medicine folklore medicine of Latin America since many years ago (Tu *et al.*, 2015). Pepper was also reported that it has been used in folk medicine to treat several ailments (Wan Salleh *et al.*, 2014). Table 1 shows some of the species along with their traditional uses. Most of the species contain antioxidant activities which can be used to fight against fever, asthma, coughs, diarrhoea and many more. Based on previous reports, there were only a few studies on the chemical compounds of Piperaceae which can be used as bio-pesticides.

Table 1. List of pepper and their traditional uses (Wan Salleh *et al.*, 2014).

Species	Traditional uses
Piper caninum	Chewing, hoarseness, flavour, throat ache, antiseptic
Piper lanatum	Malaria, toothache, rheumatism, deworming, fever, influenza, ulcer
Piper abbreviatum	Splenomegaly, stimulant, carminative, coughs & colds, flatulence
Piper aborescens	Rheumatism, antiplatelet aggregation, cytotoxic
Piper porphyrophyllum	Leprosy, abdominal pain, skin disease, postpartum treatment, bone pain
Piper erecticaule	No reports
Piper ribesioides	Asthma, diarrhoea, abdominal pain, flavour, alleviate chest congestion, treat urticaria
Piper miniatum	Spice, food flavour, food natural preservative, antibacterial
Piper stylosum	Vegetables, seasoning, poultice/ decoction, confinement
Piper majusculum	No reports

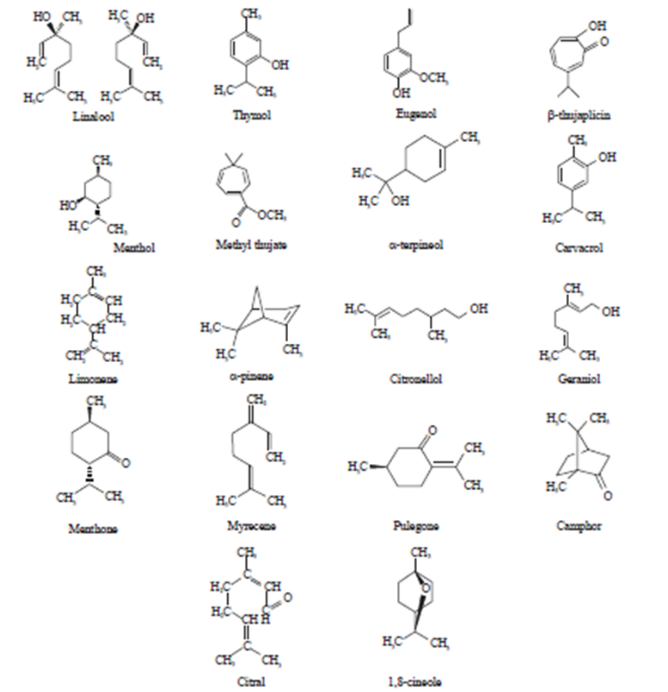

Figure 1. Chemical structures found in essential oil (Mossa, 2016).

3. Bio-pesticide

Bio-pesticide is an alternative to synthetic pesticides. It produces the same effects the chemical pesticides but it is made from naturally occurring formulations to control pests through non-toxic mechanisms and in an eco-friendlier manner (Kumar and Singh, 2015). Bio-pesticide was derived from plants, animals, bacteria as well as minerals that were used for pest control (Kachhawa, 2017; Lengai and Muthomi, 2018). It is included in the strategy used in Integrated Pest Management or IPM to control pest and disease and it has been proven to be successfully reduced the usage of chemical pesticides in the field (Krishnen *et al.*, 2016). Figure 1 shows some of the chemical structures found in an EO that has insecticidal activities.

3.1 Essential oil

Essential oils (EOs) can be classified into volatile, semi-volatile and non-volatile compounds depending on their nature (Eslahi *et al.*, 2017). EOs are antimicrobials that occurs naturally where it can be found in many plants and it has shown to be effective in many applications by lowering the growth and survival capabilities of microorganisms (Calo *et al.*, 2015). It plays many important in a plant's defence system against herbivores and pathogens. EOs' synthesis and accumulation were associated with secretory structures such as oil cells, secretory ducts or cavities, glandular trichomes, resin ducts (Pavela and Benelli, 2016; Morsy, 2017).

Generally, EOs have been known for their biological properties such as insecticidal, ovicidal, nematicidal, bactericidal and fungicidal effects against pests and pathogens that were very important in the agricultural yield including having positive effects on inflammatory processes, cardiovascular diseases, oxidative diseases, analgesic, anti-inflammatory activities (Isman *et al.*, 2011; Andrés *et al.*, 2012; González-Coloma *et al.*, 2013; Pacheco *et al.*, 2016; Santana *et al.*, 2016; Andres *et al.*, 2017; Eslahi *et al.*, 2017). Essential oils can be categorized into terpenoids and phenylpropanoids. Terpenoids are the major constituents for EOs. It consists of monoterpenes and sesquiterpenes of low molecular weight while phenylpropanoids have a lesser extent (Regnault-Roger *et al.*, 2012; Roman and Benelli, 2016).

Essential oils are being used as bio-pesticide because of its various biological activities against different insects, pest and pathogen. Table 2 below shows some of the species in the family of Piperaceae, type of insect or pathogen tested, chemical component extracted, properties identified, and the results observed. As we can see from the table, Gram-positive bacteria were effective when it was against essential oils. In order for the essential oils to be effective towards the microorganisms tested, the concentration must be taken into consideration (Premachandra *et al.*, 2014). According to Premachandra (2014), the findings on leaf extract from *Piper betle* L., has a high potency of nemato -toxic activity which can be directly related to the concentration of the leaf extract. In simple language, the higher the dose, the better the efficacy of the extract. The results demonstrated that the essential oils and plant parts showed significant bioactivity properties which can be used against various diseases as preventive agents. Based on previous studies, it is concluded that single compounds such as 1,8-cineole, myrcene, α-pinene, β-pinene and camphor are commonly found in essential oils associated with biological properties such as antifungal activity. However, the compound mentioned are absent in *Piper abbreviatum*, *Piper erecticaule* and *Piper lanatum* which proves that the antifungal activity does not depend solely on the compounds present but also the synergistic, antagonistic or additive effects of the compounds itself (Salleh *et al.*, 2011; Salleh *et al.*, 2014).

A high content of monoterpene hydrocarbons may be the reason why the essential oils lack activity against the microbial strains tested. Moreover, study shows essential oils that have a high content of oxygenated monoterpenes displayed stronger antifungal properties (Salleh *et al.*, 2012). The essential oils are weak when it is tested for antifungal property due to the small number of oxygenated monoterpenes.

The phenol, apiol and dillapiole compounds show their potential as insecticidal against several insects and also major insect pest in food crop such as termites. This is a good and important finding to maximise the uses of essential oil extracted from Piperaceae. The essential oil extracted from the plant is very limited. However, the Piperaceae essential oil shows high potential in controlling pests in a food crop with low amount which is good to be commercialised worldwide as a biopesticide.

4. Conclusion and Recommendation

The usage of chemical pesticides has caused many adverse toxic effects. One of the major concerns nowadays is the pollution and contamination of soil because of the excessive use of chemicals which can cause environmental pollution at both manufacturing and application sites. In addition to that, it causes many health and environmental problems, affected many factors such as survival range of life cycle stages, reduce reproductive capacity, changes host suitability for parasitizing and predation, reduces the emergence of parasitoids and also causes mortality. The search for alternatives to chemical pesticides has become a priority. Sustainable method to overcome this problem has become a great challenge, especially to smallholders. Thus, bio-pesticides have been invented with the help of technologies. Bio-pesticides have become one of the alternatives chosen although it does not reach the desired level of use yet. This alternative had received many positive interests to replace the synthetic pesticides which are very suitable for integrated pest management (IPM) and organic farming. The potential group of bio-pesticides were represented by EO which was known to possess many biological activities including controlling pests and repellent properties. During this globalisation era, the concept of returning to "roots" is starting to become more famous. Scientific research also proved that plants such as Piperaceae can be used as bio-pesticide. Based on Table 2, mosquitoes can be controlled by using five species of Piper which *Piper betle L., Piper dilatatum, Piper aff. Hispidum*, and *Piper sanctifelicis* due to the presence of phenol, chavicol, apiol, *trans*-caryophyllene, p-cymene and limonene. Besides, *Escherichia coli* and *Staphylococcus aureus* can be controlled by using EO from *Piper nigrum* which contains β-caryophyllene and limonene, and piperine respectively while *Xanthomonas oryzae* pv. O*ryzae and Pseudomonas fuscovaginae* can be controlled using secondary metabolite presence in *Piper sarmentosum* such as 4H-pyran-4-one,2,3-dihydro-3,5-dihydroxy- 6-methyl- (DDMP);octanamide, N,N-dimethyl;3-(4-methoxyphenyl) propionic acid. Moreover, brown planthopper and leaf folder pathogen can be controlled using *Piper divaricatum* which contains eugenol and methyl-eugenol. *Piper guineense* contains sesquiterpene β-sesquiphellandrene and linalool which possessed many biological activities. Being exposed to many pest and diseases ensures plants produce resistance mechanisms such as secondary metabolites to protect themselves. *Piper aduncum* L. exhibit potential insecticidal activity against caterpillar soybean looper (*Chrysodeixis includes* Walker*)* through ingestion. *Piper nigrum* was the most researched species because *Piper nigrum* is the most abundant species in this genus. Thus, more research should be done on the chemical compounds of the other species of *Piper* in order to carry out comparative studies with emphasis on the mechanisms, to publish and to organize a workshop where new findings are presented and control methods are critically analysed in relation to the feedback from farmers.

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Table 2. List of different Piper species, chemical compound and its properties.

Species	Pathogen / Pest	Compounds	Properties	Result	References
P. nigrum	- *Staphylococcus aureus* - *Escherichia coli* - *Escherichia coli* - *Salmonella* sp. - *Proteus vulgaris* G.	β-caryophyllene; limonene	Antimicrobial	Gram-positive bacteria were more sensitive than gram-negative bacteria. The inhibition zones measured were between 8 to 10 mm and the minimum inhibitory concentrations was greater than 600ppm. Gram-negative bacteria showed inhibition zones between 8 to 12.5 mm and a minimum inhibitory concentration of 6 ppm.	Teneva *et al.* (2016)
	- *Staphylococcus aureus* - *Bacillus subtilis* - *Pseudomonas aeruginosa* - *Escherichia coli* - *Aspergillus flavus* - *Candida albicans*	α-Pinene; δ-3-carene; Limonene; Sabinene; B-caryophyllene	Antimicrobial	The essential oil from black pepper is tested against Gram-positive bacteria and the inhibition zones are as follow: *Bacillus subtilis*-23.9±0.58 mm; *Staphylococcus aureus*-19.2±1.5 mm. While the inhibition zones for gram-negative bacteria is *Escherichia coli*-21.6±1.2 mm and fungi (*Candida albicans*) exhibited the largest inhibition zones which is between 18.3±0.58 mm. The essential oil were shown to have the listed components as major components and it showed an inhibitory activity against food-borne pathogens.	Nashwa *et al.* (2017)
	- *Staphylococcus aureus* - *Bacillus cereus* - *Streptococcus faecalis* - *Pseudomonas aeruginosa* - *Salmonella enterica* ser. Typhi - *Escherichia coli*	Piperine	Antimicrobial	The gram-positive bacteria were determined to be the most effective against the piperine compound compared to gram-negative bacteria. The gram-negative bacteria were less susceptible to black pepper.	Shityakov *et al.*, 2019
Piper betle L.	*Meloidogyne incognita*	Phenol	Nematicidal	Root infestations in form of gall formation, egg production and second-stage juvenile population densities of the nematode were reduced in the meanwhile, the growth of the tomato plants also being enhanced.	Premachandra *et al.* (2014)
	Aedes aegypti Liston (larvae)		Insecticidal	The insect is shown to be susceptible to *Piper betle* L. extract.	Vasantha-Srinivasan *et al.* (2017)
Piper sarmentosum Roxb.	*Xanthomonas oryzae* pv. *oryzae* *Pseudomonas fuscovaginae*	4H-pyran-4-one,2,3-dihydro-3,5-dihydroxy-6-methyl- (DDMP); octanamide, N,N-dimethyl; 3-(4-methoxyphenyl) propionic acid	Antibacterial	The methanol extracts of both leaves and fruits of *Piper sarmentosum* were effective against both pathogen stated at a low concentration, 25 mg ml–1.	Syed Abd Rahman *et al.* (2014)

Table 2 (cont.). List of different Piper species, chemical compound and its properties.

Species	Pathogen / Pest	Compounds	Properties	Result	References
Piper dilatatum	Termites Mosquito	Apiol; *Trans*-caryophyllene; Spathulenol; γ-cadinene	Insecticidal, larvicidal phytotoxic	The essential oils from the species stated showed strong antifeedant and phytotoxic effects. Essential oil from *Piper dilatatum* was the most effective antifeedant among the four species. Essential oils from *Piper dilatatum, Piper divaricatum* showed strong herbicidal potential on *Lodium perenne*. While, essential oil from *Piper aff. hispidum* reduced the root growth of *Lactuca sativa.*	Jaramillo-Colorado *et al.* (2019)
Piper divaricatum	Brown planthopper Leaf folder	Eugenol; Methyl eugenol; γ-elemene; Asarone; *Trans*-caryophyllene			Silva *et al.* (2014); Jaramillo-Colorado *et al.* (2019)
Piper aff. Hispidum	Mosquito	δ-3-Carene; p-cymene; Limonene; Elemol; γ-elemene; β- eudesmol			Jaramillo-Colorado *et al.* (2019)
Piper sanctifelicis	Mosquito	δ-3-Carene; Limonene; β-pinene; p-cymene; Nerolidol			Jaramillo-Colorado *et al.* (2019)
Piper aduncum L.	*Chrysodeixis* includes Walker	Dillapiole; Myristicin; Z-carpacin	Insecticidal	The mortality rate reached 90% for the highest concentration for the first 24 hrs after application. There is no significant differences until the end of the life cycle of the insect for topical application. This showed that the essential oil from this species can be used as a potential insecticidal to control this insect through ingestion.	Sanini *et al.* (2017)
Piper arborescens Roxb.	- *Staphylococcus aureus* - *Bacillus subtilis* - *Pseudomonas aeruginosa* - *Pseudomonas putida* - *Escherichia coli* - *Candida albicans* - *Aspergillus niger*	Leaves oil β-phellandrene; Sabinene; α-pinene; Terpinen-4-ol Stems oil β-phellandrene; Methyl eugenol; β-caryophyllene	Antimicrobial	Results for leaves oil showed significant antimicrobial activity against *Staphylococcus aureus*. Stems oil showed antimicrobial activity towards gram-positive bacteria which *is Pseudomonas aeruginosa* and fungi which is *Aspergillus niger*.	Salleh *et al.* (2016)

Table 2 (cont.). List of different Piper species, chemical compound and its properties.

Species	Pathogen / Pest	Compounds	Properties	Result	References
Piper caninum Blume	- *Bacillus subtilis* - *Staphylococcus aureus* - *Pseudomonas aeruginosa* - *Pseudomonas putida* - *Escherichia coli* - *Candida albicans* - *Aspergillus niger*	Safrole; β-caryophyllene; β-pinene; Germacrene D	Antimicrobial	The essential oils from leaves and stems exhibited strong activity against gram-positive and gram-negative bacteria strains. But it showed weak activity towards fungal strains.	Salleh *et al.* (2011)
Piper abbreviatum	- *Bacillus cereus* - *Staphylococcus aureus* - *Enterococcus faecalis* - *Escherichia coli* - *Pseudomonas putida* - *Klebsiella pneumoniae* - *Aspergillus niger* - *Candida albicans* - *Saccharomyces cerevisiae*	Spathulenol; (*E*)-nerolidol; β-caryophyllene;	Antimicrobial	Essential oils from the three species exhibited weak activity against gram-positive bacteria. Essential oil from *Piper erecticaule* showed the best activity against *Aspergillus niger* and followed by *Piper lanatum* oil.	Salleh *et al.* (2014)
Piper erecticaule		β-caryophyllene; Spathulenol			
Piper lanatum		Borneol; β-caryophyllene; α-amorphene			
Piper officinarum	- *Bacillus subtilis* - *Staphylococcus aureus* - *Pseudomonas putida* - *Escherichia coli* - *Candida albicans* - *Aspergillus niger*	Leaf Oil β-caryophyllene; α-pinene; Sabinene; β-selinene; Limonene Stem Oil β-caryophyllene; α-phellandrene; Linalool; Limonene; α-pinene	Antimicrobial	Both oils showed weak activity towards *Pseudomonas aeruginosa* and *Escherichia coli*. *Bacillus subtilis* was also tested against leaf oil and it exhibited weak activity towards the microorganism. For fungi, both stem and leaf oils also exhibited weak antifungal activity against *Aspergillus niger*. This is due to the small amount of oxygenated monoterpenes.	Salleh *et al.* (2012)

Table 2 (cont.). List of different Piper species, chemical compound and its properties.

Species	Pathogen / Pest	Compounds	Properties	Result	References
Piper stylosum	- *Bacillus subtilis* - *Bacillus cereus* - *Staphylococcus aureus*	Aromadendrene; Sabinene; β-caryophyllene	Antimicrobial	The essential oils showed strong antimicrobial activity. Essential oil from *Piper ribesioides* showed strong activity against *Bacillus cereus* and *Staphylococcus aureus*.	Salleh *et al.* (2014)
Piper ribesioides	- *Klebsiella pneumonia* - *Candida albicans* - *Candida neoformens* - *Saccharomyces cerevisiae*	β-caryophyllene; Camphene; δ-cadinene			
Piper porphyrophyllum N.E. Br.	- *Staphylococcus aureus* - *Bacillus subtilis* - *Pseudomonas aeruginosa* - *Pseudomonas putida* - *Escherichia coli*	Leaf oil Bicyclogermacrene; α-copaene; β-phellandrene Stem oil Sabinene; Bicyclogermacrene; α-copaene	Antibacterial	Both oils showed moderate activity against gram-positive and gram-negative bacteria.	Salleh *et al.*, 2012

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