https://doi.org/10.17576/serangga-2025-3001-11

REVIEW ON THE PESTICIDAL POTENTIAL OF PIPERACEAE AGAINST INSECT PESTS

Masdah Mawi[1], Anis Syahirah Mokhtar[1] & Norhayu Asib[1*]
[1]Department of Plant Protection,
Faculty of Agriculture,
Universiti Putra Malaysia,
43400 Serdang, Selangor, Malaysia
*Corresponding author: *norhayuasib@upm.edu.my*

Received: 14 November 2024: Accepted: 17 March 2025

ABSTRACT

Adverse effect of chemical pesticides on non- target organisms and environments leads the shifting to biopesticide implementation in agricultural industries in the recent years. Natural source biopesticide especially the plant-based biopesticide is gaining attention for their efficacy in controlling insects and because their application that employs Integrated Pest Management (IPM) approaches. Species from Piperaceae family are common herb which widely grown and spread throughout the world especially in Asia countries. Most of plants in the family contains various active chemical constituents that are responsible for biological and pharmacological activities. This paper aims to review and discuss the previous studies and research on the phytochemistry and insecticidal properties of *Piper* species in order to provide a scientific consensus for further research as a potential biopesticides. Further studies of Piperaceae plant are recommended to focus on their insecticidal actions on insect pests, thus, improving its benefits to non-target organisms and environment.

Keywords: Piperaceae, *Piper*, chemical constituent, mechanism of action, insecticidal activity

ABSTRAK

Kesan buruk racun kimia terhadap organisma bukan sasaran dan persekitaran menyebabkan peralihan kepada pelaksanaan biopestisid dalam industri pertanian sejak beberapa tahun kebelakangan ini. Biopestisid berasaskan sumber semula jadi terutamanya berasaskan tumbuhan semakin mendapat perhatian kerana keberkesanannya dalam mengawal serangga dan kerana aplikasinya yang menggunakan pendekatan Pengurusan Perosak Bersepadu (PPB). Spesies dari famili Piperaceae adalah pokok herba yang banyak tumbuh dan terdapat di seluruh dunia terutamanya di negara-negara Asia. Kebanyakan tumbuhan dalam keluarga ini mengandungi pelbagai juzuk kimia aktif yang bertanggungjawab untuk aktiviti biologi dan farmakologi. Kertas kerja ini bertujuan untuk menyemak dan membincangkan secara ringkas kajian dan penyelidikan terdahulu mengenai sifat fitokimia dan insektisid bagi spesies *Piper* bagi menyediakan konsensus saintifik untuk penyelidikan lanjut sebagai biopestisid yang berpotensi. Kajian lanjut mengenai tumbuhan Piperaceae adalah disyorkan untuk memberi

tumpuan kepada tindakan insektisid tumbuhan tersebut terhadap serangga perosak, dengan itu, meningkatkan kelebihannya kepada organisma dan persekitaran bukan sasaran.

Kata kunci: Piperaceae, *Piper*, konstituen kimia, mekanisma tindakan, aktiviti insektisidal

INTRODUCTION

Over the years, synthetic chemical pesticides have played a very significant role in managing the population of the pest compared to other control approaches. However, continuous use of chemicals can negatively affect environment and non-target organisms (Azmi et al. 2022). Thus, alternative to chemical such as plant-derived biopesticides should be implemented, as there are growing numbers of attention and priority of researches on its effectiveness because of their non harmful mechanism to non-target organisms and cost (Abdullah et al. 2020; Nurul Farah & Nurul Huda, 2024; Brito & Joshi 2016; Prabhakaran et al. 2017). Biopesticides are capable to exert the same effects as chemical pesticides but it is developed from plants, animals, bacteria as well as minerals source to manage pests (Lengai & Muthomi 2018; Kachhawa 2017; Kumar & Singh 2015). Biopesticides is a natural and biologically occurring compounds derived from natural sources like plants, animals, fungi, bacteria, and minerals (Khursheed et al. 2022).

Analysis by Shattuck et al. (2023) based on database from FAO found that in the recent years, in global and low-income countries, the pesticide use increased by 20% and 153%, respectively, during the same period. From a study by Halimatunsadiah et al. (2016) concluded that farmers' most common option for pest management practices are the use of synthetic pesticide 97.6% compared to 8.2% use of biopesticide. A latest statistic done by Siddharta (2024), pesticide usage in Malaysia has the lowest amount in 2020 (for the period 2012 to 2021) with 36,080 metric tons but increased by 25% in 2021 with amount of 45,670 metric tons. The highest recorded usage was in 2016 with 67, 290 metric tons.

This paper reviews the promising insecticidal activities of Piperaceae and briefly discussed the previous studies and researches for the phytochemistry and toxicological properties of Piperaceae in orders to provide a scientific consensus to be commercially develop into biopesticide products that are competitively toxic to target pest, safer to environment and cost-efficient.

Piperaceae

The Piperaceae family, commonly name as pepper is large flowering plants that may be small herbs, trees, or shrubs (Kuete et al. 2013). Piperaceae consists approximately 3600 species in 13 genera and the well-known genus is *Piper* with around 2000 species widely spread in warm tropical and subtropical regions and native and cultivated mostly in India (Oyemitan 2017; Tamokou et al. 2017). *Piper* are aromatic plants used as spices in the kitchen, but their secondary metabolites have also shown biological effects on human health (Shango et al. 2021). Many species from family Piperaceae were found to exhibit phytochemicals with insecticidal potency especially *Piper nigrum* and *P. guineense* (Scott et al. 2004).

Piper nigrum can be herbaceous, shrubs or climbers, cylindrical stems, alternate leaves, very small flowers, opposite inflorescences to leaf or axillary, small bracts, copious starchy perisperm seeds and drupe or nutlet-like fruit is usually a drupe or nutlet (Xu & Deng 2017). *Piper guineense* is a perennial climber vine that has greenish-yellow flower and oval reddish-brown fruits that turn black when dried (Alagbe et al. 2021). *Piper betle* is a stimulant, the leaves are pungent and have aromatic flavour and has been used in traditional medicine. *Piper sarmentosum* is a creeping herb species from family Piperaceae that have green alternate heart-shaped and waxy leaves (Rahman et al. 2016). Table 1 shows the most common species of Piperaceae all over the world.

Table 1. Piper species, origin and its usage

Piper species	**Country of Origin**	**Uses**	**References**
Piper nigrum L.	India	Used as food spice, medicinal uses for digestive and respiratory disorder	Srivastava & Singh (2017)
Piper guineense Schumach. and Thonn.	West Africa	Used as in culinary as food spices and traditional source of medicine	Oyemitan (2017)
Piper betle L.	Malaysia	Used as medicine, taken raw as food, leaf and areca nut use in cultural ceremonies	Biswas et al. (2022)
Piper sarmentosum Roxb.	Vietnam	Use as food source and for treatment of wind-cold cough, fever, rheumatism arthralgia, diarrhea dysentery, postpartum foot swelling, stomachache, toothache, diabetes, and traumatic injury.	CABI 2022; Sun et al. (2020)
Piper aduncum L.	Brazil	Possess fungicidal and insecticidal activities, antibacterial, antileishmanial, antioxidant, cytotoxic/antitumor, larvicidal, antiplatelet, molluscoidal and antiviral ones	Morais et al. (2023)
Piper tuberculatum Jacq.	Mexico to Tropical America	Used in folklore medicine as antidiuretic, analgesic and sedative and antidote for snakebites and to treat digestive disorders	Salehi et al. (2019)
Piper methysticum Forster f.	Southern Pacific islands	Use for recreational and therapeutic purposes. Traditional medicine to reduce anxiety and is sometimes paired with alcohol for recreational use.	Srivastava & Kumar (2021)

Piper longum L.	India	Antifungal, insecticidal, antimicrobial, antiamoebic, antidiabetic, antioxidant, anti-cancerous and effect on respiratory system.	Pandey (2008)
Piper auritum Kunth	Southern Mexico to Colombia	Medicinal uses for chest pain, colic, cramps, dyspepsia, fever, gout, headaches, high blood pressure, inflammation, rheumatism, sores, wounds and snake-bite.	Narayanswamy (2013)
Piper cubeba L.f.	Java and Borneo	Herbal medicine used for the treatment of many diseases, such as respiratory and digestive disorders	Drissi et al. (2022)
Piper umbellatum L.	America	Used as a traditional medicine to cure inflammation and gastrointestinal disorders and possess anti-inflammatory and gastroprotective activity.	Arunachalam et al. (2020)
Piper marginatum Jacq.	Guatemala to Brazil	Used in traditional medicine for healing properties and to treat snakebites, inflammation, wound healing, malaria, dental caries, liver or bile related problem, haemostatic, and for its analgesic effects. Also used in food industry as sweetener and flavouring agent.	Sequeda-Castañeda & Gutierrez (2015)
Piper attenuatum Buch.-Ham. ex Miq.	India	Used as a traditional medicinal plant in India to treat headache and muscular pain, possess anti-inflammatory, antibacterial and antioxidant effects	Kim et al. (2017)
Piper ribesioides Wall.	Indonesia, Peninsular Malaysia	Used for treatment of diarrhoea, abdominal	Ridzuan et al. (2021)

		pain and asthma and also as food flavour	
Piper stylosum Miq.	Malaysia	Eaten as raw vegetable, as food seasoning and confinement medicine	Wan Salleh et al. (2014)

Chemical Constituents of Piperaceae

Piper nigrum is the most well-known spice due to its pungent smell caused by the presence of piperine and its worldwide popularity as a food flavour (Salehi et al. 2019; Shango et al. 2021). Diverse metabolites content of *Piper nigrum* such as piperine, alkaloids, oleoresin, phenolic, terpenoids, lignan, carotenoids, flavonoids, amides, essential oil and aromatic compound illustrate pharmacological characteristic and combination of these substances produce the odour, scent and tint of *P. nigrum* (Ashokkumar et al. 2021; Bermawie et al. 2019; Emira et al. 2021: Goswami & Malviya 2020). Such chemical constituents like alkaloids, glycosides, tannins, flavonoids, terpenes and some secondary metabolites were also found from the extraction of *P. guineense* and it was confirmed that they produced several medicinal properties (Alagbe et al. 2021). Another review by Rahman et al. (2016) has been investigated the chemical compounds, ethnomedicinal uses and pharmacological properties and summarized that *P. sarmentosum* contain compounds including alkaloids, sarmentosine, phenylpropanoids and several more and possess antimicrobial, antioxidant and anticancer properties. *Piper betle* leaf extract also shows the presence of phytochemicals including tannins, alkaloids, saponins and glycosides (Nayaka et al. 2021).

The essential oil leaves extract was found able to fight against insect attacks and bacterial, fungal, and protozoan infections (Biswas et al. 2022). High level of antioxidant properties is discovered in phytochemicals and essential oils of *P. nigrum* as compared with artificial antioxidants and showed antibacterial and antifungal characteristics towards human pathogens (Salehi et al. 2019). A review by Abdullah et al. (2020) stated that essential oil from *P. nigrum* can control infestation of *Escherichia coli* and *Staphylococcus aureus* because the presence of β-caryophyllene and limonene and piperine while components such as 4H-pyran-4-one,2,3-dihydro-3,5-dihydroxy- 6-methyl- (DDMP);octanamide, N,N-dimethyl;3-(4-methoxyphenyl) propionic acid that isolated from *P. sarmentosum* can controlled *Xanthomonas oryzae* and *Pseudomonas fuscovaginae*. Table 2 shows some studies of Piperaceae compound on insect pests and their efficacy.

Table 2. Summary of key studies

Study	**Piperaceae**	**Major Compound**	**Target Pests**	**Observed Efficacy**
Rohimatun et al. (2023).	*Piper aduncum*	Dillapiole	*Sitophilus oryzae Callosobruchus maculatus*	Showed higher toxicity to female adults of *C. maculatus* than *S. oryzae*
Weluwanarak et al. (2023)	*Piper nigrum*	α-pinene, sabinene, limonene, and β-caryophyllene	*Stomoxys calcitrans*	Higher mortality compared to control in contact and fumigant toxicity
Fazolin et al. (2022)	*Piper aduncum*	Dillapiole	*Spodoptera frugiperda*	Dillapiole contents between 68% - 88% and 82% - 100% promote, respectively, optimal and stable residual and topical contact toxicity against S. frugiperda

				larvae
Kumrungsee et al. (2022)	*Piper ribesioides*	piperine, phenethylcinnamamide and cinnamic acid	*Spodoptera exigua*	Toxicity test of the compounds produced synergistic, additive, and antagonistic action after combining with thymol
Subaharan et al. (2021)	*Piper betle*	Eugenol and eugenol acetate	*Musca domestica*	Caused higher ovicidal activity, fumigant toxicity to adults, contact toxicity caused higher mortality to larval and adult stages compared to essential oil.
AraÚjo et al. (2020)	*Piper aduncum*	Dillapiole	*Plutella xylostella*	Caused the highest toxicity and feeding deterrence
Hematpoor et a. (2017)	*Piper sarmentosum*	asaricin 1, isoasarone 2, and trans-asarone 3	*Sitophilus oryzae* *Rhyzopertha dominica* *Plodia interpunctella*	Asaricin 1 and isoasarone 2 were the most toxic to the insect pests and significantly reduced oviposition and adult emergence
Wan Salleh et al. (2014)	*Piper ribesioides*	Camphene β-Caryophyllene	*Bacillus cereus* *Staphylococcus aureus*	Microbial activity to bacteria *B. cereus* and *S. aureus*
Wan Salleh et al. (2014)	*Piper stylosum*	Sabinene β-Caryophyllene Aromadendrene	*Staphylococcus aureus* *Candida albicans* *Candida neoformens*	Exhibited the highest zones of inhibition against bacteria *S. aureus* strong antifungal activity towards fungus, *C. albicans* and *C. neoformans*
Scott et al. (2008)	*Piper nigrum*	pipercide, pellitorine and piperine	*Callosobruchus chinensis*	Seed extract was found to be toxic to *C. chinensis*
Scott et al. (2008)	*Piper guineense*	Guineensine	*Callosobruchus maculatus*	Topical application of guineensine isolated from seed extract causd toxicity to *C. maculatus*.
Scott el at. (2004)	*Piper nigrum* *Piper guineense* *Piper tuberculatum*	Isobutyl amides	*Malacosoma americanum* *Neodiprion sertifer* *Yponomeuta cagnagella* *Pyrrhalta viburni* *Acalymma vittatum* *Leptinotarsa decemlineata* *Popillia japonica* *Blissus leucopterus hirtis*	Caused lethal effect
Scott el at. (2004)	*Piper nigrum* *Piper guineense* *Piper tuberculatum*	Isobutyl amides	*Lilioceris lilii* *Ostrinia nubilalis*	Repellent properties

Terpenoids Compound

Essential oils of *P. nigrum* were reported to produce monoterpene hydrocarbons, sesquiterpene hydrocarbons, small amount of oxygenated monoterpenoids, oxygenated sesquiterpenoids, β-caryophyllene, camphene, sabinene, limonene, 3-carene, α-pinene and β-pinene (Milenković & Stanojević 2021). In a study by Nugroho et al. (2020), it was found that essential oil of eight species of *Piper* extracts (*P. acutilimbum, P. sarmentosum, P. betle, P. porphyrophyllum, P. majusculum, P. Molissimum P. caninum* and *P. baccatum*) consist terpenoid compounds that classified into three diterpenes, four monoterpenes and 14 sesquiterpenes. Another study by Baldoqui et al. (2008) had successfully isolated nine compounds from *Piper umbellata* leaves extract including one terpenoid glucoside, five two lignans and 4-nerolidylcathecol

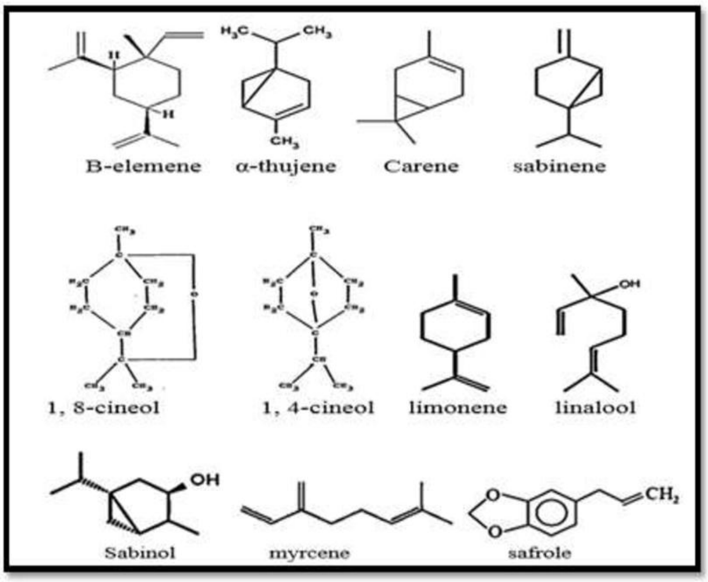

Figure 1. Monoterpenes structure isolated from *Piper cubeba* (Abdul-Jalil & Nasser 2020)

Alkaloids Compound

Previous report confirmed that several number of amide alkaloids isolated from Piper species possess piperidine, isobutyl, pyrrolidine, benzylamine moieties, dihydropyridone, dimeric amides and aristolactams. These alkaloids responsible for such biological activities like adulticidal, insecticidal, antibacterial, antidepressive, larvicidal and antifeedant actions by disturbing acetylcholinesterase receptor site, interfere neuromuscular juncture permeability, produce new nerve impulses which caused spasmodic contractions, slow larval development that eventually leads to insects' death (Boate & Abalis 2020; Xiang et al. 2016). Piperine is a yellow crystalline material of molecular formula $C_{17}H_{19}NO_3$, an alkaloid isolated from *P. nigrum* that is responsible for the plant spiciness (Milenković & Stanojević 2021). Amides are component isolated from Piperaceae family that produce piperine which possess insecticidal properties and it has been proven that the insecticidal action was derived from *P. nigrum* (Fazolin et al. 2014). Piperine, piperlonguminine, dihydropiperlonguminine, dihydropiperineand and pipercide are piperamides that were isolated from *P. nigrum* seed and *P. tuberculatum* leaf extract (Scott et al. 2008).

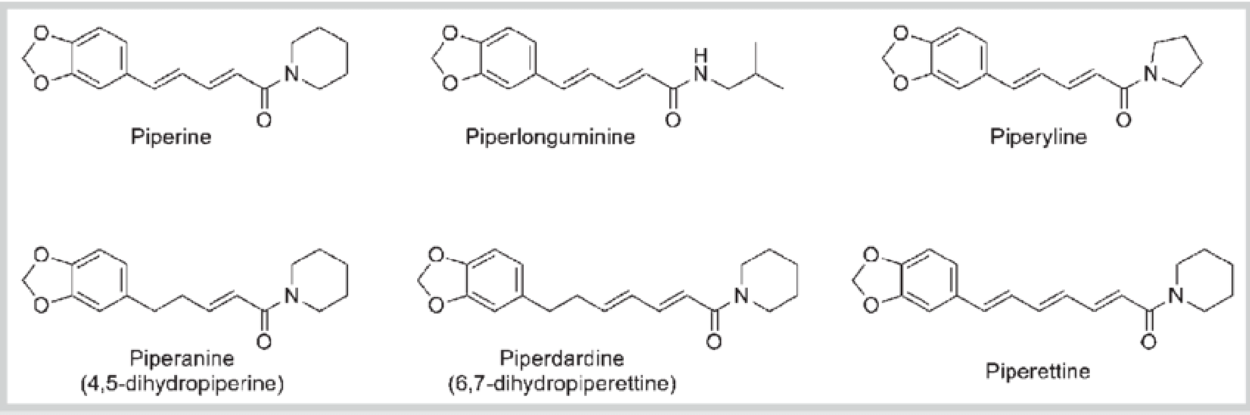

Figure 2. Chemical structure of piperamides isolated from *Piper nigrum* (Gurley 2012)

Phenolic Compound

Polyphenols are naturally occurring organic compounds of plant origin with different chemical structures. Polyphenols and essential oils content in *P. betle* leaves possess several bioactivities such as antimicrobial, antioxidant and antibacterial activities (Tagrida & Benjakul 2021). According to Milenković and Stanojević (2021), phenols in *P. nigrum* are a mixture of phenolic acids (hydroxybenzoic, hydroxycinnamic, quercetin and kaempferol) and flavanol glycosides (isoquercetin, isoramnetin, kaempferol-3-O arabinoside-7-ramnoside, kaempferol-3-O-β-glucoside, 3-O-β-D-rutinoside and quercetin-3-O-β-D-rutinoside). Piper genus was reported to exert more than three types of lignans and neolignans that control themethylenedioxyphenyl (MDP) functionality. Lignans which act as plant defense mechanism can be found from several plant parts such as stem, root, bark, leaves and seed are vary in amounts, sizes and models (Fazolin et al. 2014; Scott et al. 2008; Xiang et al. 2016). Tannins leads to antifeedant action and death of insects by interfering the biochemical activity like precipitates and inactivates adhesion enzymes and cell development proteins of the insects (Boate & Abalis 2020). Flavonoid is another plant metabolite that can be classified into isoflavonoids and proanthocyanidins that can control insects' behaviour, growth, feeding, obstruct their development and cause mortality (Fazolin et al. 2014).

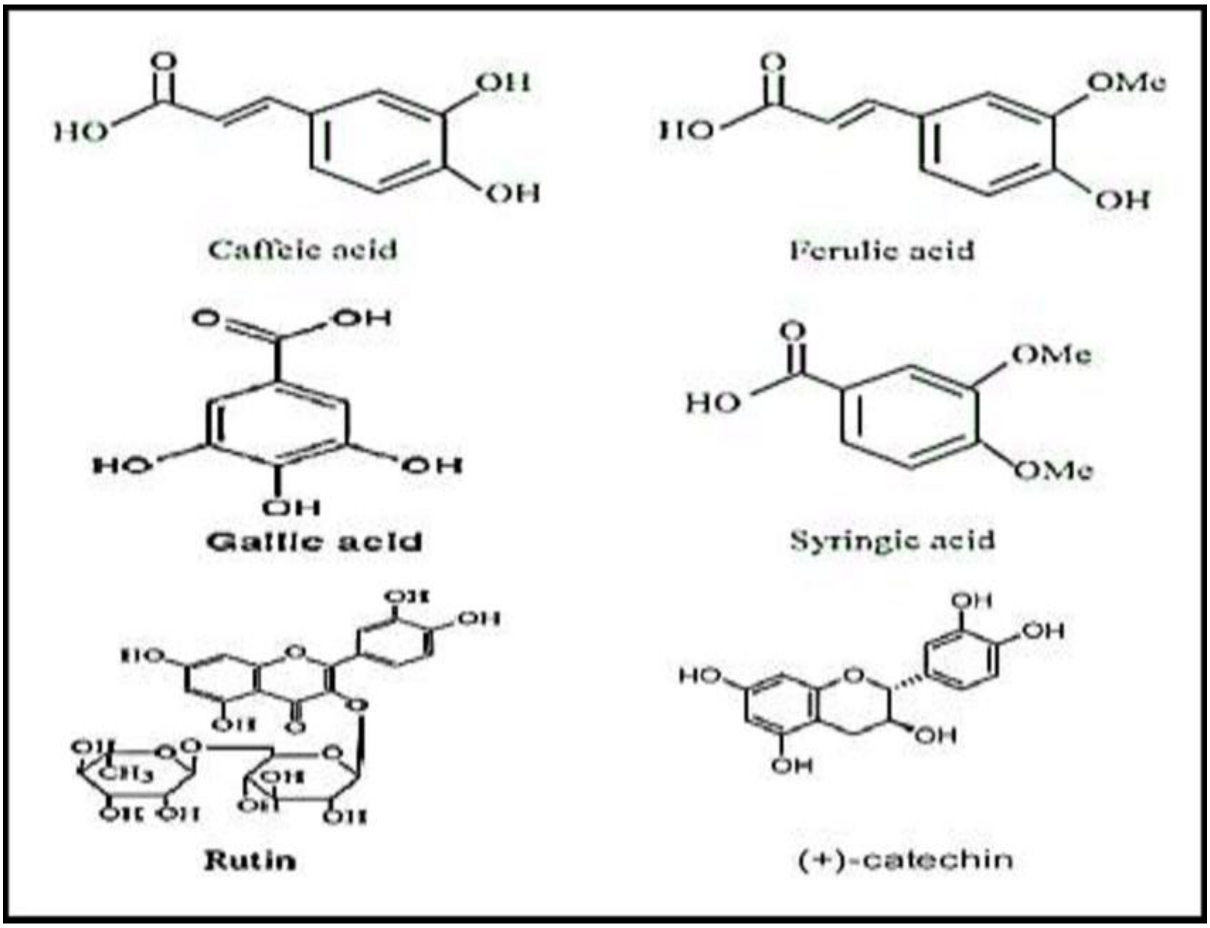

Figure 3. Phenolic acid and flavonoid chemical structure isolated from *Piper cubeba* (Abdul-Jalil & Nasser 2020)

Insecticidal roperties of Piperaceae

Lignans in Piperaceae can form an important cytochrome P450-dependent monooxygenase inhibitors that produce synergistic effect for natural insecticide when they associated with methylenedioxyphenyl group (Fazolin et al. 2014). Aliphatic chain amides and isopentyl amides also isolated from Piperaceae were found to produce insecticidal characteristics against *Aedes aegypti, Culex pipiens* pallens and *Mycobacterium tuberculosis* H37Ra (Xiang et al. 2016).

Piper nigrum was identified to be potentially competent to act as molluscicide compared other plant derivatives and synthetic because *P. nigrum* possess important secondary metabolites which promotes anti-feedant and molluscicidal activities at varying levels (Daud et al. 2023; Srivastava et al. 2009). *Piper nigrum* fruit powder extracted from ethanol, chloroform and acetone solvents confirm the presence of molluscicidal activities in the plant (Srivastava et al. 2009). *Piper nigrum* and piperine were fed to *Anopheles gambiae* and it was concluded that *P. nigrum* produce higher mortality number at 24 hours after treatment compared to by piperine at 48 hours after treatment (Samuel et al. 2016). Investigation on the toxicity of *P. nigrum* extract against *Sitophilus zeamais* show 100% mortality 96 hours after treatment (Choden et al. 2020). Evaluation of the insecticidal efficacy of *P. nigrum* against stable fly, *Stomoxys calcitrans* expressed a linear relationship between *S. calcitrans* mortality, essential oil concentration and time of exposure (Weluwanarak et al. 2023). Another insecticidal study of *P. nigrum* was conducted by Sleem (2021) agreed that the plant extract can cause toxicity and repellent to *Rhyzopertha dominica* with mortality of 56.67% after 72 hours of treatment at 0.25% concentration while mean percentage repellency of 76% in 2% concentration. On the other study, the acute toxicity test demonstrated that *P. nigrum* essential oil present high toxicity properties against larvae and adult *Anopheles gambiae* with lethal concentration of 15 ppm and repellency varied at vary concentrations (Kemabonta et al. 2018). Isolation of piperamides (piperine, pipercide and peelitorine) from *P. nigrum* and guineensine isolated from *P. guineense* caused toxicity to *Callosobruchus chinensis* and *Callosobruchus maculatus*, respectively (Scott et al. 2008). Several reports confirmed the efficacy of *P. guineense* in controlling stored grain pests, caused 100% mortality rate of *Plutella xylostella* larvae infesting beans and possess repellent properties against *Cosmopolites sordidus* (Alagbe et al. 2021).

A review from Radwan and Gad (2021) revealed that GCMS analysis of the *P. betle* oil extracts contains molluscicidal activity against *Pomacea canaliculata* and depend on time and concentration of treatments. A statistical analysis by Yushananta and Ahyanti (2021) to determine the effect of *P. betle* leaf extract concentration on the mortality of *Musca domestica* found that all five concentrations were significantly different to the control treatment with the highest mortality was at concentration of 25%, with dead rate of 8.37, the lowest mortality was at a concentration of 5%, 4.50 and 0.12 in the control treatment. Another study on *M. domestica* concluded that *P. betle* essential oil of and its chemical compound caused toxicity to larvae and adults of *M. domestica* either via topical application and ingestion action. However, components from the essential oil which are eugenol acetate and eugenol exhibited higher toxicity compared to *P. betle* essential oil against *M. domestica* (Subaharan et al. 2021). In an antibacterial test against *Escherichia* coli, *Staphylococcus aureus*, *Klebsiella* and *Pseudomonous*, *P. betle* aqueous and ethanolic extract showed the highest antibacterial activity. In the same study to determine larvicidal activity against *Culex quinquefasciatus*, 100% of mortality the produced from ethanolic extract of *P. betle* (Prabhu et al. 2022).

Another review by Azelan et al. (2020) discussed about chemical content and biological activities of *P. sarmentosum* including antioxidant, antimicrobial and antidepressant properties. *Piper sarmentosum* essential oil displayed contact toxicity and antifeedant effects in the first and second instar larvae and showed fumigation effect against eggs and pupae of *Brontispa longissimi* (Qin et al. 2010). Asaricin 1 and isoasarone 2 are the chemical constituent extracted from *P. sarmentosum* roots that produced the highest mortality rate against storage pests *Sitophilus oryzae*, *Rhyzopertha dominica*, and *Plodia interpunctella* after exposed to the treated grains for 72 hours (Hematpoor et al. 2017). Othman et al. (2021) has conducted a study on larvicidal activity of the *P. sarmentosum* leaves extracts against *Aedes aegypti* in different solvents and found that hexane extract exhibited a remarkable highest larvicidal activity compared to other solvents with LC_{50} of 39.04 µg/mL and contain the highest total flavonoid and total phenolic content.

Piper As Natural Insecticide

In a study by Scott et al. (2008), they concluded that combining Piper extracts with other insecticide like pyrethrum can decrease insect resistance toward insecticides. Another research by Kumrungsee et al. (2022) revealed that there were synergistic, additive, and antagonistic action produced from combination of piperine, phenethyl cinnamamide and cinnamic acid isolated from *P. ribesioides* extract with thymol against *Spodoptera exigua*. Combination of three amides; piplartine, 40-desmethylpiplartine and cenocladamide isolated from *P. cenocladum* was found to be synergistic in delaying growth, weakening survival rate, reducing pupal weight and feeding deterrent against *S. frugiperda, Eois* spp. and *P. clavata* (Dyer et al. 2003).

In a study by Oliveira et al. (2023) to compare the effect of synthetic insecticide deltamethrin and essential oil of *P. aduncum* (EOPA) against *S. zeamais* concluded that deltamethrin caused greater toxicity compared to EOPA but the combination of these two produced synergistic effect against the insects. Another research to compare the effectiveness of natural insecticide extracted from *Allium sativum, P. nigrum* and *Syzygium aromaticum* with synthetic insecticide containing prallethrin against ants found that the both mixture of natural insecticide and prallethrin shows almost similar effect 9.67 and 10.0 average number of ants killed, respectively (Nawi 2021). From a research by Agbor et al. (2023), it was found that there is no significant difference in controlling maize pests, fall armyworm and snails between synthetic pesticides (cypermethrin) and *P. guineense* emulsion (piperamides). Figure 1 shows the mechanism of action of Piperaceae.

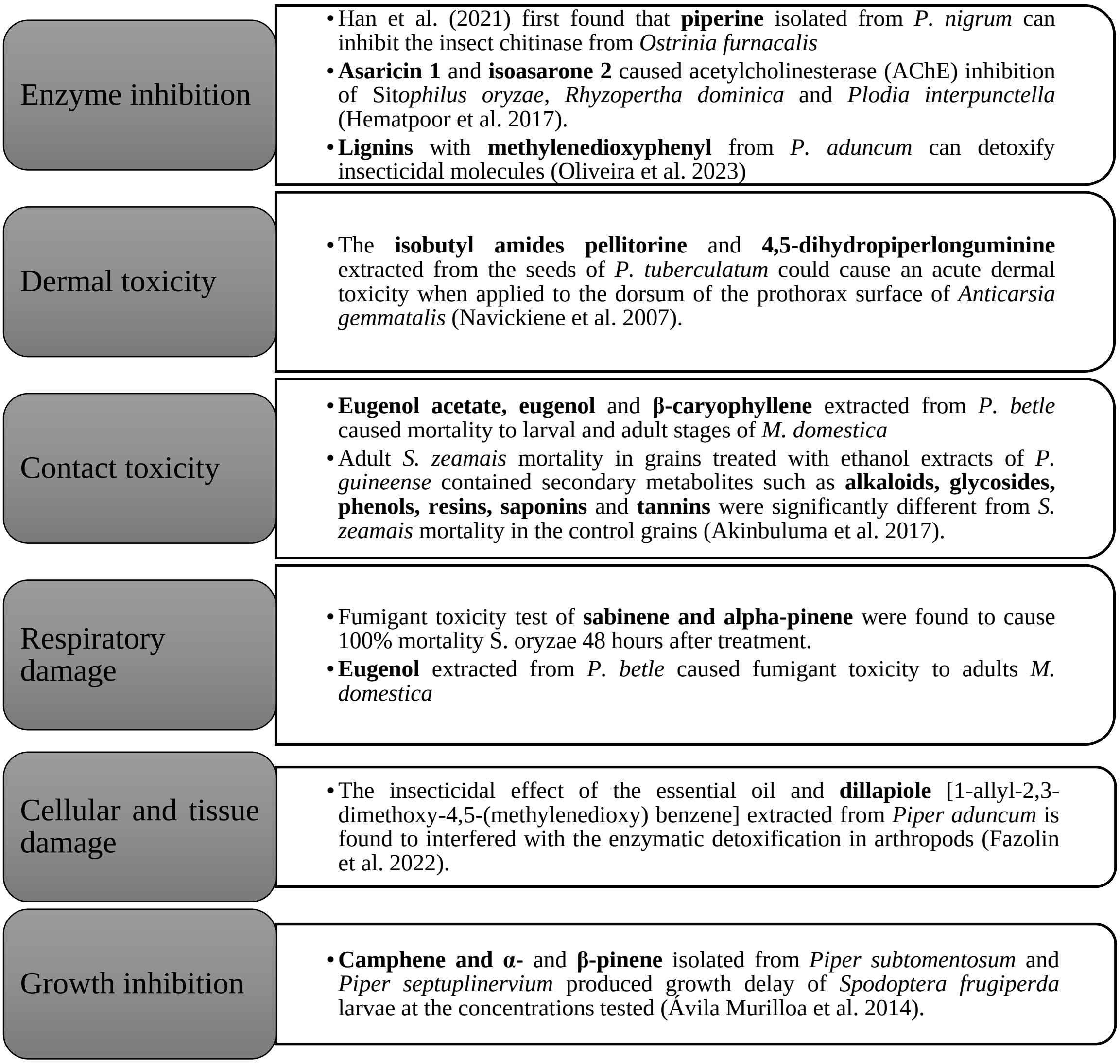

Figure 1. Mechanisms of action of Piperaceae compounds on insect pests

CONCLUSION

Research on Piper species and other plant extracts with insecticidal potential has gaining researchers' attention for their promising natural defence compounds and that is why the mechanism and secondary metabolism of these plant and plant products should be further explored and study. A special attention should also be given to the synergism produced from these plant combinations that can encounter insect resistance to formulation, low toxicity on non-target organism, reduce environmental pollution and novel target site. However, there are some challenges and limitation faced by biopesticides integration and shifting into pest control practices even though they meet the requirements of sustainable development in integrated pest management (IPM) practice. Hence, adequate awareness is important to convince farmers on the availability, benefit, and prospects of implementing biopesticide as alternative insect control. Thus, this review paper will definitely helpful in providing information of potential Piper species that can be develop into biopesticide that will be acceptable in the global communities.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Universiti Putra Malaysia and Ministry of Higher Education for providing financial assistance through grant number LGRS/1/2020/UPM/01/2/3.

AUTHORS DECLARATIONS

Funding Statement
This research was supported by Ministry of Higher Education under grant number LGRS/1/2020/UPM/01/2/3.

Conflict of Interest
The authors declare that they have no conflict of interest.

Ethics Declarations
No ethical issue is required for this research.

Data Availability Statement
This manuscript has no associated data.

Authors' Contributions
Masdah Mawi (MM) and Norhayu Asib (NA) developed the scope and outline of the review. MM performed the literature search, analysis and drafted the manuscript. NA and Anis Syahirah Mokhtar (ASM) contributed to the interpretation of the results and reviewed the manuscript. All authors reviewed and edited the manuscript and approved the final version.

REFERENCES

Abdullah, N.A., Zain, W.Z.W.M., Hamid, N.A. & Ramli, N.W. 2020. Essential oil from Piperaceae as a potential for biopesticide agents: a review. *Food Research* 4(5): 1 – 10.

Abdul-Jalil, T.Z. & Nasser, Z.A. 2020. *Piper cubeba*: phytochemical and pharmacological review of a routinely used spices. *International Journal of Pharmaceutical Research*: 761-768.

Agbor, D., Eboh, K., Sama, D.K., Lony, T., Tanyi, G. & Nkongho, R. 2023. Maize-legume intercropping and botanical Piper mitigating effect on pest populations while enhancing the yield of maize. *Journal of Natural Pesticide Research* 6: 100060.

Akinbuluma, M.D., Ewete, F.K. & Yeye, E.O. 2017. Phytochemical investigations of *Piper guineense* seed extract and their effects on *Sitophilus zeamais* (Coleoptera: Curculionidae) on stored maize. *Journal of Crop Protection* 6: 45-52.

Alagbe, O.A., Alagbe, G.O., Adekunle, E.A., Ayodele, O.O., Olorode, E.M., Oyediran, R.I., Oloyede, E.O., Oluwaloni, F.O. & Oyeleye, A.O. 2021. Ethnomedicinal uses and therapeutic activities of *Piper guineense*: a review. *Journal of Applied Sciences and Environmental Management* 25(6): 927-937.

Nurul Farah, A. & Nurul Huda, A. 2024. Exploring the repellent and insecticidal effects of black pepper (*Piper nigrum* L.) against sawtoothed grain beetle (*Oryzaephilus surinamensis* L.). *Serangga* 29(3): 59-72.

AraÚjo, M.J.C., Camara, C.A.G.D., Moraes, M.M., & Born, F.S. 2020. Insecticidal properties and chemical composition of *Piper aduncum* L., *Lippia sidoides* Cham. and *Schinus terebinthifolius* Raddi. essential oils against *Plutella xylostella* L. *Anais da Academia Brasileira de Ciencias* 92(1): e20180895.

Arunachalam, K., Damazo, A.S., Macho, A., da Silva Lima, J.C., Pavan, E., de Freitas Figueiredo, F., Oliveira, D.M., Filho, V.C., Wagner, T.M. & de Oliveira Martins, D.T. 2020. *Piper umbellatum* L. (Piperaceae): Phytochemical profiles of the hydroethanolic leaf extract and intestinal anti-inflammatory mechanisms on 2,4,6 trinitrobenzene sulfonic acid induced ulcerative colitis in rats. *Journal of Ethnopharmacology* 254: 112707.

Ashokkumar, K., Murugan, M., Dhanya, M.K., Pandian, A. & Warkentin, T.D. 2021. Phytochemistry and therapeutic potential of black pepper [*Piper nigrum* (L.)] Essential oil and piperine: A review. *Clinical Phytoscience* 7: 52.

Ávila Murilloa, M.C., Cuca Suareza, L.E., & Cerón Salamanca, J.A. 2014. Chemical composition and insecticidal properties of essential oils of Piper septuplinervium and P. subtomentosum (Piperaceae). *Natural Product Communications* 9(10): 1527–1530.

Azelan, A., Taher, Z.M., Sasano, S., Ariga, T. & Aziz, A.A. 2020. Chemical constituents and bioactivity of *Piper sarmentosum*: a mini review. *Food Research* 4(2): 14 – 18.

Azmi, W., Khoo, S.C., Chuen, N., Baharuddin, N., Aziz, A. & Ma, N.L. 2022. The current trend in biological control approaches in the mitigation of golden apple snail *Pomacea* spp. *Biological Control* 175: 105060.

Baldoqui, D., Bolzani, V., Furlan, M., Kato, M. & Marques, M. 2008. Flavones, lignans and terpene from *Piper umbellata* (Piperaceae). *Química Nova* 32*:* 1107-1109.

Bermawie, N., Wahyuni, S., Heryanto, R. & Darwati, I. 2019. Morphological characteristics, yield and quality of black pepper Ciinten variety in three agro ecologicsrivasal conditions *IOP Conference Series: Earth and Environmental Science* 292: 012065.

Biswas, P., Anand, U., Saha, S. C., Kant, N., Mishra, T., Masih, H., Bar, A., Pandey, D. K., Jha, N. K., Majumder, M., Das, N., Gadekar, V. S., Shekhawat, M. S., Kumar, M., Radha, Proćków, J., Lastra, J. M. P., & Dey, A. 2022. Betelvine (*Piper betle* L.): A comprehensive insight into its ethnopharmacology, phytochemistry, and pharmacological, biomedical and therapeutic attributes. *Journal of Cellular and Molecular Medicine* 26(11): 3083–3119.

Boate, U.R. & Abalis, O.R. 2020. Review on the bio-insecticidal properties of some plant secondary metabolites: types, formulations, modes of action, advantages and limitations. *Asian Journal of Research in Zoology* 3(4): 27-60.

Brito, F.C. & Joshi, R.C. 2016. The golden apple snail *Pomacea canaliculata*: a review on invasion, dispersion and control. *Outlooks on Pest Management* 27(4): 157-163.

Centre for Agriculture and Bioscience International (CABI). 2022. *Piper sarmentosum*. CABI Compendium. https://doi.org/10.1079/cabicompendium.119782 [14 April 2024].

Choden, S., Yangchen, U. & Tenzin, J. 2020). Evaluation on Efficacy of *Piper nigrum* as a bio-pesticide against *Sitophilus zeamais*. *Naresuan University Journal: Science and Technology* 29(2): 84-95.

Daud, D., Setiawan, H. & Budin, K. 2023. Anti-feedant and molluscicidal activities of selected spices against *Achatina fulica* (Gastropoda: Achatinidae). *Journal of Science and Mathematics* 11(2): 66-73.

Drissi, B., Mahdi, I., Yassir, M., Ben Bakrim, W., Bouissane, L. & Sobeh, M. 2022. Cubeb (*Piper cubeba* L.f.): A comprehensive review of its botany, phytochemistry, traditional uses, and pharmacological properties. *Frontiers in nutrition* 9: 1048520.

Dyer, L.A., Dodson, C.D., Stireman, J.O., Tobler, M.A., Smilanich, A.M., Fincher, R.M. & Letourneau, D.K. 2003. Synergistic effects of three piper amides on generalist and specialist herbivores. *Journal of Chemical Ecology* 29(11): 2499–2514.

Emira, I.A.A., Rahim, N.A.A., Raduan, S.Z. & Safii, R. 2021. A preliminary study on larvicidal efficacy of *Piper nigrum* L. (Piperaceae) extracts against dengue vector, *Aedes albopictus* (Diptera: Culicidae). *Serangga* 26(1): 80-94.

Fazolin, M., Monteiro, A., Bizzo, H., Gama, P., Viana, L. & Lima, M. 2022. Insecticidal activity of *Piper aduncum* oil: variation in dillapiole content and chemical and toxicological stability during storage. *Acta Amazonica* 52: 179-188.

Fazolin, M., Estrela, J.L.V., Yamaguchi, K.K.L., Pieri, F.A. & Veiga-Junior, V.F. 2014. Amazon piperaceae with potential insecticide use. *Medicinal Plants: Phytochemistry, Pharmacology and Therapeutics* 3: 423-440.

Goswami, A. & Malviya, N. 2020. Reassessing the restorative prospectives of the king of spices black pepper. *Journal of Drug Delivery and Therapeutics* 10: 312-321.

Gurley, B.J. 2012. Pharmacokinetic herb-drug interactions (part 1): Origins, mechanisms, and the impact of botanical dietary supplements. *Planta Medica* 78(13): 1478–1489.

Halimatunsadiah, A.B., Norida, M., Omar, D. & Kamarulzaman, N.H. 2016. Application of pesticide in pest management: The case of lowland vegetable growers. *International Food Research Journal* 23(1): 85-94.

Han, Q., Wu, N., Li, H.L., Zhang, J.Y., Li, X., Deng, M.F., Zhu, K., Wang, J.E., Duan, H.X. & Yang, Q. 2021. A piperine-based scaffold as a novel starting point to develop inhibitors against the potent molecular target of ChtI. *Journal of Agricultural and Food Chemistry* 69(27): 7534–7544.

Hematpoor, A., Liew, S., Azirun, M. & Awang, K. 2017. Insecticidal activity and the mechanism of action of three phenylpropanoids isolated from the roots of *Piper sarmentosum* Roxb. *Scientific Reports* 7: 12576.

Kachhawa, D. 2017. Microorganisms as a biopesticides. *Journal of Entomology and Zoology Studies* 3: 468-473.

Kemabonta, K.A., Adediran, O.I. & Ajelara, K.O. 2018. The insecticidal efficacy of the extracts of *Piper nigrum* (Black Pepper) and *Curcuma longa* (Turmeric) in the control of *Anopheles gambiae* Giles (Dip., Culicidae). *Jordan Journal of Biological Sciences* 11(2): 195 – 200.

Khursheed, A., Rather, M.A., Jain, V., Wani, A.R., Rasool, S., Nazir, R., Malik, N.A. & Majid, S.A. 2022. Plant based natural products as potential ecofriendly and safer biopesticides: A comprehensive overview of their advantages over conventional pesticides, limitations and regulatory aspects. *Microbial Pathogenesis* 173: 105854.

Kim, Y.J., Deok, J., Kim, S., Yoon, D.H., Sung, G.H., Aravinthan, A., Lee, S., Lee, M.N., Hong, S., Kim, J.H., Son, Y.J. & Cho, J.Y. 2017. Anti-inflammatory effect of *Piper attenuatum* methanol extract in LPS-Stimulated Inflammatory Responses. *Evidence-based complementary and alternative medicine: 4606459*.

Kuete, V., Sandjo, L. P., Wiench, B. & Efferth, T. 2013. Cytotoxicity and modes of action of four Cameroonian dietary spices ethno-medically used to treat cancers: *Echinops giganteus, Xylopia aethiopica, Imperata cylindrica* and *Piper capense*. *Journal of Ethnopharmacology* 149(1): 245–253.

Kumar, S. & Singh, A. 2015. Biopesticides: present status and the future prospects. *Journal of Fertilizers & Pesticides* 2: 1-2.

Kumrungsee, N., Dunkhunthod, B., Manoruang, W., Koul, O., Pluempanupat, W., Kainoh, Y., Yooboon, T., Piyasaengthong, N., Bullangpoti, V. & Nosathian, S. 2022. Synergistic interaction of thymol with *Piper ribesioides* (Piperales: Piperaceae) extracts and isolated active compounds for enhanced insecticidal activity against *Spodoptera exigua* (Lepidoptera: Noctuidae). *Chemical and Biological Technologies in Agriculture* 9(38): 1-11.

Lengai, G. & Muthomi, J. 2018. Biopesticides and their role in sustainable agricultural production. *Journal of Bioscience and Medicines* 6: 7-41.

Milenković, A.N. & Stanojević, L.P. 2021. Black pepper - chemical composition and biological activities. *Advanced Technologies* 10(2): 40-50.

Morais, V.P., Cabral, F.V., Fernandes, C.C. & Miranda, M.L.D. 2023. Brief review on *Piper aduncum* L., its bioactive metabolites and its potential to develop bioproducts. *Brazilian Archives of Biology and Technology* 66: e23220314.

Narayanswamy, B. 2013. *Piper auritum*. CABI Compendium. https://doi.org/10.1079/cabicompendium.41359 [19 April 2024]

Navickiene, H.M.D., Miranda, J.E., Bortoli, S.A., Kato, M.J., Bolzani, V.S. & Furlan, M. 2007. Toxicity of extracts and isobutyl amides from *Piper tuberculatum*: Potent compounds with potential for the control of the velvetbean caterpillar, *Anticarsia gemmatalis*. *Pesticide Management Science* 63: 399-403.

Nawi, A.A., Shah Ruddin, N.I. & Zainudin, M.H.M. 2021. The effect of garlic, black pepper, and clove as natural insecticide toward ants. *Multidisciplinary Applied Research and Innovation* 2(1): 145-149.

Nayaka, N.M.D.M.W., Sasadara, M.M.V., Sanjaya, D.A., Yuda, P.E.S.K., Dewi, N.L.K.A.A., Cahyaningsih, E. & Hartati, R. 2021. *Piper betle* (L): Recent review of antibacterial and antifungal properties, safety profiles, and commercial applications. *Molecules* 26(8): 2321.

Nugroho, L.H., Lexinta, E.C., Priyono, Y. & Susandarini, R. 2020. Short Communication: Composition of terpenoid compounds in essential oils extracted from stems of eight Piper species and their role in taxonomic relationships. *Biodiversitas* 21(8): 3438-3443.

Oliveira, R.V., Sousa, A.H.de., Tamwing, G. da S., Mota, B.B. & Silva, M.C. 2023. Toxicity and synergism of the essential oil of *Piper aduncum* L. in populations of *Sitophilus zeamais* (Coleoptera: Curculionidae)1. *Pesquisa Agropecuária Tropical* 53: e76287.

Othman, A.N., Zainudin, N.F.S., Zaidan, U.H. & Shamsi, S. 2021. A comparative study on the larvicidal effects of *Piper sarmentosum* (Kaduk) leaves extracts against *Aedes aegypti*. *Pertanika Journal of Science & Technology* 29(4): 2811 – 2827.

Oyemitan, I.A. 2017. African medicinal spices of genus Piper. *Medicinal Spices and Vegetables from Africa: Therapeutic Potential Against Metabolic, Inflammatory, Infectious and Systemic Diseases*: 581-597.

Pandey, D.K. 2008. *Piper longum*: A concise review on botany, phytochemistry and pharmacology. *Journal of Emerging Technologies and Innovative Research* 5(12): 711-717.

Prabhakaran, G., Bhore, S.J. & Ravichandran, M. 2017. Development and evaluation of poly herbal molluscicidal extracts for control of apple snail (*Pomacea maculata*). *Agriculture* 7(3): 22.

Prabhu, K., Sudharsan, P., Ganesh Kumar, P., Chitra, B. & Janani, C. 2022. Impact of *Piper betle* L. bioactive compounds in larvicidal activity against *Culex quinquefasciatus*. *Journal of Natural Pesticide Research* 2*:* 100013.

Qin, W., Huang, S., Li, C., Chen, S. & Peng, Z. 2010. Biological activity of the essential oil from the leaves of *Piper sarmentosum* Roxb. (Piperaceae) and its chemical constituents on *Brontispa longissima* (Gestro) (Coleoptera: Hispidae), *Pesticide Biochemistry and Physiology* 96(3):132-139.

Radwan, M.A. & Gad, A.F. 2021. Essential oils and their components as promising approach for gastropod mollusc control: a review. J*ournal of Plant Diseases and Protection* 128:923–949.

Rahman, S.F.S.A., Sijam, K. & Omar, D. 2016. *Piper sarmentosum* Roxb.: A Mini Review of Ethnobotany, Phytochemistry and Pharmacology. *Journal of Analytical & Pharmaceutical Research* 2(5): 00031.

Ridzuan, P.M., Sathiya, S.V., Draman, S., Maizatu-Syamemy, M.N., Masharudin, A.W., Amilin, A.N., Farihah, S.N., Aisyah, B. & Faiza, N. 2021. The effect of non-polar solvent extraction of *Piper ribesioides* (sireh hutan) on *Candida albicans* morphology. *Asian Journal of Medicine and Health Sciences* 4(2): 37-46.

Rohimatun., Aisyah, M.D.N., Pupasari, L.T. & Rusmin. D. 2023. Toxicity and chemical compounds of Piper aduncum fruit extract against storage pest Sitophilus oryzae and Callosobruchus maculatus. *IOP Conference Series: Earth and Environmental Science:* 1253: 012001.

Salehi, B., Zakaria, Z.A., Gyawali, R., Ibrahim, S.A., Rajkovic, J., Shinwari, Z.K., Khan, T., Sharifi-Rad, J., Ozleyen, A., Turkdonmez, E., Valussi, M., Tumer, T.B., Monzote Fidalgo, L., Martorell, M. & Setzer, W.N. 2019. Piper species: A comprehensive review on their phytochemistry, biological activities and applications. *Molecules* 24(7): 1364.

Samuel, M., Oliver, S.V., Coetzee, M. & Brooke, B.D. 2016. The larvicidal effects of black pepper (*Piper nigrum* L.) and piperine against insecticide resistant and susceptible strains of *Anopheles malaria* vector mosquitoes. *Parasit Vector* 9: 238.

Scott, I.M., Jensen, H.R., Philogène, B.J.R. & Arnason, J.T. 2008. A review of *Piper* spp. (Piperaceae) phytochemistry, insecticidal activity and mode of action. *Phytochemistry Reviews* 7: 65-75.

Scott, I.M., Jensen, H., Philogène, B. & Arnason, J.T. 2007. A review of Piper spp. (Piperaceae) phytochemistry, insecticidal activity and mode of action. *Phytochemistry Reviews* 7: 65-75.

Scott, I.M., Jensen, H., Nicol, R., Lesage, L., Bradbury, R., Sanchez-Vind, P., Poveda, L., Arnason, J.T. & Philogene, B.J.R. 2004. Efficacy of Piper (Piperaceae) extracts for control of common home and garden insect pests. *Journal of Economic Entomology* 97(4): 1390-1403.

Shango, A.J., Majubwa, R.O. & Maerere, A.P. 2021. Morphological characterization and yield of pepper (*Piper nigrum* L.) types grown in Morogoro District, Tanzania. *CABI Agriculture and Bioscience* 2: 6.

Shattuck, A., Werner, M., Mempel, F., Dunivin, Z. & Galt, R. 2023. Global pesticide use and trade database (GloPUT): New estimates show pesticide use trends in low-income countries substantially underestimated. *Global Environmental Change* 81*:* 102693.

Siddharta, A. 2024. Volume of pesticides used in Malaysia from 2012 to 2021. Statista. https://www.statista.com/statistics/1101033/malaysia-pesticide-use-volume/#statisticContainer [23 March 2024].

Sleem, F.M. 2021. Insecticidal effect of *Piper nigrum* L. (Pipeaceae) and *Prunus cerasus* L. (Rosaceae) seeds extract against *Rhyzopertha dominica* F. (Coleoptera: Bostrichidae). *International Journal of Agriculture Innovations and Research* 9(3): 2319-1473.

Srivastava, P., Kumar, P., Singh, V.K. & Singh, D.K. 2009. Molluscicidal activity of *Piper nigrum* (Black) against the snail *Lymnaea acuminata* and *Indoplanorbis exustus* in the control of fascioliasis. *Journal of Herbal Medicine and Toxicology* 3(1); 81-86.

Srivastava, A.K. & Singh, V.K. 2017. Biological action of Piper nigrum - the king of spices. *European Journal of Biological Research* 7(3): 223-233.

Srivastava, A.K & Kumar, P. 2021. *Nutraceuticals in anxiety and stress*. *Nutraceuticals*: 63-72.

Subaharan, K., Senthoorraja, R., Manjunath, S., Thimmegowda, G.G., Pragadheesh, V.S., Bakthavatsalam, N., Mohan, M.G., Senthil-Nathan, S., David, K.J., Basavarajappa, S. & Ballal, C. 2021. Toxicity, behavioural and biochemical effect of *Piper betle* L. essential oil and its constituents against housefly, *Musca domestica* L. *Pesticide Biochemistry and Physiology* 174: 104804.

Sun, X., Chen, W., Dai, W., Xin, H., Rahmand, K., Wang, Y., Zhang, J., Zhang, S., Xu, L. & Han, T. 2020. *Piper sarmentosum* Roxb.: A review on its botany, traditional uses, phytochemistry, and pharmacological activities. *Journal of Ehnopharmacology* 263*:* 112897.

Sequeda-Castañeda, L.G. & Gutierrez, S.J. 2015. *Piper marginatum* Jacq. (piperaceae): phytochemical, therapeutic, botanical insecticidal and phytosanitary uses. *Pharmacologyonline* 3(1): 136-145.

Tagrida, M. & Benjakul, S. 2021. Betel (*Piper betle* L.) leaf ethanolic extracts dechlorophyllized using different methods: antioxidant and antibacterial activities, and application for shelf-life extension of Nile tilapia (*Oreochromis niloticus*) fillets. *Royal Society of Chemistry Advances* 11: 17630-17641.

Tamokou, J., Mbaveng, A. & Kuete, V. 2017. Antimicrobial Activities of African Medicinal Spices and Vegetables. *Medicinal Spices and Vegetables from Africa: Therapeutic Potential Against Metabolic, Inflammatory, Infectious and Systemic Diseases*: 207-237.

Wan Salleh, W.M.N.H., Farediah, A. & Khong, H.Y. 2014. Chemical composition of *Piper stylosum* Miq. and *Piper ribesioides* Wall. essential oils and their antioxidant, antimicrobial and tyrosinase inhibition activities. *Boletin Latinoamericano y del Caribe de Plantas Medicinales y Aromaticas* 13: 488-497.

Weluwanarak, T., Changbunjong, T., Leesombun, A., Boonmasawai, S. & Sungpradit, S. 2023. Effects of *Piper nigrum* L. fruit essential oil toxicity against stable fly (Diptera: Muscidae). *Plants* 12(5): 1043.

Xiang, C.P., Shi, Y.N., Liu, F.F., Li, H.Z., Zhang, Y.J., Yang, C.R. & Xu, M. 2016. A survey of the chemical compounds of Piper spp. (Piperaceae) and their biological activities. *Natural Product Communications* 11(9): 1403–1408.

Xu, Z. & Deng, M. 2017. P*iperaceae. In Identification and Control of Common Weeds: Volume 2.* Dordrecht: Springer, Dordrecht.

Yushananta, P. & Ahyanti, M. 2021. The effectiveness of beetle leaf (*Piper betle* L.) extract as a bio-pesticide for controlled of houseflies (*Musca domestica* L.). *Open Access Macedonian Journal of Medical Sciences* 9(E): 895–900.