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CLERODENDRUM SPP AS POTENTIAL SOURCE OF BOTANICAL PEST MANAGEMENT- A CRITICAL REVIEW

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ABSTRACT:
The extensive use of synthetic pesticides in agriculture has led to unchanged biological effects such as resistance development, non-target toxicity, decreased bioefficacy, environmental contamination and a serious risk to global health. In the realm of pest management, botanical extracts possess active compounds with adverse effects against a wide range of pest species providing ecological and functional benefits over synthetic insecticides. The genus *Clerodendrum* (Family: Lamiaceae) used in traditional medicine has drawn attention for its phytochemicals with insecticidal properties. With multiple effects encompassing antifeedant, larvicidal, ovicidal, repellent, fumigant, inhibitor and growth disruptor, has the potential to be the finest biopesticide. Through a comprehensive analysis of available literatures, this review summarizes the phytochemical diversity of the genus, focusing on clerodane diterpenoids, triterpenoids, flavonoids, phenylethanoid glycosides, steroids, and cyanogenic glycosides. It also evaluates their insecticidal activity against various insect pests and discusses modes of action pertinent to sustainable pest management. Furthermore, by integrating botanical description, phytochemistry, bio-efficacy, mode of action and nanotechnological implications in *Clerodendrum* genus flexible and promising foundation for the next-generation, eco-friendly insect control.

KEYWORDS: *Clerodendrum*, Insecticidal activity, Ecofriendly pest management

Abbreviations
cm - Centimeters m - meters
ω - omega
EO - Essential Oil
LC_{50} - Median Lethal Concentration, GI50 - Growth inhibition
EI_{50} - Emergence Inhibition, w/w - weight by weight,
LD_{99} - Lethal Dose
µg – microgram, µg/L - Microgram per liter
mg/cm2 - Milligrams Per Square Centimeter,
ppm - Parts per million, mg - Milligram
% - Percent or percentage, mg/ml - Milligrams per milliliter
µg/cm2 - Microgram per square centimeter, mg/L - Milligrams per Liter
nL/cm2 - Nanolitres per square centimeter, µg/g - Microgram per gram.
g/filter paper - Grams per filter paper
µg/64 mm2 - Micrograms per sixty-four square millimeters
µg/mL - Microgram per millilitre
µgcm-3 - Micrograms per cubic centimeter, mg mL−1 - Milligrams per milliliter
mg/g - Milligrams per gram, µM - Micromolar
g/ml - Grams per milliliter
µg/mosquito - Micrograms per mosquito, µg/Larvae - Micrograms per larva
µg/µL - Micrograms per microlitre
ALT - Alanine transaminase
AST - Aspartate transaminase
ALP - Alkaline phosphatase

INTRODUCTION

Arthropod pests are responsible for an estimated 18-20% reduction in global annual crop production, leading to economic losses of more than US$470 billion (Sharma *et al.* 2017). Currently, insect pests alone account for about 38% of total agricultural losses (Junaid and Gokce 2024). In certain situations, insect damage resulted in severe yield losses and even complete crop failure (Grzywacz *et al*. 2014). In India, pests infest around 25% of food grains annually (Singh *et al*. 2021), contributing approximately 6% to the country's total food grain wastage (Jha *et al*. 2015). Global agricultural pesticide usage has reached 3.73 million tonnes (MT) of active ingredients, a 14% increase over the past decade, highlighting the rising dependence on pesticides and the associated risks of severe health hazards (FAO 2023). Continuous application of synthetic chemical pesticides also leads to insect resistance, environmental contamination, pesticide residues in food, and increased application costs. Prolonged reliance on and excessive application of chemical pesticides also posed environmental safety risks to natural enemies (Silva *et al*. 2002). Several studies have demonstrated the insecticidal properties of different botanical extracts and have confirmed their safety to non-target organisms. In ancient China, Egypt, Greece and India, the use of botanicals for pest management has a long history, dating back to more than two millennia (Isman 2006). Traditional botanical-based pest management is still widely practiced by substantial and transitional agricultural groups (Gerken *et al*. 2001). Botanicals are generally applied as formulations, using whole or ground plant materials to manage pests on stored products or field crops.

As safer alternatives to synthetic insecticides, botanical pesticides such as neem (*Azadirachta indica*) and notchi (*Vitex negundo)* have gained considerable attention because of their safety to non-target organisms and public health. Although many botanical pesticides are widely used in agriculture, several plant species with pesticidal properties remain poorly explored and underutilized. *Clerodendrum* spp. represent one such promising group of plants with immense insecticidal potential and could emerge as effective botanical insecticides comparable to neem and notchi, further investigation and exploitation for sustainable pest management. As a genus in ornamental and landscaping, *Clerodendrum* is also grown as shrubs, woody vines, perennial herbs, and small trees. The name *Clerodendrum* is derived from two Greek words: kleros, meaning "chance" or "destiny," and dendron, meaning "tree" (Rueda 1993). The genus *Clerodendrum* comprises several species and is widely known for its insecticidal properties (Muthu *et al*. 2013).

Historically, *Clerodendrum* species are recognized for their folk and traditional properties across diverse regions, including Africa, China, Japan, Korea, India and Thailand to treat a broad spectrum of ailments such as anorexia, asthma, arthrophlogosis, colds, dysentery, furunculosis, hypertension, hyperpyrexia, leucoderma, leprosy, mammitis, rheumatism, toothache and other inflammatory conditions (Chethana *et al*. 2013). The greatest diversity of *Clerodendrum* occurs in India and China, which harbor approximately 23 and 40 species, respectively (Deori *et al*. 2013). *Clerodendrum inerme* (Linnaeus) is an extensively branched shrub attaining a length of 0.9 - 2.1 m, commonly found in wastelands, hedges, riverbanks, seashores and other tropical habitats of India (Kirtikar and Basu 1918). *Clerodendrum* inerme is known to be a reservoir of several major chemical constituents, including α- and β-amyrins, β-sitosterol, betulin, clerodermic acid, dehydroroyleanone, neo-clerodane diterpenoids and royleanone (Chatterjee and Pakrashi 1991). This review highlights potential of the *Clerodendrum* genus for crop pest management, focusing on its chemical constituents and insecticidal properties, responsible for it's therapeutic properties. They do have insecticidal properties too as an effective biorational pest management tool.

Distribution of *Clerodendrum*

Globally, the genus comprises 701 recorded species, of which only 327 are currently recognized as accepted taxa (Plants of the World Online 2025), with the greatest diversity in tropical Africa and Southern and South-Eastern Asia and limited occurrence in the Americas (Wang *et al*. 2018). *C. inerme* is a widely distributed tropical species mainly found in India, Sri Lanka, Nepal, Bangladesh, Southeast Asia and the Mediterranean region (Rabiul *et al*. 2011), while *Clerodendrum* trichotomum is distributed across India, Japan, Korea, and China (Das *et al*. 2014).

Botanical description of *Clerodendrum* Leaves are simple and arranged in a decussate-opposite, ternate, or apically clustered pattern, exhibiting variation in size. Leaf morphology varies among species, being lanceolate in *C. wallichii*, elliptical in *C. aculeatum* and ovate in *C. japonicum*. Inflorescences are found in both axillary and terminal positions, with lengths ranging from 1 to 39 cm and widths from 1 to 25 cm, and are cymose, solitary, or paniculate. They can be either determinate or centrifugal, with flowers arranged densely or sparsely. *Clerodendrum* species possess foliaceous bracts and linear to lanceolate bracteoles (Rueda 1993). The wood is yellowish or whitish with moderate luster and a fine texture. The wood contains scanty paratracheal parenchyma and the fibers are partly septate with numerous medium sized pits (Record and Hess 1941).

The stamens are four, didynamous and positioned at the same level on the corolla tube. The pollen grains are spheroidal and have echinate projections on the tectum (Rueda 1993). The pollen of *C. inerme* is spheroidal with a spinuliferous surface and reticulate interspinular areas (Rao and Tian 1974). The pollen grains are binucleate and occasionally trinucleate and are most commonly triaperturate (Cronquist 1981). The ovary is superior, bicarpellary, four-loculed and glabrous, with each locule containing a single pendulous, laterally attached, hemianatropous ovule. The style is elongated and apically bifid (Rueda 1993).

Ecological Significance of *Clerodendrum*

Pollination and seed dispersal

In *Clerodendrum* species, pollination is primarily mediated by butterflies, moths, and bees, which collect nectar from the base of the corolla tube. In most species, the stamens and style extend from the base of a horizontally oriented flower, resulting in pollen transfer to visiting insects (Rueda 1993). Flowers of *C. aculeatum* remain open for more than one day, during which the stamens initially extend outward and later curve backward beneath the flower, exposing the style (Corner 1952). However, in species such as *C. serratum,* the stamens and style arch over the top of the flower and one petal is altered into a lower lip that acts as the landing platform for pollinators, allowing pollen to transfer to the insect's body surface. The fruits of the genus *Clerodendrum* are pulpy, often brightly colored, and are dispersed by birds by endozoochory (Ridley 1930; Moldenke 1985).

Mutual Interaction with Insects

The association between *Clerodendrum* species and ants has been reported in several studies. Beccari (1884) reported that the *C. fistulosum* had internodes inhabited by *Camponotus clerodendri.* Dreisig (1988) recorded ant species such as *Wasmannia auropunctata, Camponotus floridanus* and *Conomyrma sp*. visiting the inflorescences of *C. speciosissimum* o feed on the nectar secreted by the bracts, suggesting a potential protective role of ants in deterring herbivores and each inflorescence was typically occupied by a single ant species. *Clerodendrum* species possess extrafloral nectaries, a characteristic commonly linked to ant-plant defensive mutualisms, in which nectar secretion attracts ants that help protect the plant from herbivory (Elias 1983).

Chemical constituents of *Clerodendrum*

The genus *Clerodendrum* exhibits remarkable phytochemical diversity, with fatty acids, phenylethanoid glycosides, flavonoids, terpenoids, sterols, and volatile aromatic compounds representing the dominant classes of metabolites. Among these, verbascoside and its derivatives (isoverbascoside, acteoside, martynoside, leucosceptoside A) are the most characteristic and widely distributed bioactive compounds across several species, contributing significantly to antioxidant, insecticidal and defensive properties. Fatty acids such as linoleic, palmitic, oleic, linolenic, and stearic acids are abundant in species such as *C. splendens*, *C. speciosum*, and *C. inerme,* indicating their importance for membrane integrity and insect deterrence. Terpenoid constituents, including ferruginol, β-caryophyllene, β-pinene, nerolidol, clerodinin A, lupeol and squalene, represent another major chemical group associated with insecticidal, antifeedant and antimicrobial activities. Additionally, volatile aromatic compounds such as benzaldehyde, linalool, benzyl acetate and methyl salicylate impart characteristic fragrances present in different plant parts possess multifarious chemical components as shown in Table1.

Table 1. Major Chemical Constituents in *Clerodendrum* Species

Species	Plant Part	Major Chemical Constituents	Chemical Class	Reference
Clerodendrum inerme	Leaves	Tetradecane, Pentadecane, Tetradecanoic acid, Hexanoic acid, Tridecanoic acid, Kaempferol, Tannic acid, Dodecanoic acid ethyl ester, Gallic acid	Hydrocarbons, Fatty acids, Flavonoids, Phenolics	Kalavathi (2022)
	Leaves	1,2-Benzenedicarboxylic acid, 9-Octadecenoic acid (Z)-ethyl ester, 9,12-Octadecadienoic acid ethyl ester, n-Hexadecanoic acid, Dodecanoic acid, Eicosane, Nonadecane, Oleic acid, Hexadecane, Heptacosane, Tetradecanoic acid	Fatty acids, Esters, Hydrocarbons	Anandhi & Ushadevi (2013)
	Leaf, Twig, Root	Esters (28.59-69.76%), Fatty acids (19.27-41.85%), ferruginol	Esters, Fatty acids, Meroterpenes	Li *et al*. (2012)
Clerodendrum phlomidis	Leaves	Fatty acids, esters and hydrocarbons	'atty acids, Esters, Hydrocarbons	Balaji & Kilimozhi (2014)
Clerodendrum chinense	Leaves	Cornoside, Decaffeoylverbascoside, Hispidulin, Isoverbascoside, Icariside B5, Lupeol, Verbascoside, Rengyolone	Phenylethanoid glycosides, Flavonoids, Triterpenes	Wahba *et al*. (2011)
Clerodendrum speciosum	Leaves	Linoleic acid (30.64%), Verbascoside, Isoverbascoside, Scroside B, Calceolarioside C, Rhamnazin-O-rutinoside, Tiliroside, Rosmarinic acid, Quinic acid	Fatty acids, Phenylpropanoid glycosides, Flavonoids, Phenolic acids	Elhady *et al*. (2025)
Clerodendrum splendens	Leaves	Linoleic acid (41.65%), Palmitic acid (29.33%), Linolenic acid (16.96%), Oleic acid (5.03%), Stearic acid (3.65%), Capric acid	Polyunsaturated fatty acids	Rachael *et al*. (2016)

Clerodendrum viscosum	Whole plant	Clerodinin A (4.10 mg/g), Lupeol (1.10 mg/g)	Diterpenoids, Triterpenoids	Srivastava *et al*. (2019)
Clerodendrum multiflorum	Whole plant	Sterol derivatives	Sterols	
Clerodendrum serratum	Roots	Squalene, Methyl palmitate, Hexadecenoic acid, Stigmasterol	Triterpenes, Fatty acids, Sterols	Reddy *et al*. (2021)
Clerodendrum buchholzii	Leaves	Benzaldehyde (96%), Octen-3-ol (0.9%)	Aromatic compounds,Alcohols	Nyegue *et al*. (2007)
Clerodendrum capitatum	Essential oil	Octen-3-ol (39%)	Alcohols	Ogundajo *et al*. (2016)
Clerodendrum infortunatum	Essential oil/Leaves	Fatty acids (60%), Verbascoside, Acteoside, Isoacteoside, Martynoside, Leucosceptoside A, Apigenin 7-O-glucuronide, Acacetin 7-O-glucuronide	Fatty acids, Phenylethanoid glycosides, Flavonoids	Khound *et al*. (2023); Uddin *et al*. (2020)
Clerodendrum polycephalum	Leaves (Essential oil)	β-Caryophyllene (28.9%), α-Muurolene (9.0%), β-Pinene (8.6%), (E)-Nerolidol (5.5%)	Sesquiterpenes, Monoterpenes	Wong & Tan (2005)
Clerodendrum fragrans	Flowers	Linalool (33.4%), Benzyl acetate (20.0%), Benzyl benzoate (7.3%), Methyl salicylate (4.2%)	Monoterpenes, Aromatic esters	Ogundajo *et al*. (2016)

Insecticidal properties of phytochemicals of *Clerodendrum* species

The genus *Clerodendrum* contains a wide range of phytochemicals that possess notable insecticidal properties such as prunasin, a cyanogenic glycoside reported exclusively from *C. grayi* (Miller *et al*. 2006), and 8-O-acetylharpagide, a monoterpene derivative unique to *C. thomsonae* Jacke and Rimpler (1983), both exhibit insecticidal activity against aphids and Drosophila. *C. inerme* is particularly rich in bioactive metabolites, including acacetin, verbascoside, apigenin, betulinic acid, cynaroside, friedelin, lupeol, glutinol, stigmasterol, pectolinarigenin, salvigenin, β-sitosterol, uncinatone, clerodin, and epicaryoptin, clerodendrin A, B, C, α- amyrin, β-amyrin, representing major classes such as flavonoids, triterpenoids, phenylethanoid glycosides, steroids, and diterpenoids (Krishna Kumari *et al*. 2003; Al-Snafi 2016). Other species also possess diverse compounds of ecological and pesticidal significance. *C. bungei* contains verbascoside and β-sitosterol (Liu *et al*., 2014), while *C. villosum* similarly accumulates verbascoside (Somwong *et al*. 2015) and in some reports, betulinic acid, lupeol, and β-sitosterol. *C. trichotomum* exhibits an extensive chemical profile, including aloe-emodin, clerodin (Diterpenoids), emodin, betulinic acid, clerodendrin A, B, D, H and I, friedelin, lupeol, sitosterol, stigmasterol, rengyolone, taraxerol, and uncinatone (Munakata 1975; Krishna Kumari *et al*. 2003; Nishida *et al*. 2004). *Clerodendrum serratum* contains luteolin, bis (2-ethylhexyl) phthalate, stigmasterol, oleanolic acid, and α-spinasterol (Fan *et al*. 2008), whereas *C. thomsonae* is characterized by the presence of aucubin, Jacke and Rimpler (1983). Additional triterpenoids and diterpenoids occur across the genus, such as betulinic acid, coleon U, lupeol, lupeol acetate, and β-amyrin acetate in *C. canescens* (Dong *et al*. 1999); clerodin and 3-epicaryoptin in *C. paniculatum* (Krishna Kumari *et al*. 2003) and kaempferol in *C. fragrans* (Gao *et al*. 2003). *C. indicum* contains lupeol, stigmasterol, taraxerol, and pectolinarigenin (Somwong *et al*. 2015), while *C. bungei* also produces glochidone, rengyolone, taraxerol, α-amyrin, and uncinatone (Gao *et al*. 2003; Zhu *et al*. 2014; Liu *et al*. 2014). β-Sitosterol is the characteristic compound of *C. quadriloculare* (Macabeo *et al*. 2008), and C. japonicum synthesizes tricin and ursolic acid, Tian Jun and Sun HanDong (1995). *C. infortunatum* contains unique diterpenoids such as 15-methoxy-14,15-dihydroclerodin, 15-hydroxy-14,15-dihydroclerodin, and clerodin (Gholamreza *et al*. 2014). *C. phlomidis* is a source of pectolinarigenin (Muthu *et al*. 2015), and *C. siphonenthus* contains uncinatone (Pal *et al*. 1989). Together, these phytochemicals highlight the chemical diversity of the *Clerodendrum* genus and support its potential as a reservoir of insecticidal compounds. The major phytochemical constituents of different parts of *Clerodendrum inerme* are presented in Fig. 1, while compounds from the genus *Clerodendrum* are also reported in other plant species against insects belonging to major phytophagous orders are summarized in Table 2.

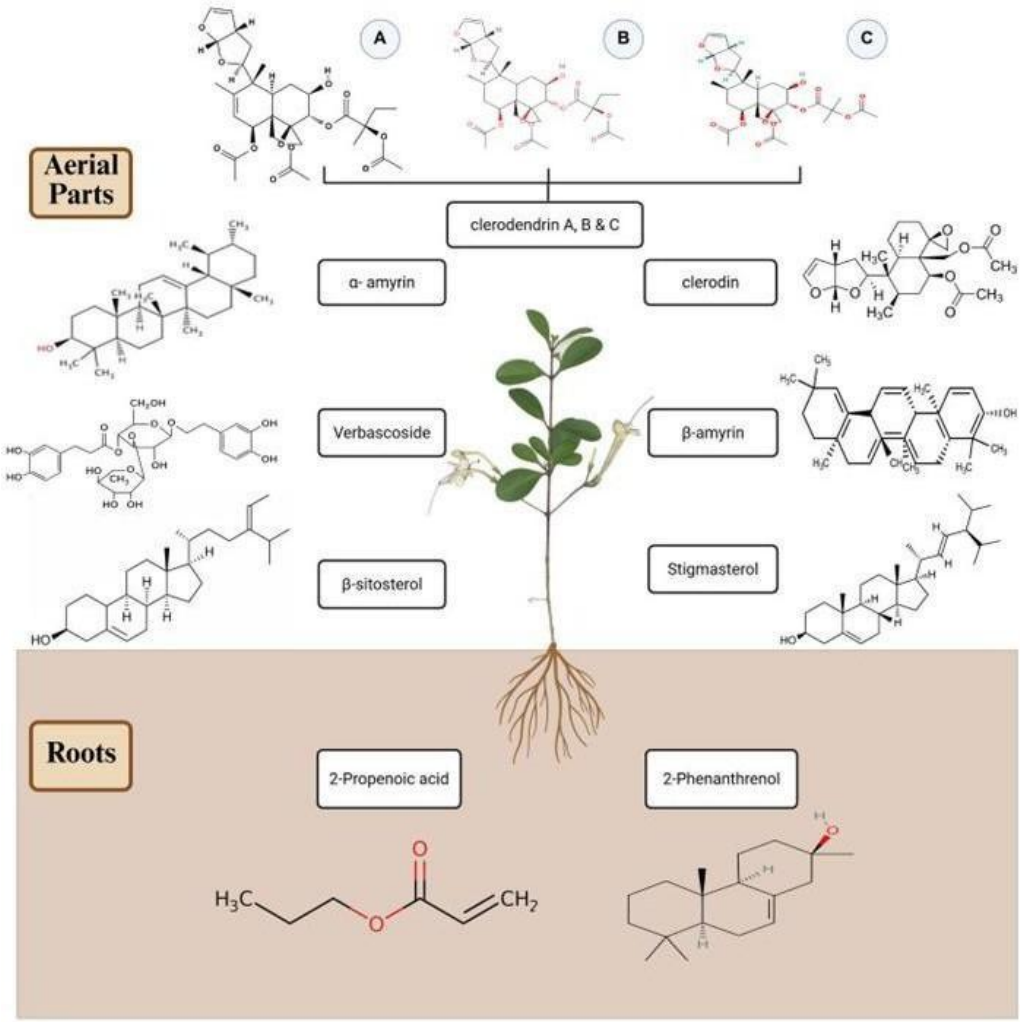
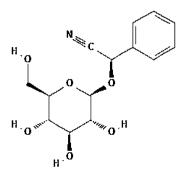
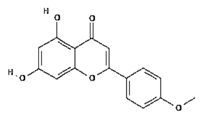
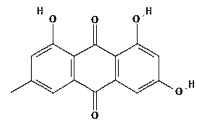
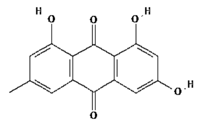
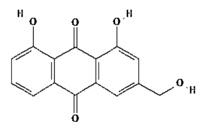
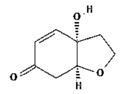
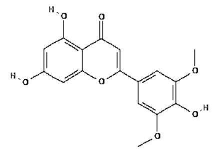
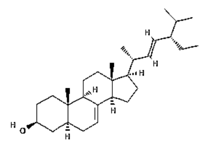
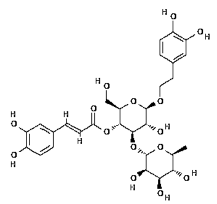
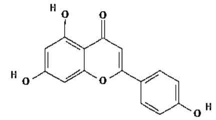
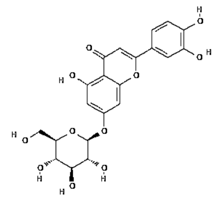
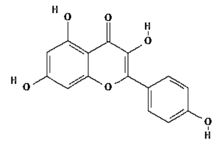
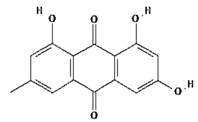
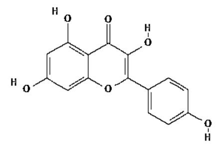


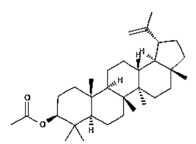
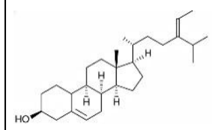
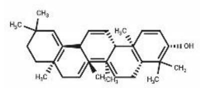
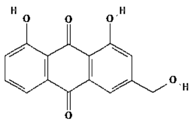
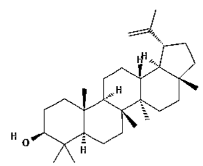
Fig.1 Major phytochemical constituents of different parts of *Clerodendrum* inerme

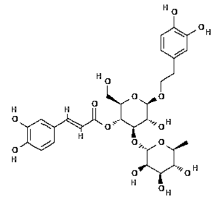
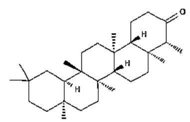
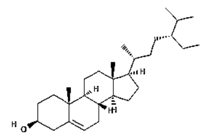
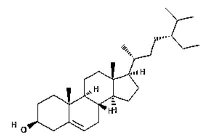
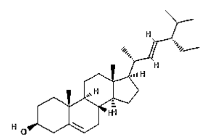
Table 2. Phytochemical of genus *Clerodendrum* with insecticidal activities present in other

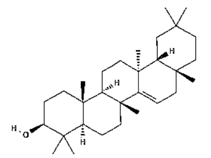
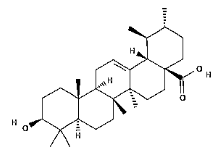
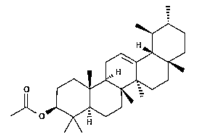
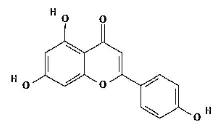
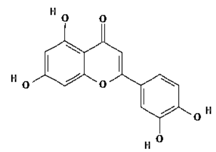
SI.NO	Name of the phytochemical	Source	Pest species	Mode of action	Effective dose	Chemical structure	References
HEMIPTERA							
1	Prunasin	Bird cherry *Prunu spadus,* Blackcherry *Prunus serotina*	Bird cherry-oat aphid, *Rhopalsosiphum padi*	Antifeedant	0.10%		Halarewicz and Gabrys (2012)
2	Acacetin	Violet Trumpet Vine, *Clytostoma callistegioides*		Feeding deterent	50 µg/cm²		Castillo *et al*. (2013)
3	Emodin	Black cassia*,* *Cassia nigricans*	White fly, *Bemesia tabaci*	Disruption of Midgut ephthelium	5.05 µg/mL		Georges *et al*. (2008)
4	Emodin	Chinese rhubarb, *Rheum palmatum*	Brown plant hopper, *Nilarparvata lugens*	Inhibition of Acetylcholinesterase (AChE)	84.30 µg/mL		Shang *et al*. (2019)

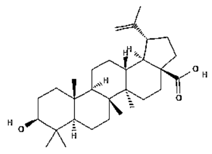
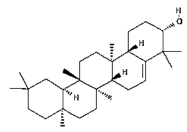
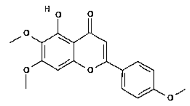
5	Aloe-emodin				127.30 µg/mL		
6	Rengyolone	Willow-leaved foxglove, *Digitalis obscura*	Green peach aphid, *Myzus persicae*	Antifeedant	17.6 µg/cm²		Quílez del Moral *et al*. (2021)
7	Tricin	Rice, *Oryza sativa*	Brown planthopper, *Nilaparvata lugens*		500 µg/ml		Bing *et al*. (2007)
8	Spinasterol	Bitter apple, *Citrullus Colocynthis*	Cabbage Aphid, *Brevicoryne brassicae*	Aphicidal	32.36 µg/mL		Ahmed *et al*. (2022)
			Green peach aphid, *Myzus persicae*		173.8 µg/mL (Greenhouse bioassay) & 180.9 µg/mL (Residual bioassay)		
LEPIDOPTERA							
9	Verbascoside	Pocketbook Plant, *Calceolaria talcana*	Fall armyworm, *Spodoptera frugiperda*	Antifeedant	50 µg/ml		Munoz *et al*. (2013)

<table>
<tr><td>10</td><td>Apigenin</td><td rowspan="3">White butterfly bush, Buddleja albiflora</td><td rowspan="2">Diamondback moth, Plutella xylostella</td><td rowspan="3">Antifeedant</td><td>0.967 mg/ mL</td><td></td><td rowspan="3">Zhang et al. (2017a)</td></tr>
<tr><td>11</td><td>Cynaroside (luteolin-7-O-β-glucoside)</td><td>0.073 mg/ mL</td><td></td></tr>
<tr><td>12</td><td>kaempferol</td><td rowspan="2">Oriental armyworm, Mythimna separata</td><td>1 mg/ mL</td><td></td></tr>
<tr><td>13</td><td>Emodin</td><td>Chinese rhubarb, Rheum palmatum</td><td>Inhibition of Acetylcholinesterase (AChE)</td><td>548.74 µg/mL</td><td></td><td>Shang et al. (2019)</td></tr>
<tr><td>14</td><td>Kaempferol</td><td>Castor bean plant, Ricinus communis</td><td>Fall armyworm, Spodoptera frugiperda</td><td>Prolongs larval and pupal duration</td><td>800 ppm</td><td></td><td>Rodriguez-Cervantes et al. (2024)</td></tr>
</table>

15	Lupeol acetate	Dioscorides fleaban, *Conyza dioscoridis*	Egyptian cotton leafworm, *Spodoptera littoralis*	Inhibition of Acetylcholinesterase (AChE)	0.50%		Matloub *et al.* (2021)
16	β-sitosterol	Yellow oleander, *Thevetia neriifolia*	Cotton bollworm, *Helicoverpa armigera*	Inhibition of Midgut Enzymes (ALT, AST, ALP)	10 µg/mL		Mishra *et al.* (2020)
17	β-amyrin	Somlata, *Sarcostemma acidum*	Tobacco cutworm, *Spodoptera litura*	Antifeedant	10 µg/cm^2		Kannan *et al.* (2013)
TROMBIDIFORMES							
18	Aloe-emodin	Chinese rhubarb, *Rheum palmatum* root extract	Two-spotted spider mite, *Tetranychus urticae*	Acaricidal	240 µg/mL		Jang and Kuk (2018)
		Indian aloe, *Aloe vera*	Carmine spider mite, *Tetranychus cinnabarinus*		0.484 mg/ mL		Zhang *et al.* (2017b)
			Citrus red mite, *Panonychus citri*		0.328 mg/mL		
19	Lupeol	British yellowhead, *Inula Britanica*	Carmine spider mite, *Tetranychus cinnabarinus*	Inhibition of Glutathione-S-transferase (GST)	2 mg/mL		Ma *et al.* (2012)
DIPTERA							

20	Verbascoside	Pocketbook Plant, *Calceolaria talcana*	Fruit fly, *Drosophila melanogaster*	Antifeedant	10 g/ml		Munoz *et al.* (2013)
21	Friedelin	Tangut cacalia, *Cacalia tangutica*	Housefly, *Musca domestica*	Stomach poison	129.27 µg/g		Huang *et al.* (2009)
22	β sitosterol	*Opposite-leaved nuxia, Nuxia oppositifolia*	Yellow fever mosquito, *Aedes aegypti*	Adulticidal	2.1 µg/mosquito		Al-Massarani *et al*. (2021)
		Bael, *Aegle marmelos*	Yellow fever mosquito, *Aedes aegypti*	Inhibition Sterol Carrier Protein-2 (SCP-2)	480.19 ppm		Angajala and Subashini (2018)
			Indian malaria mosquito, *Anopheles stephensi*		510.64 ppm		
			Southern house mosquito, *Culex quinquefasciatus*		450.19 ppm		
23	Stigmasterol	Siam weed, *Chromolaena odorata*	Southern house mosquito, *Culex quinquefasciatus*	Inhibition of Acetylcholinesterase (AChE)	70.84 µg/ml		Gade *et al*. (2017)

24	Taraxerol	Croton, *Codiaeum variegatum*			73.03 mg/L		Johnson and Singh (2020)
25	Ursolic acid	Periwinkle, *Catharanthus roseus*	Yellow fever mosquito, *Aedes aegypti*	Larvicidal	0.99 ppm		Kamatchi *et al.* (2023)
			Indian malaria mosquito, *Anopheles stephensi*		0.73 ppm		
			Southern house mosquito, *Culex quinquefasciatus*		1.27 ppm		
26	α-amyrin acetate		Indian malaria mosquito, *Anopheles stephensi*	Contact toxicity	1.60% (76.9% mortality)		Chenniappan and Kadarkari (2012)
				Prolongs the probing time	1.60%		
COLEOPTERA							
27	Apigenin	False flax, *Camelina sativa*	Crucifer flea beetle, *Phyllotreta cruciferae*	Feeding stimulant	0.10%		Onyilagha *et al.* (2012)
28	Luteolin			Feeding deterent	0.10%		

29	Betulinic Acid	Jujube, *Ziziphus jujuba*	Pulse beetle, *Callosobruchus chinensis*	Juvenile Hormone (JH) Mimic	2 to 10 µg/µL		Madhavi and Srinivas (2019)
30	Glutinol	Tower of jewels, *Echium wildpretii*	Colorado potato beetle, *Leptinotarsa decemlineata*	Antifeedant	0.2-10 µg/cm²		Gonzalez-Coloma *et al*. (2011)
31	Salvigenin	Sweet basil, *Ocimum basilicum*	Red palm weevil, *Rhynchophorus ferrugineus* adult	Inhibition of Acetylcholinesterase (AChE)	1143 µg/mL (Adult) 10.8 µg/Larvae		Darrag *et al*. (2024)
				Inhibiting midgut proteolytic enzymes	1189 µg/mL (Adult) 11.4 µg/Larvae		

Bio-efficacy of *Clerodendrum* against insects

The insecticidal potential of *C. capitatum* leaf powder against *Callosobruchus maculatus* and *Sitotroga zeamais* was due to mating disturbance (Adesina Mobolade *et al*. 2015). The insecticidal property of *C. inerme* has been reported against the larvae of *Corcyra cephalonica* (Chander and Ahmed 1986), and the diterpenoid compound Clerodendrin-A in C. inerme was insecticidal in function (Kato *et al*. 1973). Zahurul *et al*. (2010) reported that petroleum ether extract of *C. viscosum* against S. oryzae and *Rhyzopertha dominica* showed moderate toxicity to *T. castaneum,* whereas ethyl acetate and chloroform extracts showed moderate toxicity against *S. oryzae* but no toxic effect against *T. castaneum* and *R. dominica*. *C. inerme* had an LC_{50} of 1460 µg/cm² against *R. dominica* adults (Azim 2004). *C. viscosum* root, leaf and stem extracts, when tested against *Sitophilus oryzae*, showed the order of contact toxicity as ethyl alcohol > ethyl acetate > chloroform, with root > stem > leaf, and the root extract exhibited stronger repellency. *C. inerme* leaf extract produced 56.66% mortality against S. oryzae (Yankanchi and Gadache 2010). Ahmed *et al*. (1981) incorporated *C. inerme* leaf extract into the diet of house flies, resulting in reduced pupal weight and adult emergence. The hexane extract was also active against third-instar *Culex quinquefasciatus*, with an EI_{50} of 3.74 mg/L, approximately twice the concentration required to inhibit 50% adult emergence in *A. aegypti*. Methanolic leaf extracts of *C. infortunatum* and *Chromolaena odorata* against sixth-instar *Orthaga exvinacea* larvae showed that *C. odorata* was more effective than *C. infortunatum* in reducing carbohydrate concentration in haemolymph (Nambiar and Ranjini 2018). *C. infortunatum* leaf powder at 5%, 10% and 20% (w/w) mixed with cow dung against third-instar grubs of *Oryctes rhinoceros* caused notable morphological changes (Sreeletha and Geetha 2011). C. inerme 1% extract significantly reduced the larval population of *P. xylostella*. Guruprasad and Pasha (2015) reported that methanol extract of *C. inerme* leaves showed the highest LD_{50} and LD_{99} values for *C. chinensis* and the lowest for *R. dominica* compared with *T. castaneum*. The order of repellency was *C. chinensis* < *R. dominica* < *T. castaneum*. Diterpenoid compounds Clerodendrin-A and Clerodendrin-B in C. inerme exhibited feeding-deterrent activity against larvae of *Calospilos mirands*, *Ostrinia nubilalis* and *Euproctis subflava*. These compounds are also present in *C. fragrans*, *C. calamitosum*, *C. cryptophyllum* and *C. japonicum* and showed strong antifeedant activity against *Manduca sexta* (Munakata 1977). Table 3 presents the insecticidal activities of different *Clerodendrum* species against various insect pests Group.

Kato *et al*. (1973) isolated Clerodendrin-A and Clerodendrin-B from C. trichotomum, which exhibited strong antifeedant activity against Euproctis pseudoconspersa and *Cicadella viridis.* Jadhav *et al*. (2016) evaluated leaf extracts of various Clerodendron species against third-instar larvae of *Spodoptera litura* and *H. armigera. H. armigera* showed lower mortality than *S. litura*. The antifeedant efficacy order for *S. litura* was *C. inerme* > *C. viscosum* > *C. philippinum* > *C. splendens* > *C. multiflorum* > *C. calamitosum* > *C. serratum* > *C. panniculatum*, whereas for *H. armigera* it was *C. inerme* > *C. viscosum* > *C. multiflorum* > *C. splendens* > *C. calamitosum* > *C. paniculatum* > *C. philippinum* > *C. serratum. C. philippinum* exhibited the highest growth inhibition (66%) against *S. litura*, while *C. serratum* caused up to 75% larval growth inhibition against *H. armigera*. Gholamreza *et al*. (2014) reported that 15-hydroxy-14,15-dihydroclerodin (HD) was the major contributor to the antifeedant activity of dried *C. infortunatum* leaves against *H. armigera*. Adesina *et al*. (2019) reported repellent activity of ethyl extract of *C. capitatum* against adults of *Sitophilus oryzae*, *Rhyzopertha dominica* and *Tribolium castaneum* at 1.58 mg/cm². Husain and Rahman (2006) reported that adult and larval stages of *T. castaneum* were consistently repelled by food media treated with *C. viscosum* leaf dust at 100, 500, 1000 and 2000 ppm. Lu *et al*. (2021) reported repellency of C. bungei methanol extract against *T. castaneum, Lasioderma serricorne* and *Liposcelis bostrychophila*.

The hexane extract of *C. capitatum* showed high fumigant toxicity with LC_{50} values of 25-32 µg/L against *S. oryzae*, slightly higher than Eucalyptus essential oils (Lee *et al*. 2001) but considerably lower than *Rosmarinus officinalis* essential oils (Kiran and Prakash 2015).

Abbaszadeh *et al*. (2012) isolated clerodin, 15-methoxy-14,15-dihydroclerodin and 15-hydroxy-14,15-dihydroclerodin from *C. infortunatum* and evaluated their growth-inhibitory effects on *H. armigera*. The GI_{50} values under topical application were 11, 13 and 21 ppm, respectively, while under diet incorporation they were 10, 11 and 9 ppm. Pereira and Gurudutt (1990) isolated 3-epicaryoptin from *C. inerme* by petroleum ether and reported reduction in pupal weight of Musca domestica and *C. quinquefasciatus* larvae at 20 and 40 ppm. Nishida *et al*. (2004) reported that 3-epicaryoptin, ajugachin A, athaliadiol, clerodendrins B, D and H, and clerodin induced strong feeding responses in *Athalia rosae ruficornis* adults at doses of 10-8-10-7 g per filter paper. Kawai *et al*. (1998) attributed pharmacophagous feeding of A. rosae ruficornis on *C. trichotomum* to bitter neo-clerodane diterpenoids in glandular structures on leaf surfaces; among clerodendrins A-H, only clerodendrins B, D and H exhibited feeding stimulant activity. Nishida *et al*. (1989) also reported clerodendrins B and D as feeding stimulants for *A. rosae ruficornis larvae*. Amano *et al*. (1999) isolated ajugachin A and athaliadiol from body extracts of *A. rosae ruficornis* adults showing compulsive feeding on *C. trichotomum*. Clerodendrin I, along with clerodendrins B, D and H, isolated from *C. trichotomum*, exhibited feeding stimulant activity against adult turnip sawfly at doses of 1 and 3 µg per 64 mm2, respectively (Ritsuo *et al*. 1989; Kawai *et al*. 1999). Clerodendrins A and B isolated from C. trichotomum exhibited antifeedant activity against larvae of *Ostrinia nubilalis* and *Euproctis subflava* at 5000 and 1000 ppm, respectively (Munakata 1975). Insecticidal efficacy of bioactive compounds from *Clerodendrum* species against pests are listed in Table 4.

Muthu *et al*. (2013) fractionated chloroform extract of *C. phlomidis* into twelve fractions and evaluated them against *Erias vittella*. Fraction 5 showed the highest ovicidal activity (68.49%) with 100% oviposition deterrence at 1000 ppm. Further purification identified the *flavonoid pectolinaringenin*, which showed 64.29% ovicidal activity and 100% oviposition deterrence at 100 ppm against *E. vittella*. Similarly, *C. calamitosum* contains 3-epicaryoptin, *C. cryptophyllum* contains Clerodendrin-A (Hosozawa *et al*. 1974; Munakata 1975), and C. capitatum contains 2-heptanone, 3-methyl and hexahydrofarnesyl acetone (Chu *et al*. 2013). The modes of action of Chemical components of *Clerodendrum* spp. against insect pests are depicted in Fig. 2.

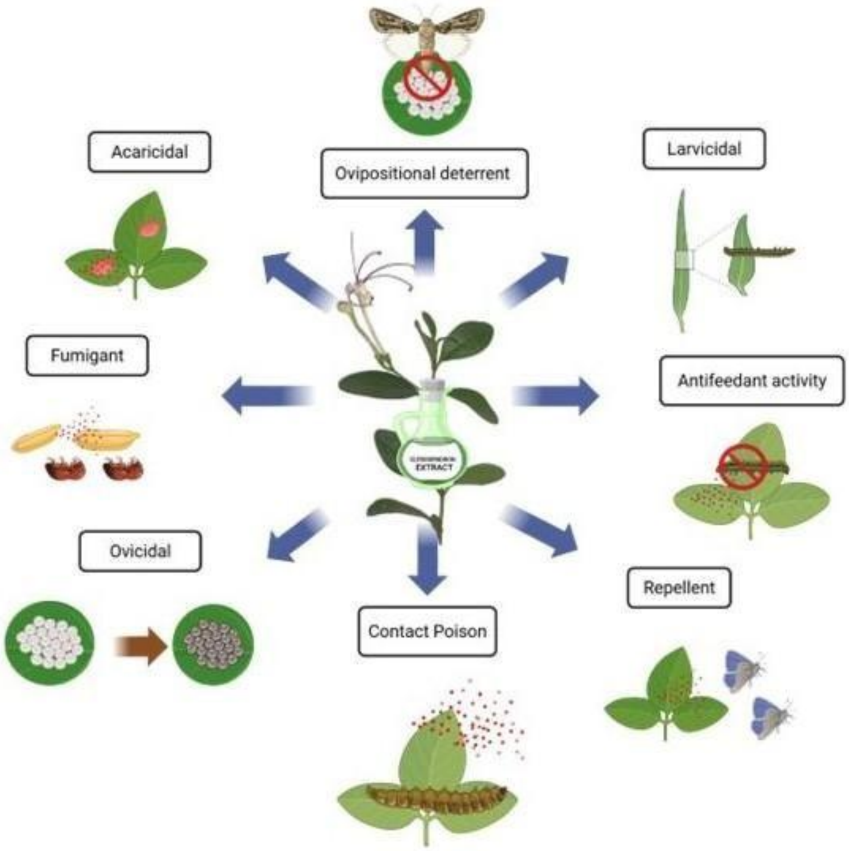


Fig. 2 Different mode action of *Clerodendrum* spp. against insect pest

Table 3. Insecticidal Activities of Different *Clerodendrum* Spp. Against Different Insect Pest Group

	Plant Species	Insect species	Susceptible stage	Part used	Solvent used for extraction	Mode of action	Effective dose	References
Coleoptera								
1	*Clerodendrum capitatum*	Rice weevil *Sitophilus oryzae*, Lesser grain borer *Rhyzopertha dominica*, and Redflour beetle *Tribolium castaneum*	Adult	Leaf	Hexane	Fumigants	25 and 32 µg/L	Adesina *et al*. (2019)
					Ethyl extract	Repellent	1.58 mg/cm^2	
2	*Clerodendrum siphonanthus*	Rice weevil, *Sitophilus oryzae*	Adult	Whole plant	Petroleum ether Methanol	Antifeedant	5%	Roychoudhury (1994)
3	*Clerodendrum scandens*				Methanol		5%	
4	*Clerodendrum siphonanthus*						5% (100% mortality in 6 days)	Roychoudhury (1993)
5	*Clerodendrum nepalensis*						5% (100% mortality in 11 days)	
6	*Clerodendrum viscosum*	Redflour beetle, *Tribolium castaneum*	Adult	Stem	Ethyl alcohol	Contact poison	0.42 mg/ml	Waliullah *et al*. (2014b)
				Root			0.52 mg/ml	
				Leaf			2.94 mg/ml	
				Root	Ethyl acetate		0.95 mg/ml.	
				Stem			1.50 mg/ml	
				Leaf			1.60 mg/ml	

				Root	Chloroform		5.75 mg/ml	
				Stem			15.85 mg/ml	
				Leaf			26.70 mg/ml	
				Root	Ethyl alcohol		0.06 mg/cm^2	
				Leaf			0.12 mg/cm^2	
				Stem			0.25 mg/cm^2	
				Leaves	Petroleum ether	Repellent	372.57 mg/cm^2	Zahurul *et al*. (2010)
		Lesser grain borer, *Rhyzopertha dominica*					25.172 mg/cm^2	
		Lesser grain borer, *Rhyzopertha dominica*			Ethyl acetate		4509.30 mg/cm^2	
		Rice weevil, *Sitophilus oryzae*			Acetic chloroform		512.97 mg/cm^2	
7	*Clerodendrum inerme*	Lesser grain borer, *Rhyzopertha dominica*	Adult	Leaves	Methanol	Inhibition of acid phosphatase and cholinesterase enzymes	1460 $\mu g/cm^2$	Azmi (2004)
8	*Clerodendrum bungei* essential oil (EO)	Redflour beetle, *Tribolium castaneum*		Aerial parts	n-Hexane	Repellent	3.15 nL/cm^2	Lu *et al*. (2021)
		Cigarette beetle, *Lasioderma serricorne*		Ground parts	Methanol		15.73 nL/cm^2	
9	*Clerodendrum viscosum*	Rice weevil, *Sitophilus oryzae*	Adult	Root	Ethyl alcohol	Contact poison	0.51 mg/ml	Waliullah *et al*. (2014a)

				stem			0.88 mg/ml	
				Leaf			1.81 mg/ml	
				Root	Ethyl acetate		1.30 mg/ml	
				Leaf			2.40 mg/ml	
				Stem			1.25 mg/ml	
				Root	Chloroform		5.76 mg/ml	
				Stem			8.65 mg/ml	
				Leaf			44.77 mg/ml	
				Root and Stem	Ethyl alcohol	Repellent	0.39 mg/ml	
				Stem			0.43 mg/ml	
10	*Clerodendrum inerme*	Rice weevil, *Sitophilus oryzae*	Adult	Leaf	Ethanol	Contact poison & ovicidal	5% (56.66% mortality)	Yankanchi and Gadache (2010)
11	*Clerodendrum infortunatum*	Rhinoceros beetle, *Oryctes rhinoceros*	Third instar (grub)	Leaf powder	_-	Inhibitors of acetyl-CoA carboxylase	20%	Sreeletha and Geetha (2011)
12	*Clerodendrum inerme*	Lesser grain borer, *Rhyzopertha dominica*	Adult	Leaves	Methanol	Contact poison	0.65 mg/cm^2	
		Redflour beetle, *Tribolium castaneum*					1.28 mg/cm^2	
		Pulse beetle, *Callosobruchus chinensis*					1.74 mg/cm^2	

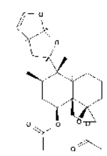
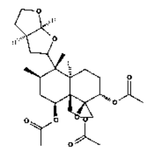
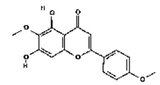
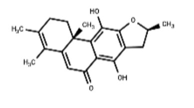
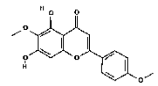
Psocoptera								
13	*Clerodendrum bungei* essential oil (EO)	Book lice, *Liposcelis bostrychophila*	Adult	Aerial parts	n-Hexane		78.63 nL/cm^2	Lu *et al*. (2021)
				Aerial parts	n-Hexane		2.53 nL/cm^2	
Trombidiformes								
14	*Clerodendrum viscosum*	Tea red spider mite, *Oligonychus coffeae*	Adult	Leaves and succulent stems	Petroleum ether	Acaricidal	0.05%	Roy *et al*. (2011)
					Water		1.88%	
					Methanol		1.44%	
					Acetone		0.86%	
			Egg			Ovicidal	2 and 4%	
15	*Clerodendrum infortunatum*	Tea red spider mite, *Oligonychus coffeae*	Egg		Water	Ovicidal	10.00%	Sarmah *et al*. (2009)
			Adult			Acaricide	5.00%	
Lepidoptera								
16	*Clerodendrum inerme*	Castor semilooper, *Achaea janata*	Larvae	Leaves	chloroform	Antifeedant	10%	Yankanchi (2009)
17	*Clerodendrum infortunatum*	Cabbage butterfly, *Pieris brassicae*	Larvae	Whole plant	Methanol	Antifeedant	500 ppm	Geuskens *et al*. (1983)
18	*Clerodendrum inerme*	Common castor butterfly, *Ariadne merione*	Larvae	Leaves	Hexane	Antifeedant	4.96 ppm	Dharani Priya and Srinithi (2024)
					Petroleum ether		14.7 ppm	

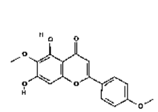
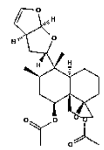
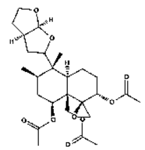
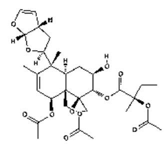
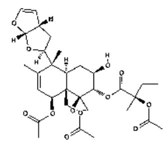
					Acetone		9.74ppm	
19	*Clerodendrum inerme*	Tobacco cutworm, *Spodoptera litura*	Third instar Larvae	Leaves	Ethanol	Contact and respiratory toxins	2.5 % (76.66% mortality)	Jadhav *et al*. (2016)
		Cotton bollworm, *Helicoverpa armigera*					2.5% (58.88% mortality)	
20	*Clerodendrum inerme, Clerodendrum viscosum, Clerodendrum Phillipinum, Clerodendrum splendens, and Clerodendrum multiflorum*	Tobacco cutworm, *Spodoptera litura*				Antifeedant	100-mg/ 21cm^2	
21	*Clerodendrum philippinum*					Growth inhibition activity	2.5% (66% growth inhibition)	
22	*Clerodendrum serratum*	Cotton bollworm, *Helicoverpa armigera*					2.5% (75.50% growth inhibition)	
23	*Clerodendrum tricotomum*	Tobacco cutworm, *Spodoptera litura*	Larvae	Young leaves	Benzene	Repellent	5 to 10%	Kato *et al*. (1972)
				Matured leaves			1%	
24	*Clerodendrum infortunatum*	Mango leaf webber, *Orthaga exvinacea*	Sixth instar Larvae	Leaves	Methanol	Reduction of carbohydrate in haemolymph	5%	Nambiar and Ranjini (2018)
25	*Clerodendrum inerme*	Diamondback moth, *Plutella xylostella*	Larvae	Leaves	Ethanol	Larvicidal	1%	Yankanchi and Patil (2009)
Hemiptera								
26	*Clerodendrum viscosum*	Tea mosquito bug, *Helopeltis theivora*	Adult	Leaves and Succulent stem	Water	Antifeedant	10% and 20%	Roy *et al*. (2010)
27	*Clerodendrum inerme*	Cowpea aphid, *Aphis craccivora*	Nymph and Adult	Root exudate	–	Prolong the life cycle	7 to 21%	Hasoon and Mohmed (2021)

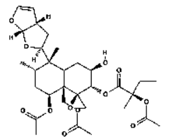
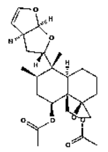
Diptera								
28	*Clerodendrum inerme*	Yellow fever mosquito, *Aedes aegypti*	Third instar larvae	Leaves	Methanol	Insect growth disruptor	37.45 mg/L	Patil *et al*. (2014)
					Chloroform		14.79 mg/L	
					Petroleum ether		2.56 mg/L	
					Hexane		1.96 mg/L	
			Fourth instar larvae		Methanol		70 mg/L	
					Chloroform		30 mg/L	
					Petroleum ether		6 mg/L	
					Hexane		4 mg/L	
			Pupa		Methanol		50 mg/L	
					Chloroform		20 mg/L	
					Petroleum ether		4 mg/L	
					Hexane		4 mg/L	
		Southern house mosquito, *Culex quinquefasciatus*	Adults	Leaves			3.74 mg/L	

			Fourth instar larvae	Leaves			32 mg/L	
		Brown plant hopper, Nilaparvata lugens	Adult	Whole plant	Methanol	Contact poison	0.5 µg/g	Hiremath *et al*. (1997)
		Southern house mosquito, *Culex quinquefasciatus*	Fourth instar Larvae	Leaf, Stem, Seed and Flower	Petroleum ether	Larvicide	87.1 ppm	Kalyanasundaram and Das (1985)
		Yellow fever mosquito, *Aedes aegypti*		Leaves	Leaf powder mixed with diet	Disrupt the digestive process	160 mg	Patil *et al*. (2006)

Table 4. Insecticidal efficacy of bioactive compounds from *Clerodendrum* species against pests

SI. NO	Plant Species	Active compound	Insect species	Affected stage	Part used	Solvent used for extraction	Mode of action	Effective dose	Chemical structure	References
1	*Clerodendrum inerme*	Clerodin	Egyptian cotton Leafworm, *Spodoptera littoralis*	Third-instar larva	Aerial parts	n-Hexane	Antifeedant	50 ppm		Krishna Kumari *et al*. (2003)
			Spotted bollworm, *Earias vitella*					15 µg/g		
		Epicaryoptin	Egyptian cotton Leafworm, *Spodoptera littoralis*					200 ppm		
			Spotted bollworm, *Earias vitella*					30 µg/g		
2	*Clerodendrum siphonanthus*	Pectolinarigenin	Rice weevil, *Sitophilus oryzae*	Adult	Dry stems and leaves	Petroleum ether	Antifeedant	250 ppm and 500 ppm		Pal *et al*. (1989)
		Uncinatone						250 ppm and 500 ppm		
3	*Clerodendrum phlomidis*	Pectolinarigenin	Spotted bollworm, *Earias vitella*	Third instar larvae	Matured leaves	Hexane: ethyl acetate (1:1)		36.2 ppm		Muthu *et al*. (2015)
			Indian malaria mosquito, *Anopheles stephensi*	Second and fourth instar larvae				0.35 and 0.55 ppm		
			Spotted bollworm,	Third instar larvae			Larvicidal	10.23 ppm		

			Earias vitella							
			Southern house mosquito, *Culex quinquefasciatus*	Fourth-instar larvae	Matured leaves	Chloroform		0.62 ppm		Muthu *et al.* (2012)
			Yellow fever mosquito, *Aedes aegypti*					0.79 pm		
4	*Clerodendrum infortunatum*	Clerodin						50ppm		Kato *et al.* (1973), Hosozawa *et al.* (1974) and Munakata (1975)
5	*Clerodendrum calamitosum*	3-Epicaryoptin	Tobacco cutworm, *Spodoptera litura*	Larvae	Whole plant	Benzene	Antifeedant	200 ppm		Hosozawa *et al.* (1974) and Munakata (1975)
6	*Clerodendrum crytophyllum*	Clerodendrin A						200 ppm		
7	*Clerodendrum tricotomum*	Clerodendrin A	Tobacco cutworm, *Spodoptera litura*	Larvae	Leaves	Benzene	Antifeedant	300 ppm		Kato *et al.* (1972)

		Clerodendrin B						200 ppm		
		Clerodin						80 ppm		

Nano formulation of *Clerodendrum* species

Farooqui *et al*. (2010) synthesized silver nanoparticles using *C. inerme* leaf extracts prepared under three conditions namely fresh leaves, sun-dried leaves and hot-air oven-dried leaves. Their results showed that nanoparticles produced from fresh leaf extracts were the smallest in size, with average length, width, and area measurements of 156.95 mm, 113.40 mm and 18,920.81 mm², respectively. Khan *et al*. (2020) synthesized gold (Au) and silver (Ag) nanoparticles by using leaf extracts of *C. inerme* through various methods, including green synthesis approaches in which plant metabolites served as reducing agents for metal ions. The synthesised nanoparticles were evaluated for their biological activities and for antibacterial effects against *Bacillus subtilis, Staphylococcus aureus, Klebsiella*, and *Escherichia coli,* as well as antimycotic activity against Asp*ergillus niger, Trichoderma harzianum,* and *Aspergillus flavus.* Govindarajan *et al*. (2016) fabricated silver nanoparticles (AgNPs) from *C. chinense* leaf extract and compared the acute toxicity of the crude extract with that of the biosynthesized AgNPs against larvae of *Anopheles subpictus, Aedes albopictus* and *Culex tritaeniorhynchus.* The aqueous leaf extract of *C. chinense* demonstrated good larvicidal activity, with LC_{50} values of 61.74, 66.51 and

71.72 µg/ml against *A. subpictus, A. albopictus* and *C. tritaeniorhynchus*, respectively. In contrast, the LC_{50} values for the *C. chinense* synthesised AgNPs were comparably lower 10.23, 11.10 and 12.38 µg/ml for the same mosquito species which indicates that it exhibits higher toxicity than the aqueous leaf extract. In Addition to that they also confirmed that the AgNPs were safe to non-target aquatic organisms, including *Diplonychus indicus, Anisops bouvieri* and *Gambusia affinis.*

CONCLUSION:

Pest control is most crucial component in shaping agriculture. Injudicious use of synthetic insecticides to manage insect pest has led to serious consequences such as ecosystem imbalance due loss of natural enemies and leaching of these insecticide leads to contamination of soil and ground water which leads to serious hazards and impact in marine ecosystem. Botanicals which contain phytochemicals with insecticidal properties were found effective and safe alternative over synthetic insecticide. *Clerodendrum* spp. with their phytochemical constituents with potent anti-insect activities are promising candidate in ecofriendly pest management of crop pests. The insecticidal, antifeedant, fumigant, repellent, larvicidal, ovicidal and acaricidal property of *Clerodendrum* has been demonstrated against an array of insect pest. Further studies to standardize the extraction method of these phytochemicals and its formulation will bring a development of a novel botanical insecticide with minimum harmful to natural enemies and non-target organisms.

Author contributions

Conceptualization: Sathyanathan S. K and Ganesan K; Resources: Sathyanathan S. K and Ganesan K; Formal analysis: Suganthy M, Bharani A, Vellaikumar S, Jeyarani S, Murugan M; Writing-Drafting and Editing: Sathyanathan S. K and Ganesan K. All the authors read and approved the final manuscript.

Data availability

No datasets were generated or analyzed during the current study.

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Declaration Ethical approval Not applicable

Conflicts of interest

The authors declare no competing interests.

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