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Review Article

Neem: A Novel Biocide for Pest and Disease Control of Plants

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Plant extracts have recently captivated scientists' attention as a potential source of biocide for plant protection. This is due to the health and environmental risks associated with the widespread use of synthetic chemicals with adverse effects on humans, nontarget organisms, and the agroecosystem. As a result, more environmentally friendly and safe alternative approaches to synthetic compounds are desirable. Neem (*Azadirachta indica*) has been identified as a promising biocontrol agent with low toxicity and high efficacy among several plant products for potential chemotherapeutic elements in plant pest and disease management systems. The biocidal potency of neem is attributed to its azadirachtin active ingredient, which impacts some metabolic processes in insects such as protein synthesis, changes in biological fitness, impaired sexual communication, and chitin synthesis. This systematic review intends to gather all the available scientific data regarding the application of neem and its formulations in pest and disease control of plants. The PRISMA (preferred reporting items for systematic reviews and meta-analysis) framework was employed in collecting data for the study. Findings from this review study have demonstrated the use of neem as an effective biocontrol agent for plants' pests and diseases and have provided a solid foundation for future studies on the plant.

1. Introduction

Natural chemicals used by plants for their defense against pests and disease organisms have recently become the choice for integrated pest management and disease control for plants. Due to their eco-friendliness and safety compared to synthetic compounds, they have the potential to solve worldwide agricultural, public health, population, and environmental challenges [1]. Thousands of plants have been tested for pest and disease control, and numerous horticultural mineral oils, botanicals, plant essential oils, and detergents are now utilized for pest and disease control around the world [2]. Among the numerous biopesticides and disease-control plants, neem has cropped up as the finest option.

The neem tree (*Azadirachta indica*) is a tropical evergreen tree in the Meliaceae family. It is native to East India and Burma, and it can be found across Southeast Asia and West Africa, with a few trees lately planted in the Caribbean and Central America, including México [3]. Neem is now well recognized as a natural product with several uses in agriculture, industry, medicine, and the environment. The usefulness of neem in agriculture is presently being studied by researchers all around the world. Many agricultural products are made with this miraculous tree. Neem products include insecticides, pesticides, pest fumigants, fertilizers, manures, compost, urea coating agents, and soil conditioners [4, 5]. Products generated from neem trees are used as effective insect growth regulators (IGRs) and can also help manage nematodes and fungi [5]. The active element in neem is azadiractin, which repels and kills many caterpillars, thrips, and whitefly species [6].

Pesticides derived from natural sources, such as plants, animals, microbes, and certain minerals, are known as botanical pesticides. Natural pesticides have little toxicity to nontarget creatures such as humans, animals, natural enemies, and the environment [6]. Farmers are increasingly turning to neem as a natural insecticide for pest control and integrated pest management. Neem's pest-control properties have been known for ages on the Indian subcontinent for combating storage and soilborne pests [7]. According to Senthil-Nathan et al. [8] and Tavares et al. [9], neem oil is promising for the control of many pests, with target insect species including *Ceraeochrysa claveri, Cnaphalocrocis medinalis, Diaphorina citri, Helicoverpa armigera, Mamestra brassicae, Pieris brassicae, excavatum, and Spodoptera frugiperda*. More than 105 insect pests of 10 orders are controlled with neem formulations made from kernels in crops and gardens [7].

Neem's various bioactive components have been demonstrated to be beneficial in controlling a variety of crop pests and diseases. More than 400 species of insect pests of significant food crops and 16 plant parasitic nematodes have been discovered to be controlled by the bioactive compounds of neem, according to Alam [10]. In black gram, aerosols from the seed kernel extract and oil of neem suppress *Cercospora* leaf spot, anthracnose, and *Alternaria* leaf blight diseases [11]. Kuepper [12] added that rust, powdery and downy mildew, scab and blossom, twig and tip blight, and Botrytis blight are among the diseases that neem oil is used to cure. Given the potential for synthetic pesticides to cause environmental and human health problems, the utilization of neem in botanical disease management is advantageous.

Many studies have been carried out to explore the probable use of neem as a botanical pest and disease control, an alternative to synthetic biocides, which can generate detrimental effects with time. The numerous scientific data available on neem and neem products such as biopesticides and biofungicides are not well organized. Hence, this systematic review aimed at compiling and bringing out the feats achieved by the use of neem in pest and disease control of plants. With this, the present study is focused on reviewing neem as a fumigating, pesticidal, and disease-control agent for plants, together with its chemistry. In addition, the prospect of neem in agriculture and other fields will also be evaluated in this review. The outcome of this study will provide a valuable background for future studies on neem towards the pursuit of developing more cost-effective and environmentally friendly plant biocides. The agricultural-related applications of neem and neem products are displayed in Figure 1.

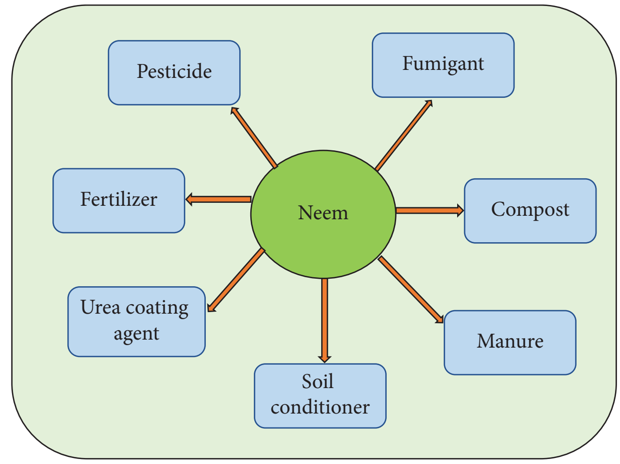


Figure 1: Various applications of neem in the field of agriculture [3].

2. Methodology

The search for important literature for the present review was executed through key scientific databases comprising Scopus, Google Scholar, and ScienceDirect for journal articles published from 1990 to 2022. Keywords such as neem, *Azadirachta indica*, pests, diseases, and plant protection were used to search for available research and review articles from peer-reviewed journals. The numerous citations obtained were combined with the EndNote X9 citation tool (Thomson Reuters, Toronto, Canada). The PRISMA (preferred reporting items for systematic reviews and meta-analysis) framework for data collection for this review is displayed in Figure 2.

3. Taxonomical Classification of Neem

Neem, a member of the Mahogany family, has the following taxonomical hierarchy from kingdom to species (Table 1).

4. Morphological Description of Neem

Neem is a perennial tree that grows quickly and has a straight trunk, long spreading branches, and somewhat thick, rough, and longitudinally fissured bark [14]. A mature tree can reach a height of 7.15 meters [15]. In around 4 years, the tree begins to produce yellowish ellipsoidal drupes (fruits), becomes fully productive in 10 years, and can live for more than 200 years [15]. The leaves are imparipinnate and complex, with around 15 leaflets grouped in alternate pairs with a terminal leaflet. The leaflets are small and lanceolate, with a length of up to 6 cm [15]. The flowers are the fragrant white panicles seen in the leaf axils. They usually attain maturity in May [15]. When ripe, the fruits are yellow and oval-shaped, ranging around 2 cm in length [15]. The thickness of the bark varies greatly depending on the age and portion of the tree from which it is obtained [14]. A plate of a neem tree with indicated discrete parts is shown in Figure 3.

5. Chemical Constituents/Bioactive Compounds of Neem

Neem is rich in many bioactive compounds. The most essential active ingredient that forms the highest fraction of neem is azadirachtin [16]. The azadirachtin component of neem is considered the compound of greatest biological importance, as it accounts for over 90% of the neem's pest-control actions [17].

This active substance repels, deters feeding, and impairs insect growth and reproduction rather than killing them rapidly [17]. Apart from the azadirachtin compound, other active ingredients that are essential in pest control include nimbin, gedunin, salannin, meliantriol, nimbidin, mahmoodin, nimbolinin, sodium nimbinate, 22,23-dihydronimocinol, gallic acid, and quercetin [18]. The remarkable biopesticide and biofungicide properties of neem are due to all of these essential bioactive components in the plant. Some of the useful active compounds found in neem are presented in Table 2, along with their chemical structures and biological activities.

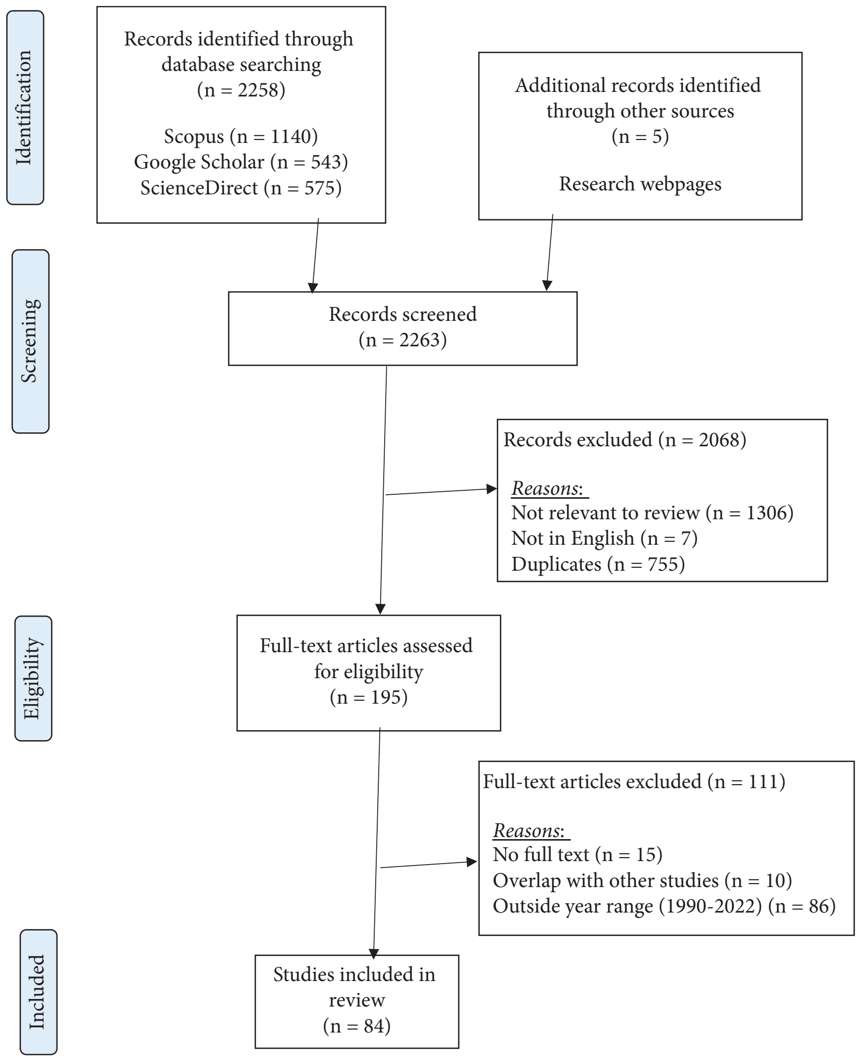


Figure 2: Flowchart for the review methodology.

Table 1: Taxonomical classification of neem [13, 14].

Rank	Neem
Kingdom	Plantae
Division	Magnoliophyta
Class	Dipsacales
Order	Rutales
Suborder	Rutinae
Family	Meliaceae
Subfamily	Melioideae
Tribe	Meliae
Genus	*Azadirachta*
Species	*Indica*

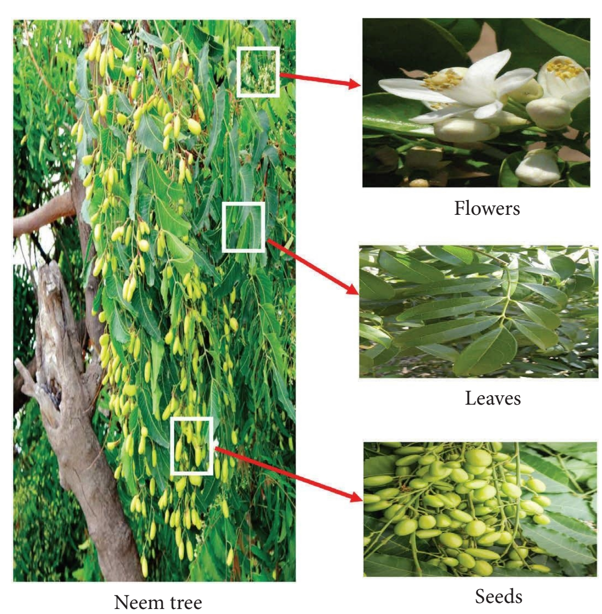


Figure 3: The whole tree of neem with indicated individual parts.

6. Mechanism of Action of Active Compounds of Neem

Neem has shown some therapeutic effects on insect pests and diseases of plants. Different parts of neem have demonstrated great biological activities against microbes through the inhibition of growth and breakdown of their cell walls [24]. The chemical molecule azadirachtin in the

Table 2: Bioactive compounds with chemical structures and biological activities in distinct parts of neem.

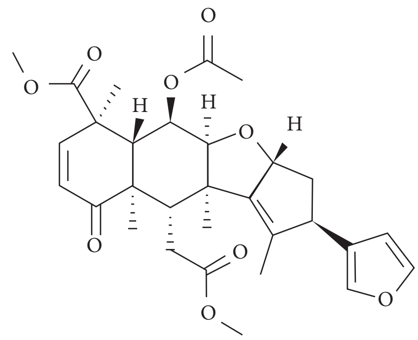
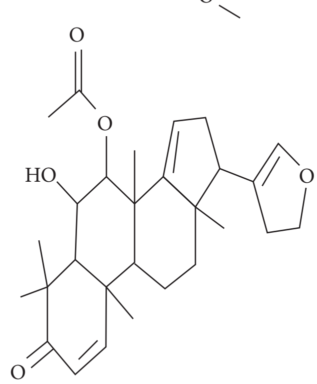
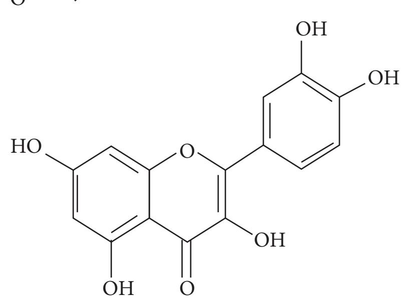
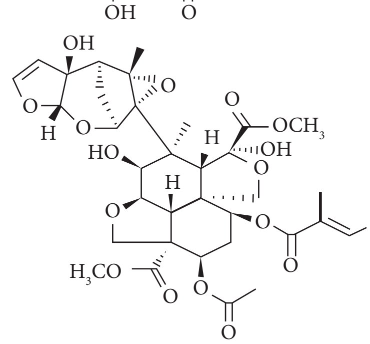
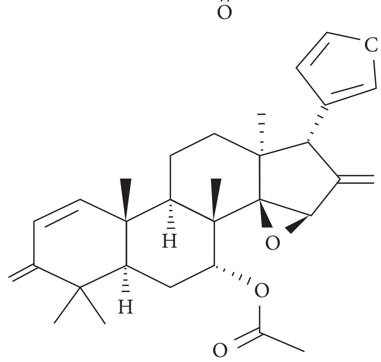
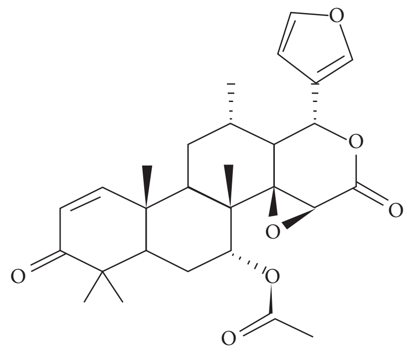
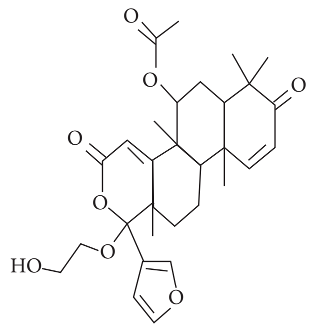
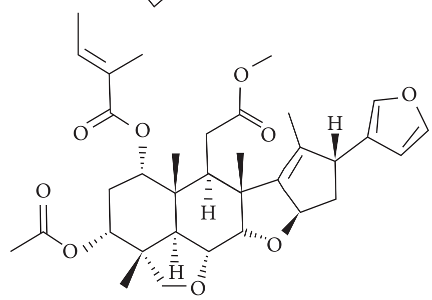
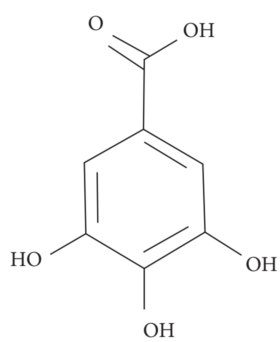
Source	Compound	Chemical structure	Biological activity	Reference
Leaf	Nimbin		Pesticidal and antifungal	[19]
Leaf	22,23-Dihydronimocinol		Insecticidal	[20]
Leaf	Quercitin		Hypoglycaemic	[20]
Seed/seed oil	Azadirachtin		Antifeedant, insecticidal, and growth inhibition	[17, 19]
Seed oil/bark	Nimbinin		Antiviral, antifungal, and antibacterial	[21]

Table 2: Continued.

Source	Compound	Chemical structure	Biological activity	Reference
Seed oil/ root	Gedunin		Insecticidal antibacterial and antifungal	[22]
Seed oil	Mahmoodin		Antibacterial	[21]
Bark	Salannin		Insecticidal and antifeedant	[23]
Bark	Gallic acid		Antiviral and antibacterial	[23]

limonoid family is the main chemical component of neem [19]. Mordue (Luntz) and Nisbet [25] identified azadirachtin as the main ingredient accountable for the antifeedant and poisonous effects in insects. The chemical ingredients of neem are taken up systemically by plants through the roots in soil drench treatments. The active components' biological activity is diluted, yet it remains unchanged and spreads uniformly to actively growing plant portions. On insects and pathogens, systemically treated plants have antifeedant, oviposition deterrent, growth-inhibiting effects, and other biological properties. Depending on the test plant or insect species, the degree of systematicity and the effect on insects vary [7].

7. Neem in Pest Control

Products made from neem contain a variety of compounds that are effective against pests. Neem components act on the insect's endocrine system rather than its neurological or digestive system like chemical insecticides do, which prevents the development of resistance in subsequent generations [10]. Neem has been used to make what is known as a

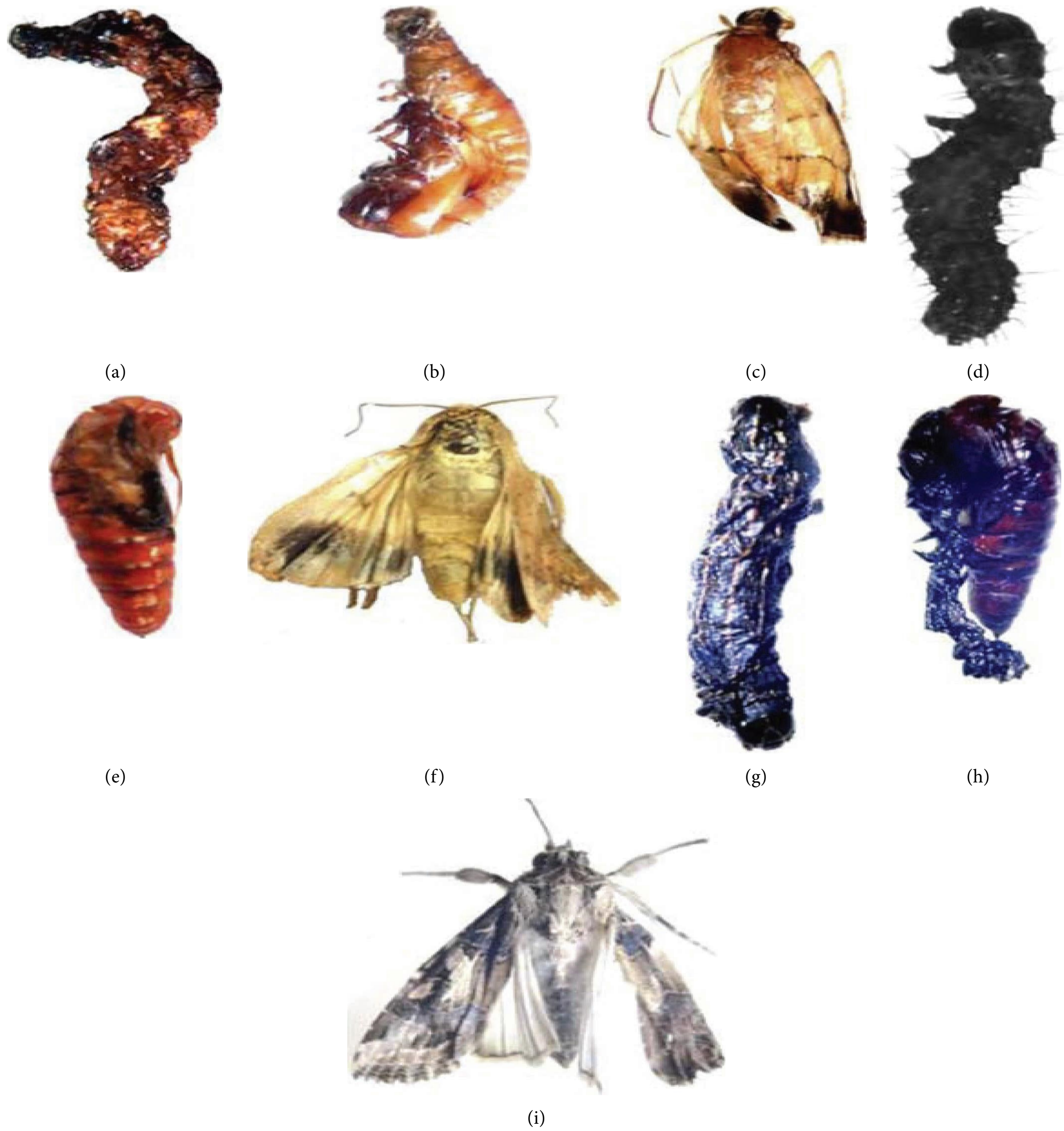


Figure 4: Defects in the metamorphosis of some *Lepidopteran* insects larvae, following treatment with 0.5 ppm of neem: *Cnaphalocrocis medinalis* larval, pupal, and adult defects (a)–(c), *Helicoverpa armigera* larval, pupal, and adult defects (d)–(f), and *Spodoptera litura* larval, pupal, and adult defects (g)–(i) [38].

biopesticide, which is environmentally beneficial and has no adverse effects on plants or soil [26]. The major element in neem used to produce these biopesticides is azadirachtin [27]. This azadirachtin active compound in neem has demonstrated typical insect growth regulating (IGR) actions in the larval stages of insects [28]. The numerous limonoid allomones with proven biological functions produced by neem have shown an amazing effect against 413 species in 16 different insect orders, including Homoptera [20]. Neem's insecticidal effects were evaluated by Jackai et al. [29] on two significant cowpea pests (*Maruca testulalis Geyer* and *Clavigralla tomentosicollis Stäl*) using water extracts at various concentrations and powders made from the seed and kernel of the plant. Even at concentrations as low as about 9 percent solution (9% w/v), neem was effective in controlling the growth rates of both pests. Neem treatment to crops in the field or under storage conditions has been revealed to exert certain biological activities on insect pests. Neem treatment to crops in the field or under storage conditions has been revealed to exert certain biological activities on insect pests, including feeding and oviposition deterrence, metamorphosis inhibition, and insect repellence [30]. Such important biological actions exerted by neem on insect pests are described as follows.

Table 3: Insect pests are controlled with neem treatments on a variety of crops.

Crop/plant	Insect pest	Neem treatment	Reference
Cowpea (Brazil)	*Spodoptera eridania* (southern armyworm)	Neem oil (0.35% and 0.7%)	[45]
Brinjal	Shoot and fruit borer	Neem oil	[46]
Cowpea	*Maruca vitrata*	Multinucleopolyhedrovirus + neem oil	[47]
Kinnow mandarin	*Penicillum digitatum and p. italicum*	Neem essential oil	[48]
Cultivated crops	*Helicoverpa armigera*	Neem oil	[49]
Cotton	Cotton pest	Beauveria bassiana + neem oil	[50]
Cabbage	Cabbage aphid	Neem oil (1%)	[51]
Okra	Whitefly	Mineral oil + neem oil	[52]
Western white pine	*Zootermopsis angusticollis* (damp wood termite)	Neem oil	[53]
Cashew trees	*Toxoptera odinae*	Neem oil	[54]
Stone fruit	*Monilinia fructicola*	Neem oil	[55]
Watermelon	*Aphis gossypii*	Neem oil	[49]
Coconut	*Aceria guerreronis*	Neem oil (3%)	[56]
Cultivated crops	*Helicoverpa armigera*	PONNEEM (neem + pongamia oil, 1 : 1 rate)	[57]
Jasminum auriculatum	Eriophyid mite	Neem oil (30 mL/L)	[58]
Tomato	White fly and leaf miner	Neem oil	[59]
Cashew	*Ferrisia virgate*	Neem oil	[60]
Okra	*Bemisia tabaci*	Neem	[61]
Tomato	*Tuta absoluta*	Neem seed oil	[62]
Phaseolus vulgaris	*Bemisia tabaci*	Neem	[63]
Eggplant/cucumber	Flower bud thrip	Neem seed kernel power, neem leave extract, and neem oil	[47, 63]
Cowpea	Cowpea pod borer	Neem seed kernel power, neem leave extract, and neem oil	[47, 64]
Cowpea	Cowpea bruchid	Neem seed kernel extract	[65]
Cultivated cowpea	Giant coreid bud	Neem seed oil and neem seed kernel extract	[66, 67]
Fruit vegetable/field crops (apples, corn)	Spiny brown bug	Neem seed oil and neem seed kernel extract	[66, 68]
Wheat, sorghum, rice, and sugarcane	Pink stalk borer	Neem seed oil	[69]
Sugarcane	Sugarcane borer	Neem seed oil	[69]
Tomato	Tomato fruit worm	Neem seed oil	[16]
Pepper, beans, and potato	European corn borer	Neem seed kernel extract	[66, 70]
Maize	Maize weevil	Neem seed kernel powder	[71]
Apples and grapes	Leafhopper	Neem seed kernel extract	[72]
Carrot, sweet potato, and okra	Southern armyworm	Neem seed oil	[70]

7.1. Antifeedant. Antifeedants are organic substances made by plants to prevent insects and scavenging attacks. These chemical substances are often categorized as secondary metabolites since they confer prolonged existence rather than a requirement for the metabolism of the plant. Neem possesses azadirachtin active compound, which has powerful antifeedant properties against a wide variety of insect species. Neem's antifeedant effects are mediated by two mechanisms: contact sensory reception (primary antifeedant) and interior response mechanisms (secondary antifeedant) [31]. Neem preparations have been proven to be efficient antifeedant insecticides against leaf folders, leaf borers, gall midges, grasshoppers, rice, pulse beetles, predatory spiders, citrus blackflies, houseflies, bunch, and psychid [22]. The behavioral reactions of insects to neem vary greatly between species and orders. The order Lepidoptera was found to be highly sensitive to neem with powerful antifeedants from 1 to 50 ppm, in contrast to Hemiptera, Coleoptera, Orthoptera, and Hymenoptera orders, according to a study by Mordue (Luntz) and Nisbet [25] on various insect orders. In a screen house trial, Muhammad and Kashere [16] discovered that neem-treated cowpea seedlings given to grasshoppers, *Zonocerus variegatus* L. (Orthoptera: Pyrgomorphidae), had an antifeeding effect. Aerts and Mordue Luntz [32] also conducted a study on the antifeedant nature of neem, where the larvae and nymphs of the locust *Schistocerca gregaria* and moth *Spodoptera littoralis* showed considerable antifeedant action by neem products.

7.2. Oviposition Deterrence. Oviposition refers to the act of laying eggs by insects on a given substrate. Insect females can lay a large number of eggs on substrates, due to high reproductive abilities. Because of their immense reproductive potential, insects have the potency to cause huge damage to plants. It has been revealed that the several bioactive components in neem have strong oviposition deterrent properties, which prevent insects from laying eggs on substrates treated with the plant product. Numerous research on various insect species has demonstrated this assertion. Mahmoud and Shoeib [33] used the filter paper immerse technique to examine the effects of neem at various doses of 18.7, 37.5, 75, 150, 300, and 600 ppm on the sterilizing and oviposition actions of *Bactrocera zonata*. Results showed that when compared to the control, neem formulation significantly inhibited *B. zonata* ova at all dosages utilized. Nisbet et al. [34] also found in a study that during the first 26 hours, the reproductive capacity of *Myzus persicae* that nourished on an azadirachtin-containing diet was less than half of that of *Myzus persicae* that fed on the control diet and that nymph production essentially stopped after 50 hours. Furthermore, Rahman and Talukder [35] investigated oviposition prevention on stored products, finding that the control treatments had the largest mean number of eggs compared to the neem-treated products. These findings from previous studies support neem's oviposition deterrent ability in lowering insect colonization on a particular substrate.

7.3. Metamorphosis Inhibition. The development of an insect or an amphibian from the juvenile stage to the adult form in two or more discrete phases is referred to as metamorphosis. Depending on the insect species, these stages often range from three (egg, nymph, and adult) to four (egg, larva, pupa, and adult). Neem has been shown to disrupt these transformative changes in insects. According to Ascher [36], the prothoracicotropic hormones, neuroendocrine system, and allotropic hormones, which regulate the titers of both molting and juvenile hormones in insects, are suppressed by azadirachtin in neem. Ferdenache et al. [30] added that the insect hormones known as "ecdysones" regulate metamorphosis as the insect progresses from larva to pupa to adult. It is worth noting that neem does not exterminate insects; rather, it disrupts their life processes [35]. Neem oil and supplemented neem seed kernels applied directly to the two species of rice planthoppers (*Nilaparvata lugens* and *Sogatella furcifera*) caused disruptions in the molting process, an expansion of the larval period, and dosage-dependent deaths in the insect pests [37]. Muhammad and Kashere [16] also found that treating yellow mealworm larvae with 0.1 g of azadirachtin affected the life cycle of *Tenebrio molitor*. Even though the larvae of *T. molitor* retained their juvenile traits, they were unable to molt. Some abnormalities in the transformational process of Lepidopteran insect larvae caused by neem treatments are shown in Figure 4.

7.4. Insect Repellence. Insect-repellent substances deter insects from settling or crawling up surfaces. These substances do not kill insects but rather deter them away from the treated surface. Neem has been established to possess great insect-repellent properties, which have been attributed to the repugnant odor of the plant [39]. The neem insect repellent operates by interacting with the odorant and gustatory receptors in the insect. The active compounds in the plant then bind to "odor-binding proteins" in the insect's antenna and cause it to flee [40]. Studies have reported the insect-repellent actions of neem on many insect species of plants. In a study by Schmutterer [37], it was discovered that treated crops had lesser adults of *Nilaparvata lugens*, the brown rice planthopper, following an application of 3% neem oil in an ultralow volume spray. The Chinese sweet shrub, *Calycanthus chinensis* adults, ceased producing offspring when neem oil at 1% was applied to red gram seed as a surface protectant [41]. All these reported findings demonstrate the insect-repellent capabilities of neem on insect pests of plants.

8. Neem as Pest Fumigant

Fumigants are simply substances used in disinfecting. They are volatile and harmful substances that are applied to plants, storage foods, human residences, and other objects to eradicate insects and other creatures. Weevils, flour beetles, bean-seed beetles, and potato moths have all been shown to succumb to the natural fumigant capabilities of neem [29]. A neem fumigant destroys insects by acting as an antifeedant, oviposition deterrent, mating disruptor, and growth inhibitor [29]. Several studies have demonstrated the fumigation potential of neem on numerous insect pests. The effectiveness of neem oil and the chemical compound phosphine as fumigants against the pulse beetle was assessed by Gandhi and Srivastava [42]. The study's findings showed that neem oil, an organic fumigant, caused greater or equivalent mature pulse beetle fatality at high doses than at low doses of inorganic phosphine. The effectiveness of neem seed oil as a fumigant on wood-destroying insects was also studied by Pant and Tripathi [43]. In that study, *Lyctus africanus* larvae were exposed to wooden blocks that had been fumigated with the seed oil of neem in six dosages. Neem seed oil was found to be effective on *L. africanus* larvae at all the dosages experimented on. Under laboratory conditions, Michaelraj and Sharma [44] investigated the efficiency of neem as a fumigant against two significant maize storage pests (*Sitophilus oryzae* and *Rhyzopertha dominica*). The study found that both pests died completely, with *Sitophilus oryzae* being more vulnerable to the fumigation than *Rhyzopertha dominica* at various dosages of the neem product. Also, unlike synthetic fumigants, this natural fumigant does not mislay any residue on plants [3]. A list of insect pests being controlled with neem and neem products on a variety of crops is presented in Table 3.

9. Neem in Disease Control

Plants have a diversity of defense mechanisms that can be activated in response to pathogens such as fungi, bacteria, and viruses. The use of agrochemicals to treat plant disease is neither cost-effective nor environmentally safe. As a result, integrated disease management systems utilizing cultural and eco-friendly bio-agents are required for sustainable agriculture production. According to Goel et al. [73], neem and its constituents are effective at inhibiting the growth of a wide range of microorganisms, including viruses, bacteria, and fungi. Some of the demonstrated antimicrobial potency of neem in the management of plant diseases is described as follows.

9.1. Antifungal Activity. Over time, the growing use of synthetic fungicides to combat fungal crop diseases has resulted in an increase in antimicrobial resistance as well as harm to the environment and animal health [74]. Owing to this, many scientists are now concentrating on generating new approaches to treating fungal plant diseases. The use of neem as a natural biofungicide is one of these techniques that has received a lot of attention. Darwish and Shaker [75] assessed the effectiveness of the seeds and leaves of neem against two fungal species. The growth of both *Fusarium solani* and *Rhizoctonia solani* fungi were greatly suppressed in the study at percentages of 52.4 percent and 37.5 percent, respectively, by the water and ethanol extracts of the seeds and leaves at a proportion of 30 : 70 (v/v). Chaudhary et al. [76] also investigated the fungicidal properties of neem against *Alternaria alternata*, which causes early blight of potatoes and found that neem extracts had the second-highest inhibition of *A. alternata* (54%) in the study. Jabeen et al. [77] assessed the antifungal properties of neem against the fungal species, *Alternaria solani Sorauer*. In that study, the portion of ethyl acetate of neem was shown to be the most efficient in inhibiting fungal growth, with a minimum inhibitory concentration of 0.19 mg. With a minimum inhibitory concentration of 0.78 mg, this portion was also revealed to be more effective than the synthetic fungicide (metalaxyl + mancozeb).

The antifungal actions of the seed powder of neem on a tomato cultured with *Fusarium oxysporum* and *Meloidogyne incognita* were also studied by Hadian et al. [78]. The plants were plucked and analyzed 60 days after inoculation. The study's findings showed that Fusarium and Meloidogyne fungi produced a significantly lesser infection on the neem-treated tomatoes than in the control. The numerous demonstrated antifungal actions of neem in several investigations substantiate the plant's potency as a biofungicide in controlling fungal diseases of plants.

9.2. Antibacterial Activity. Plant bacterial infections are often difficult to eradicate. A novel method based on natural substances such as botanical extracts is required for efficient protection against plant infections. Traditionally, neem has been utilized to combat plant-attacking bacterial species. Mahfuzul Hoque et al. [79] studied the antibacterial activity of neem extracts against 21 strains of food-borne pathogens, and the results showed that neem extract contains antibacterial components that could be effective in suppressing food-borne pathogens and spoilage organisms. Yerima et al. [80] investigated the antibacterial properties of neem extracts from the leaf, seed, fruit, and bark on bacteria isolated from the mouths of adults. Results of the study established that the neem bark and leaf extracts have significant antibacterial activity against the test bacterial species. Only at greater doses did the seed and fruit extracts demonstrate antibacterial action. Perumal et al. [81] reported significant antibacterial action against *Xanthomonas axonopodis* with the leaf extract of neem. *Pseudomonas syringae pv. syringae, Xanthomonas arboricola pv. corylina,* and *Agrobacterium tumefaciens* were all shown to be highly suppressed by neem seed extract in a study by Goel et al. [73]. Neem extracts from specific parts of the plant have exhibited direct inhibitory effects on phytobacterium proliferation and survival, demonstrating the plant's potency against such pathogenic microorganisms.

9.3. Antiviral Activity. Viruses are accountable for a broad spectrum of major plant diseases, as well as significant losses in agricultural yield and quality. Plant viruses, according to Pennazio et al. [82], are a huge danger to an array of crops, with virus-related economic losses placing second to other pathogen-related losses. Infected plants can display a variety of symptoms depending on the infection, but leaf distortion, leaf yellowing, and other growth abnormalities are common [82]. Unlike fungal and bacterial diseases, once a viral disease infects a plant, nothing can be done to rid it off the virus, and hence, there are no data on the efficacy of neem in treating viral infections in plants. Owing to this, the most efficient approach is to use an effective biocontrol agent or product to eradicate the disease-spreading insect vector. Viral insect vectors include aphids, whiteflies, leafhoppers, and mites (gall mites) [83]. Interestingly, these vectors have been demonstrated to be controlled by neem extracts through the current study. The numerous findings documented in this review strongly support neem and its formulations on diseased plants for effective treatments.

10. Prospects of Neem in Pest and Disease Management

With synthetic biocides posing health and environmental risks, neem-based pesticides appear to be a promising alternative in pest management systems. It is established that neem-based pesticides have no residual effect on agricultural produce; with populations opting for green technology, neem can be the best option as a pest control agent. Through the current study, it has been substantiated that neem biopesticides are systematic and offer long-term insect protection to plants. Schmutterer and Singh [20] reported a list of 413 insect pest species responsive to neem treatments. Concerning plant diseases, neem and its formulations have shown high efficacy against many pathogenic microorganisms. This largely encompasses fungi and bacteria. Moslem and El-Kholie [84] stated that more than 14 common fungus species are sensitive to neem formulations. Other several plant diseases including anthracnose, downy mildew, rust, and black spot have also been shown to be treated with neem extracts [22]. With several reports on the biological actions of neem and its formulations in plant pest and disease management, neem deserves an in-depth investigation to explore the plant's worth against phytopathogenic microorganisms and pests. In addition to the biocidal potential of neem, the plant has a fascinating prospect in other areas including medicines, the environment, and industries.

11. Conclusion

Neem has demonstrated multidisciplinary actions against pests and diseases of plants. The current review documented the biocidal potency of the neem plant. Through this study, neem has been established to be rich in many bioactive compounds, which are responsible for its biological actions such as antifeedant nature, oviposition deterrence, insect repellence, and growth inhibition in insect pests. The potent plant has also demonstrated effectiveness in fumigation. Activities of plant pathogens from widespread disease-causing fungi, bacteria, and viruses have also been proven to be inhibited by neem extracts. Findings from the study have revealed the effectiveness, safety, cost-efficiency, and eco-friendliness of neem in plant pest and disease management. This present review, therefore, recommends extensive research into neem to tap into the full potential of the plant. In addition, a study on the amalgamation of neem products with other bioproducts is recommended to ascertain their synergistic nature on pests and pathogens of plants. Neem extract and products can therefore be utilized as a safe and efficient alternative to synthetic biocides in plant pest and disease management systems, particularly for low-income farmers.

Data Availability

The quantitative data supporting this systematic review are from previously reported studies and datasets, which have been cited. The processed data are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this article.

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