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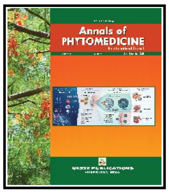

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Chemical diversity and therapeutic potential of phytochemicals and essential oils in Brinjal: A comprehensive review

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Abstract

Brinjal (*Solanum melongena* L.) is an economically important solanaceous vegetable crop widely cultivated across subtropical regions, but its productivity is severely constrained by the shoot and fruit borer, *Leucinodes orbonalis* Guenée (Lepidoptera: Crambidae). Conventional management has relied heavily on chemical insecticides, leading to problems of pest resistance, environmental contamination, and adverse effects on non-target organisms. These limitations have spurred interest in eco-friendly alternatives, particularly phytochemical-based strategies. Brinjal naturally synthesizes defensive compounds such as glycoalkaloids, phenolics, and flavonoids, which confer resistance against herbivory. In addition, volatile organic compounds (VOCs) and semiochemicals play key roles in pest-plant-natural enemy interactions, offering opportunities for innovative integrated pest management (IPM). Botanical extracts and essential oils from plants such as neem, papaya, marigold, garlic, and citrus have demonstrated ovicidal, larvicidal, antifeedant, and repellency effects against *L. orbonalis*. Field trials indicate that certain botanicals not only reduce infestation but also enhance yield and cost-benefit ratios, while being compatible with natural enemies. Advances in breeding, biotechnology, and nano-formulation approaches further strengthen the scope of phytochemical-based pest suppression. However, challenges such as variability in phytochemical content, lack of standardized extraction and formulation protocols, shorter residual activity, and cost-effectiveness constraints limit large-scale adoption. Future research should focus on standardization, field validation across agro-climatic zones, and integration of phytochemicals with pheromone traps, cultural practices, and biological control agents to develop robust IPM modules. Overall, phytochemical-based strategies represent a sustainable, residue-free, and environmentally safe alternative to synthetic insecticides for the effective management of *L. orbonalis*.

1. Introduction

Brinjal (*Solanum melongena* L.), a solanaceous vegetable crop, is widely cultivated in subtropical regions and valued for its culinary versatility (Kalloo, 1993). It is the third most consumed vegetable after potato and tomato and is often referred to as the "king of vegetables" (Chapman, 2019). Brinjal yield varies with cultivar, season, and crop management practices, with hybrids generally out performing open-pollinated varieties, producing 600-800 q/ha compared to 300-500 q/ha (Nayak *et al*., 2024). Despite its agricultural and economic importance, brinjal cultivation is severely constrained by insect pests, particularly the shoot and fruit borer (*Leucinodes orbonalis* Guenée; Lepidoptera: Crambidae). It also infests other solanaceous crops, including *Solanum tuberosum* and *Solanum lycopersicum* (Borah and Dutta, 2025). Under severe infestations, yield losses due to *L. orbonalis* may reach up to 64.84% (Singh *et al*., 2016). For decades, farmers have primarily relied on intensive chemical insecticide use to manage this pest. Active groups include diamides and avermectins (Meena and Chandra, 2024), as well as organophosphates (Singh and Sachan, 2015) and carbamates (Ramesh, 2014). However, *L. orbonalis* has developed resistance to several commonly used insecticides, such as chlorpyrifos (Shirale *et al*., 2017), phosalone, flubendiamide, fenvalerate, emamectin benzoate, and thiodicarb (Kariyanna *et al*., 2020). This underscores the declining effectiveness of chemical control, with continued reliance accelerating resistance development rather than resolving the problem.

Excessive insecticide use also generates serious ecological concerns. Residual contamination in soil and water negatively impacts non-target organisms, including natural enemies and pollinators, which otherwise play crucial roles in biological control (Ali *et al*., 2021). These limitations have renewed interest in sustainable pest management strategies, including the use of biopesticides, botanical extracts, and semiochemicals (Panwar *et al*., 2024). Conventional management through synthetic insecticides faces limitations such as pest resistance, residues, and environmental hazards. Consequently, phytochemical-based, eco-friendly alternatives have emerged as promising strategies for sustainable management of this pest.

2. Phytochemicals in brinjal

Phenolics represent a major class of secondary metabolites that include phenolic acids, flavonoids, lignans, stilbenes, and tannins, which exhibit wide structural diversity, ranging from simple

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monomeric acids to complex polymers such as tannins. Reported chemical constituents and functional properties of brinjal mentioned in Table 1. These compounds, abundant in fruits and vegetables, are among the most important natural sources of antioxidants in the human diet. More broadly, secondary metabolites such as terpenoids and steroids, alkaloids, fatty acid-derived substances, polyketides, non-ribosomal peptides, and enzyme cofactors perform critical ecological functions, particularly in mediating plant insect interactions through the exchange of volatile chemical signals that contribute to ecological balance (Talukder *et al*., 2021). Flavonoids represent an important subclass of phenolics in eggplant. Quercetin, myricetin, kaempferol, and isorhamnetin are among the most widespread flavonoid aglycones. Their concentrations vary significantly across tissues, with eggplant leaves containing 10- to 20-fold higher levels of flavonoids compared to fruits. Notably, apigenin and isorhamnetin were absent from fruits, suggesting that leaves represent a rich source of natural antioxidants. Within leaves, greenish violet types contained significantly higher concentrations of flavonoids than green leaves, while early-flowering accessions exhibited elevated levels of myricetin and kaempferol (Min *et al*., 2014). In addition, various steroidal glycoalkaloids, including khasianine, solamargine, solasonine, and solasodine, were detected in the roots, while solamargine and solasonine were also found in leaves, stems, and fruits, highlighting their systemic distribution and potential health benefits for humans. Terpenes, particularly monoterpenoids and sesquiterpenoids, were more abundant in the leaf and root, while glycoside flavonoids such as quercetin 3-O-glucoside, quercetin 3-O-malonyl glucoside, cyanidin 3-O-rutinoside, rutin, luteolin 7-glucoside, delphinidin 3-rutinoside, and isorhamnetin 3-glucoside-4'-glucoside predominated in the leaf and stem. Saponins were detected primarily in the root and fruit (Contreras - Angulo *et al*., 2022).

Fruits contain arginine, aspartic acid, histidine, 5-HT, delphinidine –3 bioside (nasunin), oxalic acid, solasodine, ascorbic acid, tryptophan, *etc*. Leaves contain chlorogenic, hydrocaffeic and protocatechuric acids (Ahmad *et al*., 2017). Some of the alkaloids present are tropane, pyrrolidine, quinazolizidine, steroid alkaloids and glycoalkaloids. Two steroidal saponins melongoside L and melongoside M, and three new saponins melongoside N, O and P, have been isolated from seeds. Catechol oxidase has been isolated and characterised from *Solanum melongena*. A bioflavonoid glycoside named solanoflavone is present in the leaves and fruits of *S. melongena* (Das and Barua, 2013). Biochemical mechanisms underlying resistance in brinjal have been further elucidated. Lalitha and Kashyap (2020) demonstrated that higher levels of glycoalkaloids (particularly solasodine), total phenols, and elevated activities of polyphenol oxidase and peroxidase are strongly correlated with resistance. These findings emphasize that biochemical traits are more reliable predictors of resistance than morphological characteristics, highlighting the central role of phenolics, flavonoids, and oxidative enzymes in defense.

Table 1: Phytochemical constituents identified in brinjal (*S. melongena*)

S. No.	Compound/class	Specific examples	Source (Plant part/extract)	Properties/notes	References
1.	**Anthocyanins**	Nasunin (Delphinidin 3-glucoside, Petunidin 3RGc5G 3-(p-coumaroy-lrutinoside) -5-glucoside), Delphinidin 3-rutinoside, Delphinidin	Peel	Pigments; antioxidant, iron chelator	Mazza *et al*., 2004
2.	**Nasunin isomers**	Cis- & Trans-delphinidin glycosides	Peel	Antioxidant, chelates iron, inhibits hydroxyl radical generation	Ichiyanagi *et al*., 2005
3.	**Phenolic acids**	Chlorogenic, hydrocaffeic, protocatec huic acids	Leaves, fruit flesh	Antioxidant activity; cultivar-dependent variation	Luthria, 2006
4.	**Flavonoids**	Solanoflavone (bioflavonoid glycoside)	Leaves and fruits	Antioxidant	Shen *et al*., 2005
5.	**Alkaloids and glycoalkaloids**	Solasodine, tropane, pyrrolidine, quinazolizidine, steroid alkaloids, glycoalkaloids	Fruits, roots, callus	Bitterness in fruit due to glycoalkaloids	Saleh, 2015
6.	**Steroidal saponins**	Melongosides L, M, N, O, P	Seeds	Isolated novel compounds	Kintia *et al*., 1985
7.	**Other compounds**	Catechol oxidase enzyme	Fruit	Isolated and characterized	Sharma *et al*., 1980
8.	**Amino acids and related metabolites**	Arginine, aspartic acid, histidine, tryptophan, serotonin (5-HT), oxalic acid, ascorbic acid	Fruits	Nutritional metabolites	Rai and Pandey, *et al*., 1997
9.	**Sugars and Proteins**	Free reducing sugars, amide proteins	Fruit	Nutritional quality	Rai *et al*., 1997

3. Metabolic components in brinjal

These interactions are governed by semiochemicals, chemical signals that mediate communication between organisms, signaling molecules that drive insect plant/insect-insect and tritrophic interactions (Ruhanen *et al*., 2025; Rodriguez-Flores *et al*., 2025). Recent studies by Nusra *et al*. (2021) identified key compounds, including 2,2-(Ethane-1,2-diylbis(oxy)) bis (ethane-2,1-diyl) dibenzoate, 3,7-dimethylocta-1,6-dien-3-ol, and benzyl alcohol, from various plant parts like fruits, shoots, leaves, and flowers emitted by eggplant. Interestingly, these volatiles play an intricate role in the attraction of insect pests. Reported VOCs associated with Brinjal mentioned in Table 2.

Table 2: Volatile organic compounds (VOCs) identified in brinjal

S. No.	VOCs present in brinjal	Released on attack of pests	References
1.	2,22 -(Ethane-1,2-diylbis(oxy) bis (ethane-2,1-diyl) dibenzoate, 3,7-dimethylocta-1,6-dien-3-ol, Benzyl alcohol	Brinjal shoot and fruit borer	Nusra *et al.*, 2021
2.	Nerolidol 2; beta-Cyclocitral; 1,3-Cyclohexadiene-1-carboxaldehyde, 2,6,6-trimethyl, and beta. -iso-Methyl ionone), Cyclohexanone, 2,2,6-trimethyl. (Furan, 2-pentyl, 2-Butenoic acid, 3-hexenyl ester, (E, Z) and (E)-Hex-3-enyl (E)-2-methylbut-2-enoate], Benzaldehyde and 2-Ethylbenzaldehyde, Cyclohexanol, 2,6-dimethyl, and 1-Octen-3-ol)	Tomato pinworm	Chen *et al.*, 2021
3.	Geraniol	Brinjal shoot and fruit borer	Ghosh *et al.*, 2023
4.	(Z)-3-hexen-1-ol] and terpenoids [α-pinene, (E)-β-caryophyllene, α-humulene, azulene	Whitefly	Darshanee *et al.*, 2017
5.	Geraniol, (*Z*)-3-hexen-1-ol, phenylacetaldehyde, and methyl salicylate,	Brinjal shoot and fruit borer	Byers, 2013
6.	Heptanal, octanal, hexanol <2-ethyl->, dihydrofloralol, Benzaldehyde, 2,4-dimethyl-and Benzothiazole and 1, 2-Benzenediol, o-(4- methoxybenzoyl)-o’-(2,2,3,3,4,4,4-heptafluorobutyryl)- and their production was not observed in non-infested plants. In contrast, isophthalaldehyde and 1,2-Benzenediol, o-(4-methoxybenzoyl)-o’-(2, 2, 3, 3, 4, 4-heptafluorobutyryl)	Whitefly	Mansour *et al.*, 2015

4. Essential oils in Brinjal and other chemicals

4.1 Roles of essential oils in Brinjal

- **Plant defense:** Essential oils act as natural protectants against fungi, bacteria, and some insect pests (Batish *et al.*, 2008). Plant-based compounds and their reported effects in brinjal mentioned in Table 3.
- **Medicinal properties:** Many components (*e.g.*, eugenol, geraniol, caryophyllene) possess antioxidant, anti-inflammatory, and antimicrobial activities, adding to the nutraceutical value of brinjal (Keservani *et al.*, 2024).
- **Aroma and flavor:** Though not strongly aromatic, the subtle fragrance of brinjal fruits and flowers is due to its essential oils (Singh *et al.*, 2004).

Table 3: Botanical extracts and formulations reported from brinjal studies

S. No.	Plant (common/ scientific)	Extract/formulation tested	Target brinjal pest (s) (reported)	Reported effect on pest
1.	Neem - *Azadirachta indica*	Neem seed / kernel extract, neem oil, commercial neem formulations	Shoot and fruit borer, aphids, general lepidopteran/chewing pests	Antifeedant, growth regulator, reduced population and oviposition; used widely as a botanical insecticide in brinjal IPM.
2.	Basil - *Ocimum basilicum*	Essential oil (EO); formulations (EO + carriers/kaolinite)	Sucking pests and several lepidopteran larvae (laboratory/ farm studies)	Insecticidal and repellent activity; reduced survival, development and oviposition in lab and field formulations.
3.	Lemongrass - *Cymbopogon citratus*	Essential oil (leaf EO)	Brinjal hadda beetle (*Henosepilachna vigintiocto punctata*) and other chewing pests	Toxicity/LC$_{50}$ in bioassays; higher mortality than some botanical checks in lab tests.
4.	Garlic -*Allium sativum*	Aqueous/ethanolic extract (crushed garlic sprays)	Shoot and fruit borer, aphids, general pests	Repellent and population suppression reported in field trials; often used as a homemade botanical spray.
5.	Chili / Capsicum-*Capsicum annuum*	Aqueous extract (chili-garlic mixes commonly used)	Shoot and fruit borer, lepidopteran pests	Repellent/antifeedant activity; used alone or in combination (*e.g.*, chili+garlic) in field trials with reduced SFB damage.

6.	Eucalyptus - *Eucalyptus globulus*	Leaf extract/EO	Sucking pests, general brinjal pests	Significant reduction in pest numbers and yield improvement reported in brinjal when applied as extract.
7.	Tulsi/Holy basil - *Ocimum tenuiflorum*	Aqueous extract/EO	Sucking pests (aphids, whiteflies)	Reduced populations in field plots; recommended as an IPM component for brinjal.
8.	Mustard -*Brassica* spp.	Mustard seed/leaf extract	Aphids and other sucking pests	Repellent and population suppression (reports from vegetable trials).
9.	Mahogany-*Swietenia mahagoni*	Seed extract	Chewing pests in field trials	Reported reduction in pest infestation in brinjal field experiments.
10.	Marigold-*Tagetes erecta*	Leaf/flower extract or companion planting	Several pests (general deterrent)	Reported as one of several botanicals that reduce pest incidence; also used in intercrops.
11.	Black seed/Nigella -*Nigella sativa*	Essential oil (lab assays)	Stored-product pests (example studies exist) - limited brinjal-specific data	Insecticidal in lab assays; relevance to field brinjal pests is promising but less documented.

4.2 Limitations of synthetic pesticides and advantages of botanicals

Although, synthetic pesticides are target specific and effective, their effects on the environment are mostly deleterious. Plant-based pesticides contain active ingredients with low half-life period and their effects on the environment are not too detrimental making them more acceptable for pest management (Sharma *et al*., 1995).

4.3 Neem and its derivatives

The results from the experiment for both crops in the major and minor seasons showed that *L. orbonalis* and *E. olivacea* densities throughout the experiment were lower compared with that recorded on the control plots. Thus, Levo was as effective as lambda super in reducing *L. orbonalis* and *E. olivacea* densities on eggplant. Ahmed (2000) reported that lepidopterous insects are highly sensitive to neem compounds and that the order lepidoptera, to which these insects belong, was classified as one group of the insects well controlled with many botanical insecticides. The report concluded that, the results held a promise for the management of the other members of this order, which attack okra and cotton. Several reports have also confirmed the ovicidal, insecticidal, antifeedant, and growth-regulating properties of neem extracts and commercial neem formulations on *L. orbonalis* and other lepidopteran pests.

4.4 Other plant extracts for management of *L. orbonalis*

To combat agricultural pests like BSFB, insecticides play a crucial role, with significant implications for both agriculture and public health (Ali *et al*., 2021). In recent years, there has been a growing concern about the harmful effects of synthetic pesticides on the environment and human health, leading to an increased interest in the use of plant extracts for pest control in agriculture (Isman, 2000). Plant extracts contain natural compounds that possess the ability to repel or eliminate pests, making them a promising alternative to conventional pest control methods. Extracts from neem leaves and seeds (*Azadirachta indica*), marigold (*Tagetes erecta*), papaya (*Carica papaya*), and *Murraya paniculata* leaf extracts have demonstrated effectiveness. Crude methanolic extracts of *Citrus limon* and *Aloe vera* also caused high mortality in *L. orbonalis* larvae (Pavani *et al*., 2023; Madhavi *et al*., 2023). Sangma *et al*. (2019) evaluated the efficacy of several indigenous botanicals against *L. orbonalis* in field experiments conducted at Allahabad during July-November 2016. Eight treatments were tested, including papaya leaf extract (92 g/l), jatropha leaf extract (50 g/l), tamarind fruit extract (50 g/l), tulsi leaf extract (50 g/l), neem oil (20 ml/l), onion bulb extract (30 g/l), garlic bulb extract (30 g/l), and an untreated control, using a randomized block design with three replications. Applications were made at 15-day intervals. All the botanicals significantly reduced shoot and fruit infestation compared to the control. Among them, neem oil (2%) showed the lowest shoot infestation (13.44%), followed by jatropha leaf extract (14.19%) and papaya leaf extract (15.03%). Similarly, fruit infestation was lowest in neem oil (15.88%), followed by jatropha leaf (16.28%) and papaya leaf extract (16.66%). Neem oil also recorded the highest cost-benefit ratio (1:3.11), demonstrating its superior economic viability. These findings corroborate earlier reports on the pesticidal potential of botanicals such as neem, garlic, papaya, and ash (Mochiah, 2011).

4.5 Efficacy of spice extracts in brinjal pest management

The study evaluated the prospects of aqueous extracts of five Nigerian spices against garden eggplant defoliators and *L. orbonalis* in the field. The treatments consisted of *Piper guineense, Aframomum melegueta, Eugenia aromatica, Zingiber officinale*, and *Capsicum annum*. All extracts reduced leaf damage compared to the control, with *P. guineense* and *E. aromatica* being the most efficacious. These extracts not only reduced defoliation but also minimized fruit borer infestation and increased yield (Ugwu *et al*., 2021).

4.6 Comparative efficacy of botanicals with synthetic insecticides

In order to evaluate the bioefficacy of certain botanicals alone and in combination with a synthetic insecticide, Wargantiwar *et al*. (2010)

conducted a field trial during the Kharif season of 2009–10 at Allahabad (U.P.) against *L. orbonalis*. The treatments included neem seed extract (NSE 5%), brinjal leaf extract (BLE 5%), and neem oil (2%), either applied individually or in combination with endosulfan (0.035%), as well as endosulfan alone (0.07%). Results revealed that endosulfan (0.07%) was the most effective treatment, followed by NSE (5%) + endosulfan (0.035%), neem oil (2%) + endosulfan (0.035%), and BLE (5%) + endosulfan (0.035%). The individual botanicals (NSE 5%, BLE 5%, and neem oil 2%) provided moderate efficacy, ranking in the middle order. Maximum yields were recorded in plots treated with endosulfan (0.07%), followed by its combinations with botanicals, while all treatments performed significantly better than the untreated control. In southeastern Nigeria, comparative trials over two seasons evaluated the efficacy of botanicals like *Ageratum conyzoides, Annona muricata,* and *Elaeis guineensis* against *L. orbonalis* on *Solanum gilo*, alongside lambda-cyhalothrin. Although, the synthetic insecticide provided the lowest fruit damage, goat weed (*A. conyzoides*) performed comparably, achieving low infestation levels and high yields. These findings suggest that certain botanicals can effectively substitute chemical sprays in smallholder farming (Emeasor and Uwalaka, 2018). A recent field trial was conducted at the Central Research Farm, SHUATS, Prayagraj, Uttar Pradesh during the Kharif season of 2023 in a randomized block design with three replications, comprising eight treatments: neem oil (2%), chlorantraniliprole 18.5% SC, spinosad 45% SC, flubendiamide 480 SC, indoxacarb 14.5% SC, pongamia + flubendiamide, neem oil + flubendiamide, and an untreated control. All insecticidal treatments significantly reduced shoot and fruit damage of brinjal compared to the control. The lowest shoot and fruit infestation was recorded in plots treated with chlorantraniliprole 18.5% SC (4.03% and 3.20%, respectively), followed by spinosad 45% SC (4.43% and 4.15%). Yields ranged from 85.00 to 225.50 q/ha across treatments, with the maximum yield in chlorantraniliprole (225 q/ha), followed by spinosad (190 q/ha), flubendiamide (175 q/ha), indoxacarb (160.35 q/ha), pongamia + flubendiamide (140.33 q/ha), neem oil + flubendiamide (132.40 q/ha), and neem oil (120.50 q/ha). The highest cost-benefit ratio was also obtained with chlorantraniliprole 18.5% SC (1:10.3), followed by spinosad 45% SC (1:8.5), flubendiamide 480 SC (1:7.5), indoxacarb 14.5% SC (1:7.4), pongamia + flubendiamide (1:6.0), neem oil + flubendiamide (1:5.5), and neem oil (1:5.4), compared to the control (1:4.2) (Upadhyay *et al.*, 2024).

4.7 Induced plant defense mechanisms

Prasannalaxmi and Rani (2016) studied directly induced defence mechanisms in brinjal infested with *L. orbonalis*. The pest attack elevated carbohydrate, protein, amino acids, and chlorophyll contents in leaves, and also increased production of reactive oxygen species, lipid peroxidation, total phenols, flavonoids, and phenylalanine ammonia lyase activity. Several phenolic acids such as gallic, caffeic, hydroxybenzoic, and vanillic acid were upregulated. Induced oxidative enzymes including catalase and peroxidase were strikingly higher in infested plants. These systemic biochemical and enzymatic responses constitute a multicomponent defence mechanism, reducing pest survival and forming the basis for exploiting natural plant resistance in breeding and management.

4.8 Farmer-level practices and challenges

At the farmer level, pest management often relies on calendar sprays of conventional insecticides regardless of actual infestation. This has led to higher costs of production, pest resurgence, health risks, and residue problems (Kumar, 2019). Studies show that integration of physical and mechanical methods such as light traps and shoot removal with botanicals like neem seed kernel extract (NSKE) can provide effective, eco-friendly alternatives. For organic cultivation, combining removal of infested shoots, light traps, and NSKE sprays proved superior in maintaining yield and profitability.

Several plant-derived extracts and oils exhibit insecticidal and deterrent activities against *L. orbonalis*. Neem (*Azadirachta indica*) seed extract (NSE) has been widely tested, showing oviposition deterrence and significant reduction in fruit infestation (Vijay Kumar, 2019). Similarly, methanolic extracts of *Citrus limon* and *Aloe vera* demonstrated larvicidal potential (Pavani *et al.*, 2023). Nigerian aromatic spices including *Piper guineense* and *Eugenia aromatica* significantly reduced leaf damage and fruit infestation in field conditions (Ugwu *et al.*, 2021). Other botanicals such as soursop (*Annona muricata*) seeds, *Ageratum conyzoides* leaves, and *Elaeis guineensis* bunch ash have also been reported effective (Emeasor *et al.*, 2022). These studies confirm the potential of botanical insecticides as viable alternatives to chemical sprays.

5. Role of phytochemicals and biotic components and essential oils to control insects

Semiochemicals are broadly classified into pheromones and allelochemicals triggering intraspecific and interspecific communication between and among the insects (Upadhyay *et al.*, 2024). These chemical cues are capable of either attracting or repelling insects, influencing their behavior and physiological responses.When herbivores attack plants, the plants do not rely on physical defenses; instead, they produce distress signals from as volatile organic compounds (VOCs). Role of brinjal VOCs in attraction by Nusra *et al.* (2019) revealed that volatiles from brinjalbrinjal fruits, leaves, and shoots significantly enhanced the attraction of male *L. orbonalis* to its sex pheromone, with fruit volatiles being the most potent. Such findings open up new ways by strategically manipulating volatile profiles in both brinjal and its alternate host plants, providing a promising semiochemical-based integrated pest management approach. As we delve deeper into the intricate web of interspecies and intraspecies chemical communication, it becomes clear to design an elegant and sustainable pest management system. Early studies by MacLeod and Troconis (1983) laid the foundation for understanding its unique VOCs emission in egg plant.

How parasitoids locate their hosts via chemical cues- Volatiles act as cues that attract parasitoids to the pests (Leo *et al.*,2024). Among the parasitoids, *Trichogramma chilonis* Ishii utilizes various cues to locate its host. These cues include larval frass, body washings from females and adults, volatiles released during oviposition, and pheromones emitted by adult insects, as well as synthetic pheromone blends that mimic those of larvae. Collectively, these signals guide the parasitoid to its target (Rahman *et al.*, 2021). *L. orbonalis* lays its eggs on the lower surface of the leaves in host plants (Mannan *et al.*, 2021). Under controlled conditions, the egg parasitoids *T. chilonis* showed greater movement and parasitism on *L. orbonalis* eggs than *T. pretiosum*. However, *T. pretiosum* achieved the highest parasitism and emergence on 1-day-old eggs (Ranjith *et al.*, 2018). Additionally, scientists have discovered that the extracts from infested brinjal larvae frass and synthetic pheromone blends can amplify the parasitization of *L. orbonalis* eggs by *T. chilonis* (Laxmi and Rani, 2019). By copying the natural signals used by plants or insects, scientists have discovered a way to improve natural methods of controlling pests. Chlorogenic acid (CGA), the most abundant phenolic in brinjal, plays a dual role in providing antioxidant protection and contributing to pest resistance. Talukder *et al.* (2021) reported that *L. orbonalis* larvae feeding on phenolic-rich tissues encounter adverse effects on survival, while these metabolites also mediate tritrophic interactions with natural enemies. Plant breeding for pest resistance has focused on identifying resistant cultivars with elevated phytochemical profiles. Marker-assisted selection targeting glycoalkaloids, phenolics, and flavonoids may enhance inherent resistance. Biotechnological approaches, including metabolic engineering, aim to boost levels of defensive metabolites. Bt brinjal represents a transgenic strategy against *L. orbonalis*, which can be complemented with natural phytochemical defenses for durable resistance.In brinjal (eggplant), secondary metabolites constitute an essential line of defense against herbivory. Glycoalkaloids such as solasodine, solasonine, and solamargine exert toxic and antifeedant effects on insect larvae, while phenolics and flavonoids act as oviposition and feeding deterrents. Experimental evidence shows that infestation by insects induces the accumulation of phenolics, flavonoids, and oxidative enzymes such as catalase and peroxidase in eggplant tissues, underscoring their defensive role. Resistant cultivars consistently maintain higher levels of these compounds compared to susceptible varieties, which often exhibit weaker biochemical defenses (Prasannalaxmi and Usha Rani, 2016).

Phytochemical-based tactics are most effective when integrated into broader IPM frameworks. Push-pull strategies employ repellent volatiles to drive pests away while attractive VOCs or pheromone traps draw them towards lethal sinks. Field evaluations confirm that combining neem seed extract with cultural practices such as shoot removal and light traps can effectively suppress *L. orbonalis* (Kumar, 2019). Botanical sprays are generally compatible with natural enemies, making them suitable for ecological IPM designs. Rahul *et al.* (2018) emphasized that botanicals are a rich source of bioactive compounds with insecticidal, fungicidal, antifeedant, and repellent properties, making them highly suitable for incorporation into sustainable pest management. They highlighted that phytochemicals such as phenolics, terpenoids, alkaloids, flavonoids, and essential oils provide multiple ecological services direct toxicity to pests, disruption of feeding and reproduction, as well as antimicrobial protection while remaining safe for beneficial organisms and the environment. Moreover, their biodegradability and compatibility with biological control agents position them as ideal components of IPM programs, particularly in developing countries where reliance on synthetic pesticides poses economic and health challenges. Together, these findings reinforce the potential of phytochemicals to serve not just as standalone control agents but as integral components of comprehensive IPM strategies, improving crop protection while reducing ecological risks.

6. Challenges and future prospects

Despite encouraging results, several challenges hinder the large-scale adoption of phytochemical-based management for *L. orbonalis*. One of the primary issues is the variability in phytochemical content across cultivars, seasons, plant age, and environmental conditions, which affects consistency in pest control efficacy. For example, the levels of phenolics, flavonoids, and glycoalkaloids may fluctuate considerably, making standardized recommendations difficult. approval process for commercializing botanical pesticides is often lengthy and inconsistent across countries, delaying their field availability. However, these challenges also open avenues for future innovation. Commercial formulations of promising botanicals such as neem, pongamia, *Murraya paniculata*, and semiochemical blends (*e.g.,* green leaf volatiles with sex pheromones) can enhance adoption if developed with optimized delivery systems such as nanoformulations, controlled-release matrices, and encapsulation techniques. Advances in molecular biology and metabolomics provide opportunities to identify key phytochemicals, elucidate their modes of action, and guide breeding programs for resistant cultivars with elevated defensive metabolites. Future research should prioritize multi-location field trials to validate the performance of phytochemical-based strategies under diverse agro-climatic conditions. Additionally, integrating these approaches with pheromone-based monitoring, biocontrol agents, and cultural practices can provide robust, farmer-friendly IPM modules. Extension and capacity-building programs will also play a pivotal role in scaling up adoption, ensuring that phytochemical-based pest management becomes a practical and economically viable alternative to synthetic insecticides.

7. Conclusion

Phytochemical-based management strategies represent a promising and sustainable alternative to conventional insecticides for managing the eggplant shoot and fruit borer, *L. orbonalis*. By harnessing naturally occurring plant defenses, including glycoalkaloids, phenolics, flavonoids, essential oils, and semiochemicals, these approaches align closely with the goals of eco-friendly and residue-free agriculture.The accumulated body of evidence highlights that botanicals such as neem, papaya, marigold, and lemon extracts, along with innovative combinations of volatiles and sex pheromones, can significantly suppress *L. orbonalis* infestations. Furthermore, phytochemicals are generally compatible with natural enemies, enhancing their suitability in ecological pest management systems.The way forward lies in integration: combining phytochemical-based sprays with pheromone traps, shoot removal, light traps, and biological control agents can create robust IPM modules. Such multi-pronged strategies not only reduce pest pressure but also delay resistance development, safeguard biodiversity, and minimize health hazards associated with synthetic pesticides. As agriculture faces growing demands for sustainability, phytochemicals and semiochemicals offer a vital tool to bridge traditional knowledge with modern IPM. Continued research into refining formulations, developing cost-effective delivery systems, and promoting farmer awareness will be crucial for scaling up adoption. Ultimately, the integration of phytochemical-based management into main stream agricultural practices has the potential to reduce pesticide dependence, improve crop yields, and contribute to healthier agroecosystems.

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Conflict of interest

The authors declare no conflicts of interest relevant to this article.

References

Ahmed, F.A.; Mubassara, S. and Sultana, T. (2017). Phytoconstituents, bioactivity and antioxidant potential of some commercial brinjal (*Solanum melongena* L.) cultivars of Bangladesh. Jahangirnagar University Journal of Biological Sciences, **5**(2):41-50.

Ahmed, S.M.S. (2000). Laboratory evaluation of some biological activity of *Ricinus communis* seed extracts against the rice weevil, *Sitophilus oryzae* (L.). Arab Univ. J. Agric. Sci., **8**(3):853-861.

Ali, S.; Ullah, M.I.; Sajjad, A.; Shakeel, Q. and Hussain, A. (2021). Environmental and health effects of pesticide residues. In: Inamuddin; Ahamed, M.I. and Lichtfouse, E. (eds) Sustainable Agriculture Reviews 48. Springer, Cham., pp:205-240.

Batish, D.R.; Singh, H.P.; Kohli, R.K. and Kaur, S. (2008). Eucalyptus essential oil as a natural pesticide. Forest Ecology and Management, **256**(12):2166-2174.

Borah, N. and Dutta, J.K. (2025). Incidence of brinjal shoot and fruit borer, *Leucinodesor bonalis* Guenée (Lepidoptera: Pyralidae) on potato in Biswanath District, Assam, India. Insect Environ., **28**(1):16-18.

Byers, K.J. (2023). Reducing eggs on eggplant: a common naturally emitted plant volatile could replace insecticides in the 'king of vegetables'. New Phytologist, **240**(3):915-917.

Chapman, M.A. (2019). Introduction: The importance of eggplant. In: Chapman, M. (ed) The Eggplant Genome. Compendium of Plant Genomes. Springer, Cham., pp:1-10.

Chen, L.; Li, X.; Zhang, J.; He, T.; Huang, J.; Zhang, Z.; Wang, Y.; Hafeez, M.; Zhou, S.; Ren, X.; Hou, Y. and Lu, Y. (2021). Comprehensive metabolome and volatilome analyses in eggplant and tomato reveal their differential responses to *Tuta absoluta* infestation. Front. Plant Sci., **12**:757230.

Contreras-Angulo, L.A.; Moreno-Ulloa, A.; Carballo-Castañeda, R.A.; León-Felix, J.; Romero-Quintana, J.G.; Aguilar-Medina, M.; Ramos-Payán, R. and Heredia, J.B. (2022). Metabolomic analysis of phytochemical compounds from agricultural residues of eggplant (*Solanum melongena* L.). Molecules, **27**(20):7013.

Darshanee, H.L.C.; Ren, H.; Ahmed, N.; Zhang, Z.F.; Liu, Y.H. and Liu, T.X. (2017). Volatile-mediated attraction of greenhouse whitefly *Trialeurodesva porariorum* to tomato and eggplant. Front. Plant Sci., **8**:1285.

Das, M. and Barua, N. (2013). Pharmacological activities of *Solanum melongena* Linn. (Brinjal plant). International Journal of Green Pharmacy (IJGP), **7(4).**

Emeasor, K.C. and Uwalaka, O.A. (2018). Control of fruit borer of garden egg *Leucinodesor bonalis* (Lepidoptera: Pyralidae) using organic and inorganic pesticides. Net J. Agric. Sci., **6**(2):16-19.

Ghosh, R.; Metze, D.; Sant, S.; Shaikh, M.; Deshpande, A.; Firake, D.M. and Pandit, S. (2023). Chemical ecology of Himalayan eggplant variety's antixenosis: Identification of geraniol as an oviposition deterrent against the eggplant shoot and fruit borer. New Phytologist, **240**(3):1259-1274.

Ichiyanagi, T.; Kashiwada, Y.; Shida, Y.; Ikeshiro, Y.; Kaneyuki, T. and Konishi, T. (2005). Nasunin from eggplant consists of cis–trans isomers of delphinidin 3-[4-(p-coumaroyl)-L-rhamnosyl(1–6)glucopyranoside]-5-glucopyranoside. Journal of Agricultural and Food Chemistry, **53**:9472-9477.

Isman, M.B. (2000). Plant essential oils for pest and disease management. Crop Prot., **19**:603-608.

Kalloo, G. (1993). Eggplant: *Solanum melongena* L. In: Genetic improvement of vegetable crops. Elsevier, United Kingdom, pp:587-604.

Kariyanna, B.; Prabhuraj, A.; Mohan, M.; Bheemanna, M.; Kalmath, P.Y.B. and Diwan, J.R. (2020). Insecticide usage pattern and evolution of resistance in eggplant shoot and fruit borer, *Leucinodesor bonalis* Guenée (Lepidoptera: Crambidae) in India. Plant Arch., **20**(2):1255-1261.

Keservani, R.K.; Tung, B.T.; Kesharwani, R.K. and Ahire, E.D. (eds) (2024). Plant metabolites and vegetables as nutraceuticals. CRC Press.

Kintia, P.K.; Shvets, S.A. and Melongosides, N.O. (1985). Steroidal saponins from seeds of *Solanum melongena*. Phytochemistry, **24**:1567-1569.

Kumar, A.V. (2019). Non-pesticidal management of *Leucinodes orbonalis* (Guenée) in brinjal. Doctoral dissertation, Dr. Panjabrao Deshmukh Krishi Vidyapeeth.

Laxmi, K.P. and Rani, P.U. (2019). Behavioral responses of parasitoid *Trichogramma chilonis* towards infochemicals from host plant *Solanum melongena* and pest *Leucinodesor bonalis*. Int. J. Entomol. Res., **4**(3):1-9.

Lalita, S. and Kashyap, L. (2020). Biology and mechanisms of resistance to brinjal shoot and fruit borer: A review. J. Entomol. Zool. Stud., **8**(2):2111-2118.

Leo, S.; Labbé, R.; McDowell, T. and Scott-Dupree, C. (2024). Volatiles emitted by pepper weevil-infested plants and fruit strongly attract the pteromalid parasitoid *Jaliscoa hunteri*. Biol. Control, **197**:105588.

Luthria, D.L. (2006). Significance of sample preparation in developing analytical methodologies for accurate estimation of bioactive compounds in functional foods. Journal of the Science of Food and Agriculture, **86**:2266-2272.

MacLeod, A.J. and Troconis, N.G.D. (1983). Aroma volatiles of aubergine (*Solanum melongena*). Phytochemistry, **22**(9):2077-2079.

Madhavi, M.; Srikanth, B.; Mahesh, L.; Guruswamy, S. and Mayookha, L. (2023). Insecticidal efficacy of certain plant extracts against the larvae of brinjal stem and fruit borer, *Leucinodesor bonalis* Guenee (Lepidoptera: Crambidae). Indian J. Sci., **14**(78):56169-56173.

Mannan, M.A.; Islam, K.S. and Jahan, M. (2021). Mating and oviposition behaviour of brinjal shoot and fruit borer, *Leucinodesor bonalis* Guenee. Bangladesh J. Agric. Res., **46**(3):285-296.

Mansour, S.A.A.; Roff, M.; Noor, M.R.M.; Saad, K.A.; Abuzid, I. and Kermani, N. (2015). Identification of semiochemicals released by brinjal, tomato, okra and chilli plants infested with whitefly, *B. tabaci*. Libyan Journal of Basic Sciences (LJBS), **2**(1):25-40.

Mazza, G.; Cacace, J.E. and Kay, C.D. (2004). Methods of analysis for anthocyanins in plants and biological fluids. Journal of AOAC International, **87**:129-145.

Meena, O.P. and Chandra, A. (2024). Efficacy of novel insecticides against *Leucinodesor bonalis* Guenee (Lepidoptera: Pyralidae) in brinjal cultivation. J. Exp. Agric. Int., **46**(12):52-57.

Min, J.; Lee, Y.; Kim, S.; Bang, J.; Park, Y.; Kim, Y. and Kim, M. (2014). Metabolite profiling of different eggplant (*Solanum melongena* L.) varieties using LC-MS and their correlation with antioxidant activity. Molecules, **19**:10480-10496.

Mochiah, M.B.; Banful, B.; Fening, K.N.; Amoabeng, B.W.; Offei, B.K.; Ekyem, S.; Braimah, H. and Owusu-Akyaw, M. (2011). Botanicals for the management of insect pests in organic vegetable production. Int. J. Entomol. Nematol., **7**(4):1-13.

Nayak, S.; Reena, S.; Soni, S. and others (2024). To analyse the trend, growth rate in area, production and productivity of major vegetable crops in Chhattisgarh plain zone. Int. J. Adv. Biochem. Res., **8**(7):181-188.

Nusra, M.S.F.; Udukala, D.N.; Amarasinghe, L.D. and Paranagama, P.A. (2021). Volatiles from host plant brinjal attract the brinjal shoot and fruit borer *Leucinodesor bonalis* Guenee. J. Asia-Pac. Entomol., **24**(3):695-703.

Nusra, M.S.F.; Udukala, D.N.; Paranagama, P.A. and Amarasinghe, L.D. (2019). Synergism of pheromone and host-plant volatile blends in the attraction of *LeucinodesorbonalisGuenee* males. Proc. Int. Forestry Environ. Symp.

Pavani, M.; Madhavi, M.; Mahesh, L. and Mayookha, L. (2023). Larvicidal potential of methanolic leaf extracts of *Citrus limon* and *Aloe vera* against brinjal shoot and fruit borer, *Leucinodes orbonalis* Guenée. Int. J. Zool. Stud., **8**(3):17-21.

Panwar, C.; Yadav, U.; Meena, A. and Bhati, M.S. (2024). Bio efficacy and economics of selected biopesticides against shoot and fruit borer [*Leucinodesor bonalis* (G.)] on brinjal [*Solanum melongena* (L.)]. J. Adv. Biol. Biotechnol., **27**(7):59-65.

Prasannalaxmi, K. and Rani, P.U. (2016). Interactions between herbivore *Leucinodes orbonalis* G. and its host plant *Solanum melongena* L.: A study on insect-induced direct plant responses. Allelopathy J., **37**:273-286.

Rahman, M.A.; Islam, K.S.; Jahan, M. and Mannan, M.A. (2021). Performance of field developed parasitoid, *Trichogramma chilonis* on eggplant shoot and fruit borer, *Leucinodesor bonalis* eggs. J. Exp. Zool. India, **24**(1).

Rahul, S.N.; Sherawat, A. and Singh, A. (2018). Benefits of pharmacologically active phytochemicals for integrated pest management. In: Pharmacological Benefits of Natural Products. JPS Scientific Publications, India, pp:116-129.

Rai, M.K. and Pandey, A.K. (1997). Folk medicines of Gond tribe of Seoni district, M.P. India. Journal of Non Timber Forest Products, **4**:61-69.

Ramesh, S. (2014). Ecology and management of brinjal shoot and fruit borer (*Leucinodesor bonalis* Guen.). Doctoral dissertation, Acharya N.G. Ranga Agricultural University, Rajendranagar, Hyderabad.

Ranjith, M.; Nelson, S.J. and Sithanantham, S. (2018). Active dispersal of *Trichogramma chilonis* Ishii and *T. pretiosum* Riley towards host eggs under confined condition and their parasitisation efficiency. TANSA Conf. Proc., **1**(2):3.

Rodríguez-Flores, M.S.; Diéguez-Antón, A.; Seijo-Coello, M.C. and others (2025). Flora volatile profiles of plants visited by *Vespa velutina*: A preliminary assessment in the interaction of plant-insect. J. Plant Res., pp:1-17.

Ruhanen, H.M.; Bruns, S.; Parsons, J.; Kivimäenpää, M. and Blande, J.D. (2025). The orientation and oviposition choices of *Plutellaxy lostella* and its parasitoid *Diadegmasemi clausum* on a range of brassica plants. Arthropod-Plant Interact., **19**(3):43.

Sangma, C.D.; Simon, S. and Nagar, S. (2019). Indigenous pest control practices for the management of brinjal shoot and fruit borer (*Leucinodesor bonalis* Guen.). J. Pharmacogn. Phytochem., **8**(3):103-108.

Saleh, G.S. (2015). Chemical detection of some active compounds in eggplant (*Solanum melongena*) callus as compared with fruit and root contents. Int. J. Curr. Microbiol. Appl. Sci., **4**(5):160-165.

Sharma, R.C. and Rashid, A. (1980). Isolation and characterization of catechol oxidase from *Solanum melongena*. Phytochemistry, **19**:1597-1600.

Sharma, S.K.; Dua, V.K. and Sharma, V.P. (1995). Field studies on the repellent action of neem oil. Southeast Asian J. Trop. Med. Public Health, **26**:180-182.

Shen, G.; Kiem, P.V.; Cai, X.F.; Li, G.; Dat, N.T.; Choi, Y.A.; Lee, Y.M.; Park, Y.K. and Kim, Y.H. (2005). Solanoflavone, a new biflavonal glycoside from Solanum melongena: Seeking for anti-inflammatory components. Archives of Pharmacal Research, **28**:657-659.

Shirale, D.; Patil, M. and Parimi, S. (2017). Insecticide resistance in field populations of *Leucinodesor bonalis* (Lepidoptera: Crambidae) in India. Can. Entomol., **149**(3):399-407.

Singh, B.P.; Siddiqua, A. and Khayum, A. (2004). The Art and Science of Flavour: A Journey through Aromas in Horticultural Crops.

Singh, M.S.M. and Sachan, S.K. (2015). Comparative efficacy of some biopesticides against shoot and fruit borer, *Leucinodesor bonalis* Guenee in brinjal. Plant Arch., **15**(2):805-808.

Singh, S.P.; Nath, P.; Kumar, A. and others (2016). Sustainable management of brinjal shoot and fruit borer (*Leucinodesor bonalis* Guen.). Veg. Sci., **43**(1):19-23.

Talukder, P.; Dutta, D.; Ghosh, E.; Bose, I. and Bhattacharjee, S. (2021). Role of plant secondary metabolites in combating pest induced stress in brinjal (*Solanum melongena* L.). J. Environ. Eng. Landscape Manage., **29**(4):449-453.

Ugwu, J.A.; Kareem, K.T. and Aluko, J.O. (2021). Insecticidal activities of aqueous extracts of five Nigerian aromatic spices against garden eggplant defoliators and fruit borer *Leucinodes orbonalis* Guenée (Lepidoptera: Crambidae). Tanz. J. Sci., **47**:1322-1329.

Upadhyay, J.K.P.; Kumar, S. and Kumar, R. (2024). Semiochemicals and other insect communication signals for controlling insect pests. In: Biorationals and Biopesticides: Pest Management, pp:107.

Upadhyay, S.; Tayde, A.R. and Tripathi, A. (2024). Efficacy of certain chemicals and botanicals against shoot and fruit borer, *Leucinodesor bonalis* (Guenee) on brinjal (*Solanum melongena* L.). Int. J. Plant Soil Sci., **36**(6):882-886.

Wargantiwar, R.K.; Kumar, A. and Kumar, S. (2010). Bioefficacy of some botanicals and in combination with insecticide against *Leucinodesor bonalis* (Guenee) in brinjal under Allahabad agro-climatic condition. J. Plant Prot. Res., **50**(2):245-247.

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