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Review article

Role of botanical pesticide in agriculture: Formulation, application and field challenges

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ABSTRACT

Botanical pesticide is derived from plants which show fungicidal, insecticidal and repellent properties. Botanical pesticide is obtained from many plant parts like bark, seeds, leaves, roots which contain active component like alkaloids, phenolics, terpenoids and essential oils. Botanical pesticides act as good pesticides due to its eco-friendly and low toxicity on non- target pest. Nowdays new techniques are being used to improve botanical pesticides such as nano-emulsion, encapsulation, wettable powder formation but these techniques are useful for agriculture but their manufacturing cost is high and their large scales production is difficult. Use of botanical pesticide are also providing benefits to the soil heath, biodiversity and agriculture ecosystem in the long term as compared to synthetic pesticides.Consequently,an application of botanical pesticisedes arepreventing chemical pesticide and their residue from entering into the soil or water and it is also beneficial for pollinators and soil microbes. It has been found out from from previous research work that with benefitsof botanical pesticides, their production is equally challenging because of their limited shelf life and poor stability. It reduced effectiveness of bio pesticides in heat, light or high humidity. To overcome existing challenges, synergistic approach should be used by integrating botanical pesticide with beneficial micro-organisms. This should be produced on a large scale for field application. This review article mainly focusing on extraction, formulation and its field application of botanical pesticides.

1. Introduction:

Due to an increase in human population, food production is decreased and increasing use of man -made chemicals to control pest or increasing biotic factors (Dar et al., 2022). To meet food shortages in low- income countries, genetically modified organisms (GMO), inorganic fertilization and synthetic pesticides has made extensive use of additives to increase phase production (Ngegba et al., 2022). Approximately 67,000 species shows beneficial impact on agricultural crops, use of agrochemicals will cause losses greater than 70% without crop production without destruction and destruction measures. Click or tap here to enter text.Instead, farmers adopt quick- fix pest management solution such as synthetic pesticides that protect crops from pest attacks (Ngegba et al., 2022).

Botanical pesticides show high pesticidal activities because of their large number of metabolites such as alkaloids, phenolics and terpenes (Pereira et al., 2025). Alkaloids are formed by the shikimate pathways, in which the amino acid tryptophan work as a precursor. Some compounds show very high pesticidal activity e.g. nicotine (insecticidal), berberine (antifungal activity), and sanguinarine (nematicidal) (Pereira et al., 2025). Botanical pesticides are obtained from different plants and different families whose plant extract or essential oil is used as a pesticide. All plant parts such as barks, leaves, rhizomes, flowers, fruits, seeds, cloves, roots, or stem are used to make botanical pesticides (Lengai et al., 2020a). The source of commercially botanical pesticides is tobacco (*Nicotiana*

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tabacum), neem (*Azadirachtaindica*), sabadilla (*Schoenocaulonofficinale*) and ryania (*Ryaniaspeciosa*) (Lengai et al., 2020a).

Some botanical pesticide compounds successfully show pesticidal effects at the commercial level such as azadirachtin from neem (*Azadirachtaindica*) garlic (*Alliumsativum*), turmeric (*Curcumalonga*), rosemary (*Rosmarinusofficinalis*), *Thymusvulgaris*, and ginger (*Zingiberofficinalis*) (Lengaietal.,2020a).

Several families show pesticidal effects such as *Acoraceae, Alliaceae, Acanthaceae, Annonaceae, Solanaceae, Meliaceae, Theaceae, Asteraceae, Rutaceae, Gramineae, Zingiberaceae, Myrtaceae, Malvaceae, Achariaceae, Lamiaceae, Labiatae, Fabaceae, Zygophyllaceae, Labiatae, Cupressaceae, Polygonaceae, Euphorbiaceae, Ericaceae* (Singh and Maurya, 2023).

This review paper explains the synthesis of botanical pesticides, extraction of the active ingredients from the different parts of the plant, and various method used to make botanical pesticide. In this review,both traditional and modern techniques are used.

2. Production method of botanical pesticides

Botanical pesticides production has been changed significantly from tradition to modern methods. Traditional botanical pesticides production methods such as soxhlet extraction, essential oil extraction, cold press method etc. are low cost but their products are unstable. Modern production methods such as encapsulation, nano-emulsion, wettable powders etc. are highly efficient and have a long shelf life. **Table1** shows the different production methods.

Table 1 Different production methods of botanical pesticides

Method	Description	Advantages	Drawbacks	References
Crude Extraction Method (Solvent extraction)	Active compounds are extracted from different parts (leaves, seeds, barks) of the plants using different solvents such as methanol, water and ethanol.	Easy method to extract out active ingredients, andits reduced cost.	Reduced stability, low shelf life, and UVdegradation .	Sinha and Ray. (2024)
Essential oil Extraction	**Steamdistillation** (**SD**)- the fresh plant sample is placed in a stainless-steel container, then steam is introduced them through the inlet into the chamber containing the plant chamber. The essential oil separated from after two hr. **Coldpressmethod**-Pressing of kernels, seeds or peels at low temperature without using any extragenous temperature or chemicals.	Cover broad spectrum pest control, and enhance its stability	High extraction cost method, photodegradati on	Crescente et al.(2025)
Emulsion formulation	It is a two-phase un-immiscible mixture with droplet sizes ranging from 50 to 500nm and is stabilized with an amphiphilic surfactant.	Improve solubility of active ingredient, bioavailability, enhances stability, and enhances dispersion.	Its performance is affected by high temperature and long storage period	Hadji et al. (2023)
Encapsulation	The encapsulated material is called the core or the coating material is called the encapsulated agents. The encapsulated agents are a natural semi- Synthetic and synthetic polymers such as chitosan and alginate.	Low degradation rate of pesticide and high shelf life of pesticides	High production cost, large scale production is difficult.	Sousa et al. (2022)
Wettable Powder (WP)	Solids are not readily soluble in liquids, so they are combined with active ingredients and inert materials (clay, wetting agents, and dispersing agents)	Easy to transport and provides high & uniform coverage with very low amount of pesticides on the plants	Show low residual effect during rainy season	Sharma and Gothalwal. (2020)
Microbial botanicals (Fermentation-based microbial botanicals)	Use of both plants based and useful microbes producing pesticide metabolites	Synergistic action of plant extract and microbes, eco-friendly and enhances stability	Difficult contamination risks during culture media preparation	Wylie and Merrell. (2022)
Suspension Concentration	Concentrated liquid suspension of finely ground plant extracts particles	Good storage stability, uniform application	Requires high quality milling and anti-settling agents	Li et al. (2023)

3. Efficacy of botanical pesticides

3.1 Neem (*Azadirachtaindica*)

Azadirachtin acts on the insect by killing the female insect and making it sterile because Azadirachtin prevents the prothoracic gland from releasing ecdysteroids hormones which makes the female insect sterile (Iqbal et al., 2022). Azadirachtin act as antifeedant. Limonoides are responsible for the insecticidal properties of Neem. Many studies show that anti-ovipositional, repulsive, and insecticidal, growth regulating and toxic to many other farm pests (Dar et al., 2022; Iqbal et al., 2022; Swain et al., 2025).

3.2 Garlic (*Alliumsativum*)

Due to enzymatic degradation of allicin, a sulfur containing substance produced which is exhibits pesticidal activity. It is useful for controlling of pests such as lepidoptera, coleoptera and Hemiptera pest species (Iqbal et al., 2022).

3.3 Rotenone

Rotenone is obtained from the stem or roots of *Derriselliptica* and *Lonchocarpusutilis*. It is used for the controlling of leaf-eating insects. It may enter with cellular respiration in insect, leading to energy depletion and finally kill the insects (Thakur et al., 2025).

3.4 Pyrethrum

Pyrethrum is derived from *Chrysanthemum cinerariifolim*. The active component of pyrethrum is pyrethrin. Pyrethrin leading to paralysis and death of insects because pyrethrin directly affects the nervous system of insects (Thakur et al., 2025).

4. Methods of extraction botanical pesticides

Botanical pesticides are found in many parts of plant such as seeds, leaves, Bark, flowers, fruits etc. Some seeds, fruits, flowers contain essential oil that show pesticidal effects. These contain many bioactive constituents make them effective for application against particular pest. There are many extraction methods characterized as given below:

4.1 Maceration

Maceration is a simple method for the biopesticides extraction. Plant material is taken in a closed container with an optimum amount of solvent like hexane, ethanol, methanol, chloroform etc. according to the plant material. The sample is then kept at room temperature for 3 days so that the sample dissolves completely. Then filtered extract used for the controlling of pests (Jamunkar et al., 2024). This technique used to extract azadirachtin from *Azadirachta indica* seed kernels. Cold maceration procedure may take the freeze- dried sample with and appropriate amount of solvent in a 250mL Erlenmeyer flask and then keep the solution in an incubator shaker at 20^{o}C temperature for 30h (Jamunkar et al., 2024). Some materials are macerated with warm water to release essential oils.

4.2 Distillation Method

Mainly three types of distillation method are used for biopesticides extraction.

42.1Water Distillation:

The plant material is boiled in the presence of direct heat. This technique is used to extract biopesticides from dried plant parts. In this process, the plant material may be in direct contact with boiling water (Jamunkar et al., 2024).

4.2.2Water and steam distillation method

This method used for the both fresh and dried plant material.

4.2.3 Direct steam distillation

This method may use fresh plant material for the extraction of essentials oils. The essential oil is kept in glass column connected to water bath and condenser. After the condensation, the essential oil is obtained (Jamunkar et al., 2024).

4.3 Solid Phase Extraction

This method used for the extraction of botanical pesticide from the several plants such as tobacco, cucumber etc. it is used to detect pesticide residues in food (Jamunkar et al., 2024). This method may be use a homogenization instrument to analyse the sample. Then centrifuge it with appropriate reagents. After centrifugation, filter the supernatant with suitable filter paper and store it for further analysis. This separation method extracts biopesticides from soil samples using 50 mL propylene centrifuge tubes of different chemicals such as anhydrous magnesium sulphate, NaCl, sodium citrate and sodium citrate dehydrate and acetic acid in acetonitrile (Jamunkar et al., 2024). Then filter the supernatant. This extraction method is used for cucumber, acetate buffer for red wine and wheat samples.

4.4 Ultra – sonication extraction/ Ultrasound

When the frequency of sound waves reaches the ultrasonic range, it’s called ultrasonic waves. Ultrasonic waves are mechanical in nature or may disseminate in liquid, solid and gaseous medium. Non – destructive testing, distance measurement, medical testing and food technology done by using ultrasonic (Shen et al., 2023). Ultrasonic technologies are two types: low-intensity ultrasonic and high- intensity ultrasonic. Frequency range of low intensity ultrasonic is high frequency varying from 5 to 10MHz, and its power level less than 1W/cm2. High intensity ultrasonic technology with low frequency ranges 20 to 100 kHz and relatively power ranging from 10to 1000W/cm^2. Ultrasonic may help in emulsification, extraction and crushing (Shen et al., 2023). When high intensity sound waves are passed through a liquid in the sonication process, high and low- pressure cycles are generated. In the low-pressure cycle, ultrasonic waves create small bubbles in the solution and in the high pressure cycle these bubbles reach a fixed volume where they no longer absorb energy. At this point the bubbles collapse. This process uses high temperature and high pressure, which generates high forces on the cell wall causing the intercellular material to be, expelled (Jamunkar et al., 2024).

4.5 Soxhlet extraction

Soxhlet extractor consists a round bottom flask, siphon tube, distillation path, expansion adapter, condenser, cooling water inlet, cooling water outlet, heat source and thimble (Bitwell et al., 2023). The Soxhlet extraction method uses continuous hot solvent to extract phytochemicals. The plant material is placed in a thimble made of firm filter paper or cellulose. The thimble packed with plant material is placed in the Soxhlet compartment of paraphernalia. The extraction of solvent such as ethanol or methanol, is placed in the bottom flask. This solvent then heats and vaporizes, and the top of the apparatus may condense and then drips back, resulting in the extraction of phytochemicals (Bitwell et al., 2023).

4.6 Supercritical fluid extraction (SFE)

Supercritical fluid extraction method is used to separate one component from another component matrix. In this SFE method mostly solid matrix is used and sometime liquid matrix is used. In this method CO_2 is used as supercritical fluid and sometimes methanol and ethanol used as solvent. The suitable condition of SFE is temperature more than $31^{o}C$ and pressure should be 74 bar (Da Silva et al., 2016.).

The SFE may have pump for CO_2, a pressure cell to maintain pressure using special technology, and collecting vessels may collect the sample. The SFE is first injected in to a heating zone to heat it to critical conditions. It is then passed through and extractor vessels where the solid matrix is diffused and the dissolved material is extracted (Da Silva et al., 2016). This dissolved material is then passed at low pressure through a separator where it then settles. The CO_2 is cooled, recycled, discharged in the atmosphere. The extracted material is collected in a collected in a collecting vessel (Da Silva et al., 2016).

4.7 Microwave assisted extraction (MAE)

MAE is performed in a microwave. The irradiation is set to low medium level for 20min as per the manual instruction. After 20min, the mixture is transferred to a cool Ookridge centrifuge where it is spun at 1200 rpm for 10min (Geetha et al., 2016). The supernatant is transferred to a clean petri dish or hold on to in a hot air oven at $60^{o}C$for 2 days (Geetha et al., 2017).

5. Biopesticides formulation

5.1 Micro – emulsions(MEs)

MEs are finely, transparent, dispersed or thermodynamically stable formula with particles ranging in size from 1 to 100nm. It's having three components: water, surfactant, and liquid dissolved organic solvent and co- surfactant which makes up to 30% mixture (Sarmah et al., 2025). There are two types of surfactants like water soluble surfactant which is further divided into anionic or non- ionic which has high hydrophilic balance and the second is oil soluble surfactant which has low HLB (Sarmah et al., 2025).

Micro- emulsion promotes the physiochemical properties such as solubility, bioavailability, and penetration power of active target sites.

5.2 Nano- emulsion

A nano- emulsion is a two-phase mixture (oil and water) stabilized by an amphibilic surfactant. The nano-emulsion process may result in particle size ranging from 50to 500nm (Hadji et al., 2023b). Nanotechnology is therefore used to enhance the stability, solubility, improving pest control, wettability during application, bioavailability and treatment efficacy of the formulation (Hadji., 2023b).

5.3 Encapsulation

Encapsulation plays a very important role in the making of any pest control release formulation (Li et al., 2021). These are made by using a various method. The capsule material may be used polymers of synthetic, semisynthetic and natural origin based. The solid or liquid pesticide capsule material coated with the target pest or pathogen to be used to kill the pest (N. Li et al., 2021).

5.4 Wettable powder formulation

Wettable powders are solid that easily suspended in water. When they are not soluble in water or oil, they are transformed into wettable powder (Sharma and Gothawal, 2020). Wettable powders are made from an active ingredient or inactive substance such as clay and adding wetting and dispersing agents. Dispersing agents are added so that when mixed with water, they can easily disperse on the field. Wetting agents wet the active constituents when mixed with water. Its main aim is that when applied evenly to every part of the plant, which increases its efficacy, and an increases in production (Sharma and Gothwal, 2020).

6. Identification of bioactive compound from botanical pesticidal extraction

Botanical pesticides are obtained from different parts of plants like leaves, seeds, barks etc. **Fig.1** shows how botanical pesticide extraction is done from plant parts.

6.1 High performance liquid chromatography (HPLC)

This method is used to extract many botanical compounds such alkaloids, terpenoids, flavonoids etc. It is useful for the quality control or rapid analysis (Oladimeji et al., 2020). It may help in the production of high rates of botanical pesticides. This technique provides high accuracy or high precision in quantifying molecules (Oladimeji et al., 2020).

6.2 UV- Vis spectrometry

It is a quantitative method. UV – visible spectrophotometry measures the absorption of ultraviolet or visible radiation by a substance present in a solution. It works on Beer- Lambert law. (Guemari et al., 2022). It purifies, extract and characterized the constituent present in the solution (Guemari et al., 2022).

6.3 Fourier – transformation infrared spectroscopy (FTIR)

FTIR spectrum mainly detects secondary amines, carboxylic acids, aromatic, alkyl group, alcohol, dienes, aromatic functional groups in aqueous extract in plant (Geetha et al., 2017). The scraped powder sample of all the botanical plants was used for FTIR analysis. Approximately 10 mg of the dried powder was encapsulated in 100 mg of KBr and change it into pellet under a pressure of 7845 kPa for 2min Load the entire plant sample in to the FTIR and record the entire spectrum come under the 4000 to 40 cm measure at room temperature (Geetha et al., 2017).

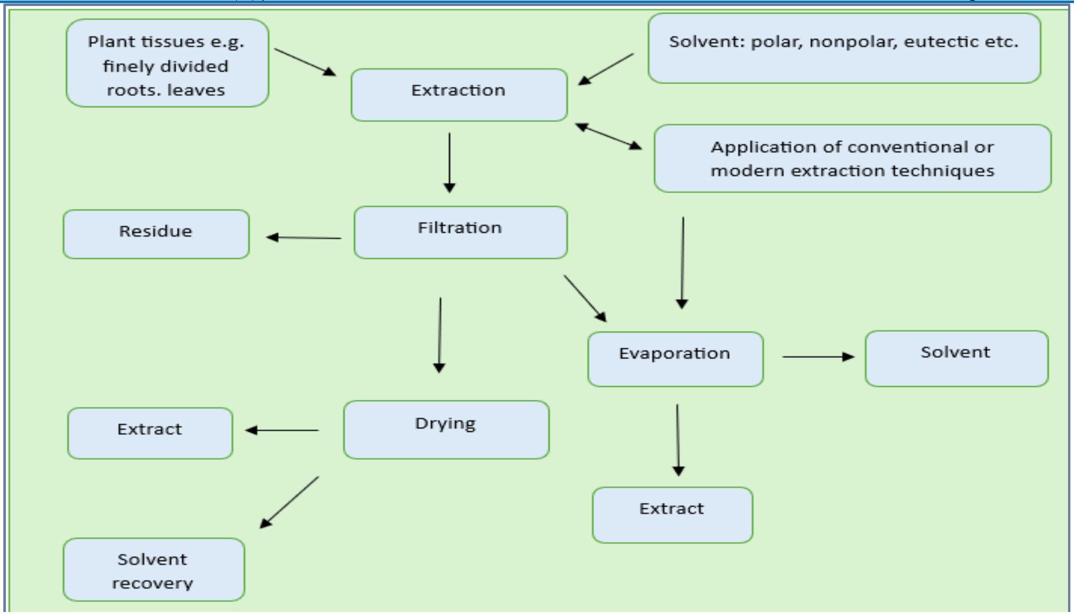

Fig. 1 Steps involved in extraction of bioactives compound from plant source (Bitwell et al., 2023)

7. Current status of botanical pesticides

Botanical pesticides are registered under the Insecticide Act 1968 for the purpose of pest control agriculture or for any other use (Pushpalatha et al., 2025). Its guidelines and regulations are implemented under the Central Insecticide Board and Registration Committee (CIBRC). Three types of botanical pesticides have been registered in India and are being produced on commercial level. Out of them Neem, based Pyrethrum and Eucalyptus leaves based botanical pesticides also (Pushpalatha et al., 2025).

The market for botanical pesticides has grown significantly as people are increasingly inclined towards sustainable farming practices. Fig. 2 shows the market value of botanical pesticides is increasing rapidly in current scenario. Demand for organic products is increasing in the market today and in the upcoming days.

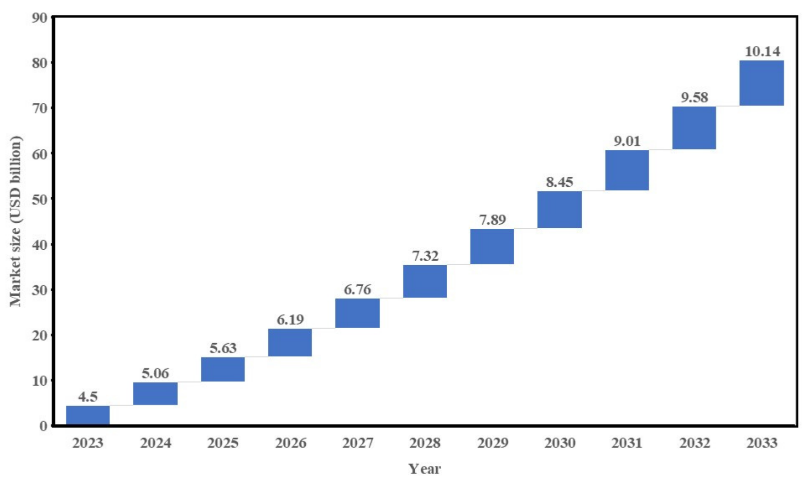

Fig. 2 Botanical pesticides market report 2023-2033 (Salceanu et al., 2023)

8. Application of botanical pesticides

Plants are a source of botanical pesticides which are accessible in the environment and have multiple- purpose uses like ornamentals, medicines, food, spices and as feed. Table 2 shows the botanical pesticides and their application plants. Their accessibility makes them low- priced and hence they can be integrated in agricultural production. Plants like neem, pyrethrum, sabadilla, garlic etc. are less toxic to non- targeted organisms and highly toxic to targeted organisms. Botanical pesticides are well founded, effective, and allowable for sustainable crop protection.

9. Challenges and future prospect

From the formulation to the delivery of botanical pesticides, many challenges have to be addressed. From the formulation of botanical pesticide to its effectiveness, it is required many parameters (Kumar et al., 2025). Botanical compounds are susceptible to degradation because they are affected by factors such as UV lights and high temperature. In such problems, nano-formulation techniques like nano – encapsulation and micro – emulsion are very useful. However, these more difficult when they have to be produced on a large scale. Botanical pesticides made using nano – formulation require confirmation of their efficacy, environmental well- being, and harmlessness to non – target organisms to prove their effectiveness (Kumar et al., 2025).

Botanical pesticides face many problems, whereas synthetic pesticides are easy to manufacture, also both their formulation and application are easy (Lengai et al., 2020b). For future use, the stability or effectiveness of botanical pesticide should be improved under various condition, and attention should also be paid to optimizing cost – effective production method or manufacturing processes (Kiri et al., 2024). To enhance collaboration with association stakeholders and supervisory agencies to solely registration process and promote eco - friendly pesticides instead of synthetic pesticides thus promote the use of botanical pesticides worldwide.

10. Conclusion

Our environment is a wide source of plant on a large scale. Some of these plants help in curing human and plant disease, whereas the use of chemical pesticides poses a threat to human health, environmental safety, soil, water and plant disease. Botanical pesticide is biodegradable and it is less toxic due to which it is less harmful for the ecosystem. Botanical pesticides do not cause soil or water pollution and safe for human health. With the production of botanical pesticides, the farmer will not have to pay much for purchasing the pesticide. The demand for organic products increasing day by day due to which the demand for organic pesticides is also increasing. Therefore, the production of botanical pesticides should be increases. Botanical pesticides contribute to renewable nature and environmental safety.

11. Future Recommendation

If the formulation and standardization is improved, then good agricultural yields can be seen in the upcoming years. Eeco-friendly extraction methods should be used to achieve crop consistency and high -quality products like supercritical CO_2, ultrasound assisted extraction, microwave assisted extraction method etc. Advanced methods like encapsulation, micro-emulsion, micro- emulsion should be used to improve the stability and efficacy of botanical pesticides. To increase the plant productivity, we should combine plant extracts with useful micro-organisms and observe their effect on plants. Future research interest should be created to promote public-privet partnership.

Table 2 Application of selected Botanical Pesticides on selected crop Pest (Divekar, 2023; Lengai et al., 2020)

Source of plant	Active ingredient	Mode of Action	Target Pest
Neem (*Azadirachta indica*)	Azadirachtin	Bonding to acetylcholine there by disrupting nervous system, repellence, feeding deterrence, inhibition of oviposition, egg hatching and moulting	Lepidopteran and sap sucking pests such as aphids, mealybugs, scale insect, white and leafhoppers
		Neurotoxic cause: rapid knockdown effect, along with hyperactivity and convulsion, pyrethrum blocks voltage- gated sodium channels in nerve system (half-life 2hr)	Western flower Thrips *Frankliniella occidentails*
Garlic (*Allium sativum*)	Allicin	Antifeedant, inhibitor, repellent of moulting and respiration Delay and inhibit spore germination Inhibit protein and DNA synthesis Cuticle disruption and fecundity reduction	Fungi Tenebrio molitor
Turmeric (*Curcuma longa*)	*Tanacetum cineraiaefolium*	Shows suppressive activity on insect growth antifeedant	Cabbage looper Trichoplusia
Hing (*Ferula asafoetida*)	Asafoetida (oleo gum-resin)	Insect repellent	Pomegranate fruit moth
Bitter melon*(Momordica charantica*)	Bitter momordin Crude extract leaf	Antifeedant	Mung bean weevil

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Author Contribution
Deepika Mishra has conceptualized, prepared the draft of the article and formal analysis. Jiwan Singh has reviewed, edited and validated the manuscript.

Conflict of Interest
There is no conflict of interest declared by author.

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