Acta Scientific AGRICULTURE (ISSN: 2581-365X)
Volume 7 Issue 2 February 2023

Review Article

Botanical Pesticides: An Eco-Friendly Approach for Management of Insect Pests

Pratap Divekar*

ICAR-Indian Institute of Vegetable Research, Varanasi, Uttar Pradesh, India

***Corresponding Author:** Pratap Divekar, ICAR-Indian Institute of Vegetable Research, Varanasi, Uttar Pradesh, India.

Received: November 16, 2022
Published: January 18, 2023

Abstract

Insect pest management is a global economic and ecological concern, due to the risks to people and the environment posed by the injudicious application of synthetic pesticide chemicals. To address the issue of insect resistance, it is crucial to identify new and powerful insecticides. Since botanicals are said to be less harmful to the environment and human health than synthetic chemical pesticides, they have long been promoted as appealing substitutes for synthetic agrochemicals. Commercial usage of pyrethrum and neem is well established, pesticides based on plant essential oils have entered the market and rotenone application seems to be declining. A plethora of plant compounds have been investigated for use as insect antifeedants, repellents and toxicants, however apart from some naturally occurring repellents, plant compounds that alter arthropod behaviour have only had limited commercial success. Several studies have shown the compatibility and synergism of botanicals with entomopathogens. The success of botanicals appears to be hindered by a range of variables, chief among them being regulatory obstacles and the availability of substitute products (newer synthetics and fermentation products) that are more affordable and generally risk-free than their forerunners. Botanicals offer residue-free food and a safe environment while also being considerably safer to natural enemies of insects. Thus, botanicals with multiple mode of actions are useful to protect the crops under organic agriculture. In order to reduce the detrimental effects of conventional pesticides, botanical pesticides can be employed as alternative or complementary tools in integrated pest management to achieve better results in a sustainable way.

Keywords: Botanicals; Neem; Pyrethrum; Compatibility and Synergism; Sustainable Crop Production

Introduction

Pests regularly expose and/or endanger the agricultural crops, which has an impact on their development and quality over time. Farmers typically rely on quick pest management techniques, primarily synthetic insecticides, to safeguard their crops against pest infestation [1]. Despite the effectiveness of synthetic pesticides, their prolonged application creates problems, such as the emergence of pests that are resistant to insecticides [2]. Synthetic pesticides can be used excessively or improperly, which can have detrimental consequences on biodiversity [3] as well as adverse effects on humans, the environment and non-target organisms. Chronic human diseases have been linked to constituent components of synthetic pesticides [4] either through exposure or ingestion. The majority of synthetic pesticides are difficult to biodegrade; as a result, they build up in the environment and pollute soil and ground water in addition to thinning the ozone layer [3].

Although several eco-friendly pest control tactics viz., host plant resistance [5], secondary plant metabolites [6], biocontrol agents [7-9] and defense proteins [10,11] are available, farmers prefers the synthetic pesticides. The synthetic pesticides were immediately embraced due to their effectiveness and efficacy in managing serious crop pests like borers, defoliators and sucking insect pests. Alternative pest management strategies are now more necessary than ever due to the drawbacks connected with the misuse and overuse of synthetic pesticides.

With considerable effectiveness, plants that contain bioactive chemicals have been employed to control several crop pests [12]. Examples of plants that have been effectively used as sources of safe pesticides for the management of insect pests include pyrethrum (*Tanacetum cinerariifolium*) flowers [13]. Until the advent of technology and the creation of synthetic pesticides, pest management using plant-based remedies was a common practice [14]. Consuming food produced with secure, preferably natural plant protection products is currently popular throughout the world. Certain pesticides have been banned from use in agricultural production as a result of the discovery of dangerous chemical pesticide residues in food and raised consumer awareness of food safety [15].

The effectiveness, biodegradability, variety of modes of action, low toxicity and accessibility of source materials are factors that contribute to the importance of botanical pesticides [16]. Additionally, they have brief pre-harvest and re-entry phases. Commonly used botanical pesticides are widely employed in organic farming because the crop is more expensive [17]. Botanicals may be used safely on crops raised for human consumption and because there is currently a large market for customers prepared to pay more for organically grown food, botanical insecticides are becoming more and more popular.

Several research have been conducted with known and untapped plant species that have pesticidal characteristics [18]. The plants pyrethrum (*Tanacetum cinerariifolium*), neem (*Azadirachta indica*), sabadilla (*Schoenocaulon officinale*), tobacco (*Nicotiana tabacum*), and ryania (*Ryania speciosa*) are examples of sources of commercially accessible botanical pesticides [19]. In the past, farmers have employed crop protection agents with plant origins to manage pests after harvest, particularly to preserve grains during storage. Botanical pesticides are derived from plants and are used to eradicate, ward off, or deter pests [6]. The majority of botanical pesticides are used to manage insect pests has received significant attention.

Sources of botanical pesticides

Botanical pesticides originate from a wide range of plant families and can be used as plant extracts, essential oils, or a combination of the two [20]. Barks, leaves, roots, flowers, fruits, seeds, cloves, rhizomes and stems of plants are used to manufacture botanical insecticides. The intended bioactive chemicals and their concentration within the chosen plant portion determine which section of the plant is employed. There have been reports of plants in the Myrtaceae, Lauraceae, Rutaceae, Lamiaceae, Asteraceae, Apiaceae, Cupressaceae, Poaceae, Zingiberaceae, Piperaceae, Liliaceae, Apocynaceae, Solanaceae, Caesalpinaceae, and Sapotaceae families containing bioactive compounds with activity against crop pest [21,22]. Azadiractin from neem (*Azadirachta indica*) and pyrethrin from pyrethrum (*Tanacetum cinerariifolium*) are two botanical chemicals having pesticidal action that have been successfully identified and commercialised [23]. Garlic (*Allium sativum*), turmeric (*Curcuma longa*), rosemary (*Rosmarinus officinalis*), ginger (*Zingiber officinale*) and thyme (*Thymus vulgaris*) are additional plants with pesticidal effects.

Phytochemical composition of botanical pesticides

Research on the chemical nature of many plant families has been sparked by the growing interest in natural plant products in agriculture, medicine, and the food sector [24]. The secondary metabolites of plants usually alkaloids, tannins, terpenes, phenols, flavonoids, and resins, which have antifungal, antibacterial, antioxidant, or insecticidal characteristics [6]. For instance, the leaves of *Mentha piperita* contain tannins and flavonoids as the main bioactive chemicals [25], whereas the seed kernels of *Jatropha carcus* have significant levels of phenolics, esters and flavonoids [26]. Certain plant species are efficient against a particular class of pests due to the specific chemicals found in those species. The bioactive chemicals found in plants also influence the mode of action against the target pests (Table 1).

Mechanisms of action of botanical pesticides

Depending on the botanical ingredient and pest, the modes of action may include repulsiveness, inhibition, denaturation of proteins, and other consequences. For example, pyrethrum-based pesticides attack an insect's nerve cells, causing paralysis and ultimately death, whereas neem-based pesticides have antifeedant and repellent characteristics, cause aberrant moulting, impede oviposition, and interfere with the endocrine system [6]. Synthetic pesticides have more narrowly defined targets and are typically neurotoxicants with outcomes comparable to those of botanical pesticides [27]. In order to effectively manage pests, it is important to understand the mode of action, including the physical, biological and chemical interactions between the insect and the pesticide [28].

Mode of action against insect pests

Most plant extracts have a broad range of effects on insects, including toxicity, fatal activity, feeding deterrent, oviposition and interfering with metabolic processes [29]. Botanical pesticides are more widely used since they have several effects on the insect pests [6]. For instance, it has been observed that commercialized products made from plants like pyrethrum, among other things, have neurotoxic effects on insect pests that cause paralysis, knockdown, and ultimately results in death [6]. Additionally, botanical pesticides hinder the growth and development of organisms by interfering with the production of vital enzymes including those involved in moulting [30]. The red flour beetle (*Tribolium castaneum*) is killed by garlic (*Allium sativum*) and turmeric (Curcuma longa) extracts, which also have poisonous, repulsive and toxic effects on them [31]. The oviposition, egg hatching, and overall growth of the insect pests have all been said to be affected by extracts from these plants. Some botanical pesticides have been linked to immobility, toxicity and paralysis of insects' respiratory systems as well as inhibition of electron transport [32].

Source plant	Active ingredient	Mode of action	Target pests	References
Neem (*Azadirachta indica*)	Azadirechtin	Binding to acetylcholine receptors thereby disrupting the nervous system Repellence. Feeding deterrence Inhibition of oviposition, egg hatching and moulting	Lepidopteran and sucking insects	[33]
Turmeric (*Curcuma longa*)	ar-turmerone and turmerone	Inhibitory activity on insect growth, antifeedant	Cabbage looper, *Trichoplusia ni*	[34]
Lemon grass	Citronellal	Fumigant and contact insecticidal property. It interferes with the neuromodulator: octapamine and GABA-gates chloride channels. (Volatile thus, limited persistence in field)	Gram pod borer (*H. armigera)*	[35]
Tanacetum cinerariaefolium	pyrethrum daisy	Neurotoxic: causes rapid knockdown effect, along with hyperactivity and convulsions. Pyrethrum blocks voltage-gated sodium channels in nerve axons (Half-life: 2 h)	Western Flower Thrips, *Frankliniella occidentalis*	[33]
Ferula asafoetida (Hing)	Asafoetida (oleo-gum-resin)	It acts as an insect repellent and consists of a characteristic. unpleasant smell	Pomegranate fruit moth, *Ectomyelois ceratoniae*	[36]
Allium sativum	Allicin (gives the pungent characteristic odor to crushed garlic)	Antifeedant, repellent, inhibitor of molting and respiration, cuticle disruption and fecundity reduction	*Tenebrio molitor*	[37]
Momordica Charantia (Bitter Melon)	Crude leaf extract, bitter Momordin	Antifeedant	Mung bean weevil (*Callosobruchus chinensis*)	[38]

Table 1: Source of botanicals with active ingredient containing insecticidal activities.

Compatibility and Synergism of Botanical pesticides with other pest management options

Agriculture faces many issues and among them insect pests is major one and to manage them with existing methods i.e., use of synthetic chemicals, use of microbial-based biopesticides and applying botanicals have their own merits and demerits. Worldwide still emphasis is on the use of single technology aspect to mitigate insect and disease menace. So to achieve long term success in a sustainable way one should look into the novel approaches like combination of botanicals with different entomopathogenic fungi, bacteria and nematodes also integration of botanical pesticides with chemical pesticides. By combining two or more methods for pest control we can get economic and environmental advantage provided that these methods needs to be compatible with each other.

Botanicals and entomopathogenic bacteria work together harmoniously. Early studies on synergism claimed that Bt demonstrated synergism against various agricultural pests whether administered sequentially or in combination [39] with neem treatments. Other plants, besides neem, have the ability to repel pests. One of these is palmarosa oil (*Cymbopogan martini* Wats.) (1%), which shown synergistic efficacy with three Bt products, Delfin®, Spicturin®, and Agree®, against *Spodoptera litura* and *H. armigera*. The extracts of neem, mentha, and *Prosofis juliflora* are proven to work well with Delfin®, but not with Spicturin® and Agree®. This might be as a result of the formulation's additions [40]. Other plants, including *Annona squamosa* L., *Datura stramonium* L., *Eucalyptus globulus* (Labile), *Ipomea carnea* Jacq., *Lantana camara* L., *Nicotiana tabacum* L., and *Pongamia pinnata* (L.), all worked in concert with Btk, with D. stramonium having the greatest effect on the mean larval mortality of *S. litura* [41].

Several researchers have demonstrated the compatibility of various *Beauveria bassiana* strains with various neem preparations. Neem products in particular have been shown to be compatible with EPF and work well against *S. litura* and *Bemisia tabaci* [42]. Combining EPF like *B. bassiana, M. anisopliae*, and *L. lecanii* with neem oil at half of their recommended dosages could be a practical environmentally acceptable solution for controlling the sucking pests of okra while also preserving natural enemies [43]. Neem, *Tagetus patula*, and *Calotropis gigantean* are some of the botanicals that have a synergistic effect with entomopathogenic viruses. *Helicoverpa armigera* NPV (HaNPV) is one of these viruses [44]. Botanicals and entomopathogenic nematodes work together in harmony. Entomopathogenic nematodes (EPN) are both synergistic and compatible with azadirachtin [45]) and Bt [46].

The majority of the instances under examination demonstrated some degree of insect population control when botanicals were combined with entomopathogenic agents. The effectiveness of these combination products is particularly important to overcome the unique drawbacks of each product and the combinations can develop a new exceptional commercial bioinsecticide formulation supporting organic farmers. However, there is an urgent need for more research on the impact of these botanical biopesticide combinations on pest behaviour, the significance of application technique and the relevance of application time.

Barriers in commercialization and future prospects for botanical pesticides

One of the possible challenges to achieving food security is increasing global food production while enhancing crop quality and reducing the environmental effect of agricultural practises [47]. The use of synthetic pesticides must be controlled, and the use of eco-friendly, plant-based insecticides must be encouraged, in order to reduce the problem of herbivore insects sustainably. To promote plant growth and health, secondary plant metabolites can be used as an alternative to synthetic pesticides [48]. In order to find prospective pest control products globally, a number of phytochemicals were examined. Compared to the 5.5% annual growth rate of conventional pesticides, the market for biopesticides is developing at a rate of 16% [49]. But there are key difficulties to the commercialization of plant-based pesticides, such as: (a) the availability and sustainability of botanical resources; (b) the strength, standardisation, and quality control of chemically composite extracts based on quantification of active ingredients; and (c) regulatory support, which typically requires an expensive toxicological evaluation of the potential product [50]. The clear guidance provided by policymakers to the regulatory authorities will undoubtedly open the door for easier manufacture and better marketing of botanical pesticides in the creation of sustainable agriculture in the coming years.

To develop a new generation of highly effective botanical pesticides, novel methodologies are required that take into account the behaviour and controlled release of particular botanical components. PSMs can only be employed as efficient pesticides if the manufacturing difficulties/restraints are removed utilising cutting-edge biotechnological technologies like metabolic engineering and plant tissue culture. Plant-derived products should be given preference in regulatory processes where extra attention is paid to environmental safety even though they cannot completely replace traditional synthetic pesticides.

Conclusion

Farmers need to adapt to crop protection methods that are more efficient and environmentally friendly. Biological inputs are the fastest expanding market, even though chemicals may currently dominate. The biological approach offers the best substitute for keeping insect populations under control while not harming other organisms and ecosystem-beneficial flora. Additionally, it takes a long time and a lot of work to get a chemical pesticide on the market, whereas biopesticides can be marketed in about a year, giving them an excellent chance to fill the pest management gap left by chemicals. Botanical insecticides are products made with various components derived from plant parts that include naturally occurring compounds. The untapped treasure of nature is found in botanical pesticides. The obstacles to the commercialization of botanical pesticides on their road to becoming a registered product must be removed. By using botanicals, the annoyance caused by synthetic pesticides will be reduced. Research is urgently needed in areas including altering stability, preventing insect resistance by creating novel formulations, and alternative application.

Declarations

Author Contributions

PD: Conceptualization, Data curation, Writing-original draft, Writing- review and editing. The author read and approved the final manuscript.

Availability of Data and Materials

The datasets supporting the results of this article are included within the article.

Ethics Approval and Consent to Participate

This study does not contain any research requiring ethical consent or approval.

Consent for Publication

Not applicable.

Competing Interests

No competing interests are involved.

Bibliography

1. EF Nkechi., *et al.* "Effects of aqueous and oil leaf extracts of *Pterocarpus santalinoides* on the maize weevil, *Sitophilus zeamais*, pest of stored maize grains". *African Journal of Agricultural Research* 13 (2018): 617-626.
2. YM Shabana., *et al.* "Efficacy of plant extracts in controlling wheat leaf rust disease caused by *Puccinia triticina". Egyptian Journal of Basic and Applied Sciences* 1 (2017): 67-73.
3. D Sande., *et al.* "Environmental impacts from pesticide use: a case study of soil fumigation in Florida tomato production". *International Journal of Environmental Research and Public Health* 12 (2011): 4649-4661.
4. CA Damalas and SD Koutroubas. "Farmers' exposure to pesticides: toxicity types and ways of prevention". *Toxics* 1 (2015): 1-10.
5. Divekar P., *et al.* "Screening of maize germplasm through antibiosis mechanism of resistance against Chilo partellus (Swinhoe)". *Journal of Entomology and Zoology Studies* 7.3 (2019): 1115-1119.
6. Divekar PA., *et al.* "Plant Secondary Metabolites as Defense Tools against Herbivores for Sustainable Crop Protection". *International Journal of Molecular Sciences* 23.5 (2020): 2690.
7. Shinde PG., *et al.* "Bio-pesticide management strategy for mustard aphid *Lipaphis erysimi* (Kaltenbach) (*Homoptera: Aphididae*)". *Journal of Pharmaceutical Innovation* 10 (2021): 397-400.
8. Dukare A., *et al.* "Biological Disease Control Agents in Organic Crop Production System". In book: Pesticide Contamination in Freshwater and Soil Environs: Impacts, Threats, and Sustainable Remediation (Hard ISBN: 9781771889537). Publisher: Apple Academic Press, USA (2020).
9. Dukare AS., *et al.* "Role of Bacterial and Fungal Chitinases in Integrated Management of Pest and Diseases of Agro-Horticultural Crops". In: Khan, M.A., Ahmad, W. (eds) Microbes for Sustainable Insect Pest Management. Sustainability in Plant and Crop Protection, vol 17. Springer, Cham (2021).
10. Divekar PA., *et al.* "Protease Inhibitors: An Induced Plant Defense Mechanism Against Herbivores". *Journal of Plant Growth Regulation* (2022).
11. Divekar P., *et al.* "Trilogy: Plants-Proteases- Insects". In Plant Protection: Present Developments and Future Strategies (2022): 143-157. Today and Tomorrow's Printers and Publishers, New Delhi - 110 002.
12. S Thiruppathi., *et al.* "Antimicrobial activity of Aloe vera (L.) Burm. f. against pathogenic microorganisms". *Journal of Bioscience and Research*4 (2010): 251-258.
13. M Sarwar. "Microbial insecticides- an eco-friendly effective line of attack for insect pests management". *The International Journal of Engineering and Advanced Technology* 2 (2015): 4-9.
14. Mahmood SR., *et al.* "Effects of pesticides on environment". In: Plant, Soil and Microbes, Springer, Cham (2016): 253-269.
15. G Karaca., *et al.* "Effects of some plant essential oils against fungi on wheat seeds". *Indian Journal of Pharmaceutical Education and Research* 3 (2017): S385-S388.
16. GS Neeraj., *et al.* "Evaluation of nematicidal activity of ethanolic extracts of medicinal plants to *Meloidogyne incognita* (kofoid and white) chitwood under lab conditions". *International Journal of Pure and Applied Bioscience*1 (2017): 827-831.
17. D Srijita. "Biopesticides: an eco-friendly approach for pest control". *World Journal Pharmacy and Pharmaceutical Science* 6 (2015) 250-265.
18. TF Erenso and DH Berhe. "Effect of neem leaf and seed powders against adult maize weevil (*Sitophilus zeamais* Motschulsky) mortality". *Agricultural Research* 2 (2016) 90-94.
19. JT Arnason., *et al.* "Natural products from plants as insecticides". *Encyclopedia of Life Support Systems (EOLSS)* (2012): 1-8.
20. ES Mizubuti., *et al.* "Management of late blight with alternative products". *Pest Technology* 2 (2007): 106-116.
21. MM Gakuubi., *et al.* "Bioactive properties of *Tagetes minuta* L. (Asteraceae) essential oils: a review". *American Journal of Essential Oils and Natural Products* 2 (2016): 27-36.
22. W Ahmad., *et al.* "Phytochemical Screening and antimicrobial study of *Euphorbia hirta* extracts". *Journal of Medicinal Plants Studies* 2 (2017): 183-186.
23. B Joseph and S Sujatha. "Insight of botanical based biopesticides against economically important pest". *International Journal of Pharmaceutical and Life Sciences* 11 (2012): 2138-2148.

24. Plata-Rueda LC., *et al.* "Insecticidal activity of garlic essential oil and their constituents against the mealworm beetle, *Tenebrio molitor* Linnaeus (Coleoptera: Tenebrionidae)". *Scientific Reports* 7 (2017): 46406.

25. DM Pramila., *et al.* "Phytochemical analysis and antimicrobial potential of methanolic leaf extract of peppermint (*Mentha piperita*: Lamiaceae)". *Journal of Medicinal Plants Research* 2 (2012): 331-335.

26. E Oskoueian., *et al.* "Bioactive compounds and biological activities of *Jatropha curcas* L. kernel meal extract". *International Journal of Molecular Sciences* 12 (2011): 5955-5970.

27. PC Stevenson., *et al.* "Pesticidal plants in Africa: a global vision of new biological control products from local uses". *Industrial Crops and Products* 110 (2017): 2-9.

28. M Wink. "Modes of action of herbal medicines and plant secondary metabolites". *Medicines* 2 (2015): 251-286.

29. C Laxmishree and S Nandita. "Botanical pesticides -a major alternative to chemical pesticides: a review". *International Journal Life Sciences* 4 (2017) 722-729.

30. Ntalli NG and Menkissoglu-Spiroudi U. "Pesticides of botanical origin: a promising tool in plant protection". Pesticides-formulations, effects, fate (2011): 1-23.

31. S Ali., *et al.* "Insecticidal activity of turmeric (*Curcuma longa*) and garlic (*Allium sativum*) extracts against red flour beetle, *Tribolium castaneum*: a safe alternative to insecticides in stored commodities". *Journal of Entomology and Zoology Studies* 3 (2014): 201-205.

32. UP Singh., *et al.* "Role of garlic (*Allium sativum* L.) in human and plant diseases". *Indian Journal of Experimental Biology* 39 (2001) 310-322.

33. Isman MB. "Botanical insecticides, deterrents, and repellents in modern agriculture and an increasingly regulated world". *Annual Review of Entomology* 51 (2006): 45-66.

34. De Souza Tavares W., *et al.* "Turmeric powder and its derivatives from *Curcuma longa* rhizomes: Insecticidal effects on cabbage looper and the role of synergists". *Scientific Reports* 6 (2016): 34093.

35. Papulwar PP., *et al.* "Studies on insecticidal properties of citronella grass (lemon grass) essential oils against gram pod borer (*Helicoverpa armigera*)". *International Journal of Chemical Studies* 2 (2018): 44-46.

36. Kavianpour M., *et al.* "Effect of fresh gum of asafoetida on the damage reduction of pomegranate fruit moth, *Ectomyelois ceratoniae* (Lep., Pyralidae) in Shahreza City". *International Journal of Biosciences* 5 (2014): 86-91.

37. Plata-Rueda A., *et al.* "Insecticidal activity of garlic essential oil and their constituents against the mealworm beetle, *Tenebrio molitor* Linnaeus (Coleoptera: Tenebrionidae)". *Scientifi Reports* 7 (2017): 46406.

38. CT Wahyutami., *et al.* "Insecticidal Activity of Bitter Melon (*Momordica charantia* L.). Leaf Extract on Mung Bean Weevil (*Callosobruchus chinensis* L.). 4th International Conference on Sustainable Agriculture (ICoSA 2021). IOP Conf. *Series: Earth and Environmental Science* 985 (2022) 012053.

39. Trisyono A and Whalon ME. "Toxicity of neem applied alone and in combinations with *Bacillus thuringiensis* to Colorado potato beetle (Coleoptera: Chrysomelidae)". *Journal of Economic Entomology* 92.6 (1999): 1281-1285.

40. Venkadasubramanian V and David PMM. "Insecticidal toxicity of commercial Bacillus thuringiensis (Berliner) products in combination with botanicals to *Spodoptera litura* (Fabricius) and *Helicoverpa armigera* (Hubner)". *Journal of Biological Control* 13 (1999): 85-92.

41. Rajguru M., *et al.* "Assessment of plant extracts fortified with *Bacillus thuringiensis* (Bacillales: Bacillaceae) for management of *Spodoptera litura* (lepidoptera: Noctuidae)". *International Journal of Tropical Insect Science* 31 (2011): 92-97.

42. Mohan MC., *et al.* "Growth and insect assays of *Beauveria bassiana* with neem to test their compatibility and synergism". *Biocontrol Science and Technology* 17.10 (2007): 1059-1069.

43. Halder J., *et al.* "Compatibility of entomopathogenic fungi and botanicals against sucking pests of okra: an ecofriendly approach". *Egyptian Journal of Biological Pest Control* 31.30 (2021).

44. Rabindra RJ., *et al.* "Evaluation of certain botanicals as stressors of nuclear polyhedrosis virus in larvae of *Helicoverpa armigera". Journal of Biological Control* 8 (2 (1994): 129-130.

45. Stark JD. "Entomopathogenic nematodes (Rhabditida: Steinernematidae): toxicity of Neem". *Journal of Economic Entomology* 89 (1996): 68-73.

46. Kaya HK., *et al.* "Integration of entomopathogenic nematodes with *Bacillus thuringiensis* or pesticidal soap for control of insect pests". *Biological Control* 5 (1995): 432-441.

47. Del Buono D. "Can biostimulants be used to mitigate the effect of anthropogenic climate change on agriculture? It is time to respond". *Science of The Total Environment* 751 (2021): 141763.

48. Cuadrado JLC., *et al.* "Insecticidal Properties of Capsaicinoids and Glucosinolates Extracted from *Capsicum chinense* and *Tropaeolum tuberosum"*. *Insects* 10 (2019): 132.

49. Marrone PG. "Market opportunities for biopesticides". In Proceedings of the American Chemical Society, 246th National Meeting and Exposition, Indianapolis, IN, USA, 8-12 84 (2013): 104.

50. Isman MB and Paluch G. "Needles in the Haystack: Exploring Chemical Diversity of Botanical Insecticides". InGreen Trends inInsect Control; López, O., Fernández- Bolaños, J.G., Eds.; RSC: Washington, DC, USA (2011): 248-265.