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Sanjay Singh
Department of Botany
CMP Degree College, University of Allahabad, Prayagraj, Uttar Pradesh, India

Preeti Maurya
Department of Botany
CMP Degree College, University of Allahabad, Prayagraj, Uttar Pradesh, India

Corresponding Author:
Sanjay Singh
Department of Botany
CMP Degree College, University of Allahabad, Prayagraj, Uttar Pradesh, India

Natural pesticides: Current status and prospects

Sanjay Singh and Preeti Maurya

Abstract
The recent population growth seen around the world has contributed to a greater need for food supplies, which can only be met by increasing agricultural productivity. Using chemically based fertilizers, pesticides, and growth stimulants can cause serious environmental issues and a shortage of finite resources like phosphorus and potassium, which raises the price of fertilizers. As a result, agricultural practices should become more sustainable. Conventional pesticides contributed to several environmental problems, including ecosystem imbalances, decreased soil fertility, and worsening conditions for marine life. These synthetic pesticides' non-target toxicity, persistent effects, and difficult biodegradability have grown to be a severe concern, necessitating the urgent adoption of environmentally friendly and cost-effective pest management alternatives. Growing concern over environmental safety has sparked interest in pest control strategies using environmentally benign plant-based insecticides. Farmers' attitudes toward the usage of pesticides for crop protection and crop production have significantly changed.

Keywords: Bioactive compounds, growth stimulation, microalgae, sustainable agriculture**,** pest management

Introduction

The world's population is increasing. Between 1999 and 2011, this number increased from 6 billion to 7 billion, and it is expected to increase to 9 billion in 2050 [1, 2]. This development increased the demand for food products and greatly affected agriculture. On the one hand, the increase in the world population causes an increase in food consumption, necessitating more agriculture [1-4, 6]. Researchers are focusing their efforts on biobased products to find greener and more profitable products to increase agricultural production.

Microalgae and cyanobacteria have become important sources for crop production and protection because of their ability to biofertilizer and promote crops [1-3, 5-7]. Algae have long been used in agriculture [5, 7]; For example, on the European coast, farmers are using seaweed algae directly or after composting them for their culture and reaping the benefits of soil fertilization. Algal biomass has been widely used in agriculture since then, but in the 20th century products made from algae sap have attracted the attention of farmers worldwide [5]. Many physiologically active substances from cyanobacteria and algae such as phenols, terpenoids, free fatty acids (FFA), polysaccharides, and carotenoids have been shown to have the potential to affect crop growth [2, 6]. Studies have shown that algal metabolites are important for (i) soil purification and fertilization, (ii) protection of plants from biotic and abiotic stresses, and (iii) plant growth. Phytohormones are also found in microalgae and cyanobacteria and are known to promote plant growth [6, 8, 9]. Given the benefits of biomass and microalgae and cyanobacteria extracts in promoting sustainable agriculture, both are being sold [7].

In the 1950s and 1960s, the era of the Green Revolution, crop output was increased to fulfill the need for food in low-income countries by heavily relying on inputs like inorganic fertilizers, synthetic insecticides, and genetically engineered organisms [10-12]. The biological functions of botanical pesticides, which can be solitary compounds or complex combinations, include functioning as deterrents, insecticides, fungicides, nematicides, and bactericides [13]. According to studies, botanical pesticides prevent certain mosquito species, including species important to agriculture, from ingesting food, growing at different phases of development, and laying eggs [14-17]. Evidence suggests that botanical pesticides can exert their effects through a variety of pathways in insects and mammals, operating particularly on the nervous system and potentially influencing sodium channels, acetylcholinesterase, nicotinic acetylcholine receptors (nAChR), octopamine and tyramine receptors, acetylcholinesterase, and GABA-gated chloride channels [17-19].

It is recognized that pathogenic microbes such as viruses, bacteria, fungi, protozoa, and nematodes are the culprits behind plant disease. Plants are frequently harmed by insect assaults and compete with weeds, which is another source of stress. It is tentatively estimated that between 31 and 42% of all crops produced globally are affected by, or destroyed by, diseases, insects, and weeds each year. Diseases, insects, and weeds account for 14%, 10.2%, and 12.2%, respectively, of the average 36.5% total losses. According to Oerke and Dehne (2004), the factual losses for the 1996-1998 period were estimated at 26-30% for sugar beet, barley, soybean, wheat, and cotton, and 35%, 39%, and 40% for maize, potatoes, and rice. Plant diseases cause roughly $ 220 billion worth of agricultural losses worldwide each year [20, 21]. Arthropod-related, disease-related, and weed-related yield losses are thought to account for around 35% of major crop losses globally. In underdeveloped countries with few pest control alternatives, losses could surpass 50% [22]. In some circumstances, crop failure or even larger losses can result from pest damage, specifically arthropod damage [23-26].

Agrochemicals can enter through direct application, including crop control and seed treatment, and indirectly through spraying of above-ground crops, treated leaves or fruits falling into the soil, and contaminated water that crosses the soil profile from the soil surface [27–30]. These substances can interact with the active substances of the soil (microbiota) and biodegrade once collected in the soil. Once in the soil, they can move through leaching and runoff, undergo chemical processes such as hydrolysis, photolysis, and chemical degradation, and may undergo chemical processes such as hydrolysis, photolysis, and chemical degradation [31-35]. Many bioactive substances provided by plants are important for the interaction between plants and their natural environment.

Table 1: Botanical plants with target pest

Scientific Name	Family	Part Utilized	Target Pest	References
Acorus calamus	Acoraceae	Leaf, Rhizome, Stem	*Microsporum gypseum, Penicillium marneffei, Trichophyton rubrum, Sitophilus zeamais*	[36]
Adhatoda vasica	Acanthaceae	Leaf, Root, Bark, Fruit, Flower	*Xanthomonas oryzae*	[37]
Allium cepa	Alliaceae	Seed	*Alternaria solani, Cochliobolus heterostrophus, Phytophthora infestans, Ramularia areola*	[38-40]
Allium sativum	Alliaceae	Bulb, Leaf	*Bemisia tabaci, Curvularia lunata, Fusarium guttiforme, Helicoverpa armigera, Pseudomonas syringae*	[41-44]
Annona squamosa	Annonaceae	Seed	*Fusarium wilt, Phytophthora blight, Rhizoctonia solani*	[45]
A. indica	Meliaceae	Leaf, Bark, Root, Seed, Fruit	*Aphis spp., Aspergillus niger, B. tabaci, Colletotrichum spp, Echinochloa crus-galli, Fusarium oxysporum, Geotrichum candidium, H. armigera, Meloidogyne incognita, Meloidogyne javanica, Rhizopus stolonifer, Sitophilus zeamais*	[46-48]
Camellia oleifera	Theaceae	Stem, Leaf		[49]
Capsicum frutescens	Solanaceae	Fruit	*A. solani, Bacillus subtilis, Escherichia coli, F. oxysporum, Phytophthra infestans, Pseudomonas aerugionsa, Staphylococcus aureus*	[40, 50]
Chromolaena odorata	Asteraceae	Leaf, Stem, Root	*A. niger, Dolichodorus sp., F. oxysporum, G. candidium, Helicotylenchus sp., M. incognita, R. stolonifera*	[47]
Citrus hystrix	Rutaceae	Leaf	*Acarina spp., Acheta domesticus, Aphis spp., Botrytis cinerea, Siphonaptera spp., Uromyces appendiculatus,*	[43, 51]
Cymbopogon citratus	Gramineae	Leaf	*A. solani, Alternaria brassicae, P. infestans, Pectobacterium carotovorum*	[52]
Curcuma longa	Zingiberaceae	Root stem	*Spodoptera frugiperda, Spodoptera litura*	[53-55]
Datura stramonium	Solanaceae	Leaf, Fruit	*A. alternata, Aspergillus flavus, Aspergillus fumigatus, A. niger*	[56, 57]
Eucalyptus globules	Myrtaceae	Leaf, Bark	*A. brassicae, Alternaria triticina, A. solani, F. oxysporum, P. infestans, Pythium ultimum R. solani*	[58-60]
Gossypium herbaceum	Malvaceae	Leaf	Rice stripe virus, Southern rice black-streaked dwarf virus, Tobacco mosaic virus	[61]
Hydnocarpus anthelminthicus	Achariaceae	Leaf, Fruit	*Colletotrichum falcatum, Colletotrichum higginsianum, Phytophthora palmivora, P. oryzae, R. solani*	[62-63]
Lantana camara	Verbenaceae	Leaf, Stem, Fruit	*A. flavus, A. niger*	[64-65]
Mentha piperita	Lamiaceae	Shoot	*A. alternata, B. cinerea*	[66-67]
N. tabacum	Solanaceae	Leaf	*Aphis sp., Acarina sp., Bradysia sp., Circulifer tenellus, F. oxysporum, Penicillium digitatum, Rhizopus sp.*	[68]
Ocimum basilicum	Labiatae	Leaf	*A. solani, Alternaria heveae, P. infestans*	[40, 69]
Ocimum sanctum	Malvaceae	Leaf	*F. oxysporum, Macrophomina phaseolina, Sarocladium oryzae*	[70-72]
Ocimum tenuiflorum	Lamiaceae	Leaf	*Phyllosticta zingiberi*	[73]
Origanum vulgare	Lamiaceae	Leaf, flower	*Bacillus spp., Serratia marcescens*	[74]
Peganum harmala	Zygophyllaceae	Leaf, Stem	*Bursaphelenchus xylophilus*	[75]
Prosopis juliflora	Fabaceae	Leaf, Fruit	*A. alternata, A. solani, B. cinerea, B. subtilis, Candida albican, Geotrichum candidum,*	[76]

			P. infestans, S. aureus, Xanthomonas campestris	
Psidium guajava	Myrtaceae	Leaf	*Chromobacterium violaceum, P. carotovorum, Pseudomonas aeruginosa, S. aureus, S. marcescens*	[52, 77]
Reynoutriasachalinensis	Polygonaceae.	Leaf, Stem, Flower	*Leveillulataurica*	[78-79]
Ricinus communis	Euphorbiaceae	Leaf	*R.solani, Fusarium wilt*	[45]
Rhododendron molle	Ericaceae	Flower	*Pieris rapae*	[80]
Rosmarinus officinalis	Lamiaceae	Leaf, Seed	*A. flavus, Phytophthora capsici, P. megakarya, P. palmivora*	[81]
Salvia officinalis	Lamiaceae	Shoot	*Penicillium aurantiogriseum, Verticillium dahlia*	[82]
Tithonia diversifolia	Asteraceae	Leaf	*A. niger, F. oxysporum, G. candidium, R. stolonifer*	Veeran, S. *et al.* 2019 [113]
T. diversifolia	Asteraceae	Leaf	*Cercospora arachidicola, Cercosporidium personatum*	[83]
Tridax procumbens	Asteaceae	Leaf	*C. arachidicola, C. personatum*	[83]
Thuja orientalis	Cupressaceae	Leaf	*Watermelon mosaic virus*	[84]
Thymus citriodorus	Lamiaceae	Leaf	*M.incognita, M.javanica*	[50]
Trigonella foenumgraceum	Fabaceae	Leaf, Seed	*P. capsici*	[85]
Vernonia amygdalina	Asteraceae	Leaf	*F. oxysporum*	[59]
Withaniasomnifera	Solanaceae	Leaf	*Trichothecium roseum*	[86]
Zingiber officinale	Zingiberaceae	Rhizome	*B.tabaci, Caliothrips fasciatus, Colletotrichum lindemuthianum, Fusarium lycopersici, F. oxysporium, F. solani, Phaeoisariopsis, griseola, P.infestans, P. oryzae, P. digitatum*	[43, 87-88]

Microalgae as a Source of Biofertilizers, and Biostimulants

Microalgae and cyanobacteria are important sources of physical molecules, including phenolic compounds, polysaccharides, hormone analogs, and proteins, which serve many purposes, including being antioxidants and promoting plant growth. In addition, bacteria, including prokaryotes (such as nitrogen-fixing cyanobacteria) and eukaryotes (such as microalgae and macroalgae/algae), are widely recognized for their roles in soil fertilization and plant growth promoting [3]. In addition to these important features, microalgae/cyanobacterial biomass production has many advantages over the production of other biological products.

Biofertilizers are products of natural origin that promote crop growth through the action of the soil. In general, these chemicals and/or bacteria are responsible for increasing soil fertility and providing essential nutrients (such as nitrogen, phosphorus, and potassium) for plant growth.

Biofertilizers can be divided into the following groups according to their beneficial effects and organisms of this nature [89-90]: plant growth-promoting bacteria, composts, nitrogen-fixing bacteria, P and K solubilizing biofertilizers, and P mobilizing biofertilizers can stimulate plants. The use of biofertilizers in agriculture has many benefits: [90–91]: (i) more crops per area and time; (ii) reduced energy requirements; (iii) management and monitoring soil quality and fertility; (iv) reduction the risk of soil and water pollution; Biostimulants act directly on plants to increase yield.

This substance is responsible for promoting ion uptake, respiration, photosynthesis, nucleic acid synthesis, and other plant metabolic processes. The activity of biostimulants has been demonstrated in both positive and negative ways, indicating that these substances are important for the development of stress and resistance in plants [3-4].

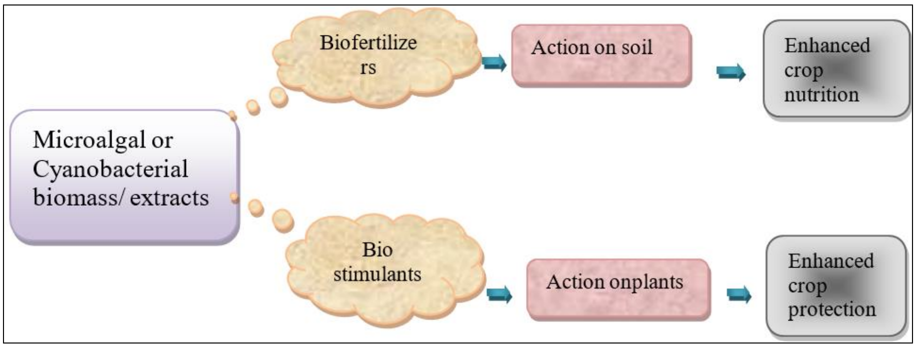

Fig 1: Microalgae as a source of biofertilizers and Biostimulants

Microalgal/Cyanobacterial Metabolites and Phytohormones with Potential Interest for Agriculture

Due to their biological activity, a large range of metabolites produced by microalgae and cyanobacteria can be employed in agriculture as biofertilizers, biostimulants, or biopesticides. Phenolic chemicals, terpenoids, FFAs, polysaccharides, carotenoids, and phytohormones are among these metabolites that are of particular interest because they have already been recognized as plant growth promoters [2, 6, 92]. The primary biologically active substances that can be isolated from microalgae and cyanobacteria for use in agricultural activities are listed in Table 2.

Table 2: Microalgal and cyanobacterial metabolites with potential interest in agriculture [93]

Metabolites	Examples	Microalgal/Cyanobacterial Sources	Biological Activity	Role in Agriculture
Phenolic compounds	Polyphenols; phenolic acids; flavonoids; Phenylpropanoids	*Botryococcus braunii; Chaetoceros calcitrans; Chlorella vulgaris; Isochrysis galbana; Isochrysis sp.; Neochloris oleoabundans; Odontella sinensis; Phaeodactylum tricornutum; Saccharina japonica; Skeletonema costatum; Tetraselmis suecica*	Antibacterial; antioxidant; antifungal	Crops' protection against pathogens or other biotic and abiotic stress conditions
Terpenoids	Hemiterpenes; monoterpenes; sesquiterpenes; diterpenes; triterpenes; polyterpenes	*Chondrococcus hornemanni; Hypneapannosa; Oscillatoria peronata; Planktothrix raciborskii; Plocamium cornutum; Plocamium leptophyllum; Portieria hornemannii; Pseudanabaena articulate; Pseudanabaena sp.; Sph aerococcus coronopifolius; Synechocystis sp.; Thermosynechococcus elongatus*	Antibacterial; anticarcinogenic; antioxidant	Crops' protection against bacteria, insects, and other organisms Stimulation of preliminary growth and development of plants Attraction of pollinators
Free fatty acids	Saturated and unsaturated fatty acids	*Anabaena; Chlorella; Dunaliella; Nannochloropsis; Porphyridium; Scenedesmus; Spirulina*	Antibiotic; anticarcinogenic; antifungal; antioxidant; antiviral	Crops' protection against pathogens or other biotic and abiotic stress conditions
Polysaccharides	Extracellular polysaccharides; structural polysaccharides; energy-storage polysaccharides	*Aphanothece; Arthrospira; Chlamydomonas; Chlorella; Cylindrotheca; Dunaliella; Navicula; Nostoc; Phaeodactylum; Porphyridium; Rhodella; Scytonema*	Antibacterial; anticancer; anticoagulant; anti-inflammatory; antioxidant	Improvement of soil quality Plant growth stimulation Crops' protection against biotic and abiotic stress conditions
Carotenoids	Alpha-carotene; beta-carotene; lutein; lycopene; astaxanthin; zeaxanthin	*Chlorella protothecoides; Chlorella pyrenoidosa; Chlorella zofingiensis; Dunaliella salina; Haematococcus pluvialis; Muriellopsis sp.; Phaeodactylum tricornutum; Spirulina sp*	Anticancer; anti-inflammatory; antioxidant	Soil bioremediation and fertilization Crops' protection against bacteria, insects, and other biotic and abiotic stress conditions Crops' fortification
Phytohormones	Auxins; abscisic acid; cytokinins; ethylene; gibberellins	*Arthrospira; Chlamydomonas; Chlorella; Phormidium; Protococcus; Scenedesmus*	Chemical messengers	Plant growth stimulation Regulation of cellular activities in crops Crops' response to stress conditions

Table 3. Microalgae and cyanobacteria (and their metabolites) impact soils' improvement [93]

Mode of Action	Algal Extracts	Target Crop/ Soil	Observed Improvement
Nitrogen fixation	Cyanobacterial inoculum composed of Aulosira fertilissima, Anabaena sphaerica, Nostoc hatei, *Cylindrospermum* majus and Westiellopsis prolifica	Rice	Increase in nitrogen availability in the soil Increase in grain and straw yields
	Wild-type and herbicide-resistant strains of Anabaena variabilis	Rice	Increase in grain, straw, and seed yields Increase in plant height and leaf length
	Nostoc sp. vegetative cells	Rice	Increase in grain yields comparable to those obtained with a chemical fertilizer
	Nostoc Conophytum and Oscillatoria *angustissima*	Pea	Increase in nitrogen fixation Increase in growth parameters, germination percentage, and photosynthetic pigments Increase in the nutritional value of pea seeds
	Anabaena torulosabiofilm	Wheat	Increase in nitrogen availability in the soil
	Cyanobacterial-bacterial biofilms including the species: *Calothrix* sp., Anabaena laxa, Anabaena torulosa, Anabaena *doliolum*, Nostoc carneum, Nostoc piscinale, Trichoderma viride, Pseudomonas fluorescens, and Azotobacter chroococcum	Soybean and mungbean	Increase in nitrogen availability in the soil Increase in plant fresh weight
Nutrients' availability in soils	Calothrix ghosei, Hapalosiphon intricatus, and Nostoc sp	Wheat	Increase in organic carbon content in the soil Increase in grain yield
	Cyanobacterial consortia including the species: Anabaena doliolum, *Cylindrospermum* sphaerica, and Nostoc calcicola	Wheat and Millet	Increase in nitrogen and phosphorus availability in the soil Decrease in soil density Improvement of water retention capacity Increase in grain yields Improvement of nutritional properties (increase in protein content of grain and leaves)
	Microalgal-bacterial flocs and Nannochloropsis oculata	Tomato	Increase in ammonium, phosphorus, and potassium availability in the soil Improvement of fruit quality (increase in sugar and carotenoids contents)
	Consortia and biofilms including the species:	Okra	Increase in zinc and iron availability in the soil

	Azotobacter sp., Anabaena sp., Providencia sp., and Calothrix sp.		Beneficial changes in the microbiome Increase in root yield and weight
	Microalgal-cyanobacterial unicellular and filamentous consortia including species of Chlorella, Scenedesmus, *Chlorococcum*, *Chroococcus*, Phormidium, Anabaena, *Fischerella* and Spirogyra	Wheat	Increase in nitrogen, phosphorus, and potassium availability in the soil Increase in organic carbon content in the soil Improvement of product quality (increase in nitrogen, phosphorus, and potassium contents in roots, shoots, and grains)
	Microalgal-cyanobacterial unicellular and filamentous consortia including species of Chlorella, Scenedesmus, Chlorococcum, Chroococcus, Phormidium, Anabaena, Fischerella and Spirogyra	Wheat	Increase in zinc, iron, copper, and manganese availability in the soil Increase in organic carbon content in the soil Increase in grain yield Improvement of plant nutritional value (increase in grain micronutrient contents)
	Chlorella sorokiniana	Soil from a vineyard	Increase in nitrogen availability in the soil
Soil physical and chemical amendments	Microcoleus vaginatus, Phormidium tenue, Scytonema javanicum, Nostoc sp. and *Desmococcus Olivaceus*	Unconsolidated sand	Increase in crust cohesion Increase in the resistance to wind erosion
	Nostoc strains	Poorly aggregated tropical soils	Increase in aggregates' stability
	Phycocyanin extract from Spirulina platensis and inactive biomass of Spirulina platensis	Soil contaminated with diesel and biodiesel	Reduction in diesel and biodiesel concentration using S. platensis and Phycocyanin, respectively

Table 4: Impacts of microalgae and cyanobacteria (and their metabolites) on direct growth stimulation of plants [93].

Algal Extracts	Target Crop	Observed Improvement	References
Anabaena strains (Anabaena Spiro ides, Anabaena osillarioides, Anabaena torulosa and Anabaena variabilis)	Rice	Increase in germination rate Increase in plant height and shoots length Increase in fresh and dry weights of leaf, stem, and root Improvement of soil properties (increase in soil moisture and porosity	
Laurencia obtusa, *Corallina* elongata and *Jania rubens*	Maize	Increase in plant length and fresh and dry weight Increase in the number of leaves Improvement of plant nutritional value (increase in potassium, phosphorus, and nitrogen contents)	
Exopolysaccharides extracts from Dunaliella salina	Wheat	Increase in germination rate and seedling growth Increase in root and coleoptiles height Increase in tolerance to salt stress	
Aqueous extracts from Gracilaria corticata and Enteromorpha flexuosa	Maize and sunflower	Increase in shoot and root length and dry weight Improvement of plant nutritional value (increase in photosynthetic pigments, carbohydrate, proteins, and nutrients contents)	
Liquid extracts from Stoechospermum marginatum	Brinjal	Increase in shoot and root length Increase in fresh and dry weight of leaves Increase in leaf area Improvement of leaves nutritional value (increase in moisture, photosynthetic pigments, protein, amino acids, reducing sugars, and ascorbic acid contents)	
Total polysaccharides extract from Spirulina platensis	Tomato and pepper	Increase in plants' size Increase in roots' weight Increase in size and number of nodes	
Ulva lactuca and *Jania rubens*	Spinach	Increase in plant yield and height Improvement of plant nutritional value (increase in chlorophyll and nitrogen contents)	
Arthrospira platensis	Lettuce	Increase in seedling growth Increase in spermine content in leaves	
Chlorella vulgaris and Spirulina platensis	Maize	Increase in germination rate and plant yield Increase in fresh and dry weights of the shoot, root, and whole plant Increase in shoot length and the number of leaves	

Bioactive compounds from botanicals

Botanical pesticidal compounds have noticeable effects against various agricultural pest species because of their varied mechanisms of action [12].

Table 5: Bioactive compounds released by botanical plants with their Trade Name as well as biological effects [12]

Product name	Botanical name	Trade name	Main Bioactive Compound(s)	Biological Effects
Capsicum oleoresin	*Capsicum* spp. (*C. frutescens*)	Hot Pepper Wax Insect Repellent	Capsaicin	Repellent, Fungicide, Nematicide, Bactericide
Cinnamaldehyde	*Cassia tora L., Cassia obtusifolia* L.	VertigoTM, CinnacureTM	Cinnamaldehyde	Fungicide, Insect Attractant
Cinnamon essential oil	*Cinnamomum zeylanicum*	Weed ZapTM, Repellex,	Cinnamaldehyde	Insecticide, Herbicide
Clove essential oil	*Syzygium aromaticum L. Eugenia caryophyllus* Spreng	Matran EC, Burnout II, Bioganic Lawn	Eugenol (mixture of several predominantly terpenoid compounds)	Insecticide, Herbicide
Extract of giant Knotweed	*R. sachalinensis*	Milsana®, RegaliaTM	Physcion, Emodin	Fungicide, Bactericide
Jojoba essential oil	*Simmondsia californica* Nutt., *S. chinensis*	Detur, E-Rasem, Eco E-Rase, Permatrol, ERaseTM	Straight-chain wax esters	Fungicide, Insecticide
Karanjin	*Derris indica* (Lam.) Bennet	Derisom	Karanjin	Insecticide, Acaricide
Lemongrass	*Cymbopogon nardus,*	Green Match EXTM	Citronellal, Citral	Insecticide, Herbicide

essential oil	*C.citratus, Cymbopogon flexuosus D.C*			
Neem (neem oil)	*A. indica*	Ecozin, Azatrol EC, Agroneem, TrilogyTM	Azadirachtin, Dihydroazadirachtin, Triterpenoids (Nimbin, Salannin	Insecticide, Acaricide, Fungicide
Nicotine	*Nicotiana spp.*	Stalwart, No-Fid, XL-All Nicotine, Tobacco Dust	(S)-Isomer, (RS)-isomers, and (S)-isomer of nicotine sulfate.	Insecticide
Phenethyl propionate	*Component of peppermint oil (M. piperita)* and *peanut oil*	EcoSmart HC, Eco Exempt HC, Ecopco Acu	Phenethyl propionate	Insecticide, Insect Repellent, Herbicide
Pink plume poppy extract	*Macleaya cordata R. Br.*	Qwel®	Alkaloids, Anguinarine Chloride, Chelerythrine Chloride	Fungicide
Pyrethrum	*Tanacetum cinerariaefolium (Trevisan) Schultz-Bip.*	Pyganic, Diatect	Esters of chrysanthemum acid and pyrethric acid (pyrethrins I and II, cinerins I and II, jasmolins I and II)	Insecticide, Acaricide
Rosemary essential oil	*R. officinalis*	EcotrolTM, SporanTM	1,8-cineole (borneol, camphor, monoterpenoids)	Insecticide, Acaricide, Fungicide
Rotenone	*Derris spp., Lonchocarpus spp.,* and *Tephrosia spp.*	Bonide, Rotenone	Rotenone, Deguelin, (isoflavonoids)	Insecticide, Acaricide
Ryania	*Ryania spp. (Ryania speciose Vahl)*	Natur-Gro R-50, Natur-Gro Triple Plus, Ryan 50	Ryanodine, Ryania, 9,21- didehydroryanodine (alkaloids)	Insecticide
Sabadilla	*Schoenocaulon spp. (S. officinale)*	Veratran, Red Devil, Natural Guard	A mixture of alkaloids (cevadine, veratridine)	Insecticide
Thyme essential oil	*Thymus vulgaris L. Thymus spp.*	Proud 3, Organic Yard Insect Killer, Promax TM	Thymol, Carvacrol	Insecticide, Fungicide, Herbicide

Table 6: Mechanism of Action of Some Bioactive Compounds

Plant Source	Active Compounds	Target site	Mechanism of Action	References
Haloxylonsalicornicum, N. tabacum, Stemona japonicum	Nicotine	Nervous system	It competes with the neurotransmitter by attaching to acetylcholine receptors (nAChRs) at neuron synapses, producing unregulated nerve firing. The disturbance of normal nerve impulse performance caused physiological system malfunctions in the neurons	[94-96]
Chrysanthemum cinerariaefolium	Pyrethrin I & II, Cinerin I & II, Jasmolin I & II	Nerve (Axon)	Interfering with Na and K ion conversion inhibited the normal transmittal of nerve impulses, triggering paralysis in insects.	[97, 13, 98]
Lonchocarpus spp., Derris spp.,	Rotenone	Mitochondria	Cell respiratory enzyme inhibitor disrupts cellular metabolism, and reduces ATP output. Nerve and muscle cell malfunctions lead to low feeding rates.	[99-101]
Ryania spp.,	Byanodine	Muscles	Activation of sarcoplasmic reticulum. Affect calcium development and causes the improper function of muscles.	[102]
S. officinale	Sabadilla	Nerve (Axon)	Obstruct the movement of neurons and potassium ions in nerve axons.	[103, 98]
Cedrus spp., Citronella spp., Eucalyptus spp., Pinus spp.	Essential oils	Octopaminergic system	Increase the level of intracellular messenger and effectively inhibit cyclic AMP of abdominal epidermal tissue.	[98, 104]
Monarda spp., O. vulgare, T. vulgaris	Thymol	Octopaminergic system	Prevent octopamine receptors via tyramine receptors cascade	[98, 105]
A. indica	Azadirachtin, Nimbin, Salannin, Melandriol	Endocrine system	Inhibit Prothoracicotropic hormone (PTTH); distort phagostimulant disruptor by cholinergic transmission	[98, 106-107]
A. squamosa	Squamocin (annonin), Debitterizedannona oil	Mitochondria	Dunnione acts as an insecticide and fungicide, disrupting mitochondrial complex III.	[98, 108]
Capsicum annum	Protoalkaloids Capsaicin	Nerve	Induced metabolism, impaired cell membrane, and nervous system. Acts as a physical repellent.	[108]
Citrus sinensis	Limonene, Linalool	Nerve	Hyperactivity, and hyper excitation leading to rapid knockdown and immobilization. Inhibitory effects on acetylcholinesterase.	[109]
Pongamia pinnata	Karanjin, Debitterisedkaranjin oil		Serves as feeding restraint, repellent, reduced growth, oviposition suppressor, and low or no fertilization.	[98, 108]
S. officinale	Cevadine, Veratridine	Mitochondria	Interrupt nerve cell membrane process, induced nerve cell membrane, paralysis, and mortality.	[98, 108]

Applications of botanical pesticides

Research has been done on the use of botanicals as pesticides and their efficacy as an alternative to traditional pest control in sustainable agriculture and related disciplines. The products are used as insecticides, growth inhibitors for insects, antifeedants, and insect repellents. Furthermore, nematicides, fungicides, bactericides, and virucides are all applications for these botanical bioactive compounds.

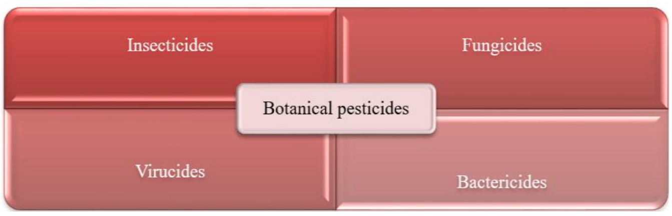

Fig 2: Applications of botanical pesticides

Table 7: An index of biologically active compounds used as nematicides [110].

Botanical Plants	Active Compounds	Activity
Abies balsamea	Juvabione	JH agonist
Acorus calamus	Asarone	Antifeedant
Ageratum houstonianum	Precocene, Anacylin	Anti-JH
Ajuga remota	Ajygarin	Feeding deterrent
Allium sativum	Diallyl sulfide	Repellent
Atlantia racemosa	Luvangetin	Antifeedant
Citrullus colocynthis	Cucurbitacin-B	Antifeedant
Citrus paradisi	Isolimonic acid	Oviposition deterrent
Clerodendron infotunatum	Clerodin	Antifeedant
Curcuma longa	Termeron	Growth inhibitor
Glycine max	Glyceollin	Antifeedant activity
Tagetes minuta	E-Ocimenone	Repellent
Ricinus communis	Ricinine	Oviposition deterrent
Medicago sativa	Butyric acid	Repellent
Ocimum basillicum	Juvocimene	JHA
Parthenium hysterophorus	Parthenin	Growth inhibitor
Piper nigrum	Piperin	Oviposition deterrent
Quassia amara	Quassin	JHA
Pongamia pinnata	Karanjin	Antifeedant, JHA

Conclusion and Prospects

Compared to synthetic pesticides, the use of botanical pesticides is an important part of the IPM program. Insects are sensitive to many behavioral and physiological effects caused by plant insecticides and it is difficult to develop resistance to these insecticides. If rural cooperatives use locally available produce, farmers do not need to spend a lot of money on expensive synthetic products. Fruit, vegetables, cotton, and residue-free water are in high demand in the world market. Most countries are constantly considering the development of sustainable agriculture to support the growing population.

Currently, organic farming is crucial to the management of mixed crops. The properties of these plants have encouraged scientists to use them as part of pest control because they are a good alternative to human pesticides. Phyto pesticides are organic chemicals isolated from pesticide-containing plants and used in plant protection as an effective alternative to pesticides or herbicides to prevent adverse effects or adverse effects. Pesticides, pesticides/antibiotics, poisons, insecticides, insecticides, and poisons are just some of the ways pesticides affect insects, such as pyrethrum, neem, nicotine, and more.

Therefore, it is better to use botanical pesticides than synthetic ones, and organic growers in developing countries are aware of the benefits of these botanical pesticides. Therefore, we now recommend using published botanical pesticides, and new sources of botanical pesticides are sought.

Fully exploiting biomass to produce different products, and different uses as well as promoting the concept of bio refining, a method where microalgae and cyanobacterial biomass can be used in agriculture and avoid high operating costs. Further research focusing on how each metabolite/biomass affects the crop is also needed to determine the best ingredient for agriculture.

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