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Role of Algae and Cyanobacteria in Crop Protection

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Abstract

As the human population grows, so does the need for increased food production. Traditional agricultural practices, especially synthetic pesticide use, are heavily criticized for their environmental impact and face significant public opposition. There is a pressing need for sustainable alternatives that are safe for both humans and ecosystems. Additionally, resistance to current pesticides poses a major challenge, making them less effective over time. Scientists are thus focusing on developing novel pesticidal compounds from unexplored chemical classes, with distinct toxicities and modes of action. These new compounds aim to minimize adverse interactions with existing treatments, offer better control over agricultural pests, and address public concerns about safety. The ultimate goal is to create a generation of eco-friendly, sustainable pesticides that protect crops while preserving ecological balance, representing a vital shift toward environmentally conscious agriculture in the face of rising food demands.

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1. Introduction

Synthetic pesticides have up until now played a major role in both insect pest suppression and maintaining high crop yields, even though managing agricultural pests is essential for agricultural sustainability. Chemical pesticides enduring presence in top soils and seepage into groundwater, along with their unfavourable effects on living organisms not intended for their use, pose a serious environmental threat. Chemical pesticides have long been used in agriculture to increase crop yields and shield crops from insect damage. However, overuse of conventional pesticides to control insect pests throws the environment out of balance and increases insect resistance to pesticides; alternative management strategies are therefore badly needed. Natural pesticides are essential and this is one of the goals of scientific research. Using botanical insecticides is an alternative, environmentally friendly method of crop protection. On the other hand, because of their greater biodegradability and strong biocidal effect at lower concentrations, natural chemicals

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are believed to be less dangerous. By providing novel structures and modes of action for safer pesticides, these organic materials may aid in the advancement of organic farming and integrated pest management. By examining natural alternative pesticides and extracts, researchers can discover new chemical entities that have never been created (Sharanappa et al., 2023).

1.1. Algae

The simplest plant-like organisms found in the aquatic environment and resemble higher plants by the presence of chlorophyll and being photoautotrophic. The very primitive algae are unicellular, but with evolution, they developed into multicellular forms, which had vertical and horizontal systems. Even now algae are found in association with damp soil and aquatic environments, both freshwater and marine. There are different groups of algae. Those are chlorophytes including green algae, euglenophytes, pyrophytes, cryophytes, phaeophytes including brown algae and rhodophytes including red algae. Algae as a group of plants show a wide variation in morphology. They are not only microscopic but also macroscopic. Their plant body could be unicellular, uninucleate, or unicellular multinucleate or multicellular multinucleate forms. Almost all of the multicellular forms show an undifferentiated body called thallus. The shape of the plant body could be filamentous, thalloid, globe-like, flattened or heterotriches forms. Some algae are motile while some are not motile. Some are attached to a substrate with the help of a holdfast. Algae show different colours because they contain different combinations of pigments. Unicellular forms show greater variation in their size and shape of the chloroplast. Colony forms of algae are common in freshwater bodies. These are aggregations of cells having fixed number of cells. Reproduction in algae is complex because they show vegetative reproduction as well as sexual reproduction.

1.2. Cyanobacteria or Blue-green algae

These are small class of photosynthetic, gram-negative, structurally complex prokaryotes that are the most varied and widespread species on Earth. They have been here for more than three billion years. The capacity of cyanobacteria to compete with native flora and fauna, their established position as diazotrophs, and their proficiency in a variety of soil ecologies make them a valuable bioresource that has been mostly employed in agriculture as a biofertilizer. Cyanobacteria are a group of bacteria. Their speciality is the ability of photosynthesis. They appear in blue-green colour, and they are also called blue-green bacteria. Cyanobacteria use carbon dioxide as the source of carbon. Moreover, photosynthesis first evolved in bacteria. Hence, it is highly probable that photosynthesis is first evolved in cyanobacteria. Thus, blue, green bacteria are present in the surface layers of seawater as well as in the surface layers of fresh water. It is thought that cyanobacteria represent a significant source of newly discovered natural antifungal and antibacterial chemicals. Research in this area is primarily restricted to in vitro screening, and the possible application of cyanobacteria in agriculture is frequently mentioned as a secondary goal. Potential applications of cyanobacterial biomass and products include agricultural pest control and These organisms have been shown to generate a remarkable variety of physiologically active substances, or metabolites, spanning several chemical classes and including a wide range of nitrogen-rich peptides and alkaloids. Many of them have a great deal of promise for use in commercial developments as herbicides, insecticides, and algaecide applications as well as for the creation of pharmaceuticals. A broad range of cyclic peptides, including anabaenopeptins, nostopeptolides, and anabaenopeptides, as well as linear cyanotoxins like aeruginosins and microginins are known to be produced by cyanobacteria; these cyanotoxins may also have bioactivities such serine protease inhibition.

1.3. Metabolites

Metabolites are small mass chemicals that microorganisms employ to control their growth and development, promote other helpful species, and repress harmful organisms. They are substances that are necessary for growth and consist of lipids, proteins, carbohydrates, and nucleic acids. A variety of structurally related low relative molecular mass chemicals are produced by microorganisms such as actinomycetes, cyanobacteria, and algae and are subsequently taken up as secondary metabolites. The secondary metabolites, often known as antibiotics, are extracted from microorganisms and show antimicrobial (antibacterial, antifungal, antiprotozoal), anticancer, and/or antiviral properties. secondary metabolites that, at the biochemical level, in minute concentrations, control growth processes, replications, and/or demonstrate some logical response (regulating, inhibiting, stimulating) to the (life cycle) of prokaryotic or eukaryotic cells. In addition to the several microscopic algae mentioned above, diatoms (Chlorophyta, Rhodophyta, Phaeophyta, Ciliophora, etc.) are also frequently generated with the approximately

1300 bioactive compounds that they create. These include seaweeds and dinoflagellates. Metabolites from algae and cyanobacteria which act as pesticides, free fatty acids, essential oils, terpene compounds, phenols, alkaloids, tannins, saponins, laurinterol, flavonoids, microcystin etc.

2. Biocontrol Potential of Algal and Cyanobacterial Metabolites

2.1. Insecticidal-Acaricidal properties

Free fatty acids are non-esterified fatty acids typically found in microalgal and cyanobacterial crude extracts. Moreover, they can be divided into unsaturated (lignoceric, palmitic, capric, behenic, cerotic, caprylic, lauric, stearic, myristic and arachidic acids) and saturated (cis- and trans-fatty acids) fatty acids, identified in microalgal biomass from different genera (*Anabaena*, *Chlorella*, *Dunaliella*, *Porphyridium*, *Scenedesmus* and *Spirulina*), which include green, red and blue-green algae. These compounds exhibited potent insecticidal and growth-inhibition activity, Including larval mortality and pupal duration, percentage of pupation and adult's emergence, pupal weight, pupal and moth malformation, fecundity, egg hatchability, adult's longevity and sex ratio. Anatoxin-a(s) (antx-a(s)) is a cyanobacteria neurotoxin structurally unrelated to the other neurotoxic alkaloids also produced by cyanobacteria. Its mechanism of action is the irreversible inhibition of acetylcholinesterase. *Ulva fasciata*, and *U. lactuca* were effective against these agricultural pests by causing nymphal mortality, adult mortality, abnormal development, or reducing adult lifespan, fecundity, and hatchability (Asaraja and Sahayaraj, 2013).

2.2. Nymphicidal and ovicidal activity

Caulerpa veravalensis (macro algae) altered the behavioral changes like adult longevity, egg hatchability, mating period, relative growth rate and ovicidal activity of *Dysdercus cingulatus*. The GC–MS results revealed that nine major compounds with nymphicidal activity against *D. cingulatus*. Tetradecanoic acid, 10, 13-dimethyl-, methyl ester as a chief constituent and possibly these may produce high mortality against the *D. cingulatus* (Sahayaraj et al., 2019).

2.3. Terpenes and saponins

Major compounds found in a hot ethanolic crud extract of *Cladophora glomerata* (macro-algae). Hexadecane -tetra methyl this compound belongs to the acyclic diterpenes. These are diterpenes that had antimicrobial activity. Saponins play an important role in increased mortality and decreased reproduction in pest insects. The mode of action of saponins in insects demonstrates a block of the uptake of sterols, the insects cannot synthesize sterol structures by themselves. Other possibility is that saponins are toxic to insect because of they increase the permeability of plasma membranes, and they are known to reason dissociation (Sahayaraj et al., 2019).

2.4. Repellent properties

Insecticidal and repellent activities were evaluated on extracts from three macroalgae (*Caulerpa sertularioides*, *Laurencia johnstonii* and *Sargassum horridum*) against *Diaphorina citri* adults. The three extracts showed alkaloids, terpenes, phenols, tannins, flavonoids, anthraquinones and saponins, which are associated with insecticidal and repellent activity. Additionally, three terpene compounds isolated from *L. johnstonii* were identified by GC/MS; debromolaurinterol, isolaurinterol, and laurinterol as potential repellent compounds (Sahayaraj et al., 2019).

Figure 1: Malformations in different developmental stages of *Spodoptera littoralis*

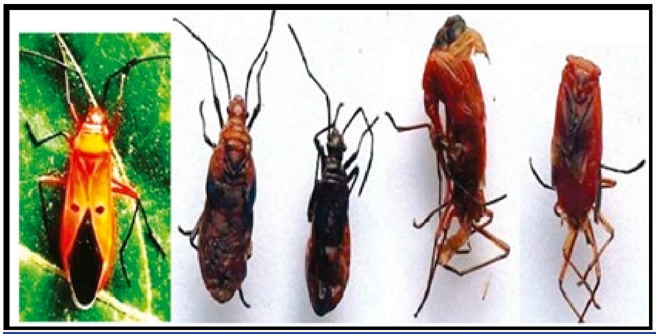

Figure 2: Morphological deformities due to *C. veravalensis* (macroalgae) on *D. cingulatus*

Figure 3: Pupal–adult intermediates of Spodoptera frugiperda resulted from the effect of cyanobacterial extracts

2.5. Nematicidal properties

Microalgae and mainly cyanobacteria are also reported to decrease the population of plant pests such as nematodes. This is achieved through the production of peptide toxins and nematicidal compounds. Tomato seedling roots dipped in culture filtrates of *Microcoleus vaginatus* led to 65.9% and 97.5% reduction in root galling and nematode population respectively. Application of some cyanobacteria (blue green algae) in soil may inhibit Plant parasitic nematodes infestation by producing hydrolytic enzymes and secondary metabolites called cyanotoxins (Gupta et al., 2013).

2.6. Antifungal properties

The mode of action of cyanobacteria antimicrobial compounds is damaging the structure or function of the cytoplasmic membrane, destruction of enzymes, and suppression of protein synthesis. Among all the compounds synthetized by cyanobacteria, chitosanase homologues, endoglucanase and benzoic acid were detected, and their presence was correlated to the activity against fungi. An antifungal substance, bromophenol bis (2, 3-dibromo-4, 5-dihydroxybenzyl) ether (BDDE), was extracted from *Rhodomela confervoides* (red alga) and from *Leathesia nana* (brown algae) and showed to inhibit Botrytis cinerea mycelial growth, spore germination and germ tube elongation. A direct antifungal activity was also showed by extracts from the green macroalga *Ulva lactuca*, which highly inhibited *Aspergillus niger*, *Penicillium digitatum* and *Rhizoctonia solani* mycelial growth (Abbassy et al., 2014)

2.7. Antibacterial properties

An array of diverse chemical compounds from algae, including alkaloids, polyketides, peptides, polysaccharides, phlorotannins, diterpenes, sterols, quinones, lipids, and glycerols, have been found to exhibit antibacterial action. The spray application of aqueous extracts from the brown algae *Cystoseira myriophylloides* and *Fucus spiralis* significantly reduced Crown gall disease incidence that was caused by the bacterial pathogen *Agrobacterium tumefaciens* in greenhouse tomato plants (Esserti et al., 2017).

2.8. Antiviral properties

Plant viruses are a serious threat to agricultural crops, affecting product quality and yields and resulting in severe economic losses. Their management is heavily dependent on synthetic chemical products, but natural compounds are continuously gaining ground. In this respect, natural compounds from algae that exhibit antiviral properties could be valuable resources. Among them are various polysaccharides, such as laminarins, agarans, alginate, carrageenans, and sulphated fucans, that can function as elicitors of defense mechanisms, as well as proteins, lipids, tannins, and terpenoids. Sodium alginate from marine algae exhibited strong inhibitory activity against the tobacco mosaic virus (TMV) that was isolated from systemically-infected leaves of *Nicotiana tabacum* L. var bright yellow (Sano, 1999).

2.9. Herbicidal activity

Natural bioherbicides have become a useful tool for the integrated management of herbaceous weeds, a major problem in agriculture that are known for impairing the growth of cultivated plants and effectively reducing crop yields. Various algal metabolites, such as cyanotoxins that exhibit cytotoxicity, have been considered as potential candidates for herbicidal activity. In many documented cases, cyanotoxins have ecological role as allelochemicals, inhibiting competitive macrophytes, algae, and microbes. Inhibit the germination of weeds, such as *Avena fatua* and *Plantago lanceolata*; suppress the growth of *Portulaca oleracea*, *Echinochloa crus-galli* and *Amaranthus retroflexus*; and damage the metabolism in *Arabidopsis thaliana* (Lopez-Gonzalez et al., 2020).

3. Mechanism of Action

The biocidal activity of algae and cyanobacteria is very similar to the plant and microbial insecticides in their spectrum and mechanism of action.

Algal and Cyanotoxins represent a class of allelopathic compounds produced by cyanobacteria and generally fall into three main groups (i) Cytotoxins (ii) Neurotoxins (iii) Hepatotoxins. The effect of these extracts due to the compounds of alkaloids and other active compound that act as feeders leading to the destruction of insects, and to enter by the respiratory openings affect the nervous system and digestive system. In addition to their mortality effect, have an effect on hormones that decline egg rate. Other mode of action includes, inhibition of photosynthesis, induction of plant defense responses, inhibition of quorum sensing, neurotoxicity, production of antimetabolites, blocking virus entry into the plant (Asimakis et al., 2022).

4. Extraction of Metabolites of Algae and Cyanobacteria

4.1. Soxhlet extraction

Five grams of the powdered material was extracted using 120 ml of hexane and petroleum ether in automated Soxhlet apparatus. The extract was concentrated under a desiccator to yield crude extracts. Standard stock solutions were prepared by dissolving crude material in dimethyl sulfoxide and stored at 4°C.

4.2. Mechanical shaking method of extraction

Five grams of algal/cyanobacterial powder was soaked in 50 ml of ethanol and methanol solvent and then kept in a mechanical shaker for three days continuously for the complete extraction of bioactive compounds, and then, it was filtered through Whatman no. 1 filter paper after that extract was kept in room temperature for about one day for the evaporation of solvents and to get a concentrated form of crude extract. Standard stock solutions were prepared by dissolving crude material in dimethyl sulfoxide and stored at 4°C.

5. Conclusion

Metabolites have effect on larval and pupal duration, percentage of pupation and adult emergence, pupal weights, pupal and moth malformation, fecundity, egg hatchability, adult longevity and sex ratio, also reduced root galling and nematode population. They perform antifungal activity by inhibiting radial growth of plant pathogenic fungus.

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