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Biopesticides from algae and their potential for sustainable agriculture and environmental protection

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Abstract

Agricultural crops have become more resistant to synthetic pesticides and pressure mounts regarding their effect on our health and the environment. When these compounds leach into the ground waters, they become direct sources of human health hazards. Also, agricultural runoffs can cause widespread damage to flora fauna and in general affect the food chain in an ecosystem. To combat these deleterious effects, the race is on to bring biopesticides to market that are safe, effective at scale, affordable and can ensure future food security. In this present scenario there is an urgent need to look for alternate sources of similar compounds to replace synthetic pesticides that are sustainable, ecofriendly, and easily available to be mass produced. In this effort microalgae may play a very significant role as they have the capacity to produce a wide array of bioactive compounds with pesticidal properties. As a part of their daily metabolic activities through different physiological pathways they are known to produce and release compounds with anti-bacterial, anti-fungal, anti-protozoal, pesticidal, insecticidal properties. Microalgae, especially the cyanobacteria have very fast growth rates and are potent sources of raw material for the generation of these compounds therefore considered significant while considering biopesticides to replace synthetic ones. This review explores the use of microalgae driven release of biochemicals and secondary metabolites produced by microalgae, or microalgal biomass, that can serve as future promising biopesticides to replace the agrochemicals used these days in agriculture.

Keywords: Algae; Cyanobacteria; Secondary metabolites; Biomass; Biopesticide; Ecofriendly; Anti-Bacterial; Anti-fungal; Anti-viral

1. Introduction

The steep rise in population worldwide has escalated the food demand many folds with very few solutions of bridging this gap. In the quest to produce more food to meet the ever-increasing demands, agriculture is now becoming intensive with more and more use of chemical fertilizers and pest control chemicals. These agrochemicals used as pesticides control the pests but in turn cause huge damage to the ecosystem [1-4].

Massive loss of crops due to pests is one of the bottle necks in agriculture and responsible for less crop productivity and gross production. This encouraged researchers to consider alternate ways of controlling the pests and this initiated the search for biopesticides.

Research on microalgal species has led to the identification of a large number of extracts and bioactive compounds with pesticidal functions for use in agricultural practices. Although these compounds have been used successfully as treatment against agricultural pests, their actual potential can be revealed by combining them with other features in the of integrated pest management. Even though a lot of progress has been made in deciphering their mode of action, more knowledge is expected to be produced in the future in this regard. Current algal species are estimated to be around 1,00,000 [5]. Yet, a very small percentage of these species have been investigated for their antimicrobial properties.

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Considering the evolutionary history of algae and their unique distributions in nature, one can expect a huge range of different metabolites from algae. This seems to be the reason why novel secondary metabolites are constantly being reported from various algal species. Most of the research on bio- actives from algae has been done in the medical side, so it's fair to assume that same type of results may be expected on plants pathogens too. Records of these compounds show a limited number of bio- pesticidal extracts or compounds from microalgae and cyanobacteria, so it's justified to say these organisms are an unexplored resource of newer bio pesticidal compounds.

2. Why Algae and cyanobacteria?

The microalgae in general and cyanobacteria are a large and morphologically diverse group of eukaryotes and prokaryotes that are ubiquitous in nature and found in every conceivable ecological niche on earth. They survive under the most adverse and challenging conditions due to their great adaptability, sometimes on the borderline of life. These microorganisms are photosynthetic in nature like the higher plants and the cyanobacteria possess the unique ability of trophic independence to C and nitrogen making them the most potent organisms for exploitation for various biotechnological products. Biopesticides from microalgae therefore are the most attractive prospect with fewer negative environmental effects and totally biodegradable [6].

Microalgae have potential advantages over plants and other organisms that make them very suitable for biopesticide production. They have fast growth rates and therefore high biomass per unit area, minimal nutrient requirements and can be grown on wastewaters if required. Also because of their presence in every ecological niche and wide variety of adaptations they can be grown in any part of the world where required. In addition, the cyanobacteria have many additional properties that are not found in higher plants like the ability to fix atmospheric nitrogen, breakdown and release organic phosphates to inorganic form via inducible phosphatase enzymes and of course fix CO_2 via photosynthesis which give them an unique trophic independence [7,8,9,10] and help them perform as potent biofertilizers in addition to biopesticides and other bio active's.

The newly implemented laws and legislation on biopesticides have stringent rules of no safety period between addition of the biochemical and time of harvest and require them to be totally biodegradable. Although biopesticides make up only 5% of the total worldwide pest control market presently they are expected to occupy far greater percentages in the global market and prominence where food production and safety are concerned in the coming years.

3. Algae with bio pesticidal properties: Role in agriculture

Algal extracts are known for their antimicrobial, nematocidal, herbicidal, and insecticidal/acaricidal properties against crop pathogens and can be used as biopesticides [11,12,13]. The word biopesticide refers to naturally occurring biochemical compounds such as exopolysaccharides, hydrophobic biomolecules, and hormones (14) that are commonly produced by various microorganisms like bacteria, fungi, virus and algae or by genetically modified plants with the genes from these microbes that are used to control pests in agricultural practices. The types of antimicrobial compounds produced by algae differ in composition, and their production depends on the type of culture medium used for growth, incubation period, pH, temperature, and light intensity during culturing. The antibacterial activity depends on the microalgal species with more hydrophobic biomolecules such as polyketides, amides, alkaloids, fatty acids, indoles, and lipopeptides being most effective (15). The microalgae have been shown to lower pathogenic bacterial infection in plants, including the genera *Agrobacterium, Pseudomonas, Xanthomonas*, and *Erwinia*, that cause serious diseases in potent agricultural crops that are the staple food for many [16,17,18]. Similar compounds which have antifungal effects on crops have been identified. Mycelial growth was found to be inhibited with algal compounds and resistance to the disease was induced in plants against common fungal genera such as *Fusarium, Verticillium, Rhizoctonia, Phytophthora*, and *Phoma* [19-21].

Antifungal activities have also been reported against soil-borne or foliar fungal pathogens [22]. Fungal species like *Chaetomium globosum*, *Cunninghamella blakesleeana*, and *Aspergillus oryzae*, and plant pathogens such as *Rhizoctonia solani* and *Sclerotinia sclerotiorum* saw a great decrease in pathogenicity with microalgal application because of some specific antifungal compounds having been isolated [14]. Additional biophysical protection of plant foliar tissue and roots are brought about by mucilaginous sheaths and biofilms produced by microalgae [14]. Studies on strawberries have found cell constituents of cyanobacteria, provided biophysical protection and reduced the incidence of *Botrytis cinerea, Erysiphe polygoni* powdery mildew on turnips and damping off disease in tomato seedlings [22]. Cyanobacterium *Fischerella muscicola* showed antifungal activity against *Uromyces appendiculatus* (brown rust) and *Pyricularia oryzae* (rice blast) in grains. Another cyanobacterium *Nostoc muscorum* has displayed antifungal against soil fungi and especially those producing “damping off” and *Sclerotinia sclerotiorum*, or “white mold,” in lettuce, vegetables, and other species of rosette plants [22].

Cyanobacterial activity also extends to viral pathogens, such as tobacco mosaic virus (TMV) and potato virus X (PVX), which are inhibited either directly or by inducing plant defense mechanisms [23 – 25].

In addition to controlling pathogens on plants, algal compounds have been tested against animal species. Nematode egg hatching decreases with algal extract addition and immobility and mortality of juvenile plant parasitic nematodes increased [26]. In desert biocrusts containing microalgae reduce exotic annual grass germination to reduce invasive species [27-28]. Soil-borne nematodes, plant or fruit feeding insects (e.g., fruit fly larvae) and mites, as well as insects that bring about transmission of diseases have been found to be controlled by algae [29-32]. Herbaceous weeds that hinder crop development, as well as algal species that grow uncontrollably resulting in harmful algal blooms, can also be treated with algal products. Based on cytotoxicity or the inhibition of photosynthesis [33,34] weeds that cause crop growth decrease can be controlled by adding algal extracts [35-36].

4. Synthetic verses Biopesticides

Presently many restrictions have been imposed on the use of commonly used synthetic pesticides that has made it imperative to increase the production of alternate sources of biopesticides to meet the increasing demands. There are a few advantages of using synthetic pesticides like low cost of production,[37] higher yields and broad range of products that treat fruits, vegetables, and grains together [38]. This leads to the widespread and predominant use of these synthetic organo- chemicals in traditional agriculture while the use of algae-based pesticides are a part of organic farming and agriculture[37]. Since the deleterious effects caused by the use of synthetic pesticides on the environment and human health are well documented their use in agriculture is being discouraged and, in its place, biopesticides are slowly but surely falling into place because their application is considered safe to use and can maintain high crop yields[39].

5. Production of pesticides from micro-algae

Microalgae are potent photosynthetic organisms that produce various biochemical compounds and active metabolites through their physiological pathways. These organisms can be cultivated easily because of their trophic independence to C, N and P via CO_2 and nitrogen fixation and P via inducible phosphatases. Because of these unique features they are capable of growth in almost all ecological niches and a wide variety of substrates .Waste waters ,both municipal and industrial, are rich in N and P from a very good medium for their growth. This not only reduces the cost of production of algal biomass, but algae are known to clean the wastewaters too [40].

The most important aspect of biopesticide production is the identification of the pathways and mechanism of production of compounds from microalgae and cyanobacteria with the anti-pesticidal properties and their mode of action. An example is the cyanobacterium *Scytonema hofmannii* is known to produce herbicidal compounds, but it has not been mass produced and commercialized. Also, recent trends in algal biotechnology are more focused on production of biofuels, application in pharma and nutraceuticals etc. and smaller number of studies on biopesticide characterization and research. To improve the production of biopesticides an integrated cultivation approach of growing strains of algae that produce bio pesticidal compounds along with other useful chemicals from algae are needed [41]. Using such a process *Synechococcus nidulans* was able to produce different proteins some of them with antimicrobial properties [42]. Municipal wastewater grown *Chlorella* sps showed defense against several pathogens and could be used as an effective biopesticides for agriculture (43). Recycled culture media grown *Spirulina* species showed 98% increase in carbohydrate content that helped in the formation of biofilms that induced pathogen control [44]. Other examples are *Chlorella sorokiniana, Chlorella vulgaris, Chlorella zofingiensis* and *Galdieria sulphuraria* with increased polysaccharides, lipids and terpenes that showed a defense mechanism against pathogens [44].

6. Conclusion

Pesticide use in agriculture is resulting in the contamination of the environment as a whole and reducing crop productivity, which is the need of the day to feed the ever-increasing population.

In this review we get a clear picture that microalgae and cyanobacteria can be used as a source of biopesticides and help in controlling pests on crops in an efficient way with the additional benefits that it causes no harmful effect to the environment and is totally biodegradable with time. This has opened new vistas for ecofriendly control of diseases using broad spectrum biochemicals isolated from cyanobacteria and other microalgae against the conventional pesticides which are otherwise hazardous and unsafe to use.

Most of the algae and cyanobacteria contain a wide range of products that are important industrially. However full documentation of the potent strains is yet to be done. With the recent advances in algal biotechnology and new keen interest in natural product biochemistry it is expected that many more agro- products, especially biopesticides and other control agents will be identified and synthesized from microalgae. Bioprospecting of microalgae and cyanobacteria is a fast-emerging discipline with potential economic implications and may solve the problems of pesticide addition if exploited in a proper manner.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The author has no potential conflict of interest to declare.

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