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Plant Growth Promoting Hormones from Algae - Review

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Abstract:- Plant hormones are naturally occurring small molecule compounds that play an important role in the normal functioning of the plant. It is present in very low concentrations in plants and regulate plant development, growth, longevity and reproductive processes. Based on their action, plant hormones are categorized into two categories, Plant Growth Promoters & Plant Growth Inhibitors. List of plant hormones include auxins, abscisic acid (ABA), gibberellins (GA), Cytokinin (CK), ethylene (ET), salicylic acid (SA), jasmonate (JA), peptides and brassinosteroids (BR) have been found in a broad spectrum of microalgal lineages. These hormones carry wide applications in stress resistance, pathogen defence, enriching soil nutrient content. Besides plants, these hormones are widely found in various algal taxa in concentrations comparable with their content in higher plants. This can be used as growth regulators for crops growth and development. These hormones from algae are determined using reverse-phase liquid chromatography - tandem mass spectrometry with multiple reaction monitoring. Their characterization methods, sources, types and usable synthetic hormones were reviewed in this article.

Keywords:- *Phytohormones, growth & development, synthetic hormones, algal plant hormones.*

I. INTRODUCTION

Plants are multicellular eukaryotic organisms consisting about 3,00,000 species under the kingdom plantae. They are useful for both animals and humans. They have a wide range of beneficial uses in both industries and domestic settings. Industrially, plants are used in the production of a variety of products such as medicines, perfumes, textiles and building materials(Oguntona & Aigbavboa, 2023). Additionally, they play a vital role in the food and beverage industries as they are used as ingredients for various food products and beverages. Moreover, plants are also used in the production of cosmetics, detergents(Huang et al., 2019), and food flavorings. Apart from industrial uses, plants also have numerous benefits in domestic uses. Many indoor plants are also known for their ability to purify the air, making them a popular choice for improving indoor air quality. Furthermore, plants are used as home remedies and can contribute to overall health and well-being. Studies have shown that being around plants can reduce stress levels and boost cognitive function. In addition, plants can also be grown in home gardens for personal consumption or decorative purposes(Medina et al., 2017). Overall, plants have diverse uses and benefits in both industrial and domestic settings, making them an essential resource for human well-being and economic development.

These plants require factors like sunlight, oxygen, nutrients etc for the development. They also produce internal factors like plant hormones or phytohormones. Furthermore, they play role in growth promotion and inhibition activities, as well as stress tolerance and defence mechanism (Egamberdieva et al., 2017). They are chemical substances that present in smaller concentration mostly found in higher plants and microorganisms like algae, bacteria (Backer et al., 2018), & fungi, yeast (Nimsi et al., 2023). In various taxa they were found in comparable concentrations as in higher plants (Tarakhovskaya et al., 2007). Among eukaryotes algae are a diverse group of photosynthetic organisms that can be found in a variety of aquatic environments such as ponds, lakes, oceans, and even snow. They range in size from single-cell microalgae to multicellular seaweeds(Lekshmi et al., 2018). Their derived compounds and biomass have preferred applications. They have shown that algal biofertilizers were important nutrient supplier to cereal crops (Shalaby, 2011). Algae biofuels have developed as a clean, environmentally responsible, and economically viable alternative to other fuels. There are five different types of algae fuels: bio-ethanol, biogas, biohydrogen, biodiesel, and biooil. The use of algae as a food source for various purposes, such as the synthesis of single-cell proteins, pigments, bioactive compounds, medicines, and cosmetics (Sharma et. al, 2017).

II. PHYTOHORMONES

Plant hormones are also said to be plant growth promoting hormones. It is also claimed that plant hormones encourage plant development. They are organic substances produced naturally that manage and regulate plant development, including cell division, root and shoot lengthening, blooming, fruit ripening, and photosynthetic efficiency. They also help plants better withstand stress. (Wang et al., 2021). Plant growth regulators (PGRs) are the term for synthetic or man-made plant hormones. These hormones are responsible for their altered functions because they contain carotenoids, fatty acids, indole, terpenes, steroids, and substitutes for adenine (Asif et al., 2022).

The latest analysis infer that these hormones can reduce human diseases like cancer, diabetes. They are all around in plants in some cases they move from one site to other specific sites and found to confine with receptors resulting in varied cell function (Mukherjee et al., 2022). It is found that the phytohormones were involved in potato sprout formation, tuber initiation and its maturation as individual or combined ones(Saidi & Hajibarat, 2021). They were also known to taking part in fruit development and ripening process (Fenn & Giovannoni, 2021). By managing several enzymatic activities as well as interactions between various phytohormones were identified to raise flower & seed count for the increased oil yield (Ashfaq & Khan, 2017). At the time of plant subjection to various stresses these hormones act us chemical messengers admitting them to function effectively (Rhaman et al., 2020). Recent research has shown that exogenous phytohormone treatment greatly reduced heat-induced damage and increased plant heat tolerance, suggesting that phytohormones play a key role in the plant's response to heat stress (Grover et al., 2013). One of the primary advantages of algae is their ability to produce a variety of bioactive compounds including phytohormones. Every class of marine algae, ranging from Euglenophyta, Cryophyte, Pyrrophyta, Chlorophyta, Rhodophyta, and Phaeophyta,(Veronico & Melillo, 2021) contains phytohormones such as auxins, gibberellins, cytokinins, abscisic acid, and ethylene. These phytohormones have been found to be beneficial in multiple industries such as agriculture, food and nutraceuticals, cosmetics(Ferri et al., 2019), pharmaceuticals, and even biofuels.

III. DIFFERENT TYPES OF PHYTOHORMONES

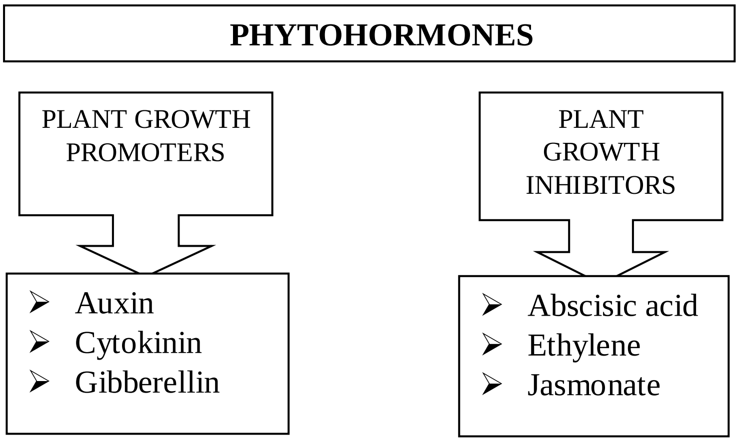

Fig. 1: Classification of phytohormones and their types

IV. PLANT GROWTH PROMOTERS

A. *AUXIN:*

Indole-3-acetic acid (IAA), one of the naturally occurring major hormone in plants. These short-term proteins can be incorporated from tryptophan through the tryptamine (TAM), indole-3-pyruvic acid (IPA) pathways (Santner et al., 2009). This auxin is predominantly found in the apical meristem of shoots, immature leaves & seeds. It also consists of Indole-3-Butyric Acid (IBA), 4-chloro-indole-3-acetic acid as well. At minimized concentration auxin activates stem elongation, synthesis of enriched biomolecules & biomass. Where as in greater concentration auxin can constrain cell growth (Wang et al., 2021). It is scattered all over the plant via cell-cell transport system, regulating transcription and also involved in inducing cell-wall related gene. Developing fruit and seed comprise high levels of auxin. They improve the formation of adventitious and lateral roots (Vaishnav & Chowdhury, 2023). The 2,4-dichlorophenoxyacetic acid an artificial auxin is extensively used as herbicide in horticulture and agriculture. Its production is comparably high in young leaves (Paque & Weijers, 2016). They activate differential growth in regards to light incentive and gravity. A commonly known plant pathogen called Agrobacterium was found to produce auxin to steal plant cells for the nutrient synthesis (Zhao, 2010). By acting on the molecular bonds of the carbohydrates that make up plant cell walls, the hormone has an impact on plants. The process entails the introduction of water, the creation of new cell-wall material, and the irreversible deformation of the cells. Auxins may work similarly to many animal hormones in that they may affect protein synthesis to exert their effects.

B. *CYTOKININ*

The cytokinin is derivative of N6-substituted adenine compounds has a vital role in the development of nitrogen-fixing nodules. This plant hormone is a material of purine which has the ability to trigger cell proliferation in tissue culture. Naturally occurring cytokinins are zeatin and isopentenyl adenine while synthetic cytokinins are benzyl adenine, kinetin, diphenyl urea. They were initially produced in roots then moves through the xylem to shoot (Vaishnav & Chowdhury, 2023). When cytokinins are enforced with auxin they set off callus differentiation into root. They are major signalling molecules maintain cell division in root and shoots. Activate seed germination & assist lateral bud development. It shows a beneficial impact on cotton seedling and performs an important role in pathogenesis of plants by improving disease resistance (Osugi & Sakakibara, 2015). They involve in varied developmental processes such as root growth and branching, leaf senescence, apical dominance in shoot, chloroplast production in leaves. A compound namely glycosidic conjugates takes part in cytokinin transport, its degradation, reversible and irreversible inactivation (Werner et al., 2001). Cytokinins, which are necessary for healthy growth and differentiation, work with auxins to speed up cell division and slow down senescence, which, at least in its early stages, is an organised phase of metabolism rather than simply the destruction of tissue. Senescence is exemplified by the fading of lone leaves, which happens as proteins age.

C. GIBBERELLIN:

Gibberellins (GA) are tetracyclic, diterpenoid growth regulators also called as gibberellic acid. They consist of about 135 components with gibberellin as a basic structure, of which 70 gibberellins has been isolated. These diterpenoid components take part in cell elongation, seed development, fruit growth, control of flowering & regulate sex determination. The levels of gibberellins can be altered by other hormones like auxin and ethylene (Yamaguchi, 2008). GA3 is the mostly inquired plant growth hormone, it helps to reduce varied dwarf kinds of genetic restrictions. Gibberellins, which are common in seeds, are also produced in young leaves and roots. There is evidence that gibberellins, especially when administered to the entire plant, encourage the growth of major stems. Gibberellins, in contrast to auxins, have little impact on coleoptile fragments in tissue culture. Gibberellins are involved in the bolting (elongation) of rosette plants like carrots and dwarf pea growth promotion. After being exposed to specific environmental stimuli (such as cold or prolonged periods of sunlight), rosette plants elongate. This is accompanied by an increase in the gibberellin content of the afflicted plant. They were found in rice (Ueguchi-Tanaka et al., 2005). During the absence of light, light sensitive plants like lettuce, tobacco germinates badly that can be treated with gibberellic acid to meet with the need for light. They are mobile signalling members in plants. GA manipulation has a well-known contribution to agriculture through the establishment of dwarfing alleles into staple crops this give rise to the rice & wheat production extensively (Binenbaum et al., 2018).

V. PLANT GROWTH INHIBITORS

A. ABSCISIC ACID:

Abscisic acid (ABA) is a plant hormone that control numerous parts of plant development and improvement, including undeveloped organism development, seed lethargy, germination, cell division and lengthening, flower enlistment, and reactions to ecological burdens(Finkelstein, 2013). The mode of action of ABA involves binding to specific receptors and activating signal transduction pathways that regulate gene expression and promote stress tolerance (Cutler et al., 2010). It takes part in production of protective proteins such as dehydrins, osmoprotectants (Vaishnav & Chowdhury, 2023). When exposed to environmental challenges like drought, high salinity, and low temperature respond through the mediation of ABA. It is necessary for the development of seed nutrient reserves and desiccation tolerance.

B. ETHYLENE:

Ethylene is a volatile compound well known for its role in ripening of fruits such as apples, bananas, peaches, tomatoes etc. Depending on its concentration, application timing, and plant species it either helps or hinders growth and senescence processes. In slower growing species, a favourable effect on the rate of leaf elongation was also observed at lower concentrations. This effect was reversed at higher concentrations, indicating an inhibitory effect (Iqbal et al., 2017). Treatment with ethephon, an ethylene releasing compound, increased both ethylene biosynthesis and leaf area expansion (Khan et al., 2008). The effects of ethylene on leaf growth can be auxin-dependent or auxin-independent. Auxin stimulates ethylene production and many of exogenous auxin are actually response to ethylene (FB Abeles et al., 2012). It encourages negative geotropism, which makes sure that the roots grow downward. Therefore, the presence of more roots in the soil denotes easy mineral absorption (Vaishnav & Chowdhury, 2023).

C. JASMONATE:

Jasmonate (JA) is a lipid-derived plant hormone that regulates developmental processes such as pollen development, spike formation, fruit ripening, senescence and response to biotic and abiotic stress. JA not only occurs during plant growth, but also during seed germination (Yang et al., 2012). In plants, stomata regulate gas exchange, water loss and help control plant resistance to plant pathogens. JA is also involved in stoma closure. It serves as the main trigger for the amplification of secondary metabolites (Sohn et al., 2022). It is said as stress hormone that regulates plant responses to both biotic and abiotic stresses, such as those brought on by pathogens and herbivores, as well as wounding and ultraviolet radiation. It confers resistance to necrotrophic pathogens (Gomi, 2020). It has been reported that JA decreases the number of grains in sorghum(Dampanaboina et al., 2019).

VI. DIFFERENT SOURCES OF PLANT HORMONES

- Plant sources: Plants themselves are a rich source of plant growth promoting hormones, with auxins, cytokinins, gibberellins, abscisic acid, and ethylene being the most common. These hormones can be extracted from plant tissues or synthesized artificially. The use of plant-derived hormones in agriculture is a cost-effective and sustainable approach to improve plant growth and productivity (Rademacher, 2015).
- Microbial sources: Microorganisms such as bacteria, fungi, and actinomycetes produce various plant growth-promoting hormones such as auxins, cytokinin, gibberellins, and abscisic acid. These hormones are produced by the microbes to establish a symbiotic relationship with the plants they colonize, providing the plants with essential nutrients and growth regulators. Several studies have shown that the application of microbial-derived plant growth-promoting hormones can improve plant growth, yield, and stress tolerance (Mokrani et al., 2020)(de-Bashan et al., 2012). The hormones like gibberellins and abscisic acid can be produced using microbial formation methods(Shi et al., 2017).
- Chemical synthesis: Chemical synthesis is another source of plant growth promoting hormones. The most common synthetic plant growth promoting hormones are synthetic auxins such as indole-3-acetic acid (IAA) and naphthaleneacetic acid (NAA), and synthetic cytokinins such as kinetin and benzyl adenine. These synthetic hormones are widely used in agriculture to promote plant growth, development, and yield (Sinha and Chaudhary, 2016).

- Bio stimulants: Bio stimulants are a group of natural or synthetic substances that enhance plant growth and productivity by stimulating natural plant processes such as nutrient uptake, photosynthesis, and stress tolerance. Bio stimulants may contain plant growth promoting hormones as well as other biologically active compounds such as amino acids, vitamins, and enzymes. The use of bio stimulants in agriculture is gaining popularity due to their environmentally friendly nature and potential to enhance crop performance (du Jardin, 2015).
- Waste sources: Waste sources such as compost and vermicompost are rich sources of plant growth promoting hormones. Compost and vermicompost contain high levels of auxins, cytokinins, and gibberellins, which can stimulate plant growth and improve soil health. The use of compost and vermicompost as soil amendments can enhance plant growth and yield while reducing the dependence on synthetic fertilizers.

VII. ALGAL PLANT GROWTH PROMOTING HORMONES:

Phytohormones were found in high concentrations in a variety of algal species. Most of the time, the range of biological activities that algal hormones perform matches those of the higher plant hormones(Tarakhovskaya et al., 2007). Due to the presence of plant hormones in the seaweed and microalgae extracts, these extracts are employed commercially as growth stimulants or regulators in agricultural crops(Stirk, 2006). Micro and macroalgal phytohormones are thought as exogenous growth regulators that influence the capacity to tolerate diverse abiotic and biotic stress conditions. The phytohormones such as auxins, abscisic acid (ABA), salicylic acid (SA), jasmonates (JA), Gibberellins (GA), cytokinins (CK), ethylene, brassinosteroids (BR) and strigolactones (SL) were also found to be present in algal species. Phytohormones were sought after in a number of algal taxa throughout the 1960s and 1970s. During this time.

A. CHLOROPHYTA:

A phylum made up of green algae that inhibit aquatic environments. Several of them can be found on terrestrial habitats and in fresh water.

B. PHAEOPHYTA:

A class of algae where the brown pigment fucoxanthin frequently covers the green chlorophyll pigments, known as Brown algae.

C. RHODOPHYTA:

The oldest type of eukaryotic algae primarily found in freshwater lakes. They contain the pigment phycoerythrin responsible for their red colour.

All these algal taxa contain a variety of substances with hormonal activity(Tarakhovskaya et al., 2007).

VIII. CHARACTERIZATION OF PLANT GROWTH HORMONES

The development of effective analytical techniques for plant hormone analysis is necessary for the precise determination of plant hormones using chromatographic techniques with an MS system, multi class plant hormones can be analysed efficiently. Using ultra-high performance liquid chromatography mass spectrometry (UPHLC-MS), most of the plant hormones can be identified and quantified (Z.-Y. Cao et al., 2016). Samples were homogenised. 5µ of the ISTD (Phytohormone standards and internal standards) working solution and 1ml of 80% acetonitrile (ACN) containing 1% acetic acid (AcOH) were added to the extraction solvent. Samples were then kept at 20ºc for 5 mins. Following that, samples were centrifuged at 15,900 rcf for 10 min at 4ºC. For hormone extraction, the supernatant was transferred to a fresh 1.5ml Eppendorf tube and dried using a rotational hoover concentrator. The dried extract was purified with sep-pak tC18 cartridge and reconstituted in 1 ml of 1% AcOH. A 1 ml of methanol wash followed by a 1 ml 1% AcOH equilibration step was used to clean the tC18 cartridge. After the samples was loaded into the cartridge, 1% AcOH was used as a wash. In a fresh 1.5 ml Eppendorf tube, the extract was eluted with I ml of 80% ACN containing 1% AcOH. A rotational hoover concentrator was used to dry the eluted extract before reconstituting it in 20L of 1% AcOH. The extract was centrifuged at 15,900 rcf for 10 minutes at 4ºC after being vortexed for 30 seconds to dissolve the dried extract. Prior to UPLC-MS/MS analysis, samples were put into vials with glass inserts and kept at 80ºC. For the phytohormone profiling calibration, working solutions were prepared at 100 g mL-1 in methanol. To create the calibration ranges at 0, 0.1, 0.5, 1, 5, 10 and 100 ng mL-1, phytohormone working solutions were mixed and serially diluted with starting mobile phase [0.5% formic acid (FA) in MilliQ water]. The ISTD concentration used for phytohormone extraction was also added. C18 have been widely used for phytohormone quantification (D. Cao et al., 2020).

Other techniques such as enzyme-linked immunosorbent assay and bioassays are also used to characterize phytohormones. These methods help in characterizing the structure, function, and biological activity of phytohormones (Killiny & Nehela, 2020). Recent research has reported use of UPLC MS/MS for the profiling of up to 43 phytohormones in a single analysis. Some of the other characterization methods used were tabulated below. (Table -1).

Table 1: Phytohormones & their characterization methods

S.NO	PHYTOHORMONE	CHARACTERIZATION METHOD	REFERRENCE
1.	Auxin	Microplate technique using Salkowski reagent	(Anguiano-Cabello et al., 2017)
2.	Cytokinin	Using pipette tip solid-phase extraction	(Svačinová et al., 2012)
3.	Gibberellin	Gas chromatography-mass spectrometry (GC-MS)	(Okamoto et al., 2009)
4.	Abscisic acid	High throughput quantitative real time immune-PCR (qIPCR)	(Su et al., 2018)
5.	Ethylene	Gas chromatography	(Cristescu et al., 2013)
6.	Jasmonate	Gas chromatography-mass spectrometry (GC-MS)	(Zhang et al., 2008)

IX. COMMERCIALLY AVAILABLE ALGAL PLANT GROWTH PROMOTING HORMONES

The plant growth regulators are described as substances that are produced intentionally by humans to control the growth and development. These growth-controlling agents are directly applied to a targeted plant in order to change its structure or internal functions in order to improve quality, boost yields or ease harvesting. They are either sprayed on the plant foliage or infused into the soil around a plant's base. Its effects are typically transient, and they might need to be applied again to have the intended effect.

Each plant hormone can be created in synthetic forms which can be used as plant growth regulators. The synthetic form of some plant hormones is

- Indole-3-butryic acid (IAA)
- Indole-butyric acid (IBA)
- Beta naphtoxy acetic acid (NOA)
- 1-naphthaleneacetic acid (NAA)
- (2,4-dichlorophenoxy) propionic acid (2,4-D)
- 6-benzyl adenine
- Ethephon
- Glucophosphate isopropyl amine and so on.

Auxins and cytokinins (IAA and BA), which were endogenously produced phytohormones by cyanobacteria (*A. oryzae and N. muscorum)* and Chlorophyta (*C. vulgaris*) species, have been effectively identified and quantified. The fresh weight of soybean callus bioassays and morphological characteristics of tomato plantlets (shoot length, branching, leaves number, and root initiation) were significantly affected by the algal extracts produced on various concentrations of treated wastewater mixed with BG11 or BG110 media. Hormones, vitamins, enzymes, and a variety of micro- and macronutrients were found in algal and cyanobacterial extracts, which can be employed as bio stimulants (or biofertilizers) for various plant growth and development (Elakbawy et al., 2022). Sea weed extracts are used in agriculture to lessen the usage of toxic agrochemicals while also assisting in environmental protection. Their incorporation into widespread farming techniques can increase crop yield in ways that are environmentally friendly.

Widely produced species of microalgae such as *Arthrospira, Chlorella, Dunaeliella, Nostoc* and numerous species of cyanobacteria were used as a source for the production of bio-stimulant for plants (Ronga et al., 2019).

X. CONCLUSION

The phytohormones are essential compounds for the plant growth and developmental processes. As they were present in low concentrations, they can be obtained by other resource such as algae which has wide range of applications. These algal growth promoters were found to increase crop yield, improve the quality of plants. They also help in enriching the nutrient content in the soil, develops pests and disease control in the plants. Help the plants to endure various stress such as biotic and abiotic stress. Hence the plant hormones can be produced or synthesized exogenously from algae.

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