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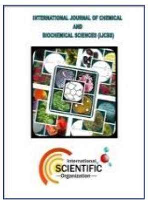

Plant growth regulators (PGRs) and their applications: A review

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Abstract

Plant growth regulators (PGRs) or plant hormones are the chemical species that profoundly influence the growth and differentiation of various parts of plant. The activities of PGs depends on their concentration and environmental factors affecting their absorption and plant's physiological state. PGRs have the ability to effect cell division, cell structure, cell expansion, cell function, and mediate environmental stress even at low concentrations. Direct application to roots, leaf, flowers, buds and shoots has been shown to enhance resistance to biotic and abiotic stress. Products of PGRs are generally employed throughout viticulture, floriculture, agriculture and horticulture to increase crop yield in sub-optimal soil and harsh environmental conditions. Present review aimed to study the brief introduction and applications of various plant growth regulators including auxins, gibberellins, cytokinins, ethylene, abscisic acid, brassinosteroids and jasmonates, triacontanol, triazoles and polyamines.

Keywords: Hormones, plant growth regulators, brassinosteroids, cytokinins, triacontanol, jasmonates, polyamines

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1. Introduction

All plants naturally produce hormones in response to their surroundings that regulate their growth, development, and metabolism. Hormones are synthesized at various sites such as roots, buds and leaves, and are transferred to targeted locations after binding with specific receptors [1]. Hormones control cell division, cell elongation, cell differentiation and influence plants responses to environment stress [2]. They can elicit multiple responses depending upon targeted tissues, plant's developmental stages, relative concentrations, uptake and storage of water and other nutrients, and climatic conditions [2]. There are a small number of hormones with the ability to regulate plant physiological processes that have been studied since 1930s to improve plant production and development [1]. These hormones occur at low concentrations in plant tissue, which causes great challenges in the isolation, identification, and extraction of appropriate amounts for laboratory tests. Using synthetic hormones, similar processes can be controlled, such as the formation and growth of buds, flowers, fruits and roots [3]. These findings resulted in the commercial production of synthetic hormonal products, also known as plant growth regulators (PGRs). Plant growth regulators are widely used in agriculture, viticulture, and horticulture to enhance growth in non-ideal or stressful conditions (e.g. short growing seasons, low soil fertility, and diseases) and to improve yields and ease of harvesting (e.g. prevention of immature fruit drop, accelerating maturity, and ripening etc.) [4]. Types of plant growth regulators reviewed in this article include auxins, Cytokinins, Gibberellins, Abscisic acid, Ethylene, Triazoles, Brassinosteroids, Jasmonates, Polyamines and Triacontanol.

2. Auxins

Auxins are low molecular weight organic phytohormones that are involved in all aspects of growth and development of plant including morphogenesis regulation, stimulation and elongation [5-6]. Polar and organic in nature, auxins can be carried long distances throughout plant via vascular tissues. Previous literature reveals that auxins are produced in meristematic areas and growing organs including leaf, root tips, seedlings, and buds. Concentrations are highest in leaf, shoots, and tips of branches and lowest in roots. Consequently, auxins are more often found in younger plant parts (juveniles and seedlings) and play an important role in the early stages of plant development [5]. Because light directly affects them, auxins are responsible for phototropism (growth of plant in response to light); however, auxins also effect apical dominance, lateral root initiation, angiogenesis and gravitropism [7]. Auxins interact with salicylic acid and abscisic acid to regulate plant growth during abiotic stress [8]. It is believed that foliar application of natural or/and synthetic auxins improves physiological processes that control plant growth directly. When applied to plant cuttings, auxins can stimulate root formation [4]. It was found that different plant parts (i.e. roots, shoots, buds) react differently to auxins. Therefore, the type and concentration of auxin selected for improving plant growth should depend on the plant species, the rate of uptake and transport to the target cells, existing natural auxins levels in the plant, auxin sensitivity, metabolic rate and interaction between plant hormones [5]. Although auxins are essential for survival of plant, higher concentrations can lead to negative effects, involving oxidative stress, often leading to cell death [3]. As a result, auxins have been found to act as stimulants and growth inhibitors, depending on the concentration used. This discovery led to the development of auxin derived selective herbicides. Natural auxins are synthesized by the plant or extracted from bacteria; natural products are believed to degrade quickly, limiting the product applicability [9]. Table 1 shows the structures and functions of natural auxins. Indole-3-acetic acid (IAA) is least stable form because it rapidly degrades in light and is vulnerable to destruction by IAA-oxidase enzyme in plants. Synthetic auxins are considered more effective than natural Auxins because they do not oxidize in plant tissue. Synthetic auxins are now commercially available in both liquid form (dip solutions and post-planting sprays) and powdered; liquid forms have been shown to be absorbed faster than powdered forms [9]. Table 2 shows the structures and functions of synthetic auxins.

Table 1 Structures and functions of natural auxins

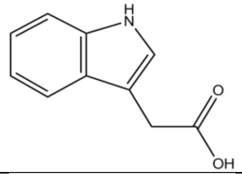
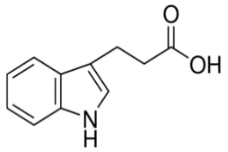
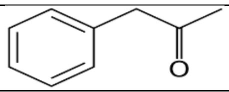
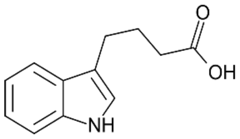
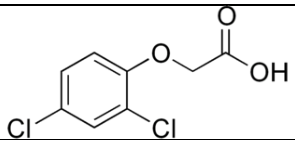
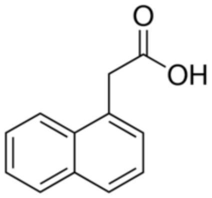
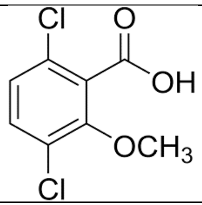
Natural Auxins	Structures	Functions	Ref.
Indole-3-acetic acid (IAA)		Cell enlargement in plant, cell division in plant, root initiation, leaf and fruit abscission and leaf senescence	[7-10]
Indole-3-propionic acid (IPrA)		Regulate vascular functions of plants	[11]
Phenyl acetic acid		Functions in maintaining normal cellular growth and antimicrobial activity in plants	[10] [12]
Indole-3-butyric acid		Promote adventitious root growth and development of food crops	[13]

Table 2 Structures and functions of synthetic auxins

Synthetic Auxins	Structures	Functions	Ref.
2,4-Dichlorophenoxyacetic acid		Function as a herbicide for control of broadleaf plants and as a plant growth-regulator	[14]
α-Naphthalene acetic acid		Used as an indicator of better rooting, An agent for thinning fruit sets in apples, pears and olives. Induces root formation on cuttings and transplants. Inhibits fruit drops	[15]
2-Methoxy-3,6-dichlorobenzoic acid (Dicamba)		Kills weeds by causing abnormal cell growth (use as herbicide), causes uncontrolled growth	[16]

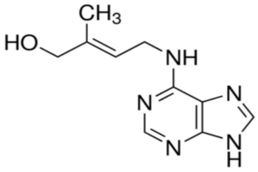
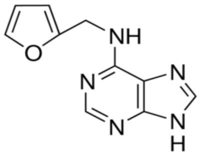
3. Gibberellins

Gibberellins are endogenous growth hormones of plants which are biosynthesized by them as a result of different developmental or environmental stimuli [17]. First discovery of this hormone, Gibberellins, was made in a fungus named "*Gibberella*" and after that it has been located in a number of plant areas which show active growth. Names have been assigned to different gibberellins on the basis of the order in which these were discovered (GA_1-GA_7). Gibberellins are known to control stem internode elongation, grass leaf elongation, general cell elongation and division of cells in plant shoot as a result of their direct influence on ribonucleic acid and protein synthesis in plant. But the actual action mode and site of biosynthesis of gibberellins is still unclear [4-5-18-19]. As a consequence, stimulation in longitudinal growth which occurs as a result of meristematic tissue development is shown by the plant. Gibberellins show this type of growth in a response to the stimulus of light. The presence of appreciable amounts of gebberellins in pollen proves it to be capable of regulating development and growth of flowers as well as fertility of seed [9]. The formation of normal flowers has been made possible by direct application of bioactive gibberrellins to an abnormal plant without viable pollen. This growth regulating hormone which is produced endogenously by plant, is also found in seeds and is involved in breaking seed dormancy [20-21]. Research investigations on germinating seeds have also reported that gibberellins, when applied externally, also play role in breaking seed dormancy even when the external conditions are stressful, harsh or non-ideal. The growth potential of a germinating seed is enhanced by the induction of hydrolytic enzymes and nutrients under the action of gibberellins. As slow germination and establishment of native plants is well known, an improvement of even a few days in the seed germination has been proved to be valuable in grass establishment [22]. Before testing for viability and germination of seed, the use of gibberellic acid for breaking seed dormancy is being tested by different techniques. This leads to a better and more accurate seed quality assessment [23]. The effects of water stress on germination and growth of seedling are also known to be diminished or even reversed by the action of gibberellic acid. Moreover, in case of salt stress (NaCl) on soya beans, the adverse conditions are known to be assuaged by Gibberellic acid (GA3) which not only restores normal growth but also helps in further development [24]. A study reported the maintenance of regular growth and development of plants in saline conditions as GA3 counteracts such conditions by enhancing permeability of membrane and improving nutrient supply [24]. If GA3 is applied as pre sowing treatment(100 mg/L), the ion accumulation as well as partitioning in plant tissues is modulated by GA3 which results in the reduction of stress caused by increased osmotic pressure [17]. Plant biomass (dry weight), grain yield and plant height of spring wheat cultivars under saline conditions (15 dS/m) have been reported to be improved when seed priming with GA3 (150 mg/L) is done [17]. Nitrogen metabolism of plants is also influenced by gibberellins as it improves soil-derived nitrogen re-distribution in plants [25]. Vegetative parts and seeds of mustard showed an increased nitrogen accumulation and hence increased partitioning of nitrogen into seeds when the cultivars were sprayed at a concentration and rate of 10−5 M and 600 L/ha, respectively [25]. Thus, gibberellins may also represent a novel nitrogen-use efficiency product.

4. Cytokinins

Meristematic tissues and organs (i.e., shoot apex, immature organs, root tips) of a developing plant naturally produce a phytohormone named as "Cytokinins" [26]. There are roughly 20 natural plant cytokinins. Although exact mode of action of cytokinins is not clear enough, but literature has reported its effect on growth and development of plant. The cell division of plant is critically affected by direct action of cytokinins on protein synthesis which are known to be involved in mitosis. Cell cycle has been observed to enter a standstill condition in the absence of Cytokinins [5]. The lateral plant growth which involves production of lateral shoots and lateral roots is promoted by cytokinins as opposed to auxins which are involved in apical dominance [1]. The generation of shoot from internodes, choloroplast maturation, initiation of callus formation, spreading of thick roots and releasing of buds in dormancy is promoted by cytokinins as these are known to stimulate protein synthesis, transport of amino acids, cell enlargement, cell division and senescence [4-5]. As a consequence, whole life cycle of a plant is influenced by cytokinins. Table 3 shows structures and functions of cytokinins in plants. This phytohormone also controls the response shown by a plant to different stimuli such as water availability, light, nutrients abiotic stressors and biotic stressors. This regulation of response to stimuli results through signaling of protein synthesis, degrading cells and enhancing production of protective enzymes like antioxidents [27]. Plants have shown mobilization of nutrients to a location of specific application when synthetic or natural cytokinins were added to them [28]. For example, a reduction in protein and chlorophyll degradation was noticed on direct application of cytokinins to leaves. And in case of dormant buds, an early development of bud is reported as a result of cytokinin application [28]. Therefore, earlier vegetative stages of plant are characterized by more prominent role of cytokinins whose effects are observable as well as measureable in the developmental stage when it is applied. During the stage of root formation, for example, root growth will be enhance and if stem growth stage is being focused by plant then growth in stem is observed and so forth. Plant stress is also regulated by cytokinins. The amount of cytokinin present in a plant may also act as an indicator for the level of plant stress. Plants found in highly saline conditions of soil had very low levels of cytokinins. A combination of phytohormones "Cytokinin" (cell division stimulators and mitosis influencers) and auxins (for cell cycle initiation and DNA replication) has been suggested to be required for plant division. In coordination to each other, the two hormones control promotion and maintenance of root and its meristem [6]. Cytokinins and auxins must be applied in a balanced ratio to the plant. If a balance is not maintained in the quantities of two hormones, then accumulation of cytokinin may be inhibited by auxins and cytokinins can affect the activity of auxins [5]. Different plant species are reported to have a different balancing ratio of the two growth regulating hormones.

Table 3 Structures and functions of cytokinins

Natural cytokinins	Structures	Functions	Ref.
Zeatin		Regulation of plant development and defense responses to pathogen and herbivore attack, role as 'novel' stress-response markers	[29-30]
Kinetic		Effective in senescence delay, by minimizing breakdown of chlorophylls and carotenoids; and by bringing down peroxidase and protease activity, and sugar accumulation.	[31]

5. Abscisic Acid

During varying physiological changes and environmental conditions, the stress signals and responses are integrated and controlled by abscisic acid [32]. ABA is biosynthesized when plants are exposed to abiotic environmental stress, including drought, low and high temperatures, salinity and flooding; ABA production triggers plant acclimatization and stress tolerance [5-18-24-32-33]. Biosynthesis of abscisic acid has also been noticed in some phyto-pathogenic fungi including *Botrytis cinerea* and *Cerosporarosicola*. ABA used for external application to the plants is being extracted from *Botrytis cinerea* [1]. ABA, when synthesized endogenously by plant, influences plant growth by reducing it and also causes changes in permeability of cellular membrane and uptake of water and nutrient. ABA also has the potential of regulating drought conditions as it influences leaves for their stomatal conductance that reduces overall intercellular water loss as well as transpiration [1]. For this purpose, guard cells directly receive ABA signals for the closure of stomata. While in favorable conditions, ABA assists the plant to overcome stressful conditions and start the process of seed germination and growth [32]. Delayed growth and eventual death of plant has been reported in the absence of abscisic acid as the plant fails to come out of environmental stress wilt [32]. Other regulatory functions played by ABA include freezing tolerance and osmotic stress, leaf abscission, regulation of protein encoding genes, controlling ion and water uptake by roots, seed dormancy, protein and lipid synthesis for storage purposes, defense against pathogens, control of gene expression in developing embryo and during maturation, growth and morphogenesis of tissues [3-9-34]. In conditions of abiotic stress, plant tissues produce more abscisic acid which initiates signals and activates signal pathway and regulate modification in gene expression which results in plant adaptation to stressful environmental conditions [33]. Further synthesis of abscisic acid by plant (via β-carotene and multiple enzymatic steps) has been noticed when it is applied externally to the plant in the form of spray, as it poses to mimic stressful conditional effects [32-35].

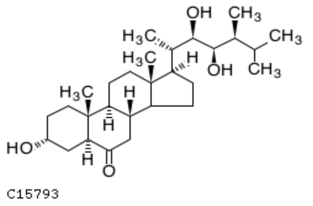
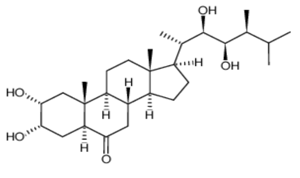
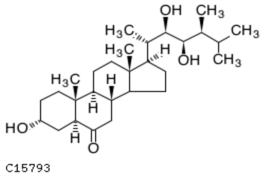
6. Ethylene

Tissues of plants which play role in plant growth regulation are known to produce ethylene (C_2H_4). The regulation of plant growth and development by ethylene depends and also vary according to amount of cytokinins, ABA, carbon dioxide, light and auxins present in the plant. Plant maturation is controlled by ethylene which gives its name as an "aging hormone" [36]. Active division of cells in some plants produces ethylene as by-product which then regulates size of cells. An enhanced production of plant-derived auxins has been associated with biosynthesis of ethylene in plants, which not only plays role in auxin synthesis but also in its metabolism and transport [1-5-37]. With a rise in cytokinin levels, plant roots are reported to synthesize more ethylene [33]. Major regulatory functions performed by ethylene in plants include regulation of cellular division, size and stolon formation, flowering, fruit ripening, stimulation of root initiation, secondary metabolite modulation and overall plant growth. Different environmental stress conditions like drought, salinity, plant wounding and toxicity also trigger ethylene production in plant [18-38]. When ethylene is accumulated in plants at higher concentrations, it effects negatively on plant as it causes loss of cellular membrane integrity and leakage from membrane. Therefore, plant stress can be estimated by calculating the amount of ethylene present in a certain plant. Under stressed and also in normal conditions, primary and secondary dormancy breakage as well as seed germination is also known to be regulated by ethylene [39]. The germination of seed requires a certain threshold concentration of ethylene below which seeds show lack of germination. This is applicable to both dormant and non-dormant seeds. In stressful environmental conditions such as salinity, water scarcity, and higher temperatures, both exogenous and endogenous application of ethylene work synergistically with other plant growth regulatory hormones for the breakage of seed dormancy.

7. Brassinosteroids

Certain plant classes including monocotyledonous and dicotyledenous angiosperms, Gymnosperms as well as algae produce hormones which are steroids in nature and are capable of regulating growth and development of plant. These steroid based hormones are categorized as "Brassinosteroids" (Table 4) [40]. More than 60 different types of this hormone have been discovered in plants by now, out of which only 19 have been characterized. Although extremely low concentrations (i.e., nanograms; ng) of brassinosteroids are known to be found in plant tissue, but these are considered to be essentially present in plant kingdom. A study reported 0.5 ng and 10 ng concentrations of brassinosteroids actively functioning in rice and bean [41]. This suggests that the application of minimal concentrations of this hormone, would be beneficial in attaining desired plant growth. For exogenous application, only 5–50 mg/ha of brassinosteroids can result in appreciably enhanced growth of agricultural plants. Chemically synthesized analogues of biosynthesized brassinosteroids are now being developed and patented as the extraction of later in small concentrations is a costly process. The growing tissues (i.e., shoots, roots) and reproductive organs of plant are found to have highest concentrations of brassinosteroids but its actual mode of action in these places is still unknown. A higher quantity of brassinosteroids is found to be released in shoots as compared to roots [42]. Growth and developmental processes which are regulated by brassinosteroids include rhizogenesis, germination of seeds, flowering and senescence along with abscission and maturation. Brassinosteroids influence basic cellular processes such as triggering nucleic acid and protein synthesis, cellular fission and cell elongation. Moreover, these also play a role in regulating fatty acid (including membrane integrity) and amino acid composition along with improving product translocation so that a balance among other phytohormones can be maintained. In a plant overall, brassinosteroids help the plant to tolerate both abiotic and biotic stress, increase quality and quantity of fruit, improve fertilization, increase aboveground biomass and to shorten growth period [9].

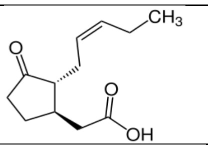
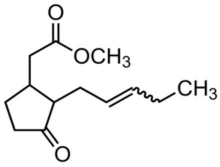
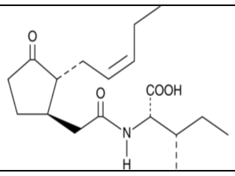
Table 4 Structures and functions of Brassinosteroids

Brassinosteroids	Structures	Functions	References
Brassinolide		Increase rates of stem elongation, pollen tube growth, leaf bending at joints, leaf unrolling, proton pump activation, reorientation of cellulose microtubules, and xylogenesis as well as elevated ethylene production	[43]
Castasterone		improved the antioxidant potential of plants and improved the antioxidant potential of plants	[44]
Typhasterol		improve growth and yield under various stress conditions including drought, salinity, extreme temperatures, and heavy metal (Cd, Cu, Al, and Ni) toxicity	[45]

8. Jasmonates

Environmental conditions, developmental stage of plant and particular type of cell or tissue decide the amount and type of Jasmonate to be present in it [46]. Jasmonates are found to be essentially present throughout the plant kingdom and have been reported in more than 206 plant species including fungi, mosses and ferns [47]. Reproductive structures like seed, flowers or fruits of higher plants are reported to have higher concentrations of this hormone. Plants suffering from environmental stress like water scarcity or wounding also show release of higher jasmonate concentrations. Biosynthesis of this hormone is found to be receptor-mediated as membrane damage and production of linolenic acid triggers its initiation. Jasmonates (Table 5) have an impact on plant growth and development at many edges as these can travel throughout plant in liquid or vapor form. A research investigation has reported that jasmonates may have a role in the mobilization of seed reserves as its higher concentrations are found in the seeds struggling for the imbibition of water. Also during disease and insect attack the amounts of jasmonate production have been reported to increase significantly. Hence, larger concentrations of jasmonates are expected to be generated by plants during environmental stresses like physical wounding and biotic and abiotic stresses and also during plant reproduction. Some studies have mentioned direct positive influences of jasmonate production under stress conditions as these provide defense against disease and insect attack e.g. necrotopic pathogens and chewing insects, when the plant is wounded [33]. Related molecules are produced under the influence of jasmonates for systematic signaling which then interact with plasma membrane receptors so that a defense against insect and disease is maintained. The exogenous application of jasmonates also plays role in synthesis of anti-fungal proteins which not only prevents infections but also provides resistance to fungus. Both stimulation as well as inhibition may be caused by jasmonates according to the required conditions in different plants. For example, the growth and development of a plant may be improved or suppressed in order to manage stress by exogenous application of jasmonates. Jasmonates whether biosynthesized by plant or applied exogenously, are known to promote senescence. Other effects of jasmonates on plants include reduction of callus growth resulted from cytokinins, inhibition of seedling growth and induction of stomata closure to prevent water loss. Basic cellular processes that are influenced by jasmonates include variation in mRNA populations in cells, changes in transcription and translation [46].

Table 5 Structures and functions of Jasmonates

Jasmonates	Structures	Functions	References
Jasmonic acid		Induction of specific polypeptides, root elongation and fruit ripening	[48-49]
Methyl jasmonate		Induction of formation of protective compounds in plants, play an active role in senescence and root elongation	[48-50]
Jasmonoyl-isoleucine (JA-Ile)		Controls gene expression and production of secondary metabolites after (a) biotic challenges	-

9. Other plant growth regulators

9.1. Triacontanol (TRIA)

Triacontanol as a "plant growth regulator" was found for the first time in alfalfa (Medicagosativa L.) in 1977. Research investigations have reported tracontanol (TRIA) to play a beneficiary role in improving nitrogen fixation, yield, enzyme activities, reducing sugars, soluble proteins, free amino acids and overall growth of plants. The biochemical and physiological processes of plant like photosynthesis are regulated and controlled by triacontanol (TRIA) as it plays its role in plant growth promotion. The growth promotion caused by this growth regulator proves to be helpful in enhancing yield, growth and quality of crops. Moreover, the important constituents of aromatic and medicinal plants are also produced in good concentrations both in normal and stressful abiotic environmental conditions. Therefore, exogenous application of this growth promoter may help to attain higher production of active constituents and essential oils from aromatic and medicinal plants. However, physiological activities , plant growth and secondary metabolite synthesis must be investigated to find out the actual regulatory mode of action of triacontanol (TRIA) on these processes occurring in medicinal and aromatic plants during abiotic stresses [51]. Also, the results obtained showing plant behaviour on application of triacontanol (TRIA) and l-adenosine must be ensured by concocting more promising protocols and their application to plants in greenhouses, growth chambers, hydroponic studies and other field studies. Generally, expensive plant growth regulators (PGRs) are available and being used to enhance overall production of crop, development of cost effective plant growth regulators (PGRs) would be of great help. Monetarily easily available triacontanol (TRIA) have this edge on its side. Moreover, further research investigations may be made to explore whether the use of triacontanol with other cost effective plant growth hormones could further enhance the crop productivity up to desirable levels. Another prospective research area for further investigations may refer to mechanism and mode of action of triacontanol (TRIA)-mediated plant metabolism, secondary messengers synthesized by (TRIA) and other growth regulating hormones. Moreover, collaborative application of plant growth hormones along with triacontanol (TRIA) to achieve more advantageous, effective and feasible solutions for producing higher quantities of active constituents and essential oils from aromatic and medicinal plants should be made with an extra emphasis on economical and ergonomical benefits. The global market has a high demand for these products but their production is too small to fullfil the demands [51]. In acidic mist treated *Erythrina variegate* (Indian coral tree) plants, enhanced leaf area and density, dry and fresh biomass accumulation and root and shoot growth with the use of triacontanol (TRIA) has been reported in different studies. These results were attributed to the improved enzyme activities, CO_2 fixation, chlorophyll (chlorophyll a, b and carotenoids) and sugar and starch production in *E. variegata* seedlings. Same results were also reported even in cadmium and salt stressed situations and acid mist or flooded conditions. Triacontanol (TRIA) influence plant growth by stimulating photosynthesis, increased effective leaf area and promted enzyme activities including Nitrate reductase (NR) and Ribulose-1,5-bisphosphate carboxylase/oxygenase (RuBisCO). During water scarce conditions, lowered relative growth rates, leaf area index (LAI) and shoot growth rates in *E. Varietaga* seedlings were improved by the application of triacontanol (TRIA). Also in salt stressed conditions, improvement in carotenoid and chlorophyll contents was obtained in the same plants. *Lycopersicon esculentum* (tomato) cultivars have given results which showed the amelioration in plant growth in moisture stress conditions through the application of mixtalol and triacontanol (TRIA). Some research studies have also mentioned decrease in Photosystem II (PS-II) activity inhibition by 22% when *E. variegata* plants are facing water scarcity. Moreover, suppressed Ribulose-1, 5-bisphosphate carboxylase/oxygenase (RuBisCO) activity was also improved in such plants as triacontanol (TRIA) is sprayed. In plants with low water availability, leaf senescence is delayed and photosynthetic machinery is maintained by Triacontanol (TRIA)-mediation. By means of triacontanol (TRIA) application a successful amelioration of salt stress in soybean plants in terms of leaf weight ratio, relative water content, chlorophyll pigments, nucleic acids, soluble sugars, and soluble proteins. Triacontanol (TRIA) reversed the damaging effect of drought-stress in terms of membrane leakage on Jack pine seedlings. A research investigation also mentioned that this hormone can also help in taking plant out of stressed conditions such as chilling by making it to regain its growth rate, yield and resuming physiological activities of plant. But a few factors i.e. water saturation deficit, proline content and electrolyte leakage were found to be increased by the application of triacontanol (TRIA). However, a supporting overall effect was recorded in *Ocimumbasilicum L.* (sweet basil) for chilling stress with Triacontanol (TRIA) application 0.10 mg dm^3, inspite of these few limitations. The role of triacontanol (TRIA) in enhancing growth, yield and quality of crop plants as well as in improving physiological and biochemical attributes and active constituents of medicinal and aromatic plants under normal and stressful conditions [51].

9.2. Triazoles

Triazoles are important pesticides which are included in the plant protection technology. A wide range of highly active, crop tolerant, least toxic to mammals and flexibly applicable azole based herbicides are being prepared and applied. Specifically, triazoles play an important role among classes of heterocyclic compounds [52]. Fungus related diseases of plants can effectively be controlled by triazoles which are also relatively less ecotoxic. Hence, these are possibly more favorable recommendations for the treatment of fungal diseases of plants but the quantity of fungicide being used should be according to environmental conditions and level of plant infection so that their use remains ecofriendly and bearable for plant itself [53].

9.3. Polyamines

A number of plant development and growth processes are regulated by small, ubiquitous polycations "Polyamines" which are also known for their involvement in anti-stress and anti-senescence effects as these possess antioxidant and acid neutralizing properties along with their capability to stabilize cell wall and cell membrane. A variety of adverse environmental stresses such as drought, salinity, chilling stress, oxidative stress and metal toxicity are suggested to be modulated by polyamines as these contribute to defense response of plants. Moreover, it has also been suggested that in order to increase crop productivity by improving stress tolerance and management by plants, polyamines can be applied exogenously to the plant. This technique has provided successful tolerance induction in plants in response to water logged flooding, high temperature, heavy metals, osmotic stress, cold and salinity. On the other hand, several basic cellular processes of plants which may range from cell proliferation, DNA replication, translation and transcription to membrane stability and cation-anion balance are known to be regulated by polyamines. Another aspect of action of polyamines in a plant involves their regulatory role in other types of growth and development like germination of seeds, embryogenesis, cell division, development, stimulation and support of flowering buds, breaking of dormancy of tubers, fruit ripening, response to abiotic and biotic stress and plant morphogenesis [54].

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