

THE ROLE OF PLANT BIOSTIMULANTS AND GROWTH REGULATORS IN CLIMATE-RESILIENT AGRICULTURE: A REVIEW

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ABSTRACT

The need for the most up-to-date, environmentally friendly techniques of controlling plant diseases and pests necessitates keeping an eye out for effective tools that provide a safe environment for human and animal fitness. In recent years, the usage of plant biostimulants (BS), which are derived from various organic materials through hydrolysis reactions, has increased. Soil microbes and plants immediately absorb these Biostimulants, which often consist of peptides, amino acids, polysaccharides, humic acids and phytohormones with less energy requirement. This benefits not only growth but also the yield and quality of the harvested grain or fruit. These items are intended to promote and increase plant metabolism, reduce stress, etc., rather than to supply nutrients. These days, a variety of biotic and abiotic stresses hinder plant development, seed germination and seedling growth due to shifting climatic conditions, which reduces biological and economic yields. Plant growth regulators (PGRs) helps plant in mitigating different abiotic stresses and also enhances the adaptability of plants in stress conditions. A variety of PGRs, including ethylene (ET), salicylic acid (SA), abscisic acid (ABA) and jasmonates (JAs), are linked to improving plants' ability to respond to various stimuli. On the other hand, under both normal and stressful environmental conditions, PGRs like auxin, cytokinins (CKs), gibberellins (GAs) and relatively novel PGRs like strigolactones (SLs) and brassinosteroids (BRs) are engaged in plant growth and development. These PGRs are crucial for regulating stress adaptation through modulates physiological, biochemical and molecular processes and activation of the defense system, upregulating of transcript levels, transcription factors, metabolism genes, and stress proteins at cellular levels.

KEYWORDS: Abiotic stress, Biostimulant, Climate change, Climate resilience Agriculture, Growth regulator, Stress tolerance.

INTRODUCTION

Plant biostimulants are any microorganisms and materials applied to plants to enhance crop quality, nutrition efficiency and tolerance towards abiotic stress. Furthermore, it produces goods for sale that incorporate living things and materials (Drobek et al., 2019). The term "biostimulant" was first used by horticultural experts to describe substances that encouraged plant growth without being insecticides, fertilizers or soil conditioners (<http://grounds-mag.com>). In this 1997 online publication, Zhang and Schmidt (2000) defined biostimulants as compounds that, in trace amounts, promote plant development. The goal of the study was to distinguish biostimulants from soil amendments and fertilizers, which promote plant growth but are applied in larger amounts. They achieved this by referring to biostimulants as "minute quantities." Additional research by Zhang et al. (2003) similarly utilized the term "enhancer" for metabolism. Biostimulation is the process of adding limited nutrients to encourage microbial growth. It depends on local organisms and involves altering the environment to promote naturally occurring bacteria with bioremediation capabilities (Piehler et al., 1999; Rhykerd et al., 1999). By eliminating the nutrients that normally prevent biodegradation—nitrogen, phosphorus, and oxygen—from the saturated zone and groundwater, a process called "biostimulation," or stimulated aerobic "biodegradation," is used to increase the number and activity of autochthonous microorganisms that are capable of biodegradation (Romantschuk et al., 2023; Margesin, et al., 2001). Macro and micronutrient solutions can be obtained by directly applying these techniques

to soil and groundwater. Oxygen was the main factor limiting the growth of many microorganisms that break down hydrocarbons.

Importance of biostimulants

A crop's natural processes are supported and enhanced by biostimulants. The effects of biostimulants on plants are similar to those of vitamins on people. It increases the availability of water and nutrients for plants. A biostimulant is a microorganism that increases a plant's ability to withstand abiotic stressors and maximizes crop quality and output by stimulating natural processes and metabolism. In addition to facilitating the rhizosphere and increasing soil microflora activity, biostimulation products improve fertilization efficiency by stimulating biochemical soil processes. They are not crop protection products; rather, they are directly preventing disease and pests. Biostimulants for plant metabolism can be used during various phases of a plant's life to enhance aspects including growth, reproduction, and quality. Plants can cope with environmental stresses such as drought, high temperatures, salinity, and UV radiation damage with the aid of mitigation biostimulants. One well-known and successful remediation technique for soil metals is urease-based microbially induced carbonate precipitation (MICP). In terms of sustainable crop management, it has beneficial effects on plant development, yield, and chemical composition (Ma et al., 2022; Nephali et al., 2020; Figure 3.1).



Figure3.1: Important of Biostimulant of different environmental stress

3.2.1. Soil heavy metal remediation

Heavy metals have accumulated as a result of the rapid growth of urbanization and industrialization, which has significantly increased the generation of waste and new types of pollutants. This has increased the discharge of industrial waste to the environment, primarily soil and water. Human health and ecosystems are negatively impacted by the widespread contamination caused by heavy metals from different industrial and agricultural wastes (Nriagu and Pacyna 1988). Leaching, plant absorption, erosion and deflation all contribute to the gradual depletion of heavy metals. Because heavy metals cannot be broken down into non-toxic forms and have long-lasting effects on the ecosystem, their indiscriminate release into the soil and rivers is a serious global health concern. Numerous elements, including arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, and zinc, are hazardous even at extremely low quantities (Salim et al., 2000). In soil contaminated with heavy metals, microorganisms are ubiquitous and have the ability to readily transform heavy metals into non-toxic forms. Microorganisms in bioremediation operations mineralize organic pollutants to produce end products like CO₂ and H₂O. Biosorption, metal-microbe interactions, bioaccumulation, biomineralization, biotransformation, and bioleaching are among the recognized bioremediation methods. By employing chemicals for growth and development, microorganisms eliminate heavy metals from the soil. Microorganisms and their byproducts are used in the bioremediation method to eliminate pollutants from the soil (USEPA 2000, 2012; Leung 2004). Native soil microorganisms, in particular, are essential to soil bioremediation as biogeochemical agents that convert complex organic molecules into simpler inorganic compounds or into their component elements. We call this process mineralization. Ionic exchange is the method by which the microorganisms are adsorbed to soil particles. Generally speaking, soil particles are negatively charged, and an ionic bond involving polyvalent cations can bind soil and bacteria together (Killham, 1994).

3.2.2. Sustainable practices

Using plant biostimulants appears to be a good way to improve sustainable practices. Utilizing biological processes to restore the environment to its initial state is known as bioremediation. More realistically, bioremediation seeks to reduce environmental toxicity. Growth stimulants, enzymes, bacteria and fungi are used in the application sense of bioremediation to break down, transform, sequester, mobilize and contain contaminating organics, inorganics and metals in soil, water, air and microorganisms that are unable to break down. Actually, the term "biostimulant" can be used to describe any agent that is good for plants but isn't a pesticide, fertilizer, or soil management. First, biostimulants are characterized as commonly utilized compounds, such as insecticides and fertilizers. In the second stage, bacteria and fungi can also deliver chemical biostimulants that promote growth, modulate development and quality traits, and boost resistance to environmental stress. For instance, PGPRs, or "plant growth-promoting rhizobacteria," are characterized by their positive effects on plants; they are not pesticides, nutrients, or soil enhancers. PGPRs are also referred to as "biofertilizers" and "biocontrol agents" in relation to the anticipated agricultural results. Based on their biological origin, biostimulants are divided into two distinct classes: those derived from pathogens or plants themselves, and those derived from all other products, including chemicals and physical factors (Rafiee et al., 2016).

3.2.2. Mitigation Stress

Due to the quickly changing climate, plants are more often exposed to biotic and abiotic stresses, such as changes in plant physiology, growing season, and phytosanitary hazards, as well as increased losses in global agricultural production of between 30% and 50% (Sangiorgio et al., 2020).

Without sacrificing crop productivity, quality or production, biostimulants have shown a remarkable potential for reducing the stressors that climate change has made worse. This will ensure both physiological and nutritional security. These organic inputs seem to be a viable substitute for synthetic ones, offering a way to develop extremely environmentally friendly and sustainable farming methods. Because it can increase plant flexibility against pressures related to climate change, it is one of the sustainable ways to ensure food security (Calvo et al., 2014; Yakhin et al., 2017). Due to high evapotranspiration, decreased soil moisture and quality, overwhelming insect proliferation and increased disease occurrences, biostimulation may eventually make a sizable agricultural region unsuitable for cultivation (Prasad and Chakravorty, 2015). These could cause ethylene release (Ali et al., 2014) and dangerous reactive oxygen species (ROS) accumulation (Smirnov, 1993; Devi et al., 2017). According to Juárez-Maldonado et al. (2019), biostimulation significantly raised growth or yield, improved tolerance to opposing environmental influences, and improved metabolic process change that enables the most efficient use of environmental resources.

According to Bhupenanchandra et al. (2020) and Rouphael and Colla (2020), biostimulation is a combination of different organic amalgams of natural origin that can support plant growth or yield under a variety of environmental conditions. Botanical extracts, protein hydrolysates, vitamins, cell-free microbial products, antioxidants, anti-transpirants, and their derivatives are only a few of the major categories into which the BSt can be divided (Khurana and Kumar, 2022).

3.2. Different roles of biostimulant

In order to create a healthy environment for the health of people and animals, new environmentally friendly methods of controlling plant diseases and pests must be developed (Adriano et al., 2014). According to Vernieri et al. (2005), biostimulants are natural, eco-friendly compounds that can increase vegetative growth, mineral nutrient uptake, plant fitness to various pedoclimatic situations and resistance to abiotic stimuli. For quick absorption and availability within the plant, the biostimulants are organic products made of peptides, amino acids, polysaccharides, humic acids, phytohormones etc. Because they are immediately taken by the plant, their absorption is independent of photosynthetic activity, which reduces energy expenditure. Instead of providing nourishment, the purpose of these goods is to improve and boost the plant's metabolism, reduce plant stress, etc.

According to Parrado et al. (2008), they are also said to improve crop development and production through a variety of widely different methods, such as the activation of soil microbial activity and the stimulation or augmentation of the activities of important soil enzymes or plant growth hormones. The potential of plant growth-promoting rhizobacteria (PGPR) formulations to improve root growth, mineral availability and nutrient usage efficiency in the crop rhizosphere makes them one of the primary biostimulant classes.

Nguyen, Minh Luan (2014). Extracts of plant structures such as leaves, stems, fruits and flowers can provide certain biostimulants (Franzoni et al., 2022). These extracts are full of bioactive substances that can improve plant performance by stimulating physiological and metabolic processes (Zulfiqar et al., 2020). For instance, it has been demonstrated that root extracts from carrots and licorice enhance the growth of cowpea, beans, pear trees, and fennel. Additionally, in a variety of ornamental plants (like dwarf umbrella trees) and horticultural crops (like lettuce, tomato, eggplants, guar, and olive trees), leaf extracts from borage, aloe, garlic, and green tea enhanced growth and several physiological processes (Ali et al., 2018; Elzaawely et al., 2018; Moreno-Hernandez et al., 2020; Zulfiqar et al., 2020).

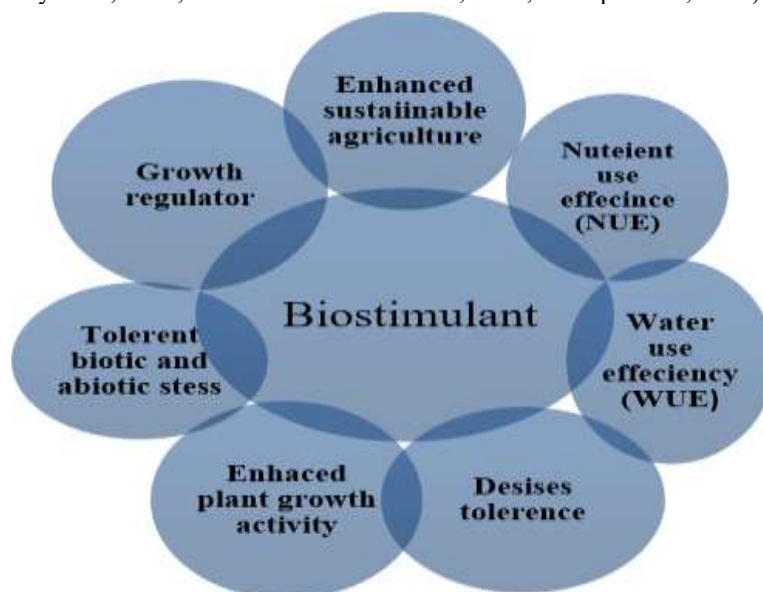


Fig-3.3. Role of biostimulant

By increasing the activity of antioxidant enzymes, seagrass aqueous extracts lessen the detrimental effects of salt stress in tomato plants (Vinoth et al., 2017). Additionally, *Moringa oleifera* leaf extract is utilized to boost plant development in a number of crops, including common beans, peas, and pumpkin (Del Buono, 2021). High concentrations of minerals, carbs, protein, amino acids, hormones, and antioxidant enzymes are linked to this advantageous effect (Zulfiqar et al., 2020; Del Buono, 2021).

3.4. Growth Regulators in Climate-Resilient Agriculture

The most recent hazard is climate change, which causes a number of abiotic pressures such as drought, floods, increased temperatures and erratic rainfall. Abiotic stressors negatively impact plant growth and development, which lowers yield. (Hossain et al., 2020; EL Sabagh et al., 2020b). Numerous biotic and abiotic challenges under this climate change scenario result in poor seed germination, restricted seedling growth and reduced plant development, which severely reduces biological and economic yield (EL Sabagh et al., 2021a,b; Shabbir et al., 2021). Plant growth regulators such as auxin, gibberellins, cytokinin, abscisic acid, ethylene and others including jasmonic acid, brassinosteroid, nitric oxide, salicylic acid, and strigolactone are biosynthesized to assist plants withstand the effects of climate change-related stressors. Plants naturally produce these phytohormones, also known as plant growth regulators (PGRs), which improve growth and development, change or initiate flowering or fruiting and partially ameliorate abiotic stresses. In addition to playing a significant role in enhancing photosynthetic efficiency, accumulation of stress proteins and other regulatory functions, they can function as thermoprotectants and reactive oxygen scavengers (Sharma et al., 2020). Significant changes in the hormonal perception signal can be observed under stress, which enables plants to reduce stress and experience healthy growth and development. A number of ligands and receptors are essential for the perception of hormones. For instance, strigolactone by the DWARF 14 hydrolase receptor, salicylic acid by NPR proteins, etc. (Chakraborty et al., 2019; Wang W. et al., 2020).

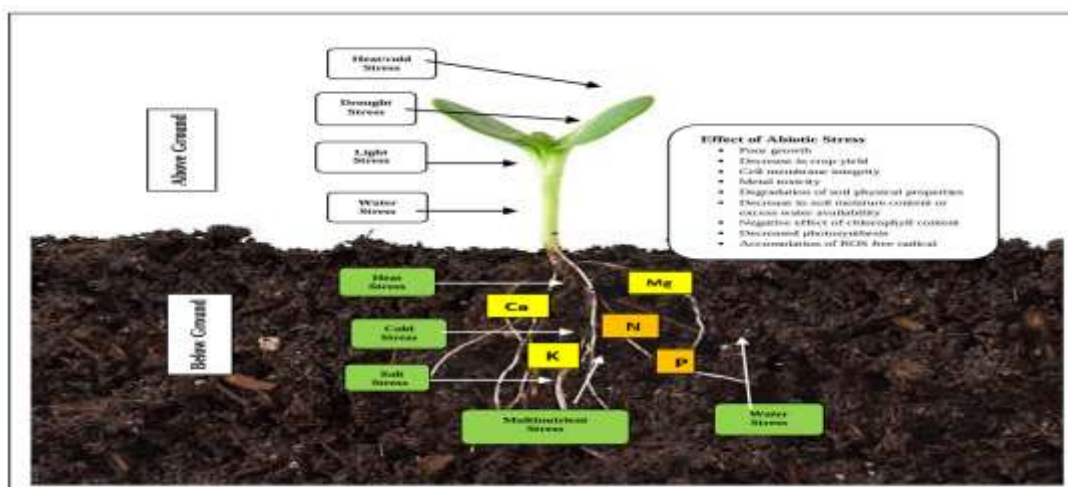


Figure 3.4.: Abiotic stress conditions and their effect on growth & development of plant

3.4.1. Auxins

By affecting a number of physiological processes, including as cell elongation, phototropisms and gravitropism, phyllotactic patterning, apical dominance, and control of root development, auxins are essential for plant growth and development (fig 3.4). The hormones that control cell growth and development interact with auxins (Mao et al., 2020; Xu et al., 2020). Auxins and metabolism are linked to plant growth under abiotic stress conditions (Shen et al., 2010; Casanova-Sáez et al., 2021). Auxins interact with stress-responsive signaling elements including calcium (Ca^{2+}) and reactive oxygen species (ROS) when plants are subjected to biotic and abiotic stress, and they accumulate in the plant to counteract stress conditions (Tognetti et al., 2017). Plants use a variety of stress-induced morphogenic responses (SIMR) as a means of tolerance. The main nutrients that supplement auxins to promote lateral root development are nitrogen, phosphorus, and potassium. Research indicates that auxin-linked low phosphate driven lateral root development involves auxin receptor genes/proteins such SIZ1, AFB2, AFB3, and AXR3/IAA7 (Pérez-Torres et al., 2008; Kazan, 2013). Therefore, it may be concluded that auxins have a significant impact on the alteration and switching of root architecture under stressful and nutrient-deficient conditions. Additionally, it has been discovered that auxins control the hydrotropism response in roots during drought conditions in relation to soil moisture (Kaneyasu et al., 2007). Because of the antagonistic phenomena of hydrotropism and gravitropism that coexist in the soil, auxins and ABA encourage the formation of root hair. Compared to gravitropism, auxin has a less role in hydrotropism (Cassab et al., 2013). However, auxin-mediated gravitropism can overpower ABA in the final direction of root expansion towards moist soil (Taniguchi et al., 2010). According to Liu et al. (2020), salinity is a sort of stress that has a significant impact on plants by causing physiological dryness because of excessive osmosis in soil solution, which results in an ion imbalance that impedes root development. Higher salinity prevents root development, whereas mild salinity reduces lateral root elongation and increases lateral root size (Zolla et al., 2010). Lateral root development in plants under salinity stress is regulated by a number of salt-responsive auxin signaling genes, including AXR1, AXR4, IAR4, and TIR1. Auxin accumulation rises in response to flooding or waterlogging stress, which encourages the growth of adventitious roots and aerenchyma to counteract the stress (Vidoz et al., 2010). According to Fahad et al. (2019), oxidative stress causes cells' redox status to fluctuate, which encourages the production of ROS. ROS production is regulated by important regulators such as glutathione (GSH) and thioredoxin (TRX) (Hasanuzzaman et al., 2020). Auxin signaling has a role in growth and development processes (Bashandy et al., 2010).

3.4.2. Gibberellins

Through a number of physiological and biochemical processes, including cell division, seed dormancy, germination, etc., gibberellins significantly contribute to the growth and development of plants. Under stressful conditions, gibberellin biosynthesis is suppressed, which results in poor plant development. Through quick inter-node elongation, gibberellin provides water logging stress tolerance, enabling the shoots to emerge from the water's surface. Gibberellin accumulation in submerged plants is caused by a number of ethylene-responsive factors, including SNORKEL1 and SNORKEL2, which results in internode formation (Hattori et al., 2009). By preventing shoot elongation, the expression of the submergence tolerance-1 (Sub1A) gene (Xu et al., 2006) aids in avoiding brief deep flooding, and rice has higher levels of the DELLA protein SLR1 (Claeys et al., 2014). Additionally, during salt stress, gibberellin is in charge of maintaining osmotic adjustments. During abiotic stressors, gibberelic acid, ethylene, and abscisic acid aid in controlling cell division and leaf expansion (Skirycz et al., 2010). It has been noted that during drought conditions, there is a decrease in Gibberellin concentration, which results in a decrease in leaf area and transpiration rate to improve plant water use efficiency.

3.4.3 Cytokinines

Plant cell discrepancy, leaf senescence delay, and other key developmental processes like integrating compounds, sink asset, and source/sink connections are all regulated by cytokinins. The enzyme that codes for isopentenyl transferase (IPT) catalyzes the creation of cytokinin (CK), which increases sink capacity and mitigates nutrients to the cells or tissues for utilization. Cytokinin enhances the assimilation of carbon and nitrogen during water stress, boosting metabolic pathways and the physiological reaction linked to sink. Drought stress causes a rise in cytokinin concentration, which delays leaf senescence and raises proline levels in plants (Alvarez et al., 2008). Salinity stress has been shown to enhance cytokinin, which sustains photosynthesis by promoting the expression of genes that support the manufacture of chlorophyll (Ma et al., 2016). Cytokinin strengthens the plant's antioxidant defense mechanisms to shield cells from ROS accumulation, preserve chloroplast integrity, lessen electrolyte leakage, and raise malondialdehyde (MDA) levels. Cytokinin inhibits the growth of roots and shoots as well as other agro-botanical characteristics such vascular tissue variation and root tissue lignification in environments with limited water.

3.4.4. Abscisic acid

In plants, abscisic acid, often known as stress hormone, has a variety of purposes to lessen a range of abiotic challenges. Abscisic acid concentration rises in response to abiotic stressors such drought, salinity and cold, which improves cellular dehydration and water balance (Malaga et al., 2020). ABA controls several physiological systems to help plants adapt to abiotic stress. During stress, ethylene and ABA have an impact on stomatal function. In order to finish their life cycle under low water potentials, it increases dormancy in seeds, inhibits seed germination and shoot growth and encourages root growth, senescence in leaves and the transition from vegetative to reproductive phase. In order to battle water stress or drought conditions, ABA decreases water absorption through roots, keeps plants turgid under low water potential, shortens leaves, closes stomata and alters gene expression. Osmotic stress causes an overabundance of ABA to be generated, which degrades and inactivates ABA production. ABA inhibits the growth of lateral roots under salt stress and a thick casparian strip develops in lateral roots to reduce the transport of sodium ions via the endodermis. ABA-mediated signaling, which is essential for the synthesis of osmoprotectants like proline and dehydrins under salinity stress, often regulates salt-associated genes. ABA alters root properties in relation to root water intake during flooding or water logging and reduces leaf transpiration.

3.4.5. Ethylene

Fruit ripening, senescence and leaf abscission are all controlled by ethylene. When a plant experiences abiotic stressors such as heat stress, toxicity, salt, drought, waterlogging and soil acidity, the quantity of ethylene rises. The plant's growth rate is slowed and senescence is started by this rise in ethylene concentration. Salinity stress causes a decrease in plant growth rate, an increase in leaf epinasty, an increase in the osmolality of leaf cells, a decrease in leaf size and a change in the amount of soluble protein in shoots. It lessens the uptake of nitrate, sulfate and ROS, and controls the redox reaction during salinity stress to maintain cell homeostasis. It supports cell signaling by interacting with other plant growth regulators. A rise in ethylene either totally or partially halts the aerobic system when there is water logging stress. When a plant's roots experience hypoxia due to waterlogging stress, ACC synthase (ACS) initiates the production of ethylene. Ethylene inhibits development, encourages leaf abscission, and improves plants' water-use efficiency during drought stress. Exogenous ethephon ($C_2H_6ClO_3P$) treatment aids in controlling protein metabolism, antioxidant defense, pollen viability and heat shock responses during heat stress (Jegadeesan et al., 2018). Ethylene improves lipid stability, antioxidant defense and protein metabolism during cold stress (Hu et al., 2017). Additionally, ethylene helps in root architecture (Abozeid et al., 2017), root-shoot communication (Alves et al., 2017), oxidative stress management and antioxidant transportation in plants (Wang Y. et al., 2020).

3.4.6. Brassinosteroids

By altering plant metabolism under various abiotic stressors, naturally occurring steroidal chemicals called brassinosteroids boost agricultural yields (Figure 3.4). It controls the growth of anthers, pollen production, stem elongation, vascular differentiation, root development and cellulose biosynthesis (Iqbal, 2015). Brassinosteroids improve resistance to a variety of abiotic stressors, including salinity, heat, cold and drought. Exogenous brassinosteroid administration preserves net photosynthetic rate, chlorophyll content, transpiration rate, stomatal conductance and maximum quantum efficiency of PSII during salinity stress (Yue et al., 2018). It lowers ROS and lipid peroxidation while increasing abscisic acid levels during drought stress.

3.4.7. Salicylic acid

By preventing salinity stress and restoring membrane potential, it lessens the negative effects of a number of abiotic stressors.

3.4.8 Nitric Oxide

Numerous plant growth processes, including seed germination, root growth, floral transition, pollen tube growth, fruit ripening, photosynthesis, mitochondrial function, senescence, seed dormancy, gravitropism and stomatal motions, are regulated by nitric oxide. It triggers the plant's antioxidant defense mechanism when under stress (Sami et al., 2018; Sharma et al., 2020). It controls water levels during drought stress to preserve plant metabolism, oxidative defense, and nutritional balance (Majeed et al., 2020; Wang X. et al., 2020). Under salt stress, it raises the cytoplasmic viscosity and osmotic pressure of plant cells (Dong et al., 2014).

3.4.9. Jasmonic acid and methyl jasmonates (MeJA)

Plant growth and physiological processes like reproduction, sex determination, fruit ripening, storage organ creation and senescence are all enhanced by it and interacts with other plant growth regulators to provide protection against environmental challenges.

3.4.10. Strigolactones

In the symbiotic relationship between plants and arbuscular mycorrhizal fungus (AMF), strigolactone (SL) controls hyphal branching. It is essential for the development of roots and shoots, senescence, reproduction and the control of shoot branching. It works in tandem with ABA to reduce stress.

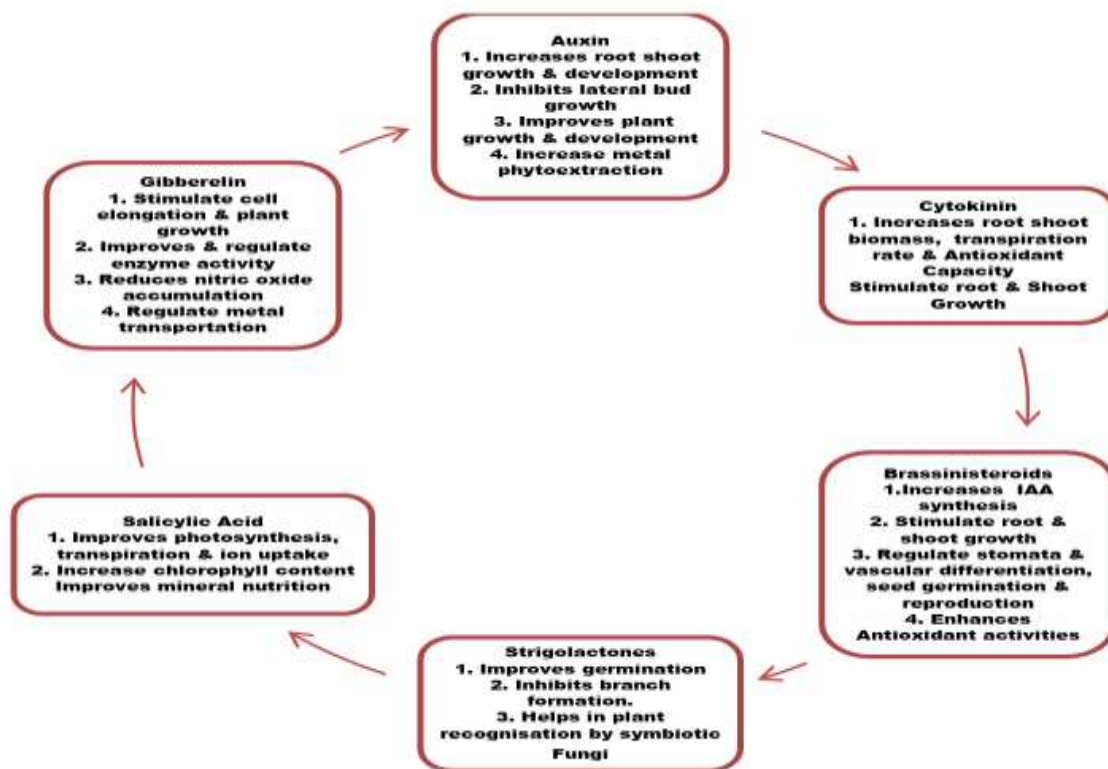


Fig 3.4: Role of different phytohormones on morphophysiological attributes of plant

CONCLUSION

Bio stimulant treatments have been shown to be a useful strategy for improving plant resilience to environmental disturbances and enabling vegetable growers to cultivate under unfavorable conditions without suffering negative consequences. Techniques and Bio stimulant-plant specificities may have the greatest effect on stress prevention. We won't be able to get to the next generation of bio stimulants, where synergies and complimentary mechanisms can be functionally designed and optimized to improve photosynthetic efficiency, transpiration and chlorophyll content, until we have a solid understanding of these mechanisms. Although there are a number of situations when bio stimulants are required to improve application techniques, it appears that there are crop and product specificities that need to be addressed, and there have also been reports of negative or no impacts. The diverse composition of bio stimulants, which are natural matrices that contain a variety of compounds from various classes and activities, as well as uncertainties in application times, methods, and doses, are typically the cause of these variable effects documented in the review. Lastly, as the genotype greatly influences the reaction to bio stimulant chemicals, particularly in stressed situations, the crop component is also significant. In conclusion, plant bio stimulants and plant growth regulators represent promising, sustainable, and eco-friendly approaches for enhancing crop productivity and resilience under changing climatic

conditions. By regulating key physiological, biochemical, and molecular processes, these bioactive compounds improve plant growth, stress tolerance, and yield quality while reducing dependence on conventional agrochemicals. Their ability to activate defense mechanisms and enhance plant adaptation to both biotic and abiotic stresses highlights their significant potential in modern climate-smart agriculture. Continued research into their mechanisms of action and field-level applications will further facilitate their integration into sustainable crop management strategies, contributing to global food security and environmental sustainability.

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