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Plant Growth Substances in Crop Production: A Review

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ABSTRACT

Plant growth regulators are chemical substances and when applied in small amounts, they bring rapid changes in the phenotypes of the plant and also influence the plant growth, right from seed germination to senescence either by enhancing or by stimulating the natural growth regulatory system. Plant growth substance are known to enhance the source – sink relationship and stimulate the translocation of photo-assimilates there by helping in effective flower formation, fruit and seed development and ultimately enhance the productivity of crops. Attempt is made to review the influence of some important growth regulating substances such as abscisic acid, auxin, cytokinin, ethylene, and gibberellins. Hormones are transported within the plant utilizing four types of movements; localized, cytoplasmic, streaming within cells and slow diffusion of ions. Abscisic acid is produced in leaves of plants, originated from chloroplast, especially when plants are under stress. Auxins influence cell enlargement, bud formation and root initiation. Auxins promotes the production of other hormones, they control growth of stem, roots and fruits and convert them into flowers. Cytokinin influence cell division and shoot formation. Ethylene on the other hand inhibits leaf expansion. While gibberellins produce abnormal growth especially in rice crops. It also promotes cell elongation and transition between vegetative and reproductive growth and are required for the functioning of pollen during fertilization. Other growth regulators such as, polyamines, triacontanol, and nitic oxide (NO) also serves as a signal to danger to plants, as defense mechanism and finally as a growth stimulant to the plants. The foregoing review concluded that, plant growth substances help to bring rapid and significant changes in the phenotypes of plants and also improve growth, translocation of nutrients from source to sink, increase economic part of plants and finally productivity of crops.

Keywords: Hormones, abscisic acid, phenotype, source – sink relationship

INTRODUCTION

Nutrients are important and crucial elements, which are required for the plant for its growth and development. The translocation of photosynthates from source to sink is very important for the development of economic part. Plant growth regulators are chemical substances and when applied in small amounts, they bring rapid changes in the phenotypes of the plant and also influence the plant growth, right from seed germination to senescence either by enhancing or by stimulating the natural growth regulatory system. Plant growth regulators are known to enhance the source-sink relationship and stimulate the translocation of photo-assimilates thereby helping in effective flower formation, fruit and seed development and ultimately enhance productivity of the crops.

Plant growth regulators/substances (also known as growth regulators or plant hormones) are also chemicals used to alter the growth of a plant or plant part. Hormones are substances naturally produced by plants that control normal plant functions, such as root growth, fruit set and drop, growth and other development processes. Plant hormones (also known as phytohormones) are signal molecules produced within plants, that occur in extremely low concentrations. They exert strong control over plant development and can either act locally or in more distant part of the plant. Plant hormones control all aspects of development, from embryogenesis, the regulation of organ size, pathogen defense, stress tolerance and through to reproductive development. The word hormone is derived from Greek, meaning *set in motion*. Plant hormones affect gene expression and transcription levels, cellular division, and growth. They are naturally produced within plants, though very similar chemicals are produced by fungi and bacteria that can also affect plant growth. A large number of related chemical compounds are synthesized by humans. They are used to regulate the growth of cultivated plants, weeds, and in vitro-grown plants and plant cells; these manmade compounds are called plant growth regulators or PGRs. Plant hormones are not nutrients, but chemicals that in small amounts promote and influence the growth, development, and differentiation of cells and tissues. The biosynthesis of plant hormones within plant tissues is often diffuse and not always localized. Hormones are transported within the plant by utilizing four types of movements. For localized movement, cytoplasmic streaming within cells and slow diffusion of ions and molecules between cells are utilized. Vascular tissues are used to move hormones from one part of the plant to another; these include sieve tubes or phloem that move sugars from the leaves to the roots and flowers, and xylem that moves water and mineral solutes from the roots to the foliage.

Growth regulators can improve the physiological efficiency including photosynthetic ability and can enhance effective partitioning of the accumulates from source and sink in the field crops (Solaiman *et al.*, 2001). Foliar application of growth regulators and chemicals at the flowering stage may improve the physiological efficiency and may play a significant role in raising the productivity of the crop (Dashora and Jain, 1994). This publication provides the meaning and definition of the term, "plant growth regulator," addresses patterns of use for plant growth regulators, and provides a listing of plant growth regulators. It can also be any substance or mixture of substances intended, through physiological action, for accelerating or retarding the rate of growth or maturation or for otherwise altering the behavior of ornamental or crop plants or the produce thereof, but not including substances intended as plant nutrients, trace elements, nutritional chemicals, plant inoculants, or soil amendments.

According to the American Society for Horticultural Science, plant growth regulators fall into six major classes. Table 1, below, lists these classes with the plant development function(s) that are controlled by the plant growth regulators. Table 1 also provides examples of the practical uses with which plant growth regulators are typically associated.

Table 1: Plant growth regulator class, associated function(s), and practical uses

Class	Function(s)	Practical uses
Auxins	Shoot elongation	Thin tree fruit, increase rooting and flower formation
Gibberellins	Stimulate cell division and elongation	Increase stalk length, increase flower and fruit size
Cytokinins	Stimulate cell division	Prolong storage life of flowers and vegetables and stimulate bud initiation and root growth
Ethylene generators	Ripening	Induce uniform ripening in fruit and vegetables
Growth inhibitors	Stops growth	Promote flower production by shortening internodes
Growth retardants	Slows growth	Retard tobacco sucker growth

Source: Agronomy Department, UF/IFAS Extension. http://edis.ifas.ufl.edu. Retrieved on 30th July, 2018.

Table 2 provides specific information on plant growth regulators. This table also includes major commodities that are associated with plant growth regulators and the primary function(s) of plant growth regulators and includes examples of trade names for plant growth regulators.

Table 2: Specific information on plant growth regulators

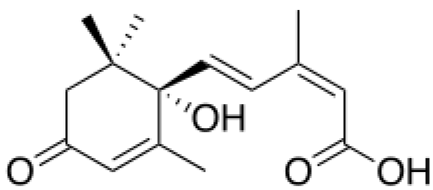
Active ingredient	Registered crops and functions	Trade names®*
2,4-D	Citrus-control fruit drop and increase fruit size	Citrus Fix
Ancymidol	Ornamental plants—growth inhibitor	Abide, A-Rest
Butralin	Tobacco—shoot inhibitor	Butralin
Alcohols	Tobacco—shoot inhibitor	Fair, Royaltac M, Sucker-Plucker, Off-Shoot, Contact-85
Chlormequat chloride	Ornamental flowers—shoot inhibitor	Citadel, Cycocel, E-Pro
Cytokinin#	Ornamental plants, vegetables, fruits including citrus—hasten maturity, enhance fruit color, growth enhancer, enhance tuber color, improve tuber quality	Conklin, Culbac, Cytoplex, Early Harvest, Foli-Zyme, Goldengro, Happygro, Incite, Megagro, Ascend, Radiate, Stimulate, Suppress, Validate, X-Cyte
Daminozide	Ornamental plants – growth inhibitor	B-Nine, Compress, Dazide
Ethephon	Turfgrass—reduces mowing frequency Various fruits, vegetables, and nuts—hastens ripening and maturity, enhance fruit color and floral stimulant Cucurbits—increases flowering Ground covers—inhibits flowering Ornamental trees—inhibits fruiting Tobacco and cotton—hastens maturity Cereal grains and grasses grown for seed—reduces lodging	Boll Buster, BollD, Cerone, Cotton Quik, Ethrel, Finish, Flash, Florel, Mature, MFX, Prep, Proxy, Quali-Pro, SA-50, Setup, Super Boll, Whiteout
Flurprimidol	Ornamental woody plants and ground covers—reduces pruning Turfgrass—reduces mowing frequentcy	Cutless, Legacy, Mastiff, Topflor
Gibberellic acid#	Small fruits, cucurbits—increase fruit set Citrus—promote rind/peel integrity, prevent fruit drop Rice, cotton—growth enhancer	Ascend, Cytoplex, Early Harvest, Falgro, Florgib, Foli-Zyme, GA3, GibGro, Green Sol, Incite, N-Large, PGR IV, Pro-Gibb, Release, Rouse, Ryzup, Stimulate
Gibberellin mixtures	Cut flowers—plant preservative Tree fruit—increase fruit size, hasten maturity, shoot stimulant Evergreen trees—floral stimulant, stimulate germination	BVB, Chrysal, Fascination, Procone
Indole-3-butyric acid (IBA)#	Ornamental plants and trees—root stimulant	Numerous trade products
Maleic hydrazide, potassium salt	Tobacco—shoot inhibitor Stored bulbs—sprout inhibitor	Fair, Rite-Hite, Royal, Sucker Stuff,
Mefluidide	Ground covers, shrubs, ornamental trees—reduces pruning Turfgrass—reduces mowing frequency	Embark, Sta-Lo
Mepiquat chloride	Cotton—growth inhibitor, enhance uniform fruit maturity	Pix
Mepiquat pentaborate	Cotton—growth inhibitor, enhance uniform fruit maturity	Pentia
Naphthalene-acetic acid (NAA)#	Ornamental plants—stimulates rooting, increase vegetative growth	DipN Grow, Goldengro, Hi-Yield
1-Naphthaleneacetamide (NAD)	Woody ornamental cuttings—rooting stimulant	Rootone
n-Decanol	Tobacco—shoot inhibitor	Antac, FST-7, Royaltac
Paclobutrazol	Ornamental flowers—promotes uniform flowering	Bonzi, Cambistat, Cutdown, Downsize, Florazol, Paclo, Paczol, Piccolo, Profile,

Active ingredient	Registered crops and functions	Trade names®*
	Ornamental plants—reduces internodal length Ornamental trees—growth inhibitor Turfgrass—increased plant thickness, growth inhibitor	Shortstop, Trimmit, Turf Enhancer
Prohexadione calcium	Peanut, Tree fruit, turfgrass grown for seed—growth inhibitor, reduce vegetative growth	Apogee
Trinexapac-ethyl	Turfgrass—reduces mowing frequency	Armor Tech, Goldwing, Governor, Groom, Legacy#, Primeraone, Primo, Provair, Solace, T-Nex, T-Pac
Uniconazole	Ornamental plants—growth inhibitor	Concise, Sumagic

Source: Agronomy Department, UF/IFAS Extension. http://edis.ifas.ufl.edu. Retrieved on 30th July, 2018.

Among the important internal factors that play role in plant growth are the plant hormones (phytohormones). They are plant growth regulators or substances which are not produced by the plants, Different hormones can be sorted into different classes, depending on their chemical structures. Within each class of hormone the exact structures vary, but they have similar physiological effects. Initial research into plant hormones identified five major classes: abscisic acid, auxin, cytokinins, ethylene and gibberellins

Abscisic acid



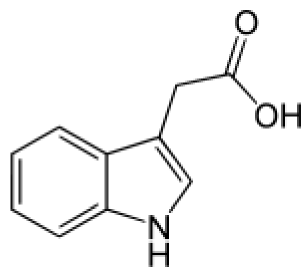
Abscisic acid

Role of Abscisic acid in plant growth: Abscisic acid (also called ABA) is one of the most important plant growth regulators. It was discovered and researched under two different names before its chemical properties were fully known, it was called *dormin* and *abscicin II*. Once it was determined that the two compounds are the same, it was named abscisic acid. The name "abscisic acid" was given because it was found in high concentrations in newly abscised or freshly fallen leaves.

This class of Plant growth regulators (PGR) is composed of one chemical compound normally produced in the leaves of plants, originating from chloroplasts, especially when plants are under stress. In general, it acts as an inhibitory chemical compound that affects bud growth, and seed and bud dormancy. It mediates changes within the apical meristem, causing bud dormancy and the alteration of the last set of leaves into protective bud covers. Since it was found in freshly abscised leaves, it was thought to play a role in the processes of natural leaf drop, but further research has disproven this. In plant species from temperate parts of the world, it plays a role in leaf and seed dormancy by inhibiting growth, but, as it is dissipated from seeds or buds, growth begins. In other plants, as ABA levels decrease, growth then commences as gibberellin levels increase. Without ABA, buds and seeds would start to grow during warm periods in winter and be killed when it froze again. Since ABA dissipates slowly from the tissues and its effects take time to be offset by other plant hormones, there is a delay in physiological pathways that provide some protection from premature growth. It accumulates within seeds during fruit maturation, preventing seed germination within the fruit, or seed germination before winter. Abscisic acid's effects are degraded within plant tissues during cold temperatures or by its removal by water washing in out of the tissues, releasing the seeds and buds from dormancy.

In plants under water stress, ABA plays a role in closing the stomata, Opik, *et al* (2005). Soon after plants are water-stressed and the roots are deficient in water, a signal moves up to the leaves, causing the formation of ABA precursors there, which then move to the roots. The roots then release ABA, which is translocated to the foliage through the vascular system and modulates the potassium and sodium uptake within the guard cells, which then lose turgidity, closing the stomata. ABA exists in all parts of the plant and its concentration within any tissue seems to mediate its effects and function as a hormone; its degradation, or more properly catabolism, within the plant affects metabolic reactions and cellular growth and production of other hormones, Ren, H. *et al* (2007). Plants start life as a seed with high ABA levels. Just before the seed germinates, ABA levels decrease; during germination and early growth of the seedling, ABA levels decrease even more. As plants begin to produce shoots with fully functional leaves, ABA levels begin to increase, slowing down cellular growth in more "mature" areas of the plant, Yuan, J. *et al* (2007). Stress from water or predation affects ABA production and catabolism rates, mediating another cascade of effects that trigger specific responses from targeted cells. Scientists are still piecing together the complex interactions and effects of this and other phytohormones.

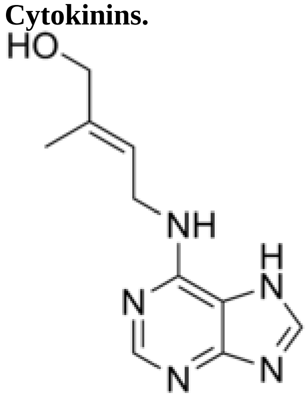
Auxins.



The auxin, indole-3-acetic acid

Effects of Auxins on plants: Auxins are compounds that positively influence cell enlargement, bud formation and root initiation. They also promote the production of other hormones and in conjunction with cytokinins, they control the growth of stems, roots, and fruits, and convert stems into flowers. Auxins were the first class of growth regulators discovered. They affect cell elongation by altering cell wall plasticity, Lindsey, K. *et al* (2002). They stimulate cambium, a subtype of meristem cells, to divide and in stems cause secondary xylem to differentiate. Auxins act to inhibit the growth of buds lower down the stems (apical dominance), and also to promote lateral and adventitious root development and growth. Leaf abscission is initiated by the growing point of a plant ceasing to produce auxins. Auxins in seeds regulate specific protein synthesis, as they develop within the flower after pollination, causing the flower to develop a fruit to contain the developing seeds; Kermade, A.R (2005). Auxins are toxic to plants in large concentrations; they are most toxic to dicots and less so to monocots. Because of this property, synthetic auxin herbicides including 2,4-D(2,4-dichlorophenoxyacetic) and 2,4,5-T have been developed and used for weed control. Auxins, especially 1-Naphthaleneacetic acid (NAA) and Indole-3-butyric acid (IBA), are also commonly applied to stimulate root growth when taking cuttings of plants. The most common auxin found in plants is indole-3-acetic acid or IAA.

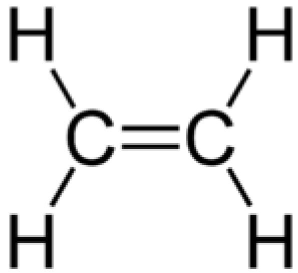
Cytokinins.



The cytokinin, zeatin

Uses of Cytokinin: Cytokinins or CKs are a group of chemicals that influence cell division and shoot formation. They were called kinins in the past when the first cytokinins were isolated from yeast cells. They also help delay senescence of tissues, are responsible for mediating auxin transport throughout the plant, and affect internodal length and leaf growth. Cytokinins and auxins often work together, and the ratios of these two groups of plant hormones affect most major growth periods during a plant's lifetime. Cytokinins counter the apical dominance induced by auxins; they in conjunction with ethylene promote abscission of leaves, flower parts, and fruits.

Ethylene.



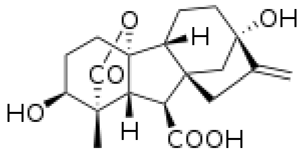
Ethylene

Effect of Ethylene: Ethylene is a gas that forms through the breakdown of methionine, which is in all cells. Ethylene has very limited solubility in water and does not accumulate within the cell but diffuses out of the cell and escapes out of the plant. Its effectiveness as a plant hormone is dependent on its rate of production versus its rate of escaping into the atmosphere. Ethylene is produced at a faster rate in rapidly growing and dividing cells, especially in darkness, Swarup, P. (2007). New growth and newly germinated seedlings produce more ethylene than can escape the plant, which leads to elevated amounts of ethylene, inhibiting leaf expansion (*Hyponastic response*). The **hyponastic response** is an upward bending of leaves or other plant parts, resulting from growth of the lower side. This can be observed in many terrestrial plants and is thought to be linked to the plant hormone auxin. Submerged plants often show the hyponastic response, where the upward bending of the leaves and the elongation of the petioles might help the plant to restore normal gas exchange with the atmosphere.

As the new shoot is exposed to light, reactions by phytochrome in the plant's cells produce a signal for ethylene production to decrease, allowing leaf expansion. Ethylene affects cell growth and cell shape; when a growing shoot hits an obstacle while underground, ethylene production greatly increases, preventing cell elongation and causing the stem to swell. The resulting thicker stem can exert more pressure against the object impeding its path to the surface. If the shoot does not reach the surface and the ethylene stimulus becomes prolonged, it affects the stem's natural geotropic response, which is to grow upright, allowing it to grow around an object. Studies seem to indicate that ethylene affects stem diameter and height: When stems of trees are subjected to wind, causing lateral stress, greater ethylene production occurs, resulting in thicker, more sturdy tree trunks and branches. Ethylene affects fruit-ripening: Normally, when the seeds are mature, ethylene production increases and builds-up within the fruit, resulting in a climacteric event just before seed dispersal. The nuclear protein Ethylene Insensitive2 (EIN2) is regulated by ethylene production, and, in turn, regulates other hormones including ABA and stress hormones.

Plants produce ethylene, and normally this dissolves in the air quite easily. But when the plant is submerged ethylene is trapped in the plant. Plants that are exposed to elevated ethylene levels in experimental set-ups also show the hyponastic response.

Gibberellins.



Gibberellin A1

Importance of Gibberellins: Gibberellins (GAs) include a large range of chemicals that are produced naturally within plants and by fungi. They were first discovered when Japanese researchers, including Eiichi Kurosawa, noticed a chemical produced by a fungus called *Gibberella fujikuroi* that produced abnormal growth in rice plants, Srivastava, L.M (2002). It was later discovered that GAs are also produced by the plants themselves and they control multiple aspects of development across the life cycle.

Effects of Gibberellin to plants: The synthesis of GA is strongly upregulated in seeds at germination and its presence is required for germination to occur. In seedlings and adults, GAs strongly promote cell elongation. GAs also promote the transition between vegetative and reproductive growth and are also required for pollen function during fertilization.

Other identified plant growth regulators include:

- **i.** Plant peptide hormones – encompasses all small secreted peptides that are involved in cell-to-cell signaling. These small peptide hormones play crucial roles in plant growth and development, including defense mechanisms, the control of cell division and expansion, and pollen self-incompatibility. The small peptide CLE25 is known to act as a long-distance signal to communicate water stress sensed in the roots to the stomata in the leaves.
- **ii.** Polyamines – are strongly basic molecules with low molecular weight that have been found in all organisms studied thus far. They are essential for plant growth and development and affect the process of mitosis and meiosis.
- **iii.** Nitric oxide (NO) – serves as signal in hormonal and defense responses (e.g. stomatal closure, root development, germination, nitrogen fixation, cell death, stress response). NO can be produced by a yet undefined NO synthase, a special type of nitrite reductase, nitrate reductase, mitochondrial cytochrome c oxidase or non-enzymatic processes and regulate plant cell organelle functions (e.g. ATP synthesis in chloroplasts and mitochondria).
- **iv.** Karrikins – are not plant hormones as they are not produced by plants themselves but are rather found in the smoke of burning plant material. Karrikins can promote seed germination in many species. The finding that plants which lack the receptor of karrikin receptor show several developmental phenotypes (enhanced biomass accumulation and increased sensitivity to drought) have led some to speculate on the existence of an as yet unidentified karrikin-like endogenous hormone in plants. The cellular karrikin signalling pathway shares many components with the strigolactone signalling pathway.
- **v.** Triacontanol – a fatty alcohol that acts as a growth stimulant, especially initiating new basal breaks in the rose family. It is found in alfalfa (lucerne), bee's wax, and some waxy leaf cuticles.

CONCLUSION

From the foregoing review it can be concluded that plant growth substances help to bring rapid and significant changes in the phenotypes of the plants and also improves the growth, translocation of nutrients from source to sink, increase economic parts and ultimately improve the productivity of the crops. The other identified growth regulators such as karrikin, triacontanol, polyamines, and nitric oxide (NO) also serves as a signal to danger to the plants, as defense mechanism and finally as a growth stimulants to the plants in order to increase production.

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