Concepts and Types of Plant Growth Hormones and their role in Field Crop Production

Addis Tadesse, Tekle

Ethiopian Biodiversity Institute, Crop and Horticulture Directorate, Addis Ababa, Ethiopia

Po.Box; 26307

Abstract

This paper is intended to revise those findings in the area of plant growth hormones; concepts, type and their role in field crop production for the better understanding of previous and current research findings. The plant hormones are defined as organic compounds which regulate plant physiological process regardless of whether these compounds are naturally occurring and/or synthetic; stimulating and/or inhibitory; local activators or substances which act at a distance from the place where they are formed. Hormones are chemical signals that are produced in one part of the body /tissue and transported to other parts of the plant bind to a specific receptor and trigger responses in the target cell and tissue. Plant development was thought to be regulated by only five types of hormones; auxins, gibberellins, cytokinins, abscisic acid, and ethylene. However, there is no compelling evidence that has a wide range of morphological effects on plant development. Current study indicate that plant growth hormones has play a significant role in the growth, physiological, biochemical, quality and yield characteristics of pulse crops which include length, fresh and dry weight of root, leaf number, leaf area, leaf area index (LAI), net assimilation rate (NAR), chlorophyll content, photosynthesis, nitrate reductase activity (NR), carbonic anhydrase activity (CA), nutrient accumulation, nitrogen, phosphorus and potassium contents, protein and carbohydrate content and various other growth, yield and quality parameters.. So the present review indicates that the process of growth and development, in addition to the yield and quality of plants is highly affected by the plant growth hormones and plant growth regulators. Finally, the objective of this term paper is to point out those research results in the area of plant growth hormones; their major classifications and role in field crop production through the review of different papers in this area.

Keywords: *development; growth; inhibitor; plant hormone*

1. Introduction

Plant growth substances called hormones are well-known to improve the source-sink connection and encourage the translocation of photo-assimilates thereby helping ineffective flower formation, fruit, and seed development and ultimately increase the yield of crops (Davies.p, 2014). In non-classical concept Plant, hormones are chemicals that regulate plant growth. Plant hormones are signal molecules produced at a specific location in the plant and in extremely low concentrations. They are naturally produced within plants, though very similar chemicals are produced by fungi and bacteria that can affect plant growth (Srivastava, 2002). Also, a large number of related chemical compounds synthesized in the laboratory that function as hormones are called plant growth regulators (PGRs).

Plant hormones affect gene expression and transcription levels, cellular division and growth. Davies.p, (2014), It is generally known that there are five major classes of plant hormones, some of which are made up of different chemicals that can vary in structure from one plant to the other. Each class has positive and inhibitory functions, and they often work in a cycle with each other, with varying ratios of one or more interplaying to affect growth regulators. Hormones like cytokines and auxins are chemicals that regulate plant growth. As such, they shape the plant and affect seed growth, time of flowering, sex of flowers and the senescence of leaves and fruits. Also, they affect the tissues that grow upward and downward, the formation of the leaf and the growth of the stem (Helgiopik and Stephen, 2005).

Plant growth hormone has played a major role in affecting different parts of the plant, growth, and development. Indole butyric acid (IAA) and naphthalene acetic acid (NAA) which is auxins are compounds that positively influence root initiation and in conjunction with cytokinins, they control the growth of stems, roots, flowers and fruits (Helgiopik and Stephen in Gana, 2010). Cytokinins which include 6-benzyl aminopurine (BAP) and zeatin are a group of chemicals that influence cell division and shoot formation. Plants need hormones at very specific times during plant growth and at specific locations; they also need to disengage the effects hormones have when they are no longer needed (Helgiopik and Stephen, 2005). Plant growth hormones (PGH) can change growth and development in various ways under different growth conditions. GA3 is responsible for stimulating the production of mRNA molecules in the cells, which in turn improves the chances of fast growth (Richards *et al*., 2001; Olszewki and Gubler 2002; Emongor, 2007). Nonstructural carbohydrates (NSC) and crude protein (CP) contents in rice straw were significantly increased by spraying GA3, especially on the 15th d after anthesis, and the fermentation quality of rice straw silage was improved with the increase of NSC and CP contents, Single panicle weight was also significantly increased by spraying GA3 after anthesis (Dong *et al*., 2012). Priming with GA3 was very effective in improving salinity-induced decrease in a number of grains per ear on the main stem in both wheat cultivars, which can alter the uptake and pattern of accumulation of different ions between shoots and roots in the adult plants of wheat under saline conditions. PBZ is a member of the triazole plant-growth inhibitor group. Like many plant growth regulators, triazoles have plant growth regulatory effects. Triazoles also increase tolerance of various plant species to biotic and abiotic stresses, including fungal pathogens, drought, air pollutants, and low and high-temperature stress, by reducing oxidative damage via elevation of antioxidants or reducing the activity of oxidative enzymes (Lin *et al*., 2006; Bahram, 2009). Generally, the objective of this review paper is to point out those research results in the area of plant growth hormones; their major classifications and role in field crop production thought to review different papers in this area.

2. Concepts of plant hormones

The presence of growth-regulating hormones in plants was first suggested by Julius von Sachs in 1980. He proposed that there were certain ‘organ-forming substances’ in plants which were produced in the leaves and translocated downward in the plant body. Also in 1880, Charles Darwin, an evolutionist, studied the effect of unilateral light on plant movements. While conducting his experiments on canary grass (Phalaris canariensis), he found that if the coleoptile tip is provided light from one side only (i.e., unilateral illumination), the tip would bend towards the light. In the absence of illumination, however, no curvature could be induced (Parthier B, 2004).

According to (Gaspar *et al*., 2003) the term ‘hormone’ was first used in medicine about 100 years ago for a stimulatory factor, though it has come to mean a transported chemical message. The word, in fact, comes from the Greek, where its meaning is ‘to stimulate’ or ‘to set in motion’. Thus the origin of the word itself does not require the notion of transport per se, and the above definition of a plant hormone is much closer to the meaning of the Greek origin of the word that is the current meaning of hormone used in the context of animal physiology. Plant hormones are a unique set of compounds, with unique metabolism and properties (Davies P, 2014). Their only universal characteristics are that they are natural compounds in plants with an ability to affect physiological processes at concentrations far below those where either nutrients or vitamins would affect these processes (Gaspar *et al*., 2003).

A hormone is a substance which stimulates growth in animal or plant cells. Plant growth substances are biochemically produced in a plant (endogenous) or synthetic substances applied to plants externally (exogenous) which cause modifications in plant growth and development. Plant growth substances produced by the plant are referred to as phytohormones. Plant hormones are a group of naturally occurring, organic substances which influence physiological processes at low concentrations. The processes influenced consist mainly of growth, differentiation, and development, though other processes, such as stomatal movement, may also be affected.

3. Plant growth hormones mode of action

Hormones act as internal signals within the plant. In exactly the same way as environmental signals, they must be perceived and then initiate a series of responses. Plant hormones (a hormone/ receptor complex) interact directly with the DNA of plant Cell to regulate gene expression. Plant hormones interact to affect cell physiology; transcriptional and translational changes. The steps between the initial perception and the final response are known as signal transduction – another set of chemical changes, this time occurring inside the cell, which alters the biochemistry and/or patterns of gene expression of that cell. These changes may then in turn act as signals initiating yet further responses(H. O pick & S. Rolfe, 2005).

4. Types of plant growth hormones

Plant growth hormones classified depending on the nature of production into major two classes; endogenous and exogenous, hormone produced naturally inside the plant tissue or cell and those produced chemical synthetic hormones respectively. The concentration of a plant growth hormone at a particular site will depend upon many different factors including the rate of synthesis, degradation, and transport to and from the target cell. In addition, plant growth hormones are often chemically modified, which may inactivate them, although as this process is often reversible it can also increase the effective concentration of a plant growth hormone in a cell. Finally, as the activity of plant hormones is thought to require binding to specific receptors, transport in and out of subcellular compartments also controls the concentration perceived by the cell. As all of these processes have the potential to be regulated by the environment, it can be seen that plant growth hormones act as a means of integrating environmental signals and distributing them around the plant (Gana. S, 2010).

Classically there are five major groups of plant growth hormones. These are the auxins, gibberellins, cytokinins, abscisins, and ethylene. However, many more compounds exist in plants which have all of the characteristics of the more established plant growth hormones, and their role in regulating plant development is becoming clearer. These compounds include the jasmonates, salicylates, brassinosteroids and peptide hormones. Recently, small RNA molecules have been identified which regulate gene expression in different parts of the plants; these too might be considered to fulfill many of the criteria of being a plant growth hormone.

These have the following characteristics which can be added to the definition above. In general: 1) Plant growth hormones are small, relatively simple organic compounds. 2) Specific receptors exist which bind these compounds. 3) Often the presence of one plant growth hormone will affect the synthesis or action of other plant growth hormones (H. O pick and S. Rolfe, 2005).

4.1. Auxins; ($C_{18}H_{32}O_5$)

The name Auxins derived from the Greek word auxin, meaning to increase or to grow Auxins are compounds produced in the meristem of apical buds; embryo seed and young leave that positively influence cell enlargement, bud formation and root initiation. They also promote the production of other hormones and in conjunction with cytokines; they control the growth of stems, roots, flowers and fruits (Daphne *et al*., 2005). IAA transport is cell to cell, mainly in the vascular cambium and the procambial strands, but probably also in epidermal cells. Transport to the root probably also involves the phloem. IAA, IBA and 2, 4-dichlorophenoxy acetic acid (2, 4-D) as well as picloram are often added to nutrient media (Gana, A. S 2010).

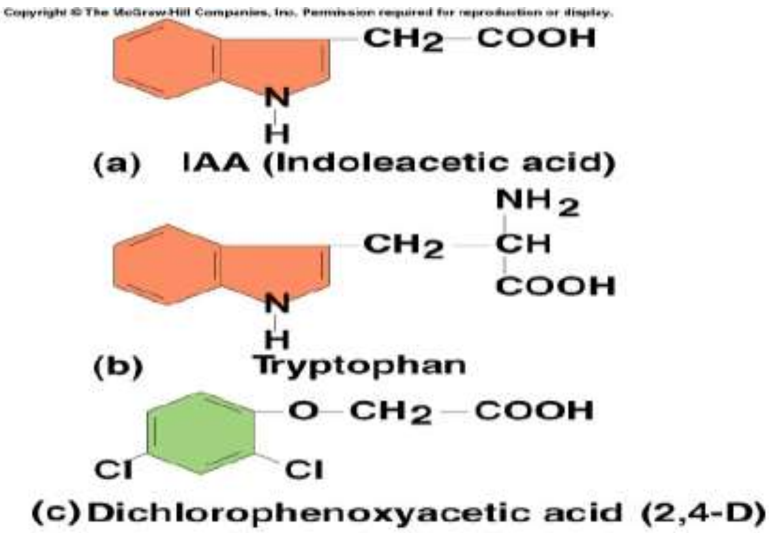


FIGURE 1. AUXIN PLANT GROWTH HORMONE CHEMICAL STRUCTURE (H. O PICK & S. ROLFE, 2005)

Auxin Biosynthesis

IAA is similar to the amino acid tryptophan which is generally accepted to be the precursor molecule from which IAA is derived by different pathways. Tryptophan is converted to indoleacetaldoxime through decarboxylation and then converted to indoleacetonitrile by a dehydration reaction.

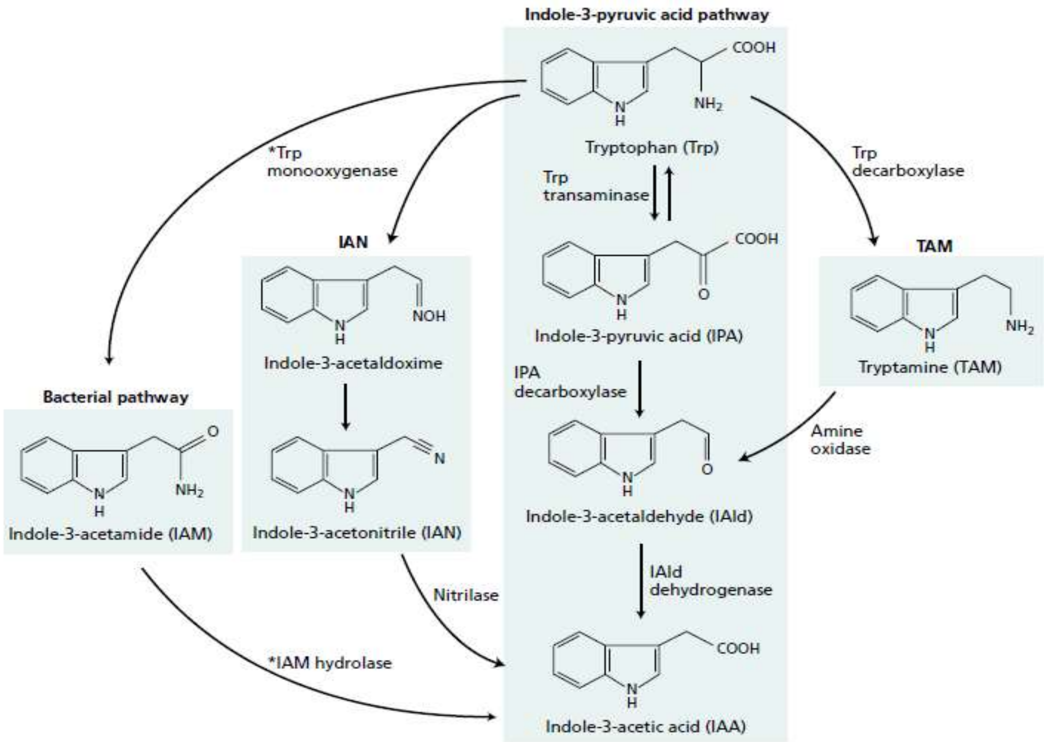


FIGURE 2. INDOLE ACETIC ACID (IAA) BIOSYNTHESIS IN PLANTS AND BACTERIA (TAIZ LINCOLN AND ZEIGE EDUARDO, 2003)

4.2. Cytokinins: $C_{10}H_9N_5O$

Cytokines (CK) biosynthesis is through the biochemical modification of adenine. It occurs in root tips and developing seeds and transport is via the xylem from roots to shoots. Cytokinins are often used to stimulate growth and development, zeatin, kinetin, BAP, 2, P and pyranyl benzyl adenine (PBA) being common. They usually promote cell division, especially if added together with an auxin. In high concentration (1 to 10 mg/ml), they can induce adventitious shoot formation, but root formation is generally inhibited (Gopi C and Vatsala, 2006). They promote auxiliary shoot formation by decreasing apical dormancy.

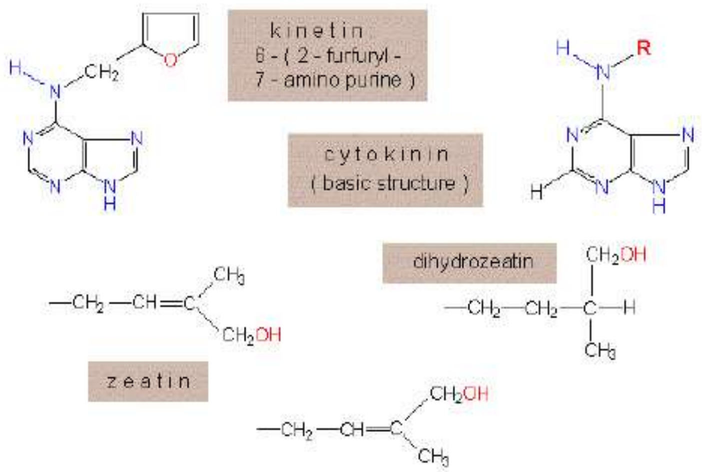


FIGURE 3. CYTOKININS HORMONE CHEMICAL STRUCTURE (CASSÁN, VANDERLEYDEN, & SPAEPEN, 2014)

Biosynthesis of Cytokinins

Cytokinins are found in more concentrations in meristematic tissues and in growing parts. They are synthesized in roots and translocated to shoots acropetally via xylem; they are synthesized as follows;

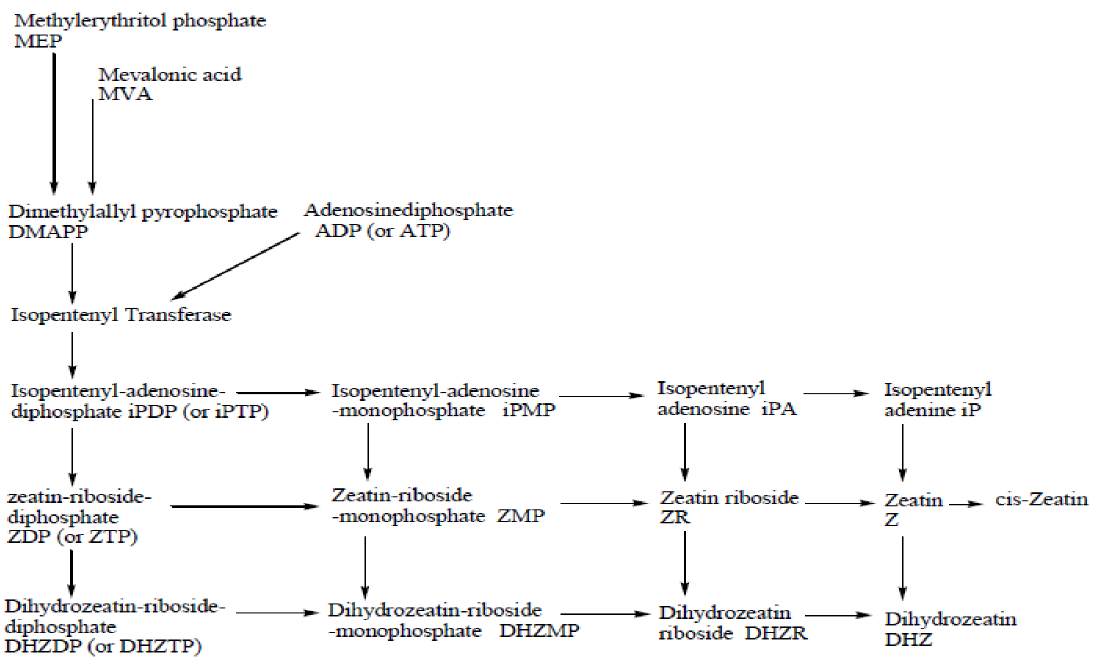


FIGURE 4 CYTOKININS HORMONE CHEMICAL STRUCTURE (CASSÁN, VANDERLEYDEN, & SPAEPEN, 2014)

4.3. Gibberellins: $C_{19}H_{22}O_6$

Gibberellins are synthesized from glyceraldehyde-3-phosphate, via isopentenyl diphosphate, in young tissues of the shoot and developing seed. Their biosynthesis starts in the chloroplast and subsequently involves membrane and cytoplasmic step. GAs are probably transported in the phloem and xylem. However, the transport of the main bioactive polar GA_1 seems restricted. Gibberellins induce elongation of internode and the growth of plants or buds *in vitro*. They also break the dormancy of isolated embryos or seeds. Gibberellins usually inhibit adventitious root formation as well as adventitious shoot formation (Slater *et al*., 2005).

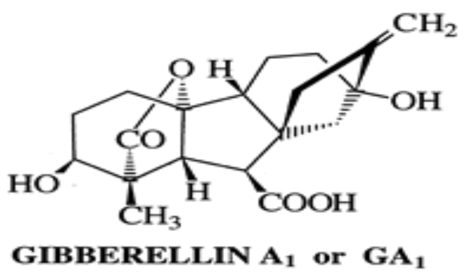


FIGURE 5. CHEMICAL STRUCTURE OF GIBBERELLIN HORMONE (DAVIES PJ, 2014)

Biosynthesis of Gibberellins

Acetyl CoA molecules are oxidized to produce mevalonic acid and CoA molecules. The primary precursor for the formation of gibberellin is acetate.

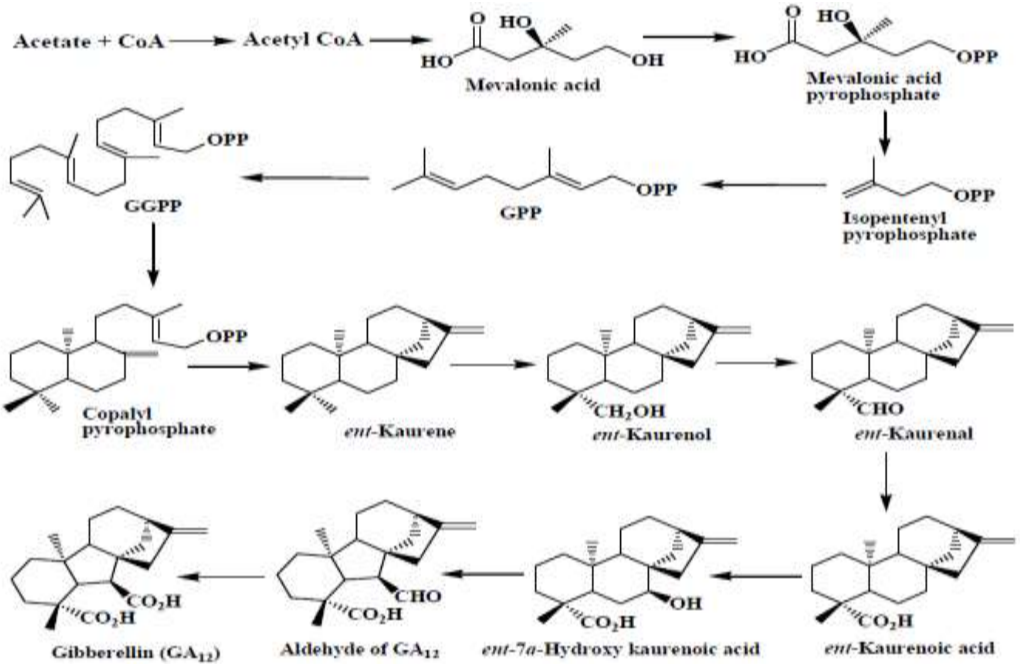


FIGURE 6. BIOSYNTHETIC PATHWAY OF GIBBERELLINS (H. O PIK & S. ROLFE, 2005)

4.4. Abscisic Acid; $C_{15}H_{20}O_4$

ABA is synthesized from glyceraldehyde-3-phosphate via isopentenyl diphosphate and carotenoids in roots and mature leaves, particularly in response to water stress. Seeds are also rich in ABA which may be imported from the leaves or synthesized in situ. ABA transport is exported from roots in the xylem and from leaves in the phloem. There is some evidence that ABA may circulate to the roots in the phloem and then return to the shoots in the xylem (Devies PJ, 2014). In general, it acts as an inhibitory chemical compound that affects bud growth, 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 (Else *et al*., 2001). 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. Without ABA, buds and seeds would start to grow during warm periods in winter and be killed when it freezes 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.

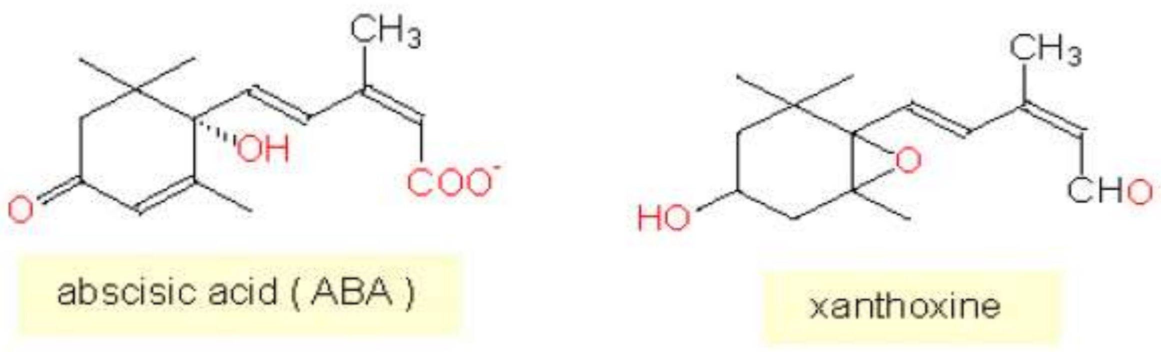


FIGURE 7 CHEMICAL STRUCTURE OF GIBBERELLIN HORMONE (ADAPTED FROM DAVIES JP, 2014)

Biosynthesis of Abscisic Acid

There are following two pathways of ABA biosynthesis. ABA is synthesized by higher plants from carotenoid precursors. Carotenoids (Violaxanthin, C40) are involved in photosynthesis;

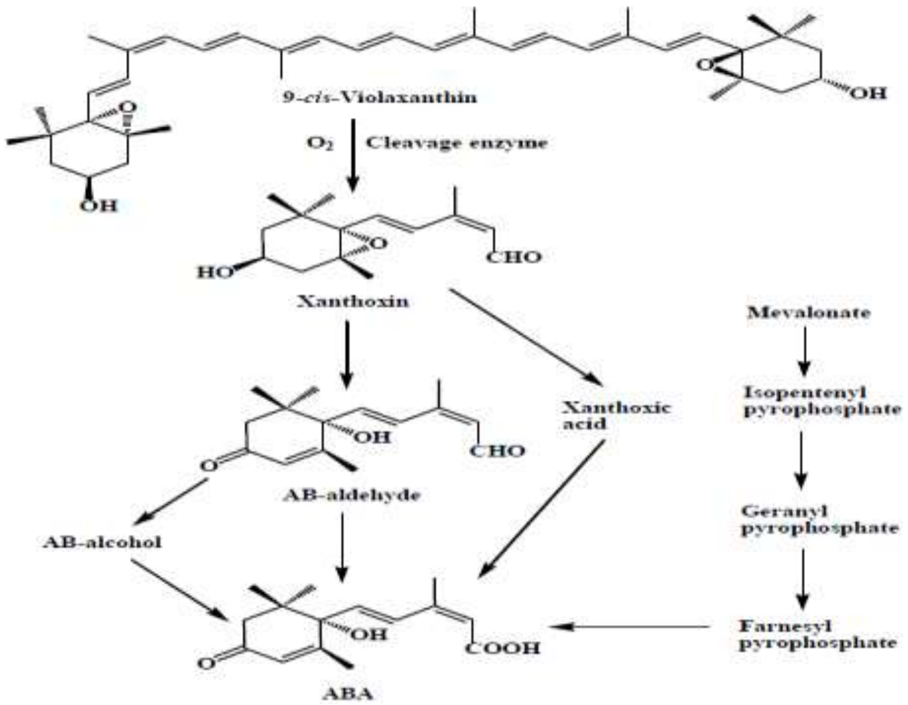


FIGURE 8. BIOSYNTHETIC PATHWAY OF ABSCISIC ACID (H. O PIK & S. ROLFE, 2005

4.5. ETHYLENE; C_2H_4

Ethylene is a gaseous, naturally occurring, plant growth regulator. The gas ethylene (C_2H_4) is synthesized from methionine in many tissues in response to stress and most commonly associated with controlling fruit ripening in climacteric fruits, and its use in plant tissue culture is not widespread. It is synthesized in tissues undergoing senescence or ripening. Transport being a gas, ethylene moves by diffusion from its site of synthesis. It does, though, present a particular problem for plant tissue culture. Some plant cell cultures produce ethylene, which, if it builds up sufficiently, can inhibit the growth and development of the culture **(**Gana A. S, 2010). The type of culture vessel used and its means of closure affect the gaseous exchange between the culture vessel and the outside atmosphere and thus, the levels of ethylene present in the culture.

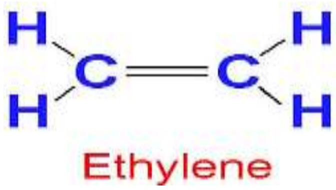


Figure 10. Ethylene molecular structure (Gaspar *et al*., 2003)

Biosynthesis of Ethylene

Ethylene is produced by methionine in all higher plants essentially in all tissues. Ethylene production varies with the type of tissue, plant species and stage.

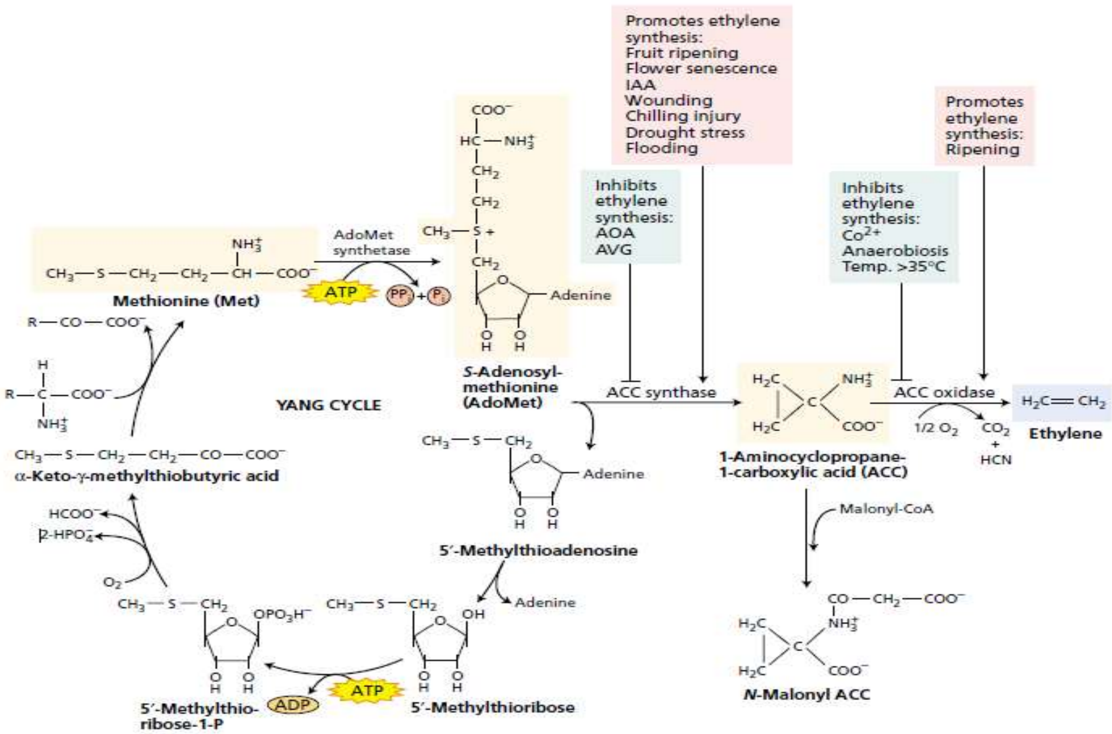


FIGURE 9. BIOSYNTHETIC PATHWAY OF GIBBERELLINS (TAIZ LINCOLN AND ZEIGE EDUARDO, 2003)

5. Plant growth regulator (PGR)

These are generally substances synthesized artificially and have either a growth suppressing or enhancing the effect. According to Davies, P. (2014) and H. O pik & S. Rolfe (2005), many more compounds found in plants which have all of the nature of the more established plant growth hormones, and their role in regulating plant development are becoming clearer. These compounds include the jasmonates, salicylates, brassinosteroids and peptide hormones. Recently, small RNA molecules have been identified which regulate gene expression in different parts of the plants; these too might be considered to fulfill many of the criteria of being a plant growth hormone.

TABLE 1. PLANT GROWTH REGULATORS THEIR RESTRICTED LOCATION AND FUNCTIONS

No	PGRs	Location	Action
1	Brassinolide (brassinosteroids)	Leaf and xylem tissue	Cell elongation; cell division;
2	Salicylic acid	Willow Bark	Activate defense gene, against pathogen invaders (is an active ingredient for aspirin)
3	Oligosaccharins(oligosaccharides)	Cell wall	Defense against pathogen
4	Systemine	Wound tissue	Defense activities as a signal molecule
5	Jasmonates	Seed	Seed germination; root growth and the storage of protein

5. Role of Plant Growth Hormones in Field Crop Production

Plant growth hormones play important roles in plant growth and development, Plant growth regulators modify growth and development in various ways under different growth conditions. GA_3 is responsible for stimulating the production of mRNA molecules in the cells, which in turn improves the chances of fast growth (Richards *et al*., 2001; Olszewki and Gubler 2002; Emongor, 2007). Nonstructural carbohydrates (NSC) and crude protein (CP) contents in rice straw were significantly increased by spraying GA3, especially after anthesis, and the fermentation quality of rice straw silage was improved with the increase of NSC and CP contents. Single panicle weight was also significantly increased by spraying GA3 after anthesis (Dong *et al*., 2012). Application of plant growth hormones in low concentration regulates growth, differentiation, and development, either by promotion or inhibition (Naeem *et al*., 2004), and allows physiological processes to occur at their normal rate (Gulluoglu, 2004). Major plant growth regulators (PGRs) significantly enhanced fiber yield in cotton (Copur *et al*., 2010), protein content in pea (Bora and Sarma, 2006), chemical constituents in Croton (Soad *et al*., 2010), fruit size in Molina (Vwioko and Longe, 2009), seed germination rate in black gram and horse gram (Chauhan *et al*. 2009b), floral buds in Jojoba (Prat *et al*., 2008) and other growth parameters in different plants.

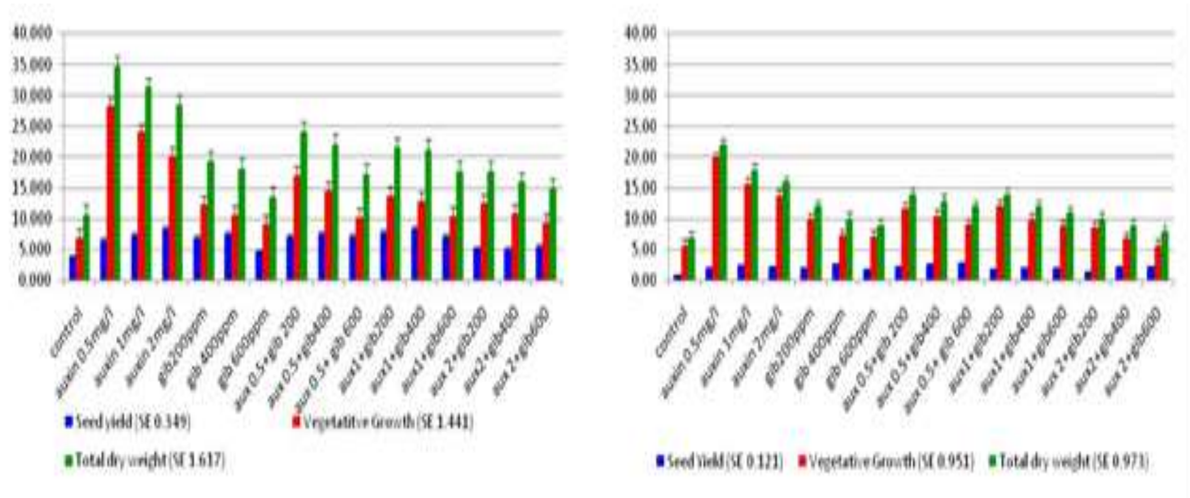
5.1. Role of PGH on Grain yield and yield component

Seed priming with GA_3 was very effective in improving salinity-induced decrease in a number of grains per ear on the main stem in both wheat cultivars, which can alter the uptake and pattern of accumulation of different ions between shoots and roots in the adult plants of wheat under saline conditions. Paclobutrazol (PBZ) is a member of the triazole plant-growth inhibitor group. Like many plant growth regulators, triazoles have plant growth regulatory effects. Triazoles also increase tolerance of various plant species to biotic and abiotic stresses, including fungal pathogens, drought, air pollutants, and low and high-temperature stress, by reducing oxidative damage via elevation of antioxidants or reducing the activity of oxidative enzymes (Lin *et al*., 2006; Baninasab Bahram, 2009). PBZ normally is applied as a foliar spray (Still and Pill, 2004). As one kind of cytokinin, 6-BA can reduce the ethylene sensitivity of cut flowerers (Yuan *et al*., 2012). Exogenous 6-BA is able to inhibit the effects of ethylene, inhibit ethylene biosynthesis, induce 1 aminocyclopropane-1-carboxylate synthase (ACS) and 1-aminocyclopropane-1-carboxylate oxidase (ACO) gene expression and is involved in the early regulation of ethylene signal transduction in plants(Hall *et al*., 2001; Gapper *et al.,* 2005).

Zhang *et al*. (2007) reported that spraying external 6-BA on the leaves at the late growth period of the late-season rice could increase seed setting rate and grain yield by delaying leaves senescence. Pan *et al.* (2013) reported that foliar application of plant growth regulator at heading stage can increase grain yields. Peizataifeng and Huayou 86 in both early and late seasons in 2007 in the early season, grain yield of Peizataifeng under PBZ and 6-BA treatments was remarkably higher than that of CK, respectively.

The higher yield was found for GA3, PBZ, and 6-BA treatments, while the lowest one was found under control treatment. Significant differences were found in the number of spikelets per panicle and grain filling percentage between GA3, PBZ, 6-BA treatment and CK in two cultivars of Peizataifeng and Huayou 86 in both early and late seasons in 2007 (Pan *et al*., 2013). Different plant growth regulators and stages of application showed significant variation in case of chlorophyll content of soybean leaf at different days after sowing. At 30 days after sowing, the highest chlorophyll content was recorded from kinetin when applied at flower initiation stage which was statistically similar to kinetin spray at the pod initiation stage. Research results were found by Hayat *et al*. (2005). Devi *et al*. (2011) in (Sonia K *et.al*, 2016) observed that application of 50 ppm salicylic acid at flower+ pod initiation stage increased the soybean yield.

FIGURE 10. EFFECT OF PLANT GROWTH HORMONES ON (A) SEED YIELD, VEGETATIVE GROWTH AND TOTAL DRY WEIGHT INFIELD AND (B) SEED YIELD, VEGETATIVE GROWTH, AND TOTAL DRY WEIGHT IN A POT. (RASTOGI *ET AL*.,2013).



(a) (b)

TABLE 2. EFFECT OF DIFFERENT PLANT GROWTH REGULATORS AND STAGES OF THE APPLICATION ON THE DRY WEIGHT AT DIFFERENT DAS AND SEED YIELD OF SOYBEAN (AGEGNEHU, GETACHEW; TAYE, 2004)

No.	**Treatment**	**Plant height(cm)**	**Dry mat-ter (g)**
1	Control (without P and plant hormone)	78.7c	5.3c
2	26 mg P	93.0b	6.1bc
3	52 mg P	104.0a	7.3a
4	26 mg P+1.0 mg ben-	93.6b	6.3abc
	zyladenine (BA)		
5	52 mg P+1.0 mg ben-zyladenine (BA)	93.9b	6.3abc
6	26 mg P+2.0 mg Gib-	88.7b	5.6bc
	berlin (GA)		
7	52 mg P+2.0 mg Gib-	91.3b	6.7ab
	berellin (GA)		
SE		1.75	0.25

CV (%)		3.80	8.15

Means in a column with different letters are significantly different ($P < 0.01$)

2.5.1. Role of PGH on Grain Qualities

One of the most essential traits in assessing planting benefit is grain quality. There were significant effects on grain qualities by spraying exogenous plant growth regulator. Du *et al*. (2010) studied that the plumpness of the inferior grain in rice was enhanced by 9.7% and 5.5% by spraying exogenous 6-BA and GA3 at 5 days before flowering, respectively. Application of 6-BA decreased the white rice rate and white area of grain and write degree compared to the CK, respectively. Furthermore, exogenous hormones had greater effects on grain qualities of inferior spikelets than superior spikelets. Dong *et al*. (2009) reported that the effects of exogenous hormones on rice quality varied with exogenous hormone varieties and different grain positions by spraying GA3 (57.7 µmol -L) at an earlier filling stage in rice.

Significant differences in head rice rate, chalkiness rate and amylose content in the two cultivars between the treatments. The PBZ treatment significantly increased head rice rate and amylose content in the cultivar Peizataifeng in the early season. In the late rice season, significant differences in amylose content were observed among these treatments. No noticeable differences in brown rice rate and milled rice rate in the two cultivars were observed among the treatments in both early season and late season.

Head rice rate under PBZ treatment was significantly higher than that the CK in the early season, however, there were increases to some extent in head rice rate and amylose content in the late season, but not significant as compared to the CK. Although PBZ treatment showed an increase in the chalkiness of grain as compared to the CK, the difference was not significant. PBZ treatment could improve grain's milling quality trait and nutrition trait because of higher head rice rate and amylose content(Pan *et al*., 2013).

Different plant growth regulators and stages of application showed significant variation in case of chlorophyll content of soybean leaf at different days after sowing (DAS). At 30 day after sowing, the highest chlorophyll content (27.26) was recorded from kinetin when applied at flower initiation stage which was statistically similar to kinetin spray at the pod initiation stage.

Abdel-Wahid *et al.* (2008) in Sonia (2016) reported that chlorophyll content increased in Syngonium pod phylum plant with the application of salicylic acid. It might be due to the reduction in cell size resulting in dense cytoplasm. Chlorophyllase enzyme was responsible for chlorophyll growth retardant which enhanced the chlorophyll content. From photo-oxidation application of salicylic acid protected the molecule of chlorophyll and thereby increased chlorophyll content.

TABLE 3. EFFECT OF DIFFERENT PLANT GROWTH REGULATORS AND STAGES OF THE APPLICATION ON THE DRY WEIGHT AT DIFFERENT DAS AND SEED YIELD OF SOYBEAN (KHATUN *ET AL*., 2016),

Plant	**Growth**	**Stages of application**	**Chlorophyll content (SPAD value) at**			
Regulator			30 DAS	45 DAS	60 DAS	75 DAS
Control (water)		Vegetative stage	25.48 a-c	32.50 a	47.58 a-d	41.22 a-c
		(25 DAS)				
		Flower initiation stage (40 DAS)	24.62 a-c	32.20 a	44.12 a-d	40.70 a-c
		Pod initiation stage (50 DAS)	21.42 bc	31.54 a	44.66 a-d	40.60 a-c
		Flower +Pod initiation stage	21.90 bc	32.06 a	46.78 a-d	43.34 ab
		(40 and 50 DAS)				
Salicylic	acid	Vegetative stage	22.62 a-c	32.78 a	43.08 b-d	39.30 b-d
50 ppm		(25 DAS)				
		Flower initiation stage (40 DAS)	22.60 a-c	29.52 ab	45.68 a-d	42.50 a-c
		Pod initiation stage (50 DAS)	22.96 a-c	25.60 b	50.36 a	46.64 a
		Flower +Pod initiation stage (40 and 50	20.96 c	31.32 ab	49.44 ab	44.58 ab
		DAS)				
GA3 100 ppm		Vegetative stage	23.58 a-c	30.32 ab	40.70 cd	36.38 cd
		(25 DAS)				
		Flower initiation stage (40 DAS)	21.92 bc	34.08 a	50.38 a	46.54 a
		Pod initiation stage (50 DAS)	24.32 a-c	30.86 ab	47.60 a-d	39.30 b-d
		Flower +Pod initiation stage	24.46 a-c	33.64 a	44.04 a-d	33.78 d
		(40 and 50 DAS)				
Kinetin	500	Vegetative stage	22.36 a-c	32.04 a	40.56 d	36.26 cd
ppm		(25 DAS)				
		Flower initiation stage (40 DAS)	27.26 a	33.22 a	44.68 a-d	42.20 a-c
		Pod initiation stage (50 DAS)	26.10 ab	31.00 ab	47.66 a-c	44.22 ab
		Flower +Pod initiation stage	24.02 a-c	32.64 a	43.70 a-d	39.30 b-d
		(40 and 50 DAS)				
LSD(0.05)			5.081	5.939	7.086	6.274

In a column, values with a different letter(s) differed significantly at 5% level as per LSD.

TABLE 4. EFFECTS OF PLANT GROWTH REGULATORS ON BROWN RICE RATE, MILLED RICE RATE, HEAD RICE RATE, CHALKINESS AND AMYLOSE CONTENT OF CULTIVARS PEIZATAIFENG AND HUAYOU 86 IN BOTH EARLY AND LATE SEASONS IN 2007 (PAN *ET AL*., 2013)

No	Treatments		Brown rice (%)	Milled rice (%)	Head rice (%)	Chalkiness (%)	Amylose content (%)
2007 early rice							
	Peizataifeng	CK	81.5 a	73.8 a	63.4 b	9.8 b	11.8 b
		GA3	81.6 a	74.3 a	66.2 ab	13.2 a	12.5 b
		PBZ	81.9 a	75.9 a	68.9 a	10.1 b	17.1 a
		6-BA	82.0 a	75.4 a	66.5 ab	13.6 a	17.6 a
		mean	81.7 A	74.9 A	66.3 B	11.7A	14.7 A
	Huayou86	CK	81.4 a	75.4 a	66.0 b	12.9 a	15.5 a
		GA3	82.5 a	75.6 a	67.5 b	12.4 a	15.1 a
		PBZ	82.7 a	75.3 a	74.7 a	10.7 a	16.5 a
		6-BA	81.3 a	74.0 a	67.2 b	11.4 a	14.3 a
		mean	82.0 A	75.1 A	68.9 A	11.9 A	15.4 A
2007 late rice							
	Peizataifeng	CK	82.0 a	76.3 a	67.7 a	8.3 ab	14.5 b
		GA3	82.4 a	77.2 a	70.0 a	10.1 a	17.9 a
		PBZ	82.1 a	76.8 a	69.7 a	9.2 a	17.2 a
		6-BA	82.0 a	77.4 a	69.7 a	6.7 b	17.2 a
		mean	82.1 A	76.9 B	69.3 A	8.6 A	16.7 A
	Huayou86	CK	81.9 a	78.6 a	68.9 a	7.0 b	14.0 b
		GA3	81.7 a	78.6 a	70.1 a	8.7 b	18.5 a
		PBZ	82.2 a	79.0 a	71.3 a	12.1 a	18.7 a
		6-BA	81.2 a	79.0 a	70.1 a	10.1 ab	18.0 a
		mean	81.7 A	79.0 A	70.1 A	9.5 A	17.3 A

2.6 Factors affecting plant growth hormones

Plants are continuously exposed to a myriad of external signals such as fluctuating nutrients availability, drought, heat, cold, high salinity, or pathogen/pest attacks that can severely affect their development, growth, and fertility. As sessile organisms, plants must, therefore, be able to sense and rapidly react to these external inputs, activate efficient responses, and adjust development to changing conditions. In recent years, significant progress has been made towards understanding the molecular mechanisms underlying the intricate and complex communication between plants and the environment. It is now becoming increasingly evident that hormones have an important regulatory role in plant adaptation and defense mechanisms.

A variety of external or environmental stimuli can at various times be involved in regulating plant development. Most environmental stimuli are physical parameters. Light, temperature, and gravity have the most obvious and dramatic impact, environmental signals originate outside the plant, plants must have some means of perceiving the signal and converting, or transducing, the information into some permanent metabolic or biochemical change. It is becoming increasingly evident that most, if not all, environmental stimuli act at least in part through modifying gene expression or hormonal activities.

2.6.1. Temperature effect:

Temperature is one of the most influential factors affecting the plant hormonal action, and biosynthesis. According to different research results; the rate of leaf extension was faster with increasing temperature (up to 30°C) and greater, particularly above 15^0C. Applied GA3 increased the growth rate of the tall wheat cultivar, and it was proportionally more effective at temperatures lower than 15°C. Although there was no effect of applied GA3 on the extension rate of Rht3 dwarf seedlings above 20°C, there was some indication of growth stimulation by GA3 at lower temperatures. However, Stoddart and Lloyd (1986) "have not found any changes in GA3 responsiveness of three-leaf seedlings after pretreatment at 5°C for up to 10 d." by contrast, aleurone layers of mature grains of wheat cultivars carrying, RhtJ, Rht2, or Rht3 alleles do become responsive to applied GA_3 after pre-incubation at 5°C for 20 h (Singh S *et al*., 1984). Effects of temperature on leaf elongation and on its response to GA application of wheat genotypes brings change leaf size; which is also reflected in their final plant heights and yield components.

2.6.2. Light effect

Plants growing under canopy shade or in the shade of neighboring, proximate vegetation are subjected to shade light, i.e., light with lower red to far-red (R/FR) ratios (Ballare *et al*. 1990; Smith 2000). These plants usually have etiolated stems and may exhibit altered leaf growth (Ballaré *et al*. 1990; Smith 2000). These morphological differences are regulated by plant hormones, mainly gibberellins (GAs), auxin (indole-3-acetic acid (IAA), cytokinins (CKs), and ethylene (Kurepin *et al*. 2006a, 2010a). Light regulates both GA1 biosyntheses through regulation of the transcription of the gibberellin degradation gene and also causes a decrease in the responsiveness of stem elongation to the presence of gibberellins.

2.7. Commercial application of plant growth hormones

There are many areas in agriculture, horticulture, pomiculture, moriculture, etc., where phytohormones can be used in successful cultivation to obtain greater yield. Quantity and quality of agricultural products are very important factors in agricultural economics; the high percentage of germination of sown seeds in the field has a bearing on the output. Pretreatment of seeds with IAA, NAA, GA, etc. has been found to be very effective not only in increased the percentage of germination but also in the total yield of the crop plants. Suitable concentration and combination have to be determined for each and every crop plants.

The overall growth of plants, the number of tillers and branches that produce from every plant in the field contribute to the total yield. Use of GA or IAA greatly enhances the growth of plants and a total area of leaf surfaces. Some morphactins can also be used to produce more tillers. In the case of sugar cane, the use of GA has been found to increase the length of the internodes and also the sugar content.

Tissue Culture: Since the days of Haberlandt attempts to grow plant cells, tissues and organs in an artificial but defined nutrient medium have met with great success. Various methods have been established to raise plantlets starting from single cells, pith, leaf, roots, etc. By modulating the nutrients and hormonal concentration, it is possible to regenerate the entire plant body from any living cell from any part of the plant body, which suggests that all cells are totipotent. Hormonal concentrations play a significant role in culturing explants into undifferentiated callus and callus to differentiate into roots, shoots or the entire plant from eh callus.

Stimulation of fruit set: One of the first recorded effects of auxins was the stimulation of fruit set in unpollinated ovaries of solanaceous plants. It is known that pollen was a rich source of auxin and that in some species pollination alone was all that was required for fruit set to occur. In tomato, chemical stimulation of fruit set is all that is needed for fruit growth to take place as well.

Herbicidal action*:* 2, 4-D and picloram (4-amino-3, 5, 6-trichloro picolinic acid) are two auxin-type herbicides that at low concentration bring about growth responses in plants similar to IAA. At higher concentrations they are herbicidal. 2, 4-D is commonly used to control broadleaf weeds in grasses, and picloram is used for vegetation control on non-crop land because of its high activity and soil persistence Srivastava, L. M. (2002). Both compounds cause epinastic bending in leaves, a cessation in growth in length, and increased radial expansion. After several days tumors may form, followed by a softening and collapse of the tissue.

Increasing fruit size in grape: GA is used extensively on seedless grape varieties to increase the size and quality of the fruit. Pre-bloom sprays of 20ppm induce the rachis of the fruit cluster to elongate. This creates looser clusters that are less susceptible to disease during the growing season (Dong *et al*., 2012). GA also reduces pollen viability, as well as decreasing ovule fertility in grape. Application of GA at bloom, therefore, results in a decrease in fruit set, which reduces the number of berries per cluster, but increases the weight and length of the remaining fruit.

Increasing yield in sugarcane: Sugarcane growth is very sensitive to the reductions in average daily temperature normally experienced during the winter months in many canes producing regions of the world, especially Hawaii. GA application is used to overcome the reduced growth of the 3~5 internodes undergoing expansion during the cooler winter season. GA treatment has resulted in an increase in fresh weight of harvested cane of 10.9 ton/ha and has increased sucrose yield by 1.1 ton/ha or 2.8% (Jung Lee, 2001 and Davies PJ, 2014).

Malting barley: - Gibbreline is one of the major growth hormone used to increase the yield of malt barley and to decrease the time required for the malting process to undertake. Embryo growth and yield of malt extract are competitive processes, by increasing the rate of malting relative to embryo growth, a greater yield of malt extract occurs. Application of GA to germinating barley supplements the endogenous level of this hormone and accelerates the production and release of hydrolytic enzymes that degrade the storage proteins and carbohydrates of the endosperm into the sugars and amino acids that comprise the malt extract.

Cotton defoliants: The organophosphate DEF and Folex are used as leaf abscission agents before mechanical harvesting of cotton. Two new compounds are being evaluated for this purpose. Dimethipin (2,3-dihydro-5,6-dimethyl-1,4-dithiin-1,1,4,4-tetraoxide) and thidiazuron (1-phenyl-3(1,2,3-thiadiazol -55-yr)urea) induce defoliation and provide control of regrowth vegetation other leaf abscission (Kurtin *et al.*,2012).

3. Conclusion

A plant growth hormone is an organic substance produced within the plant in very low concentrations and transported to another part of the plant where it causes a response. Plant growth hormones play a crucial role in controlling the way in which plants grow and develop. While metabolism provides the power and structural blocks for plant life, it is the hormones that control the speed of growth of the individual parts and integrate these parts to produce the form that we recognize as a plant. In general, current information from different literatures tells the pivotal role played by the plant growth hormone on the plant growth and development by affecting various growth parameters like: shoot length, leaf area, leaf area index, fresh weight, dry weight, and physiological characters like chlorophyll content, photosynthesis activity of plants in addition to yield and quality attributes including seed yield, harvest index and many other important aspects. The use of plant growth regulators is being practiced by the commercial growers of plants as a part of cultural practice or economic point. There are various factors contributing to the efficacy of plant growth regulators and the method of application plays a key role in determining the effectiveness of plant growth regulators, as plant growth regulators can be effective if properly absorbed by plants. There are various methods of application of plant growth regulators but the most popular are foliar sprays, drenching, and pre-plant soaking while the efficacy of each method depends on the various factors including the mode of absorption of plant growth regulators by different plant parts, a method of application and environmental factors. Further development to focus on the variables that can affect the response of the plant to plant growth regulators will help to increase the efficiency of PGRs and avoid phytotoxicity which can maximize their productivity.

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