Plant hormones synthesized by microorganisms

Preetanshika Tracy

Abstract

Hormones can be defined as compounds that are produced in a certain tissue in small amounts that control and regulate various functions related to growth. Hormones produced by plants are known as Phytohormones. They are also termed as plant hormones. These are naturally occurring small organic molecules or substances that influence physiological processes in plants at very low concentrations (Davies, 2004). Phytohormones can also act as chemical messengers that coordinate cellular activities of plants (Fleet and Williams, 2011). Auxin was discovered as the first phytohormone (Went, 1935) and the most recent identification was of strigolactones (SL) (Gomez-Roldan et al., 2008). Nine categories of phtohormones have been identified so far, that is, auxins, cytokinins (CK),gibberellins(GA), abscisicacid (ABA), ethylene (ETH), brassinosteroids (BR), salicylates (SA), jasmonates (JA) and strigolactones (SL). The first five(auxins, cytokinins (CK), gibberellins (GA), abscisic acid (ABA), ethylene (ETH) are sometimes referred to as classical phytohormones. Drought, extreme temperature, salinity, and heavy metals are various abiotic stresses to which plants are subjected to. These have negative impact on the physiology and morphology of plants causing defects in the genetic regulation of cellular pathways. Plants use many tolerance mechanisms and pathways to avert the results of stresses that are triggered whenever alterations in metabolism are encountered. Phytohormones prove to be the most important growth regulators; which have been known to have a prominent impact on plant metabolism, and additionally, they play a vital role in stimulating plant defense response mechanisms against stresses. A method known as exogenous phytohormone supplementation has been adopted to improve growth and metabolism under stress conditions. Recent investigations have shown that phytohormones produced by root-associated microbes such as plant growth promoting rhizobacteria (PGPR) Which may include *Pseudomonas, Azospirillum, Klebsiella, Enterobacter,Alcaligenes, Arthrobacter, Bacillus, Serratia* have been reported to enhance the plant growth directly or either assisting in resource acquisition (nitrogen, phosphorus and essential minerals) (Shweta, 2017). The phytohormones produced by PGPR play a significant role in increasing the root surface area and number of root tips in many plants.

Plant hormones facilitate in coordinative numerous physiological processes in plants, as well as the regulation of seed germination and quiescence, root formation, visible radiation, branching, tillering and fruit ripening.

They may also prove to be important metabolic engineering targets for inducing host tolerance to abiotic stresses. In this chapter the role of different phytohormones and their interaction with the plants, their microbial biosynthesis are discussed.

History of the classical plant hormones :

Auxins :

Auxins were discovered during the nineteenth century as an outcome of experiments on phototropism and geotropism (reviewed by Moore, 1979). In 1880 reports on the phenomenon by which the plants bent towards sunlight were presented by Charles Darwin. In 1926, auxin was discovered by Dutch botanist Frits Went. He described it's bioassay for its quantitative detection by "Avena coleoptiles curvature test". Although he isolated auxin but he could not purify the active compound to establish its chemical structure. Biochemist Kogl Haage Smit and Erxleben in 1934, found an active substance from urine, Indole- 3- active acid (IAA), which was found to be identical to auxin. Finally, IAA was isolated from cultures of the fungus Rhizopus suinus by K.V. Thimann in 1935.

Gibberellins :

E. Kurosawa discovered Gibberellins in 1926 (Moore, 1979). In 1938 two biologically active substances were isolated and crystallized by Yabuta and Sumiki, which they named as gibberellins "A" and "B". As per recent reports about 125 different Gas (gibberellins) have been characterized up to now. (Crozier *et al*., 2001).

Cytokinins :

In 1955, Cytokinins were discovered by F. Skoog, C. Miller and colleagues throughout the Fifties as factors that promote cellular division (cytokinesis).The first growth regulator discovered was AN A (aminopurine) spinoff named kinetin (6-furfuryl- aminopurine; that was isolated as a deoxyribonucleic acid degradation product. . It was found to be active in *in vitro* in promoting mitosis and cell division in tobacco callus tissue.

Ethylene :

It is also known as "ripening hormone" and was identified some 50 years ago (Burg, 1962). Doubt discovered that ethylene aroused abscission in 1917 (Doubt, 1917). In 1934 Gane reported that plants synthesize ethylene (Gane, 1934). In 1935, Crocker projected that ethylene was the phytohormone answerable for fruit ripening additionally as inhibition of vegetative tissues (Crocker, 1935).

Abscissic acid :

Abscissic acid was discovered around 1960 as the hormone causing abscission of fruits and dormancy of buds.

Introduction

The Food and Agricultural Organization has provided an estimate of the alarmingly increasing human population, expected to reach 8–9 billion by 2030 (FAO, 2010). As a result of increasing urbanization and industrialization, threats to the environment have increased, leading to the shrinkage of agricultural and on one hand and causing significant declines in crop growth on the other hand. Abiotic stresses have the potential to limit the expansion of crop plants significantly, therefore leading to significant yield losses and posing a potential threat to global food security(Mahalingam,2015). Global warming additionally ends up in the concurrence of variety of abiotic and organic phenomenon stresses, so poignant agricultural productivity

Drought,salinity, significant metal contamination, flooding, temperature (cold and high), and UV ar the key abiotic factors that modulate the expansion of plants to the extent that a discount in yield is a certain effect. Changes in the climate patterns of different regions have resulted in shifts in vegetation, and approximately 2,000 million hectares of land worldwide has been affected by increased water scarcity and salinization (El-Beltagy and Madkour, 2012). It is believed that close to twenty fifth of world agricultural land is affected by drought and close to 5–7% is affected by salt (Ruiz-Lozano et al., 2012). Abiotic stresses inhibit plant growth by reducing water uptake and altering plant physiological and biochemical processes(Ahmadetal.,2010;Hashemetal.,2016). Heavy metals, including cadmium, lead, and mercury, are toxic and are mostly present in soils at low concentrations. Elevated concentrations of soluble aluminium (Al) reduce root growth in acid soils.
However, thanks to their high quality within the soil–plant system, they are readily taken up by plants and delivered to the shoot (Hart et al., 1998). Increases in metal concentrations cause retardation of growth, leading to necrosis, altered nutrient uptake, reduced enzyme activity and hence phytotoxicity(Groppaetal.,2012). A better understanding of the different tolerance methods for maintaining crop productivity through the manipulation of environmental conditions may be useful for maintaining the utmost genetic potential of crops as much as possible. Phytohormones(plant hormones) manage plant growth and development through the regulation of organic phenomenon. They play also a crucial role in the regulation of cellular activities including elongation, cell division and differentiation, organogenesis, pattern formation, reproduction and responses to abiotic and biotic stress conditions. Nine categories of phtohormones have been identified so far, that is, auxins, cytokinins (CK), gibberellins(GA), abscisicacid (ABA), ethylene (ETH), (classical phytohormones), bbrassinosteroids (BR), salicylates (SA), jasmonates (JA) and strigolactones (SL).

Auxins

Naturally occurring substances with indole nucleus possessing growth promoting activity square measure statedas auxins. (Garima Pant, Pawan Kumar Agrawal, 2014). This group of phytohormones has the ability to induce cell elongation in the subapical region of the stem. Besides this ability, auxins are involved in almost all aspects of plant growth and development such as stem and root elongation, stimulation of cell division, lateral and adventitious root initiation, apical dominance, vascular tissue differentiation, gravitropism and phototropism (Davies 2010). Auxin has risen to prominence as a plant signalling molecule, inspiring many to study its secrets. Past decades have seen a number of breakthroughs in the identification of a deceptively simple transcriptional response pathway

(Weijers and Wagner, 2016), as well as cellular and molecular mechanisms of directional auxin transport (Adamowski and Friml, 2015), synthesis and inactivation (Korasick et al., 2013). At the same time, auxin action has been reported in most, if not all, growth and developmental processes (Weijers and Wagner, 2016), in interactions with other hormonal signalling pathways (Vert and Chory, 2011), and even in the interaction with beneficial or pathogenic microorganisms and viruses (Boivin et al., 2016). Wang and Jiao (2018) discussed the role of auxin transport in shoot meristem development. One of the first mutants identified in the auxin field was *pin-formed1*, which produces naked, pin-like stems and no flowers. *PIN1* was later shown to encode an auxin transport protein, and mutations that reduced the biosynthesis of, or response to, auxin were found to cause similar defects. Thus, auxin is a potent regulator of flower formation at the shoot meristem. In recent years, genetic approaches, gene expression analysis and live imaging have led to new models as to how the local accumulation of auxin at the shoot meristem is controlled, and how these maxima trigger organ formation. Wang and Jiao provided an overview of this aspect of auxin action. Similar to the shoot native phytohormone accumulation within the root conjointly has sturdy morphogenetic potential. Auxin maxima trigger several successive steps in the formation of lateral roots along the primary root. Separate responses provide context to the priming, initiation and emergence of lateral roots, and both the auxin response components and the downstream genes of these different steps have been characterized in recent years. Du and Scheres (2018) described these latest findings and provided an integrated view of auxin-dependent lateral root formation.

Indole acetic acid (IAA) is one of the most important physiologically active auxins.(Sadaf et al., 2009). IAA exhibits the greatest activity although plants are known to contain other auxins, most of them also belonging to the indole derivatives (structurally similar to IAA)(Shweta Sharma, Mohinder Kaur, 2017). Some naturally occurring molecules with auxin activity are Indole 3 butyric acid (IBA) and Phenylacetic acid. (Frick and Strader, 2018). Several synthetic analogues including 2,4-dichlorophenoxyacetic acid(2,4-D) and 1-naphthaleneacetic acid (NAA) (Dolf et al., 2018).

Biosynthesis of IAA :

Two major pathways for IAA biosynthesis have been proposed in plants: the tryptophan (Trp)-independent and Trp dependent pathways (Woodward and Bartel, 2005; Chandler, ; Normanly,2010).

In Trp-independent IAA biogenesis, indole-3-glycerol phosphate or indole is that the doubtless precursor, however very little is thought regarding the organic chemistry pathway to IAA (Ouyang et al., 2000; Zhang et al.,2008). The tryptophane freelance pathway is additional common in plants, however may be found in microorganisms Azospirillum and eubacteria.

In Trp-dependent IAA biogenesis, many pathways are postulated (Woodward and Bartel, 2005; Pollmann et al., 2006a; Chandler, 2009; Mano et al., 2010 ; Normanly, 2010; Zhao, 2010):

(i) the indole-3-acetamide (IAM) pathway; (ii) the indole-3-pyruvic acid (IPA) pathway; (iii) the tryptamine (TAM) pathway; and (iv) the indole-3-acetaldoxime (IAOX) pathway. In plant cells IAA is essentially shaped by Diamond State novo synthesis from tryptophane. for several pathways there's no genetic proof is out there and thus the presence and importance of those pathways must be uncovered. Despite of the multitude of pathways, there are a unit apparently, 2 dominant microbic pathways supported each the abundance and genetic proof for these pathways : either by intermediate indole-3-pyruvate (IPyA) or by an intermediate indole-3-acetamide (IAM). (Sharma and Kaur, 2017).

Indole-3-acetamide, IAM pathway : The IAA biosynthetic pathway via IAM was thought to be a bacteria-specific pathway because no evidence for this pathway had been found in plants. The plant pathogen Agrobacterium rhizogenes harbours a large root-inducing (Ri) plasmid and generates hairy-root disease, which is characterized by root proliferation from the infection site. A portion of the Ri plasmid, designated the T-DNA, is transferred to the host plant cell, integrated into the plant genome, and expressed in polyadenylated mRNA (Moore et al., 1979; White and Nester, 1980; Chilton et al., 1982). Hairy roots can grow aseptically in phytohormone-free media (Mano et al., 1986, 1989; Mano, 1993). In hairy roots, IAA is synthesized from Trp by a two-step reaction as a result of the expression of the integrated genes aux1 (also referred to as iaaM/tms1) and aux2 (also referred to as iaaH/tms2) of Ri TR-DNA (Yamada et al., 1985; Camilleri and Jouanin, 1991; Gaudin et al., 1993; Casanova et al., 2005). The auxin biosynthetic pathway catalysed by the aux1 and aux2 gene products is similar to that in Agrobacterium tumefaciens and Pseudomonas syringae (Comai and Kosuge, 1982; Schroder et al., 1984; Thomashow et al., 1984; Yamada et al., 1985; Camilleri and Jouanin, 1991). Trp is first converted to IAM by the enzyme tryptophan2-monooxygenase encoded by the aux1/iaaM/tms1 gene (Yamada et al., 1985 ; Camilleri and Jouanin, 1991; Gaudin et al., 1993)(Fig. 1). Then, IAM is converted to IAA by indole-3-acetamide hydrolase encoded by the aux2/iaaH/tms2 gene (Yamada et al., 1985 ; Camilleri and Jouanin, 1991; Gaudin et al., 1993 ; Nemoto et al., 2009 a, b; Mano et al., 2010).

Indole-3-pyruvate, IPyA pathway : In the IPyA pathway abundant in beneficial plant-associated bacteria. In the first step, tryptophan is transaminated to IPyA by an aromatic aminotransferase. In the second, rate limiting step, IPyA is converted to indole-3-acetaldehyde (IAAld) by decarboxylation reaction catalysed by an IPyA decarboxylase (IPDC, encoded by the *ipdC* gene). Finally, IAAld is converted into IAA.

IAA formation via IPyA and IAM is found in majority of organisms such as pathogenic bacterium *Erwinia herbicola*, saprophytic species of the genera *Agrobacterium* and *Pseudomonas*, certain representatives of *Bradyrhizobium*, *Azospirillum*, *Rhizobium*, *Klebsiella* and *Enterobacter*; *Methylobacteria*; the symbiotic nitrogen fixing cyanobacterium *Nostoc sp*; the yeast *Saccharomyces uvarum* and phtopathogenic micromycetes of the genera *Fusarium, Rhizoctonia* and *Collectotrichum* (Furukawa, 1996; Thakur and Vyas, 1983).

Besides the two pathways described above, other microbial pathways for IAA biosynthesis have been proposed, but for most of these pathways genetic evidence is lacking.

Tryptamine pathway (TAM) : In trptamine pathway, tryptophan is first decarboxylatyed by a tryptophan decarboxylase and subsequently catalyzed to IAAld by an amine oxidase.

This pathway is believed to operate in *Pseudomonades* and *Azospirilla*, unidentified mycorrhizal fungus of orchid (Barraso, 1986) and the cyanobacterium *Chlorogloea fritschii* (Ahmad and Winter, 1969).

The indole-3-acetaldoxime pathway (IAOX) : In this pathway, Cytochrome P450 enzymes CYP79B2 and CYP79B3 convert Trp to indole-3-acetaldoxime. IAOX is synthesized from Trp by two homologous cytochrome P450 enzymes, CYP79B2 and CYP79B3, which contain a chloroplast transit peptide at the N-terminus. Both enzymes are predicted to be targeted to the chloroplast (Hull and Celenza, 2000; Hull et al., 2000 ; Mikkelsen et al., 2000). These enzymes for the formation of IAOX have only been conclusively demonstrated in Arabidopsis (Hull et al., 2000; Mikkelsen et al., 2000) and Brassica (Kindl, 1968; Ludwig-Mu ̈ller and Hilgenberg, 1988). The biochemical evidence that IAOX is not found in plants other than Brassicaceae also indicates that IAOX dependent IAA biosynthesis is not a common but rather a species-specific pathway in plants (Sugawara et al., 2009).

Pathway via Indole-3-acetonitrile : This pathway involves the conversion of Indole-3-acetonitrile by nitrilases or nitrile hydratase to IAA directly or via IAM respectively.

This pathway is found in plants, *Alcaligenes fecalis* and possibly the cyanobacterium *Synechocytis* sp. (Sharma and Kaur, 2014).

Cytokinins

Cytokinins (CK) are an important group of plant hormones which are involved in the maintaining of cellular proliferation or cytokinesis and differentiation and the prevention of senescence, therefore leading to the inhibition of premature leaf senescence (Schmulling, 2002). They also affect apical dominance, axillary bud growth, promote the light-independent deetiolation response, including greening, of dark-grown seedlings. The multiplicity of of functions performed by cytokinins allows them to regulate a wide range of physiological responses

Kinetin was the first artificial cytokinin to be discovered. It was isolated from herring sperm and named after its ability to promote cell division. The most common form of naturally occurring cytokinin in plants is zeatin, but many other natural cytokinins have been isolated, including dihydrozeatin, isopentenyladenine, or benzyladenine.

Naturally occurring cytokinins are mostly derived from adenine and modified by substitutions at N^6, including the respective ribotides, riboside and glycosides.

Cytokinins are compounds with a structure close to adenine. They have an adenine base and a five carbon isopentenyl side chain. Among these, zeatin, specifically *trans*-zeatin, is the most abundant. The synthesis of cytokinins in higher plants has been unclear and controversial for a long time, but progress finally seems to be achieved with the cloning of genes encoding isopentenyl transferases(IPTs) in Arabidopsis.

Biosynthesis of Cytokinins

They are mainly biosynthesized in situ. The main step of the cytokinin-biosynthesis pathway is the transfer of the isopentenyl group from dimethylallyl diphosphate (DMAPP) to ATP, ADP, or AMP catalyzed by isopentenyltransferases (IPTs) to generate isopentenyl adenosine-5'-phosphate. The isoprenoid-derived side chain can further be modified by hydroxylation. The cytokinin compound is then hydrolyzed to a free base by a (phosphor-) ribohydrolase (Frebort et al. 2011).

Gibberellins

The class of Gibberellins (GAs) is a broad group of more than 100 compounds that can be classified as tetracyclic diterpenoid acids. Gibberellic acids (GAs), GA_3, GA_7, GA_1, and GA_4 are the best studied phytohormones of this group. Gibberellic acid (GA_3) is an important phtohormone, which acts as a promoter and regulator of plant growth (de Oliveira J et al,). It has a vital role in seed dormancy formation of floral organs, and lateral shoot growth (Olszewski et al., 2002). Gibberellic acid was found to stimulate plant growth and development under various abiotic stress conditions (Ahmad, 2010). Enhanced plant water uptake and reduced stomatal resistance were observed in gibberellic acidtreated tomato plants grown under saline conditions (Maggio et al., 2010). Gibberellic acid induces efficient uptake and ion partitioning within the plant system, leading to enhanced growth and maintaining the metabolism of plants under normal and stress conditions (Iqbal and Ashraf, 2013). Under salt stress conditions, improved germination and growth due to gibberellic acid has been reported by several studies (Tuna et al., 2008; Ahmad, 2010; Manjili et al., 2012). In addition, gibberellins can exhibit crosstalk with other phytohormones, which elicits important responses and mediates tolerance mechanisms for enhancing stress tolerance. The synthesis of gibberellins can also be promoted through the application of other hormones, such as auxin (Wolbang et al., 2004). Recent discoveries indicate that gibberellins and strigolactones may act as a new couple in the phytohormone world in processes of plant development (Marzec M). Gibberellins are complex molecules of tetracarbocyclic diterpernes consisting of isoprene residues that usually form four rings (A,B,C and D). Certain compounds are classified with gibberellins based solely on their characteristic biological activity, though they have a different structure.

Abscisic Acid

Abscisic acid (ABA) is an ubiquitous plant hormone and one of the foremost signaling molecules, controlling plants' growth and development, as well as their response to environmental stresses. It is a naturally occurring sesquiterpenoid, which are a group of key phytohormones involved in the regulation of growth. ABA functions as an abiotic stress molecule which regulates the plants' water status (Stec N et al,). The most important role of ABA, in addition to it's role in signaling, it's ability to act as anti-transpirant after the induction of stomatal closure (Wilkinson and Davies, 2002). It also aids in fruit ripening, inhibits seed germination, bud dormance and protective responses against abiotic stresses such as drought, salt stress and metal toxicity (Dilfuza Egamberdieva, 2017). There have been many reports advocating the role of ABA in integrating signaling during stress exposure with subsequent control of downstream responses (Wilkinson et al., 2012). Under abiotic stress the expression of stress responsive genes regulated by ABA-induced and -mediated signaling, leading to better elicitation of tolerance responses (Sah et al., 2016). In addition, ABA has been reported to control root growth and water content under drought stress conditions (Cutler et al., 2010). However, an abrupt increase in ABA concentrations during stress exposures can lead to growth retardation and can also modulate tolerance responses against stresses (Asgher et al., 2015). Nevertheless, there are reports suggesting the positive implication of exogenous ABA in reversing the ill effects of stresses, such as salinity (Gomez et al., 2002), chilling (Nayyar et al., 2005), drought (Bano et al., 2012), and cold stress (Li et al., 2014). In plants exposed to stress conditions, ABA is involved in developing the deeper root system and causing other necessary root modifications to mediate optimal water and nutrient acquisition (Spollen et al., 2000; Vysotskaya et al., 2009). In addition, ABA maintains the hydraulic conductivities of shoot and root to better exploit soil water content, leading to the maintenance of tissue turgor potential and improved drought tolerance through up-regulation of the antioxidant system and the accumulation of compatible osmolytes (Chaves et al., 2003), which maintains the relative water content.

In plants, the "indirect pathway" is the route for ABA biosynthesis. In short, the carotenoid lycopene is modified in several enzymatic steps to violaxanthin, which is cleaved by a dioxygenase to xanthoxin. The latter compound is further converted to ABA in two enzymatic steps (dehydrogenase/ reductase and aldehyde oxidase) (Nambara and Marion- Poll 2005). ABA emerges as an important player in arbuscular mycorrhiza and legume-rhizobium symbiosis. The plant's use of stress hormones like ABA in regulation of those interactions directly links the efficiency of these processes to the environmental status of the plant, notably during drought stress (Stec N et al,). Moreover, ABA is not a molecule exclusive from plants but it can be found in many other organisms including bacteria, algae, fungi, animals, etc. Interestingly, it can be synthesized and secreted by a variety of human cells (Gomez-Cadenas A et al.,).

Ethylene

The gaseous phytohormone ethylene is involved in physiological and developmental processes such as seed germination, cell expansion, senescence and abscission. It is sometimes called the ripening hormone since it induces fruit ripening (Davies 2010). Ethylene is also involved in the plant dependent defense responses against pathogens. It also has a role in abiotic stress conditions.

Ethylene biosynthesis originates from methionine. Methionine is converted to 1-aminocyclopropane-1-carboxylate (ACC) and 5'-deoxy-5' methylthioadenosine via S-adenosylmethionine (SAM) by the consecutive action of a SAM synthase and ACC synthase. Finally ACC oxidase converts ACC to ethylene, CO_2 and cyanide. Bacteria that can lower ethylene levels encode for an enzyme ACC deaminase (AcdS) which can degrade the direct ethylene biosynthesis.

Strigolactones

Strigolactones (SLs) are recently characterized carotenoid derived phytohormones (Borghi L et al,). They constitute a new class of plant hormones which are of increasing importance in plant science. For the last 60 years, they have been known as germination stimulants for parasitic plants. Recently, several new bioproperties of SLs have been discovered such as the branching factor for arbuscular mycorrhizal fungi, regulation of plant architecture and the response to abiotic factors, etc (Zwanenburgh B et al). They play multiple roles in plant architecture and, once exuded from roots to soil, in plant- rhizosphere interactions. Above ground SLs regulate plant development processes, such as lateral bud outgrowth, internode elongation and stem secondary growth. Below ground, SLs are involved in latertal root initiation, main root elongation and the establishment of the plant- fungal symbiosis known as mycorrhiza (Borghi L et al).

Plants produce strigolactones with different structures and different stereospecificities which provide the potential for diversity and flexibility for function. Strigolactones (SLs) typically comprise a tricyclic ABC ring system linked through an enol-ether bridge to a butenolide D-ring. The stereochemistry of butanolide ring is converted but two alternative configurations of the B-C ring junction leads to two families of SLs, exemplified by strigol and orobanchol. Further modifications lead to production of many different strigolactones within each family. The D- ring structure is established by a carotenoid cleavage dioxygenase producing a single stereoisomer of carlactone, the likely precursor of all SLs. (Flematti GR et al).

Phytohormones produced by microorganisms :

Auxins (IAA) :

Microorganism involved	Reference

Pseudomonas Putida	Pattern C.L and Glick B.R, 2002
P.putida, Gluconacetobacter azotocaptans, Azospirillum lipofernum	Mehnaz.S and Lazarovits G, 2006
Azotobacter and fluorescent Pseudomonas	Ahmad et al., 2005
Fluorescent Pseudomonas	Karnwal A, 2009
Azospirillum brasilense	Tein et al., 1979
Azotobacter vinelandii	Lee M et al, 1970
Pseudomonas putida	Caron M et al, 1995
Azotobacter croococcum	Brown M.E and Burhingham S.W, 1968
Archromobacter, Flavobacterium, Klebsiella,Arthrobacter, Rhodococcus, Sphingomonas, Micrococcus	Belimov et al, 1999
Archaea : Sulfolobus acidocaldaris	White , 1987
Yeast : Saccharomyces, Fusarium, Rhizoctonia, Absidia, Aspergillus, Penicillium, Trichoderma	Gunasekaran and Weber, 1972
Algae : Chlorella, Dunaleilla and Fucus	Basu et al., 2002

Gibberellins

Azospirillum brasilense, Azospirillum lipofernum	Cassan et al, 2001
Azospirillum brasilense	Fulchieri et al, 1993
Azospirillum spp.	Lucangeli C and Bottini R, 1997
Bradyrhizobium japonicum	Stijn spaepen, 2015
Fungus : Gibberella fujikuroi	Rojas et al, 2001
Gibberella fujikuroi	Fernandez Martin et al, 1995
Pseudomonas, Bacillus, Acinetobacter, Flavobacterium, Micrococcus	Grapelli and Rossi, 1981 ; Cassan et al., 2001

Cytokinins

Erwinia herbicola	Lichter et al, 1995
Rhodococcus fascians	Petri et al , 2010
Rhizobium, Azotobacter, Bacillus and Pseudomonas	Shweta Sharma and Mohinder Kaur, 2017
streptomycetes	Upadhyay et al., 1991
Methylobacterium, Methylophylus, Methylobacillus, Methylomonas	Shepelyakovskaya et al., 1999

Abscisic acid

Aspergillus brasilense,	Stijin Spaepen, 2015
Brradyrhizobium japonicum	Stijin Spaepen, 2015

Conclusion

Understanding phytohormones calls for further identification and analysis of the intermediates, enzyme and genes involved in their biosynthesis as well as in the isolation of mutants defective in each pathway. Although the production of phytohormones at the free living state is well established in many microorganisms, there is still insufficient evidence for their synthesis in their natural habitats.

Despite the importance of auxin as a plant signal the pathways of its biosynthesis are still not clear.

In recent years a number of studies on phytohormones have been performed. Hormone research has focused on elucidating signal transduction pathways from hormone perception to response.

As reported, modern higher plant phytohormone biosynthesis pathways originate from ancient microalgae even though some of the microalgal phytohormone signaling pathways remain unknown. Dissection and manipulation of microalgal growth regulator systems might supply a replacement read of growth regulator evolution in plants and gift new opportunities in developing microalgal feedstock for biofuels.

One of the most important factors that limits researchers from elucidating the precise roles of phytohormones is that the extremely complicated nature of hormonal crosstalk in plants. Another issue that has to be elucidated is that the methodology used for assessing photosynthetic damage in plants that are subjected to abiotic stress.

In response to herbivore attack, plants perceive herbivore associated elicitors (HAE) and rapidly accumulate jasmonic acid (JA) and other phytohormones, which interact in complex ways, such as the crosstalk between JA and salicylic acid (SA). Although recent studies have shown that HAE-induced individual phytohormones can be highly specific among closely related species, it remains unclear how conserved and specific the relationships among HAE-induced phytohormones are.

Strigolactones (SLs) constitute a new class of plant hormones which are of increasing importance in plant science. Although strigolactone are involved in the regulation of leaf senescence, little is known about its molecular mechanism of action. Much has been known on players and patterns of SL biosynthesis and signaling and shown to be largely conserved among different plant species, however little is understood about SL distribution in plants and its transport from the root to the soil.

Various GA_3 products are available on the market. They can be found in liquid or solid formulations containing only GA_3 or a mixture of other biological active gibberellins, which can be applied on a wide variety of cultivars, including crops and fruits. However, the product's cost still limits its large and continuous application. New low-cost and efficient GA_3 production alternatives are surely welcome. This can be done by using different techniques of fermentation, solid state fermentation (SSF), submerged fermentation (SmF), and semisolid state fermentation (SSSF), and different types of bioreactors. The methods studied are inexpensive and were found to produce good proportions of GA_3,

Abscisic acid (ABA) has recently been recognized to possess multifaceted biological functions in mammals and to exert potent curative effects in various clinically relevant human diseases. Studies with human specimens have unambigously shown that ABA retains its stress-related functional attributes, antecedently identified in plants, which contribute to increased inflammatory defense mechanisms in mammals. Besides, studies performed in animal models revealed prominent anti-inflammatory properties of ABA as indicated by a marked reduction of immune cell infiltrates at the sites of inflammation. Thus, ABA treatment ultimately leads to the profound improvement of both non-communicable and communicable diseases which are associated with an overall alleviated course of inflammation. In addition to its action on the mammalian immune system, ABA was additionally shown to exert diverse physiological functions on non-immune components. One of the most remarkable features of ABA is to stimulate and expand mesenchymal stem cells, which may open a new avenue for its potential use in the field of regenerative medicine. Furthermore, ABA has been reported to play an important role in the maintenance of glycemic control. ABA can be used as novel drug candidate for the improved treatment of inflammatory and infectious human diseases.

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