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Phytohormones

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A B S T R A C T

In this study, the effects of plant hormones known as the classical quintet; auxine, cytokinin, giberellin, absisic acid, ethylene hormones as well as the ones discovered by recent studies, i.e. brassinosteroid, salicylic acid, strigolactone and jasmonic acid on plant physiology, their uses in agriculture, and effects on the environment due to misuse of these hormones were compiled and the literature on the phytohormones was updated.

1. Introduction

The plants, source of life on earth, are born like all living things, grow up, and when their time comes, their lives end. In this life cycle many chemical events occur in the plant. The plants themselves produce these essential ingredients to sustain their growth and development. In general terms, organic molecules called hormones (phytohormone-plant growth regulators) are naturally synthesized in plants. They control growth and other physiological events, and can be effective even at very low concentrations. They are effective in the plant's part where produced as well as in other parts they are transferred to (Öktüren and Sönmez, 2005).

These materials are obtained from various organs of high plants and some fungi (Morsünbül et al., 2010). The vast majority of physiological events occurring in plants are controlled by plant growth regulators (PGR). The first scientific studies on phytohormones go back until the beginning of the 18th century. Charles Darwin published his work "The power of movement in plant" in 1898, and found that plant seedlings were directed towards the light in the dark (Williams, 2011).

The plant hormone used in Turkey for the first time in 1960 was giberellic acid (GA) in seedless grapes to promote seedlessness, to increase fruit and cluster size (Algül et al., 2016). The formation of a compound as a plant hormone must be able to occur in the plant itself, be transported elsewhere, and be able to direct or regulate different life events in the place of transport, even at very low concentrations (Williams, 2011).

2. Plant Hormones

The plant hormones known as brassinosteroid, salicylic acid, strigolacton and jasmonic acid have been discovered in addition to auxine, cytokinin, gibberellin, abscisic acid and ethylene hormones known as classical quintet. It has been understood that these hormones play an active role in every step of the plant's life cycle and are classified in three main

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groups according to their physiological effects on plants (Williams, 2011) (Table 1).

Table 1. Effects of phytohormones in plants

Control of the vegetative growth	Control of the reproduction	Stress response
Auxin	Ethylene	Salicylic acid
Cytokinin	Abscisic acid	Jasmonic acid
Strigolakton		
Gibberellins		
Brassinostereoids		

2.1. Hormones Providing Control of Vegetative Development

The hormones affect the vegetative growth of the plant in the form of plant elongation, branching and organ formation. Auxine, cytokinin, strigolactones, giberellins and brassinosteroids are found in this group.

2.1.1. Auxin

Auxin encourages plant growth increasing cell elongation and proliferation. The transport of auxins synthesized in meristematic tissues, such as leaves, top buds and flowers, is downward. Indole-3-acetic acid (IAA) is the only hormone naturally synthesized in plants. However, many synthetic materials were shown to have similar effects to IAA (Williams, 2011). The IAA is found in high amounts in the growing end parts (colloquial tip, bud, leaf and root tip) of the plant (Cox et al. 2018). After clarification of the chemical structure of the auxine, it was determined that many chemical substances, more or less similar to IAA as a structure, have effects as auxin in the plants. Auxines are grouped in four classes; indole, naphthalene, phenoxy, benzene (Algül et al., 2016). In plants, auxine plays an important role in growth, phototropism and gravitropism, branching, and embryonic pattern formation. In the developmental process of plants, auxine has a role in the initiation of lateral organ formation in the apical meristem of the shoots, control of pattern formation and vascular development, identification and protection of stem cell differentiation in root apical meristem, arresting of branching in the shoot and initiation of branching in the root.

2.1.2. Cytokinin

Unlike other hormones produced in plant tissues especially during cell division, they are organic substances in quinine structure found both in plants and in animals. Cytokinins are divided into two main groups: (i) synthetic phenylurea derivatives, thidiazuron (TDZ), urea and (ii) naturally occurring adenine derivatives, kinetin (KN) and 6-benzyladenine (BA). Synthetic phenylurea derivatives have a higher level of action than TDZ adenine derivatives in particular. KN, BA and zeatin are the most common cytokinins and are usually found in young tissues. Many KN-like substances have been isolated from germinated seeds, seed core and young fruits. Zeatin, a natural cytokinin, is derived from corn cereals, coconut endosperm, and concer fruit. All tissues with active cell division contain sufficient amounts of cytokinins.

Especially in root meristems, it is synthesized and then transported to the green parts of the plant via xylem. They are hormones that are effective in cell division and delay of aging (Algül et al., 2016). Although the auxines promote root formation, cytokinins promote shoot formation. They contribute to organ formation and development in tissue culture media. It is believed that cytokinins prevent protein degradation by inhibiting nuclease and protease formation in foliage and thus delay aging (Williams, 2011). Cytokinins are also effective in breaking down dormancy, accelerating transfer of carbohydrates, and inhibiting the growth of terminal shoots.

2.1.3. Strigolactones

It is the most recently discovered hormone related to branching. Strigolactones, together with auxine, are considered in the last century to be one of the two most important hormones in the formation of apical dominance, and which is the most important hypothesis in explaining this formation (Brewer et al., 2009; Hayward et al., 2009). The strigolactones produced in the roots are transported upwards (acropetal) to the upper part of the plant via xylems and inhibit the growth of lateral buds (Ferguson and Beveridge, 2009). Strigolactones, when applied to growing shoots, shortens the shoot length (Brewer et al., 2009). Recently, strigolactones are thought to be effective in the signaling mechanism between branching-related genes (such as *rms* (ramosus), *max* (more axillary growth) and *dad* (decreased apical dominance) (Baktır, 2010). It is also believed that the auxins carry out the inhibitory effect on the side buds via strigolactone (Brewer et al., 2009).

2.1.4. Gibberellins

Gibberellins are also hormones that promote growth and development at low doses, such as auxins. The gibberellins were discovered in 1926 by a Japanese researcher from *Gibberella fujikuroi*, which caused a lot of overgrowth in the rice plant. This substance was then isolated and named gibberellic acid (GA_3) (Ferguson and Beveridge, 2009). GA_3 is the most common form of gibberellins. Now, it is known that there are at least 126 forms of gibberellin. They are found in buds, embryos, roots, young leaves, flowers, fruits and cambium of plants (Baktır, 2010). The most obvious effect of gibberellins is to increase the prolongation of the cells. Also, they are very effective in breaking down seed and bud dormancy, eliminating the dwarfism, and the need for chilling, encouraging parthenocarpic fruit bearing and germination (Olszewski et al., 2002; Rao et al., 2002). GA is used in practice to reduce the number of fruit in the cluster and to increase the size of fruit in most table and dried grapes.

2.1.5. Brassinosteroids

Brassinostreoids (BR) were first isolated purely from the pollen of the rapeseed (*Brassica napus*) by Grove et al., 1979. The name of brassinosteroids found in the streoid structure comes from *Brassica* genus of the Crucifereae family. Although the synthesis of BRs cannot be fully explained now, the starting material is mevalonic acid. BRs are hormones that are very effective in the growth of plant body. BR significantly increases stem extension when externally applied to some dwarf mutant plants that are unable to produce a streoid. Likewise, BR application to dwarf beans results in cell division and increased cell prolongation, as well as a resultant height extension (Baktır, 2010). BRs are also used for many purposes such as to provide tolerance to salt stress, cold and disease-damaging, to prevent fruit casting, to increase yield, to encourage germination and to promote root growth （Rao et al., 2002).

2.2. Hormones Providing the Control of the Reproduction

The propagation of angiosperms involves the transition from vegetative form to the reproductive phase, ripening with fruit development and germination with seed development, and maturation. All these events are affected to a certain extent by the hormonal signals. Ethylene and abscisic acid are found in this group of hormones.

2.2.1. Ethylene

Ethylene (C_2H_4) is a gaseous organic molecule at room temperature, unlike other hormones. It is known as a maturing hormone and even at very low concentrations it has a physiological effect on the plant. Ethylene is an important hormone in horticultural plants which is very effective in the taste, color texture and structure of the products. Ethylene can be synthesized from all organs depending on the development status of the plant. However, it is synthesized mainly from mature and aging tissues under stress. Leaves and flowers have the highest amount of ethylene syntheses prior to wilting and foliage (Çetin, 2002). Ethylene gas is used for the ripening and yellowing of fruit species such as banana, citrus, pear, tomato, melon and pineapple (Raven et al., 1992). Also in plants, ethylene has the effects of breaking the dormancy, foliage and fruit shedding, promoting flowering, stimulating adventitious root formation, promoting female flower formation in monocious plants and facilitating mechanical harvesting by promoting absorption (Raven et al., 1992; Seçer, 1989).

2.2.2. Abscisic Acid

In addition to natural growth promoting substances, there are also inhibitory natural substances moving in the reverse direction, and the most important is abscisic acid (ABA) (Morsünbül et al., 2010). ABA is a natural antagonist of auxin, gibberellins and cytokinins known as promoting hormones (Brewer et al., 2009). ABA is present in all organs of plant, but mostly found in green leaves, and synthesized in the cytoplasm of mesophyll cells (Baktır, 2010). Since chloroplasts are not found in the roots, ABA is not synthesized in those parts. It is thought that ABA causes proceeding of dormancy via being in high amounts in the buds and seeds in dormancy (Brewer et al., 2009). The ABA concentration in plants varies depending on environmental conditions, and the effect on physiological events is also variable. Under stress conditions, the amount of expression is increased and rapidly transported to the leaf stalk, body tissues and other parts of the plant (Raven et al., 1992; Seçer, 1989). ABA causes the closure of the stomatal pore and slowing down protein synthesis in plants via increasing its amount under water stress. It also acts as an inhibitor in the dormancy of storage organs such as seeds, buds and tubers. The synthetic production of ABA is expensive and its practical in use due to being unstable under UV light (Seçer, 1989).

2.3. The Hormones Responding to Stress

The plants encounter many stress factors during their life. Salicylic acid and jasmonic acid help plant stress response against photo oxidative stress, high temperature, drought, soil salinity, air pollution, injury and mechanical damage, cold and frost stress.

2.3.1. Salicylic acid

Salicylic acid (SA) has been taken for centuries by the well-known willow (*Salix* sp.) The leaves and barks of this tree are good for pain and fever. In 1828, the German researcher Johann Buchner isolated salicin from the willow tree barks. The commercial production of SA was realized in Germany under the name of 'Aspirin'. In recent studies, SA has been shown to be very effective in plant growth and development (Chen et al., 2009; Medina et al., 2017; Belt et al., 2018). SA is found in all organs of the plant and is transported to different organs via the phloem (Baktır, 2010). The role of SA on flowering was shown by the effect of water-soluble aspirin on the cut flowers, extending the vase life (Özeker, 2005). SA was blocked ethylene synthesis in apples, increased yield in the beans, increased rooting, and accelerated photosynthesis (Romani et al., 1989; Romanujam et al., 1998; Hayat et al., 2007). Some of the most effective uses of SA are to provide resistance to adverse conditions such as drought, salinity, high and low temperature, heavy metal and frost stress (Baktır, 2010).

2.3.2. Jasmonic acid

First, jasmonates obtained from jasmine (*Jasmine grandiflorum*) plants containing esters of jasmonic acid (JA) and methyl jasmonate (MeJA) (Fan et al., 1998). Jasmonates are synthesized by flowers, leaves, roots and immature fruits, and increase resistance to diseases and harmful effects of plants in their resistance mechanisms (Baktır, 2010; Medina et al., 2017). When jasmonates are applied externally, they inhibit photosynthesis, germination of pollens, elongation in height, growth in roots, formation of flower buds, embryogenesis, and germination of seed not under dormancy. In addition to the inhibitory properties of jasmonates, they have promoting properties such as adventitious root formation, abscission and closure of stomata, protein synthesis, eliminating the need for rest, germination of seeds under dormancy, and ethylene synthesis thereby maturation of the fruit (Fan et al., 1997).

3. The Effect of Growth Regulators on Environment

Incorrect and unconscious use of growth regulators can cause harm to the environment and human beings. These materials can mingle with the soil via agricultural applications, and involve in groundwater via infiltration as well as they can have a toxic effect causing accumulation in living bodies via food chain. Since the environmental effects of growth regulators are similar to those of pesticides, both are evaluated in the same class (Morsünbül et al., 2010). However, utilization rate and frequency of growth regulators are quite lower than pesticides, so they have much less environmental impacts. The highest permissible residual values of each growth regulator are different from each other, and their effects on the environment above these values are different from each other. No information is available about the environmental toxicity of cytokinins. They do not pose a health risk and are in category III (Category I: Very toxic, Cat II: Moderately toxic, Cat III: Mildly toxic, Cat IV: Not toxic). Giberellins are called as biochemical pesticides because of their naturally occurrence and lack of toxic effects. They leave very low levels of residue after application till consumption. Although the gibberellins in Cat III did not cause toxic effects, they were found to have some adverse effects on the animals (Robischon, 2015; Chanclud and Lacombe 2017; Cox et al., 2018). However, the formation of monochloroacetic acid, abreak down product of ethylene, can accumulate in foods and cause toxic effect; therefore it is suggested to wait for 7-21 days after its application (Çelik et al., 2002). There is no risk in terms of health below this limit. Until recently, 2,4-D and 4-CPA, commonly used in greenhouse, have been banned due to acute toxic and carcinogenic effects (Çelik et al., 2002; Tomlin, 1997).

4. Conclusions

A plant encounters various stress factors during its lifetime in its habitat. The synthesis of hormones for its development is hindered due to water and nutrient deficiencies, geographical and weather conditions. This results in undesirable consequences such as loss of yield, death from illnesses. The results of the improvements in biotechnology have resulted in an increase in the yield of plants, fodder crops, energy and medicinal plants, which are needed by the increasing human population. Application of plant growth regulators by experienced people will result in breeding of the plants without diseases and with high yield, and thereby production of cheaper and high quality foodstuff.

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