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Specific biochemical activity of plant growth regulators and their role in food and human health

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Abstract

In plant biology the problems of biochemistry and molecular biology are of particular interest, starting from the diversity of extrinsic and intrinsic factors that ensure the perpetuation of the plant kingdom. The generally known extrinsic factors includ the light, water, oxygen, nitrogen, various ions (anions, cations). Besides those, intrinsic factors known as "plant growth regulators" (PGR) also occur. The production of PGRs is ensured by the intervention of genes existing in plant cells. First a group of five PGRs were identified which includes the auxins, gibberellins, cytokinines, ethylene and abscisic acid. Later on there was discovered a second group of PGRs, including four compounds, i.e. brassicosteroids, jasmonites, strigolactones and salicylic acid. All the above mentioned substances, as intrinsic factors produced in vegetal tissues, are considered „native-plant growth regulators" (PGR-N). For applicative purposes there were „synthesized-plant growth regulators" (PGR-S) in organic chemistry laboratories. The aim of this work is to present general aspects related to PGR-N or / and PGR-S, highlighting their role in food and human nutrition as well as aspects related to the specific role of PGRs-N and PGRs-S in agrobiology (plant physiology), human physiology, physiopathology, pharmacology a.o.

Keywords: plant growth regulators in food, physiopathology and pharmacology

1. Introduction

Compounds revealing biologically active attributes in plant kingdom can be of two types, i.e. native-plant growth regulators (PGR-N) and synthesized-plant growth regulators (PGR-N) in laboratory. For this reason, they can be considered as „biochemical effectors" along with other natural compounds of plant origin (e.g. heterosides, alkaloids, tannins, essential oils etc.). Such compounds participate in biochemical interactions specific to metabolic processes, contributing to their acceleration or decelaration [1, 2, 3, 4].

From the point of view of their chemical structure, the regulators of plant growth are substances with heterogeneous structure. In their constitution there are heterocyclic nuclei, e.g. indole, giban, purine, etc. or linear chains, e.g. ethylene [5, 6, 7].

With reference to the substances mentioned above - in view of the biochemical and agrobiological importance - we agree to distinguish the term „native-plant growth regulators" as natural chemical compounds resulting from biosynthesis reactions occurred in plant organisms. These can be isolated by herbal extraction methods.

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Generally, a native-plant growth regulator must be: a) an endogenous substance - resulting by biosynthesis occured in plants; b) to act in small doses - quantities in the order of micromoles (µM); c) to be an information vector - brought to a target cell, which is sensitive to its action, influencing its physiology and morphology [8, 9].

In parallel, the term „synthesized-plant growth regulators" will refer to chemical compounds obtained in laboratories by organic chemical synthesis, and which are suitable for experiments in plant physiology, biochemistry and molecular biology. Some of them after experimental confirmations - may have an applicative importance in agrobiology, with interest in certain agricultural technologies.

Plant growth regulators also provide response to abiotic stress (high or low temperature, drought or flood) and biotic stress (presence of herbivores and the action of pathogenic agents).

1. Types of native-plant growth regulators

According to the chemical composition of PGR-N, these compounds belongs to various groups of organic compounds. In classical treatises related to the PGRs-N, the first discovered group, includes five distinct compounds, i.e. auxins, gibberellins, cytokinins, ethylene and abscisic acid.

Subsequently, a second group of PGRs-N were isolated, having four compounds: brassinosteroids, strigolactones, jasmonates and salicylates.

In the literature, substances belonging to PGR-N types are called „phytochemicals", too. Sometimes there is also used the name of „phytohormones" that we consider inappropriate. If a parallelism is made with the concept of „hormones" (in humans and animals) there are notable differences if approaching aspects related to biogenesis, biochemical mechanisms characteristics for various "biochemical pathways", specific features of molecular biology, their role in nucleic acid pathobiochemistry a.o. in which they intervene [10]. For this reason, the name of plant growth regulator is preferred.

1.1 Structural peculiarities

In order to have an image on the specificity of PGRs-N the knowledge of their structure is required. Thus, in fig.1 there are given the chemical structure for compounds belonging to the type of PGR-N [6, 3].

From the first group of PGR-N there are exposed: auxins (I) which have as basic structure the indole-acetic nucleus (originated from the amino acid tryptophan); gibberellins (II) having at their origin the tetracyclic hydrocarbon, called ,,gibbane" (derived from the tricyclic hydrocarbon pehydrofluorene). In the case of gibberellins there are distinguished two families of compounds: C_{19}-gibberellins (IIa) and C_{20}-gibberellisn (IIb). Cytokinins (III) have as their origin the purine nucleus and the typical representative is kinetine. Ethylene (IV) is an unsaturated hydrocarbon (gasous). Abscisic acid (V) is a compound of isoprenoid nature (three isoprene residues) which is formed in plant tissues by photooxidation and dehydrogenation.

The second class of plant growth bioregulators, discovered at a later stage, includes compounds with very different structures but exhibit, undoubtedly, bioregulator effects. Between them are mentioned: brassinosteroids (VI) which have a steranic nucleus and can be C_{27}, C_{28} and C_{29} compounds. This class includes also strigonolactones (VII) – having a complex polycyclic structure; jasmonic acid (VIII) – having a cyclopentanone and side chains; slycilates (IX) which contain the acetyl salicylic nucleus.

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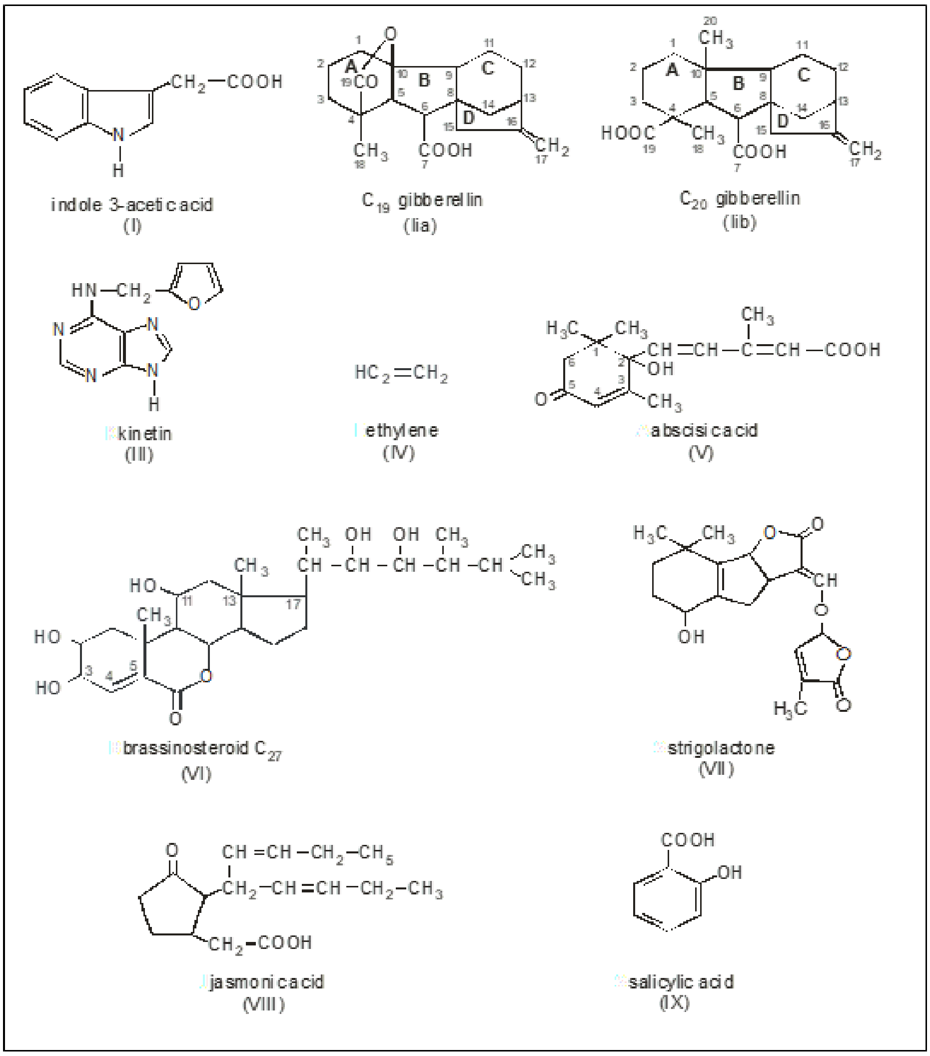

Figure 1. Structural formula of various compounds belonging to PGR-N type

1.2. Role of native-plant growth regulators in vegetal physiology

Hereinafter are presented general data on the five compounds belonging to first group of PGR-N type, as well as their role in physiology and morphogenesis.

Auxins [11], gibberellins [12] and cytokinins [13] are the major growth promoting substances found in plants. Ethylene - promotes growth, abscission and senescence, enhances respiration rate, during ripening of fruits a.o.

Abscisic acid - regulates abscission and dormancy, inhibit plant growth, increases the tolerance of plants to stress etc [14].

Regarding the compounds belonging to the second group of PGR-N type their physiological role in plants are presented below.

Brassinosteroids promote seed germination, promote senescence in wheat leaves; enhance photosynthetic rate, increase the level of nitrate reductase in the seeds of wheat

Jasmonates control plant defenses against herbivore attack and pathogen infection. They confer tolerance to biotic and/or abiotic stresses, regulate root growth, flowering, leaf senescence, stimulate the germination of dormant seeds etc.

Strigonolactones can control plant development, promote symbiotic interactions between plants and soil microbes and the formation of lateral roots and root hairs, a.o.

Salicylic acid intervenes in seed germination, vegetative growth, senescence, fight against microbial pathogens, plant response to abiotic stress (e.g. drought, heat).

2. Comparative aspects regarding the action of native-plant growth regulators

2.1. General action of native-plant growth regulators on vegetals

The action of PGR-N on plants varies from one to another class and group, but there are also some effects that interfere in the processes of growth, development, maturation during the evolution of plant organisms. Thus, there are PGR-N that interfere with the incipient stages stimulating germination, cell division (e.g. gibberellins) and others facilitate the plants development, growth or fructification (e.g. auxins).

In case of other PGR-N the effects are exactly antagonistic . Some of them accelerate the processes of the agro-alimentary products forming (e.g. ethylene) while, in the case of others, the evolutionary aspects ending a certain biological cycle is stimulated, more frequently encountered in annual plants (e.g. abscisic acid).

2.2. Aspects related to their physiological role and application in agrobiology

Native plant growth regulators are found in various tissues of plant, ensuring the metabolic processes through their intervention in growth kinetics, morphogenesis control, tropisms (phototropism, geo-tropism), photoperiodicity etc.

Generally, plant growth regulators intervene in the regulation of cellular activities, the development of vegetative and reproductive tissues, responses to stress, etc.

Data on physiological role and the agrobiological application of PGR-N are presented in Table 1.

2.3. Some data concerning synthetized plant growth regulators

Literature data regarding synthesized plant growth regulators (PGR-S) are relatively disparate. Further on, are exemplified some compounds belonging to this type.

Of the most common synthetic are: 1-naphthalene acetic acid; 2, 4- dichloro phenoxyacetic acid; indole-3-butyric acid; 2,4,5-trichloro-phenoxyacetic acid; 2-naphthyl oxyacetic acid.

As to the most known synthesized cytokinins are benzyladenine (later found to occur naturally in some plant species) and thidiazuron [15].

Synthetic gibberellins were obtained in the 1980s. The chemical substance 2-ethyl-3-methoxycarbonyl-1-(*p*-tolylcarbamoyl) isourea acts as a potent GA_3-synergist. Synthetic giberellin A3 and gibberellin A4+7 are used commercially to control plant growth and development.

Abscisic acid. Synthetic abscisic acids are: (±)-cis,trans-abscisic acid (A068); Spectrum A0792-500MG Abscisic Acid; 2′,3′-*iso*-pyridoabscisic acid (*iso*-PyABA) and 2′,3′-*iso*-franoabscisic acid (*iso*-FrABA; 2′,3′-*iso*-Benzoabscisic acid (*iso*-PhABA) are good abscisic acid (ABA) analogues.

Regarding brassinosteroids it is to mention that isocarbabrassinolide and 6-deoxo-brassinoloide are two synthetic compounds. From stigmasterol other five 5-hydroxy-6- ketone brassinosteroid analogs have been synthesized.

Synthetic jasmonic acid are represented y various chemical derivatives, e.g.: 5,7,9,10-tetrabromo derivative of methyl jasmonate; 2-hydroxyethyl jasmonate; trifluoroethyl jasmonate.

Synthetic strigolactone analogus are: (*Z*)-methyl 2-(1,3-dioxoisoindolin-2-yl)-3-((4-methyl-5-oxo-2,5-dihydrofuran-2-yl) oxy)acrylate; (3a*R**,8b*S**,*E*)-3-(((*R**)-4-methyl-5-oxo-2,5-dihydrofuran-2-yloxy) methylene)-3,3a,4,8b-tetrahydro-2*H*-indeno[1,2-*b*]furan-2-one a.o.

4. Role of plant growth regulators in human health

The probable routes of human exposure to PGR-N and PGR-S are by food intake, occupational exposure through inhalation of powder and dermal contact with these compound at work places (using in agriculture) where they are produced or used.

As plant growth regulators are present in any plants in a lesser or higher amount serve as plant originated food for many species. Once consumed and entered in the organism, the question arises whether or not they have effects on those organisms. Unfortunately there are only few studies in this domain.

Cell biology studies on various PGRs have been performed on various cell cultures. An experiment is mentioned with natural and synthetic auxins on a selected human tumor cell lines showed cytostatic effects. The authors analysed the cell-cycle and revealed that auxins indole-3-acetic acid and 2,4-dichlorophenoxyacetic acid influenced the G1-phase of cell-cycle, and decreased the S-phase cells in the tumor cell line. Thus the authors demonstrated that auxins may have antitumor action [16].

Research performed by Hosseinchi et al. [17] with gibberellic acid on the fertility of adult male rats *in vitro*, showed that the use of gibberellin type GA3 can influence the sperm number and the quality of sperm's chromatins, thus reducing the fertility.

Gibberellic acid is considered „relatively non-toxic”. Based on the available data and the toxicological profile of gibberellic acid the agreed acceptable daily intake is 0.68 mg/kg bw/day [18].

Usage of kinetin in investigations performed in vitro on different human cells in high and low doses were made by [19]. They observed that high doses of kinetin, i.e. 500 nM and higher, reduced the cell viability and mediated DNA damage while low doses, up to 100 nM, of kinetin conferred protection in cells against oxidative stress. Their results showed that pretreatment of the cells with kinetin significantly reduced the production of reactive oxygen species, too.

In studies using laboratory animals, cytokinin showed low acute toxicity [20].

According to studies of Rattan and Clark [21] and of Vermeulen et al. [22] the cytokinins kinetin and trans-zeatin showed significant anti-ageing, anti-carcinogenic, and anti-thrombotic effects.

Abscisic acid by targeting the peroxisome proliferator-activated receptor gamma in mammals, can ameliorate the symptoms of type II diabetes, like the anti-diabetic drugs from the thiazolimediones class [23].

In a review paper Zocchi et al. [24] concluded that dietary or endogenously produced abscisic acid can be considered a new human signaling molecule that regulates responses to environmental changes (metabolic, nutritional, inflamma-tory, immunological), and it is implicated in glycemic control. They showed that abscisic acid regulates not only the blood glucose levels in mice and rats, but also improve glycemic controls in humans.

Studies in healthy individuals revealed that low-dose dietary abscisic acid admi-nistration has a beneficial effect on the glycemia and insulinemia after oral glucose load [25].

In a study performed by Henriet et al. [26] is mentioned that jasmonate derivative display anti-aging effects on human skin and that jasmonate derivative can be a compound for investigating glycosamino - glicans structure - function relationships.

Other works demonstrated that jasmonic acid Inhibit aflatoxin production and delay spore germination of *Aspergillus flavus* [27].

A work performed by Pollock et al. [28] revealed that strigonolactones analogues have an inhibitory effect on human breast cancer cells.

Table 1. Physiologic effects of PGR-N and their role in agrobiology

Denomination	Physiologic effects	Agrobiological role
Auxins	Promote flowering in plants and natural detachment of older leaves and fruits; help to initiate rooting in stem cuttings; control cell division	They have effects in plant propagation; the production of fruit without prior fertilization, eradication of weeds, to allow the dominance of apical bud
Giberellins	Increase the axis length (grape stalks), delay senescence in fruits, help fruits to elongate and improve their shape	Used in brewing industry to speed the malting process; used to hasten the maturity period in young conifers and promote early seed production; promote bolting in cabbage and beet
Cytokinins	Help the formation of new leaves and chloroplasts, promote lateral shoot growth and adventitious shoot formation, help overcome apical dominance, promote nutrient mobilization, delay leaf senescence	Promote cell division, however, (only in the presence of auxins), break the dormancy of seeds and thus help in their germination, stimulate the growth of lateral buds, delay normal process of senescence in leaves
Ethylene	Affects horizontal growth of seedlings and swelling of the axis in dicot seedlings, promotes abscission and senescence, especially of leaves and flowers, enhances respiration rate during ripening of fruits, increases root growth and root hair formation	Break seed and bud dormancy and initiate germination in peanut seeds, promote sprouting of potato tubers; boost rapid petiole elongation in deep water rice plants, used to initiate flowering and synchronising fruit-set in pineapples, to induce flowering in mango, hastens fruit ripening in apples and tomatoes, accelerates abscission in cherry, walnut and cotton
Abscisic acid	Regulate abscission and dormancy; inhibit plant growth, metabolism and seed germination, stimulates closure of stomata in the epidermis, increases the tolerance of plants to different kinds of stress, role in seed development and maturation	Application of minimal quantity to leaves shall reduce transpiration; conserves water and reduces the requirement of irrigation; promotes rooting in many stem cuttings; can be used in prolonging dormancy of buds, storage organs and seeds
Brassinosteroids	Promote seed germination; increase the number of flowers in strawberry; promote senescence in wheat leaves; enhance photosynthetic rate	Improve the yield of lettuce, radish, bush bean, pepper, potato, mustard and rice; promote plant growth; inhibit the germination of potato tubers during storage
Jasmonates	Control plant defenses against herbivore attack and pathogen infection; confer tolerance to biotic/ abiotic stresses; stimulate the germination of dormant seeds	Improve crop yield and quality in different plants under stress or non-stress conditions, regulate the gene expression involved in defense responses
Strigolactones	Control plant development; promote symbiotic interactions between plants and soil microbes; promote the formation of lateral roots and root hairs	Provide an opportunity to breed plants with superior nutrient content, use efficiency and ability to form symbiotic associations, stimulate suicidal germination of witchweed seeds in the soil, before the crop is planted
Salicylic acid	Promotes seed germination, vegetative growth, photosynthesis, respiration, flower formation, response against microbial pathogens; mediate plant response to abiotic stress (e.g. drought, heavy metal tolerance, heat a.o.)	Increases vegetative growth, number of flower clusters ; utilized to enhance tolerance in plants against harsh environments; diseases control

Regarding salicylic acids it is necessary to emphasize that many foods have high or very high concentration of salicylates and can cause symptoms of food intolerance. Among these can be enumerated: cucumber, broccoli, cauliflower, radish, seaweed, spinach, grapefruit, kiwi, peaches, watermelon, oranges, apricot, tomato, pineapple, plum, grape, strawberry, etc. Tea, coffee, fruit and vegetable juices are also high in salicylates [29, 30].

Is currently known that some plant growth regulators are used as Plant Protection Products (PPP) and their placing on the market in the European Union need an authorization. These products also referred to as „pesticides" consist of, or contain at least one active substance which must be authorized according to rules and procedures laid down in Regulation (EC) no.1107/2009 [31].

Conclusive data

Compounds belonging to the plant growth regulators PGR-N class can be obtained either by extraction from plants, i.e. native compounds, noted PGR-N and by organic synthesis (PGR-S). Research on these substances are relatively numerous focused on fundamental aspects (effects on nucleic acid biosynthesis, changes in cell cycle, etc.) and applicative aspects being of interest for agrobiology (physiological effects, morphogenesis, etc.).

In vitro studies (on animal and human cellular cultures) as well as in vivo investigation on laboratory animals (rats, mice a.o.) with various PGRs revealed various effects. Among these are the effects: on animal fecundation; metabolism (glycemic index changes) the anti-aging action; antithrombotic action, anticarcino-genic action, etc. Such effects have been presented in this paper.

Considering that PGRs are used in agrobiology (physiology, morphology of plants) it is considered useful to diversify the studies on their effects at the plant level by systematizing the existing data and to link all information with the knowledge of food science and, if necessary, with the pharmacological effects.

These observations are suggested by the fact that certain PGRs are used to improve crop yield and quality in different plants, to inhibit the germination of potato tubers during storage a.o. and because some of them are tested in medicine for their effects on metabolism (i.e. carbohydrates, proteins) and the maintenance of the biochemical homeostasis.

Compliance with Ethics Requirements. Authors declare that they respect the journal's ethics requirements. Authors declare that they have no conflict of interest and all procedures involving human / or animal subjects (if exist) respect the specific regulation and standards.

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