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A Documentary Review on Plant Growth Regulators

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Abstract

Plant growth regulators (PGRs) are exogenously applied chemical compounds that regulate stem elongation through inhibiting biosynthesis of gibberellins or releasing ethylene. PGRs have been and are still mainly used in modern, high input cereal management to shorten straw and thereby increase lodging resistance. There are indications that PGRs have potential to modify cereal yield formation and plant stand structure additional to stem elongation. Often these changes occur through changes that mimic similar responses to those attributable to day length. The principal interest in this publication was to evaluate the possibilities of applying some commonly used PGRs to modify cereal growth and formation and realization of yield potential under Finnish, long day growing conditions. As PGR response may vary depending on plant height, the response of all crops was evaluated to understand better crop production. PGR effect on assimilate distribution within main shoots and tillers as well as to roots was monitored. Potential PGR induced stress-effect in treated plants was monitored by measuring post-treatment ethylene production rates from the roots and shoots and measuring carbon dioxide change rate (CER) of PGR treated and control plants. Application of PGRs at recommended times generally reduced stem elongation. When applied during early growth stages, PGRs failed to reduce canopy height measured at maturity. However, when shoot elongation was measured 14 days after early PGR application, main shoot elongation of all species and cultivars was reduced, indicating similar responsiveness to PGRs at early growth stages, independent of PGR or genotype. PGRs did not change markedly photo-assimilate distribution or translocation pattern in studied cultivars. Tillering was slightly increased by early PGR applications, but the effect was only temporary and at maturity no PGR effect on tiller number was recorded. Root growth, in terms of elongation or dry-weight accumulation, was not improved by PGRs. According to results of ethylene evolution and photosynthesis measurements, PGRs do not appear to induce marked stress in treated plants, or at least not a stress associated with elevated ethylene production or markedly reduced CER. Both yield increases and decreases followed PGR applications. Changes in grain yield were associated with changes in single grain weight or in grain number per head. Due to variable yield responses following PGR applications in the absence of lodging pressure, no general recommendations can be given and careful consideration is needed when selecting a PGR for a specific cultivar.

Key Words: *Plant growth regulators, Auxin, Gibberelin, Cytokinin, Crops, Development*

INTRODUCTION

Plant growth regulators (PGRs) comprise a large group of endogenous and exogenous chemical compounds that can regulate plant growth in numerous ways. In this thesis, the term PGR is used in a restricted sense to refer to exogenously applied chemicals, the sotermed anti-lodging agents, primarily targeted to shortening stem length.

PGRs have been and are still mainly used in modern, high input cereal management to shorten stems and thereby to increase lodging resistance (Gianfagna, 1995; Rajala and Peltonen-Sainio, 2000). Lodging that occurs at pre-anthesis or during early grain filling can cause considerable yield loss through, for example, interference with light absorption of the canopy, intra-plant water availability and nutrient and photosynthate transport and translocation. In lodged, humid plant canopies saprophytic fungi can grow and pre-harvest sprouting is likely to occur. This is especially so when high temperatures and precipitation occur simultaneously during the grain ripening period. Furthermore, lodging increases time and energy needed for combine harvesting and drying, which causes an increase in production costs. Therefore, preventing, delaying or reducing lodging of cereals promotes quantity, quality and harvestability of the grain and helps ensure a favourable economic outcome (Rajala and Peltonen-Sainio, 2000).

Plant breeders have successfully directed cereal biomass distribution from the straw to the grains, resulting in cultivars with higher harvest index (HI) and from tall cultivars to shorter, more lodging resistant ones (Austin et al., 1989; Peltonen-Sainio, 1990; Evans, 1993). These modern, short stature cultivars evidently require less exogenous lodging protection. Application of high amounts of nitrogen fertilizers increases the risk of lodging, but their use is limited by the terms of the national agri-environmental support, especially the EU-Nitrate directive. Hence, the relevance of PGRs in current cereal production may be questionable.

It is legitimate to ask if the principal aim is to shorten the stem, or if PGRs can in other ways be used to modify cereal growth. Numerous references suggest that PGRs have potential to modify cereal growth patterns additional to their primary target of stem elongation. Tillering and spikelet set are often altered through changes that mimic similar responses to those attributable to day length. Changes in assimilate demand and distribution within the plant may provide excess resources that stimulate root growth, tiller and spikelet initiation and grain set and growth. However, most studies have been conducted under a shorter photoperiod compared with the prevailing day length in Finland.

Northern growing conditions strongly influence growth, development rate and yield formation in cereals, enabling the earliest cultivars to mature in less than 90 days (Vuorinen and Kangas, 2002). High seeding rates are used in spring cereals to promote main shoot dominance in plant stands and in yield formation in Finnish growing conditions.

Therefore, PGR induced effects and the potential to manipulate cereal growth and yield formation may differ markedly according to growing conditions, especially day length and management practices. The main focus of the research that comprises this thesis was to evaluate the potential of three commonly used PGRs (CCC, ethephon and trinexapac-ethyl) to modify cereal growth and development under the long–day conditions that characterize the northern margin of cereal production.

OBJECTIVES OF THIS STUDY

The specific objectives of the study are as follows:

1. To explore commonly used PGRs to modify crops growth and development in Bangladesh.

METHODOLOGY OF THE STUDY

The study was documentary analysis type. Data and information were collected from secondary sources such as books, research report, journal, magazines, internet etc. Only qualitative data were used for the study.

REVIEW OF LITERATURE

Plant growth regulators

Plant growth regulators (PGR s) are molecules that influence the development of plants and are generally active at very low concentrations. There are natural regulators, which are produced by the plant itself, and also synthetic regulators; those found naturally in plants are called phytohormones or plant hormones.

Definition of Plant growth regulators

Plant growth regulators or phytohormones are organic substances produced naturally in higher plants, controlling growth or other physiological functions at a site remote from its place of production and active in minute amounts. Thimmann (1948) proposed the term Phyto hormone as these hormones are synthesized in plants. Plant growth regulators include auxins, gibberellins, cytokinins, ethylene, growth retardants and growth inhibitors. Auxins are the hormones first discovered in plants and later gibberellins and cytokinins were also discovered.

“Plant growth regulators usually are defined as organic compounds, other than nutrients, that in small concentrations, affect the physiological processes of plants”. In practical purpose, they are defined as either natural or synthetic compounds that are applied directly to plant to alter its life processes/structure in some beneficial way so as to enhance yield, improve quality and facilitate harvesting. When herbicides are applied to induce a specific beneficial change, then they are considered as plant growth regulators. If the compound is produced within the plant it is called a plant hormone. The term "hormone" is derived from a Greek word meaning “to arouse or stimulate or enhance an activity". A plant growth regulator is defined by Environmental Protection Agency (EPA) as “any substance or mixtures of substances intended, through physiological action, to accelerate or retard the rate of growth or maturation or otherwise alter the behavior of plants. Additionally, plant growth regulators are characterized by their low rates of application, while the high application rates of the same compounds often are considered as herbicidal”. Plant hormones are produced naturally by plants and are essential for regulating their own growth. They act by controlling or modifying plant growth processes, such as formation of leaves and flowers, elongation of stems, development and ripening of fruits. In modern agriculture practices, people have established the benefits of extending the use of plant hormones to regulate growth of other plants. When natural or synthetic substances are used in this manner, they are called Plant Growth Regulators.

The application of plant growth regulators in agriculture has started in 1930 in United States. Ethylene, a naturally occurring substance, is one of the first plant growth regulators being discovered and used successfully for enhancing flower production in pineapple. Its toxic effects to human beings are low. Synthetic substances that mimic such naturally occurring plant hormones were also produced, since then the use of plant growth regulators has been growing significantly and becoming a major component in modern agriculture.

Plant growth regulators

- Defined as organic compounds other than nutrients, that affects the physiological processes of growth and development in plants when applied in low concentrations.
- Defined as either natural or synthetic compounds that are applied directly to a target plant to alter its life processes or its structure to improve quality, increase yields, or facilitate harvesting.

Discovery of Plant Growth Regulators

Though it was serendipity, initial steps of the discovery of major Plant growth regulators began with Charles Darwin and his son, Francis Darwin. They observed the growth of coleoptiles of canary grass towards the light source-phototropism. Followed by a series of experiments, they concluded the presence of a transmittable substance that influences the growth of canary grass towards the light. That transmittable substance was what we know as auxin which was isolated later by F.W. Went. Later, many scientists discovered and isolated different plant growth regulators. Gibberellins or gibberellic acid was formerly found in uninfected rice seedlings and was reported by E. Kurosawa. F. Skoog and Miller discovered another growth-promoting substance named kinetin, which is now known as cytokinins.

Characteristics of Plant Growth Regulators

As the plants require oxygen, water, sunlight, and nutrition to develop and grow, they do require certain chemical substances to manage their growth and development. These chemical substances are known as Plant Growth Regulators and are naturally produced by the plants itself. These are simple organic molecules having several chemical compositions. They are also described as phytohormones, plant growth substances, or plant growth hormones. They can accelerate as well as retard the rate of growth in plants.

Plants growth hormones or plant growth regulators exhibit the following characteristics:

a) Differentiation and elongation of cells.
b) Formation of leaves, flowers, and stems.
c) Wilting of leaves.
d) Ripening of fruit.
e) Seed dormancy, etc.

Generally, there are five types of plant hormones, namely, auxin, gibberellins (GAs), cytokinins, abscisic acid (ABA) and ethylene. In addition to these, there are more derivative compounds, both natural and synthetic, which also act as plant growth regulators.

Types of Plant Growth Regulators

Plant growth hormones or regulators are of the following types:

1) Plant Growth Regulators or Promoters
2) Plant Growth Inhibitors

Plant Growth Regulators or Promoters

a) Auxins

Figure 1: Chemical Structure of Auxin

Figure 2: 3D Structure of Auxin

The first phytohormone to be discovered is the Auxin and it was discovered by the biologist Charles Darwin. Auxins are one of the most important plant hormones. The chief naturally occurring auxin is indole-3 acetic acid – IAA and other related compounds. The term Auxin is derived from the Greek language meaning to grow. These plant growth regulators are generally produced at the points of stems and roots from where they are transported to other parts of the plants. These plant hormones include both natural and synthetic sources. Indole-3-acetic acid and indole butyric acid are obtained from natural plant sources, whereas naphthalene acetic acid and 2, 4-dichlorophenoxyacetic acid are obtained from synthetic sources.

The main effect of auxins is to cause cell elongation, mainly due to the alteration of cell wall plasticity. Auxins are synthesised in the apical meristems and to a lesser degree in the roots. The main auxin to be synthesised naturally by plants is indole acetic acid (IAA), although others have been found such as phenylacetic acid, the chlorindoles and, more recently, indole butyric acid (IBA). The movement of these phytohormones is from the apices to the roots (basipetal) and vice versa (acropetal). However, basipetal movement is much more rapid than acropetal movement.

Functions of Auxins

1. Facilitate flowering in plants
2. Used in the process of plant propagation.
3. Used by gardeners to keep lawns free from weeds.
4. Involved in the initiation of roots in stem cuttings.
5. Prevention of dropping of leaves and fruits at early stages.
6. Regulate xylem differentiation and assists in cell division.
7. Auxins are widely used as herbicides to kill dicot weeds.
8. Used to produce fruit without preceding fertilization.
9. Promote natural detachment (abscission) of older leaves and fruits.

10. Apical dominance may occur in which the growth of lateral buds is inhibited by the growth of apical buds. In such cases, the shoot caps may be removed.
11. These are produced by the apex of root and shoot.

Some of the effects of auxins in plants include:

i) Apical dominance

It is well known among growers that when one eliminates the main apical axis (main vertical stem) of a plant, secondary apices will begin to grow and several of these will go on to form main stems. This occurs because the auxins produced by the apical meristem suppresses the growth and development of secondary buds.

ii) Rhizogenesis

Auxins are the main components responsible for the formation of root cells. This property is used by gardeners to produce cuttings: applying auxins to the base of the cut promotes the formation of new roots. This rhizogenesis occurs at very low concentrations of auxins, since higher concentrations of auxins suppress root growth and development. However, it is the presence of other phytohormones that determines whether the new cells become roots or other organs. The balance between auxins and cytokinins plays a very important role in this process. Thus when plant cells are grown *in vitro* in culture media, if the concentration of auxins is greater than that of cytokinins, new roots will be formed. However, if the concentration of cytokinins is greater than that of auxins, the cells will eventually develop into new buds. When the concentration of the two hormone types is similar, cell growth will occur without differentiation, forming a mass of developing cells called a callus.

iii) Geotropism

Gravity exerts an effect on plant development. When a plant stem is placed in a horizontal position, lateral buds will begin to develop and may form roots in the zone which is in contact with the soil. This is due to the accumulation of auxins due to the effect of gravity. This phenomenon is used to obtain new plants using a technique called layering.

iv) Phototropism

Plants tend to grow towards the light. This process is regulated by auxins, which accumulate in parts that receive less light; this results in the elongation of the cells in this zone and makes the stem curve towards the light.

v) Regulation of abscission

Abscission is the shedding of some parts of the plant. In many cases the cause is the ageing of the plant tissue, called senescence. The exogenous application of auxins will reduce abscission in many species.

vi) Fruit set

When pollination and fecundation occur, the concentration of auxins in the fruit usually increases, possibly as a result of production by the developing seeds. If fecundation does not occur, the fruit are shed instead of developing and maturing. But by applying auxins, the formation and maturation of fruit can occur without pollination or fecundation (and therefore seed formation) being necessary. The development of fruit without fecundation is called parthenocarpy and it is widely used when the formation of seeds is undesirable or when no pollination is possible. This occurs when insect-pollinated plants are grown into greenhouses. When there are no pollinating insects, exogenous auxins are applied to promote fruit set.

b) Gibberellins

These phytohormones are partly responsible for cell division and the elongation of stems and other tissues. They were discovered by Japanese researchers studying a disease in rice. The disease caused recently germinated seedlings to acquire a yellowish colour and the stem to elongate excessively, leading to the death of the plant. The researchers discovered that these symptoms were caused by the Gibberella fujikuroi fungus. This fungus produces a large quantity of these phytohormones which are introduced into the host plant.

Since then, various types of gibberelins have been discovered and isolated. These were given successive numbers as they were discovered; GA1, GA2, GA3, etc. GA3 is gibberellic acid.

Gibberelins are synthesised mainly in meristematic organs and developing tissues.

Figure 3: Chemical Structure of Gibberellins

Figure 4: 3D Structure of Gibberellins

Gibberellins are an extensive chemical family based on the ent-gibberellane structure. The first gibberellin to be discovered was gibberellic acid. Now there are more than 100 types of gibberellins and are mainly gathered from a variety of organisms from fungi to higher plants.

They are acidic and are denoted as follows – GA_1, GA_2, GA_3 etc.

Functions of Gibberellins

1. Delay senescence in fruits.
2. Involved in leaf expansion.
3. Break bud and seed dormancy.
4. Promote bolting in cabbages and beet.
5. Facilitate elongation of fruits such as apples and enhance their shape.
6. Used by the brewing industry to accelerate the malting process.
7. Used as the spraying agent to increase the yield of sugarcane by elongation of the stem.
8. In young conifers, utilized to fasten the maturity period and facilitate early seed production
9. Helps in increasing the crop yield by increasing the height in plants such as sugarcane and increase the axis length in plants such as grape stalks.
10. Gibberellins are acidic in nature.
11. It also delays senescence.

Functions of gibberelins

i) Seed germination

In seeds, some of the gibberelins combine with glucosides, and become inactive in this form. During germination, enzymes destroy this combination and the gibberelins are unlocked and activated. This stimulation of germination has been demonstrated in a number of experiments which showed how the application of gibberelins accelerated the germination of lettuce seeds. It was also shown that exposure to light accelerated the germination of lettuce seeds. Later studies showed that light accelerates the transformation of the gibberelins from the inactive conjugated form to the active form.

ii) Sex expression

In species with unisexual flowers - that is, separate male and female flowers, either on the same plant (monoecious) or on different individuals (dioecious) - gibbberelins appear to have a regulatory effect on sex expression. For example, the application of gibberelins in female asparagus plants produces the appearance of male and hermaphrodite flowers. By contrast, gibberellin application in maize plants produces the appearance of female flowers in the tassels (masculine inflorescences).

iii) Plant growth regulators

This is a close-up of a seed (left) from a spinning top conebush seed head (right). The seed (black) is suspended from a parachute of fine hairs called a pappus. The hairs help the seed to catch the wind when they are released from the seed head. The seeds can be dispersed many kilometres on the wind. Conebushes are indigenous to South Africa. The plants may be either male or female. The male plant has small narrow flower heads, while the female plant (pictured) has large green cone-shaped flower heads, that later change to a copper colour.

Influence during the juvenile period. Juvenile plants are different to adult plants - for example, developing fruit trees must mature for several years after seed germination before they are capable of producing flowers and fruits. In some cases they also have different characteristics when adult (for example, the presence of spines or leaves with different shapes). Gibberelins play an important role in the transition from the juvenile period to the adult period. In some plants, such as ivy, the exogenous application of gibberelins produces the expression of branches with juvenile characteristics.

iv) Induction of flowering

Some plants require long days or cold periods to flower, but the application of gibberelins induces flowering independently of the photoperiod or the temperature.

C) Cytokinins

The discovery of these phytohormones was due mainly to in vitro cultivation studies. The first observation was that "coconut milk" (the endosperm of the fruit) promoted the growth of several tissues cultivated in vitro. The first natural cytokinin isolated and identified was named zeatin, since it was isolated from maize (Zea mays) seeds. The main function of the cytokinins is to produce cell division and retard senescence. As mentioned above, cytokinins in combination with auxins lead to the formation of undifferentiated cell masses called calluses. They also stimulate the development of lateral apices when applied exogenously, breaking apical dominance**.**

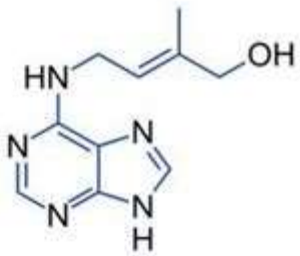

Figure 5: Chemical Structure of Cytokinins

Figure 6: 3D Structure of Cytokinins

These are produced in the regions where cell division occurs; mostly in the roots and shoots. They help in the production of new leaves, lateral shoot growth, chloroplasts in leaves etc. They help in overcoming apical dominance and delay ageing of leaves.

Functions of Cytokinins

1. Break bud and seed dormancy.
2. Promotes the growth of the lateral bud.
3. Promotes cell division and apical dominance.
4. They are used to keep flowers fresh for a longer time.
5. Used in tissue culture to induce cell division in mature tissues.
6. Facilitate adventitious shoot formation and lateral shoot growth.
7. Promote nutrient mobilization that in turn assists delaying leaf senescence.
8. Helps in delaying the process of ageing (senescence) in fresh leaf crops like cabbage and lettuce.
9. Involved in the formation of new leaves and chloroplast organelles within the plant cell.
10. Used to induce the development of shoot and roots along with auxin, depending on the ratio.

2) Plant Growth Inhibitors

a) Abscisic acid

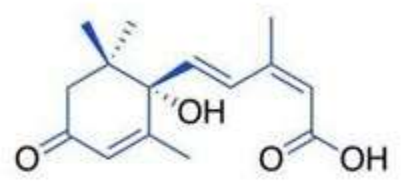

Figure 7: Chemical Structure of Abscisic Acid

It is a growth inhibitor, which was discovered in the 1960s. It was initially called dormant. Later, another compound abscisin-II was discovered and are commonly called as abscisic acid. This growth inhibitor is synthesized within the stem, leaves, fruits, and seeds of the plant. Mostly, abscisic acid serves as an antagonist to Gibberellic acid. It is also known as the stress hormone as it helps by increasing the plant-tolerance to various types of stress.

Functions of Abscisic acid

1. Stimulates closing of stomata in the epidermis.
2. Helps in the maturation and development of seeds.
3. Inhibits plant metabolism and seed germination.
4. It is involved in regulating abscission and dormancy.
5. It is widely used as a spraying agent on trees to regulate dropping of fruits.
6. Induces seed-dormancy and aids in withstanding desiccation and various undesired growth factors.

b) Ethylene

Ethylene is a simple, gaseous plant growth regulator, synthesized by most of the plant organs includes ripening fruits and ageing tissues. It is an unsaturated hydrocarbon having double covalent bonds between and adjacent to carbon atoms.

Ethylene is used as both plant growth promoters and plant growth inhibitors. Ethylene is synthesized by the ripening fruits and ageing tissues.

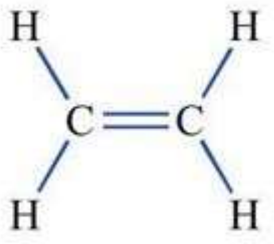

Figure 8: Chemical structure of Ethylene

Functions of Ethylene

Ethylene is the most widely used plant growth regulator as it helps in regulating many physiological processes.

1. Induce flowering in the mango tree.
2. Promotes sprouting of potato tubers.
3. Breaks the dormancy of seeds and buds.
4. Enhances respiration rate during ripening of fruits.
5. Applied to rubber trees to stimulate the flow of latex.
6. Facilitates senescence and abscission of both flowers and leaves.
7. Used to stimulate the ripening of fruits. For example, tomatoes and citrus fruits.
8. Affects horizontal growth of seedlings and swelling of the axis in dicot seedlings.
9. Increases root hair formation and growth, thus aids plant to expand their surface area for absorption.

Thus we see how important are the plant hormones or the plant growth regulators in the growth and development of plants.

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