

Plant Growth Regulators

Machi F. Dilworth, *associate program manager, Competitive Research Grants Office, Office of Grants and Program Systems*

Plant growth regulators are hormone-like chemicals that occur naturally in plants, and play a central role in their growth and development. Five major classes of plant growth regulators have been identified as plant hormones, but scientists believe that there are more waiting to be discovered.

The five growth hormones include auxins, gibberellins, cytokinins, abscisic acid, and ethylene. Collectively, they regulate many facets of plant growth and development including seed germination, root growth, stem elongation, leaf expansion, flowering, seed development, fruit ripening, and dropping of leaves and fruits.

Each of these processes is directly relevant to agriculture; what is harvested for food, feed, or fibers is the result of one of these developmental events. For example, cereal grains are the seed, potatoes are the highly specialized stem, spinach is the leaf, and cotton comes from the highly developed cell walls of the ovule, a part of the maternal reproductive structure. The more we understand these processes, the better chance we will have of developing a strategy for crop improvement. With the advent of biotechnological techniques, it is now distinctly possible to manipulate the natural regulatory mechanisms to produce improved crop varieties with desirable genetic traits.

Physiological and Biochemical Regulation

Earlier research has identified a general role for each of the five classes of

plant hormones as follows; auxin, a cell elongation hormone; gibberellin, a regulator of tissue and plant parts; cytokinin, a cell differentiation hormone; abscisic acid, a senescence regulator; and ethylene, a fruit-ripening hormone. Further research has uncovered more detailed information about their physiology and biochemistry. How these hormones regulate plant growth and development is extremely complex, yet the genetic makeup of each plant determines its precise developmental program. Moreover, the environmental factors interact with plant hormones in the regulatory process.

Interaction of Growth Hormones

The five classes of growth hormones can act independently in regulating many developmental events, but evidence is accumulating that they interact with each other as well. One of the clearest examples of this interaction is the auxin control of the biosynthesis of ethylene. Indole acetic acid, an auxin, has been demonstrated to stimulate the enzyme that catalyzes the last step of the ethylene biosynthesis. The interaction of auxin and cytokinin in determining shoot and root formation from callus tissue (a mass of undifferentiated plant cells) has been a well-known phenomenon since the 1960's. Abscisic acid has inhibited the induction of a starch-hydrolyzing enzyme by gibberellin in the seed of barley. The gibberellin-to-auxin ratio has been shown to determine the number and length of cotton fibers.

Interaction Between Growth Regulators and Environmental Factors

Examples of the interaction between the plant growth regulators and envi-



Seed development is one of the facets of plant growth affected by natural plant hormones. These soybeans are ready for harvest.

ronmental factors are equally abundant, suggesting even more complicated mechanisms of hormonal regulation. Environmental factors such as light, moisture, and temperature are important signals to which the plants react in executing their developmental programs. Light, for example, plays a crucial role in plant morphogenesis including seed germination, shoot growth, and flowering.

Some of the effects of environmental signals seem to work through the same processes as do plant hormones while others do not. The effect of light on seed germination can be replaced by gibberellin, for example, but the effect of light on the initiation of flowering cannot be replaced by a known plant growth regulator.

These observations are based on biochemical and physiological studies that have been carried out by many investigators. The diversity of the phenomena involving plant growth regulators has puzzled many researchers as to the fundamental mechanism of hormone action in regulating plant growth and development. It has led to a hypothesis that the plant hormones do not act directly in the cell, but through some secondary messengers such as a calcium ion or a small carbohydrate molecule. So far, the hypothesis has not been proved or disproved. It also should be recognized that not all plant growth regulators need to work through the same mechanism.

Plant Growth Regulators and Gene Expression

Most of the recent advances in plant growth hormone research are being made in the studies on the effect of plant hormones on gene expression. The new molecular biology and various immunological techniques have allowed new approaches to the old problem of how the plant growth regulators regulate developmental

processes.

It appears that all five plant growth regulators influence the expression of genes at the transcriptional (DNA to messenger RNA) level, the translational (messenger RNA to protein) level, and the posttranslational modification of the proteins.

Auxin. The first suggestion was made in the 1950's that auxin-regulated cell elongation may be mediated by auxin-controlled gene expression. It is only in the past few years, however, that conclusive evidence shows that auxin induces specific gene products, both messenger RNA's and proteins, in elongating shoots. The manner by which an auxin interacts with the gene and the nature of the gene products are being investigated by several laboratories.

Gibberellin. In the 1960's, it was shown that gibberellin induces the synthesis of a group of enzymes in the barley seed. These enzymes hydrolyze the material stored in the seed, converting them to usable nutrients for growing seedlings. Twenty years later, evidence is available to show that gibberellin increases the enzyme synthesis through stimulating the production of messenger RNA's specific for the hydrolytic enzymes. One of the best studied enzymes is alpha-amylase, an enzyme that converts starch to sugar molecules. The genes for alpha-amylase have been isolated and characterized by several groups of scientists. How gibberellin interacts with the alpha-amylase gene is increasing its messenger RNA's is under intensive investigation.

Cytokinin. The molecular biology research on cytokinin has led to the identification and isolation of a gene that encodes for the enzyme for the production of plant growth substances in bacteria. With a variety of

genetic engineering techniques, the bacterial gene can be used as a probe to identify cytokinin biosynthesis (chemical production) genes in higher plants, or alternatively, the bacterial gene can be inserted into higher plants and expressed.

Both approaches would not have been possible a few years ago, but are now being tried by several laboratories. The latter approach is likely to produce valuable information about the mechanisms of cytokinin regulation of cell differentiation.

Abscisic Acid. High levels of abscisic acid are found in the developing seeds of many plants. It is thought that the function of abscisic acid in the developing seed is to prevent premature germination by the embryo before the seed maturation process is completed. Studies being carried out on the developing seeds of wheat, cotton, and other plants indicate that abscisic acid exerts its regulatory influence by increasing the level of specific messenger RNA's and possibly stabilizing the messenger RNA's that are important in maintaining the embryonic state of the seed. Abscisic acid also induces a set of messenger RNA's and proteins in germinating cereal seeds where abscisic acid has been known to act as an antagonist to gibberellin. This observation suggests that abscisic acid does not simply reverse the effect of gibberellin, but rather has a distinct function, possibly being to protect young seedlings from unexpected dehydration.

Ethylene. In agreement with the general notion of ethylene as a ripening hormone, it has been shown that ethylene induces the synthesis of a series of enzymes that contribute to the softening of plant fruit tissue. The genes that are activated by ethylene have been isolated and identified as the genes encoding for cellulase and galacturonase, both enzymes involved

in cell wall degradation. How ethylene regulates the expression of these genes is being investigated.

New Technological Developments

In addition to the molecular biology studies, new developments in immunological techniques such as monoclonal antibodies are being used to identify the cellular targets of the plant growth regulator, and to isolate and assay the quantity of plant hormones from plant cells. These new biotechnology techniques are proving useful in increasing the basic understanding of the processes involving the plant growth regulators.

At the same time, genetic engineering technologies have opened up the possibilities of directly manipulating plants for agronomic traits associated with the growth and development.

It should be emphasized that recent advances in the plant growth regulator research using biotechnology are made possible because of the enormous amount of basic background information accumulated over the years about the physiology and biochemistry of plant growth regulators. Much is still to be learned about the plant growth hormones. Continued efforts in the area of physiology and biochemistry will be needed to take full advantage of the emerging biotechnological techniques in understanding plant growth and development and in applying the knowledge to crop improvement.