CHEMICAL MANIPULATION OF PLANT GROWTH AND THE RATIONAL DEVELOPMENT OF SYNTHETIC PLANT GROWTH REGULATORS

ROGER J. FIELD

Plant Science Department, Lincoln College, Canterbury

SUMMARY

Naturally occurring plant hormones are involved in all plant growth and development processes. Their genetically-linked production can be varied by environment, resulting in enhanced or retarded plant performance. Native plant hormones usually have short-term, inconsistent effects when applied to plants and generally have not been commercially developed. More stable chemical analogues of endogenous hormones and novel synthetic materials have been successfully developed to improve plant management, yield and quality. There are difficulties in the development of synthetic plant growth regulators (PGR's) by biorational design. Problems of limiting PGR activity to specific physiological and developmental processes have implications for their effective performance in field applications.

INTRODUCTION

Naturally occurring plant hormones are involved in the control of all plant growth and development events. The endogenous hormone groups; auxins, gibberellins, cytokinins, abscisic acid and ethylene, interact to determine the activity of physiological processes. The genetically-linked production of plant hormones can be varied by environment and these interactions result in promotion, cessation or retardation of plant growth and development.

The discovery and identification of the first plant hormone, auxin, took place 60 years ago. Since then there has been interest in using such materials to increase plant growth, or to manipulate development. Native plant hormones usually have short-lived, inconsistent effects when applied to plants and generally have not been commercially developed for improved crop performance and yield. There are exceptions such as gibberellins which have been used successfully to enhance barley malting, to produce parthenocarpic grapes (*Vitis* spp.) and to change the sex expression of cucumber (*Cucumis sativus* L.).

The most radical developments in the chemical manipulation of plant development have involved the use of chemical analogues of endogenous hormones and novel synthetic compounds. The development and commercial use of synthetic plant growth regulators (PGR's) has increased rapidly in recent years.

DEVELOPMENT OF SYNTHETIC PLANT GROWTH REGULATORS

The principal objectives have been to develop PGR's that:

- i) increase yield or specific yield components.
- ii) improve plant/crop management, often in association with mechanical aids to maintenance and harvesting.
- iii) improve post-harvest characteristics.

Clearly a major aim is to increase absolute yield or to improve the overall economic efficiency of production. With respect to improvements in yield the rational development of PGR's has been aimed at:

- i) increasing net photosynthesis, with a major emphasis on reducing photorespiration.
- ii) manipulating assimilate partitioning to increase the harvest index.
- iii) delaying senescence to extend leaf area duration.

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Unfortunately none of these processes is controlled by a single hormone or even regulated by a single gene. A conflict arises in the rational development of a PGR to influence yield-determining processes. The development of a simple PGR that mimics, stimulates or inhibits the action of a single endogenous hormone is inadequate for controlling the complex of physiological processes contributing to yield. Increased understanding of physiological processes confirms the complexity of hormonal regulation, particularly if environmental factors intervene. A single PGR, manipulating only a part of the overall hormone system controlling a physiological process, could reduce performance or cause adverse side effects.

SPECIFICITY OF PLANT GROWTH REGULATOR EFFECTS

Unlike animal hormones, the few plant hormones appear to have multiple roles in controlling many physiological processes involving a number of target cells and enzymes. Thus gibberellins not only promote internode extension and plant stature but also influence seed germination, flowering and many other areas of development. A single PGR may also influence several physiological processes and cause overall performance to be impaired by undesirable side effects. The control of plant stature, manipulation of ethylene production and the retardation of grass growth provide examples of the specificity of plant growth regulator effects.

Control of plant stature

The PGR combination of mepiquat chloride plus ethephon reduces straw length in cereals, prevents lodging and neck break of ear. The effect is largely attributable to the release of ethylene. Unfortunately there is frequently an associated induction of late, secondary tiller development leading to uneven ripening and difficulties in harvesting (Dutta 1984). The triazole PGR, paclobutrazol, specifically inhibits the synthesis of gibberellins by preventing the oxidation of kaurene to kaurenoic acid (Dalziel and Lawrence 1984). Stem extension growth is reduced in many species and this is seen as advantageous in preventing lodging and improving harvesting characteristics in tall stature crops that have an indeterminate growth habit, such as field beans (*Vicia faba* L.). There is typically a height reduction of approximately 15% with paclobutrazol and final seed yield is increased by 9-40%, depending on season (Attiya *et al* 1983; Attiya 1985). The increase in yield is associated with a number of yield components, particularly an increase in the number of pods per plant, which is related to greater branching, flower production and pod retention. In this case the multiple effects of a PGR gives improvements in plant performance plus a number of desirable changes in plant development.

Manipulation of ethylene production

The gaseous plant hormone ethylene is involved in senescence and may initiate the rapid deterioration of post-harvest fruit and flowers. The biosynthesis of ethylene is well understood and there are a number of synthetic compounds that enhance or inhibit the production of the key biosynthesis intermediate, 1-aminocyclopropane-1-carboxylic acid (ACC).

The identification of a low-cost, low toxicity inhibitor of ACC production would have a vast benefit in controlling the initiation of post-harvest ripening processes. The cut-flower industry is able to make use of silver ions, administered as a silver thiosulphate (STS) complex, to prolong the vase life of carnation (*Dianthus caryophyllus* L.) and other species by more than two and a half times. The silver ions in the STS complex block the ethylene receptor mechanism, reducing the sensitivity of flowers to ethylene. The application of STS and the post-harvest environment of cut carnations, particularly in relation to periods of cool storage, are important factors in managing ethylene production and its effects (Field 1985; Barrowclough 1986). While the STS complex cannot be considered to be a PGR, research has clearly shown that development of a chemical to control production of an endogenous hormone such as ethylene would result in very specific effects with pronounced economic value.

In some situations the elevation of ethylene levels is advantageous for the programmed promotion of abscission and ripening of fruit prior to mechanical harvesting. This can be achieved by the application of purely synthetic materials such as ethephon, that give pH-dependent ethylene production on contact with water. There

has been no commercial development of ethylene releasing materials that are based on natural products. A biorationally designed PGR, N-formyl ACC, has been developed (Lurssen and Konze 1985) but unfortunately the ethylene release kinetics from N-formyl ACC was inferior to that from ethephon and the product is not used commercially.

Retardation of grass growth

Arguably the largest group of PGR's are the growth retardants, particularly those whose primary mode of action is the inhibition of gibberellin biosynthesis. There are also a number of inhibitors which interfere with the primary processes of growth without apparently acting as hormone manipulators *per se*. Mefluidide effectively retards the vegetative growth of temperate grass species by interfering with cell extension and possibly cell division, (Field and Whitford 1982). Manifestations of mefluidide application are a reduction in leaf extension and tiller development. Mefluidide also prevents seed head development, leading to an overall reduction in sward height. The effects on primordia development suggest an interference with cell division which may relate to the reported action of mefluidide on cell membranes (Elkins 1983). Mefluidide and chemically unrelated retardants such as amidochlor can be used to suppress turf development, reducing the frequency of mowing and leading to significant cost savings. Typically grass growth is suppressed for 6 to 8 weeks.

The precise modes of action of mefluidide and amidochlor have not been determined. While they may be quite different they provide useful examples of PGR's acting on specific growth or physiological processes without being targeted to specific hormone changes. This approach to PGR manipulation of plant development may have advantages. If, for example, the mode of action is only associated with a single enzyme, many of the side effects that typically accompany manipulators of hormone activity will not occur.

FUTURE DEVELOPMENT OF PLANT GROWTH REGULATORS

There are almost no examples of biorationally designed PGR's that are in commercial use. Those compounds that interfere with plant hormone production have largely been discovered by empirical methods. The increasing knowledge of physiological processes and the controlling role of plant hormones suggests that PGR development targeted at manipulation of endogenous plant hormones is not a useful tactic. Biorational development of PGR's should be aimed first at understanding the physiology and chemistry of target processes and, secondly, at finding chemicals that produce desirable interference with specific enzymatic and control steps. Such an approach to PGR development should result in more specific plant responses and reduce undesirable side effects.

One major problem is designing effective screening procedures to identify desirable PGR activity. Simple tests associated with vegetative development phenomena are straightforward but screening for effects on reproductive development are difficult. There is a particular problem in developing PGR's for perennial crops. Commercial reality suggests that PGR development is only justified if it can be applied to a major market. Thus the target species are usually important annual, arable crops such as maize (*Zea mays* L.), cereals and soyabean (*Glycine max.* L.) or high volume, high cost crops like cotton (*Gossypium hirsutum* L.) and sugarcane (*Saccharum officinale* L.). The use of PGR's in low volume, speciality horticultural crops is dependent upon the development of the more major applications. There is a certain irony in that improvements to high volume crops have often been successfully brought about by plant breeding while arguably the greatest potential use of PGR's is with difficult-to-manage perennial species.

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