Growth regulators are chemicals that alter the growth and development of plants. They may be natural or artificial, and typically they are active at very low concentrations. The most important plant growth regulators are the hormones, auxin, gibberellin, ethylene, cytokinin, and abscisic acid. Other growth regulators often act by modifying the action of the natural hormones. For example, naphthyl phthalamic acid (NPA), a synthetic plant growth regulator and herbicide, acts by inhibiting movement of auxin. In this article, we summarize the role and possible usefulness of the plant hormones and other plant growth regulators for improving the postharvest life of ornamentals.

Auxin and inhibitors of auxin transport  Bend- ing of stems away from gravity or towards light, an important cause of quality loss in spike-type flowers such as snapdragon and gladiolus, is a response of the plant to a change in the distribution of auxin within the stem. Such growth responses (negative geotropism) can be prevented by pre-treating sensitive flowers with NPA.

Natural and artificial cytokinins  In addition to their important roles in controlling and stimulating cell division, the cytokinins, zeatin and its derivatives and analogs also inhibit leaf senescence. Leaf yellowing, an early symptom of leaf senescence is an important factor in loss of quality of potted plants and cut flowers. We have found that using 6-benzyladenine (6-BA), a synthetic cytokinin, together with STS markedly improved plant quality over application of either regulator alone. Leaf yellowing in cut chrysanthemums also has been reduced by application of 6-BA as a spray or dip. Some potted chrysanthemum cultivars are prone to leaf yellowing and here, too, cytokinins have success-
fully been used to reduce the problem. Application of growth retardants (often inhibitors of gibberellin synthesis or action) to potted plants frequently will increase their susceptibility to leaf yellowing. This is a common problem in the case of Easter lilies. Recently, ‘Promalin’, a growth regulating chemical formulated with cytokinin and gibberellin components to provide ‘typier’ apples, has been shown to be a very effective means of reducing leaf yellowing in lilies that have been treated with growth retardants. Cytokinins are known to reduce the sensitivity of plants to ethylene, and for some years a commercial vase preservative containing 6-BA was marketed for use with carnations, which are very sensitive to this gas.

**Ethylene**

While ethylene is a useful postharvest tool for ripening fruit such as bananas and tomatoes, it can pose considerable problems in the postharvest handling of ornamentals, causing a range of effects, including early wilting of flowers, yellowing or necrosis (death) of leaves, and shattering of leaves, buds, petals and flowers. In recent years a number of growth regulator approaches to overcoming the effects of ethylene have become available. The most important, commercially, is the anionic silver thiosulfate complex that we call STS. Silver ion is a very effective inhibitor of ethylene action, and its thiosulfate complex is very stable and moves easily in plants, allowing us to provide silver to flowers through the vase solution, and to potted plants by spraying just before buds show color.

Although only minute amounts of silver are applied when plants are treated with STS to protect them from ethylene, there is some concern about the environmental implications of using a heavy metal (silver) in this way, and certainly waste STS solutions have to be disposed of correctly. For these reasons we have been exploring alternative ways of preventing the effects of ethylene. A new gaseous inhibitor of ethylene, 1-methylcyclopropene (1-MCP), is presently being registered for use with ornamentals and appears to have considerable commercial potential as an inhibitor of ethylene action. Preliminary data indicate that the compound is non-toxic, and is quite stable under normal conditions. 1-MCP has proved to be an effective inhibitor of ethylene effects in ethylene-sensitive potted plants and cut flowers (see the following article). Concentrations of 1-MCP as low a 6 parts per billion can prevent the detrimental effects of subsequent exposure to ethylene concentrations as high as 1 part per million.

**Abscisic acid**

Abscisic acid plays an important role in plant dormancy, and is a key component of the regulation of plant water relations, considered to be primarily responsible for closing the stomates, the apertures through which plants lose water. When potted chrysanthemum plants wilted, we found that there was a rapid rise in ABA content of the leaves, and ABA treatment of potted chrysanthemum plants dramatically reduced stomatal aperture and water loss. Although the ABA-treated plants lasted 3 to 5 days longer than untreated controls the cost of this plant hormone makes the effect of scientific rather than commercial interest. Similar results were obtained with cut roses, but in roses ABA also accelerated flower senescence.

**Gibberellins and inhibitors of gibberellin biosynthesis**

Gibberellins, hormones that are mainly involved in controlling stem elongation are important in ornamental horticulture primarily from the perspective of the need to inhibit their action in order to obtain the desired height/diameter ratio for potted flowering plants. Inhibitors of gibberellin synthesis and action, such as Alar, CCC, and PP333 ‘Bonzi’ are routinely used commercially for this purpose. In some cases, the use of these regulators has undesirable effects on the postharvest life of the plants, accelerating postharvest leaf yellowing, and reducing flower life. An important commercial use of gibberellins is in preventing postharvest leaf yellowing in monocotyledonous cut flowers, such as lilies and alstroemeria. Commercial preservatives containing gibberellin have been formulated for these crops.

**Other growth regulators**

In recent years, researchers have studied the properties of a range of new chemicals with plant hormone or growth regulator activity. The anti-senescence effects of the polyamines and the various effects of jasmonic acid and methyl jasmonate are the most notable of these. Although intriguing findings have been reported, none of these effects has been unequivocally proven to be a natural regulatory process, nor have these compounds proved to be of practical commercial value in the postharvest life of ornamentals.
**Ethylene-independent senescence**

The discovery of new methods to protect flowers and plants against ethylene action is very useful for ethylene-sensitive flowers. However, there is still a large group of plants where these methods will not be effective. These are the ethylene insensitive flowers such as many bulb crops (e.g. Tulip, Iris, Freesia, and Gladiolus). Little has been done to examine the physiological basis of senescence in ethylene-insensitive flowers. This is surprising, since there is a large range of beautiful flowers of this type, which could be valuable commercial products, were their postharvest life improved. In studies of the senescence of daylily flowers, which we use as a ‘model’ for ethylene-insensitive flower senescence, we treated them with cycloheximide (CHI), an inhibitor of protein synthesis. Preventing protein synthesis increased the life of the flowers from 1 day to five days. Similar extension of life was obtained by treating iris and tulip flowers with CHI. Recent findings on the molecular basis of senescence of daylily flowers, which are also ethylene-insensitive, have provided tools for conducting basic investigations of this senescence process. We hope that such investigations will lead to longer-lived Iris in the same way that basic studies of ethylene action in plants has led to the development of 1-MCP and the potential for easily extending the life of ethylene-sensitive cut flowers and potted plants.

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