Ethylene and Postharvest Commodities

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Ethylene is a gaseous plant hormone, the simplest olefin (C2H4) and is biologically active at low concentrations (part per billion to part per million range) (Abeles, 1992; Saltveit, 1999). Since it is a gas, it is easily transported long distances via diffusion from sites of synthesis. Sources of ethylene gas include ripening fruit, senescent fruit and vegetables, wounded or stressed plant tissue (Hyodo, 1991; Morgan and Drew, 1997), combustion engines (Saltveit, 1999), bacteria from soil and water (Primrose, 1976), and a common pathogen of fruit called green mold (Penicillium digitatum) (Fukuda and Ogawa, 1991). However, ethylene gas is synthesized at some level in all plant tissues. This could be a problem in an enclosed environment, since these low levels could build up to concentrations that have an undesirable physiological/biological impact on plants. In etiolated pea seedlings ethylene levels could build up to concentrations that have an undesirable physiological/biological impact on plants. This could be a problem in an enclosed environment, since these low levels could build up to concentrations that have an undesirable physiological/biological impact on plants. As ethylene can affect its own synthesis by turning on or off genes that encode some portion of its biosynthetic pathway. It is considered auto-catalytic when ethylene stimulates its own synthesis, and anti-inhibitory when it turns off continued synthesis (Mattoo and Yang, 1979; Imaseki, 1991; Yang and Hoffman, 1984). Ethylene can affect its own synthesis by turning on or off genes that encode some portion of its biosynthetic pathway. It is considered auto-catalytic when ethylene stimulates its own synthesis, and anti-inhibitory when it turns off continued synthesis (Mattoo and Yang, 1979; Imaseki, 1991; Yang and Hoffman, 1984). A diverse multigene family encodes ACS (Zarembinski and Theologis, 1994), which is the rate-limiting step in the ethylene biosynthetic pathway. Synthesis of ethylene requires oxygen for oxidation of ACC to ethylene by ACO, and is stimulated by low levels and inhibited by high levels of carbon dioxide (especially if the response is auto-catalytic) (Abeles et al., 1992; Sisler and Wood, 1988). Wound- or stress-response ethylene is thought to enhance activity of ACS (Applebaum and Yang, 1981; Boller and Kende, 1980). Ripening, however, after onset of the climacteric, seems to stimulate ACO (Lelièvre et al., 1997).

Mechanism of Action

To have a biological effect, ethylene must bind to a receptor that is thought to reside in a membrane. If the receptor is blocked, then ethylene will have no effect (inhibition of ethylene action). Silver ions, carbon dioxide, 2,5-norbornadiene, and 1-methylcyclopropene (1-MCP) can block the ethylene receptor, and therefore inhibit ethylene-induced effects, including its own synthesis as in the case of auto-catalytic ethylene production (Abeles et al., 1992; Saltveit, 1999; Sisler et al., 1986). An ethylene receptor has also been knocked out by antisense molecular techniques in tomato, a fruit that normally needs ethylene to accelerate ripening. These mutant tomatoes ripen very slowly (Klee and Clark, 2002).

Physiological Effects

On a cellular level, ethylene can stimulate phenylpropanoid metabolism, inhibit transport of the plant hormone auxin, inhibit shoot elongation (vertical growth) (Pratt and Goeschl, 1969; Raskin, 1991), change the cell wall microfibril orientation (Takeda and Shibota, 1981), and promote synthesis of cell wall digesting enzymes (Kader, 1985; Watada, 1986). In some cases, ethylene also stimulates synthesis of anthocyanins and carotenoids (Rugini et al., 1982; Stewart and Wheaton, 1972), which are plant pigments that give blue, purple, red, orange, and yellow colors to fruit and vegetables and some of which are powerful antioxidants (Watada, 1986). At the same time, ethylene can stimulate the destruction of chlorophyll, the green pigment in plants (Kader, 1985; Saltveit, 1999; Watada, 1986). However, transgenic tomatoes with reduced ethylene synthesis did not have reduced chlorophyll loss, but did have delayed

| Table 1. Advantages, disadvantages and disorders due to ethylene. |
|---------------------------------------------------------------|
| **Effects of ethylene** |
| **Useful effects** |
| Induction and synchronization of ripening, softening, and aroma development in fruit |
| Color development of fruit |
| Degreening of citrus |
| Flowering in pineapple |
| Increased sugar development (grapes) |
| Dehiscence in nuts |
| Altered sex expression in cucurbits |
| Harvesting aid through promotion of abscission |
| Reduction of chilling injury in honeydew melon |
| Reduced black spot in potatoes |
| Decreased susceptibility to infection by certain pathogens |
| **Negative effects** |
| Senescence of flowers |
| Shortened shelf-life of fruit and vegetables |
| Synthesis of bitter compounds in carrots |
| Yellowing of some vegetables like cucumber, broccoli and cabbage |
| Sprouting of potato |
| Softening of apple |
| Hardcore in sweet potato |
| Undesirable abscission of flowers, fruit, calyces and leaves |
| Toughening of asparagus |
| Increased respiration of potato tubers |
| Increased susceptibility to infection by certain pathogens |
| **Disorders due to ethylene** |
| Core-browning in apples |
| Internal breakdown of kiwi fruit |
| Russet spotting of lettuce (stimulation of |
| Abscission of cabbage leaves |
| Increased sensitivity to chilling injury (avocado and grapefruit) |
| Internal breakdown of watermelon |
| In-rolling of flower petals |
| Closure of open flowers (Asleepy® flowers) |
| Inhibition of shoot and root elongation of some bulb species |
| Bud necrosis in tulips |
| Increased respiration of iris and tulip bulbs |
| Epinastic curvature (downward curvature) of leaves in some ornamental plants |

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Ethylene also plays a role in plant defense responses. It increases susceptibility of citrus to fungal infections such as stem-end rot, but decreases decay due to water pathogens (McCullom, 2002; Watada, 1986). Treatment of ‘Golden Delicious’ apples with ethylene action inhibitor, 1-MCP, resulted in reduced decay in the intact fruit during storage (Saftner et al., 2003). However, use of 1-MCP, on intact ‘Gala’ apples resulted in reduced ethylene synthesis (at least initially), respiration, and increased decay of the subsequent cut slices compared to fruit not treated with 1-MCP, which lowered the acceptability rating for the cut slices (Table 2). This would indicate that ethylene may play a role in the defense response of wounded apples.

**Amelioration of Ethylene Action**

There are ways to control ethylene levels in the atmosphere. Ethylene can be removed from the atmosphere by potassium permanganate, brominated charcoal, ozone, and ultraviolet light (Abeles et al., 1992). Ripening and wounded fruit could be removed from storage environments, as could combustion or gas-powered engines. Soil and water would also need to be kept free of microorganisms. There are ethylene synthesis inhibitors such as aminovinylglycine (AVG) or cobalt, which inhibit ACS (Yang, 1985), but these cannot be applied postharvest. Ethylene biosynthesis can be inhibited under conditions of low oxygen and high carbon dioxide, otherwise known as a controlled atmosphere (CA), modified atmosphere packaging (MAP), edible coatings (Baldwin, 1994) and low temperature.

Genetic engineering can also be used to reduce fruit ethylene production (Saltveit, 1999). For example, in tomato key enzymes in the ethylene synthesis pathway have been down-regulated, including ACS (Oeller et al., 1991), ACO (Hamilton et al., 1990) and an ethylene receptor, and ACC deaminase has been ectopically expressed (Klee et al., 1991). Tomatoes from plants with downregulated ACS or ACO do not produce much ethylene and do not ripen. Tomatoes with inserted ACC deaminase do not make much ethylene due to the fact that this enzyme degrades ACC to α-ketobutyric acid, a precursor of branched chain amino acids.

Once formed, ethylene can be degraded into water, carbon dioxide, carbon monoxide, and formaldehyde. When combined with atomic oxygen, carbon monoxide, ethane, propylene, acetaldehyde, propenal, butanal, hydrogen, ethylene oxide, and dihydrocarbons can be formed (Abeles et al., 1992). Thus, ethylene gas has differential effects on quality attributes of fruit and vegetables and can affect growth patterns of other plants. In enclosed spaces, ethylene evolved from plants would build up to biologically active levels that could produce physiological effects.

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**Table 2. Effect of 1-MCP-treated intact apples on quality of fresh-cut slices during storage for up to 14 d at 8 °C.**

| Parameter | Control | 1-MCP | Control | 1-MCP | Control | 1-MCP |
|-----------|---------|-------|---------|-------|---------|-------|
| Day 0     |         |       | Day 7   |       | Day 14  |       |
| Visual quality (1–9 scale) | 9.0 a | 9.0 a | 8.3 a | 8.3 a | 4.3 b | 1.0 c |
| Color L*  | 80.1 a  | 80.1 a | 73.4 c | 73.9 b | 75.1 c | 66.0 d |
| Color a*  | −6.6 d  | −6.5 d | −5.6 c | −5.6 c | −2.6 b | −1.3 a |
| Firmness (kg·cm⁻²) | 4.7 a | 4.9 a | 4.4 ab | 5.1 a | 3.9 b | 4.6 ab |
| Ethylene (µL·kg⁻¹·h⁻¹) | 0.4 d | ND* | 1.6 c | ND | 3.3 b | 5.1 a |
| Respiration (CO₂/µL/kg/h) | 9.6 a | 7.5 c | 9.4 a | 7.3 c | 9.5 a | 8.3 b |

*Means (n = 3) in the same row that are followed by the same letter are not significantly different (P < 0.05).

*ND = not detected.

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