**Felix Instruments: Ethylene Technical Note**

**ETHYLENE 101**

**What is ethylene?**

Ethylene ($C_2H_4$) is an odorless, colorless gas which acts as a plant hormone. It is a simple hydrocarbon with a double bond and is highly active at low concentrations. Ethylene can originate from several sources including plant materials, especially ripening fruit or rotting plant material. The major non plant sources of ethylene include improperly adjusted or dirty greenhouse heating units, leaky gas lines, exhausts from combustion engines and forest fires. Even cigarette smoke can be a source of ethylene.

Much of the focus on ethylene has been on the effects on harvested horticultural crops, although ethylene also plays a role during growth of all plants, and all plant parts produce ethylene.

**Ethylene production**

Ethylene production varies greatly between different species (Table 1), within a plant and at different stages of development (Table 2). The rate of ethylene production increases if the plants is stressed by wounding or mechanical damage, drought, disease and high temperatures (up to 30C). Decreasing temperatures reduces ethylene production rates as does modifying the atmospheres (lower oxygen to 8% and increasing CO2 to >2%).

**Table 1** Ethylene production at 20˚C/68˚F (adapted from Kader, 2002).

| **Class** | **Ethylene production (µl $C_2H_4$/kg-h)** | **Commodities** |
|---|---|---|
| Very low | <0.1 | Cherry, citrus, grape, strawberry, pomegranate.<br>Artichoke, asparagus, cauliflower, leafy vegetables, root vegetables, potato. Most cut flowers. |
| Low | 0.1-1 | Blackberry, blueberry, cranberry, persimmon, pineapple, raspberry, watermelon.<br>Cucumber, eggplant, olive, pepper, pumpkin. |
| Moderate | 1-10 | Banana, fig, honeydew melon, litchi, mango, plantain.<br>Tomato. |
| High | 10-100 | Apple, apricot, avocado, kiwifruit (ripe), nectarine, papaya peach, pear, plum. |
| Very high | >100 | Cherimoya, passion fruit. |

Even if a commodity has a very low ethylene production rate of 0.01 uL/kg/h it can reach levels of 120 ppb in a closed room if the produce occupies 30% of the volume.

**Ethylene sensitivity**

Ethylene is produced by plants and by external sources (e.g. combustion). Both these sources of ethylene can affect plants but in order to do so the ethylene has to bind with a receptor in the plant. This results in the typical responses that are associated with ethylene.

Ethylene production is not necessarily related to sensitivity. For example unripe kiwifruit, mature-green tomato and watermelon produced very little ethylene but are very sensitive to it, whereas ripe tomato and fig produced moderate amounts of ethylene but are not very sensitive to ethylene.

A list of ethylene production and ethylene sensitivity for a wide range of fresh produce can be found in Cantwell (2002).

**What does ethylene do?**

**Growing plants**

Elevated ethylene concentrations in field production can affect plant growth. This occurs under stressful conditions when the plant produces more ethylene, after heavy applications of compost, or when crops are grown near industrial areas of landfills. Yields of cotton have been reduced when growing within a 2 mile radius of a polyethylene plant (Hall et al., 1957).

Research on closed growing conditions, mimicking crop production in space, have highlighted the negative effects of small amounts of ethylene (50 ppb) on growth of plants including shorter plants, leaf rolling, premature senescence and sterility. Yield reductions of 36% were measured in wheat and 63% in rice after long term exposure to 50 ppb ethylene. Tomato had a 50% yield reduction at 10 ppb ethylene. Yields of lettuce and radish were also affected but not to the same extent (Abeles et al., 1992; Klassen & Bugbee, 2004).

Incomplete combustion of heating fuels can cause ethylene to accumulate in greenhouses. But even closed or poorly ventilated growth chambers or greenhouses can accumulate sufficient ethylene to damage growing plants. Typical symptoms include malformed leaves and flowers, thickened stems and leaves, lack of growth (stunting), abortion of flowers and leaves, bud and leaf abscission, epinasty (drooping and curling of leaves), and hastening senescence of cut flowers. Symptoms are also more likely to be observed in poly covered greenhouses than glass greenhouses because they are more airtight (Gibson et al., 2000).

**Fruit**

Ethylene can be beneficial or detrimental to fruit. Fruit ripening is stimulated by the use of ethylene at 10-100 ppm. This is used commercially for the ripening of several climacteric fruit. For example, bananas are harvested in the tropics when they are mature green, shipped to markets and then ripened at moderate temperatures and ethylene concentrations of 10-100 ppm. Tomatoes that are harvested mature green (no external red color) are usually ripened with ethylene to hasten the process. Other climacteric fruit can also be ripened with ethylene including avocado, kiwifruit, melons, pear, and most stone fruit.

Ethylene is used to degreen citrus fruits, which are non-climacteric fruit. In this case the ethylene causes degradation of the green chlorophyll and allows the yellow-orange colors to be visible. This occurs naturally when cold weather induces ethylene production. Only in the tropics are consumers used to eating green skinned, tasty citrus!

But aside from these beneficial effects, ethylene is predominantly detrimental. Senescence (or aging) of fruits is stimulated by ethylene resulting in soft, overripe fruit resulting in losses during postharvest handling. Ethylene can cause or exacerbate some specific disorders in fruit e.g. superficial scald of apples. or increase susceptibility to fungal decay, e.g. *Diplodia* stem end rot on citrus and *Botrytis cinerea* (gray mold) on strawberry.

**Vegetables and Herbs**

Ethylene causes some specific disorders in non-fruit vegetables. For example it stimulates the production of a bitter compound (isocoumarin) in carrots, causes yellowing of broccoli, cucumber and green leaves of many vegetables and herbs, russet spotting on lettuce, abscission of the leaves on cabbage and cauliflower, abscission of the stem and calyx from eggplants and lignification or toughening of asparagus spears. Ethylene can also stimulated *Botrytis cinerea* (gray mold) infection.

Researchers in Australia have demonstrated an extension in postharvest life for many kinds of produce not usually associated with ethylene damage, by storing them in air containing <0.005 ppm (<5 ppb) or 0.1 ppm (100 ppb) ethylene. In all cases shelf life was longer when ethylene was reduced (Figure 1)(Wills et al., 1999).

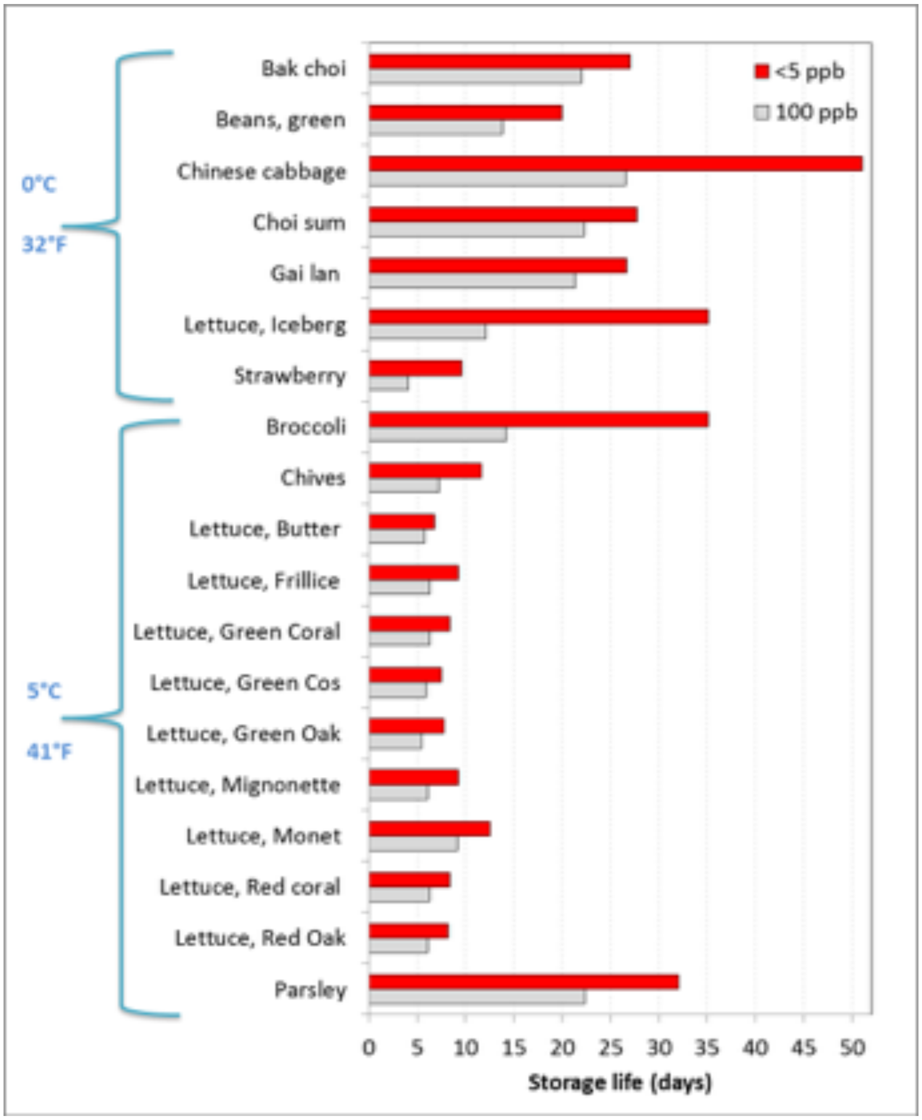


**Figure 1** Storage life (days) of various vegetables and strawberry at typical storage temperatures when exposed to air containing < 5 ppb or 100 ppb of ethylene (adapted from Wills et al., 1999).

| Produce | Storage temperature | | Storage life (days) | | | Increase in storage life (%) |
|---|---|---|---|---|---|---|
| | °C | °F | 100 ppb | <5 ppb | Increase in life | |
| Bak choi | 0 | 32 | 22 | 27 | 5 | 23 |
| Beans, green | 0 | 32 | 14 | 20 | 6 | 45 |
| Chinese cabbage | 0 | 32 | 27 | 51 | 25 | 92 |
| Choi sum | 0 | 32 | 22 | 28 | 5 | 24 |
| Gai lan | 0 | 32 | 21 | 27 | 5 | 25 |
| Lettuce, Iceberg | 0 | 32 | 12 | 35 | 23 | 190 |
| Strawberry | 0 | 32 | 4 | 10 | 6 | 134 |
| Orange | 2.5 | 37 | 80 | 130 | 50 | 62 |
| Broccoli | 5 | 41 | 14 | 35 | 21 | 147 |
| Chives | 5 | 41 | 7 | 12 | 4 | 61 |
| Lettuce, Butter Arizona | 5 | 41 | 6 | 7 | 1 | 19 |
| Lettuce, Frillice | 5 | 41 | 6 | 9 | 3 | 48 |
| Lettuce, Green Coral | 5 | 41 | 6 | 8 | 2 | 33 |
| Lettuce, Green Cos | 5 | 41 | 6 | 8 | 2 | 27 |
| Lettuce, Green Oak | 5 | 41 | 6 | 8 | 2 | 42 |
| Lettuce, Mignonette | 5 | 41 | 6 | 9 | 3 | 52 |
| Lettuce, Monet | 5 | 41 | 9 | 13 | 3 | 36 |
| Lettuce, Red coral | 5 | 41 | 6 | 8 | 2 | 33 |
| Lettuce, Red Oak | 5 | 41 | 6 | 8 | 2 | 34 |
| Parsley | 5 | 41 | 22 | 32 | 10 | 43 |

### Ornamentals

Cut flowers or potted flowering plants usually respond to ethylene in one of two ways, flower or petal abscission e.g. lily, or flower wilting (called sleepiness in carnations). In addition ethylene can causes yellowing and abscission of leaves. Presence of ethylene during the storage of tulip bulbs can cause including increased bulb gummosis and respiration, reduced rooting, vigor and height, bulb splitting and increased flower bud abortion (Liou & Miller, 2011). *Fusarium* infections of the bulbs result in high ethylene production which exacerbates these problems.

## Units of measurement

Ethylene concentrations are usually expressed in ppm (uL/L) or ppb (nL/L). (Note: 1 ppm is the equivalent of 1 sec in 11.5 days and 1 ppb is the equivalent of 1 sec in almost 32 years).

## Typical levels of ethylene in the environment, production and postharvest handling

**Table 3** List of published measured ethylene concentration in the environment, production and postharvest handling.

| Location | Season or Temp. (°C) | Average (ppb) | Minimum (ppb) | Maximum (ppb) | Number of samples | Reference |
|---|---|---|---|---|---|---|
| **Pollution or Environmental** | | | | | | |
| Rural areas | | | <1 | 5 | | OECD screening information datasets (SIDS) |
| Atlantic Ocean | | | 0 | 10 | 17 | Lawton, 1991 |
| Pacific Ocean | | | 0 | 9 | 20 | Lawton, 1991 |
| Urban areas | | | | <50 | | OECD screening information datasets (SIDS) |
| Urban areas California | | | | 500 | | Scott et al., 1957 |
| Urban areas Washington DC | | | | 700 | | Abeles & Heggestad, 1973 |
| Heavy traffic | | | | up to 1,000 | | OECD screening information datasets (SIDS) |
| Industrial production and use | | | | <160 | | OECD screening information datasets (SIDS) |
| Petrochemical plants | | | | up to 4,300 | | OECD screening information datasets (SIDS) |
| Tap water | | | | 7 | | Elzenga et al., 1980 |
| Ditch water (the Netherlands) | | | 15 | 50 | | Elzenga et al., 1980 |
| Butane fueled forklift exhaust | | | | 150,000 | | Keller et al., 2013 |
| Diesel motor exhaust | | | | 60,000 | | Keller et al., 2013 |
| Gasoil motor exhaust | | | | 60,000 | | Keller et al., 2013 |
| Cigarette smoke | | | 100,000 | 800,000 | | Keller et al., 2013; Shaikh et al. 1988 |
| **Growing Environment** | | | | | | |
| Lettuce field | | | <10 | 120 | 21 | Morris et al., 1978 |
| Soil | | | | | | |
| Waterlogged soil | | | | | | |
| Compacted soil | | | | | | |
| Soil with organic materials | | | | | | |
| Soil with diseased plants | | | | | | |
| Canopy of cotton | | | | 80 | | Heilman et al., 1971 |
| Growers | | | 0 | 7,620 | 178 (4 growers | Skog et al., 2001 |
| **Postharvest Environment** | | | | | | |
| **Field to storage** | | | | | | |
| Lettuce carton field to cooler | | 70 | 30 | 110 | 3 | Morris et al., 1978 |
| Lettuce holding area prior to cooling | | 50 | 10 | 610 | 47 | Morris et al., 1978 |
| Lettuce carton in holding area | | 160 | 10 | 800 | 12 | Morris et al., 1978 |
| Lettuce carton after vac cooling | | 120 | 10 | 290 | 11 | Morris et al., 1978 |
| **Packing house** | | | | | | |
| Kiwifruit pack house | | | 0 | 70 | 51 | Lawton, 1991 |
| **Storage** | | | | | | |
| Lettuce cold storage room | | 330 | 10 | 2,780 | 144 | Morris et al., 1978 |
| Lettuce carton cold storage | | 220 | 10 | 1,560 | 73 | Morris et al., 1978 |
| Kiwifruit cold storage | | 15 | 5 | 55 | 55 | Lawton, 1991 |
| Apple cold storage | | 15,000 | 2,000 | 25,000 | 5 | Lawton, 1991 |
| Pear cold storage | | 15,000 | 2,000 | 25,000 | 5 | Lawton, 1991 |
| Apple CA | | 71,000 | 27,000 | 243,000 | 11 | Lawton, 1991 |
| Pear CA | | 22,000 | 11,000 | 118,000 | 22 | Lawton, 1991 |
| Carnation cold storage (Kenya) | | 13,000 | | | 5 | Holcroft, 2006 (unpublished) |
| **Transportation** | | | | | | |
| Australian terminals | | 6 | 0 | 15 | 23 | Lawton, 1991 |
| New Zealand terminals | | 4 | 0 | 26 | 19 | Lawton, 1991 |
| New Zealand fruit terminals | | 10 | 2 | 38 | 20 | Lawton, 1991 |
| Belgium fruit terminals | | 10 | 3 | 15 | 12 | Lawton, 1991 |
| Ship holds with kiwifruit | | | 1 | 38 | | Lawton, 1991 |
| Ship hold with apples after loading | 2.5-5 | | 5,000 | 15,000 | | Lawton, 1991 |
| Ship hold with apples after 72 h | <5 | | 500 | 1,700 | | Lawton, 1991 |
| Reefer ship - Port | | | | 47,000 | | Lawton, 1991 |
| Reefer ship - Centre | | | | 46,000 | | Lawton, 1991 |
| Reefer ship - Starboard | | | | 10,000 | | Lawton, 1991 |
| Reefer ship - Port | | | | 42,000 | | Lawton, 1991 |
| Reefer ship - Centre | | | | 55,000 | | Lawton, 1991 |
| Reefer ship - Starboard | | | | 10,000 | | Lawton, 1991 |
| Rail cars with lettuce | | 60 | 10 | 190 | 14 | Morris et al., 1978 |
| Lettuce carton in rail car | | 10 | 10 | 20 | 3 | Morris et al., 1978 |
| Trucks with lettuce | | 80 | 40 | 220 | 9 | Morris et al., 1978 |
| Lettuce cartons in trucks | | 90 | 80 | 110 | 4 | Morris et al., 1978 |
| closed truck at 12 h - loading bay | | | | 4,500 | | Schouten, 1985 |
| closed truck at 18 h - on road | | | | 4,100 | | Schouten, 1985 |
| closed truck at 26 h - on ferry | | | | 4,300 | | Schouten, 1985 |
| closed truck at 34 h - on ferry | | | | 5,800 | | Schouten, 1985 |
| closed truck at 44 h - on arrival | | | | 6,500 | | Schouten, 1985 |
| ventilated trailer at 58 h - unloading | | | | 10,400 | | Schouten, 1985 |
| ventilated trailer at 12 h - loading bay | | | | 1,200 | | Schouten, 1985 |
| ventilated trailer at 18 h - on road | | | | 300 | | Schouten, 1985 |
| ventilated trailer at 26 h - on ferry | | | | 300 | | Schouten, 1985 |
| ventilated trailer at 34 h - on ferry | | | | 1,700 | | Schouten, 1985 |
| ventilated trailer at 44 h - on arrival | | | | 100 | | Schouten, 1985 |
| ventilated trailer at 58 h - unloading | | | | 500 | | Schouten, 1985 |

| Location | Season or Temp. (°C) | Average (ppb) | Minimum (ppb) | Maximum (ppb) | Number of samples | Reference |
|---|---|---|---|---|---|---|
| **Products and Packaging** | | | | | | |
| Strawberry clamshells | | | | 230 | | Wills & Kim 1995 |
| Green beans packages | | | | 340 | | Wills & Kim 1996 |
| Iceberg lettuce | | | | 420 | | Wills & Kim 1995 |
| Chinese cabbage (stacked cartons) | | | 860 | 1,450 | | Wills & Kim 1996 |
| Inside MAP packages | | | | <4800 | | Lawton, 1991 |
| **Processor** | | | | | | |
| Processor | | | 50 | 133,300 | 4 (3 processors | Skog et al., 2001 |
| **Wholesale markets (WM)/Distribution Centers (DC)** | | | | | | |
| WM | | | 20 | 45,000 | 0 (8 wholesale | Skog et al., 2001 |
| WM and DC | | | | 60 | | Wills et al., 2000 |
| DC and warehouses | | 250 | 30 | 2,490 | 22 | Morris et al., 1978 |
| Lettuce carton in DC/warehouse | | 80 | 10 | 780 | 43 | Morris et al., 1978 |
| WM - climacteric fruit | Spring | 158 | | | 61 | Wills et al., 2000 |
| WM - leafy greens | Spring | 74 | | | 42 | Wills et al., 2000 |
| WM - non-climacteric fruit | Spring | 67 | | | 87 | Wills et al., 2000 |
| WM - trading areas | Spring | 63 | | | 9 | Wills et al., 2000 |
| WM - climacteric fruit | Summer | 495 | | | 46 | Wills et al., 2000 |
| WM - leafy greens | Summer | 82 | | | 52 | Wills et al., 2000 |
| WM - non-climacteric fruit | Summer | 61 | | | 67 | Wills et al., 2000 |
| WM - trading areas | Summer | 70 | | | 9 | Wills et al., 2000 |
| WM - climacteric fruit | Autumn | 281 | | | 12 | Wills et al., 2000 |
| WM - leafy greens | Autumn | 61 | | | 38 | Wills et al., 2000 |
| WM - non-climacteric fruit | Autumn | 67 | | | 49 | Wills et al., 2000 |
| WM - trading areas | Autumn | 66 | | | 9 | Wills et al., 2000 |
| WM - climacteric fruit | Winter | 66 | | | 18 | Wills et al., 2000 |
| WM - leafy greens | Winter | 42 | | | 18 | Wills et al., 2000 |
| WM - non-climacteric fruit | Winter | 46 | | | 36 | Wills et al., 2000 |
| WM - trading areas | Winter | 50 | | | 9 | Wills et al., 2000 |
| WM (all areas all season) | | 65 | | | 562 | Wills et al., 2000 |
| DC1 - kiwifruit storage | 0 | 233 | | | 7 | Wills et al., 2000 |
| DC2 - kiwifruit storage | 0 | 127 | | | 6 | Wills et al., 2000 |
| DC2 - kiwifruit storage | 0 | 243 | | | 4 | Wills et al., 2000 |
| DC1 - avocado arrival | 5 | 588 | | | 4 | Wills et al., 2000 |
| DC1 - avo ripening | 20 | 896 | | | 5 | Wills et al., 2000 |
| DC1 - avocado holding room | 7 | 1,412 | | | 6 | Wills et al., 2000 |
| DC1 empty room | 17 | 288 | | | 3 | Wills et al., 2000 |
| DC1 ambient air | 17 | 68 | | | 4 | Wills et al., 2000 |
| DC2 ambient air | 16 | 72 | | | 4 | Wills et al., 2000 |
| DC3 ambient air | 15 | 31 | | | 5 | Wills et al., 2000 |
| DC3 cold room 1 | 6 | 81 | | | 5 | Wills et al., 2000 |
| DC3 cold room 1 | 2 | 80 | | | 5 | Wills et al., 2000 |
| **Retailer** | | | | | | |
| Retailer | | | 0 | 2,250 | 320 (5 retailers | Skog et al., 2001 |
| Retail storage areas | | 360 | 20 | 2,950 | 19 | Morris et al., 1978 |
| Lettuce carton in retail storage area | | 410 | 60 | 2,880 | 18 | Morris et al., 1978 |
| Retailer - receiving | | 23 | 9 | 35 | 49 (7 retailers) | Wills et al., 2000 |
| Retailer - storage | 5 | 35 | 21 | 47 | 49 (7 retailers) | Wills et al., 2000 |
| Retailer - display | 23 | 17 | 11 | 23 | 49 (7 retailers) | Wills et al., 2000 |
| **Home storage** | | | | | | |
| Refrigerators with apples | | | | 200 | | Wills et al., 2000 |
| Refrigerators without apples | | | | 29 | | Wills et al., 2000 |
| Refrigerator crisper | | 100 | 11 | 590 | 30 | Wills et al., 2000 |
| Refrigerator | | 250 | 20 | 1,580 | 33 | Morris et al., 1978 |
| Refrigerator with Produce selection A | 4 | 400 | 200 | 500 | | Rees et al., 2011 |
| Refrigerator with Produce selection B | 4 | | 1,500 | 3,600 | | Rees et al., 2011 |
| Refrigerator | 4 | | 900 | 5,000 | | Rees et al., 2011 |
| Refrigerator | | | | 66 | | Rees et al., 2011 |
| Refrigerator | | | | 9,915 | | Rees et al., 2011 |

**Physiological Active Ethylene Concentrations**

The effects of ethylene are affected by concentration, duration of exposure and temperature, as well as factors such as plant type, cultivar and developmental stage. Ethylene concentrations of 0.1 ppm (100 ppb) have often been quoted as the threshold level for ethylene activity. Abeles et al. (1992) showed that the half maximal concentrations of applied ethylene for most reactions were between 100 ppb and 1 ppm but that threshold concentrations were usually about 10 ppb. In specific cases even 1 ppb can trigger ethylene responses.

More recent research by Wills et al. (1999) and Klassen & Bugbee (2001) has shown that long term (chronic) exposure to low concentrations of ethylene (10-25 ppb) have deleterious effects on fruits, vegetables, ornamentals, greenhouse crops and field crops. In many commodities ethylene levels should be kept below 0.01 ppm (10 ppb). Flowering of some cultivars of tulip bulbs is reduced by exposure to ethylene concentration of 10 ppb for 10 days during the latter stage of storage (Liou & Miller, 2011). Kiwifruit softening during storage at 0°C/32°F was reduced by ethylene free atmospheres and even 10 ppb hastened softening (Retamales & Campos, 1997).

**Conclusions**

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