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Controlled-atmosphere disorders of commercial fruits and vegetables

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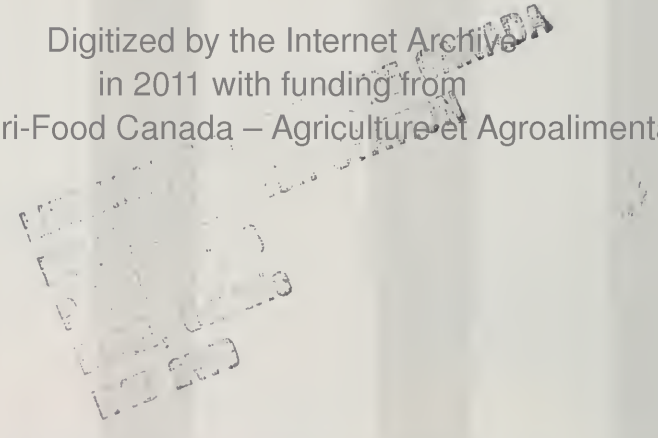

Controlled-atmosphere disorders of commercial fruits and vegetables

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LOW-OXYGEN INJURY

Low-oxygen injury occurs occasionally in controlled-atmosphere rooms in which the atmosphere sampling system has developed a leak to air, and room oxygen levels have decreased to below 2%. Usually the carbon dioxide level would be higher than recommended, and the combination of low levels of oxygen and high levels of carbon dioxide may result in severe injury without revealing whether the injury is caused by low oxygen or high carbon dioxide. Low-oxygen injury may also occur randomly in apples held under commercial conditions of low oxygen (1.0–1.5% oxygen), and in severe cases a major proportion of the apples are affected. In commercial low-oxygen storage it is unlikely that the carbon dioxide level will be high enough to interact with low oxygen levels.

Few experiments have been carried out to study cultivar sensitivity to low-oxygen injury, and this assessment may be biased by the fact that most of the work in northeastern North America on controlled-atmosphere storage of apples has been done with McIntosh. However, some preliminary comparative studies (Lougheed and Franklin 1968, 1969) and observations indicate that McIntosh may be the most sensitive to low-oxygen injury, at least to the visible injuries noted (Figs. 4, 5, 6, 7, 12, 13); Delicious is moderately sensitive; and Northern Spy, Empire, and Spartan are relatively immune. Lidster et al. (1985) indicate that Spartan may be more susceptible to low-oxygen injury than McIntosh.

The external symptoms of low-oxygen injury are similar to those described for soft scald (Pierson et al. 1971), which consist of brownish areas with definite margins on the skin, ranging from small patches (Anderson 1967) to large areas covering a major portion of the fruit. The intensity of the brown may depend on the background color, being less intense in McIntosh than in Delicious (for injury on Delicious see Anderson 1967). The internal injury, which consists of brownish corky sections with occasional cavities, appears inside the fruit and is sometimes contiguous with the external injury. The fruit tissue outside the affected areas may be firm and visibly unaffected. The site of the external injury may also be an area in which rotting occurs, but often, except in advanced stages, with the well-defined outline of the original injury remaining.

Additional symptoms are invasive alcohol injury (brownish flesh discoloration) (Smock 1977), sometimes bleaching or scalding of the skin, purpling of the blushed areas of the skin, and alcoholic odors and flavors. The detection of off-flavors is often made more difficult by the

Fig. 1 Friction discoloration caused by abrasion during poststorage handling of McIntosh apple from a low-oxygen atmosphere. The patchy areas may be confused with storage (superficial) scald.

Note: This figure appears in Lougheed et al. 1982, and permission to reproduce it is gratefully acknowledged.

Fig. 2 Superficial carbon dioxide injury on McIntosh apples.

Fig. 3 Superficial carbon dioxide injury on McIntosh apple.

Fig. 4 Epidermal darkening of McIntosh apple (*right*) as compared with nonaffected apple held at 0.2% carbon dioxide plus 1.0% oxygen at 3°C (*left*).

fact that the fruit may ripen slowly in a low-oxygen atmosphere and even in air afterwards, and the perceived off-flavor may be partly associated with the unripeness of the fruit. Occasionally, McIntosh fruit may split in low-oxygen atmospheres or if it is held subsequently in the air at room temperature. The fruit may still be firm and the ground color still green, indicating that the fruit is not senescent, although chronologically it is old.

Because of the interaction of factors, particularly oxygen level, length of exposure to low-oxygen atmospheres, and temperature, it is impossible to give definite limits. For example, a brief period in a measured atmosphere of 0% oxygen at 0 or 3°C is unlikely to cause harm, but somewhat less than 2% oxygen for extended periods may be harmful. An operational limit for commercial low-oxygen storage would be in the range of 0.8%–1.5% oxygen, with benefits being much less at the upper oxygen level. However, even long-term storage of McIntosh at 0.5% oxygen may not cause low-oxygen injury if the apples are carefully selected.

The following factors may induce additional risk of injury: late harvest, holding for considerable time (more than 1 week) before imposing the atmosphere, slow oxygen reduction, and slow removal of field heat (i.e., slow cooling) (Lidster et al. 1985). Note that these factors are generally those that lead to fruit aging, and the symptoms are more likely to be invasive alcohol poisoning and senescent-like internal disorders than those illustrated in Fig. 12.

Delayed removal of field heat, low storage temperature (below 3°C), and fluctuating oxygen levels (from 1.0 to 2.5% oxygen or more) are believed to induce low-oxygen injury in McIntosh apples (Lidster et al. 1985). High carbon dioxide levels may combine in storage with low oxygen to induce an apparently higher incidence of low-oxygen injury or more severe carbon dioxide injury (Porritt et al. 1982). Other factors that are thought to increase injury are surface water on the fruit, such as might occur in prestorage treatment for storage scald (Lidster et al. 1985) or as a result of condensation of moisture on the fruit at high relative humidity.

The risk of low-oxygen injury can be reduced by using recommended atmospheres, minimizing variation in atmospheres, selecting early harvested fruit, cooling and storing fruit promptly, and imposing atmospheres quickly.

Lidster et al. (1985) found that intermittent high and low levels of oxygen (between 1.0 and 21%) during the storage period may induce anaerobiosis and low-oxygen injury. Aeration reduces internal alcohol levels and thus removes some of the off-flavors and off-odors, if the injury is not too severe. Presumably, aeration outside the storage at room temperature would be more effective than inside the storage. However, aeration does not delay the development of other types of disorders, and the external affected tissue may develop decay.

CARBON DIOXIDE INJURY

Carbon dioxide injury often results from holding fruit in atmospheres above its tolerance for carbon dioxide. It may be found in fruit kept in controlled-atmosphere storage, packed in gas-tight containers, or transported in poorly ventilated vessels or vehicles. Carbon dioxide injury may also be found in fruit treated with high levels of carbon dioxide (e.g., 10–20% carbon dioxide for 10 days or more) before controlled-atmosphere storage.

The incidence and extent of carbon dioxide injury is influenced by carbon dioxide concentration and duration of exposure as well as by cultivar, fruit maturity, storage temperature, and oxygen concentration. Cultivars susceptible to carbon dioxide injury include Cortland, Cox's Orange Pippin, Fameuse, Golden Delicious, Granny Smith, Jonathan, McIntosh, Northern Spy, Rome Beauty, and Wealthy. Highly susceptible cultivars, such as Newton Wonder, sustain internal injury in only 3% carbon dioxide, whereas resistant cultivars, such as Worcester Pearmain, tolerate concentrations of up to 13%. The degree of the injury also varies with growing areas, orchards, and even among lots from different parts of an orchard.

A moderately high concentration of carbon dioxide interferes with the oxidation of succinic acid, which can accumulate to toxic levels in the cells. Carbon dioxide at concentrations of over 20% can lead to toxic accumulation of acetaldehyde. Cultivars and individual fruits vary in their susceptibility to injury because of anatomical differences (size of intercellular space, rate of diffusion of gases in the tissue) rather than biochemical differences. Carbon dioxide is diffused in fruit tissue more slowly than oxygen; the latter is usually near ambient concentration, so that low-oxygen injury rarely occurs even where carbon dioxide injury is excessive.

Recent knowledge of harvesting, handling, storage, and transportation of fruit has nearly eliminated carbon dioxide injury in apples stored in controlled atmospheres, the exception being certain lots of Golden Delicious treated with high levels of carbon dioxide before they are placed in commercial controlled-atmosphere storage (Couey and Olsen 1975, Lau and Looney 1978). Replacement of the high carbon dioxide treatment by a rapid controlled-atmosphere procedure (i.e., rapid loading and rapid oxygen reduction) maintains fruit firmness without causing fruit injury (Lau 1983).

EXTERNAL DISORDERS

Bronze epidermal discoloration (smooth lesions)

Bronze epidermal discoloration is a result of mechanical damage to the surface of the fruit after it is placed in low-oxygen or controlled-atmosphere storage. Color of the injured area, which is only superficially injured, varies from light to dark brown on the blushed

Fig. 5 Epidermal darkening of Spartan apple (*right*) as compared with nonaffected apple held at 0.2% carbon dioxide plus 1.0% oxygen at 3°C (*left*).

Fig. 6 Epidermal cracking of McIntosh apple stored in 0.2% carbon dioxide plus 1.0% oxygen at 3°C.

Fig. 7 Superficial low-oxygen injury on McIntosh apple. The injury is severe enough for internal injury or invasive alcohol injury to be present.

Fig. 8 Diffuse flesh browning (with cavitation) of Golden Delicious apple held in high carbon dioxide atmospheres.

areas of the fruit or brownish yellow on green areas. The margins of the injury may be well-defined, marking the edges of the abraded or bruised area (Fig. 1). The injured area may be distinguished from storage scald by the well-defined margins of the injury.

The extent of injury is usually less in fruit removed from regular controlled-atmosphere than from low-oxygen storage. There is little effect of postharvest duration or temperature (0 or 23°C) on the development of symptoms in air after injury.

This epidermal discoloration may occur in McIntosh apples as a result of low-oxygen (1.0–1.5%) storage during grading and packing procedures after long-term storage or at any time during a subsequent holding period. The incidence of the disorder can be eliminated or reduced by minimizing the bruising and scuffing–abrasion during packing and grading or in consumer packages.

Bronze epidermal discoloration (rough or sunken lesions)

External carbon dioxide injury in apples, which may or may not be accompanied by internal injury, is evident as irregular-shaped, roughened, tan to pebbly brown lesions on the skin, often partly sunken, with sharply defined edges (Figs. 2, 3). The injured areas are apparent on the skin of the fruit as early as 1–2 weeks after a prestorage high carbon dioxide treatment (i.e., 14% carbon dioxide or more for 10 days or 10% carbon dioxide for 14 days or more). The incidence and severity of the injury do not increase with subsequent duration of controlled-atmosphere storage. All parts of the fruit surface are subject to injury, but more injury occurs toward the calyx end of Golden Delicious apples and on the unblushed areas of the skin of McIntosh apples. Injured areas may range from a very small spot to as much as 75% of the skin surface.

The incidence and severity of external carbon dioxide injury are positively correlated with the carbon dioxide concentration and the duration of exposure and are also associated with immature fruit, free moisture on the fruit surfaces, and rapid establishment of carbon dioxide levels before the fruit is cooled. Fruit from vigorous trees with a light crop, fruit with a high nitrogen or manganese content, and fruit damaged by frost are more susceptible to the injury. The interactive effects of temperature and oxygen have not been clearly determined.

Epidermal pigment darkening

Anthocyanin or chlorophyll discoloration of the skin (Figs. 4, 5) is a symptom of low-oxygen injury. Darkening of the epidermal tissues may be the first visual symptoms of anoxia in apples but in some instances may not be evident, even though other symptoms are present. The anthocyanin or red coloration of the apple epiderm is the first to darken in response to anaerobiosis of the fruit. Early stages of

darkening can be reversed by removing the apples from the low-oxygen environment and placing the fruit in air at either 0 or 20°C. Continued exposure of the fruit to the injurious low-oxygen levels further darkens the anthocyanins, and severe injury results in the darkening of the nonblushed green portions (chlorophyll) of the fruit epiderm.

Epidermal cracking

Epidermal cracking (Fig. 6) in fruit stored in less than 1.5% oxygen is a form of low-oxygen injury. This disorder is distinct from mealy breakdown (Porritt et al. 1982) in that low-oxygen-induced epiderm cracking is not the result of tissue senescence but rather is a response to exposure to low-oxygen atmospheres. The flesh tissue beneath the cracked epidermis is usually dry and mealy and yields readily to pressure by the finger or thumb. Low-oxygen-induced epidermal cracking may be aggravated by high storage humidity and may be associated with epidermal darkening and other symptoms of low-oxygen injury.

Ribbon scald

Ribbon scald induced by low-oxygen atmospheres appears as smooth, brown, irregular-shaped, well-defined lesions of the skin (Fig. 7) and resembles the low-temperature-induced disorder soft scald (Porritt et al. 1982). Ribbon scald affects only the epiderm in the initial stages but extends into the flesh as the symptoms become more severe. An individual apple may be affected by one or more well-defined lesions, and all parts of the apple may be affected, irrespective of skin color. Ribbon scald, however, is more noticeable on the green portions of the fruit because of contrast in color. The detection of ribbon scald in fruit lots held in 1.5% oxygen or less indicates early stages of anaerobic respiration and suggests that the fruit should be returned to air storage at 0°C to prevent further injury.

INTERNAL DISORDERS

Core or flesh browning (brown heart)

Core or flesh browning, an internal carbon dioxide injury that is also called brown heart, is evident as brown necrotic cortex or core tissue that is fairly well defined, firm, and moist but readily becomes dry as moisture is lost to surrounding healthy tissue (Figs. 8, 9, 10). As desiccation continues, cavities develop, with light brown dry tissue forming the walls of the cavity. The external appearance of the fruit remains normal, except for severely injured fruit in which surface depressions may develop.

Fig. 9 Core browning (with cavitation forming) of McIntosh apples held in high carbon dioxide atmospheres.

Fig. 10 Medial flesh browning (with cavitation) of Northern Spy apples held in high carbon dioxide atmospheres.

Fig. 11 Corky flesh browning of McIntosh apple held in low-oxygen atmospheres.

Fig. 12 Medial flesh browning (with cavitation) of McIntosh apples held in low-oxygen atmospheres.

In some cultivars, tissue near the main vasculars of the core line is most susceptible. In others, the small scattered zones of injury may appear exclusively around the core, or the brown areas may appear at random throughout the flesh. The injury stops progressing when the conditions that cause it are removed.

In general, susceptibility to internal carbon dioxide injury increases with fruit maturity and size, delayed cooling, low storage temperature, and low oxygen. Susceptibility to external and internal carbon dioxide injury differs in fruit from one tree to another and is affected by seasonal differences. Studies on Golden Delicious show no relationship between the mineral composition of the fruit and carbon dioxide tolerance, but there is a positive correlation between the nitrogen content of the fruit and the degree of injury. Cultivars that are sensitive to carbon dioxide include McIntosh, Cortland, Cox's Orange Pippin, Fameuse, and Northern Spy; whereas Spartan, Delicious, and Golden Delicious are less likely to develop either external or internal symptoms. For additional information, see Bramlage et al. 1977, Carne and Martin 1938, Dewey 1962, Eaves and Hill 1940, Faust et al. 1969, Fidler and Mann 1972, Fidler et al. 1973, Hulme 1956, Knee 1973, Lau and Looney 1977, Meheriuk et al. 1977, Padfield 1969, Pierson et al. 1971, Plagge et al. 1935, and Smock 1977.

Corky flesh browning

Corky flesh browning is a necrosis of the flesh of McIntosh apples stored in 1.0–1.2% oxygen at 1.7°C for more than 6 months or in 2.5% oxygen at 1.7°C for more than 8–9 months. The disorder has not been observed in some fruit kept in 0°C air storage for as long as 9 months. Also, the disorder has not been found in such apple cultivars as Golden Delicious, Spartan, or Red Delicious kept in 1.0% oxygen at 0°C for 10 months.

Symptoms of corky flesh browning consist of localized areas of brown, corky, and dry tissues in the upper two-thirds of the fruit, either beneath the skin or separated from the skin by a thin area of normal hypodermal tissue (Fig. 11). The disorder is present initially in the outer cortex and may extend into the inner cortex, with cavitation occurring in more advanced stages (Fig. 12). Cavitation in apple flesh caused by low-oxygen atmospheres is usually associated with corky flesh browning.

Development of the disorder is associated with low storage temperatures (below 3°C) and low concentrations of oxygen (below 1.5%), but the fruit is unaffected by concentrations of carbon dioxide ranging from 0.5 to 2.0%. Advanced fruit maturity, evidenced by 10% or more of the fruit within a lot with internal ethylene at 1μL/L and a starch–iodine index of 5 or more, is also conducive to development of the disorder. The incidence of corky flesh browning also varies markedly from orchard to orchard and season to season and is reduced by the use of a higher temperature (near 3–4°C) in storage at 1.0 or

2.5% oxygen. The disorder is not necessarily related to low fruit calcium or a high potassium-to-calcium ratio. In a program to reduce corky flesh browning in McIntosh apples stored in 1.0% oxygen, proper storage temperature was shown to be much more important than correct harvest maturity and optimum fruit mineral levels.

Although the low-oxygen (1.0%) and low-temperature (1.7°C) regimens used in the storage of McIntosh apples retard senescence appreciably more than fruit stored in 2.5% oxygen and 3.0°C, they may also impart additional stress to the fruit tissue, leading to the development of corky flesh browning. It is also possible that under low-temperature and low-oxygen conditions, the anabolic and catabolic reactions necessary for cellular maintenance are impaired by an excessive reduction in the rate of metabolism, which then increases the sensitivity of the fruit to chilling injury or leads to the loss of membrane integrity, thus resulting in increased symptoms of corky flesh browning. Like core flesh browning in McIntosh apples or low-temperature disorder in Cox's Orange Pippin apples, corky flesh browning is a low-oxygen disorder and is aggravated by low temperature, evidenced by the fact that the use of a higher storage temperature (3.0°C instead of 1.7°C) greatly reduces the disorder in storage at both 1.0 and 2.5% oxygen. Corky flesh browning is distinguishable from either low-temperature or senescent breakdown in that corky flesh browning is initiated in the subepidermal tissue, whereas low-temperature or senescent breakdown is initiated in the hypodermal tissue.

Late storage corking of Cox's Orange Pippin

Late storage corking describes a necrosis of the flesh of Cox's Orange Pippin apples stored in 1.0–2.0% oxygen for longer than 6 months, hence the term late. Since the maximum storage life of Cox's Orange Pippin in 2.0% oxygen is about 6 months, the disorder is normally only of commercial importance in apples stored in 1.0–1.25% oxygen where storage can be extended for up to a further 2 months.

The term corking describes the lesions that are typically light brown and often dry (Fig. 13). These corky lesions occur both in the inner and outer cortical regions of the fruit and predominantly but not exclusively in the region between the stem end and the equator. Lesions are often diffuse and extensive, and in extreme cases they extend from the stem cavity to the equator of the fruit.

Development of the disorder is associated with a combination of factors that place the apple tissue under stress. The disorder is progressively aggravated by increased duration of storage, by lowering storage temperature over a range of 4–2.5°C, and by reducing storage oxygen concentration from 3.0 to 1.0%, although within the range of 1–3% the concentration of carbon dioxide in storage has no consistent effect (Johnson 1986). Fortunately, in practice, the

Fig. 13 Late storage corking of Cox's Orange Pippin apple held in low-oxygen atmospheres.

Fig. 14 Diffuse soggy flesh browning of McIntosh apples held in low-oxygen atmospheres.

necessity of maintaining a comparatively high storage temperature (3.5–4.0°C) for Cox apples in order to avoid low temperature breakdown also helps minimize the development of late storage corking.

To achieve 8 months' storage of Cox's Orange Pippin apples grown in the United Kingdom there can be no compromise on storage conditions (1.0% carbon dioxide plus 1.0–1.25% oxygen at 3.5–4.0°C), but because there is considerable orchard-to-orchard and season-to-season variation in susceptibility, the emphasis for control of the disorder is placed on preharvest factors. An imbalance in the potassium-to-calcium ratio in the fruit at harvest has proved to be of major importance. Consequently, in consignments of fruit where calcium is below 5.0 mg/100 g of fresh weight or potassium is above 150 mg/100 g of fresh weight, the fruit should be removed from controlled atmosphere storage after March (Sharples and Stow 1986). Late picking may also aggravate the disorder (North et al. 1977).

Morphologically and physiologically, considerable similarity can be found between late storage corking in Cox's Orange Pippin and corky flesh browning in McIntosh (Fig. 11). However, the latter in McIntosh is a low-temperature disorder that is aggravated by lower storage oxygen, longer storage periods, and advanced fruit maturity at harvest. Although storage temperature also affects the development of late storage corking in Cox's Orange Pippin apples, too many contributing factors are involved for any one factor to be considered the primary cause.

Diffuse soggy flesh browning

Diffuse soggy flesh browning first appears as light browning of the cortical flesh in response to atmospheres of 1.5% oxygen or less. If the fruit is not removed from the low-oxygen atmosphere the diffuse browning develops into well-defined, dark brown, water-soaked areas (Fig. 14). As the affected tissue is water-soaked and in a state of anoxia, a fermented odor is usually present.

Diffuse soggy flesh browning usually is not detected by external examination, which makes separation of the affected fruit from healthy fruit almost impossible. A low incidence of this disorder renders the entire lot unmarketable, so that care must be taken to examine fruit internally for the disorder. If the presence of soggy diffuse flesh browning is found, the entire room should be returned to air storage immediately and the affected lots removed before packing.

Tainted off-flavor

Loss of cultivar flavor is commonly the first indicator of low-oxygen injury. Indeed, periodic taste tests of apples held in low oxygen may be the only indicator required to determine if and when the oxygen should be raised to a safe level above 2.0%. If loss of cultivar

flavor is the only detectable symptom of low-oxygen injury, raising the oxygen concentration normally restores cultivar flavor, and other symptoms of low-oxygen injury do not develop. If, however, the apples are not exposed to higher oxygen concentrations, loss of cultivar flavor is followed by the development of detectable tainted flavor, which has also been described as alcoholic, tangy, and off-flavor. Continued exposure to low oxygen results in a decidedly robust, tainted flavor.

The progressive development of tainted flavor is normally associated with parallel increases in low-oxygen skin injury, low-oxygen flesh injury, and accumulations of acetaldehyde, ethyl alcohol, and ethyl acetate in the flesh. However, the three symptoms and indicators of low-oxygen injury appear to be independent of each other. Although all other symptoms and indicators of low-oxygen injury are increased by increasing the temperature during exposure to a nitrogen atmosphere, the development of tainted flavor of Cortland apples is not influenced by temperature. With Mutsu (Crispin), the development of tainted flavor is profoundly influenced by temperature, but visible symptoms of low-oxygen injury are not present.

Apples with a slightly tainted flavor eventually are restored to normal if the development of the tainted flavor is not severe and if visual symptoms of low-oxygen injury are not present. Such apples should be held in air at 0°C storage temperature to retard flesh softening while the tainted flavor factor evaporates. Severely affected apples may be of poor quality even after normal flavor has been restored.

ARTICHOKES

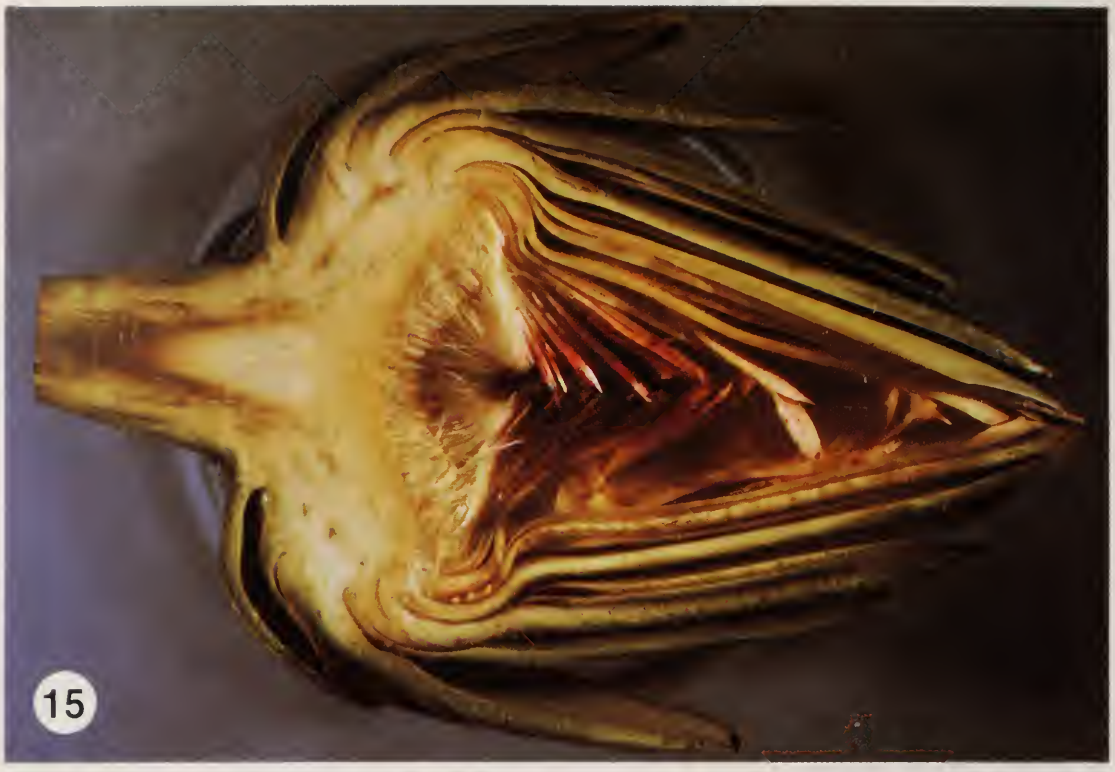
M.E. Saltveit

BLACKENING OF BRACT AND RECEPTACLE

Beneficial controlled atmospheres for artichokes range from 6% carbon dioxide plus 2% oxygen to 0% carbon dioxide plus 0.25% oxygen (Escriche et al. 1982, Isenberg 1979, Ryall and Lipton 1979, Ryder et al. 1983). A recommended controlled atmosphere of 3% carbon dioxide plus 3% oxygen at 1.5°C and 95% relative humidity gives 1 month of storage (Ryall and Lipton 1979). However, some reviewers report that controlled-atmosphere storage has no advantage over conventional air storage (Ryall and Lipton 1979, Miccolis and Saltveit 1988). The optimum controlled-atmosphere regimen is dependent on cultivar and initial bud quality (Escriche et al. 1982, Ryder et al. 1983). Controlled-atmosphere treatments reduce excessive desiccation and mold growth often found in long-term air storage. Controlled-atmosphere storage also reduces browning of the inner surface of bracts, but that response is not consistently observed (Artés et al. 1981). Atmospheres of 3–5% carbon dioxide may stimulate growth of bristles on the receptacle, whereas treatments excluding carbon dioxide may increase weight loss and internal violet coloration.

The blackening of the bracts and receptacle that is found in buds exposed to low-oxygen and high carbon dioxide atmospheres is different from bract browning resulting from aging or disease. Miccolis and Saltveit (1988) found that large, mature buds stored in air show little blackening (Fig. 15). Buds stored in controlled atmosphere show not only blackening of the bracts and surface of the receptacle but also discoloration of tissue within the receptacle (Fig. 16). Levels of bract blackening are insignificant in air after 4 weeks of storage but increase in severity as carbon dioxide increases from 2.5 to 5% and as oxygen decreases from 5 to 1%. Blackening of the surface of the receptacle is also observed at 5% carbon dioxide. In the absence of added carbon dioxide, oxygen level has no significant effect on blackening. Symptoms are more severe in more mature buds.

Bract blackening could result from low-oxygen injury, high carbon dioxide injury, or chilling injury aggravated by controlled atmospheres. The cause of this discoloration has not been clearly determined.



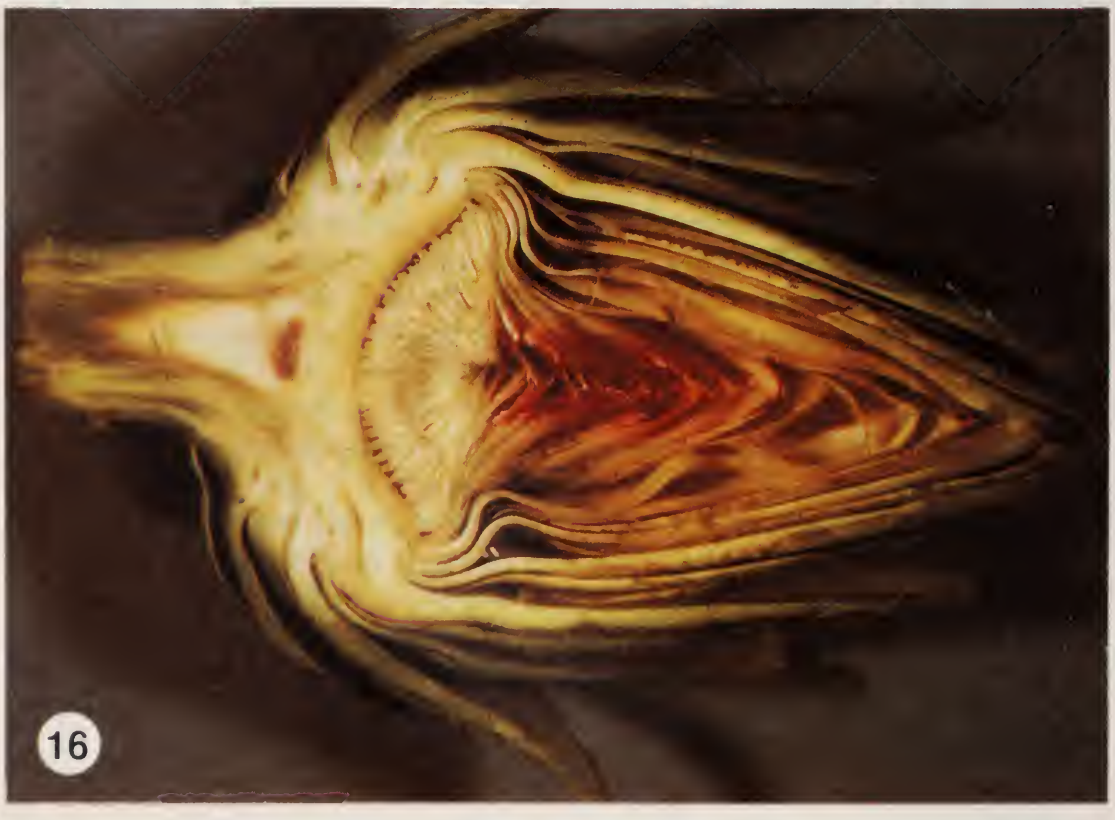


Fig. 15 Cross section through a large, mature Green Globe artichoke stored at 0°C in air for 4 weeks.

Fig. 16 Blackening of the surface of the receptacle and discoloration of tissue within the receptacle of Green Globe artichoke bud stored in 1% oxygen plus 5% carbon dioxide for 4 weeks.

Fig. 17 High carbon dioxide injury in 20th Century pear stored in 5% carbon dioxide plus air at 0°C for 6 months.

Fig. 18 Low-oxygen injury on 20th Century pears stored in 1% oxygen at 0°C for 4 months.

ASIAN PEARS

A.A. Kader

CORE OR MEDIAL FLESH BROWNING

Core or medial flesh browning first appears in the interior carpel walls and the core tissue in response to carbon dioxide levels in the atmosphere (Fig. 17). Continued exposure to the injurious levels of carbon dioxide extends the browning into the cortex tissues, and cavities may develop as a result of desiccation of dead tissue.

All cultivars of Asian pears tested are susceptible to core and flesh browning when exposed to levels above 1% carbon dioxide for 4 months or to 5% carbon dioxide for more than 1 month at 0°C. The incidence of the disorder can be eliminated by not exposing Asian pears to carbon dioxide levels above 1%, which may result from fruit wrapping or excessive waxing, use of polyethylene liners in shipping containers, or inadequate removal of carbon dioxide from controlled-atmosphere storage facilities.

BRONZE EPIDERMAL DISCOLORATION

Epidermal bronzing, which appears as discolored surface depressions (rough or sunken lesions) on 20th Century pears (Fig. 18), can result from exposure to 1% oxygen (low-oxygen injury) for 4 months or more at 0°C. Exposure of Ya Li or Tsu Li pears to 1% oxygen for 2 months, 2% oxygen for 4 months, or 3% oxygen for 6 months at 0°C may result in flesh browning (Fig. 19). These low-oxygen disorders can be avoided by not storing Asian pears in combinations of oxygen concentration and storage duration beyond those tolerated by each cultivar.

BRUSSELS SPROUTS

W.J. Lipton

DISCOLORATION OF HEART LEAVES

A reddish tan discoloration of heart leaves is the typical visible symptom of low-oxygen injury (Fig. 20; Lipton and Mackey 1987). Symptoms develop during 2 weeks of storage in 0.5% oxygen at 2.5°C, and the discoloration is frequently accompanied by an extreme bitterness of cooked sprouts. However, the bitterness can also occur without internal discoloration. The disorders are more severe when Brussels sprouts are held at 5 or 7.5°C than at 2.5°C, but do not develop when held in 1% oxygen at 0°C. Poststorage aeration for 3 days at 10°C has no consistent effect on discoloration but does intensify the bitterness.

DISCOLORATION OF VASCULAR (STEM) TISSUE

A tan discoloration of tissue adjacent to the vascular ring at the stem end is a symptom of carbon dioxide injury in Brussels sprouts (Fig. 21). Storage of Valiant Brussels sprouts for 4 weeks in 10% carbon dioxide at 2.5°C results in significant carbon dioxide injury (Lipton and Mackey 1987). The incidence or intensity of discoloration is not influenced by oxygen concentration in the range of 1–20%. Subsequent aeration at 10°C does not influence symptom development, and injured sprouts have a normal flavor.

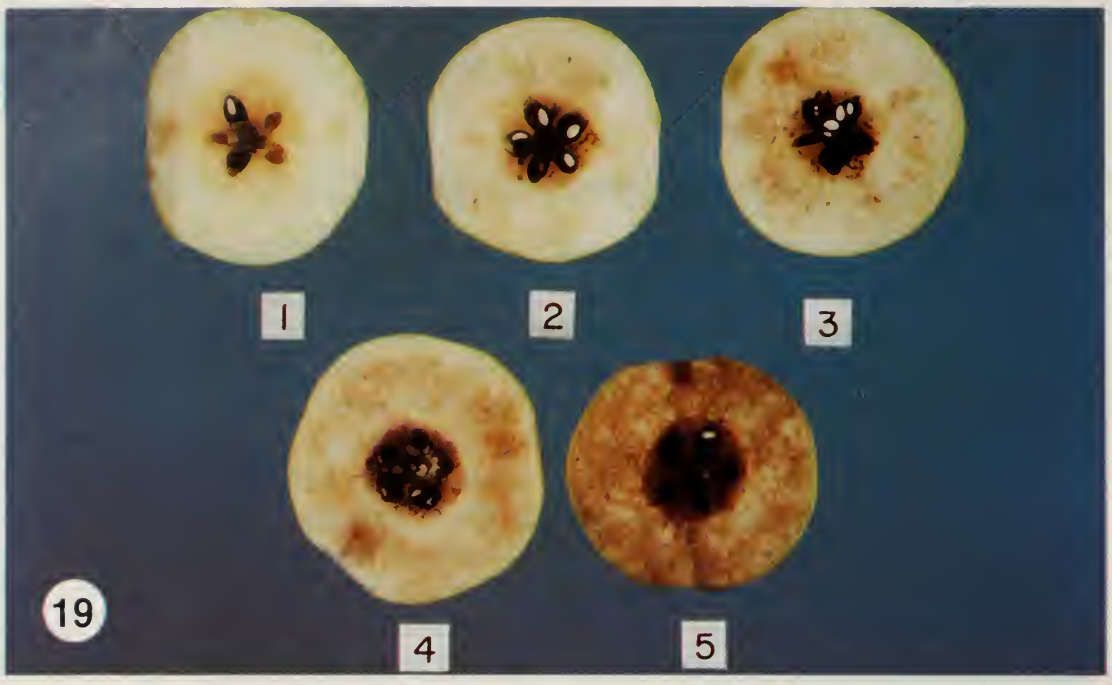


Fig. 19 Scoring system for low-oxygen injury in Ya Li pears (cross section).

Fig. 20 Low-oxygen injury of Brussels sprouts stored in 0.25% oxygen plus air at 5°C followed by 3 days at 10°C in air.

Fig. 21 High carbon dioxide injury of Brussels sprouts stored in 10% carbon dioxide plus air at 2.5°C for 4 weeks followed by 2 days at 10°C in air. ▶

Fig. 22 Browning meristem tissue of Polinius cabbage held in low-oxygen atmospheres. ▶

Fig. 23 General leaf browning of Polinius cabbage held in high carbon dioxide atmospheres. ▶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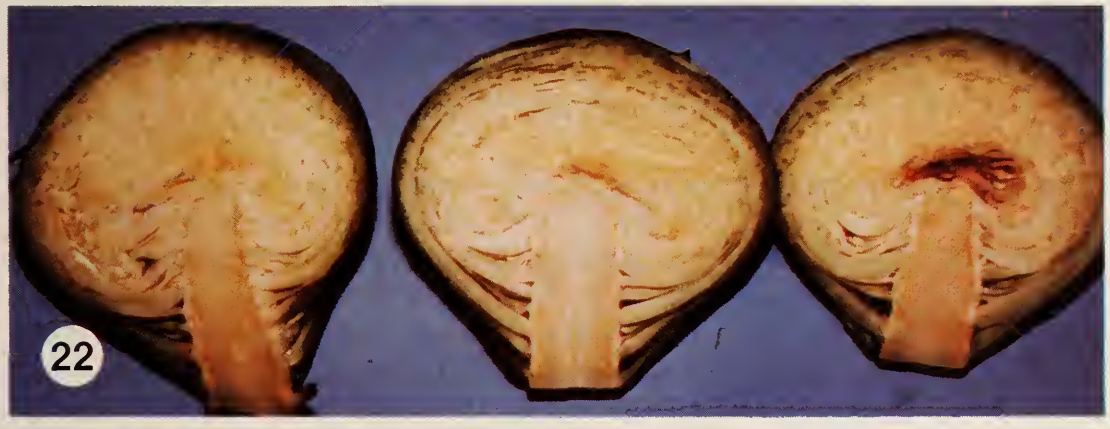
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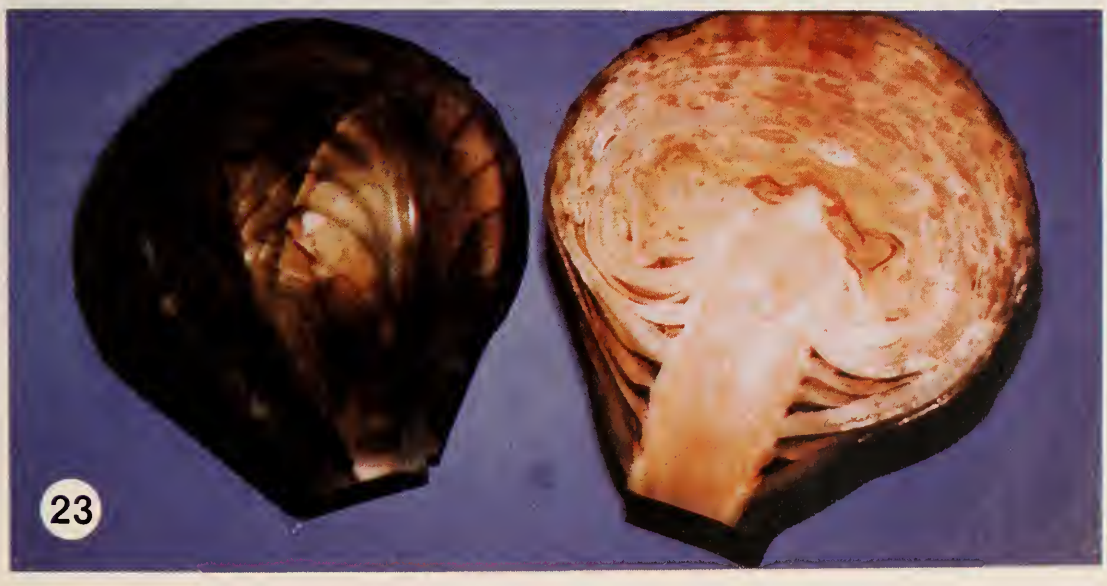
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CABBAGE

J.F. Masters and J.R. Hicks

BROWNING OF MERISTEM TISSUE

The juvenile meristem tissue, at the apex of the stem, is most susceptible to low-oxygen injury. This actively respiring tissue appears brown and desiccated in response to low-oxygen atmospheres (Fig. 22). The first evidence of low-oxygen injury may be seen after 2 months of storage at 0.5% oxygen (plus either 0 or 5% carbon dioxide) and becomes more intense in color and spreads throughout the head with extended storage. Cabbage develops similar symptoms of low-oxygen injury when exposed to 1.5% oxygen for durations of 6 months or more at 0°C.

Cultivars may differ in their sensitivity to low oxygen levels in storage. Since the meristem tissue in the centre of the cabbage is the most sensitive to low oxygen, the density of the head may affect the diffusion of gases to the growing point as well as the susceptibility of the cabbage to injury. The maturity of cabbage heads at harvest may also affect density and susceptibility to injury induced by low oxygen. For additional information see Isenberg and Sayles 1969, Geeson and Browne 1980, and Hicks and Ludford 1981.

GENERAL LEAF BROWNING

Carbon dioxide injury in cabbage first appears as browning of the tissue around the apex (meristem tissue), with a noticeable off-odor (Fig. 23). The initial symptoms of carbon dioxide injury may develop as early as 2 months in storage when cabbage is exposed to 20% carbon dioxide at 0°C, regardless of the oxygen concentration. Carbon dioxide injury continues to spread throughout the entire head if it is left at high carbon dioxide levels, and eventually the injury is evident externally by a bronzing of the outer leaves. Carbon dioxide levels in excess of 10% for storage durations of 6 months or more can result in a significant loss of the product as a result of injury. The extent of the injury in response to carbon dioxide depends on the cultivar and on the level of maturity.

CAULIFLOWER

W.J. Lipton

DISCOLORATION OF FLORETS

Cauliflower curds injured by low-oxygen atmospheres exhibit sunken, light tan florets that appear to be dry even though they are not (Fig. 24; Lipton and Harris 1976). Soft rot may also be prevalent on injured curds. Symptoms of low-oxygen injury develop during 8 days of storage in 0.25 or 0.5% oxygen at 5°C followed by 3 days of aeration at 10°C. When the injury is mild, the symptoms sometimes become evident only after cooking. Visible injuries also develop in 1% oxygen, but they are not evident in cauliflower stored at 2% oxygen. Similarly, a mildly sour odor is evident in raw cauliflower that is stored in 1% oxygen or less but not in cauliflower stored in 2% oxygen. Cooking elicits a highly offensive odor and flavor in curds stored in 1% oxygen or less and occasionally in those stored in 2% oxygen.

Aeration dissipates the sour flavor of raw curds and intensifies the objectionable flavor of cooked curds but does not aggravate the visible symptoms.

DISCOLORATION OF COOKED FLORETS

Symptoms of high carbon dioxide injury are evident only *after* the curds have been cooked (Lipton et al. 1967). Injured curds are yellowish gray and mushy, emit a strong off-odor, and have a strong off-flavor (Fig. 25). Injury is evident after 2 days of storage in 15% carbon dioxide plus 5% oxygen at 5°C. Combinations of 5% carbon dioxide plus 15% oxygen or 10% carbon dioxide plus 10% oxygen induce milder symptoms. Oxygen levels of 5% or higher without added carbon dioxide have no adverse effects. Symptoms of carbon dioxide injury disappear after aeration at 5°C for 6 hours or longer. Only perforated film wraps should be used for packaging of cauliflower to prevent carbon dioxide accumulation and carbon dioxide injury during distribution and retail.

Fig. 24 Low-oxygen injury of cauliflower curds held in 2, 0.5, or 0.25% oxygen for 8 days at 5°C (*left to right*) followed by 3 days at 10°C in air.

Fig. 25 High carbon dioxide injury of cauliflower, expressed only *after* cooking of the curd. Halves of same head stored in 15% carbon dioxide plus 5% oxygen for 7 days at 5°C (*left*) or in air (*right*).

Fig. 26 Low-oxygen injury of sweet cherries evidenced by progressive stem browning, stem dehydration, and fruit darkening after 4 days in nitrogen at 22°C.

Fig. 27 Low-oxygen injury of sweet cherries evidenced by stem deterioration and fruit darkening with fungal mycelium prominent after 9 days in nitrogen at 22°C.

CHERRIES, SWEET

M.E. Patterson

LOW-OXYGEN AND CARBON DIOXIDE INJURY IN SWEET CHERRIES

The increased size of North American crops of sweet cherry (*Prunus avium* L.) and expanded exports have increased the quantity of fruit subjected to some form of atmosphere modification.

Controlled and modified atmospheres are achieved and controlled with varying precision and accuracy. Within a safe range of oxygen and carbon dioxide in the atmosphere around the fruit, regimens of controlled and modified atmospheres retain fruit quality and condition and extend postharvest life (Schomer and Olsen 1964, Porritt and Mason 1965, Singh et al. 1970, Patterson and Melstad 1977, Patterson 1982, Chen et al. 1981). Various concentrations of oxygen and carbon dioxide are intentionally and unintentionally developed in storage, in shipping boxes, and in transport containers. Most cherries are not stored for extended periods at shipping points but may be held in cold storage for short intervals between harvest and packing, and packing and shipping. Limited volumes are placed in controlled-atmosphere storage for marketing extension. Almost all fruit is packaged in fiberboard boxes with 38-µm plastic film liners that serve as permeability barriers to gas diffusion. Many loads are sealed in transport containers and charged with carbon dioxide.

Fruit temperatures in transit may vary widely. Respiration rate, fruit volume, atmosphere leakage, initial charge or target atmosphere, package permeability, and differentially permeable area are variables that affect the gas composition of atmospheres around fruit. Temperature and time magnify influences of several variables. Wide ranges and fluctuations in the oxygen and carbon dioxide concentration in the fruit environment are likely due to variable influences between the time the fruit is harvested and the time it is consumed.

Sweet cherries are tolerant of a broad range of carbon dioxide and oxygen concentrations (Porritt and Mason 1965, Kader and Morris 1977, Patterson and Melstad 1977), but high carbon dioxide concentrations and low oxygen concentrations can cause injury. Tolerance levels of 3% oxygen and 10% carbon dioxide have been suggested at recommended storage temperatures when the other gas is near the concentration in air (Kader and Morris 1977). When Bing cherries are stored in air or in a mixture of 0, 20, 40, 60, 80, and 100% carbon dioxide at 0°C, they develop off-flavors proportionate to storage time and carbon dioxide level. Off-flavors develop within 1 week in fruit held at 80% carbon dioxide or more and slightly later at 60% carbon dioxide; no off-flavors develop at 40% carbon dioxide or less (Patterson and Melstad 1977). Elevated temperatures and prolonged exposure increase the probability of carbon dioxide injury to the fruit. Gas

tolerances change with changes in the other gas component and with changes in temperature and time.

STEM DISCOLORATION

Stem browning precedes the appearance of flesh injury symptoms. Stems are more sensitive to atmospheric extremes, and browning occurs sooner under toxic carbon dioxide levels than in low-oxygen atmospheres. Stems initially develop a red brown color in response to toxic levels of carbon dioxide, whereas anoxic stems tend to develop more of a black-brown color (Fig. 26).

FRUIT DARKENING

Before color changes that indicate injury take place, a period of improved retention of fruit harvest color and brightness may occur. This effect is due to atmospheric suppression of fruit senescence and inhibition of red pigment synthesis and darkening. After an initial delay in atmospheres of high carbon dioxide or low oxygen, an accelerated appearance of fruit darkening occurs, which is at least partly due to cell membrane rupture and subsequent leakage. In addition, expressed juice from red cherry cultivars becomes progressively more purple and less red with progressive toxicity caused by atmospheres of high carbon dioxide or low oxygen, or both (Figs. 27, 28).

FRUIT EXUDATE AND SURFACE BROWNING

High carbon dioxide causes droplets of exudate to form on the skin surface before any surface browning appears. Ultimately, brown areas appear on the fruit surface, and injury may be expressed by a blend of brown with red or mahogany and a dull water-soaked appearance (Fig. 28).

In storage experiments with a light-colored cultivar, Rainier, high carbon dioxide caused rapid development of numerous brown spots on the skin surface after removal to air. Rainier is more sensitive to high concentrations of carbon dioxide than either Bing or Lambert.

OFF-ODORS AND OFF-FLAVORS

Sour and fermented odors and flavors develop before visual symptoms appear. The development of a flavor that is similar to synthetic almond oil is characteristic of fruit injured by carbon dioxide or low oxygen. Taste tests conducted immediately upon the removal of fruit from extremely high levels of carbon dioxide reveal that juice in the fruit may be detectably carbonated. Carbonation of the juice and off-odors of the fruit may be reduced with aeration at 0°C at ambient temperatures.

Fig. 28 High carbon dioxide injury of sweet cherries evidenced by stem browning, fruit darkening with sticky liquid exudate on the surface, water-soaked flesh, browning, and surface indentations.

Fig. 29 Scald-like symptoms on the peel of Valencia orange stored in 0% oxygen for 12 weeks at 0°C.

Fig. 30 Scald and stem-end breakdown of Valencia orange stored for 12 weeks at 1°C in 5% oxygen plus 2.5% carbon dioxide.

Fig. 31 Scald-like peel injury of Marsh grapefruit stored for 8 weeks at 5°C in 25% carbon dioxide in air.

CITRUS FRUIT

A.C. Purvis and R.H. Cubbedge

Citrus fruit is classified as nonclimacteric fruit and generally does not benefit greatly from controlled-atmosphere storage. Furthermore, citrus fruit is susceptible to chilling injury, with the threshold temperature for injury dependent on the species. Oranges (*Citrus sinensis* (L.) Osbeck) can be stored safely at temperatures above 5–7°C, whereas grapefruit (*Citrus paradisi* Macf.) require storage temperatures of 13°C or higher to prevent injury.

Although citrus fruit is not normally stored under controlled-atmosphere conditions, fruit stored in fiberboard cartons in poorly ventilated rooms can be exposed to low oxygen and high carbon dioxide levels for varying periods of time, especially if decaying fruit is present. For more information see Barmore et al. 1983, Davis et al. 1973, Eaks and Ludi 1960, Hatton and Cubbedge 1977, Vakis et al. 1973, and Wardowski et al. 1975.

SCALD LESIONS ON PEEL AND OFF-FLAVORS

Oxygen levels below 5–10% lead to off-flavors caused by an increased content of ethanol and acetaldehyde in the juice. Oranges stored in 0% oxygen for 12 weeks at 0°C develop scald-like symptoms on the peel (Fig. 29).

SCALD LESIONS ON PEEL

Elevated carbon dioxide levels (>5%) before low-temperature storage of grapefruit have been reported to reduce pitting and other symptoms of chilling injury. Increased carbon dioxide also delays senescence of the peel of grapefruit, the peel remaining bright yellow when the fruit is stored at 10°C. However, high carbon dioxide levels can cause scald-like areas on the peel of orange (Fig. 30) and grapefruit (Fig. 31) at chilling temperatures. Injury frequently is more intense around the stem end of oranges.

The benefits derived from elevated carbon dioxide are marginal for citrus fruit. Consequently, citrus fruit is normally stored at nonchilling temperatures in well-ventilated rooms to reduce the potential development of off-flavors and symptoms of chilling injury.

HONEYDEW MELON

W.J. Lipton

WATER-SOAKED AND CRACKED EPIDERM

Low-oxygen injury in honeydew melons appears as water-soaked patches and cracking of tissue in the affected areas in melons that have been stored for 3 weeks in 1.5% oxygen at 7.5°C (Fig. 32). Water-soaked tissue is the only symptom induced by storage of honeydew melons in 3% oxygen, whereas no symptoms are observed in fruit stored at 6% oxygen in the absence of carbon dioxide at 7.5°C. During subsequent aeration at 20°C, low-oxygen injury, surface mold growth, and flesh decay become severe.

Water-soaking induced by high carbon dioxide is indistinguishable from low-oxygen injury (Fig. 33). The carbon dioxide injury is induced during 3 weeks of storage in 10% carbon dioxide plus 20% oxygen at 7.5°C but is minimal or absent in 5% carbon dioxide plus 2.5% oxygen. Carbon dioxide levels of 10% at 2.5°C may also induce browning of the fruit surface, which may be an interaction with chilling injury. Cracking and decay develop progressively during poststorage aeration at 20°C.

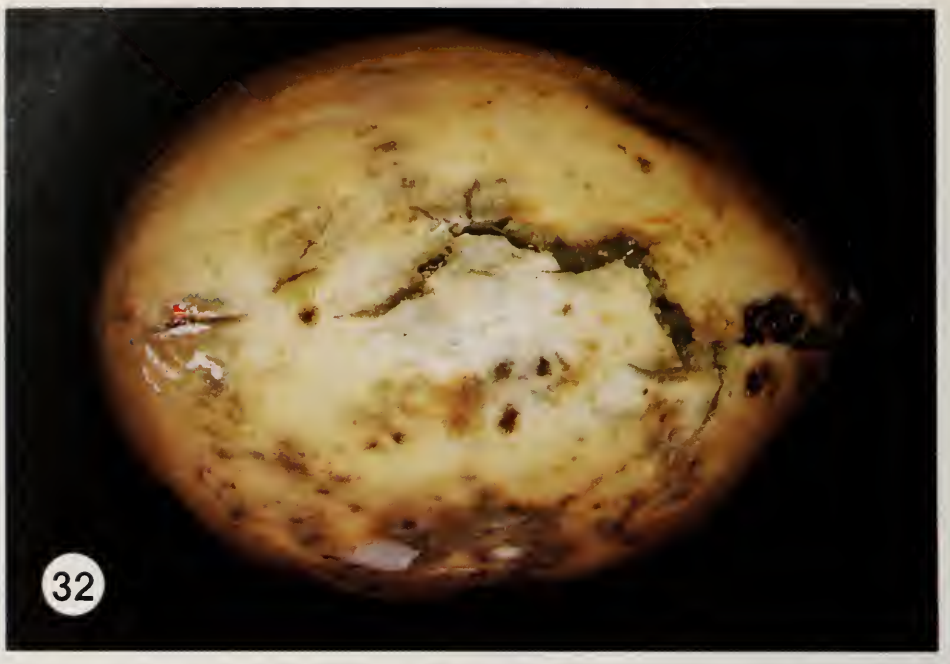

Fig. 32 Severe low-oxygen injury of honeydew melon stored for 3 weeks in 1.5% oxygen at 7.5°C followed by 2 days at 20°C in air.

Fig. 33 Severe high carbon dioxide injury of honeydew melon stored for 3 weeks in 20% oxygen plus 10% carbon dioxide at 7.5°C followed by 2 days at 20°C in air.

Fig. 34 Pericarp translucency in kiwi fruit resulting from exposure to low oxygen, high carbon dioxide, or elevated ethylene levels at 0°C. ▶

Fig. 35 Pericarp granulation in kiwi fruit resulting from exposure to high carbon dioxide in air at 0°C. ▶

Fig. 36 White core inclusion in kiwi fruit resulting from exposure to ethylene in controlled-atmosphere storage at 0°C. ▶


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KIWI FRUIT

M.L. Arpaia

Controlled-atmosphere storage of kiwi fruit (*Actinidia deliciosa*, Liang and Ferguson) has been shown to be beneficial in prolonging the storage life of the cultivars Hayward and Bruno. Controlled-atmosphere storage is beneficial primarily because it retards flesh softening. Successful controlled-atmosphere storage depends on the maintenance of carbon dioxide levels between 3 to 8%, oxygen levels at approximately 2%, and complete exclusion of ethylene (C_2H_4) from the storage atmosphere. The success of controlled-atmosphere storage is also influenced by seasonal variability. Four physiological disorders have been associated with controlled-atmosphere storage of Hayward kiwi fruit. These disorders are related primarily to injurious levels of carbon dioxide and the presence of ethylene in the storage atmosphere. For additional information see Arpaia et al. 1985, 1986; Ben-Arie and Sonego 1985; Harman and McDonald 1983; Mitchell et al. 1982; and McDonald and Harman 1982.

HARD CORE

Hard core has been described in studies on New Zealand fruit. The fruit core fails to ripen, even when the remainder of the fruit is soft and ripe. Hard core develops in fruit that has been stored for 16 weeks or longer at 0°C in 14 or 20% carbon dioxide plus 21% oxygen. This condition has also been noted in California fruit stored at high concentrations of carbon dioxide.

PERICARP TRANSLUCENCY

This disorder has been noted in kiwi fruit stored both in air and in controlled atmospheres at 0°C. The disorder appears as translucent patches in the outer pericarp tissue at the stylar end, which may extend up the sides of the fruit (Fig. 34). Researchers from New Zealand have noted similar internal breakdown in fruit after more than 16 weeks at 0°C in 10 or 14% carbon dioxide plus 21% oxygen. Pericarp translucency is more severe after prolonged storage but can be observed after 12 weeks of storage at 0°C and is most noticeable following poststorage ripening at 20°C. Less translucency develops under controlled-atmosphere conditions, and it is related to both low levels of oxygen and high levels of carbon dioxide. Very high levels of carbon dioxide (3–7%) do not further aggravate the development of symptoms. The presence of ethylene (0.50 µL/L) in the storage atmosphere exacerbates the development of symptoms. In the presence of ethylene, the development of symptoms at all carbon

dioxide concentrations is greater than or equal to the development of symptoms in air storage at 0°C.

PERICARP GRANULATION

The occurrence of granulation is predominantly at the stylar end of the fruit, but as in the case of translucency, it may extend up the sides of the fruit (Fig. 35). Symptoms of granulation have been reported for both New Zealand and California kiwi fruit after 0°C storage. This disorder also is more severe with prolonged storage or after ripening at 20°C. Unlike translucency, however, fruit stored at varying levels of carbon dioxide (0–7%) plus 2% oxygen have similar levels of severity as compared with air-stored fruit. The addition of ethylene (0.50 µL/L) to the storage atmosphere, however, results in a greater number of affected fruit.

There is no obvious correlation between pericarp translucency and granulation, because symptoms can occur independently. The possible role of storage temperature or seasonal variability has not been described for either disorder.

WHITE CORE INCLUSION

White core inclusion has been reported only in kiwi fruit grown in California. The occurrence of white core inclusion is directly related to the presence of ethylene in the controlled atmosphere and has not been noted in fruit removed from controlled atmospheres without ethylene or in air storage with or without ethylene. This disorder appears to be a result of a synergistic interaction between carbon dioxide and ethylene and apparently involves a disruption of starch metabolism in the fruit core. The development of symptoms closely parallels a rise in soluble solids content and a decline in starch content during the first 6–8 weeks of storage. This disorder results in distinct white patches of core tissue that are very obvious in ripe fruit (Fig. 36). Symptoms of the disorder have been observed as early as 3 weeks in storage at 0°C. Factors that influence the incidence and severity of the disorder include carbon dioxide and ethylene concentration within the storage, timing and duration of ethylene exposure, and storage temperature. Preliminary studies show that storage in low oxygen (2%) plus ethylene does not result in the development of white core inclusion, whereas 5% carbon dioxide in air plus ethylene does result in the development of the disorder. When fruit is stored at varying levels of carbon dioxide (0–7%), the development of symptoms is greatest at 5 and 7% carbon dioxide. Low levels in the incidence of white core inclusion may also appear in fruit stored at 3% carbon dioxide.

The occurrence and severity of white core inclusion are also dependent on ethylene concentration (0.05–5.0 µL/L). Little difference in the amount of severity or incidence is evident when fruit is exposed

for less than 4 weeks to ethylene at 5.0, 1.0, or 0.5 µL/L. The development of symptoms at these three concentrations increases rapidly after the fourth week of 0°C storage and remains at a fairly constant level between 6 and 24 weeks. Fruit exposed to ethylene at 0.1 µL/L during controlled-atmosphere storage shows an intermediate response, whereas the presence of ethylene at 0.05 µL/L results in a constant low level of symptom severity. The threshold concentration of ethylene for the development of white core inclusion is less than 0.05 µL/L.

The timing and duration of ethylene exposure (0.5 µL/L) during controlled-atmosphere storage (5% carbon dioxide plus 2% oxygen) may also influence the development of white core inclusion. When continuous exposure to ethylene is delayed for 2 weeks after the beginning of storage, a corresponding 2-week delay in the appearance and development of white core inclusion occurs. When fruit is subjected to short durations of exposure to ethylene at the beginning of storage, the occurrence and severity of the disorder are intermediate, implying that continuous exposure to ethylene is not required for the development of white core inclusion. When exposure to ethylene is delayed until after the rise in the content of soluble solids in the fruit, white core inclusion develops at very low ethylene levels, indicating that any exposure to ethylene during controlled-atmosphere storage at 0°C can result in the disorder.

Storage temperature also influences the development of white core inclusion. The severity and incidence of symptoms are similar when fruit is stored in 5% carbon dioxide, plus 2% oxygen, plus ethylene at 0.5 µL/L at either 2.5 or 0°C, although symptoms appear earlier at 2.5°C. Greatly reduced levels of white core inclusion occur at 5 or 10°C, indicating a temperature threshold of 2.5–5°C for the development of white core inclusion.

Fig. 37 Water-soaked leaves of head lettuce stored in 0.5% oxygen at 0°C.

Fig. 38 Brown stain symptoms on Prizehead lettuce stored in 5% carbon dioxide plus 2% oxygen for 10 days at 0°C.

LETTUCE

A.A. Kader and W.J. Lipton

WATER-SOAKED LEAVES

The wrapper and cap leaves of head lettuce exposed to low levels of oxygen (0.5% oxygen or lower for longer than 4 days at 0–5°C) may exhibit shiny to water-soaked, gray, and dead patches (Fig. 37; Lipton et al. 1972). Heart leaves (the youngest) may also have shallow reddish brown spots on their midribs, usually on the inner surface. This disorder may be prevented by providing adequate ventilation in air-tight transit vehicles and avoiding conditions of controlled-atmosphere storage that result in oxygen concentrations below 1%.

BROWN STAIN

Brown stain disorder appears as definite oval to irregular lesions, ranging from yellow to brown, which tend to occur on the sides of the midrib and on the basal portion of the leaf (Fig. 38; Brecht et al. 1973, Lipton 1987).

Brown stain results from exposure to carbon dioxide concentrations above 2%. It is favored by temperatures near 0°C, reduced oxygen levels, added carbon dioxide, and the presence of ethylene. Lettuce types and cultivars within each type differ greatly in their susceptibility. The injury may intensify during 2 or 3 days of subsequent aeration at 10°C.

Brown stain can be reduced by avoiding restricted air exchange or controlled-atmosphere conditions that result in the accumulation of carbon dioxide above 2% during transport or temporary storage; carbon dioxide absorbers may be used for this purpose.

HEART LEAF INJURY

Heart leaf injury disorder appears as a reddish brown discoloration of the leaf margins or the entire leaf in the heart leaves (the youngest) of iceberg (Fig. 39) or butterhead lettuce.

Heart leaf injury results from exposure to carbon dioxide concentrations of greater than 5% at any temperature (in contrast to brown stain, which is favored by lower temperatures). The incidence of heart leaf injury can be reduced by providing adequate ventilation or using carbon dioxide absorbers, thus avoiding exposure to elevated carbon dioxide levels during postharvest handling of lettuce.

PEACHES AND NECTARINES

C.Y. Wang, A.E. Watada, and R.E. Anderson

SKIN BROWNING

Sunhigh and Loring peaches develop an intense skin browning that is sharply delineated from adjacent healthy-looking skin when stored in 0% carbon dioxide plus 0% oxygen at 0°C (Fig. 40; Anderson et al. 1969). The skin browning caused by oxygen deficiency in Redhaven peaches is not as dark as that on Sunhigh or Loring, whereas Late Le Grand nectarines (Fig. 41) develop a black pitting of the skin.

FLESH DISCOLORATION

Internal injuries in fruit from 0% carbon dioxide plus 0% oxygen are well defined in the flesh tissues of Sunhigh, Loring, and Redhaven peaches (Fig. 42; Anderson et al. 1969). In these cultivars the injury appears as a grayish brown breakdown. The symptoms of injury can appear in the flesh near the skin or surrounding the stone. This same type of injury can occur in some Loring peaches in storage at 0% carbon dioxide plus 0.25% oxygen.

Late Le Grand nectarines are less susceptible to internal low-oxygen injury. When such injuries do occur, however, they, too, appear as a grayish brown breakdown surrounding the stone. The addition of 5% carbon dioxide to the atmosphere reduces the susceptibility of Late Le Grand nectarines to low-oxygen injury.

The symptoms of low-oxygen injury in peaches and nectarines are easily confused with those of internal breakdown, which is caused by chilling injury or prolonged cold storage. To help distinguish the two types of injury, a comparison of symptoms of low-oxygen injury and internal breakdown is summarized.

Table 1 Comparison of symptoms of low-oxygen injury and internal breakdown of peaches and nectarines

Low-oxygen injury	Internal breakdown
external and internal	internal
well-defined areas	diffused in flesh
can appear anytime during storage	appears mostly after transfer from low temperature to ripening temperature
browning	discoloration: red, yellow, or brown
not necessarily dry	can be dry and soft

Fig. 39 Heart leaf injury in head lettuce kept in 20% carbon dioxide plus 17% oxygen for 10 days at 0°C.

Fig. 40 Low-oxygen injury of Sunhigh peach stored in 0% carbon dioxide plus 0% oxygen for 9 weeks at 0°C followed by 6 days in air at 20°C.

Fig. 41 Low-oxygen injury of Late Le Grand nectarine stored in 0% carbon dioxide plus 0% oxygen for 3 weeks at 0°C followed by 6 days in air at 20°C.

Fig. 42 Low-oxygen injury of Redhaven peach stored in 0% carbon dioxide plus 0% oxygen for 9 weeks at 0°C followed by 4 days in air at 20°C.

PEARS

P.M. Chen

BROWN CORE OF ANJOU

Brown core disorder of Anjou pears results from prolonged controlled-atmosphere storage of the fruit in 2% oxygen when the carbon dioxide level is above 1% or in 1% oxygen when the carbon dioxide level is above 0.1%. The core tissue surrounding the carpels turns brown, with the cavities and the inner walls of the carpels also becoming brown (Fig. 43). Severe injury may be manifested in the browning of cavities in the entire core area. The injury is usually restricted mostly to inside the core area.

PITHY BROWN CORE OF BOSC

Pithy brown core disorder of Bosc pears results from prolonged controlled-atmosphere storage of the fruit in 2.5% oxygen when the carbon dioxide level is above 1% or in 1% oxygen when the carbon dioxide level is above 0.1%. The symptom of the injury is similar to that of Anjou fruit. However, the browning cavities may include both core flesh and cortex tissues of the entire fruit (Fig. 44).

FLESH BROWNING OR CAVITATION OF BARTLETT

This carbon-dioxide-related disorder of Bartlett pears develops after prolonged controlled-atmosphere storage of the fruit in 2% oxygen when the carbon dioxide level is above 1.5% or in 1% oxygen when the carbon dioxide level is above 1%. The symptoms are somewhat different from those of Anjou and Bosc fruit. The cortex tissues next to the vascular region and outside the core line turn slightly brown and show many little cavities. The entire core area may still be intact without any injury (Fig. 45).

DARK BROWN SKIN DISCOLORATION OF ANJOU

This disorder of Anjou pears is a result of prolonged controlled-atmosphere storage of the fruit in either high carbon dioxide or low oxygen, or a combination of both. The actual level of carbon dioxide or oxygen that causes the disorder has not been determined. It has been observed that fruit with advanced maturity is more susceptible to the disorder Characteristic injury is quite similar to ammonia injury, although the dark brown discoloration is not restricted to the area around the lenticels. In observation under a microscope, a few hundred epidermal cells turn dark brown. This discoloration is scattered at random on the pear skin (Fig. 46).

STRAWBERRIES

A.A. Kader

DARK OR PURPLE BERRIES

The development of dark red to purple color in the outer tissues of strawberries associated with the disappearance of red color in the inner tissues is a symptom of carbon dioxide injury in strawberries (Fig. 47; Dinamarca and Mitchell 1986). These changes in color may be due to the migration of anthocyanins from inner to outer tissues or to changes in type of anthocyanins as a result of pH changes induced by carbon dioxide. Off-flavors may also be detected.

Exposure to a carbon dioxide concentration of more than 20% for longer than 5 days at 0–5°C results in carbon dioxide injury. The severity of the disorder increases with concentration of carbon dioxide, time of exposure, and temperature. Cultivars vary in their sensitivity to carbon dioxide injury.

This type of injury can be eliminated by avoiding exposure to levels of carbon dioxide above 20% during transport and temporary storage.


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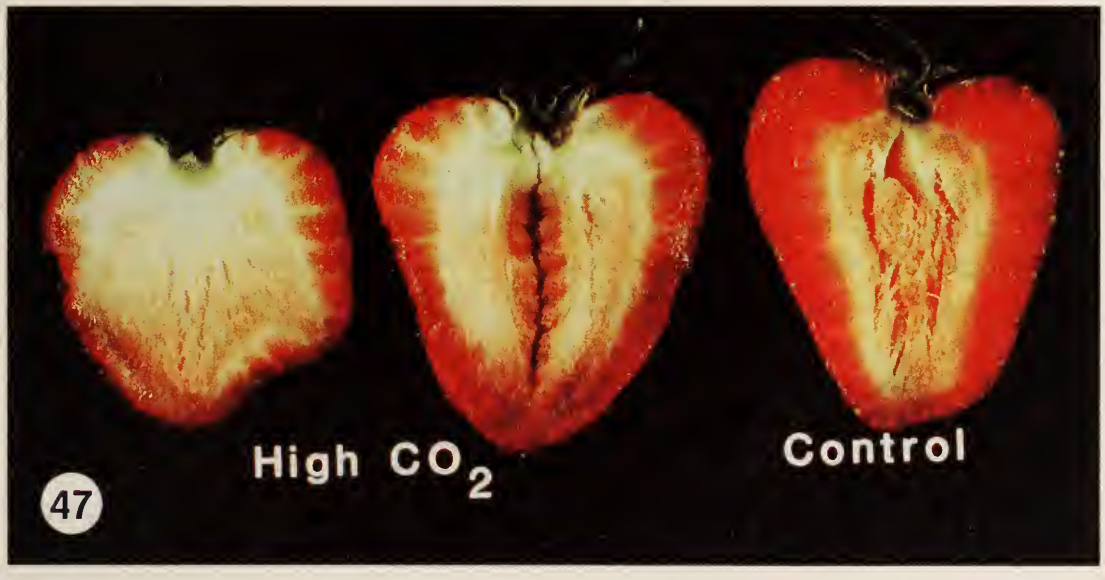

Fig. 46 Black speck of Anjou pear stored in low-oxygen or high carbon dioxide atmospheres or a combination of both.

Fig. 47 High carbon dioxide injury in Pajaro strawberries kept in 30% carbon dioxide for 10 days at 5°C.

◀ **Fig. 43** Brown core of Anjou pear stored in low-oxygen atmospheres with carbon dioxide present.

◀ **Fig. 44** Pithy brown core of Bosc pear stored in low-oxygen atmospheres with carbon dioxide present.

◀ **Fig. 45** Core browning of Bartlett pear stored for extended duration in low-oxygen atmospheres with carbon dioxide present.

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