Physiology of CA Treated Produce

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Abstract

Storage of fresh horticultural perishables within the optimum range of low oxygen and/or elevated carbon dioxide atmospheres for each commodity reduces their respiration and ethylene production rates. However, outside this range respiration and ethylene production rates can be stimulated indicating a stress response, which can contribute to incidence of physiological disorders and increased susceptibility to decay. Exposure to 30-80 kPa oxygen atmospheres stimulates respiration and ethylene production and action in some commodities. Carbon dioxide-enriched atmospheres inhibit activity of ACC synthase, while ACC oxidase activity is stimulated by low carbon dioxide and inhibited at high carbon dioxide and/or low oxygen concentrations. Ethylene action is inhibited by elevated carbon dioxide atmospheres. Optimum CA retard loss of chlorophyll, biosynthesis of carotenoids and anthocyanins, and biosynthesis and oxidation of phenolic compounds. CA reduce the activity of cell wall degrading enzymes that cause fruit softening and enzymes involved in lignification leading to toughening of vegetables. CA influence flavor quality by reducing loss of acidity, starch to sugar conversion, and biosynthesis of aroma volatiles, especially esters. Retention of ascorbic acid and other vitamins results in better nutritional quality, including antioxidant activity, of fruits and vegetables when kept in their optimum CA.

INTRODUCTION

Exposure of fresh fruits and vegetables to low O_2 and /or elevated CO_2 atmospheres within the range tolerated by each commodity reduces their respiration and ethylene production rate; however, outside this range respiration and ethylene production rates can be stimulated indicating a stress response. This stress can contribute to incidence of physiological disorders and increased susceptibility to decay. Elevated CO_2-induced stresses are additive to, and sometimes synergistic with, stresses caused by low O_2 levels, physical or chemical injuries, and exposure to temperatures, relative humidities, and/or ethylene concentrations outside the optimum range for the commodity. An overview of the general effects of elevated CO_2 and reduced O_2 concentrations on causes of deterioration of fresh horticultural perishables is presented in Table 1. Specific concentrations of O_2 and CO_2 at which these general responses occur and their magnitude vary among commodities and cultivars, maturity and ripeness stages, storage temperatures and durations, and in some cases ethylene concentrations.

RESPIRATORY METABOLISM

The shift from aerobic to anaerobic respiration depends on fruit maturity and ripeness stage (gas diffusion characteristics), temperature, and duration of exposure to stress-inducing concentrations of O_2 and/or CO_2. Up to a point, fruits and vegetables are able to recover from the detrimental effects of low O_2 and/or high CO_2 stresses (fermentative metabolism) and resume normal respiratory metabolism. Plant tissues have the capacity for recovery from the stresses caused by brief exposures to fungistatic atmospheres (>10 kPa CO_2) or insecticidal atmospheres (40 to 80 kPa CO_2). Postclimacteric fruits are less tolerant to CA stress and have lower capacity for recovery following exposure to reduced O_2 and/or elevated CO_2 levels than preclimacteric fruits. The speed and extent of recovery depend upon duration and levels of

stresses, and underlying, metabolically driven cellular repair. Severe stress CA conditions decrease cytoplasmic pH and ATP levels, and reduce pyruvate dehydrogenase activity while pyruvate decarboxylase, alcohol dehydrogenase, and lacate dehydrogenase are induced or activated. This causes accumulation of acetaldehyde, ethanol, ethyl acetate, and/or lacate, which may be detrimental to the commodities if they are exposed to the stress CA conditions beyond their tolerance limits.

ETHYLENE BIOSYNTHESIS AND ACTION

Elevated-CO_2 atmospheres inhibit activity of ACC synthase (key regulatory site of ethylene biosynthesis), while ACC oxidase activity is stimulated at low CO_2 and inhibited at high CO_2 concentrations and/or low O_2 levels. Ethylene action is inhibited by elevated-CO_2 atmospheres. These interactions among ethylene, O_2, and CO_2 provide the biological basis of CA effects on delaying ripening and senescence of horticultural perishables.

COMPOSITIONAL CHANGES

Optimum atmospheric compositions retard loss of chlorophyll (green color), biosynthesis of carotenoids (yellow and orange colors) and anthocyanins (red and blue colors), and biosynthesis and oxidation of phenolic compounds (brown color). Controlled atmospheres slow down the activity of cell wall degrading enzymes that cause fruit softening and enzymes involved in lignification leading to toughening of vegetables. Low O_2 and /or high CO_2 atmospheres influence flavor quality by reducing loss of acidity, starch to sugar conversion, interconversion of sugars, and biosynthesis of flavor volatiles. Retention of ascorbic acid and other vitamins results in better nutritional quality of fruits and vegetables kept in their optimum atmospheres.

CONCLUDING REMARKS

Much more research is needed to verify the general trends shown in Table 1. Our current focus is on changes in anthocyanins, phenolic compounds, antioxidant activity, and aroma volatiles in fruits in response to atmospheric modification. The goal is to understand the reasons why taste-life (postharvest-life based on flavor) of fruits is shorter than their postharvest-life based on appearance quality. Also, we hope to identify strategies for maintaining flavor and nutritional quality of fruits longer than is currently possible.

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Tables

Table 1. An overview of the general effects of oxygen levels below 5kPa and carbon dioxide level above 5kPa on quality attributes of horticultural perishables.

	General effect[1] of	
Cause of deterioration	**Reduced O_2**	**Elevated CO_2**
A. Respiratory metabolism		
1. Respiration rate	–[2]	–, 0, or +
2. Shift from aerobic to anaerobic respiration	+ (<1 kPa)	+ (>20 kPa)
3. Energy produced	–	–
B. Ethylene biosynthesis and action		
1. Methionine → SAM	0	?
2. Synthesis of ACC synthase	–	–
3. ACC synthase activity	0	–
4. Synthesis of ACC oxidase	–	–
5. ACC oxidase activity	–	– or +
6. Ethylene action	–	–
C. Compositional changes		
1. Pigments		
a. Chlorophyll degradation	–	–
b. Anthocyanin development	–	–
c. Carotenoids biosynthesis	–	–

Cause of deterioration	General effect[1] of Reduced O_2	Elevated CO_2
2. Phenolics		
a. Phenylalnine ammonia lyase activity	–[2]	+
b. Total phenolics	–	–
c. Polyphenoloxidase activity	–	–
3. Cell wall components		
a. Polygalcturonase activity	–	–
b. Soluble polyuronides	–	–
4. Starch-to-sugar conversion	–	–
5. Organic and amino acids		
a. Loss in acidity	–	–
b. Succinic acid	–	+
c. Malic acid	+	–
d. Aspartic and glutamic acids	?	–
e. γ-Amino butyric acid	?	+
6. Volatile compounds		
a. Characteristic aroma volatiles	–	–
b. Off-flavors (accumulation of ethanol, acetaldehyde, and ethyl acetate)	+ (<1 kPa)	+ (>20 kPa)
7. Vitamins		
a. Provitamin A (β-carotene) loss	–	–
b. Vitamin C (ascorbic acid) loss	–	–
D. Growth and development		
1. Cell division	– or +	– or +
2. Cell enlargement	– or +	– or +
3. Endogenous growth regulators	?	?
4. Periderm formation	– (<5 kPa)	– (>10 kPa)
E. Physical injuries		
1. Wound healing	See D-4 above	
2. Tissue browning	See C-2 above	
3. Stress-induced CO_2 and C_2H_4	–	–
F. Transpiration (water loss)		
1. Stomata opening	?	?
2. Wound healing	See D-4 above	

Cause of deterioration	General effect[1] of Reduced O_2	Elevated CO_2
G. Physiological disorders		
1. Chilling injury	+ [2]	− or +
2. Scald on apples and pears	−	−
3. C_2H_4-induced disorders	−	− or +
4. CA-induced disorders	+	+
H. Pathological breakdown		
1. Susceptibility to pathogens	− or +	− or +
2. Fungal growth	− (<1 kPa)	− (>10 kPa)
3. Bacterial growth	− or 0	− or 0

[1] Specific O_2 and/or CO_2 concentrations at which these effects are observed depend upon the commodity, cultivar, temperature and duration of storage, and interactions between O_2 and CO_2 levels.

[2] − = decrease or inhibit, 0 = no effects, + = stimulate or increase, ? = inadequate data for conclusion.