Agriculture and Agri-Food Canada | Agriculture et Agroalimentaire Canada

Physiology and biochemistry of aroma and off-odors in fresh-cut produce

Charles F. Forney

Agriculture and Agri-Food Canada,
Kentville, Nova Scotia, Canada

Canada

Importance of flavor

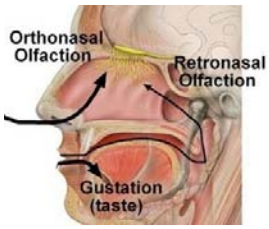
- Flavor is a human perception
- Good flavor is needed to achieve consumer satisfaction
- Acceptable flavor is often lost prior to decline in visual appearance
- Maintaining flavor in fresh-cut produce can be challenging

Role of aroma volatiles

- Provide unique flavor characteristics
  - 70-80% of flavor attributed to volatiles
- Most dynamic component
  - Can change dramatically during storage and marketing
  - Product maturity /ripening
  - Altered by storage environment
- Indicator of quality
  - Sign of spoilage

Olfaction (Smell)

- Interaction of volatile compounds with olfactory receptors in the nasal cavity
  - Orthonasal – odor/aroma
  - Retronasal – flavor
- Over 8,000 volatile compounds in food
- Fewer than 1,000 contribute to odor
  - ppb to ppt or less



Aroma of fresh-cut produce

- Chemistry
- Biochemistry
- Mechanisms controlling aroma
- Factors affecting aroma
  - Initial Quality
  - Cutting
  - Packaging

Fresh fruits and vegetables

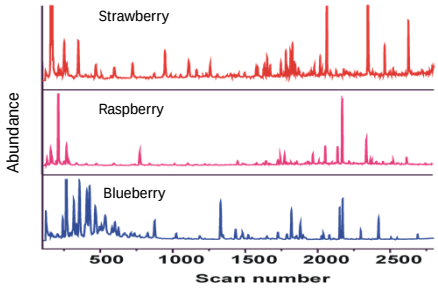
- Diverse
  - Morphology
  - Physiology
  - Chemistry




Volatile chemistry

- Analyzed using gas chromatography (GC)
  - Mass spectroscopy
  - Olfactory detection
- Volatile profiles
  - Hundreds of compounds
  - Wide range of concentrations

GC volatile profiles

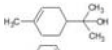
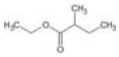
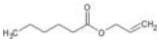


Olfactory thresholds

Compound	Olfactory Threshold (ppb)
Ethanol	10,000 - 100,000[a]
Ethyl acetate	100 - 1,000[b]
Methyl butanoate	1.0 - 10[b]
Linalool	0.1 - 1.0[b]
Ethyl hexanoate	0.01 - 0.1[b]
Ethyl butanoate	0.001 - 0.01[b]

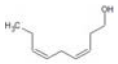
[a]Devos *et al.* (1990)
[b]Larson and Pool (1992)

Aroma impact compounds

Compound	Structure	Crop	Aroma*
Terpenoids			
α-Terpineol		Lime	Pine, terpene, lilac, citrus
α-Ionone		Raspberry	Sweet, woody, floral, violet, tropical fruity
Geosmin		Red beet	Freshly plowed soil, earthy
Esters			
Ethyl 2-methylbutyrate		Apple	Fruity, estry
Allyl caproate		Pineapple	Sweet, fruity, pineapple

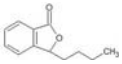
*www.thegoodscentscompany.com

Aroma impact compounds

Compound	Structure	Crop	Aroma*
Aldehydes			
Benzaldehyde		Cherry	Almond, fruity
(E)-2-Nonenal		Cucumber	Fatty, green, cucumber
(Z)-3-Hexenal		Tomato	Green, fatty, grassy
Ketones			
1-Octen-3-one		Mushroom	Herbal, mushroom, earthy
Alcohols			
(Z,Z)-3,6-Nonadienol		Watermelon	Fatty, soapy, cucumber, watermelon rind

*www.thegoodscentscompany.com

Aroma impact compounds

Compound	Structure	Crop	Aroma*
Lactones			
γ-Undecalactone		Peach	Creamy, fruity, coconut, peach
3-Butylphthalide		Celery	Herbal, celery
Furans			
Furaneol		Strawberry	Sweet, cotton candy, caramel, strawberry
Pyrazines			
2-Isobutyl 3-methoxypyrazine		Green bell pepper Peas	Green pea, green bell pepper

*www.thegoodscentscompany.com

Aroma impact compounds

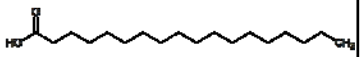
Compound	Structure	Crop	Aroma*
Sulfur compounds			
Dimethyl sulfide		Asparagus, cabbage, corn	Sulfury, onion, sweet corn, cabbage
2-Isobutyl thiazole		Tomato	Green, wasabi, privet, tomato leaf
4-methythiobutyl isothiocyanate		Broccoli	Cabbage, radish
Propyl propanethiosulfonate		Onion	Roasted alliaceous

*www.thegoodscentscompany.com

Primary pathways/precursors

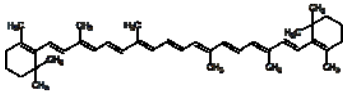
- Terpenoids pathway
  - Isoprene (C_5)

- Fatty acids
  - β-oxidation
  - Lipoxygenase (LOX) pathway

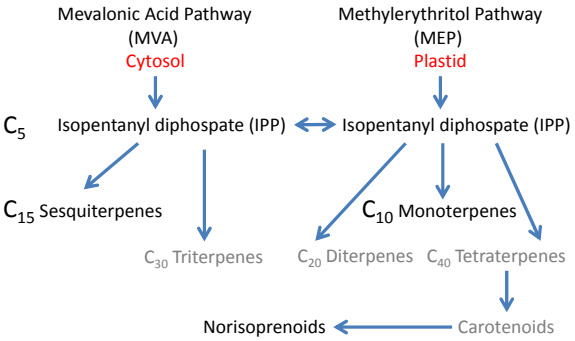


- Amino acids

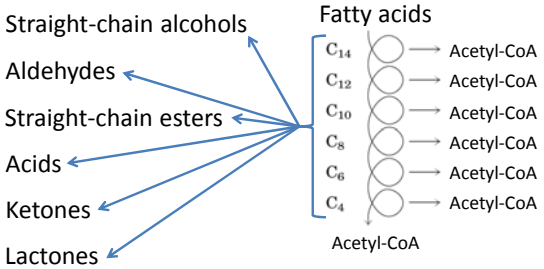
- Carotenoids
  - norisoprenoids



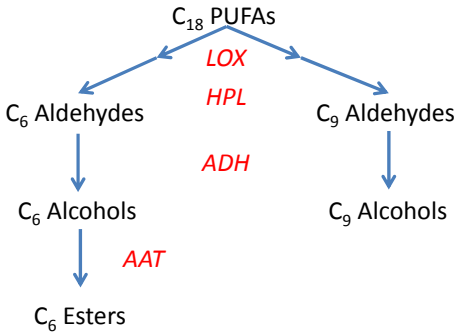
Terpenoid synthesis



β-Oxidation

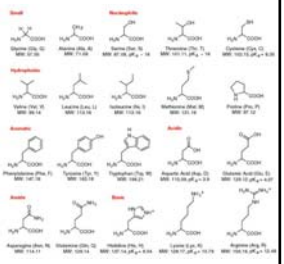


Lipoxygenase (LOX) pathway

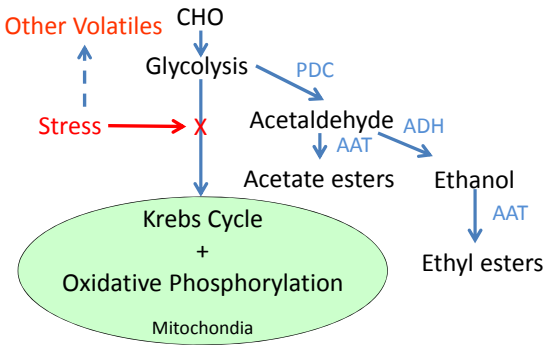


Amino acids

- Provide an array of backbones for volatile synthesis
  - Aliphatic
  - Branched
  - Aromatic
- Source of N and S
- Precursors
  - Alcohols
  - Acids
  - Esters
  - Glucosinolates/isothiocyanates
  - Sulphoxides



Fermentation

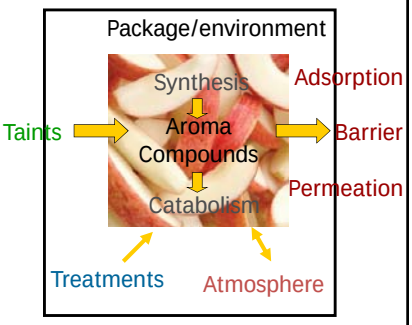


Induction of fermentation

- Ripening
- Senescence
- Stress
  - Low O_2/ high CO_2
  - Heat
  - Chilling
  - Freezing
  - Water stress
  - Ozone

Mechanisms of aroma change

- Metabolism
  - Synthesis
  - Catabolism
- Diffusion
  - Gain
  - Loss



Initial Quality

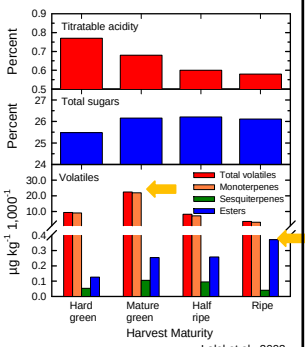
- Cultivar selection
- Production practices
  - Fertilization
  - Spacing
  - Pruning
- Environmental stress
  - Water
  - Temperature

Postharvest treatments

- Treatments prior to processing affect aroma
  - Manipulation of ripening
  - Temperature management
  - Postharvest treatments
  - Controlled atmosphere (CA) storage

Postharvest ripening – 'Kensington Pride' mango

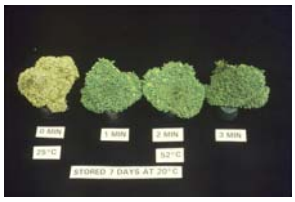
- Fruit ripened at 21 °C to 1.5 kg cm^{-2} firmness
- Total volatiles highest in mature green fruit
  - Monoterpenes
- Ripe fruit had more esters



Lalel et al., 2003

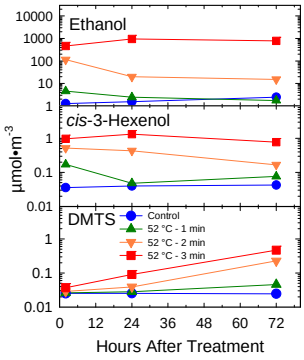
Heat treatments - Broccoli

- Hot water dips extends shelf-life
  - Delays yellowing
  - Reduces decay
- Off-odour produced by 52°C – 2 or 3 min treatment



Heat treatments - Broccoli

- Heat –stress induced volatiles
  - Ethanol
  - *cis*-3-Hexenol
  - Dimethyltrisulfide (DMTS)
- GC-Olfactory analysis
  - Identified *cis*-3-hexanol – floral, green, hay-like
  - DMTS – floral, sulfury, green

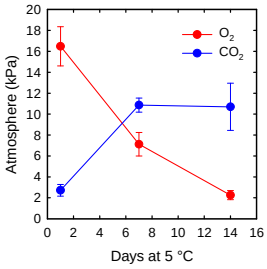


CA Storage

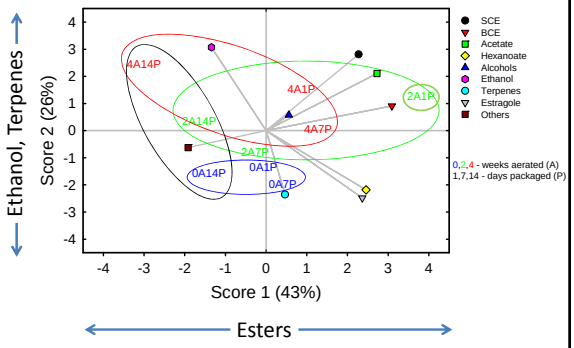
- Prolonged storage in CA may reduce fruit aroma
- Low O_2 concentrations can increase aroma loss
- May partially recover aroma by holding in air

Package atmospheres

- 'Ambrosia' Slices packaged in PE zip-loc bags
  - OTR – 3500 mL m^{-2} d^{-1}
- O_2 decreased to:
  - 2.0 kPA

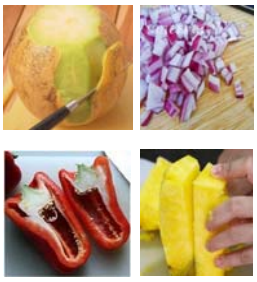


'Ambrosia' apple slice volatiles After 6 months CA



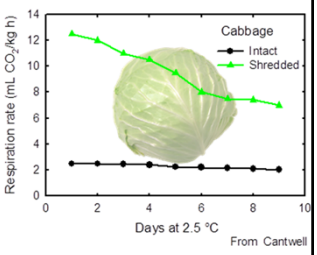
Cutting

- Alters physiology
  - Respiration
  - Volatile synthesis
- Induces production of secondary volatiles
- Removes diffusional barriers
  - Increases aroma loss



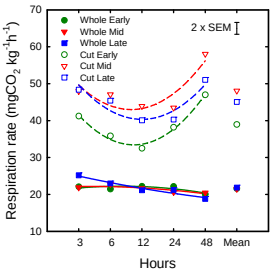
Product respiration

- Shredding cabbage
- Increased respiration 5-fold
- After 9 days remained 3.5-fold greater



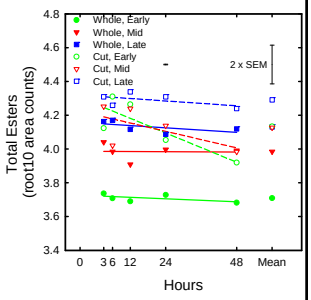
Product respiration – 'Gala' apples

- Doubles CO_2 production
- Sustained over 48 hours



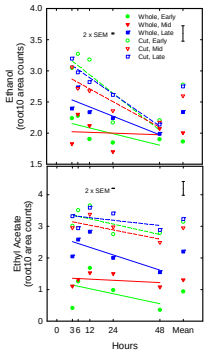
Ester release from cut apples

- Headspace ester increases with maturity
- Cutting stimulates ester production/release
  - Greatest in early harvest fruit
  - Lower MW esters



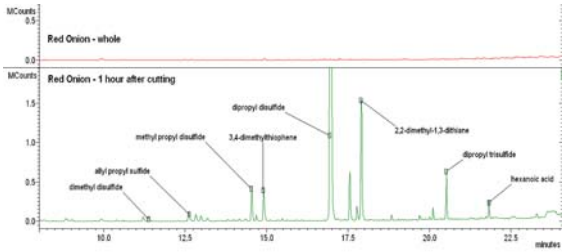
Induced fermentation

- Both ethanol and ethyl acetate increased in response to cutting
- Rise in ethanol transient
- Fermentation alters ester composition



Secondary volatile formation -Cut onion

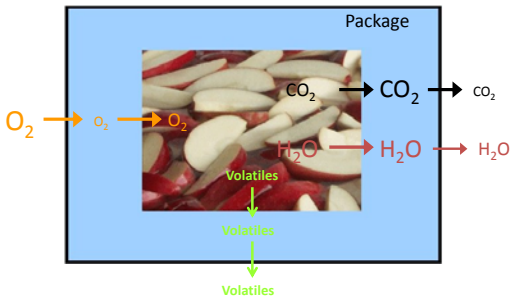
- Volatile sulfur compounds are formed after cutting
  - Reaction of alliinase and cysteine sulfoxides
- Products are unstable and continue to react



Packaging

- Integral part of the fresh-cut product
- Physical protection
- Atmosphere modification (MAP)
- Impact aroma

Modified Atmosphere Packaging (MAP)

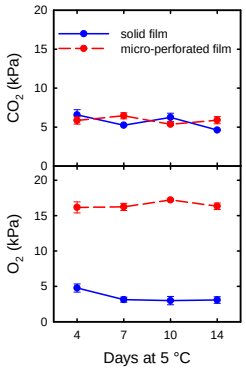


Package atmosphere effects

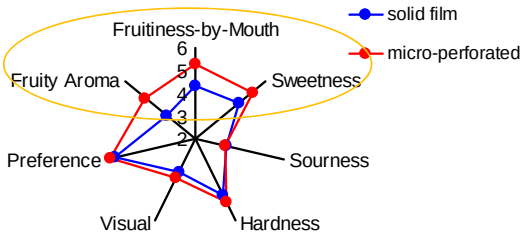
- 'Gala' apples - 12 slices/apple
- Sealed in polymer bags
  - **Solid film (S)** - multi-layered polyolefin
    - OTR – 660 mL m^{-2} d^{-1}
    - CO_2TR – 3430 mL m^{-2} d^{-1}
  - **Micro-perforated film (P)** - 2-100 µm holes/package
    - OTR – 3740 mL m^{-2} d^{-1}
    - CO_2TR – 3230 mL m^{-2} d^{-1}
- Stored at 5°C for 21 d

Package atmosphere composition

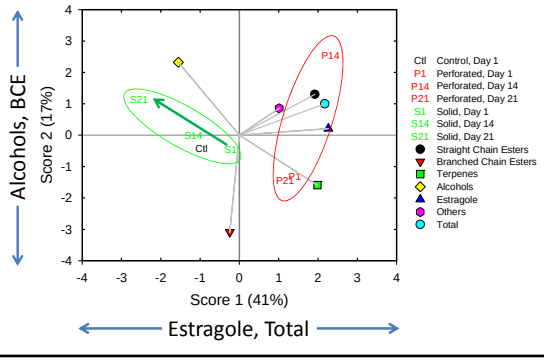
- Equilibrium package atmospheres
  - Solid film
    - 3 kPa O_2
    - 6 kPa CO_2
  - Micro-perforated film
    - 16 kPa O_2
    - 6 kPa CO_2



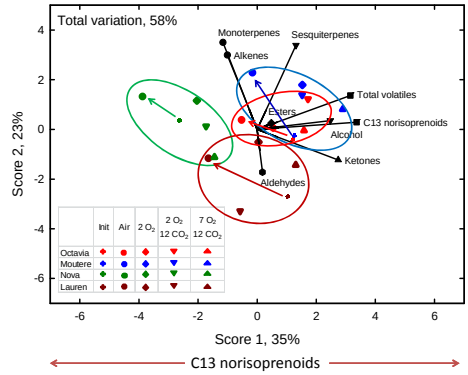
Sensory analysis



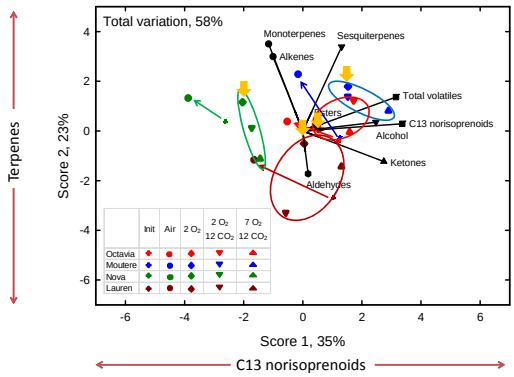
PCA of volatile composition



Raspberry volatiles

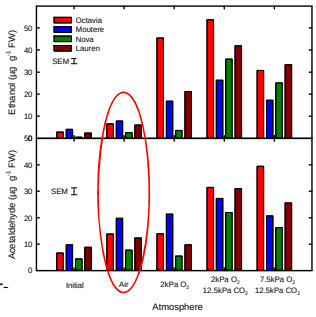


Volatiles



Anaerobic volatiles

- Induced by anaerobic conditions/stress
- Ethanol
  - Air-stored doubled
  - 2% O_2/12.5% CO_2 15-fold increase
  - 12.5% CO_2 10-fold increase
  - 2% O_2 cultivar dependent
- Acetaldehyde
  - 2% O_2/12.5% CO_2 3-fold increase
  - 12.5% CO_2 2.5-fold increase
  - 2% O_2 increase similar to air-store



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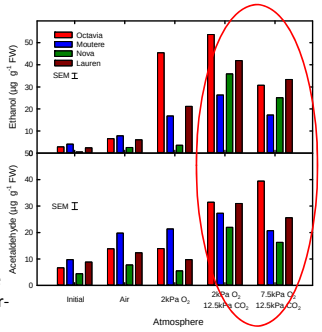

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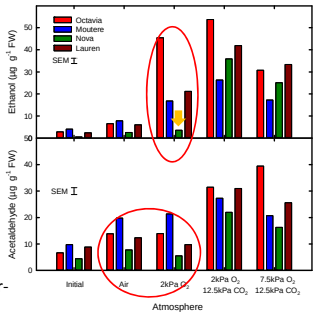
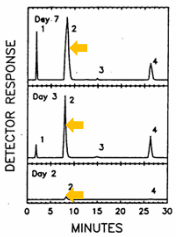


Avoid injurious atmospheres in MAP

- Low O_2 and/or high CO_2 atmospheres may induce off-odors
- Ethanol and acetaldehyde universally produced under stress
  - Not directly responsible for off-odor
- Off-odor development variable among commodities

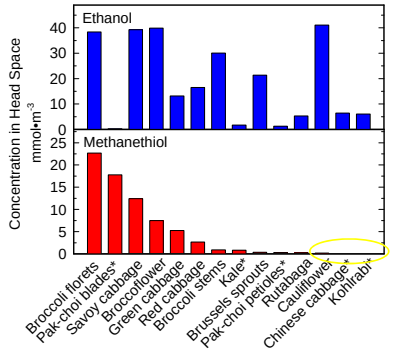
Broccoli anaerobic off-odor

- Strong off-odour induced by low O_2
  - Rotten cabbage
- Identified methanethiol as primary mal-odorant
  - 1 - Hydrogen sulfide
  - 2 - Methanethiol
  - 3 - Dimethyl sulfide
  - 4 - Dimethyl disulfide



Forney et al., 1991

Variable response of fresh-cut *Brassicas* to low O_2

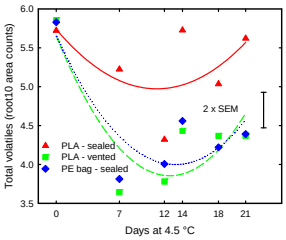


Interaction of packaging materials

- Permeation of aroma compounds
- Adsorption (scalping) of volatiles
- Determines diffusional loss
- Dependent on polymer chemistry
  - Polyolefins – high affinity for volatiles
    - Polyethylene, polypropylene
  - Polyesters – weak affinity for volatiles
    - Polylactic acid (PLA)

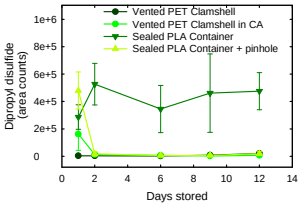
Packaging effects on aroma retention - Onions

- Sealed PLA maintained headspace volatiles
  - 9/10 S-volatiles significantly greater in sealed PLA
  - Fresh onion aroma maintained for 12 days in sealed PLA



Diced yellow onions – Loss of volatiles

- Sealed PLA maintained headspace volatiles
  - 8 S-volatiles significantly greater in Sealed PLA-stored onions



Diced yellow onions – Sensory quality

- All sensory attributes in PET-air stored onions were poorer than other packages treatments after 8 days
- Sensory quality of onions from sealed PLA not signifcantly different from those stored in PLA-vent or PET CA

Yellow onion sensory quality evaluated by 9 trained panelists after 8 days

Attribute	PLA	PLA-vent	PET CA	PET air	SEM
Appearance	1.89	1.44	1.89	2.83z	0.325
Fresh Onion Odor	3.17	2.94	3.00	4.33	0.360
Off-Onion Odor	1.78	1.56	1.22	3.56	0.276
Fresh Onion Flavor	2.72	2.67	2.56	3.68	0.356
Off-Onion Flavor	1.56	1.33	1.56	3.68	0.289

zRating scale 1 excellent, 5 poor, $P < 0.01$

Conclusions

- Fresh-cut produce aroma is complex and dynamic
  - Chemistry, biochemistry and human perception
- Cutting induces metabolic changes that affect aroma volatiles and enhances diffusional losses
- Stress can induce fermentation and production of off-odors
- Packaging can alter aroma by atmosphere modification or affecting diffusional loss

Conclusions

- To optimize the aroma of fresh-cut produce:
  - Start with high quality product
  - Minimize stress during processing and marketing
  - Maintain an environment conducive to aroma maintenance