Quality: From Tissues to Molecules

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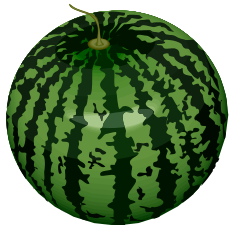
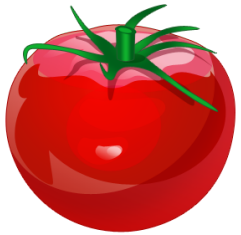
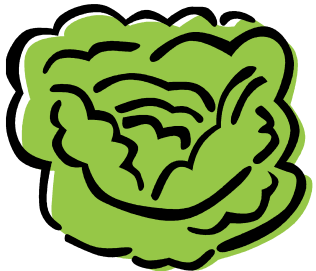
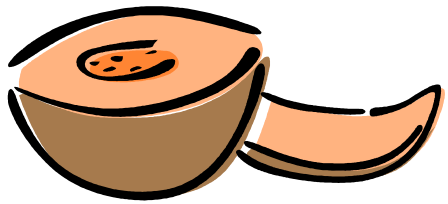
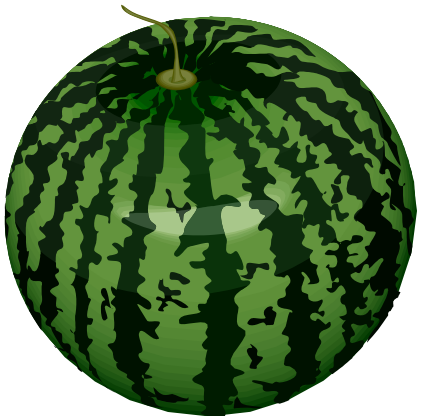
Outline of Presentation

- What molecular components and tissue types make up 'quality' attributes?
- Where are these components originally located in plant cells?
- What happens after harvest when tissues are handled, stored and/or processed?
- What do we know/don't know and where are the future opportunities?

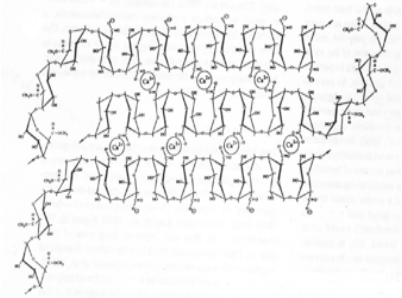





Quality Attributes of Fruits & Vegetables

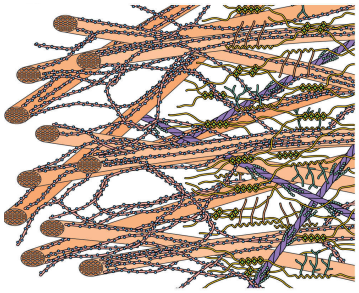
- Color
- Texture
- Flavor
- Nutrients



Plant cells – from molecules to organs

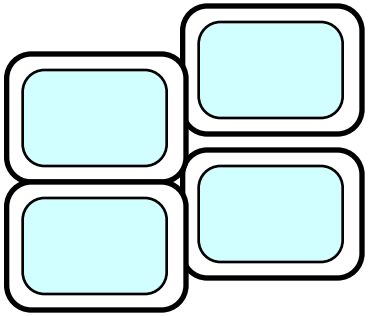


Pectin - in cell wall and middle lamella

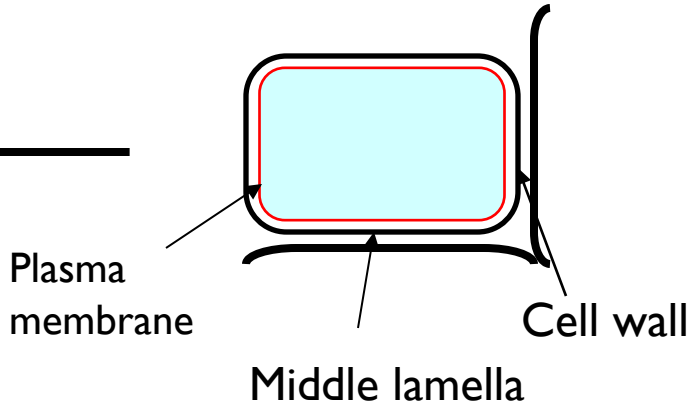


Cell wall – cellulose, pectin, hemicellulose, proteins, calcium

Organ



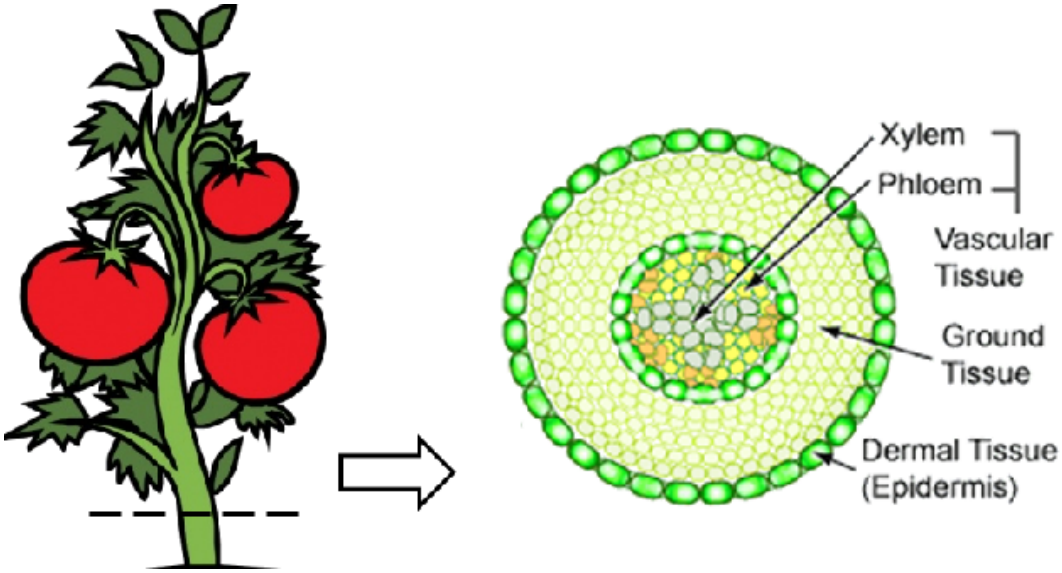
Tissue

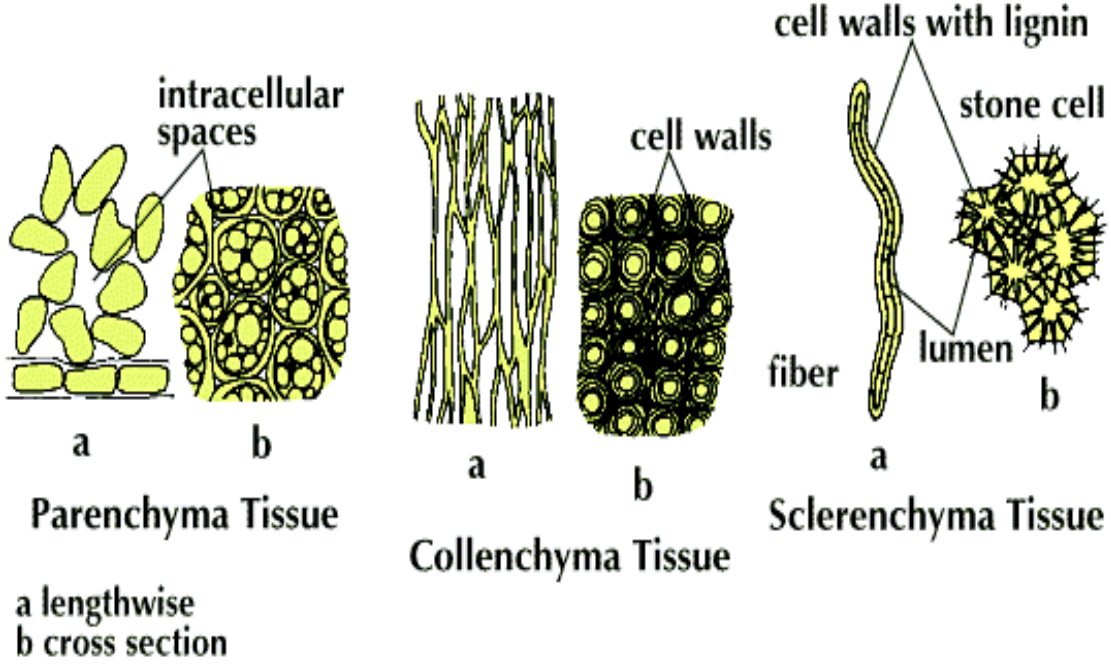


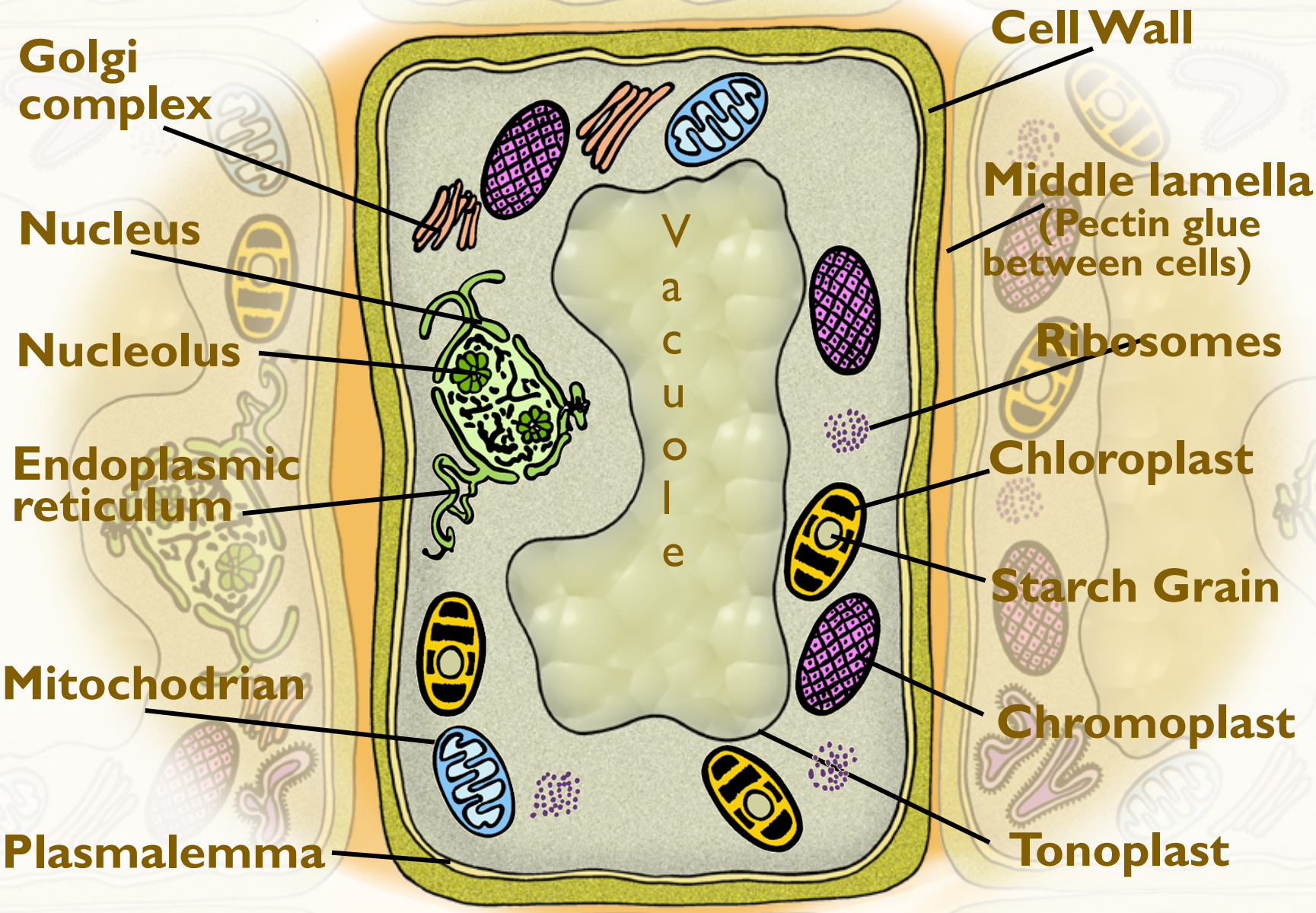
Cell

Tissues & Cell Types

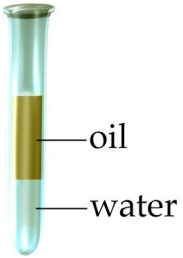
Tissues	Function	Cell Types	Location / Shape
Dermal	Protection	Epidermis	Outermost layer of cells
		Periderm	Beneath epidermis
Ground	Storage, Support & Photosynthesis	Parenchyma	"Typical" cells, throughout plant, cell wall (polyhedral)
		Collenchyma	Cell wall (elongated)
		Sclerenchyma	Cell wall, dead (very long, elongated)
Vascular	Transport water, nutrients	Xylem	Evenly spaced, water conducting, cell wall, dead (elongated, tapering)
		Phloem	Evenly spaced, nutrient conducting (elongated, tapering)


Xylem
Phloem
Vascular Tissue
Ground Tissue
Dermal Tissue (Epidermis)


intracellular spaces
a
b
Parenchyma Tissue
a lengthwise
b cross section
cell walls
a
b
Collenchyma Tissue
cell walls with lignin
stone cell
fiber
lumen
b
a
Sclerenchyma Tissue

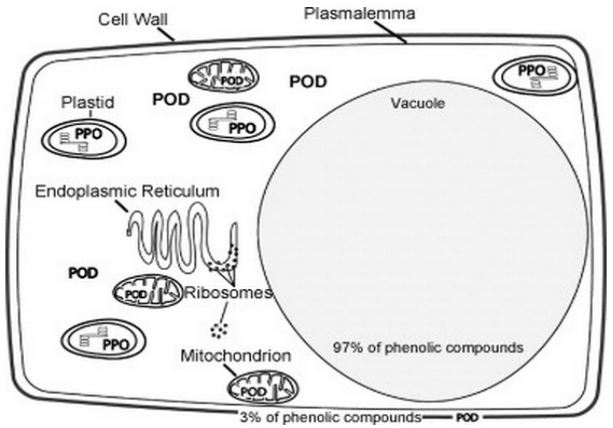

Golgi complex
Nucleus
Nucleolus
Endoplasmic reticulum
Mitochodrian
Plasmalemma
Vacuole
Cell Wall
Middle lamella
(Pectin glue between cells)
Ribosomes
Chloroplast
Starch Grain
Chromoplast
Tonoplast

Water vs. Fat Soluble?



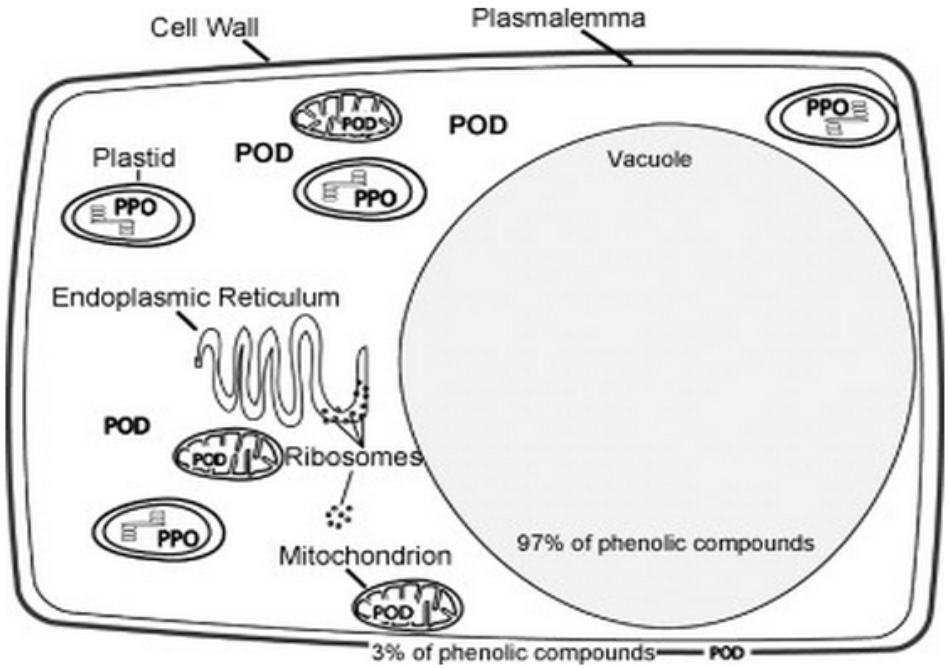
- Water soluble?
  - Cytoplasm – most of the area within the plasma membrane
  - Vacuole – lower in pH, storage of sugars, acids
  - Cell wall
  - Middle lamella

- Fat soluble?
  - Membranes
  - Lipid Globules
  - Plastids
    - Chloroplast (photosynthesis)
    - Chromoplast

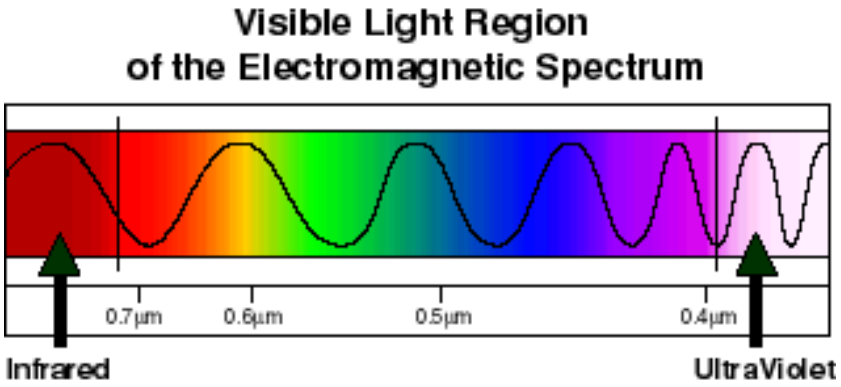


Where are the 'Quality' Components Located in Plant Cells?

- Color?
- Texture?
- Flavor?
- Nutrients?



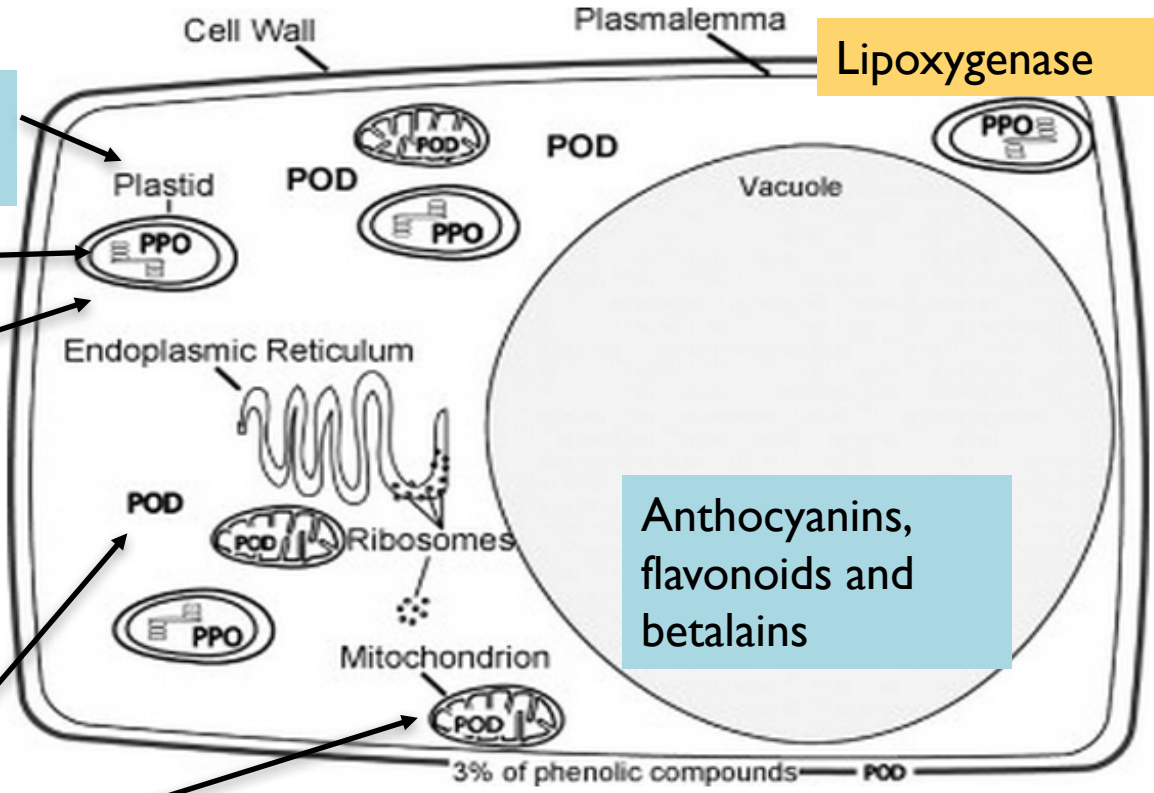
COLOR


Visible Light Region
of the Electromagnetic Spectrum
0.7µm
0.6µm
0.5µm
0.4µm
Infrared
UltraViolet

Color Components & Enzymes

- Water soluble
  - Anthocyanins (red, orange, yellow, purple)
  - Flavonoids (yellow-brown)
  - Betalains (red-yellow)
- Fat soluble
  - Chlorophyll (green)
  - Carotenoids (orange-red)
  - Xanthophylls (yellow-red, oxidized carotenoids)
- Enzymes affecting color
  - Polyphenol oxidase (browning)
  - Phenylalanine ammonia lyase (browning)
  - Peroxidase (free radicals, browning)
  - Lipoxygenase (carotenoid bleaching)

Color



Polyphenol oxidase

Lipoxygenase

Chlorophyll, carotenoids, xanthophylls

Peroxidase

Lipoxygenase

Anthocyanins, flavonoids and betalains

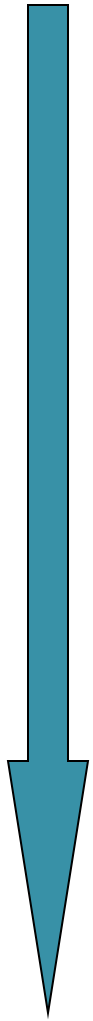
Toivonen and Brummel, 2008

Water soluble

Fat soluble

Postharvest Handling & Processing

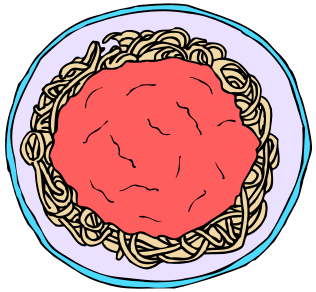
- Fresh, Transported
- Fresh, Transported & Stored
- Lightly processed
  - Fresh-cut
  - Irradiation
  - Radiofrequency
- Moderately processed
  - High pressure
  - Pasteurization
  - Blanching
  - Freezing
- Highly processed
  - Canning



Senescence, Stress and Increasing level of Tissue Disruption

Tissue Integrity in Different End Products

Example: lycopene in tomatoes



Fresh-cut sliced tomatoes

-Lightly processed
-Refrigerated
-Some cellular disruption, possible stress to all tissues
-Active enzymes
-Cut surfaces susceptible to oxidation & evaporation
-Lipid soluble lycopene – located primarily in plastids, depends on storage time/temp

Tomato paste

-Highly processed
-Packaged and stored
-Complete cellular disruption
-No active enzymes
-Oxygen exposure depends on package
-Lipid soluble lycopene – distributed throughout paste

Limited research on selection of genetic phenotypes for specific end products

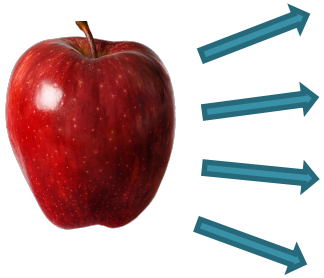
Enzymatic Browning

Enzyme		Substrate		Product
Polyphenol oxidase (PPO)	+	**Phenolic compounds**	$\xrightarrow{O_2}$	**Quinones**
Plastids		Vacuole		Cytoplasm

- One of the biggest problems in the quality of fresh and processed fruit & vegetable products.
- Occurs ONLY when tonoplast membrane is broken.
- Membrane loss occurs with normal senescence, but is accelerated when cells are bruised, cut, heated, frozen etc.
- May require 'activation'. More biochemical/plant physiology/genetic work needed!

CA Storage & Changes in Subcellular Location of Apple PPO PhD Diane M. Barrett (1989)

- Normal (2, 3, 95%) and High CO_2 (2.5-6, 8-12, 80) storage – 28 weeks
- Differential centrifugation to separate subcellular organelles

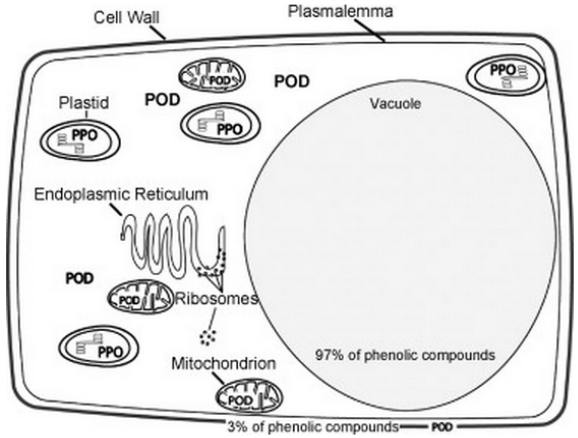


Plastids, 4,000xg

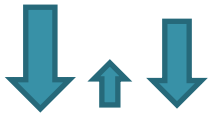
Mitochondrial, 10,000xg

Cell wall, 200xg

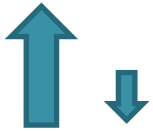
Soluble



- Plastid &
- Mitochondrial



- Cell wall &
- Soluble



- Changes more accelerated by High CO_2

Changes During Storage/Processing

- Stored apple – what is happening?:
  - release from membrane-bound organelles
  - adherence to broken thylakoids
  - changes in permeability
  - proteases, enzyme turnover
  - product (phenolics) inhibition

- Processed product
  - Changing raw material – how to process apple sauce or juice all year?
  - Addition of 'anti-browning' agents – how to add enough to last for shelf life of product?
  - Evidence that use of calcium ascorbate helps maintain cell integrity and therefore reduces browning.
- Very little research. Little comparison to different cultivars, or types of crops.

TEXTURE

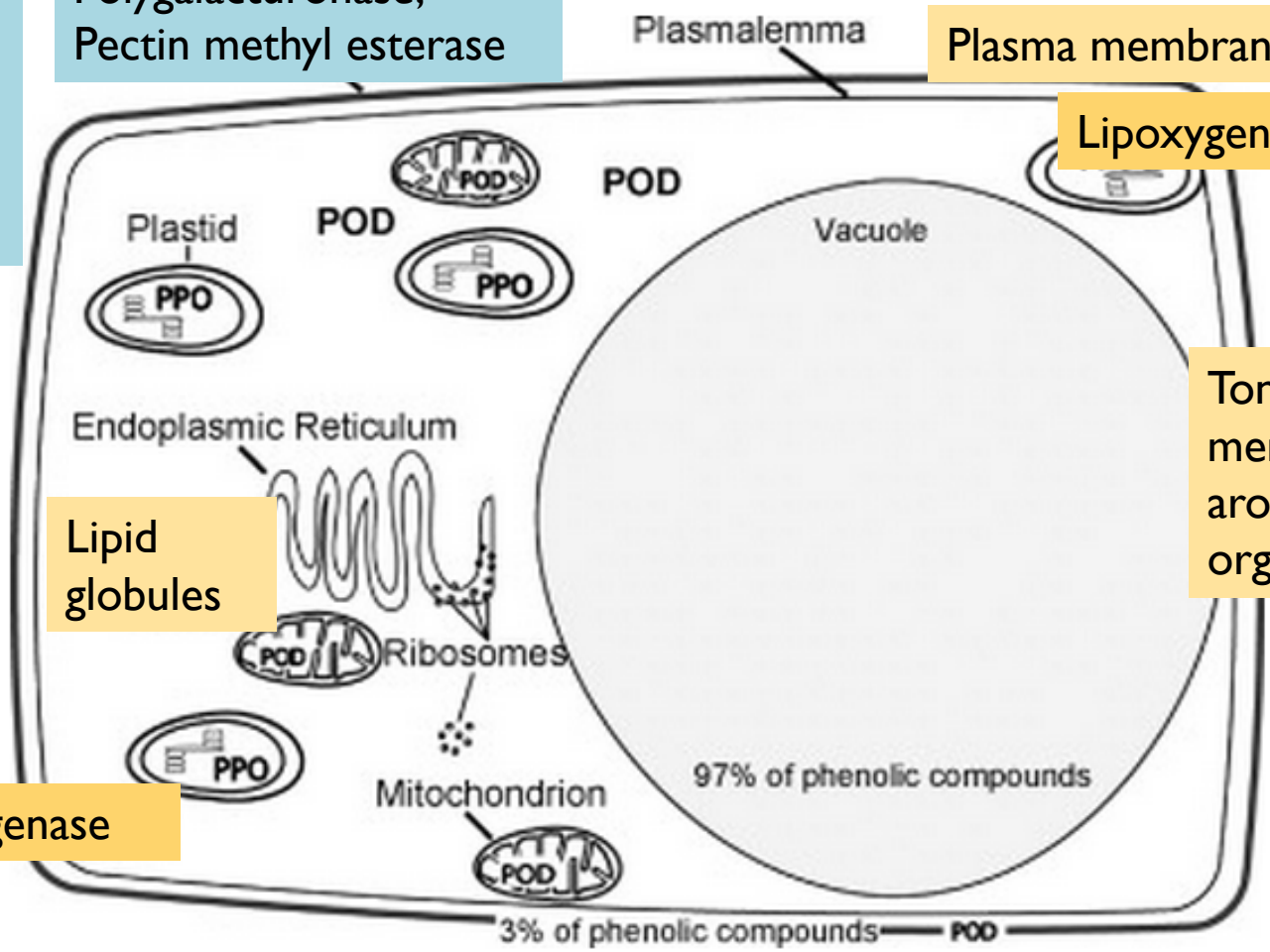
Texture Components & Enzymes

- Water soluble
  - Cell wall – pectin, cellulose, hemicellulose, lignin
- Lipid soluble
  - Plasma membrane, tonoplast and other membranes (both for oily texture and turgor/retention of cell contents)
  - Lipid globules
- Enzymes affecting texture
  - Polygalacturonase (pectin degradation)
  - Pectin methyl esterase (good/bad actor)
  - Lipoxygenase (good/bad actor)

Texture

Cell wall, pectin, cellulose, hemicelluose, lignin

Polygalacturonase, Pectin methyl esterase



Plasma membrane

Lipoxygenase

Tonoplast, membranes around all organelles

Lipid globules

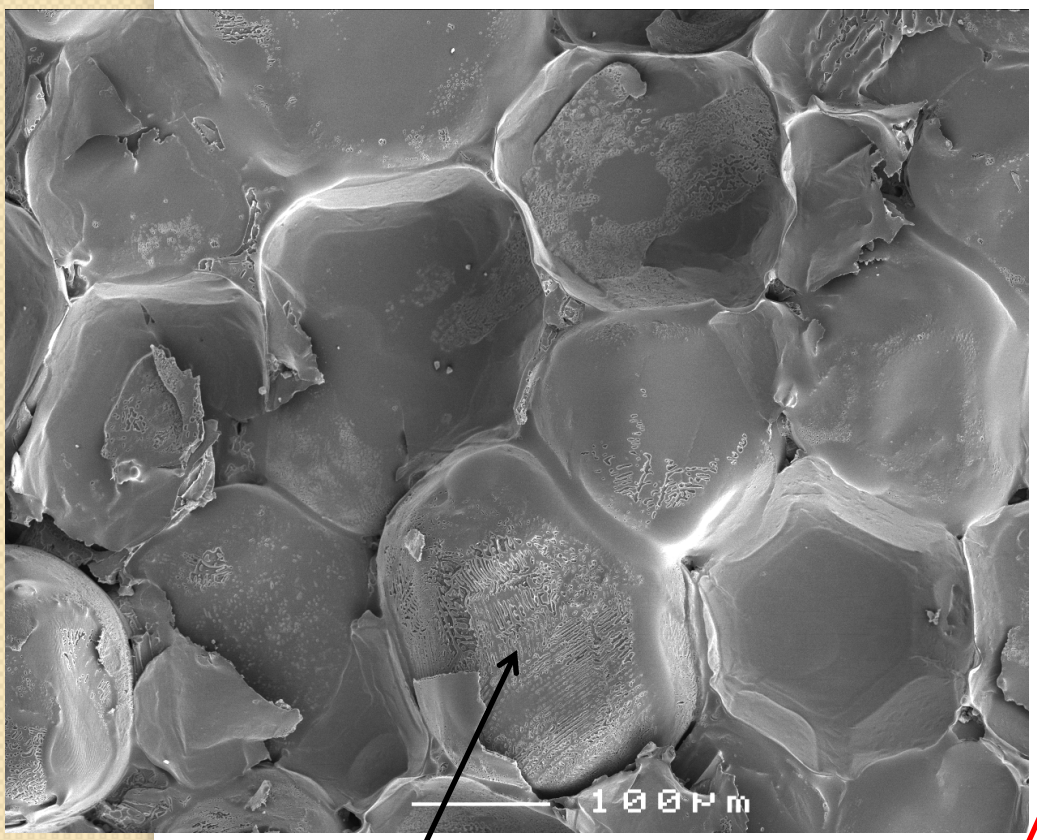
Lipoxygenase

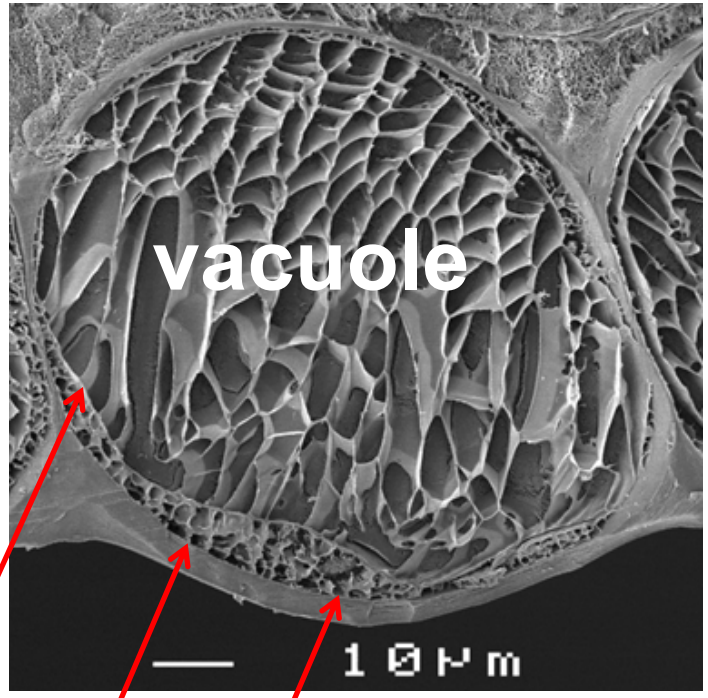
Water soluble

Fat soluble

Plant tissue

Scanning Electron Microscopy - Onions





Plant cell

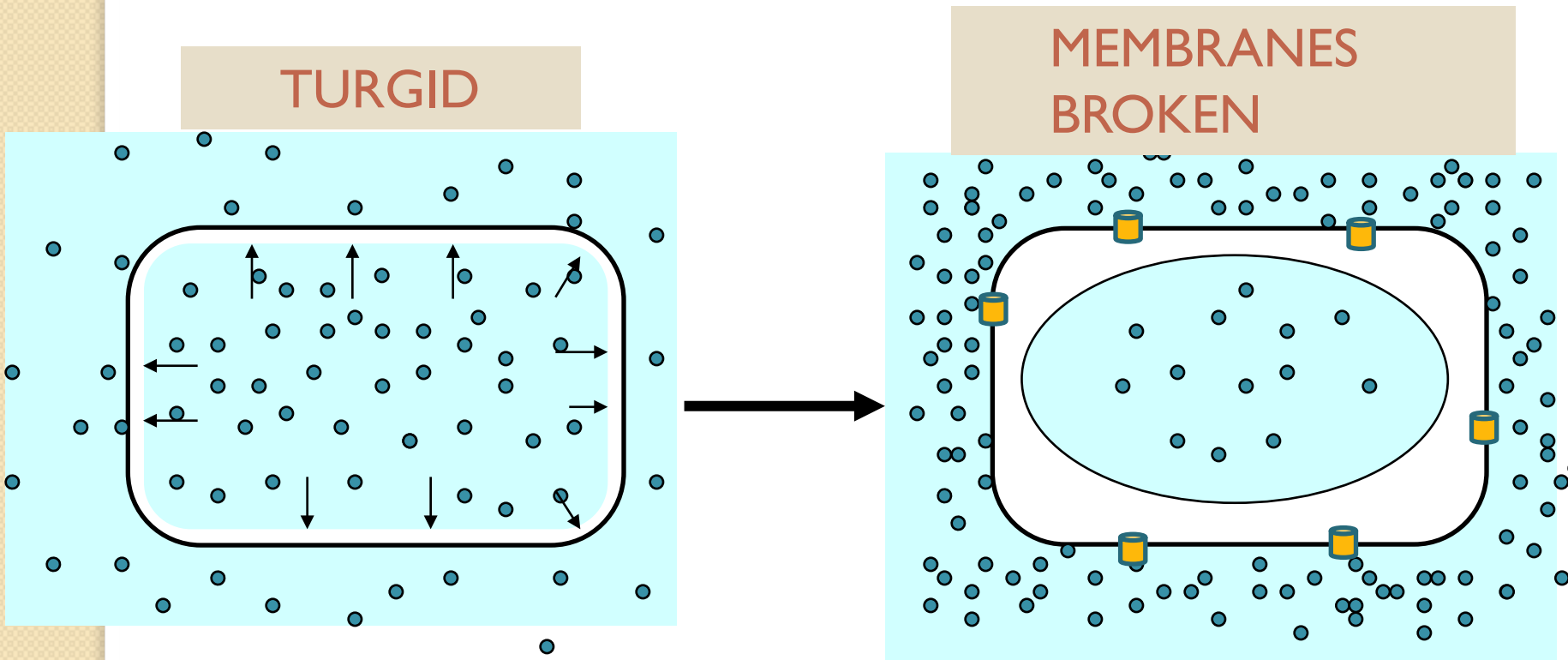
tonoplast

cell wall

plasma membrane

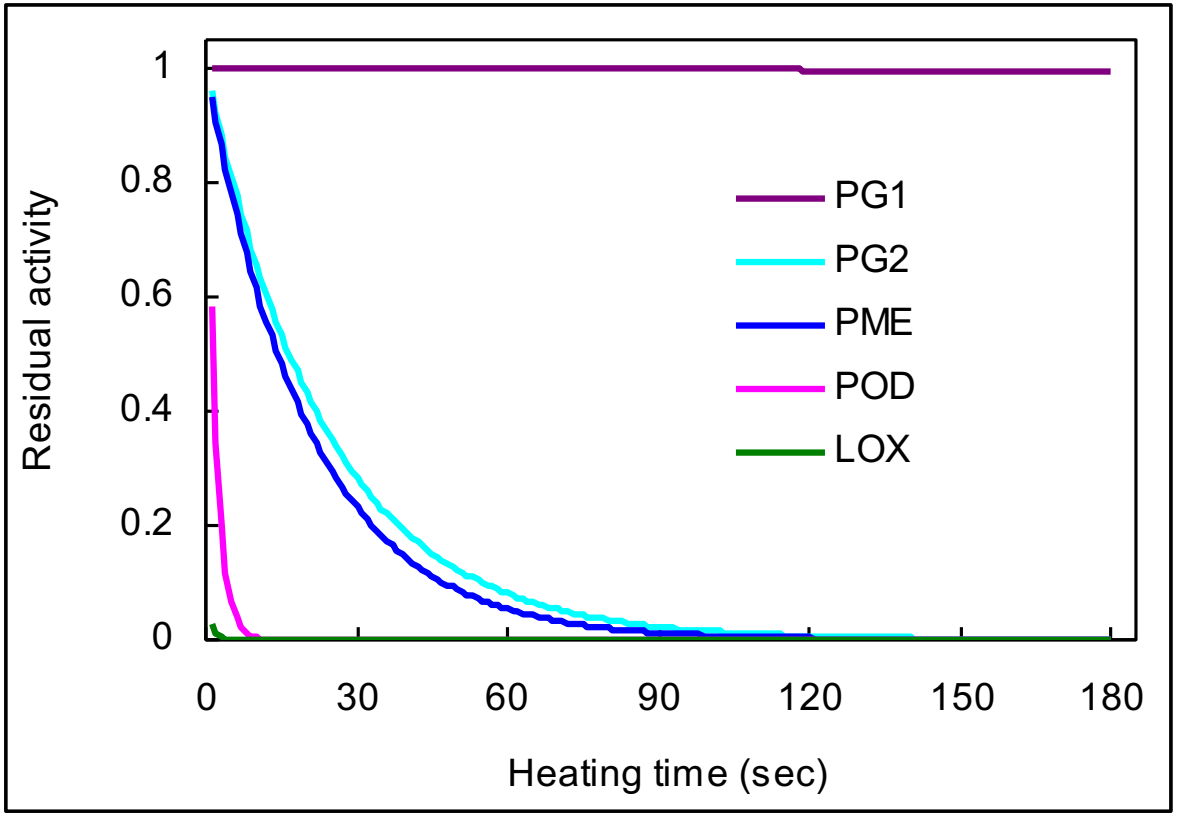
Plant Cell – Turgor Pressure

- Internal pressure of fluid contents pushing out on membrane
- Relates to the sensation of 'juiciness' or burst of liquid in the mouth when biting into a product.
- Correlated to initial slope in a firmness measurement.



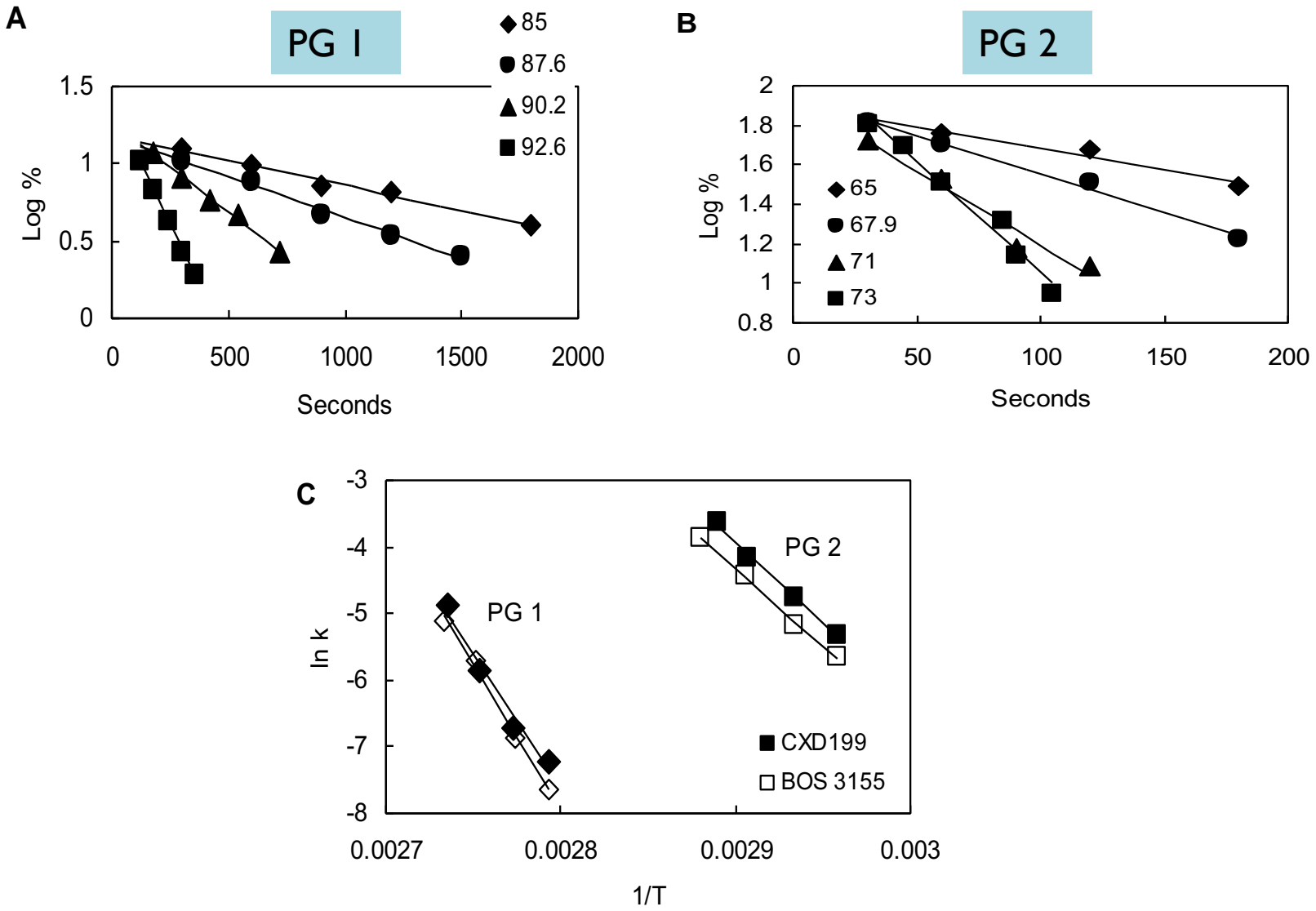
Limited research on changes to turgor with cultivar, maturity, growing conditions, environmental stress (drought etc.) and effects on product quality.

Tomato Enzyme Inactivation at 75 °C

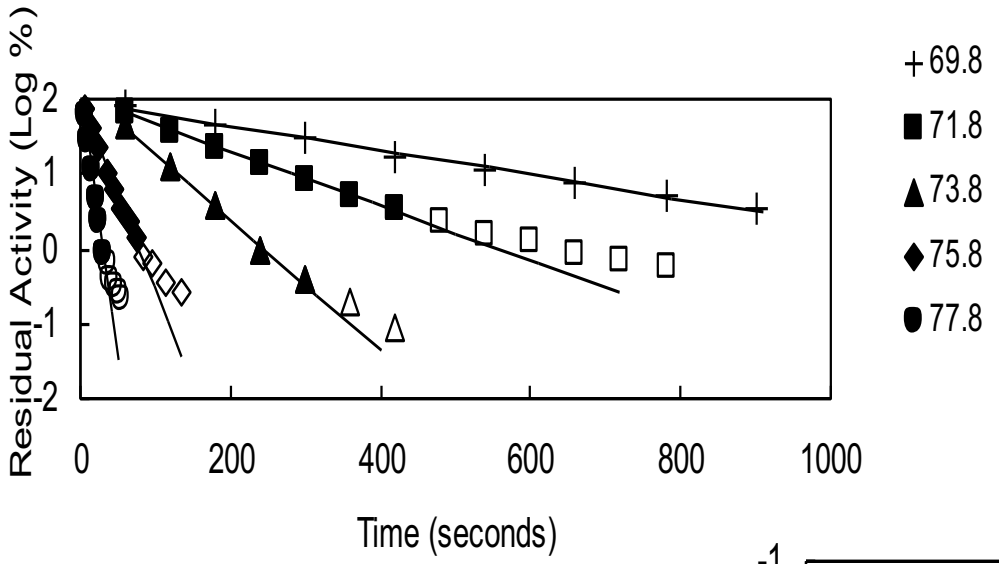


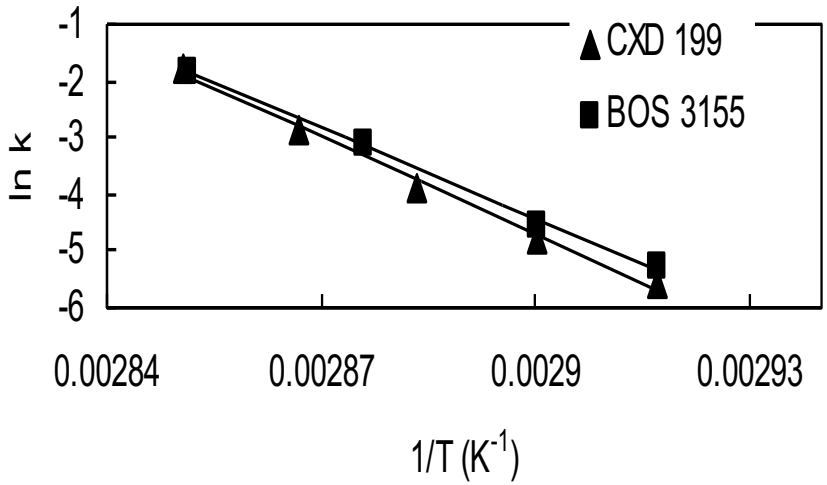
Comparison of the time required at a common temperature. PG1 is unaffected, while LOX is the most sensitive. Order of thermal sensitivity: PG1 > PG2 > PME > POD > LOX

Tomato Polygalacturonases



Tomato pectin methylesterase





In High Pressure Processing, the enzyme sensitivity is the opposite – PG is easily inactivated and PME is not - why?

FLAVOR

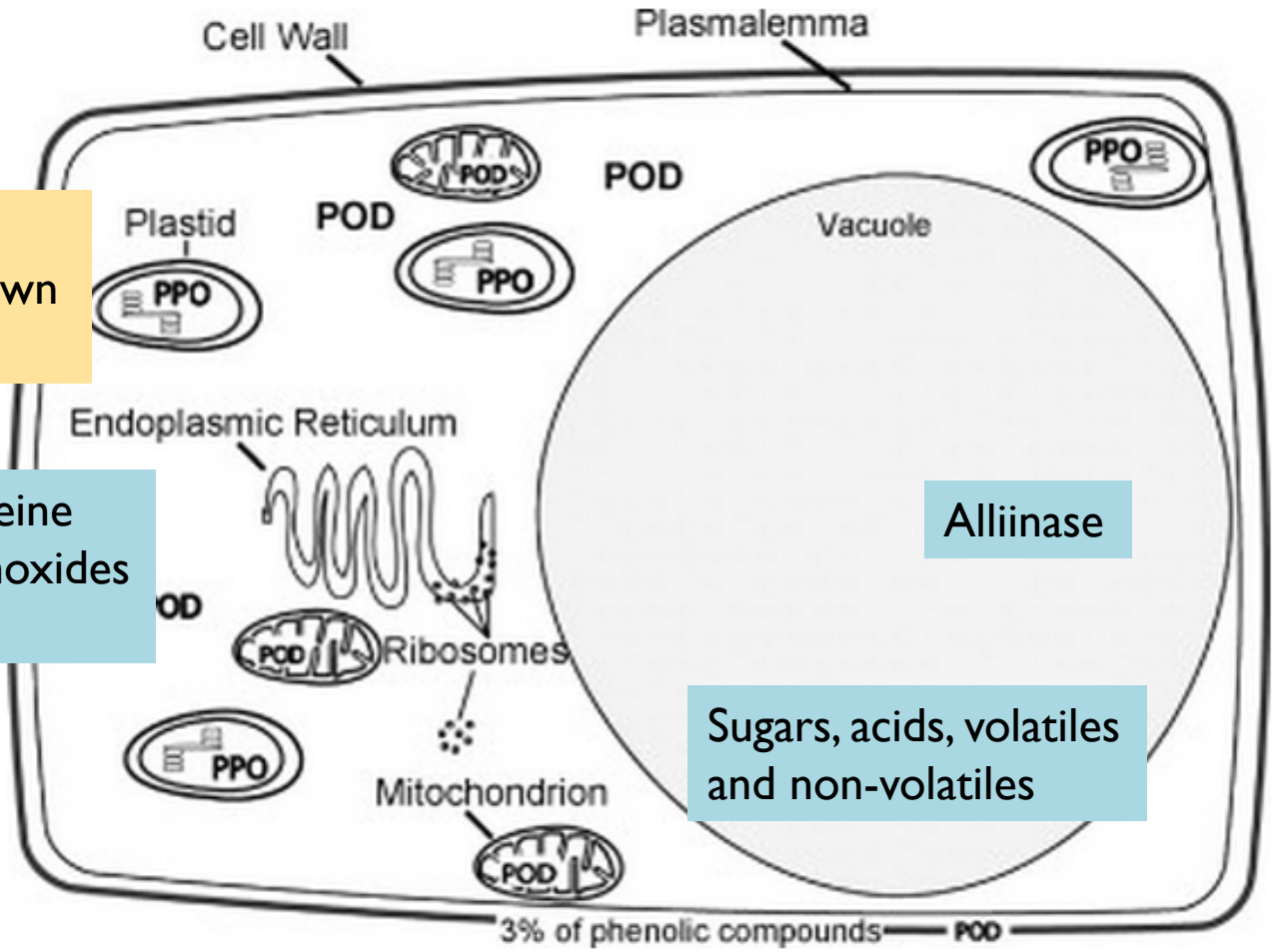
Flavor Components & Enzymes

- Water soluble
  - Sugars
  - Acids
  - Volatiles & Non-volatiles

- Fat soluble
  - Lipids
  - Volatiles & Non-volatiles

- Enzymes related to flavor
  - Lipoxygenase (good/bad actor)
  - Hydroperoxide lyase (works with LOX – good)
  - Alliinase (characteristic onion/garlic aromas)

Flavor



Carotenoids and breakdown products

Cysteine sulphoxides

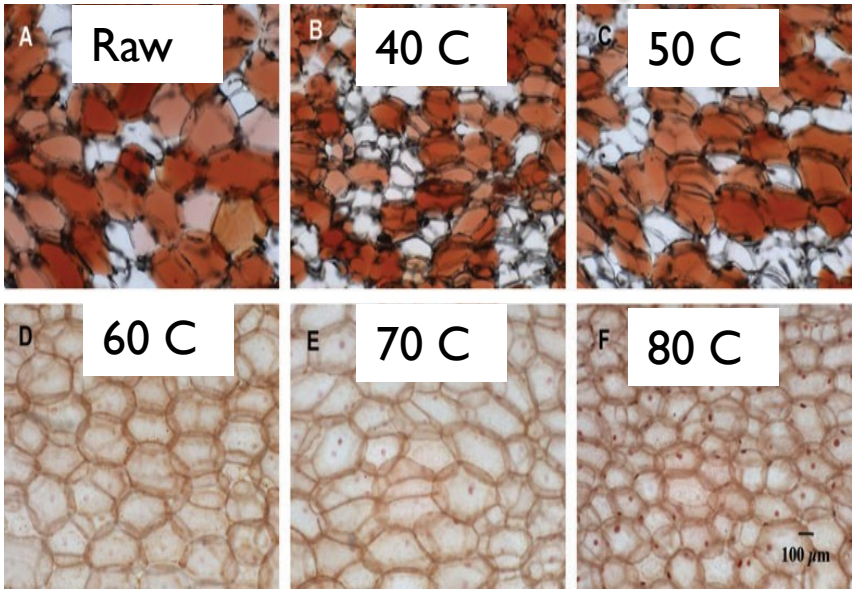
Alliinase

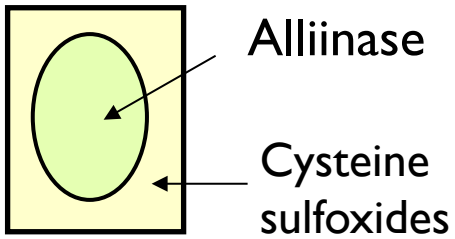
Sugars, acids, volatiles and non-volatiles

Water soluble

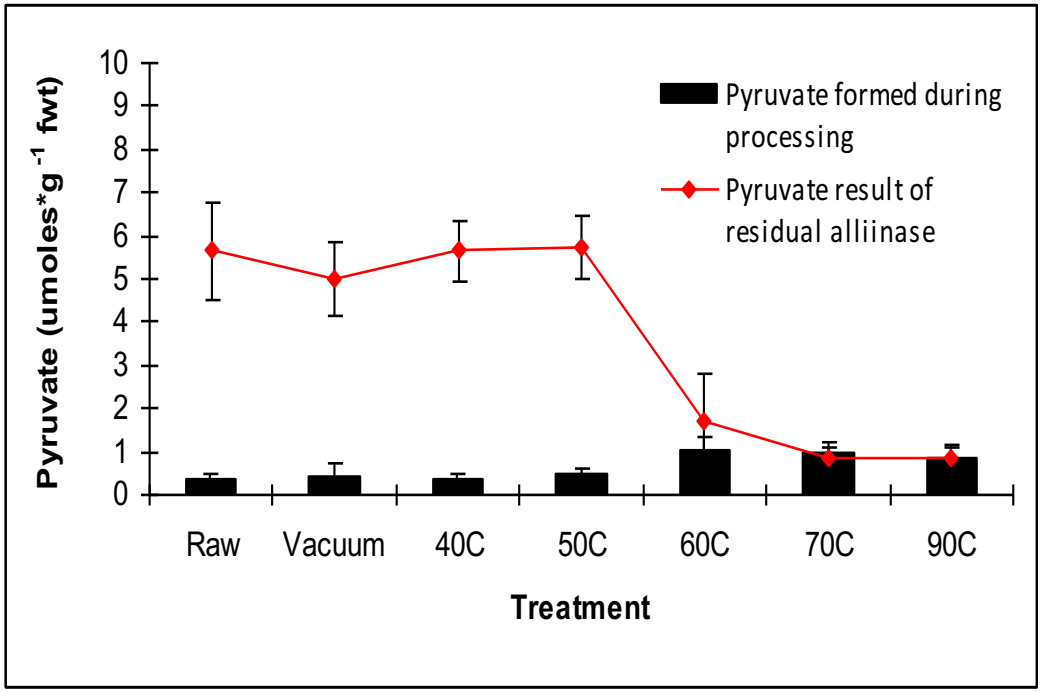
Fat soluble

Thermally Processed Onions





- (Above) Light microscopy & cell viability
- (Right) Pyruvate formation during processing increases (bars) but enzyme inactivation occurs after 50C, same time as loss of cell integrity. Not a good marker.

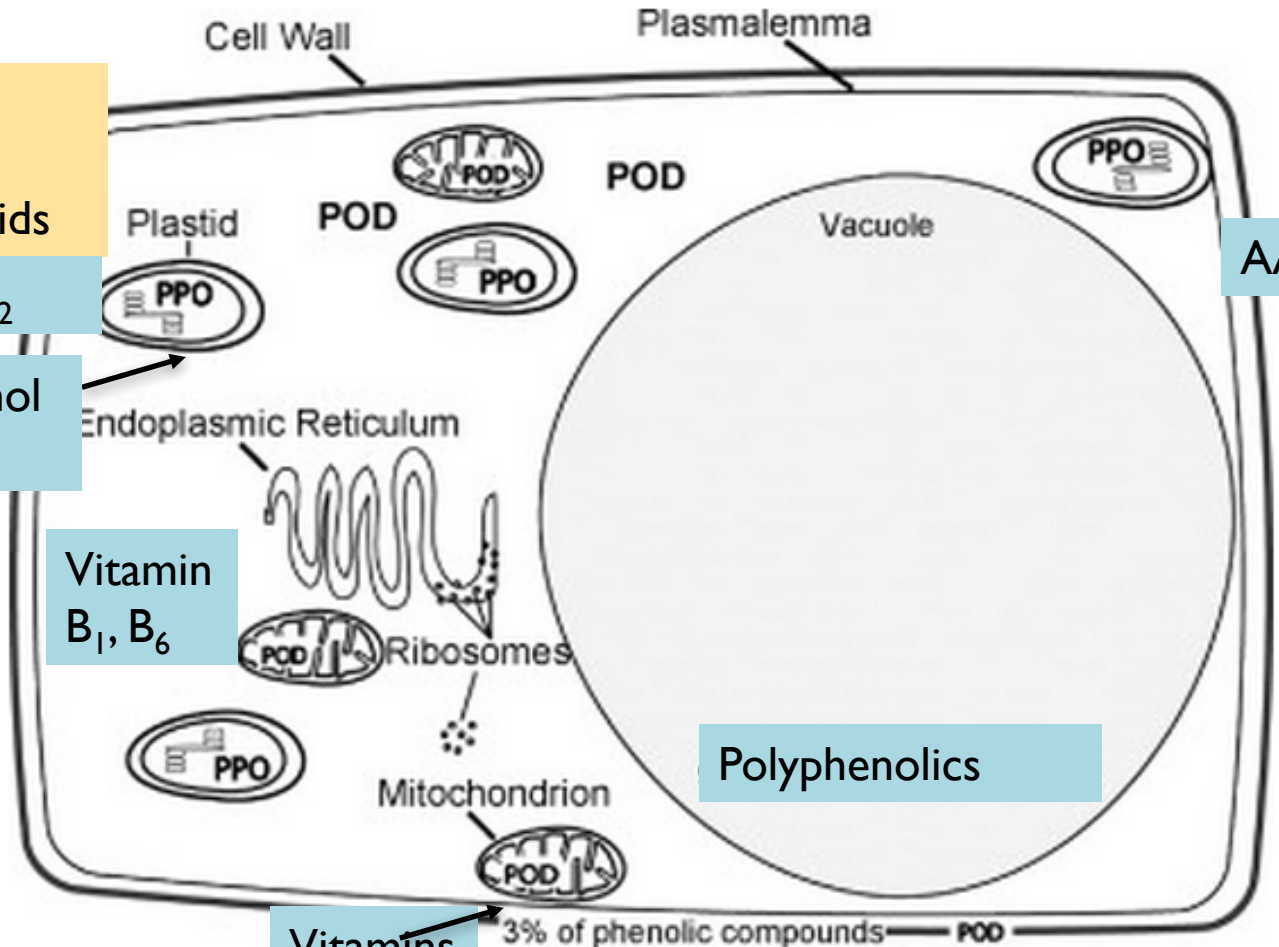


NUTRIENT CONTENT

Nutrient Components & Enzymes

- Water soluble
  - Vitamin B(s)
  - Vitamin C
  - Polyphenolics
- Fat soluble
  - Vitamin A
  - Vitamin E
  - Vitamin K
  - Carotenoids
- Enzymes affecting nutrients
  - Ascorbic acid oxidase (oxidation of AA – bad)
  - Polyphenol oxidase (oxidation of phenolics – bad)
  - Peroxidase (free radical production, generally bad)

Nutrients



Vitamins
A, E, K
Carotenoids

Vitamin B_2

Polyphenol oxidase

AA Oxidase

Vitamin B_1, B_6

Polyphenolics

Vitamins
B_3, B_7,
B_9, C

Asensi-Fabado & Bosch, 2010

Water soluble

Fat soluble

Some things to discuss…….

- Genetics – incredible resource for identifying genotypes with desired levels of quality components and enzymes
- Postharvest Handling & Processing – if the industry knew more about the raw material, they could optimize processes better for specific end products.
- Food Biochemists - some enzymes are both soluble and membrane-bound – are only the soluble ones a problem? (Ex: PPO and LOX)
- Some enzymes (PG) physically located near substrates & 'activated' by cell rupture – why?

Thanks for your attention!

UCDAVIS food science & technology