



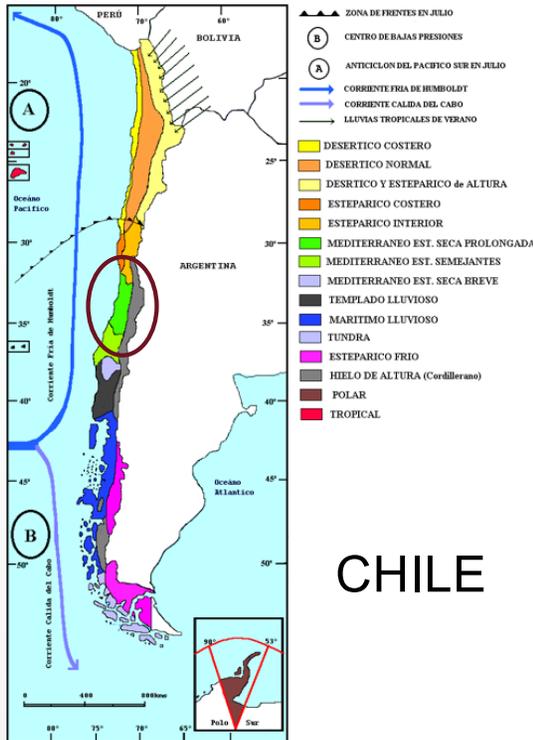
Apple Grading, Packing and Storage

Carolina Torres, Ph.D.
Associate Professor
Endowed Chair in Postharvest Systems



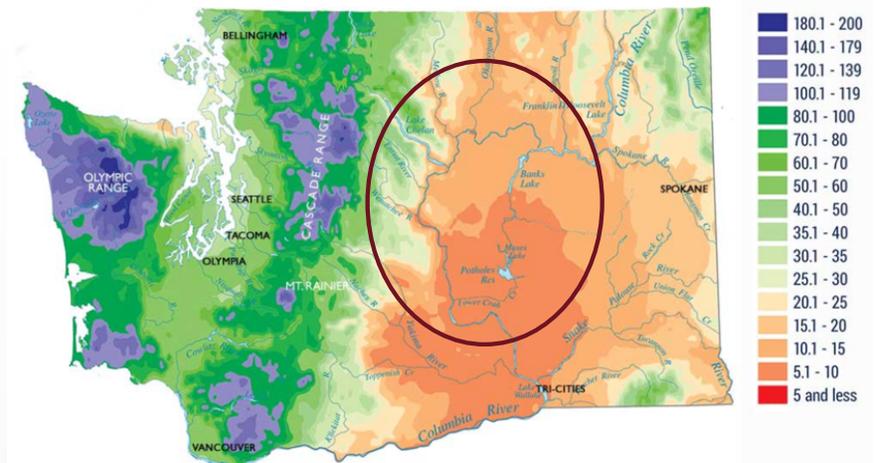
WASHINGTON STATE
UNIVERSITY





Summer: 92-95 C, 30%RH, 2000 $\mu\text{mol m}^{-2} \text{s}^{-1}$ (4 m +)

Mediterranean with a long dry season



Eastern WA, Summer: 80-90 F, 30%RH, 300 days of sunshine

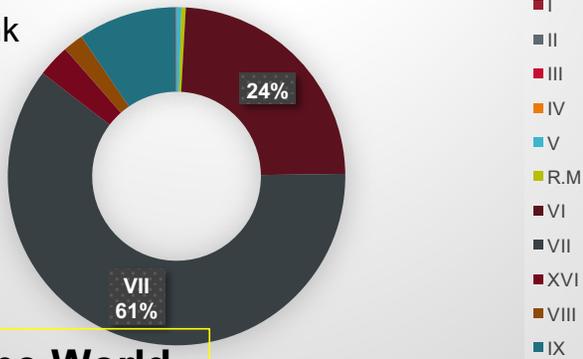
Semi-arid climate



APPLES

79,990.7 acres

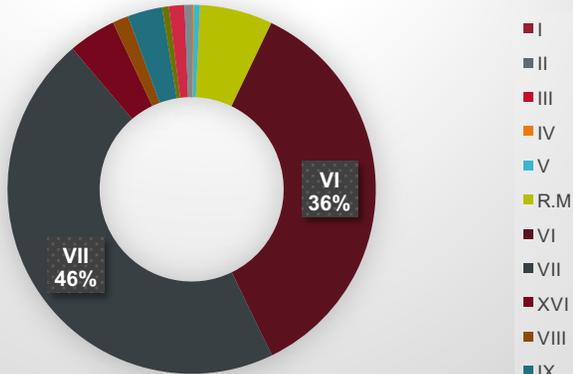
Galas
Fuji
Cripps Pink
Scarlett
(Reds)



9 in the World

Sweet Cherries

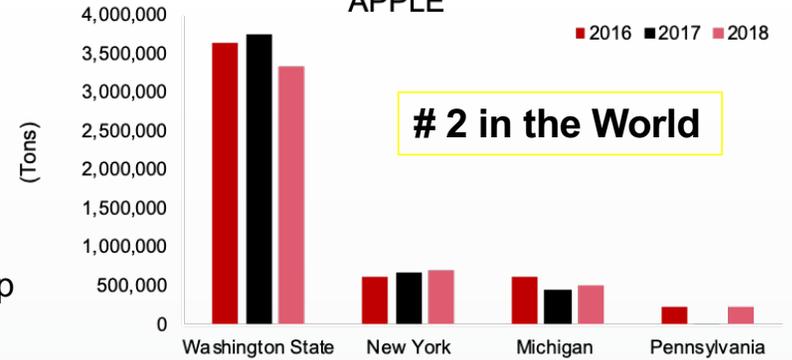
94,868.7 acres



179,146 acres

APPLE

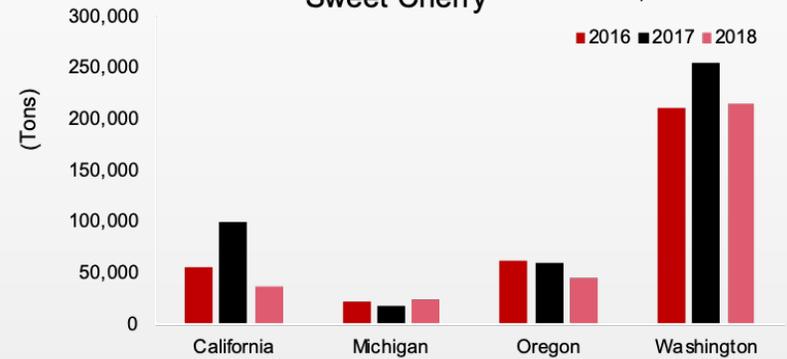
Red delicious
Galas
Fuji
Granny
Smith
Honeycrisp



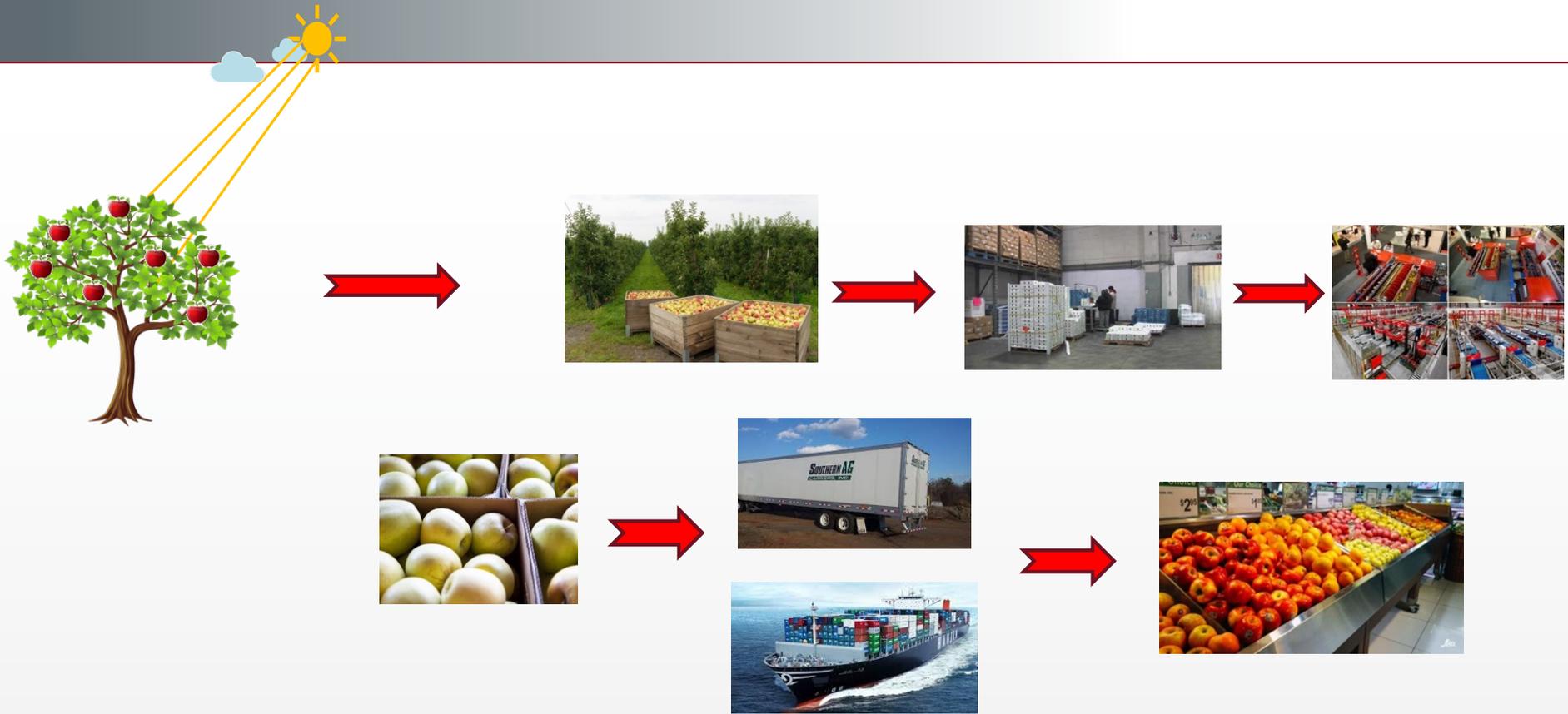
2 in the World

Sweet Cherry

42,198 acres



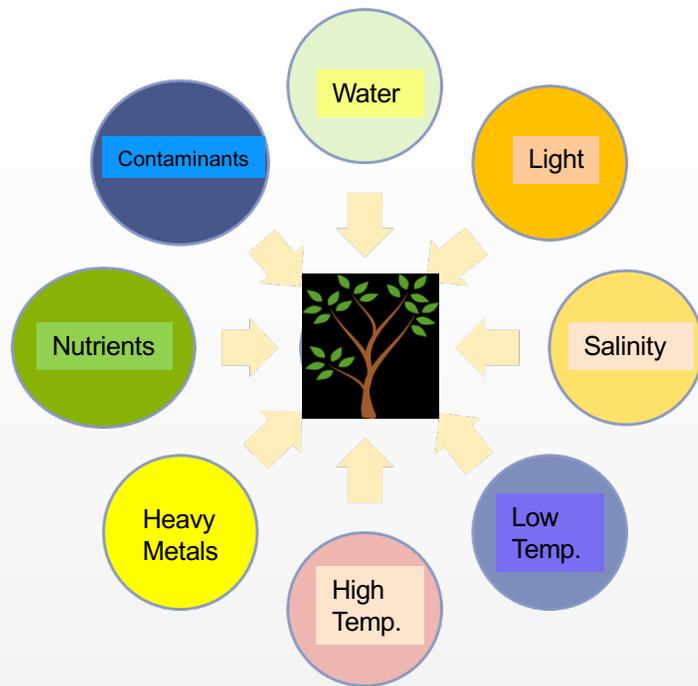
https://www.nass.usda.gov/Statistics_by_State/Washington/Publications/Fruit/2017/FT2017.pdf
 Washington State Tree Fruit Association. 2017/18. A Statistical Review of Washington State Fresh Apple Crops
https://www.odepa.gob.cl/wp-content/uploads/2019/09/catastro_maule.pdf



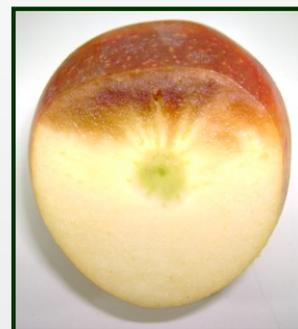
SHORT- MID- LONG-TERM STORAGE



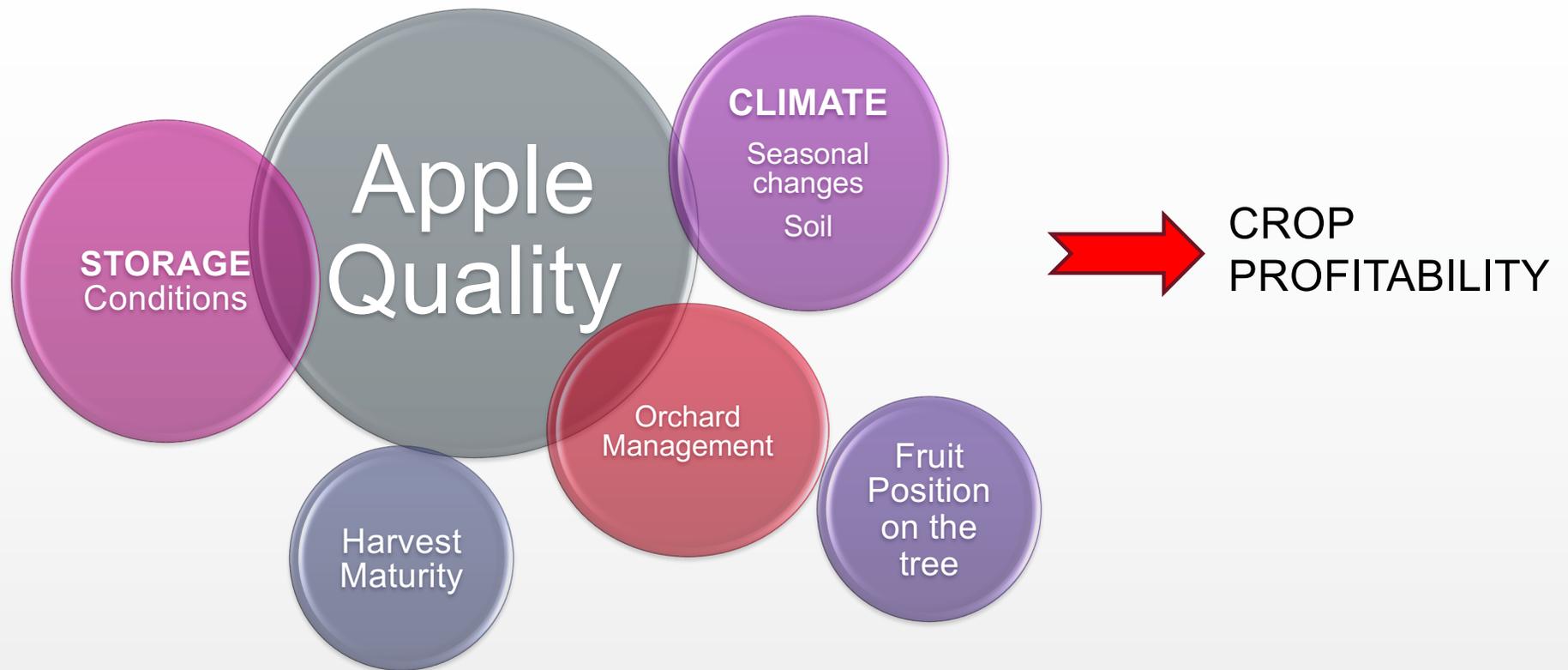
MARKETS



Fruit Quality
Pre-and Postharvest



Downgrading/product loss
= Waste





From the consumer's standpoint.....

EXTERNAL / VISUAL



DECISION TO PURCHASE

INTERNAL (discoloration of tissue..)



DECISION TO RE-PURCHASE

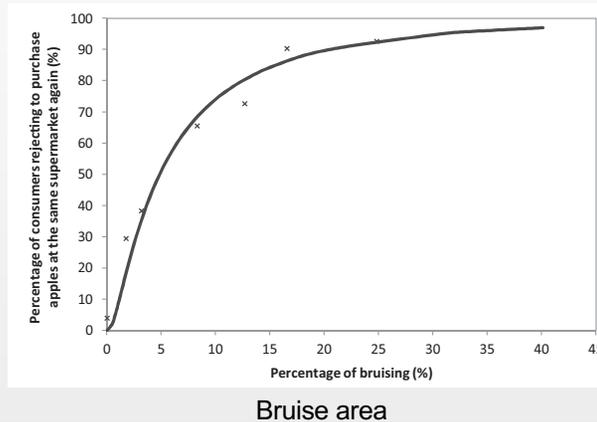
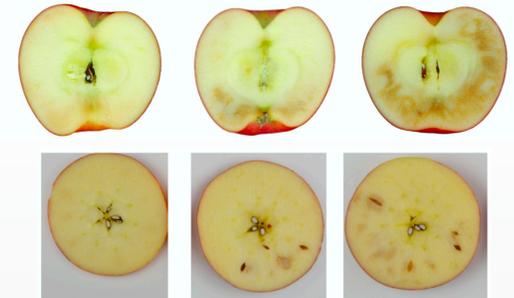
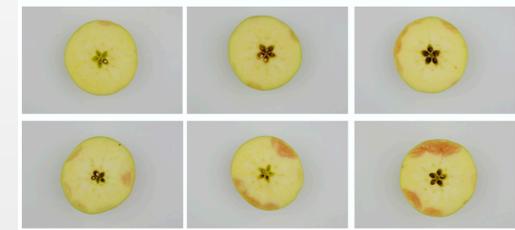


Table 1
Average values of the eye-tracking measures for apple images with different degrees of bruising, internal browning and cavities, estimated as the area of the defect, considered in the free viewing task (Obj. 1).

Defect	Area of the defect (%)	Percentage of consumers who fixated their gaze on the defect (%)	Time to first fixation on the defect (s)	Total fixation duration on the defect (s)	Fixation count on the defect
Bruising	3.2	21.1 ^a	1.58 ^b	0.56 ^a	1.8 ^a
	24.8	98.4 ^b	0.10 ^b	0.86 ^b	3.3 ^b
Internal browning	5.4	30.8 ^a	1.25 ^c	0.56 ^a	1.9 ^a
	13.3	61.7 ^b	1.05 ^b	0.66 ^b	3.3 ^b
	43.4	85.4 ^c	0.70 ^a	1.16 ^c	5.9 ^c
Internal browning and cavities	1.2	9.7 ^a	1.5 ^d	0.22 ^a	1.0 ^a
	4.8	48.8 ^b	1.1 ^a	0.68 ^b	1.8 ^b
	15.8	78.8 ^c	1.0 ^a	3.63 ^c	9.8 ^c

Note: for each eye-tracking measure within a disorder, average values with different superscript letters are significantly different at the 95% confidence level.



(Jaeger et al., 2016)



Harvest Maturity

- Correlated with consumer preferences
- Determined using Maturity Indices/Indicators
- Achieved after physical and chemical changes have started → desirable attributes for consumption (physiological vs horticultural maturity)

Apples: On the tree

Pears (winter): After harvest



Harvest
Maturity

Maturity Indices

- Simple
- Easy to use
- Low-cost equipment
- Objective
- Correlated with fruit quality



- Always searching for new ones
- Use more than one to improve maturity/quality prediction



Maturity Indices in Pome fruit

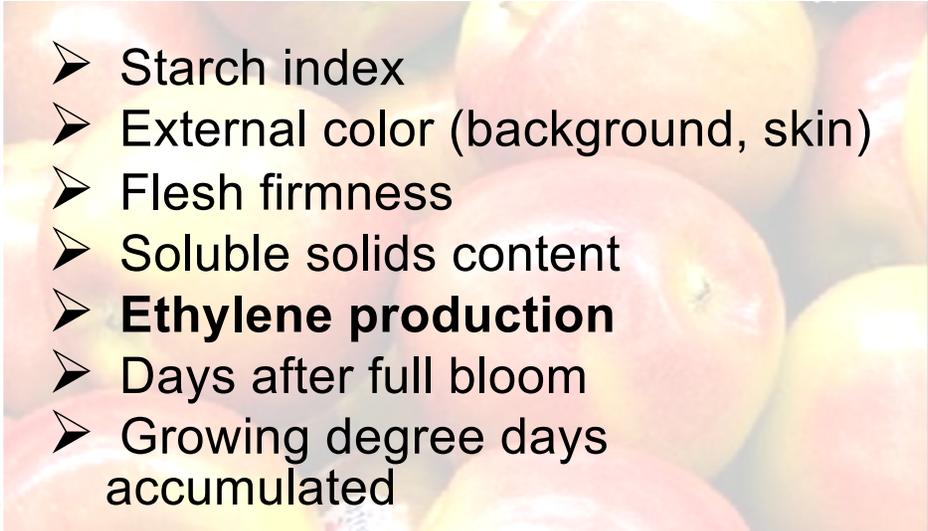
THEY ARE NOT ALWAYS CONSISTENT!

Why? They vary..

- **Growing area/season – CLIMATIC conditions**
- Tree vigor
- Crop load (biennial)
- Cultural practices
- Nutrition
-



Maturity Indices in Pome fruit

- 
- Starch index
 - External color (background, skin)
 - Flesh firmness
 - Soluble solids content
 - **Ethylene production**
 - Days after full bloom
 - Growing degree days accumulated

Cultivar-
dependent

When to harvest?

Start monitoring 2-3 wks
before – more
frequently close to
harvest

- 
- Flesh firmness
 - SSC
 - Days after full bloom
 - Starch index



Other non-destructive:

DA meter (chlorophyll degradation-
Available, <http://treefruit.wsu.edu/article/da-meter-maturity-indicator/>)



Electronic nose (Cyrano 320, Cyrano
Science Inc.)



NIR spectroscopy (F-750, Felix
Instruments)





APPLES

Early Harvest

- Less size
- Less color
- Less developed flavor, (- volatiles, sourness...)
- Susceptible to:
 - Bruising
 - Dehydration
 - Scald...

Late Harvest

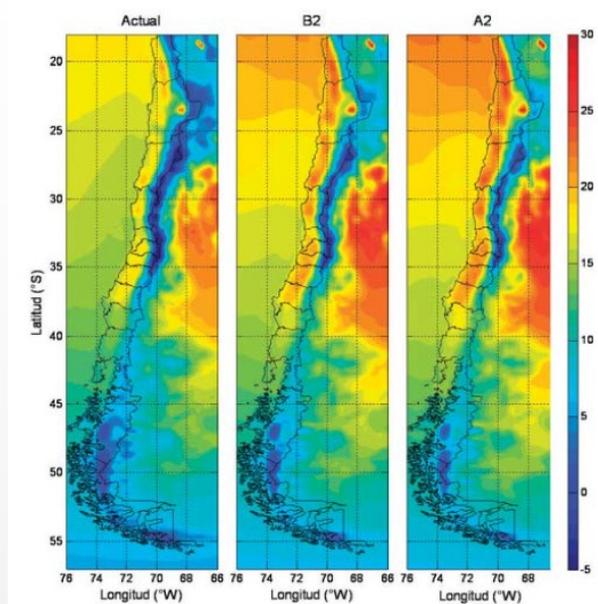
- Fruit drop
- Less flavor
- + yellow background color
- ++ softening rate
- Susceptible to:
 - Rots
 - Mealiness
 - Internal Browning
 - Watercore



CLIMATE

Seasonal changes

CLIMATE CHANGE



Av. Temp.
Oct-Mar



GDD

(Montes, 2010)



CLIMATE

Seasonal changes

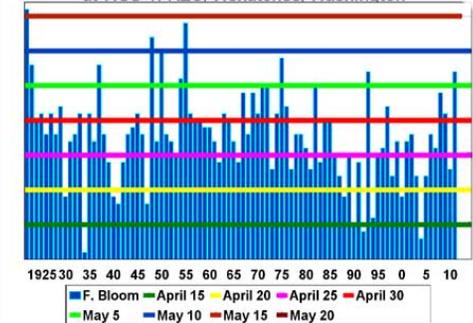
In WA State

- Annual average temperature round 1.5 F in 115 years, and projected to increase up to 9.7 F (next 50 years)
- Warmer winters/ earlier spring snowmelts
- Variable annual precipitation - increase extreme pp
- More frequent and intense HEAT WAVES

(Houston, 2018)

Red Delicious Full Bloom Dates

at WSU-TFREC, Wenatchee, Washington



Tim Smith, WSU Extension

<https://extension.wsu.edu/chelan-douglas/agriculture/treefruit/horticulture/bloomdatesrdapples/>

- Hotter days (higher than average)
- Heat waves
- Drought
- Unexpected climatic events (hail, frosts...)



Earlier and shorter bloom, shorter growing seasons, less volátiles, less red color, less yield, less acidity/firmness...

(Montes, 2010; Tromp, 1997, Warrick et al., 2011; Sugiura et al., 2013)



CLIMATE

Seasonal
changes

Galaxy/M9

Established in 1999

Location: San Clemente, Maule- CHILE

Same group trees (20), four seasons

2006/07, 2007/08, 2012/13, 2014/15



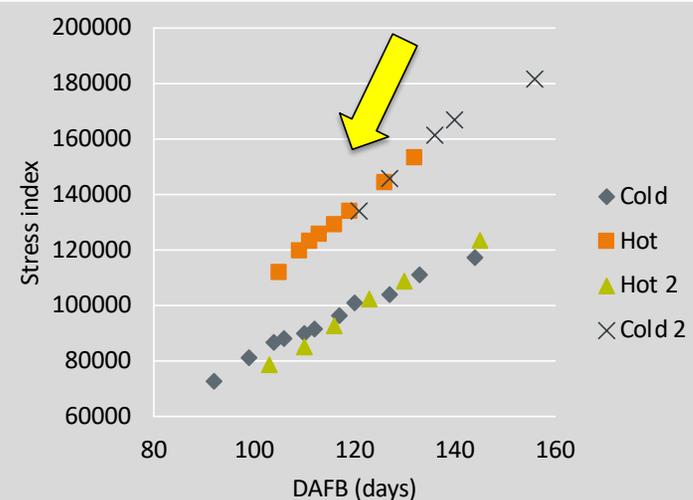
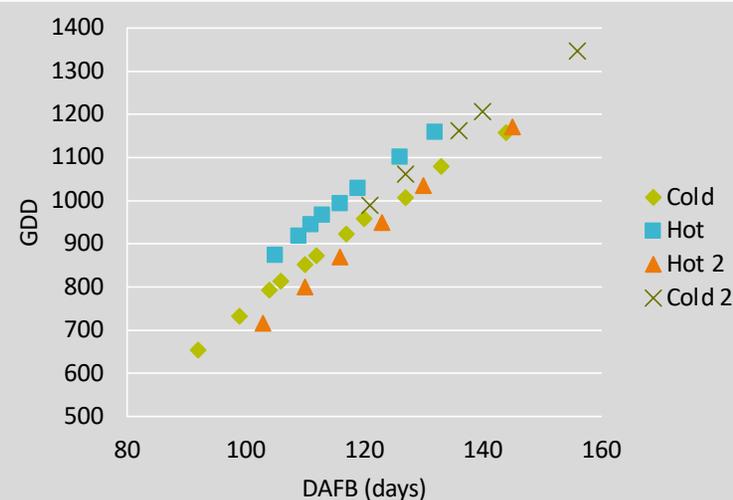
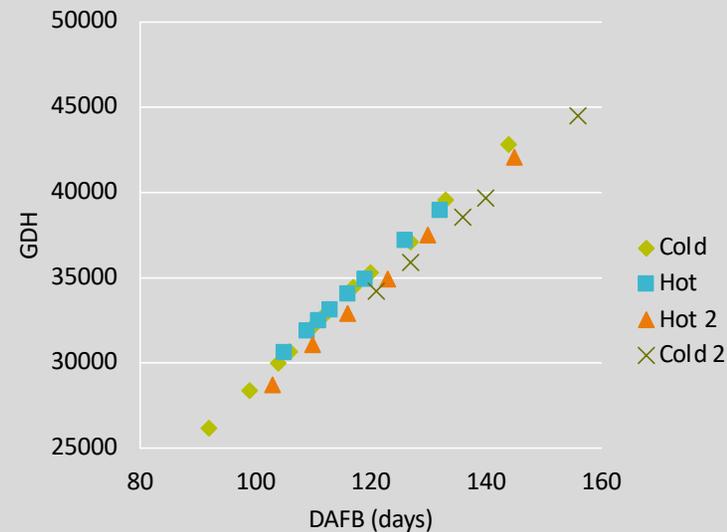


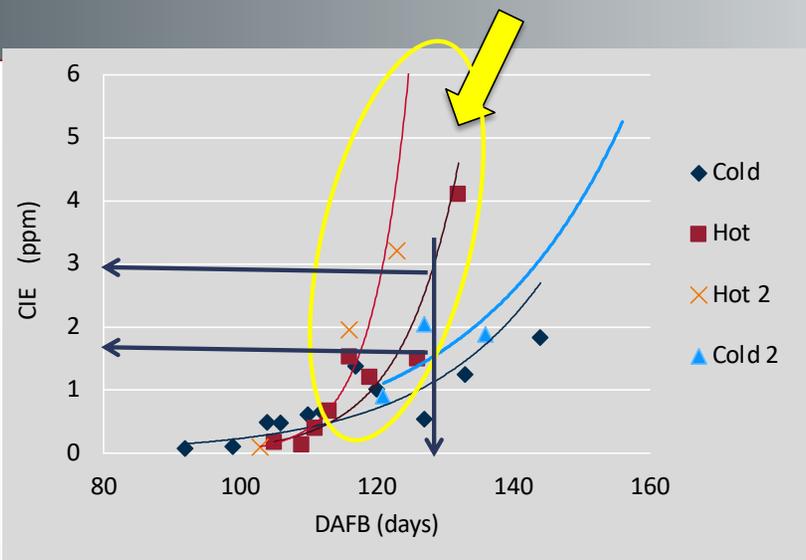
Climatic Conditions

GDD: Growing degree days (>10°C)
GDH: Growing degree hours

'Cool': 30% below average 'Warm':
30% above average

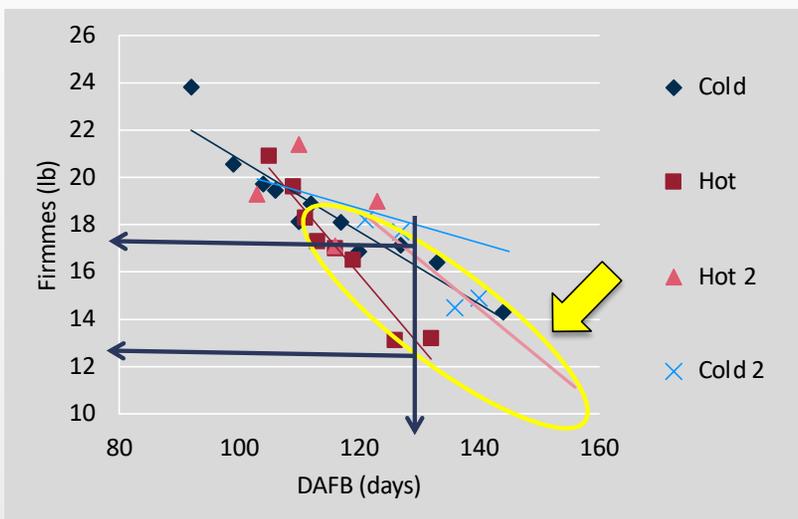
Stress units = $(T^{\circ}air - 10) (-0,2RH + 15)$





Warmer season

- Sharper increase of ethylene
- Faster decline of Pressures



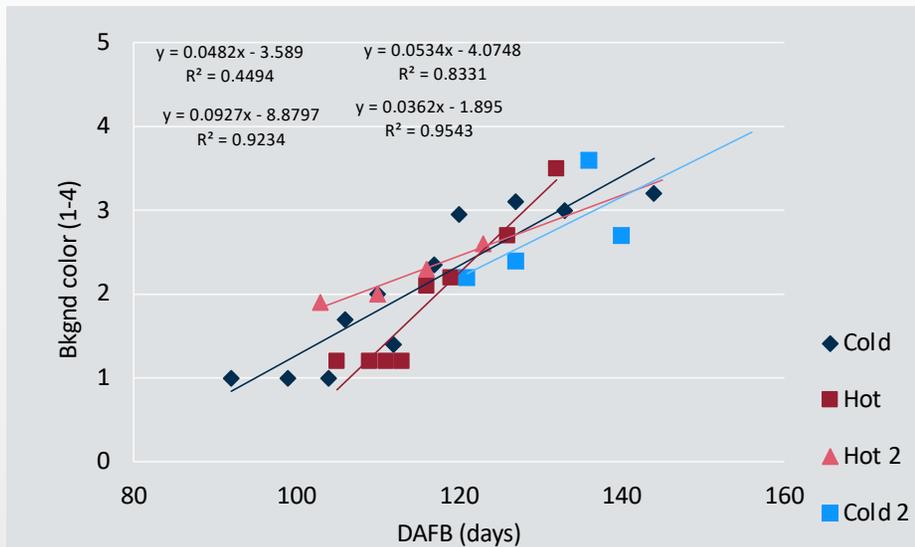
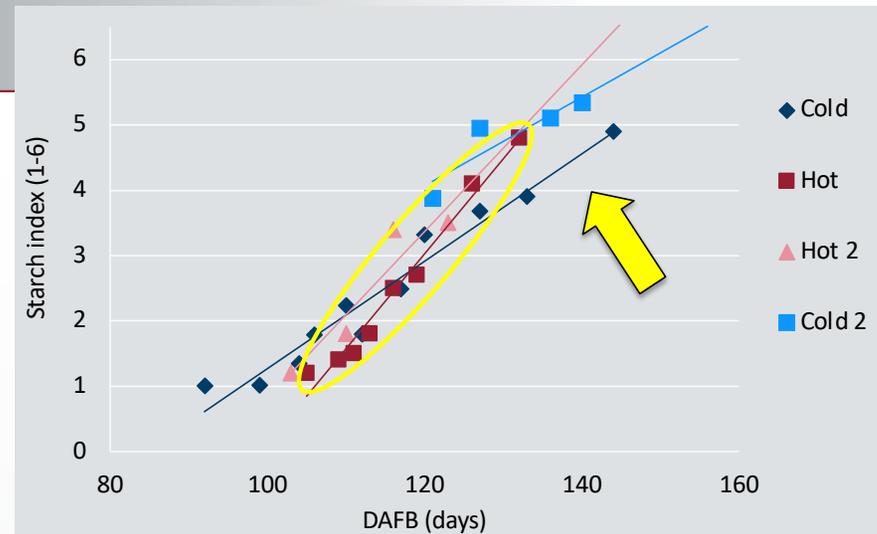


Warmer season

→ Faster starch degradation

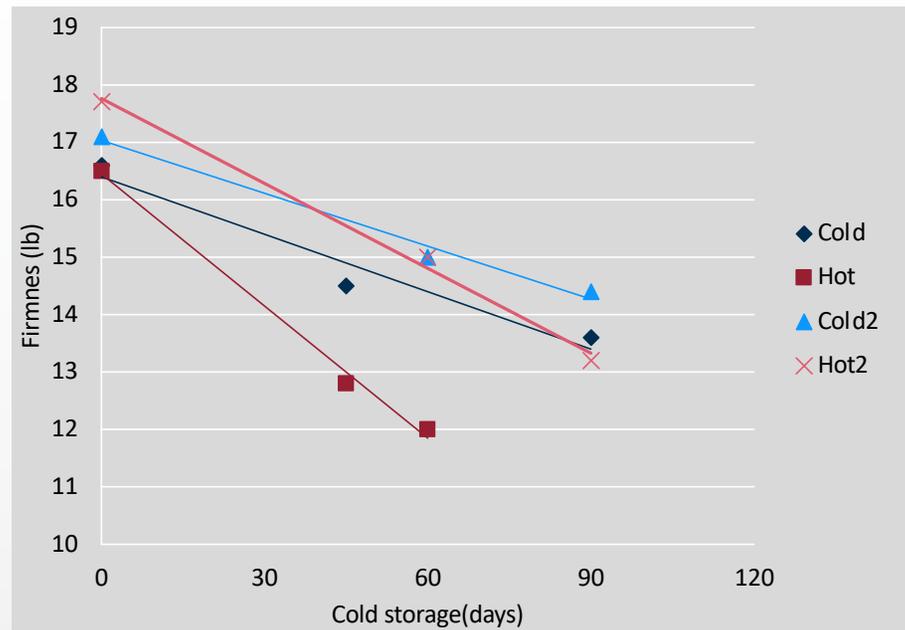
So...

Earlier Harvest --- with similar maturity indices (starch index ??...) than normal..

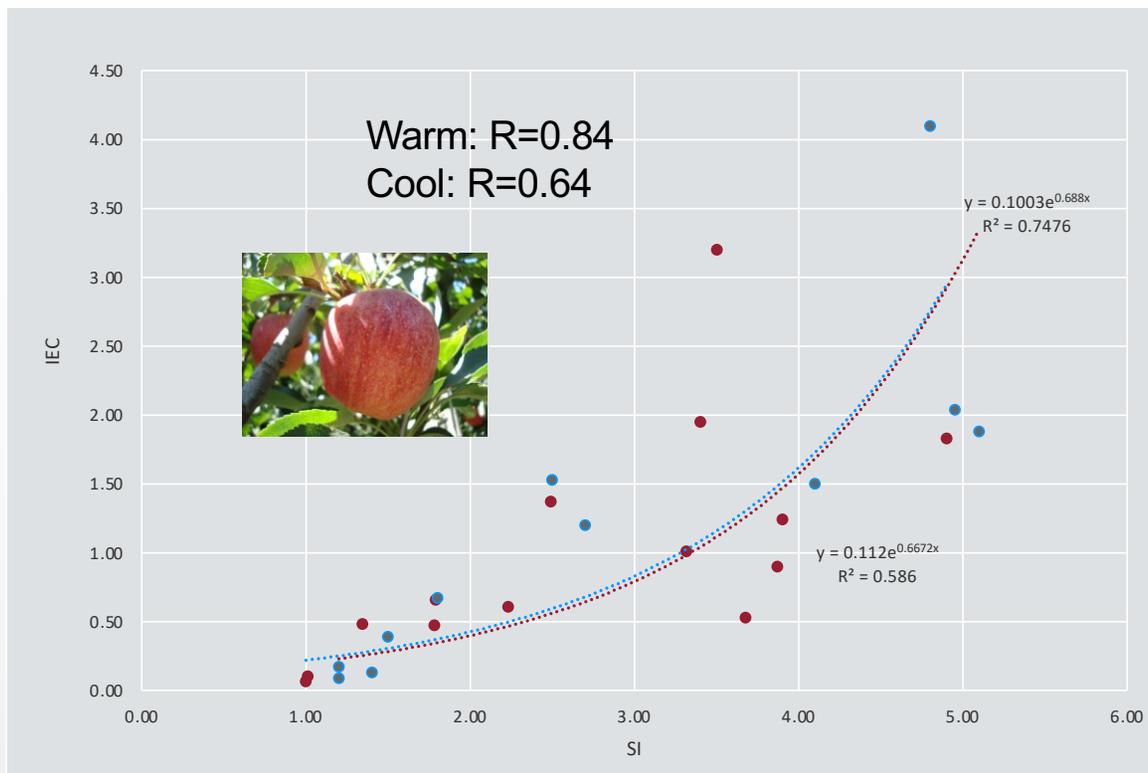




Postharvest

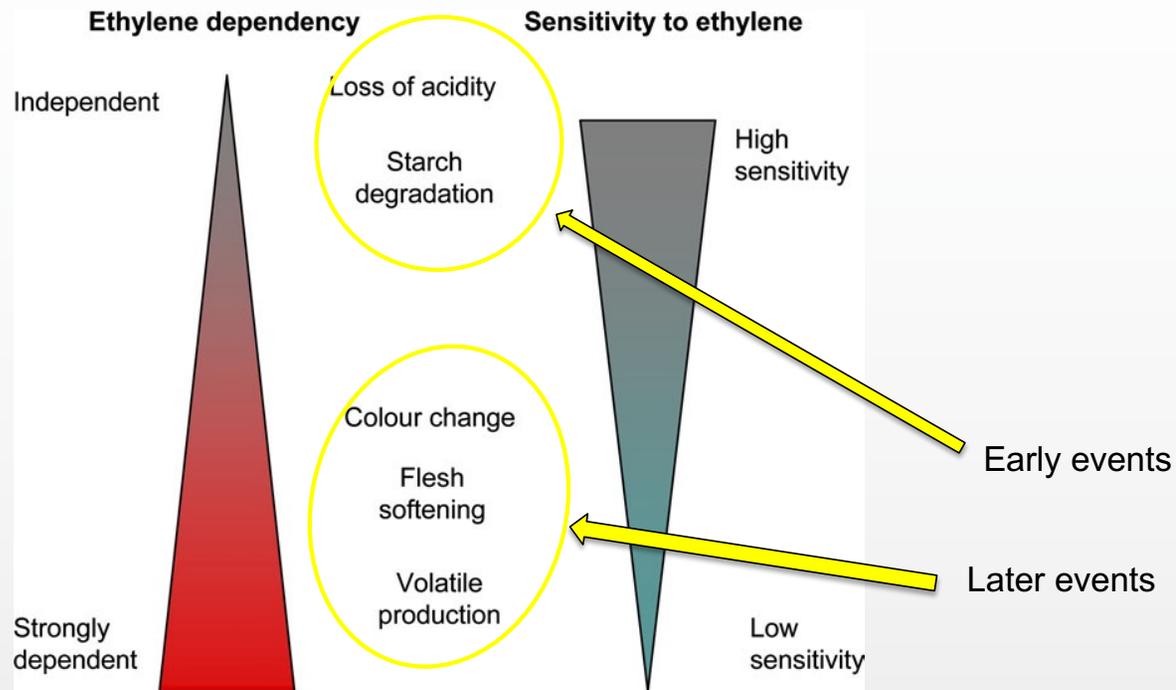
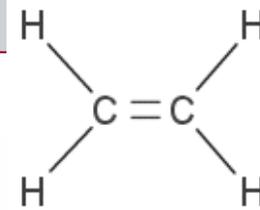


Cool Season: 1 lb/month in RA
Warm Season: 1.5-2.5 lb/month in RA





ETHYLENE

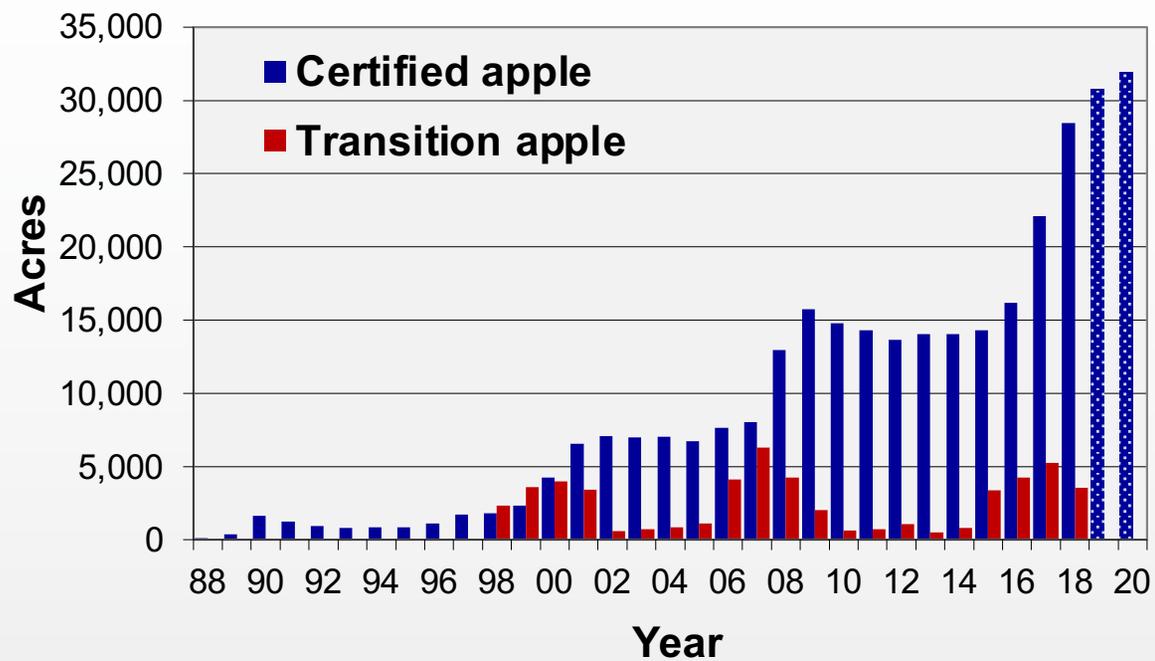


Conceptual model for control of individual ripening characters in apples (**Royal Gala**) (Johnston et al., 2009)

..not only triggering. Sustained exposure required to maintain ripening...



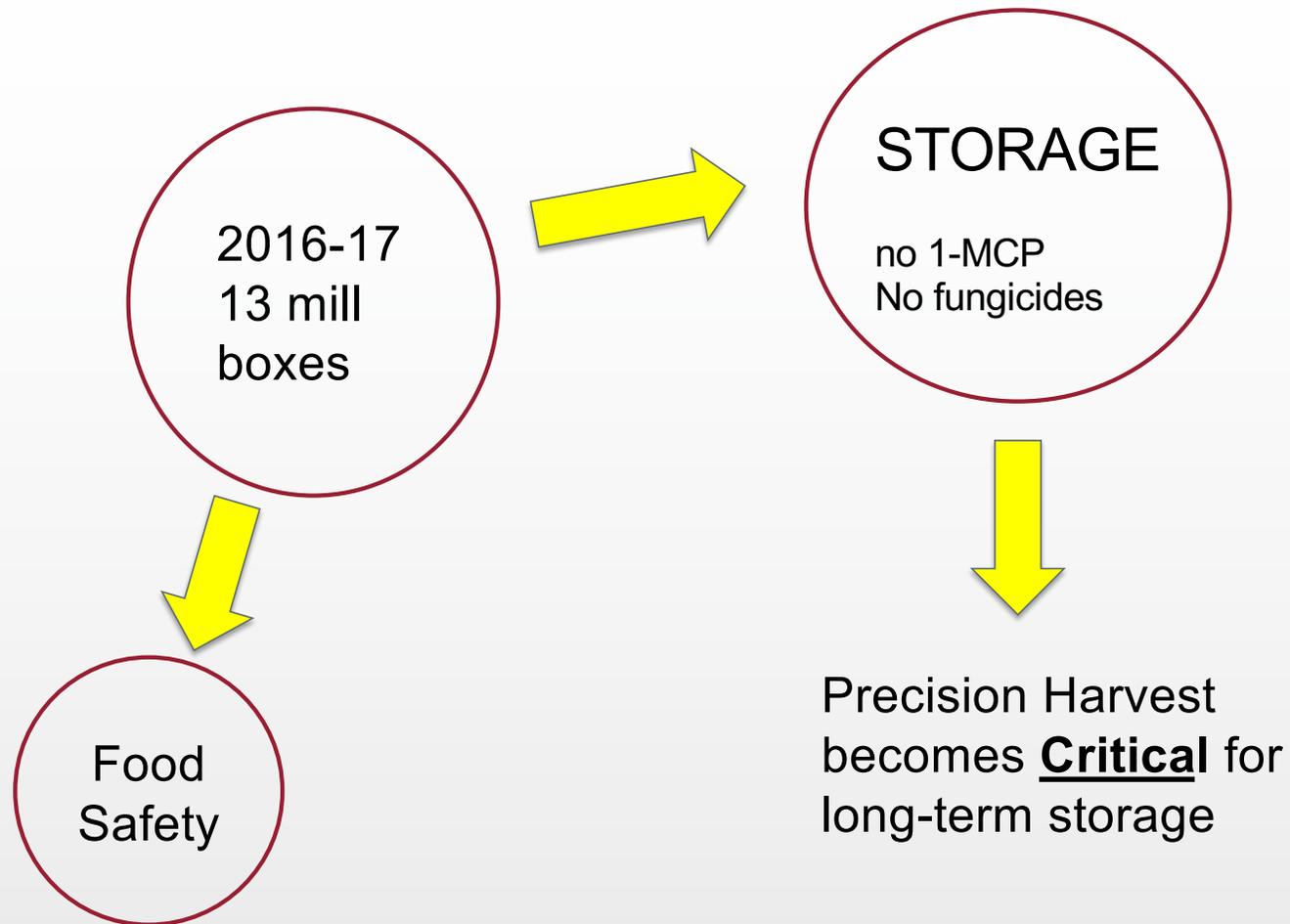
Organic Apples



David Granatstein



Great challenge for postharvest.....





Final Remarks

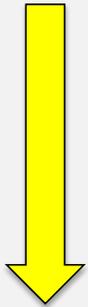
- Warmer climates cause a sharper increase in ethylene, faster decline in fruit firmness, and increase in starch index .
 - Although fruit might be harvested with same 'indices' values, it has a different metabolic makeup, favoring the development of certain physiological disorders (potential prediction tools...).
 - New maturity indices?





QUALITY DEFECTS

Hot and dry
environments



Maturity/Ripening &
Physiological
disorders (onset)

Abiotic
Stress

Light + Heat

HARVEST



Low
temperature

AFTER
2,3,4,5,6..
months of
storage





Hot and Dry Environment...



Sunburn



- Splitting – Checking - Cracking
 - Cv. dependent
 - Overmaturity
 - Rain prior harvest – presizing
 - Low RH during fruit growth





Lenticel Issues

- Nutricional → Calcium-related
- Abiotic stress+Processing postharvest (LBD)





Peel Browning/ Discolorations



Sunscald



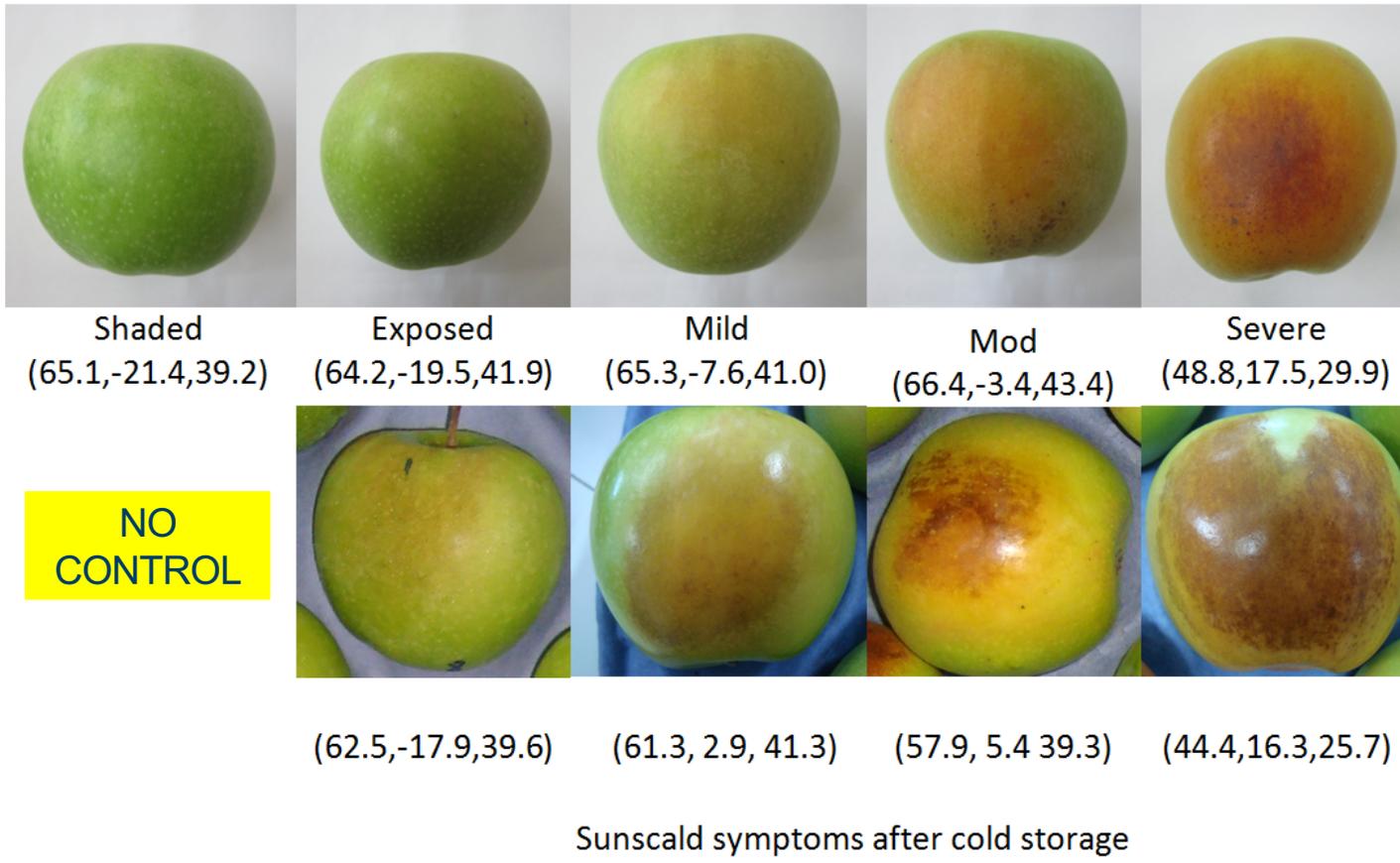
Stain



High Light
+
High
Temperature

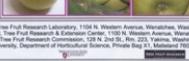


Sunburn → Sunscald





Identification is a MUST...

DESCRIPTION	LENTICEL RELATED DISORDERS	NOTE
<p>Lenticel Breakdown Generally, round girdling centered on a lenticel. Often occurs on less exposed sides or color margins. Early symptoms are like small dimples, visible in angled light. As flesh firmness decreases, pits usually grow in depth and may coalesce. Flesh is not deeply affected. There may be a cavity beneath the pit.</p>		<p>Fruit tested for LB should be cooled: 1) Briefly rinse fruit in clean cool water. 2) Dip cool fruit in warm water (40°F) for 4-10 minutes. 3) Wipe fruit by hand using a clean soft cloth. Wipe film does not need to be thick, but it should cover thoroughly. 4) Place fruit in the cool room for 24 h. *This test may only express symptoms.*</p>
<p>Blotch Pit Often found asymmetric brown patches near the calyx or on exposed side. Flash browning is deeper. See later at or "Jonathan Spoil".</p>		<p>Flesh browning will likely increase and deepen after harvest similar to jet browning. Flashing ripening will force symptoms.</p>
<p>Heat Injury Lenticels are brown or black and cracked. Usually visible at harvest. Usually only skin deep.</p>		<p>Does not progress much beyond what is visible at harvest. Occasionally worsens in storage.</p>
<p>Bitter Spot Affected lenticels are round and may be raised slightly. Early may look like pink, immature, later may also have a crusty cap.</p>		<p>May progress during storage, but develops very slowly (months).</p>
<p>Calcium Burn Lesions are superficial and localized. Affected lenticels are dark brown to black. Often visible at harvest.</p>		<p>Associated with solar and direct calcium applications. Repeated solar applications may increase severity. Does not progress during storage.</p>

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 © Cameron F. Schaefer, WSU, Tree Fruit Research & Extension Center, 1100 N. Western Avenue, Wenatchee, Washington 98801 USA
 © Tom Hammett, Washington Tree Fruit Research Commission, 220 N. 2nd St., Ste. 203, Yuba, Washington 98801-0211 USA
 © Eric Linton, Washington State University, Department of Horticultural Science, Pullman, WA 99164-5000, Pullman, WA



Postharvest Defects

Bitter Pit
Small water brown pits develop in the calyx end and are associated with lenticels. In some cases, girdling may occur in the upper half of the fruit. Fruit may not show evidence of girdling. Fruit internal appearance appears similar to other apples. Blue develop into water brown or rubbery shreds of brown tissue. Fruit internal appearance appears similar to other apples. Bitterness is not always detectable in the consumer. Bitterness may also be a symptom of bitter pit. Bitterness may only be a symptom of bitter pit in some cases.

Blotch Pit
Blotch pit is characterized by large, often star-shaped brown patches near the calyx end. The patches may be visible in the calyx end of the fruit. The patches may be visible in the calyx end of the fruit. The patches may be visible in the calyx end of the fruit. The patches may be visible in the calyx end of the fruit.

CPA Burn
Chilling injury symptoms are often found on a chilled CPA cultivars after marketing. CPA is not a chilled cultivar with a high tolerance for chilling. CPA is not a chilled cultivar with a high tolerance for chilling. CPA is not a chilled cultivar with a high tolerance for chilling.

Carbon Dioxide Injury
There is an odor difference between fruit during storage and after ripening. The odor difference is due to the presence of ethylene. The odor difference is due to the presence of ethylene. The odor difference is due to the presence of ethylene.

Freeze Damage
Freezing damage is a result of low temperatures. Freezing damage is a result of low temperatures. Freezing damage is a result of low temperatures.

Lenticel Breakdown
Flesh browning will likely increase and deepen after harvest similar to jet browning. Flashing ripening will force symptoms.

Low Oxygen Injury
Low oxygen injury may develop in apples stored in low oxygen environments. Low oxygen injury may develop in apples stored in low oxygen environments.

Postharvest Sunburn
Sunburn is a result of high temperatures during storage. Sunburn is a result of high temperatures during storage.

Senescent Browning
Senescent browning is a result of aging. Senescent browning is a result of aging.

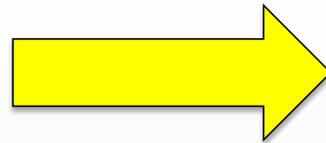
Shriveling
Shriveling is a result of water loss. Shriveling is a result of water loss.

Soft Scald
Soft scald is a result of low temperatures. Soft scald is a result of low temperatures.

Watercore
Watercore is a result of high temperatures. Watercore is a result of high temperatures.



Lack of acclimation...



+ Chilling Stress

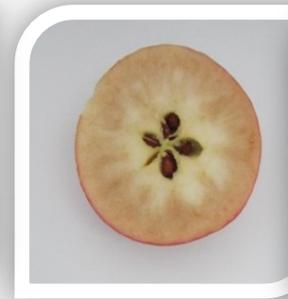
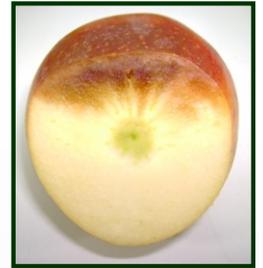
Skin browning
Superficial Scald
Soft Scald
Internal browning
...





Internal Browning

- Hot environments → watercore (IB)
- Susceptible cv. (Fuji, Crisp Pink, Gala)
- Storage atmosphere (daños por CO₂/Largo) – cellular structure
- Physiological disorder
 - Preharvest factors
 - Postharvest factors





Pardeamientos Internos

In general, 2 groups...

- Low-temperature ...chilling injury
- **Ripening and senescence**...(- correlated with fruit firmness (harvest maturity..))

(Watkins, 2007)



Fast cooling, low
storage temp.



Lower
metabolism



Induce chilling
injury



Stepwise cooling



Acclimate fruit to
cold



Decrease fruit
quality and
accelerate ripening

Susceptibility ?
(CLIMATE)



HONEYCRISP



Minnesota, 1960
Keepstake x MN1627



Bitter Pit



Multi-factorial (nutrients,
vigor, harvest maturity)



Soft scald



Soggy
Breakdown

Chilling injury



Table 3

Physiological disorders in 'Honeycrisp' apples after storage at 0.5 or 3 °C with or without one week of conditioning (C) at 10 °C in 2013, 2015, and 2016..

Treatment	Bitter pit (%)	Soft scald (%)	Soggy breakdown (%)	Senescent browning (%)	Cavities (%)	Wrinkly skin (%)	Flesh browning (%)	Decay (%)
0.5 °C	2.2	7.6	0.9	0.3	0.2	6.4	0.8	0.5
C + 0.5 °C	13.0	0.9	0.7	0.7	0.1	4.9	0.2	0.9
3 °C	10.6	0.0	0.1	1.3	0.2	0.0	0.0	3.4
C + 3 °C	20.6	0.0	0.0	1.1	0.1	0.0	0.0	1.6
P value	< .0001	< .0001	0.0006	0.09	0.6	< .0001	0.0006	0.0002

(Shoffe et al. 2020)

Good correlation with flesh firmness & ethylene

(Shoffe et al. 2016)

C: 7 d a 10°C

Table 1. Soft scald and soggy breakdown incidence in Honeycrisp apples stored at 33°F or 36°F with or without a conditioning treatment of 50°F for 7 days (modified from Watkins et al., 2004).

Temperature (°F)	Conditioning	Soft scald and soggy breakdown (%)	Bitter pit %
33	No	28a	14c
33	Yes	2d	11c
36	No	19b	20bc
36	yes	0d	34a

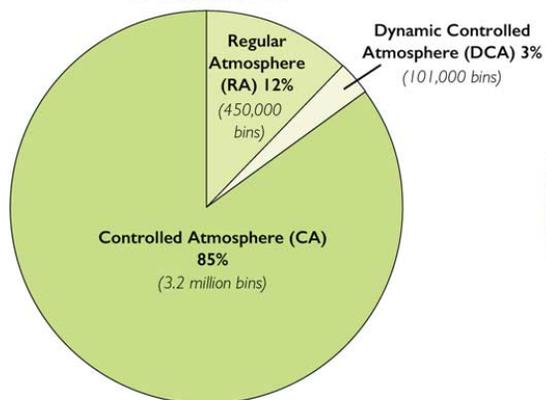
Means with different letters indicate that disorder incidence is significantly different at P=0.05.



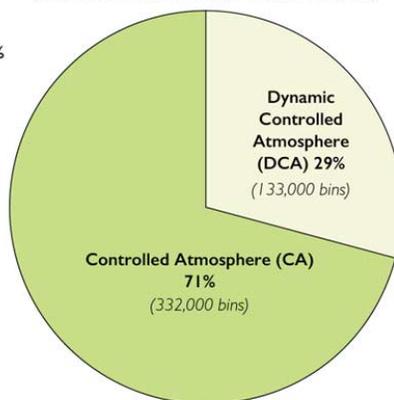
A dynamic increase in apple storage

Controlled atmosphere (CA) is the primary storage method in Washington and is expected to stay that way, with a 10 percent increase in capacity by 2020, according to a survey of storage facilities. Survey responses shown below only account for about half the total Washington apple volume, but the trends are clear. Dynamic controlled atmosphere (DCA) storage is on the rise, making up 29 percent of rooms under construction or planned for completion by 2020. Half of the survey respondents said their primary reason for building DCA rooms was for long term storage of organic fruit. None of the respondents are building more regular atmosphere (RA) rooms.

CURRENT APPLE STORAGE
IN WASHINGTON



PLANS FOR FUTURE APPLE STORAGE
(Under construction and planned for next two years.)

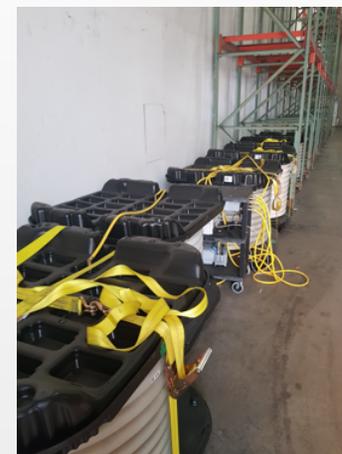


SOURCE: WASHINGTON STATE UNIVERSITY EXTENSION

JARED JOHNSON/GOOD FRUIT GROWER



- Chlorophyll fluorescence
- Ethanol concentration
- Respiratory quotient (CO₂/O₂)
- Low pressure/vacuum

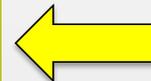




Cultivar	Huerto	Fecha de cosecha	Acondicionamiento	Atm. Dinamica
Honeycrisp	Warm 1	8/31/2019	10 days/10°C	CF: (LOL \approx 0.3%O ₂)- 3.0% O ₂ / 0.5% CO ₂ ILOS: 0.5% O ₂ / 0.5% CO ₂ - 7-11d; 1.0% O ₂ /0.7% CO ₂ RQ: 3.0% O ₂ /0.5% CO ₂ Low pressure chambers (0.5°C & 3°C)
	Warm 2	9/02/2019	10 days/10°C	
	Cool 1	9/10/2019	10 days/10°C	
	Cool 2	9/06/2019	10 days/10°C	



	Bitter Pit (%)					
Block (A)	6m	6m+4w k+1d	6m+4w k+7d	9m	9m+4w k+1d	9m+4k +7d
W42	8.9	11.6	15.1	0.2	13.8	11.1
W25	0.4	1.8	3.3	2.7	2.9	2.7
C21	7.6	10.2	11.0	0.4	5.1	5.5
C802	1.3	1.8	3.9	1.7	4.3	5.9
P value				*	ns	ns
Trat(B)						
DCA1	3.7	4.7	8.1	8.0	11.3	10.7 b
DCA2	5.3	7.7	8.2	3.7	12.7	11.0 b
DCA3	4.7	6.7	8.9	4.3	8.3	9.0 b
RL 33	n/a	n/a	n/a	4.0	1.8	1.8 a
RL 37	n/a	n/a	n/a	0.3	3.0	3.1 a
P value				ns	*	*
A x B				*	*	*



Respiration
O₂
Ethylene



Internal Browning



John Cripps, Australia
1973
Lady Williams x Golden
Delicious
Long storage – firm



Symptoms

➤ Radial browning

- associated with fruit maturity

Vascular bundles



➤ Diffuse browning

- associated with chilling injury

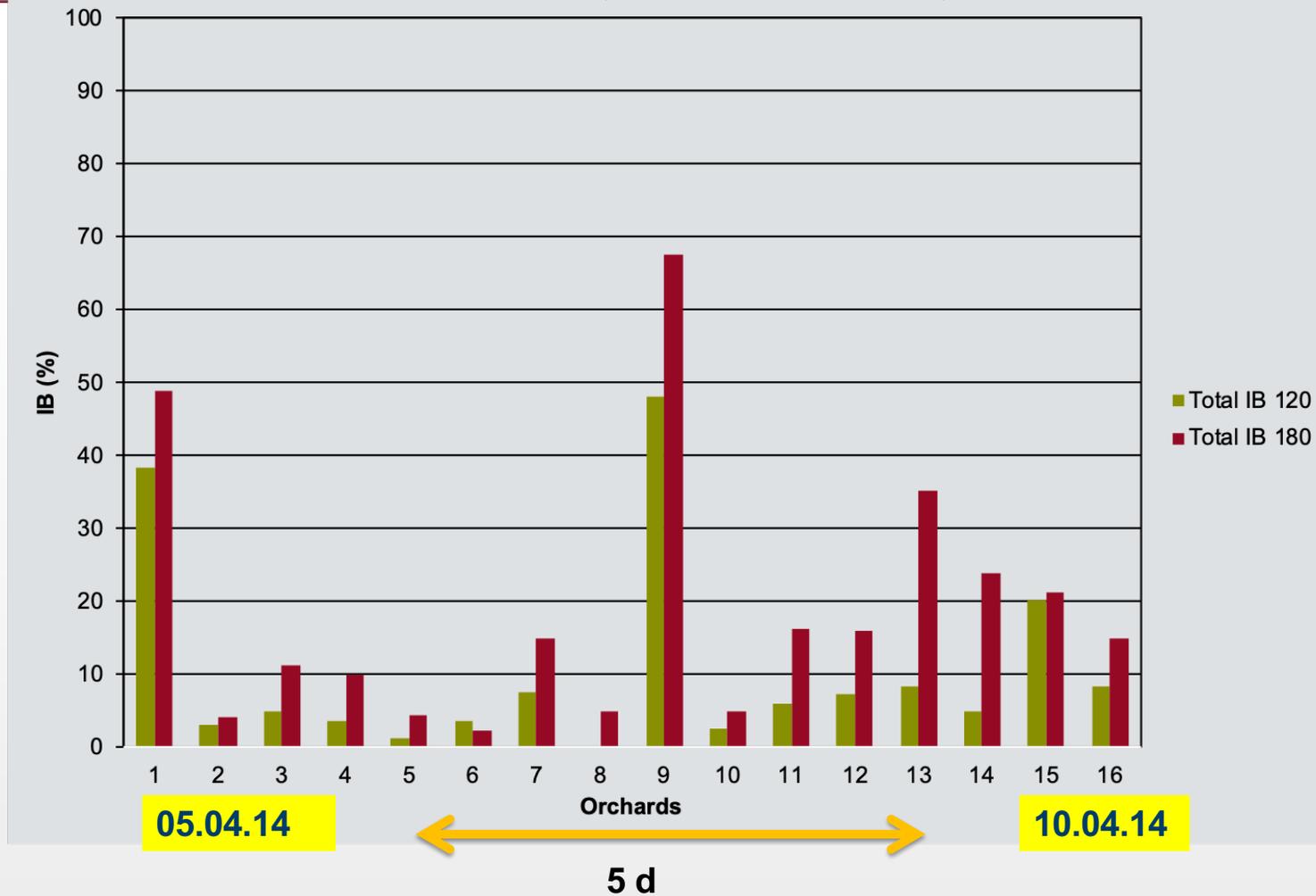
Cortical



(James et al., 2005; James & Jobbling, 2009).

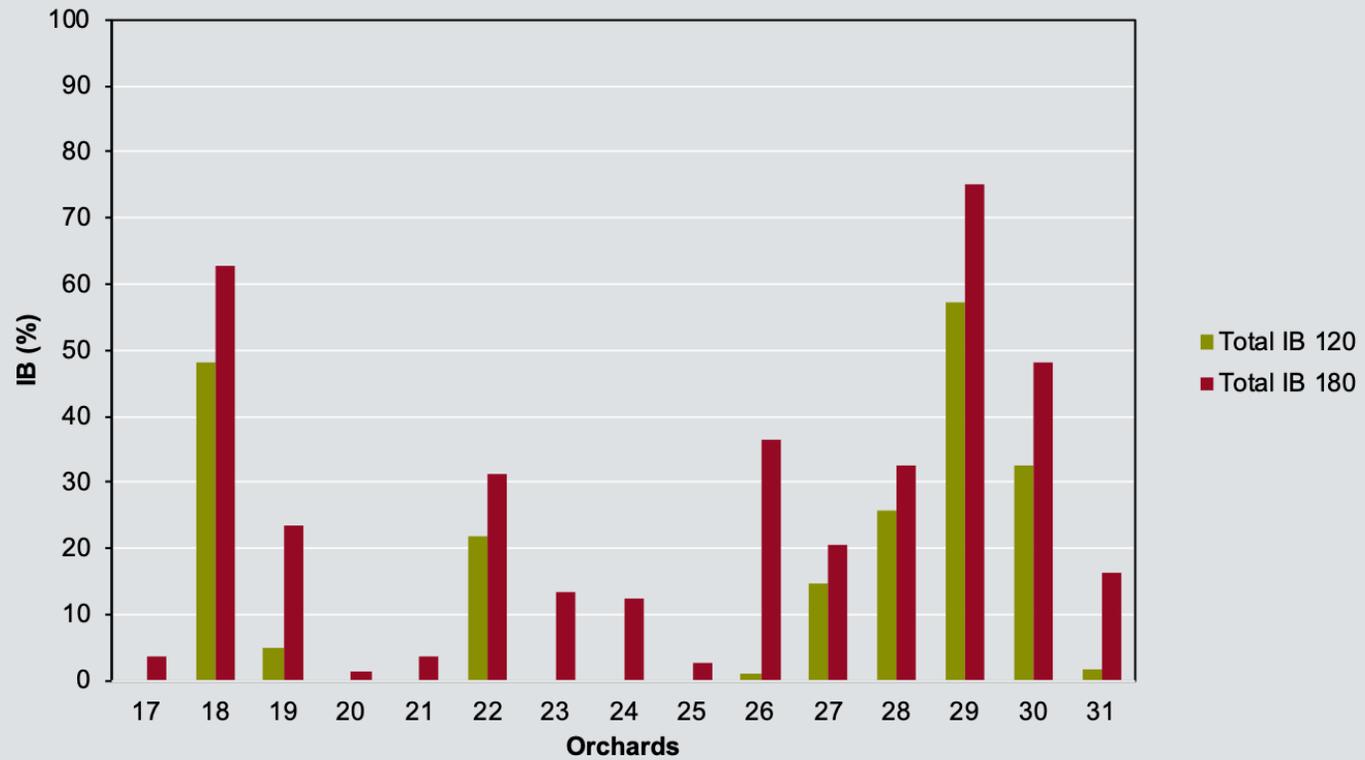


Chile (2011-2014)





Great variability between orchards...

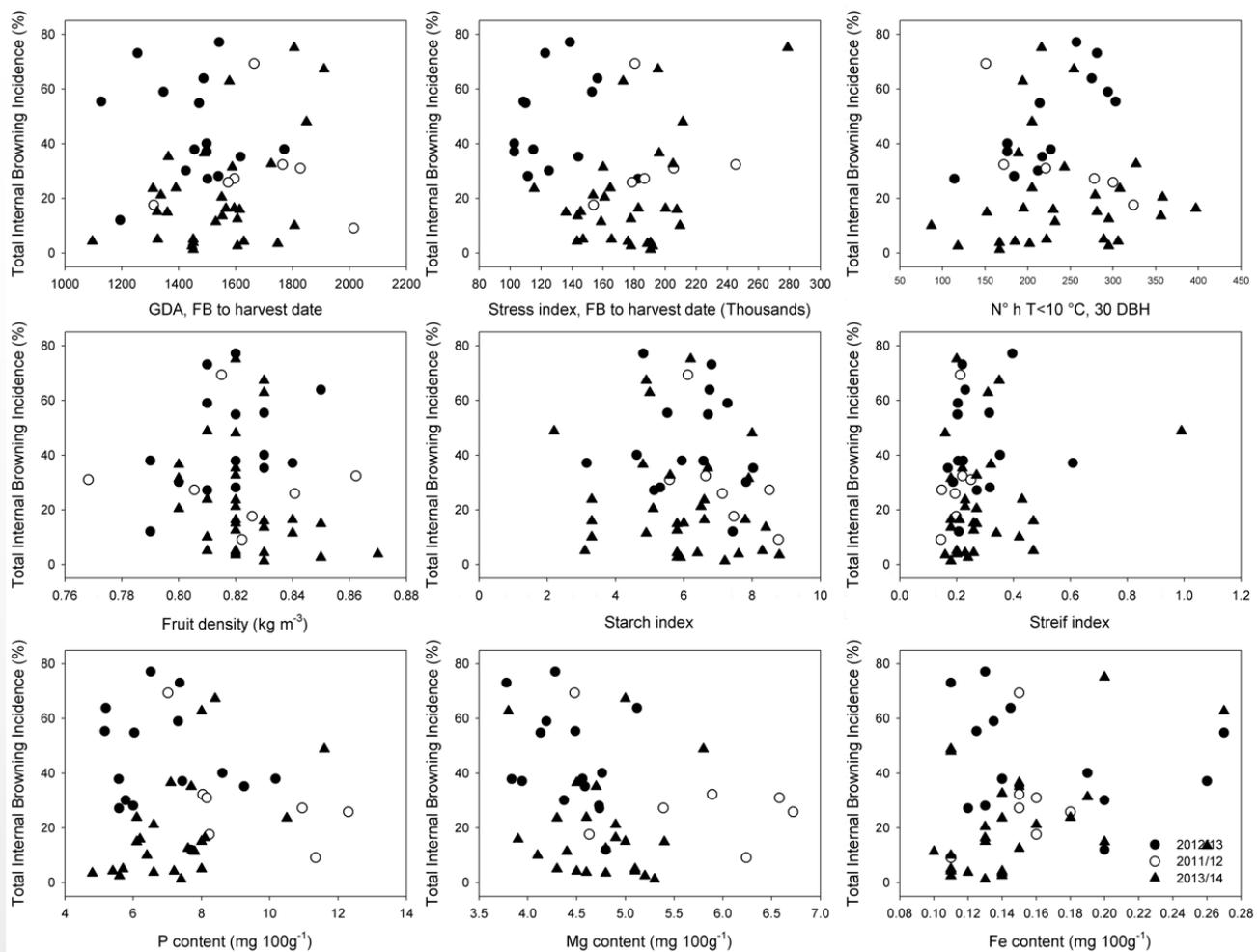


09.04.14



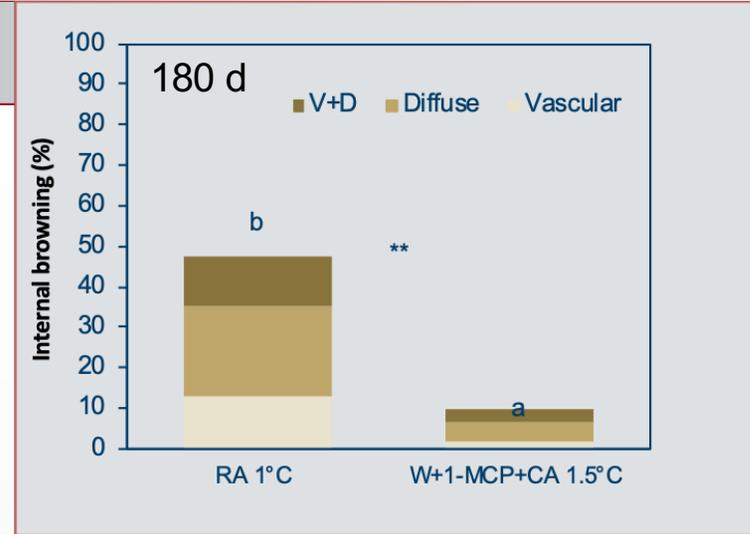
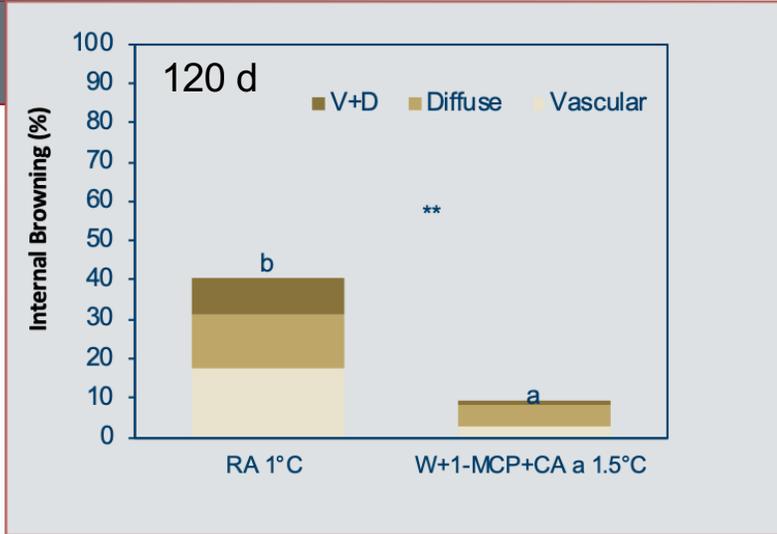
28.04.14

19 d



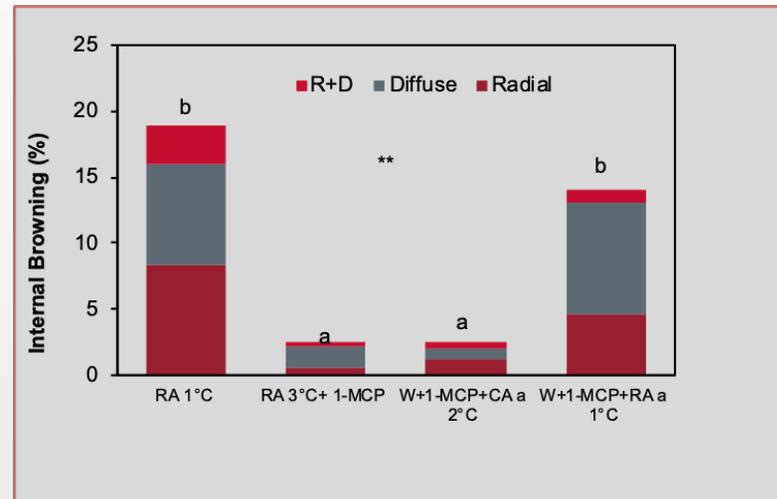
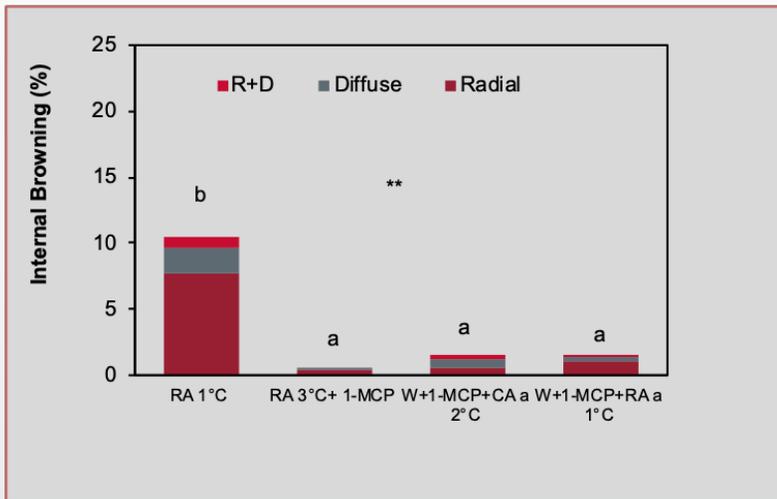


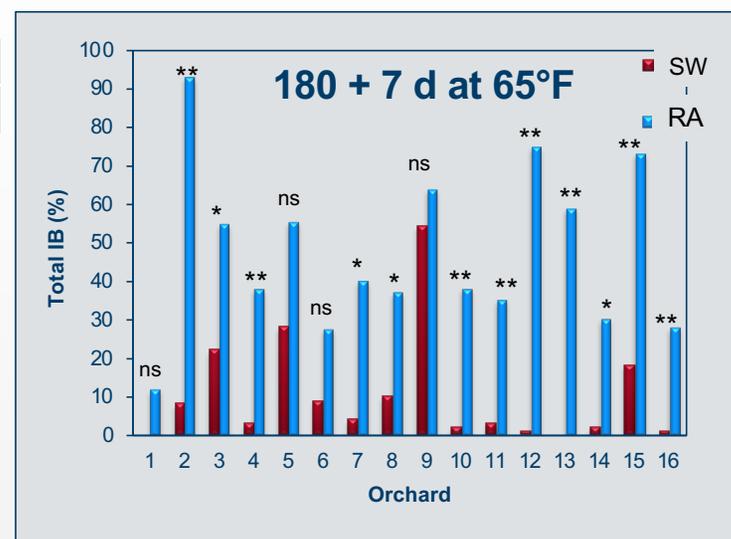
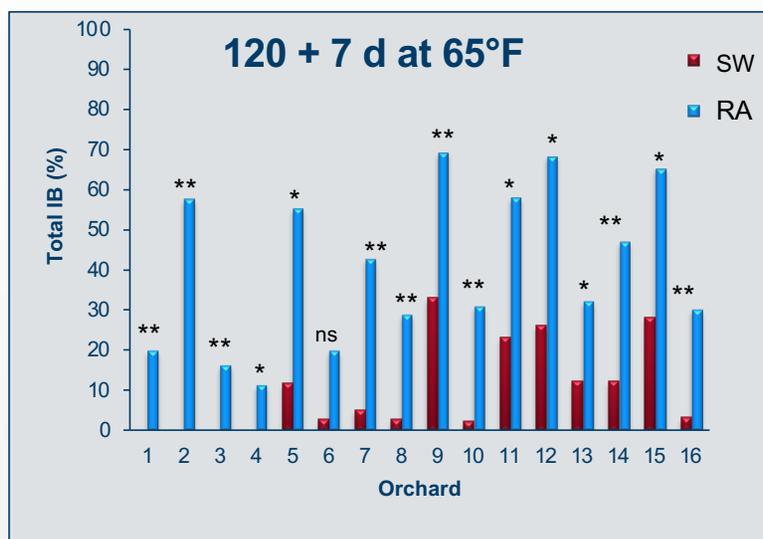
Year 2



WC: Stepwise-cooling (4°, 3° until 1.5 °C)+1-MCP (1000 ppb) & CA (O₂ 2.0%, CO₂ <0,8 %)

Year 3



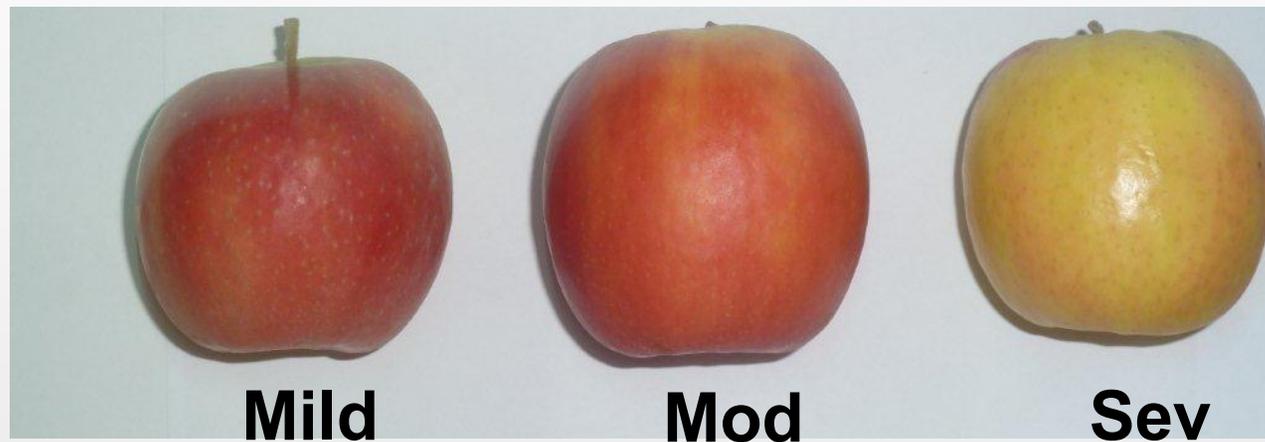


* $P \leq 0.05$
** $P \leq 0.01$
n.s.



1-MCP/CA is a 'must' when storing at temperatures above 2C to keep fruit quality and fast ripening

Greasiness





Final Remarks

- Higher storage temperatures (> 2.5 °C) and conditioning significantly reduced IB (vascular and diffuse) on Cripps Pink apples. Nonetheless, this was not true for highly susceptible batches of fruit, revealing its multi-factorial origin.
- Higher storage temperatures increased fruit greasiness and yellow background color, both of which downgrade Pink Lady quality. Therefore, they must consider 1-MCP applications and/or CA regimes in order to maintain fruit quality on long-term storage (6 m).



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