Crop Management Strategies: Balancing Yield and Quality

New Technology for Commercial Production (VIII)

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Outline

- Quality: Phytochemicals, sugars, sensorial
- Stress: oxidation – antioxidation
- Factors affecting Yield & Quality = Genetics, Environment, Management

<table>
<tr><th>Species</th><th>Strategies</th></tr>
<tr><td>Melon</td><td rowspan="5">Soils, Tillage
Irrigation, Nitrogen,
Plant Density
Tunnel, Open field
Grafting
Conventional-Organic
Bioregulators</td></tr>
<tr><td>Watermelon</td></tr>
<tr><td>Artichoke</td></tr>
<tr><td>Spinach</td></tr>
<tr><td>Tomato</td></tr>
</table>

- Discussion

Phytochemicals

Polyphenolics

- Flavonoids

- Anthocyanins	Eggplant, red vegetables (cabbage, radish, onion)
- Quercetin	Onion, Kale, Broccoli, Turnip, Pepper
- Luteolin	Pepper, Tomato, Eggplant, Garlic, Onion, Celery

- Phenolic acids

- Caffeic, chlorogenic	Artichoke, Potato, Sweet Potato

- Carotenoids

- β-carotene	Carrot, Melon, Eggplant, Sweet Potato, Kale
- lycopene	Watermelon, Tomato
- lutein	Spinach

...Phytochemicals

Vitamin C	Pepper, Tomato
Dietary Fiber	Cruciferous crops, artichoke
Organo sulfur	
➢ Glucosinolates	Cruciferous crops
➢ Thiosulfides	Allium crops (Onion, Garlic & Leek)
Folates	Cruciferous crops, Spinach
Selenium	Cruciferous crops, Allium *crops*

Carotenoids in Vegetable Species

Crop	Alpha-carotene	Beta-carotene	Lutein + Zeaxanthin	Lycopene
		($\mu g \bullet g^{-1}$)		
Asparagus	0.1	4.9	-	-
Snap Beans	0.7	3.8	6.4	0
Broccoli	0	7.8	24.5	0
Cabbage	0	0.7	3.1	0
Carrot	46.5	88.4	0	0
Carrot, A-plus cv.	106.5	182.5	0	0
Celery	0	1.5	2.3	0
Collards	2.4	33.2	-	-
Kale	0	92.3	395.5	0
Turnip Greens	0	45.8	84.4	0
Cucumbers	0.1	1.4	0	0
Lettuce	0	1.9	3.5	0
Melon	0.3	16	0.4	0
Okra	0.3	4.3	3.9	0
Onion	0	1.2	-	-
Peas	0.3	3.2	13.5	0
Peppers, Sweet	0.2	2	-	-
Pumpkins	48	69.4	0	0
Spinach	0	56	119.4	0
Squash	0	0.9	2.9	0
Sweet Corn	0.3	0.3	8.8	0
Sweet Potato	0	91.8	0	0
Tomato	1.1	3.9	1.3	30.3
Watermelon	0	3	0.2	48.7

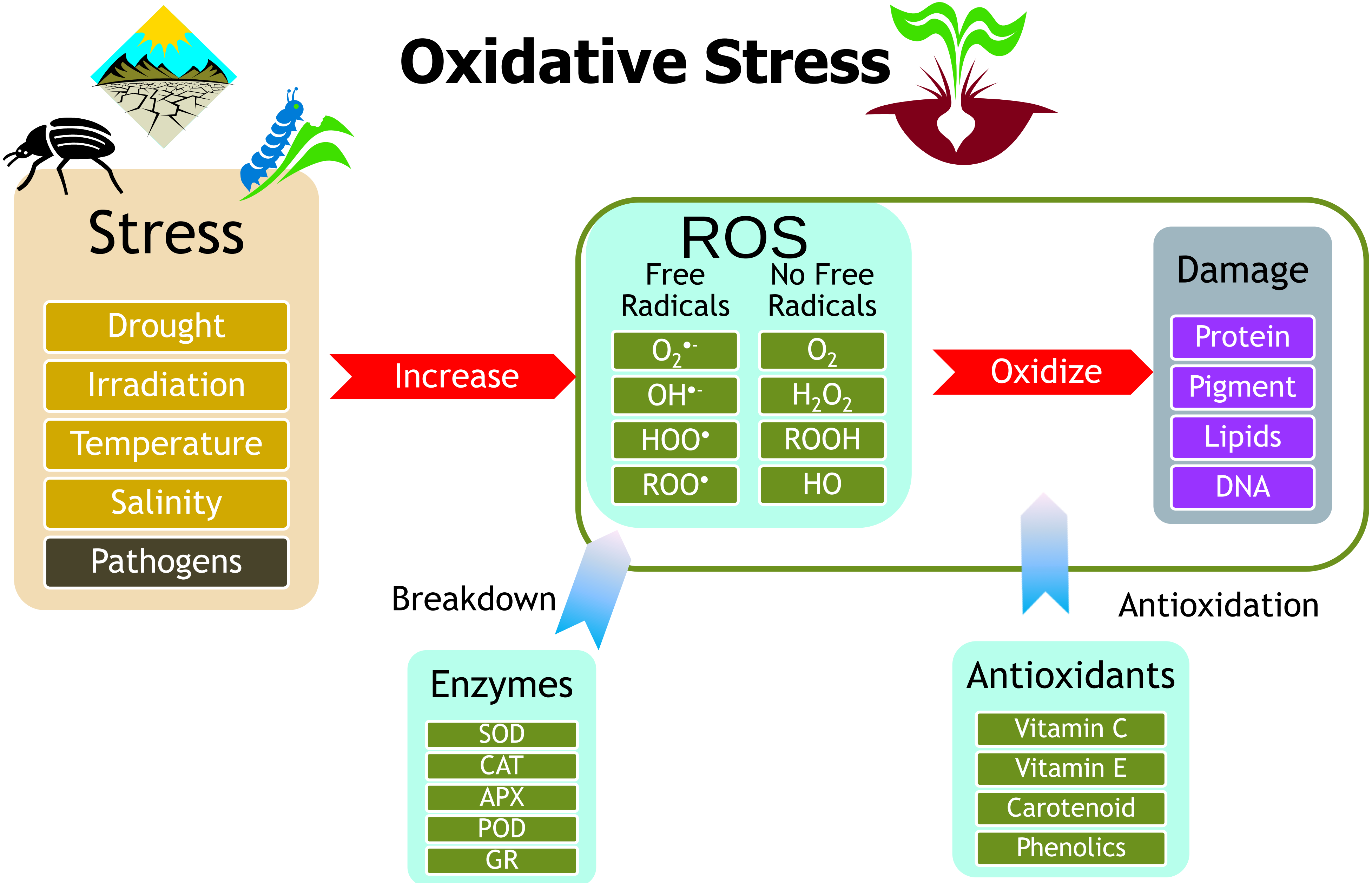
Carotenoid Database for U.S. Foods (USDA-NCC, 1998)

Carotenoids

- Light harvesting in photosynthesis
- Protection of plants from photo-oxidation (β-carotene)
  - *- Excess energy dissipation*
- Pigmentation
- Essential components of the human diet
- Beneficial health-promoting compounds

  - cancer - heart disease

  - immune system - macular disease



Adapted from Apel & Hirt (Annu. Rev. Plant Biol. 2004

Can we increase the levels of phytochemicals in Fruits & Vegetables ?

Can we define optimum conditions to maximize the biosynthesis of phytochemicals ?

Difficult because differences in:

Old vs New varieties

Fresh weight vs. Dry weight soil

Nutrient management

Irrigation systems and management

Maturity (harvest times)

Protected vs open field environments

G × E × M ➡ GROWTH, YIELD & QUALITY

Genetics

- Variety

Environmental

- Light
- Temperature
- Soil type
- Rainfall
- O_2
- Radiation

Crop Management

- Irrigation
- Nitrogen
- P, Ca, K, S, Se
- Salinity
- Compaction
- Grafting
- PGR's
- Biostimulants
- Cultivation
  - Tunnels, GH
  - Open field
- Organic vs. conventional
- Plant population
- Harvest time

G x E x M : MELON

Subsurface Drip

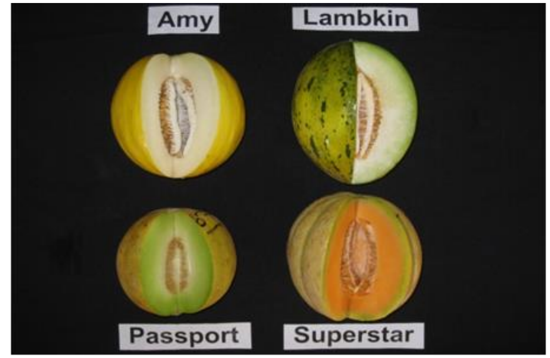
Deficit Irrigation

↓

Culture

↓

Genetics



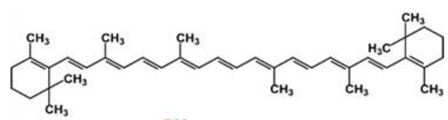
Cultivars

- **Water savings**
- **Yield**

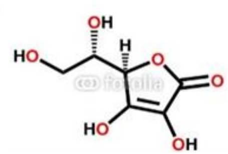
- **Flavor**
- **Phytochemicals**

High productivity

β - carotene



Ascorbic acid



Fruit quality

G x E x M: WATERMELON


Growth regulation – Drought

How ?

When ?

Deficit Irrigation + Culture + Genetics

Where ?


Fruit set


Improved Stand Establishment

- Yield
- Water savings

- Quality, Flavor
- Phytochemicals


Center Pivot

IMPROVED IRRIGATION TECHNOLOGIES

Drip

Center Pivot

SDI

LEPA: spray mode

PLANT DENSITY: SPINACH

Low plant density – 40 " bed
2 cuts/season

High plant density – 80 " bed
Several cuts /season – babies/teen size
Improved genetics (R to White Rust)

ORGANIC SOIL AMENDMENTS

Integrating HS soil amendments with deficit irrigation could provide growers an optional practice for managing watermelon growth in water-limited regions and organic matter degraded soils.

TOMATO GRAFTING & ROOTSTOCKS

Grafting can improve heat stress tolerance, disease resistance, yield, and quality in protected and open field systems – conventional and organic - in Texas

- Rootstocks screening
- Scion (cv) screening
- Environmental impact

LIGHT SPECTRAL QUALITY

Screening lettuce germplasm to improve growth and anthocyanin content in hydroponic production systems

CASE STUDIES

Muskmelon: location, cultivar and soil type

Watermelon: irrigation, maturity, cultivar, tillage

Artichoke: irrigation and harvest time

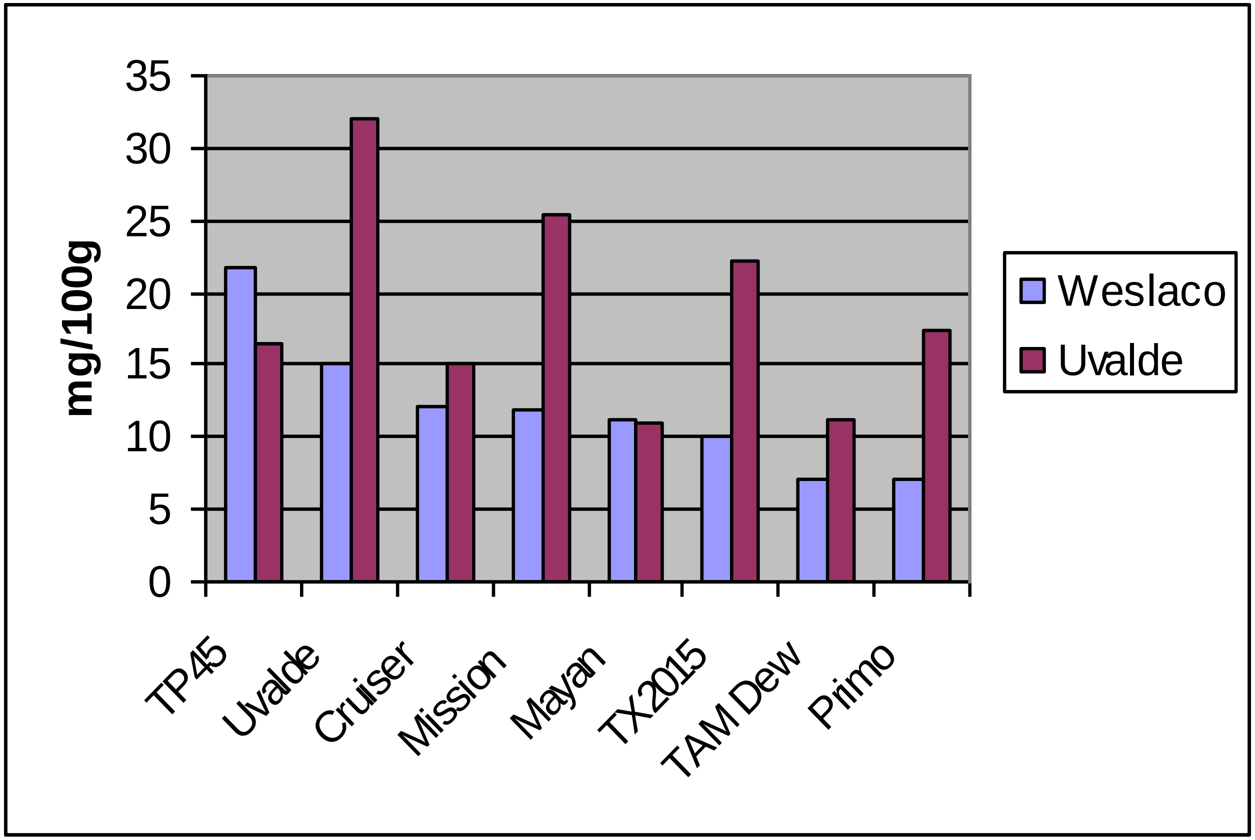
Spinach: irrigation, NUE, genetics

Tomato: salinity, grafting, location-environment

Vegetables: N fertilization – Deficit irrigation

Location and Cultivar - Muskmelon

Vitamin C



Soil Type – Muskmelon

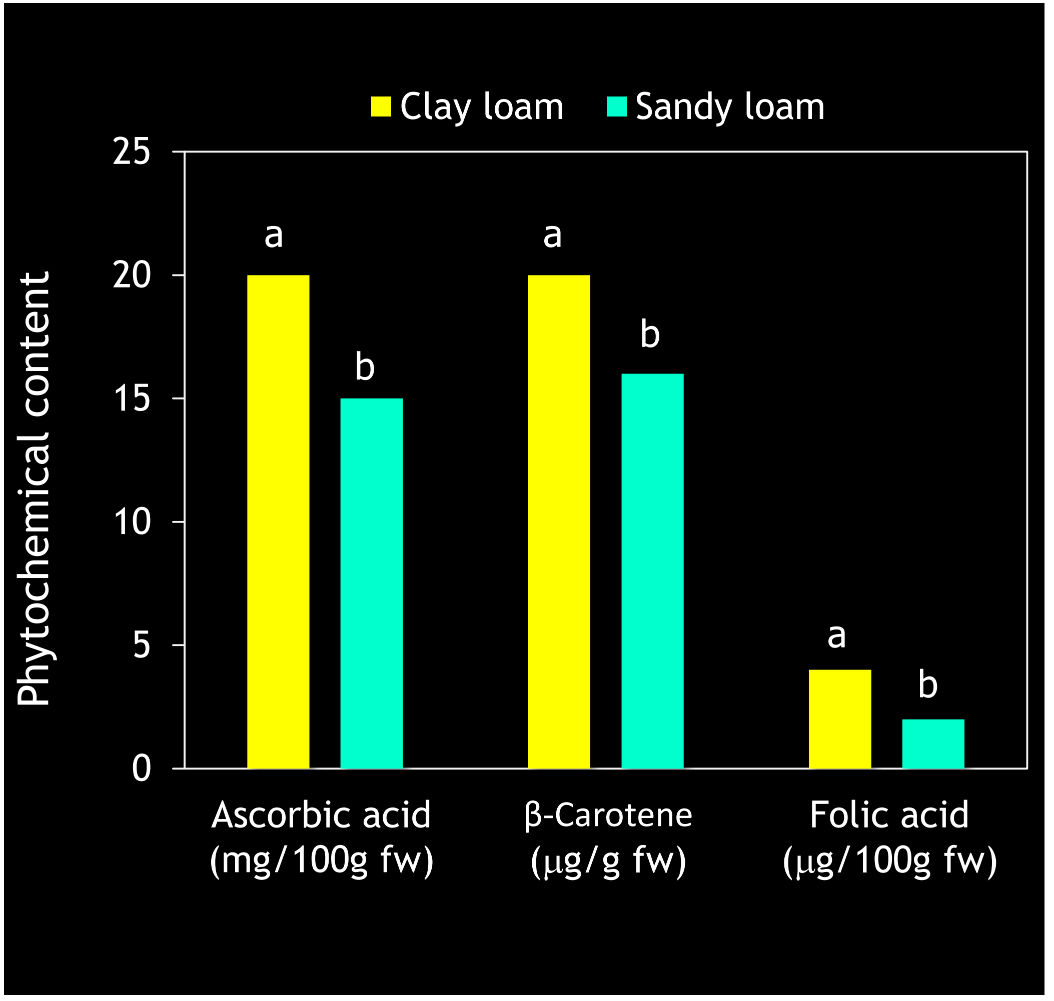
Vitamin C, β-Carotene & Folic Acid

Soil type

- Clay loam vs. Sandy loam

Soil type	pH	OM (%)	CEC (meq/100g)	K (kg/ha)
Clay loam	8.1	1.4	41.0	1053
Sandy loam	7.2	0.5	8.9	502

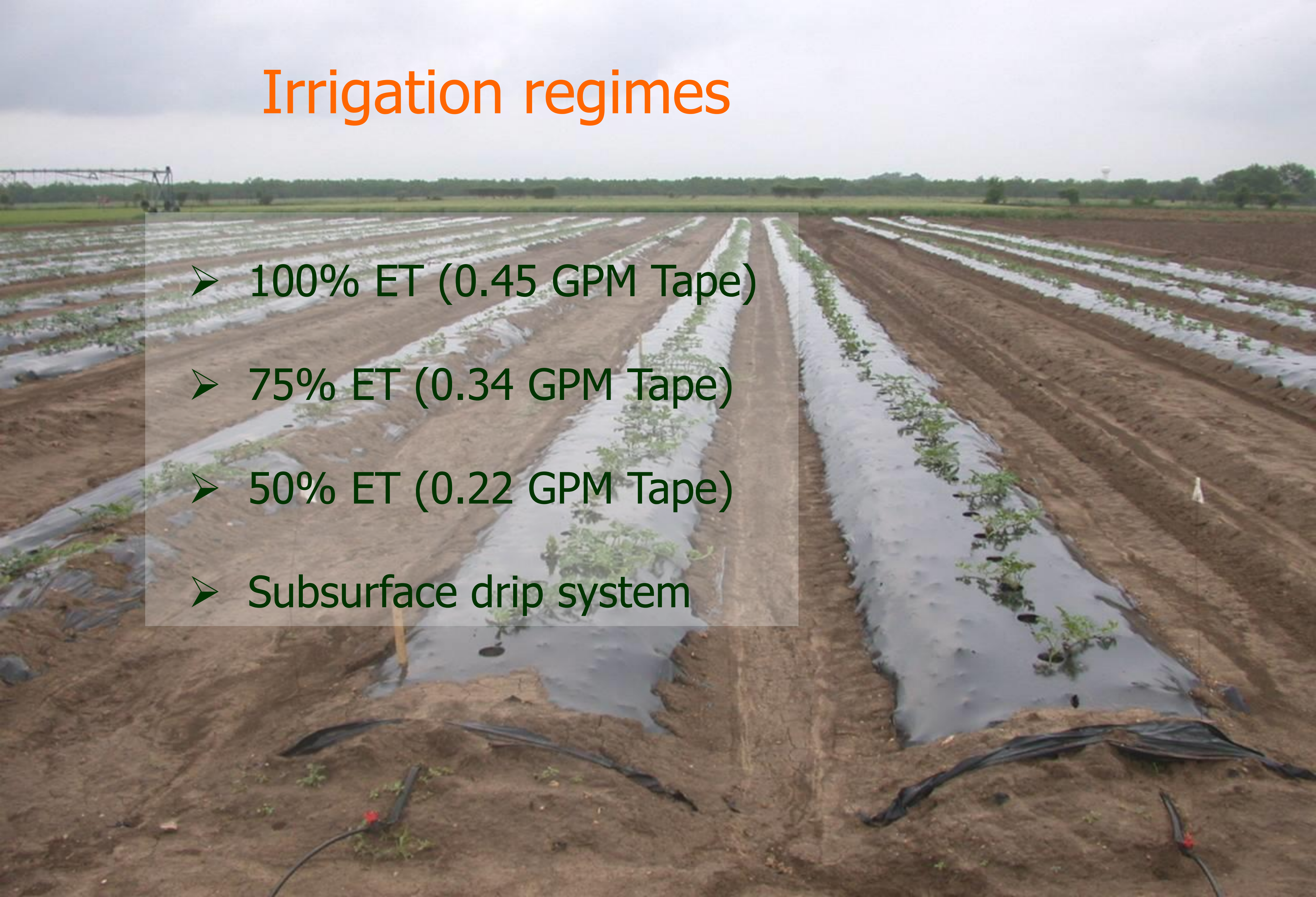
"Clay loam with higher OM, CEC, and mineral contents improved the phytochemical contents in muskmelon compared to sandy loam"

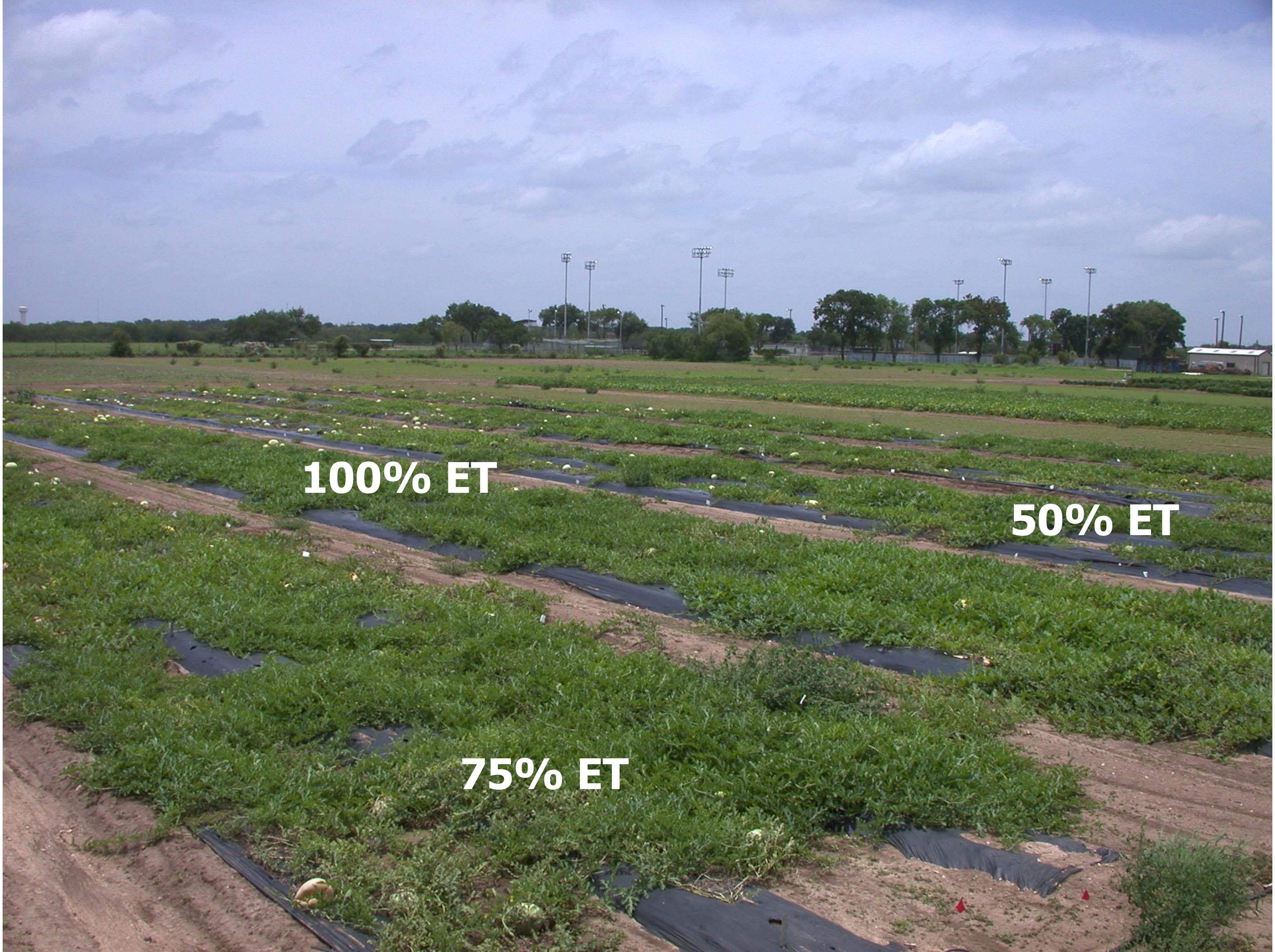


G. Lester (HortScience 2006)

Irrigation regimes

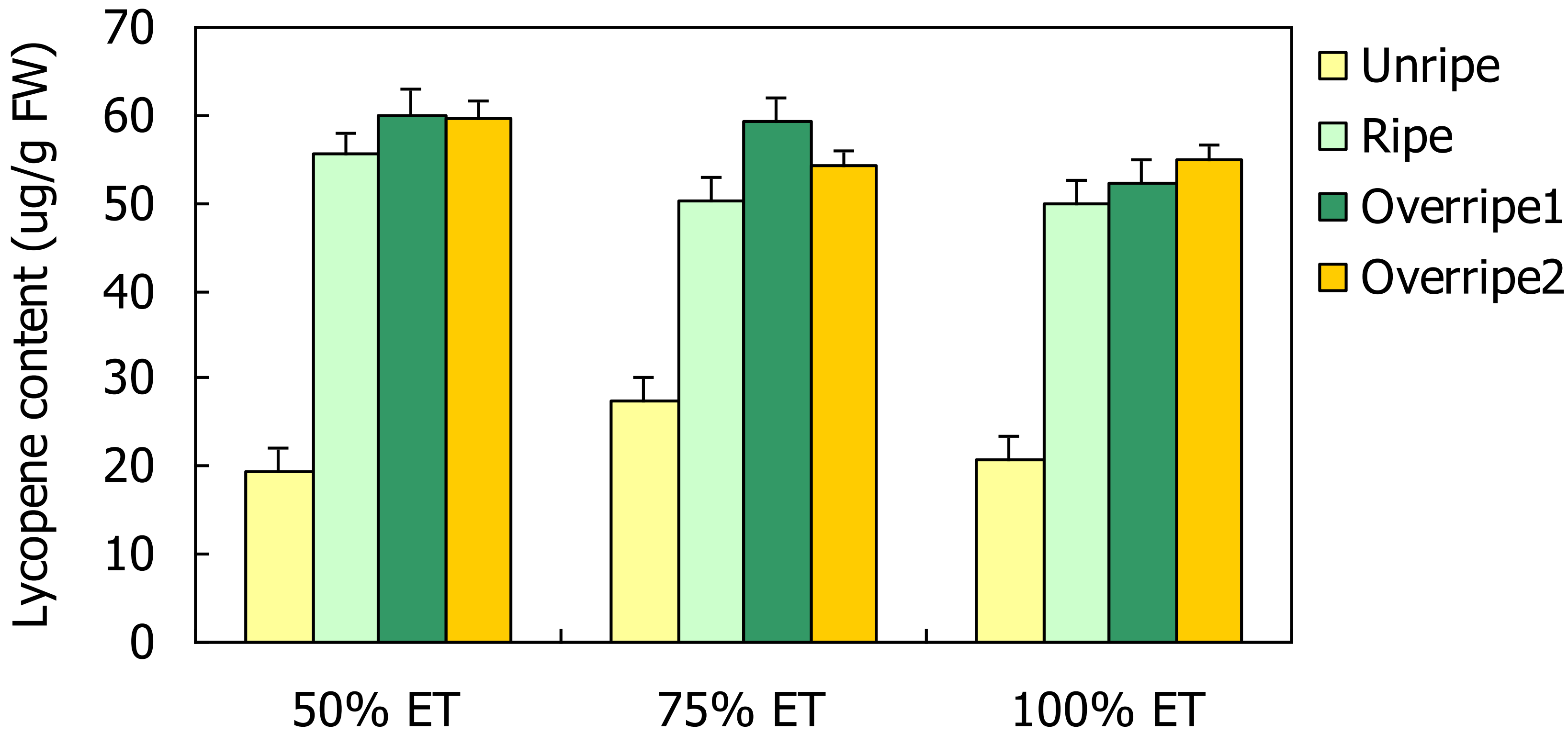
- 100% ET (0.45 GPM Tape)
- 75% ET (0.34 GPM Tape)
- 50% ET (0.22 GPM Tape)
- Subsurface drip system




100% ET
50% ET
75% ET

Irrigation rate: Impact on fruit size – Uvalde, TX

Irrigation & Maturity Impact on Lycopene content



Uvalde, TX

Irrigation, Cultivar, Maturity

Lycopene

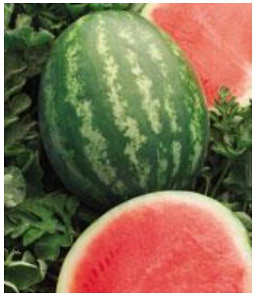
Lycopene

Limited irrigation and maturity increased lycopene content.

Lycopene content was higher and less variable for 3x (60-66 ug/g) than 2x (45-80 ug/g).

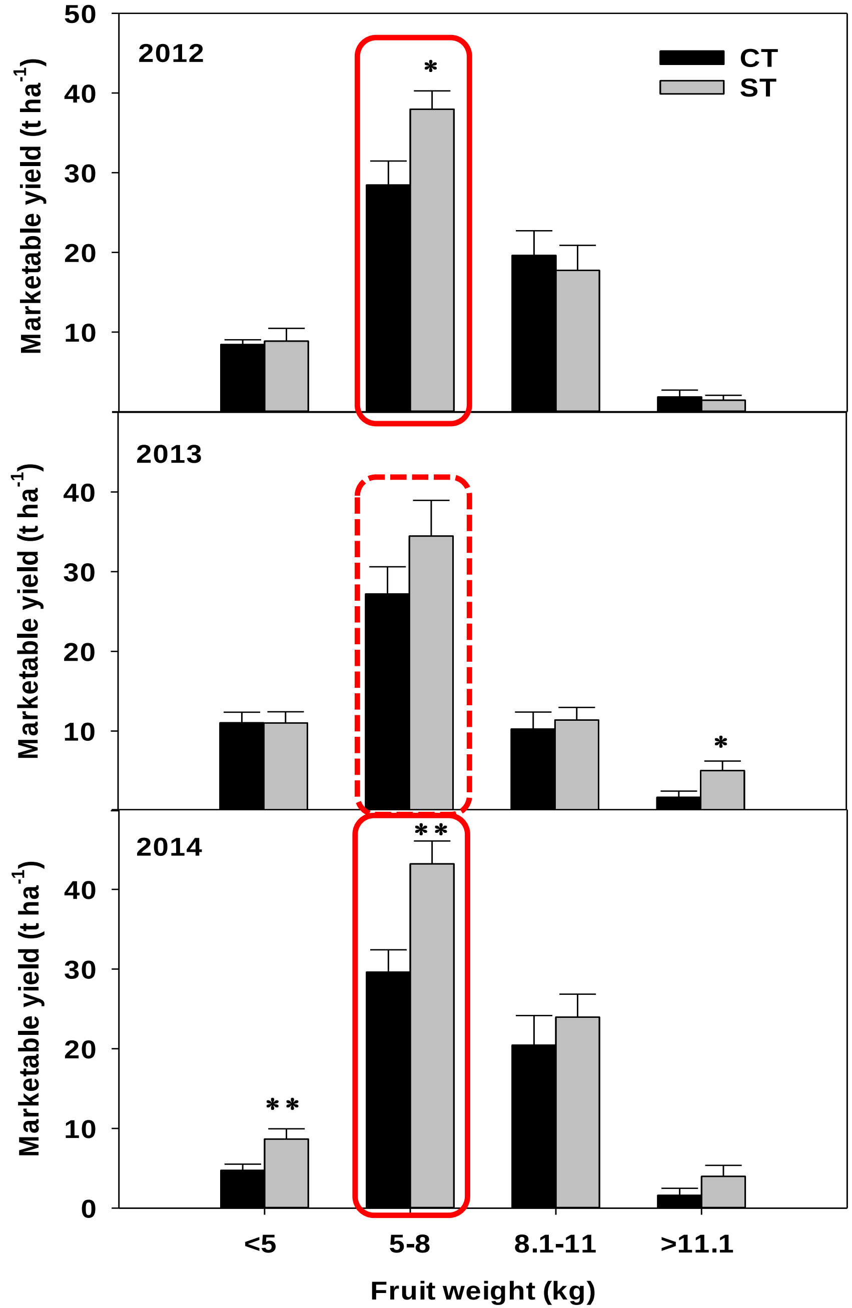
Treatment		Ploidy	Lycopene (ug/g FW) Ripe	Lycopene (ug/g FW) Overripe
Irrigation Regime	100% ET		54.3 b	58.8 b
	75% ET		57.9 a	62.4 a
	50% ET		55.3 ab	59.6 b
	LSD (0.05)		2.5	2.1
Cultivar	SF 710	2X	77.3 a	80.6 a
	RWM 8036	2X	50.1 cd	62.3 b
	Allsweet	2X	43.5 e	45.7 c
	Sugar Lee	2X	48.2 cd	49.0 c
	SWD 7302	2X	47.2 de	46.8 c
	SS 5244	3X	62.2 b	65.9 b
	SWT 8706	3X	58.8 b	63.8 b
	Sugar Time	3X	62.5 b	66.3 b
	Tri-X-Sunrise	3X	51.8 cd	61.6 b
	LSD (0.05)		4.6	6.2

Leskovar, Bang, Crosby, Maness, Franco, Perkins-Veazie (JHSB, 2004)

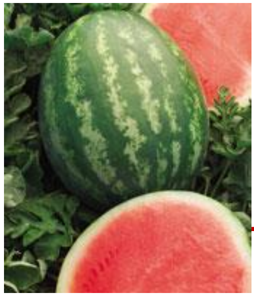


Strip vs. Conventional Tillage

- ✓ Across three years, strip tillage increased marketable yield mostly in the fruit size category **11–17 lbs**, which was about 50% of the total yield.



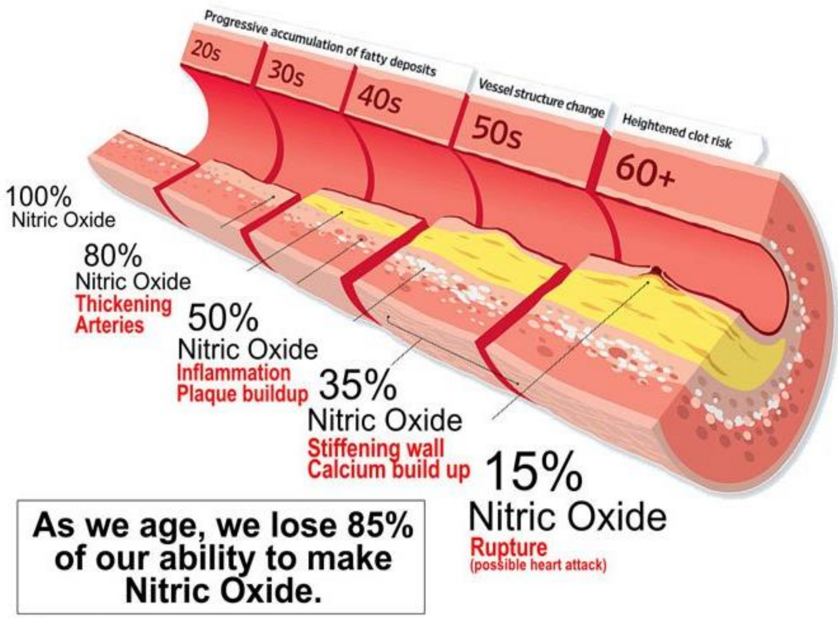
Leskovar, Othman, Dong (Soil & Tillage Research, 2016)



Strip tillage improved sugar content

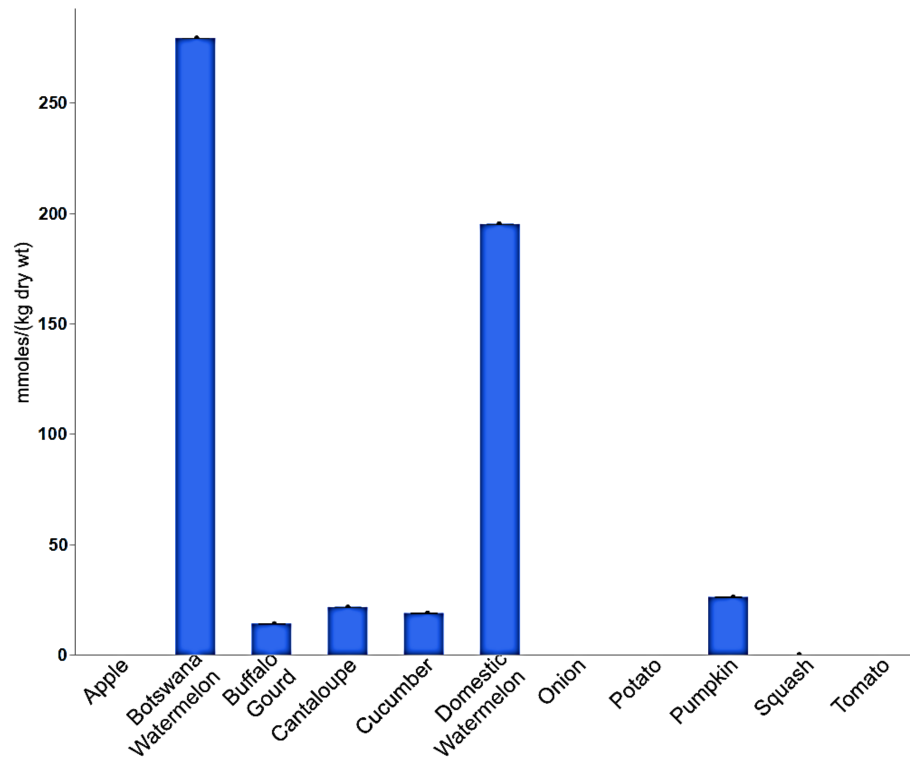
		Sugar content (°Brix)		
		2012	2013	2014
Tillage (T)	Conventional (CT)	11.1	11.2	11.6
	Strip (ST)	11.6	11.7	12.0
Irrigation (IR)	1.00 ET	11.2	11.3	11.6
	0.75 ET	11.4	11.5	11.8
	0.50 ET	11.5	11.6	11.7
P-value	T	0.02	0.001	0.03

Citrulline in watermelons and Health



1998 Nobel Prize : Robert F. Furchgott, Louis J. Ignarro, and Ferid Murad

- Source of endothelial nitric oxide (NO) synthesis against cardiovascular diseases



Goal: Develop varieties with the highest citrulline accumulation

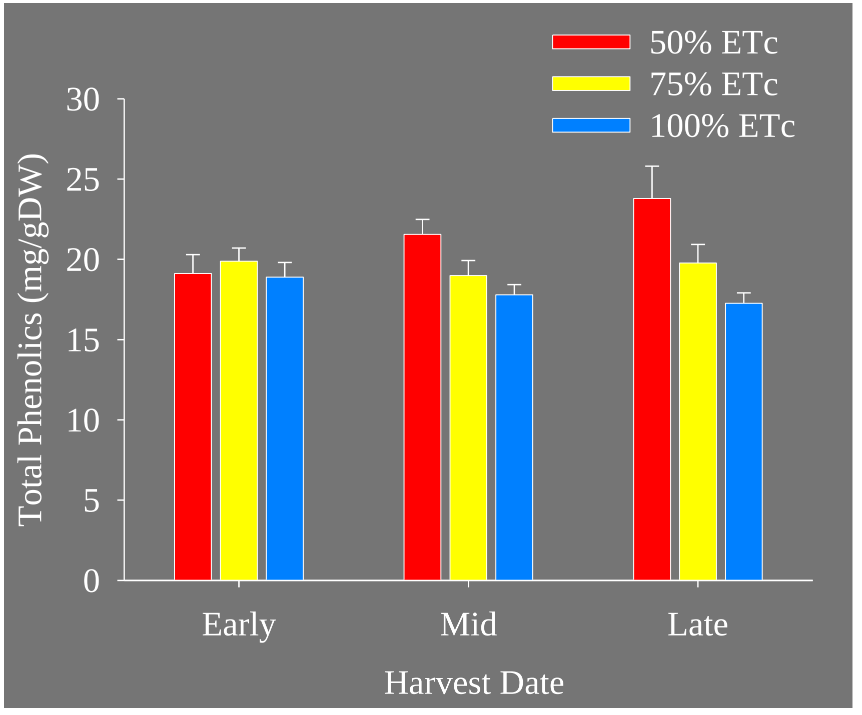
Irrigation & Harvest Time - Artichoke

Phenolics

- Irrigation rate: 100% ETc
  75% ETc
  50% ETc
- Harvest time: Early, Middle and Late

Total Phenolics
Deficit irrigation significantly increased total phenolics as harvest season progressed.

Average yield decreased by 27% with deficit irrigation.



Shinohara, Agehara, Yoo & Leskovar (2007)

Irrigation - Spinach

Ascorbic Acid & Carotenoids



Irrigation rate	Ascorbic acid (µg/g fw)	Carotenoid (µg/g fw)				
		β-carotene	Lutein	Neoxanthin	Violaxanthin	Total
100% ETc	172	15.7	64.2	18.4	41.7	141
75% ETc	175	16.1	67.5	20.8	43.9	148
50% ETc	217	19.8	71.5	20.5	45.8	157
$LSD_{0.10}$	35	3.2	4.6	1.6	NS	11

Phytonutrients: Responses to Deficit Irrigation

Crop	Deficit Irrigation Phytochemical	Deficit Irrigation Yield	Irrigation Rate	Reference
Artichoke	↑ Phenolics	↓	100, 75, or 50% ETc	Shinohara et al. 2014
Carrot	↔Vitamin C	↔	- 0.03, -0.06, or -0.12 MPa (water to FC)	Sorensen et al. 1997
Celery	↑ α-Carotene ↑ β-Carotene ↔Thiamine	↓	Irrigation (404 mm) or no irrigation (248 mm)	Evers et al., 1997
Leek	↑ Vitamin C	↓	-0.03 or -0.09 MPa (water to FC)	Sorensen et al., 1997
Pepper	↑ Vitamin C ↑ β-Carotene	↓	100 or 50% ETc	Leskovar et al. (unpublished)
Spinach	↑ Vitamin C ↑ β-Carotene ↑ Lutein	↓	100, 75, or 50% ETc	Leskovar et al. (unpublished)
Tomato	↑ Vitamin C ↑ Lycopene ↔β-Carotene	↓	100 or 20-30% FC	Zushi and Matsuzoe 1998
Watermelon	↑ Lycopene ↔Lycopene	↓ ↓	100, 75, or 50% ETc 100, 75, or 50% ETc (3 locations)	Leskovar et al., 2004 Bang et al., 2004

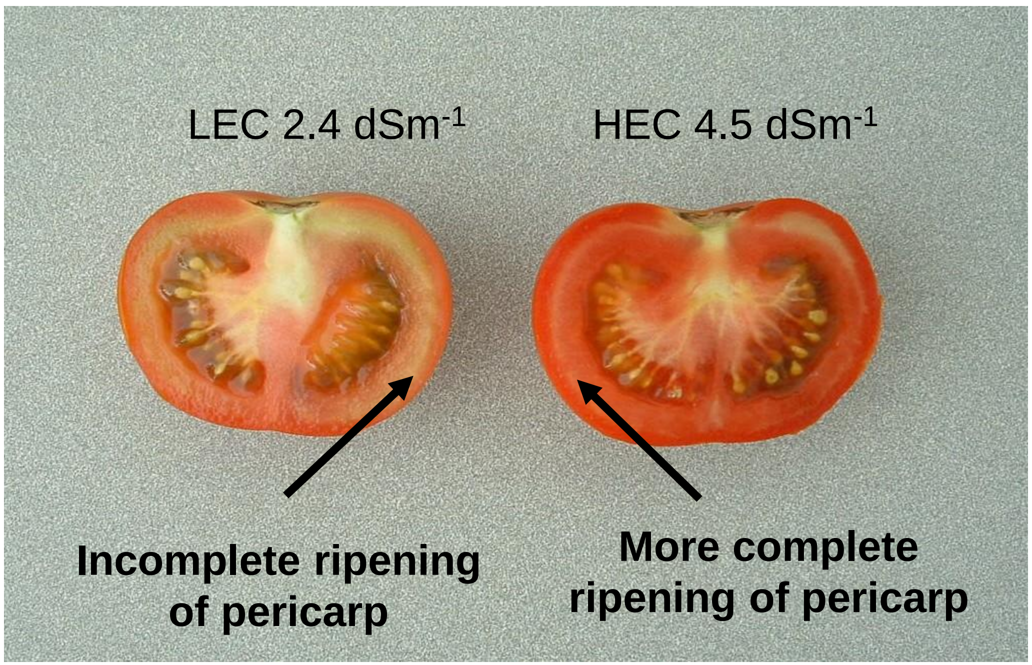
Tomato Production in Controlled Environment (CE) in Arizona

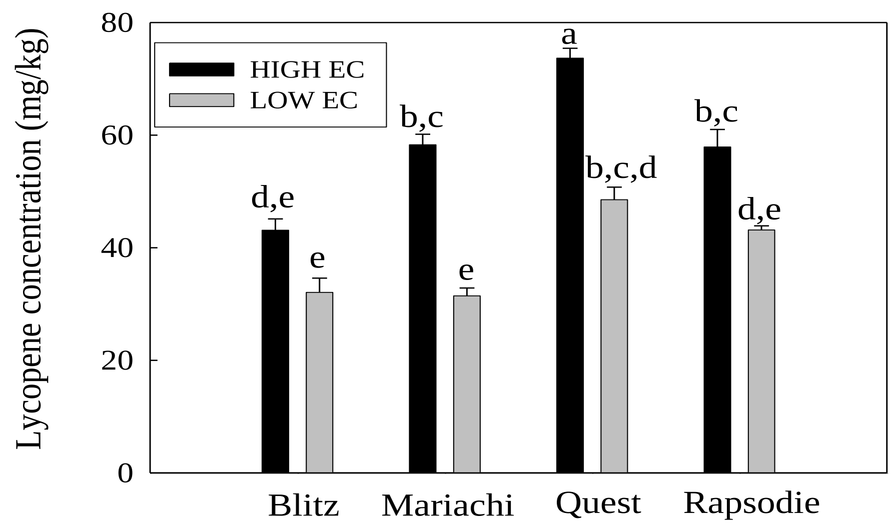
Salinity & Cultivar in CE - Tomato

Lycopene

Lycopene and Quality

Under control environment (CE) lycopene increased from 34% to 85%, depending on cultivar. Moderate salinity also increased fruit quality.





Wu, Buck & Kubota (Acta Hort. 2004)

N rates on phytochemicals and yield ?

Nitrogen – Grape Tomato

Vitamin C & Carotenoid

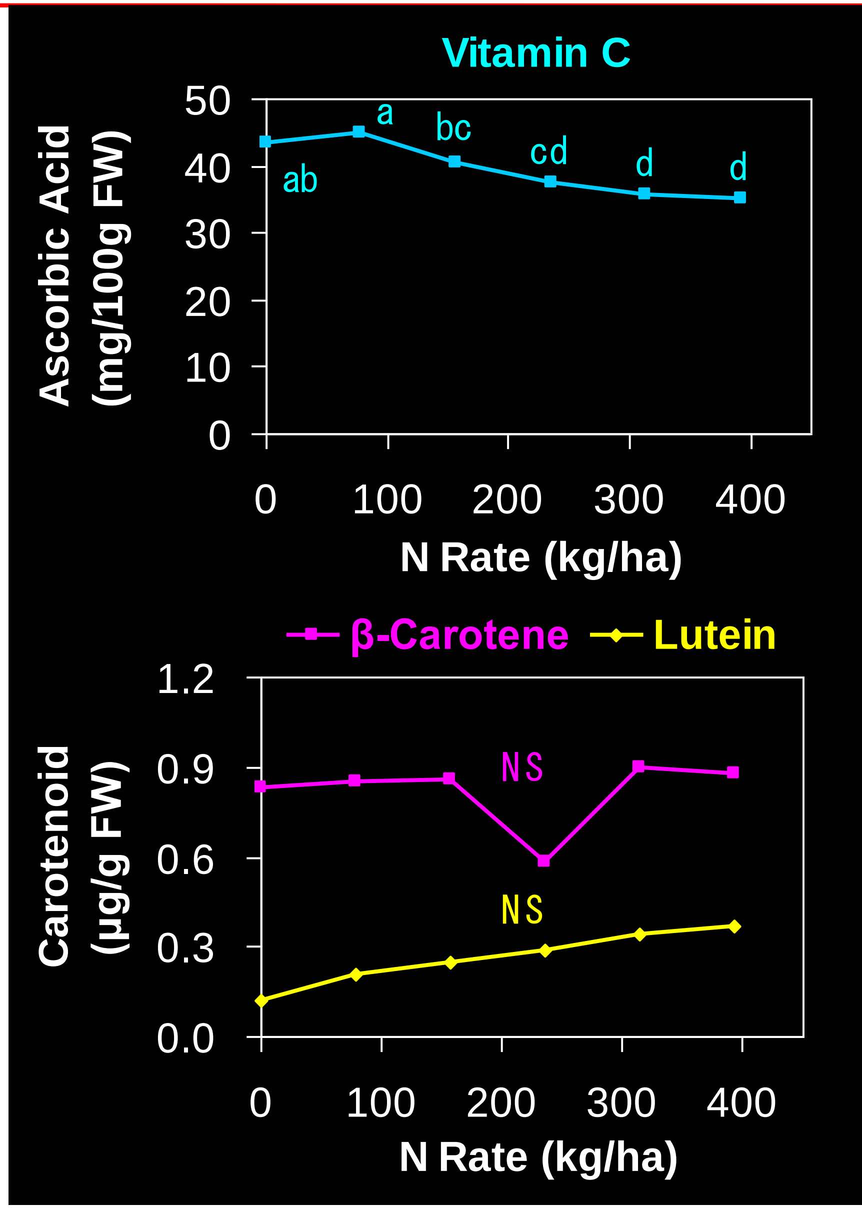
Experimental

- Field Exp. in FL (2005)
- cv. Honey Bunch
- Nitrogen: 0, 78, 157, 235, 314, 392 kg/ha

Conclusion

Vitamin C
Ascorbic acid was significantly reduced (22%) by increasing N supply.

Carotenoid
β-Carotene was unaffected by N supply. Lutein showed a trend of increasing with increasing N supply.



Simonne, Fuzere, Simonne, Hochmuth, Marshall (J. Plant Nutr. 2007)

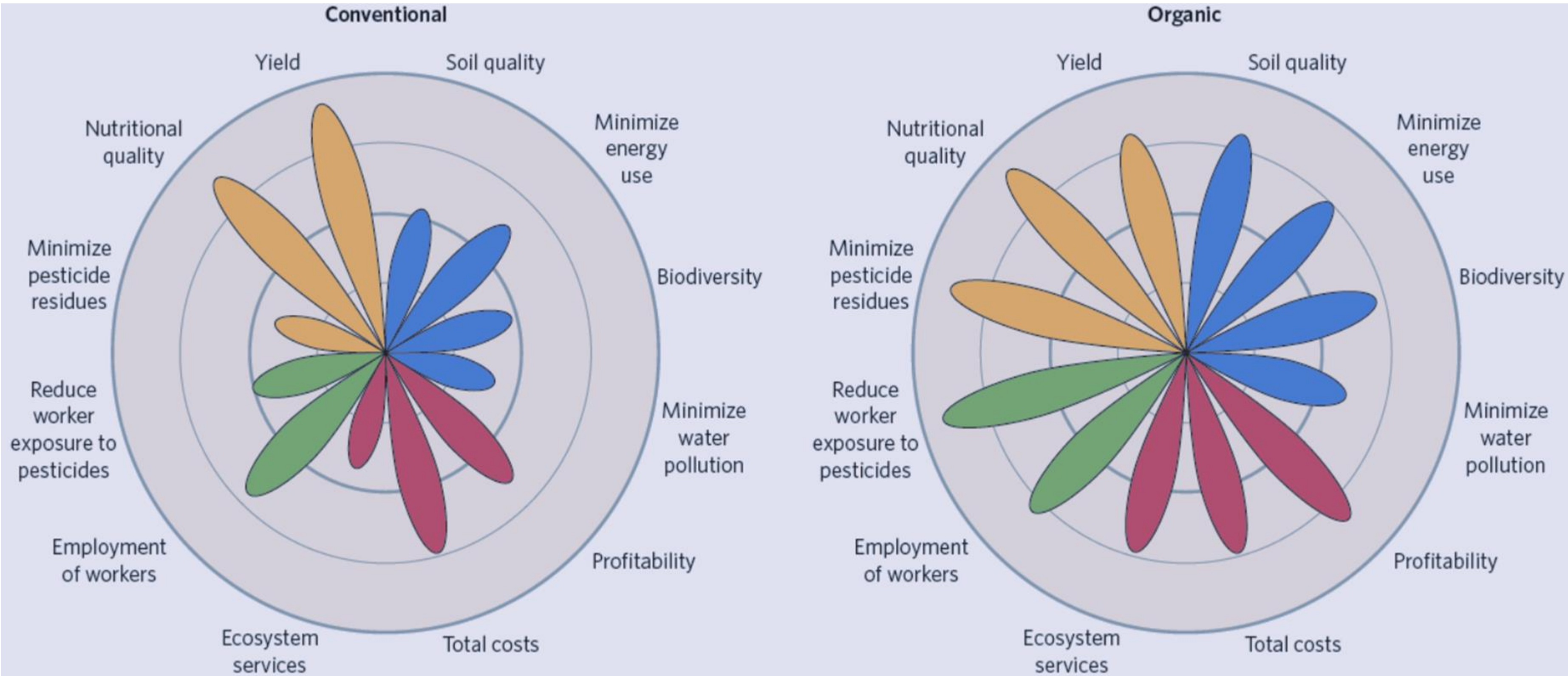
Phytochemicals: Responses to Increased N Supply

Crop	Increasing N Supply Phytochemical	Yield	N Rates	Reference
Broccoli	↓ Glucosinolate	↑	1 or 4 g/6.4 kg soil (pot)	Schonhof et al., 2007
Cabbage	↓ Vitamin C ↓ Glucosinolate	↑ ↑	0,100,200,300, 400, or 500 kg/ha (field) 125 or 250 kg/ha (field)	Freyman et al., 1991 Rosen et al., 2005
Cauliflower	↓ Vitamin C	↔	80 or 120 kg/ha (field)	Lisiewska and Kmiecik, 1996
Celery	↓ Vitamin C ↔ β-Carotene	↑	30, 60, or 90 kg/ha (field)	Evers et al., 1997
Kale	↔ Lutein ↔ β-Carotene	↑	6, 13, 26, 52, or 105 mg/L (greenhouse)	Kopsell et al., 2007
Leek	↔ Vitamin C	↑	0, 50, 100, or 200 kg/ha (field)	Karic et al., 2005
Lettuce	↓ Vitamin C	↑	50, 100, 150, or 200 kg/ha (field)	Sorensen et al., 1994
Onion	↔ Quercetin	↔	112 or 192 kg/ha (field)	Mogren et al., 2006
Potato	↑ Vitamin B ↓ Vitamin C	NA NA	336 or 672 kg/N (field) 45, 134, or 224 kg/N (field)	Augustin, 1975 Augustin, 1975
Tomato	↓ Vitamin C ↓ Vitamin C	↑ NA	0, 150, 300, or 600 kg/ha (pot) 0, 78, 157, 235, 314, or 392 kg/ha (field)	Montagu and Goh, 1990 Simonne et al., 2007

Organic vs Conventional Growing Systems

Organic Production and Demand on rise

Organic Fruits & Vegetables dominate organic sectors with sales of $14.4 billion; **up by 10.5 %** (OTA survey, 2016)



Reganold and Wachter; Nature Plants, 2016

Organic Spinach Research at Uvalde AgriLife Research

Project : Improving Spinach Productivity by Developing Cultivars Adapted for Conventional and Organic production in Texas

Objectives:

1. Improved nitrogen use efficiency as the first step toward developing cultivars adapted to organic production in Texas.
2. Develop molecular tools for marker assisted selection by mapping the genes associated with enhanced nitrogen uptake and utilization

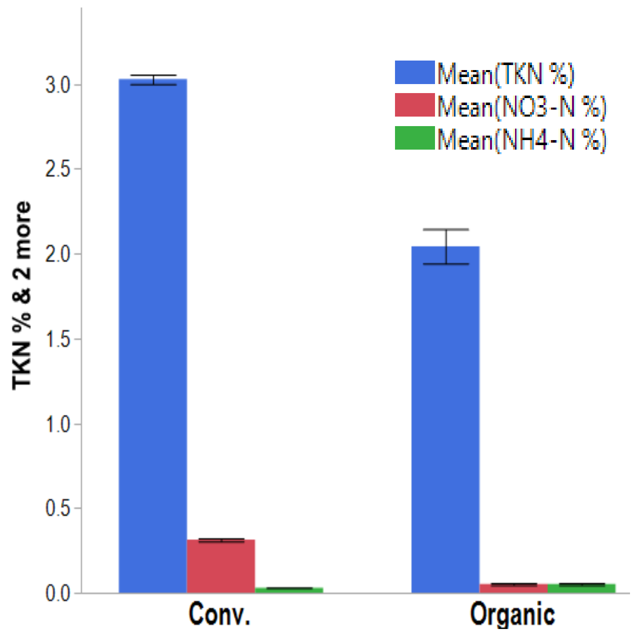
Approach:

- A panel of 355 spinach world accessions representing total genus diversity (44% Europe, 16% Americas, 39% Asia) from the USDA-GRIN

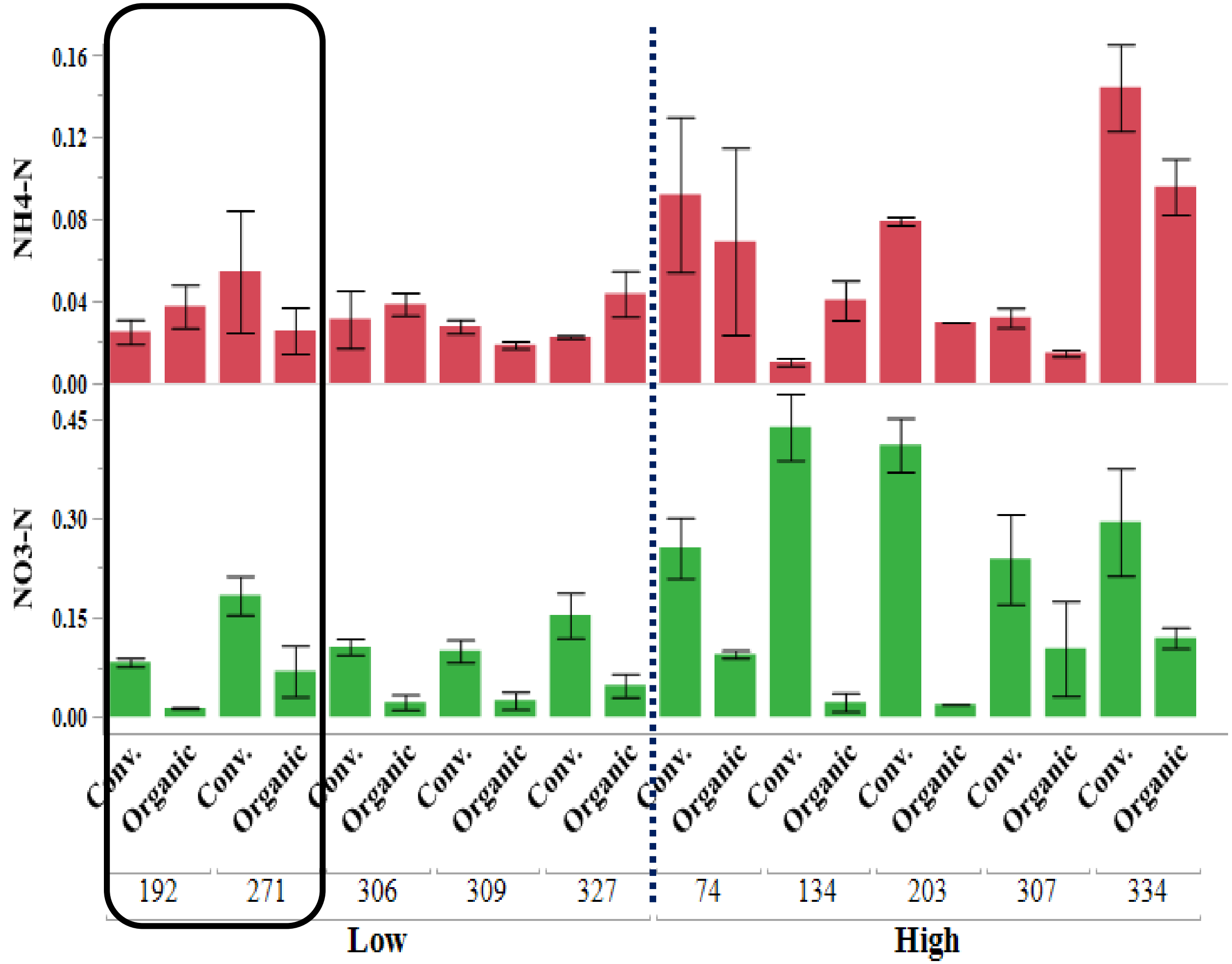
- Germplasm is being evaluated for biochemical traits associated with the Nitrogen Use Efficiency like free NO3 and NH4, amino acids, mineral contents (Fe, Mn, Cu, Ca) and proteins

Joshi Lab

Conventional spinach had 4-5 times higher nitrates than organics



Low Oxalate High Oxalate



NO_3 accumulation correlated with oxalate levels in selected accessions

Joshi Lab

Tomato Grafting: High Tunnel vs Open Field

Grafting and High Tunnel: Effects on Yield and Quality

Season: Spring (February - July 2017 and 2018)

2017

Graft treatments (G) n=6

Rootstock	Scion: Tycoon	Scion: TAM Hot
Estamino	TY/ES	TAM/ES
Multifort	TY/MU	TAM/MU
	TY	TAM

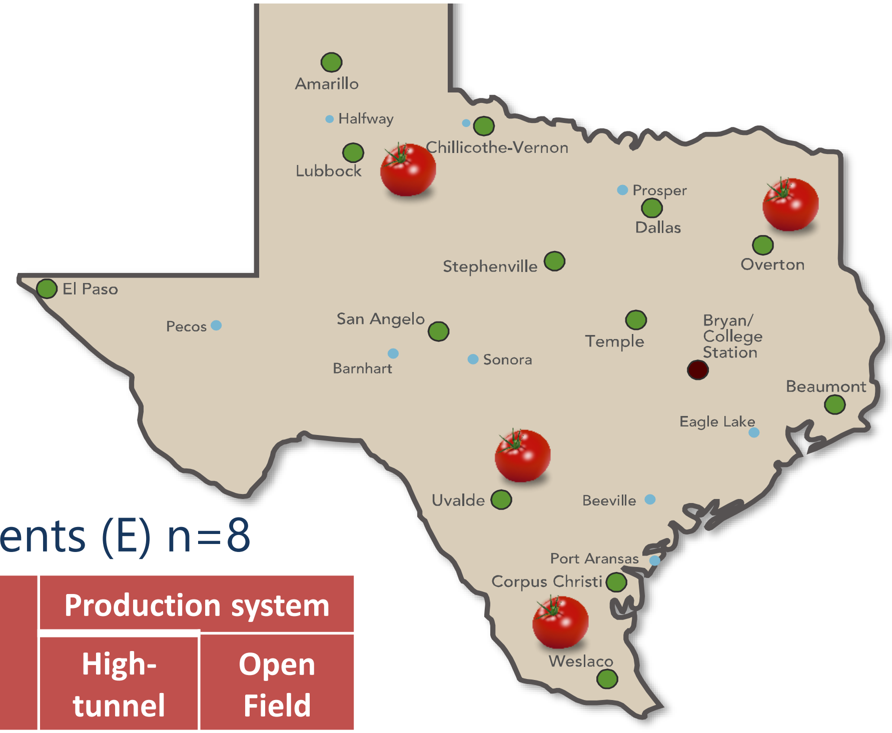
2018

Graft treatments (G) n=6

Rootstock	Scion: HM1823	Scion: TAM Hot
Estamino	HM/ES	TAM/ES
Multifort	HM/MU	TAM/MU
	HM	TAM

Environments (E) n=8

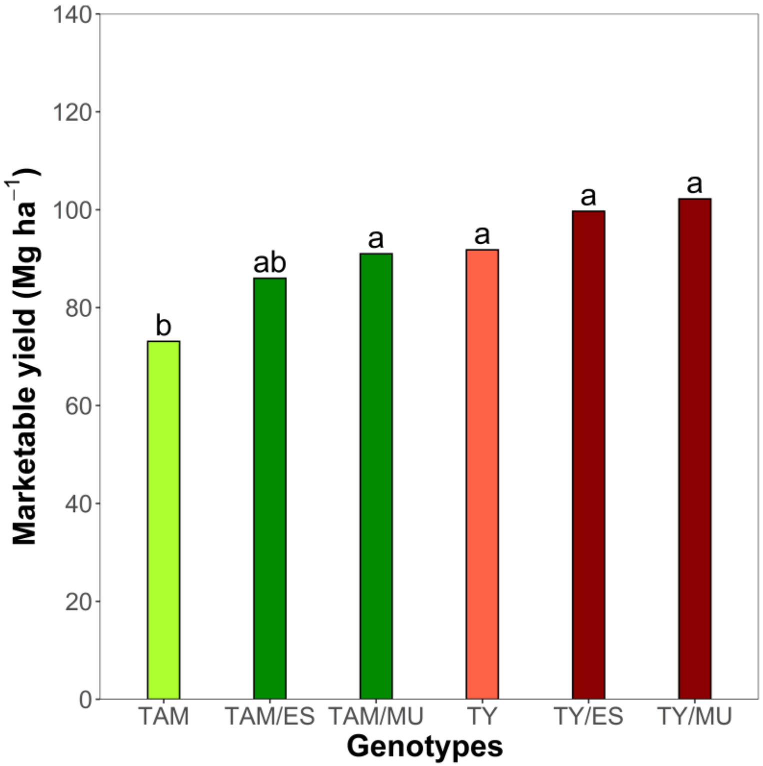
Locations	Production system: High-tunnel	Production system: Open Field
Lubbock	LU-HT	LU-OF
Overton	OV-HT	OV-OF
Uvalde	UV-HT	UV-OF
Weslaco	WE-HT	WE-OF

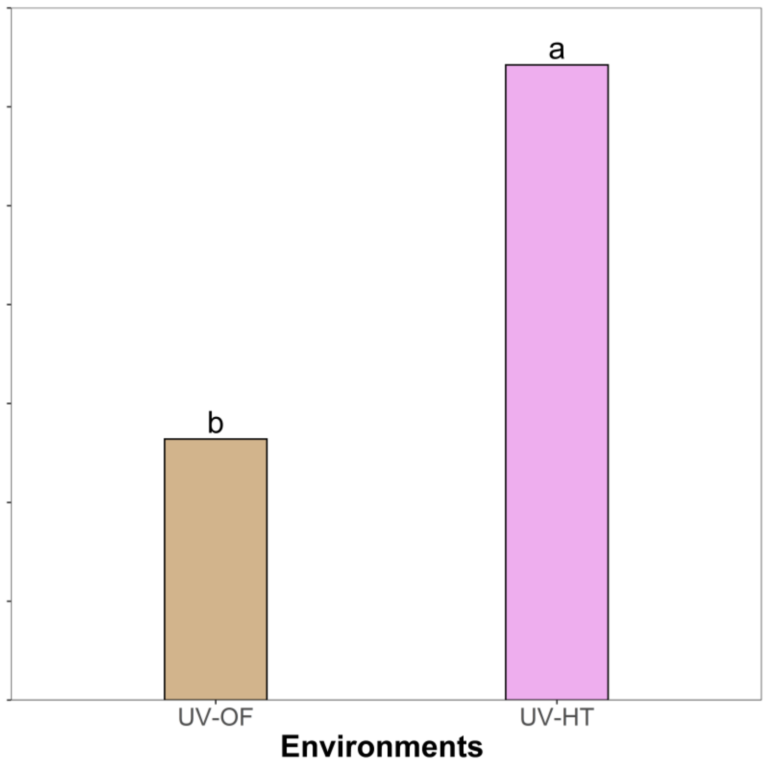


Yield: Response to Genotypes and Environments

Marketable yield in grafted plants increased by 21% in TAM and 10 % in TY

Marketable yield in HT was 143% higher than those in OF



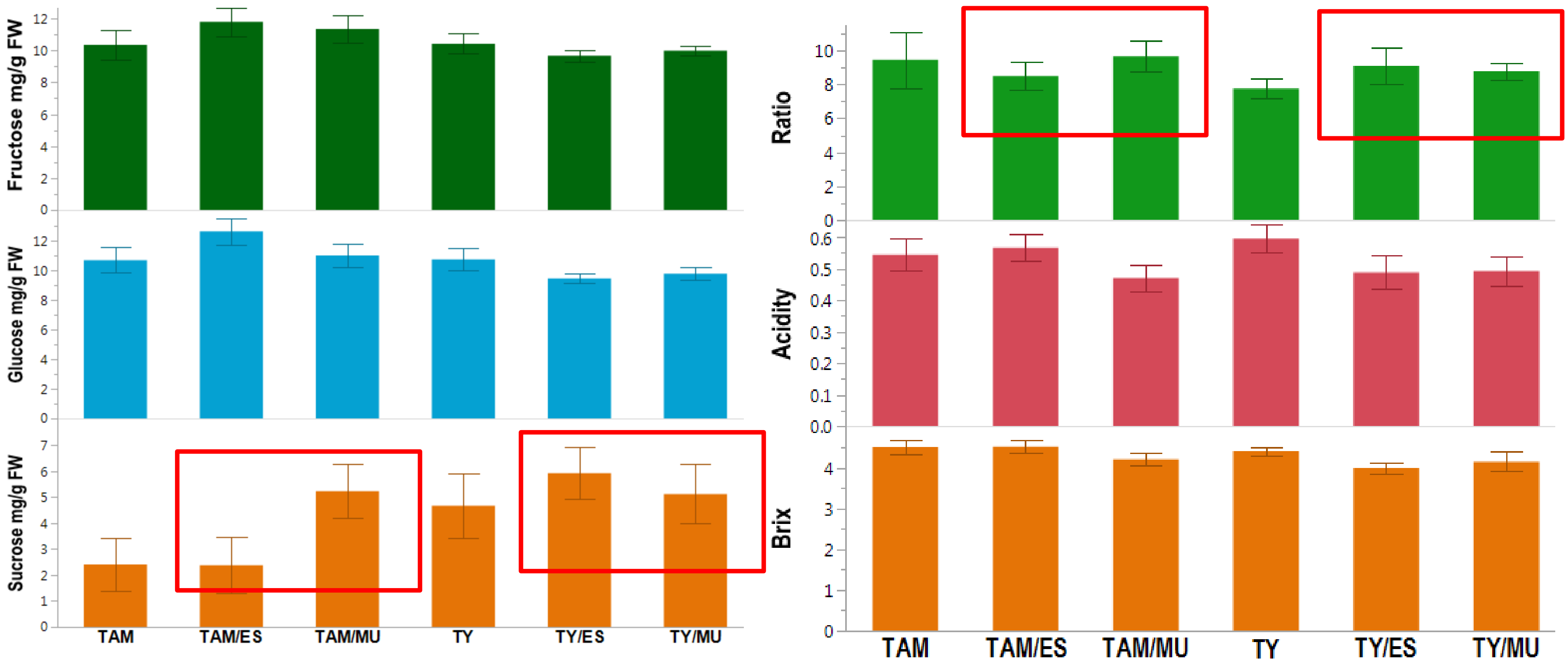


TEXAS AGRILIFE RESEARCH

Uvalde-2017

Grafting: maintained sugar composition and Brix /acidity ratio

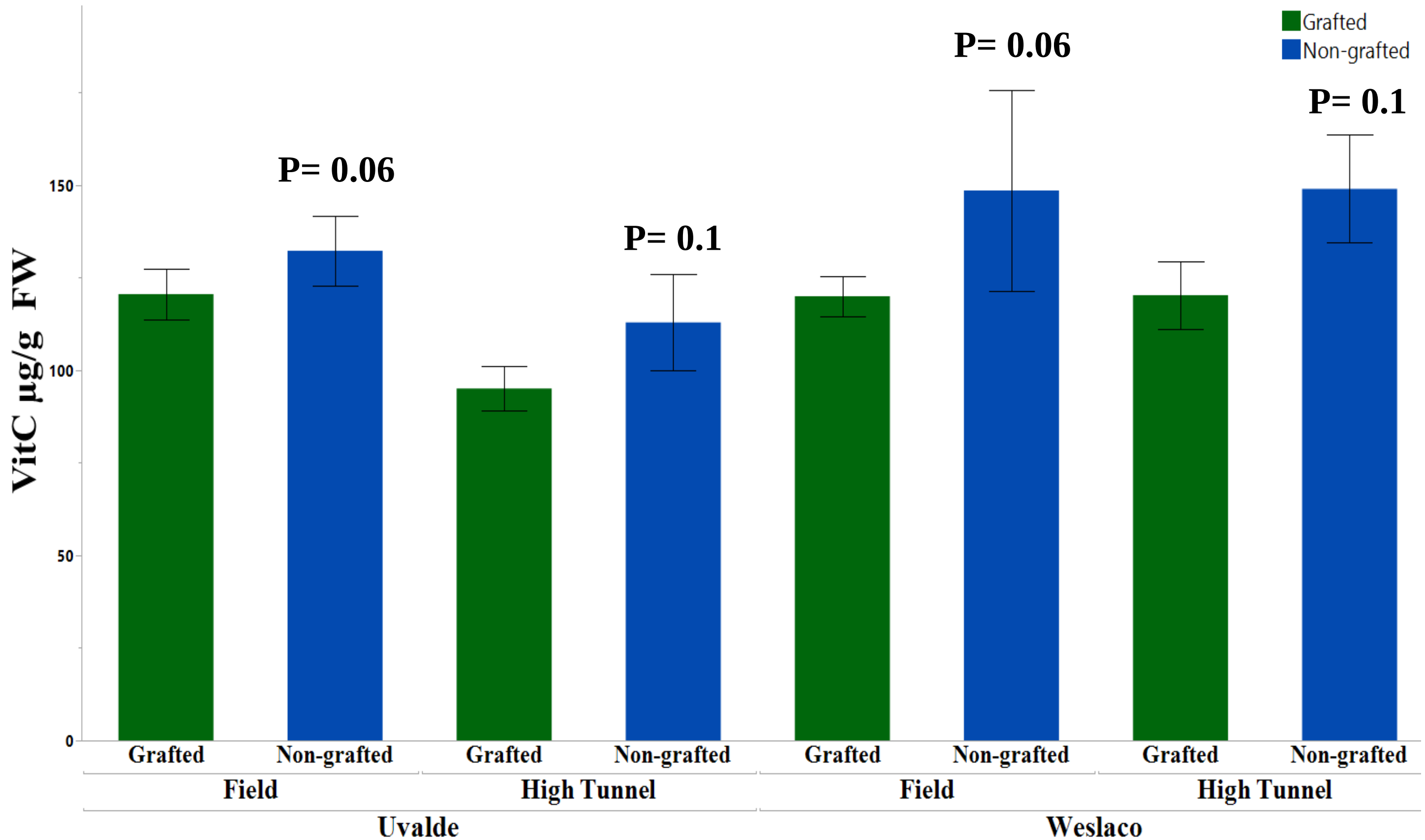
Uvalde-2017



Joshi, Leskovar, Djidonou, Jifon, Masabni, Avila, Crosby (to be submitted)

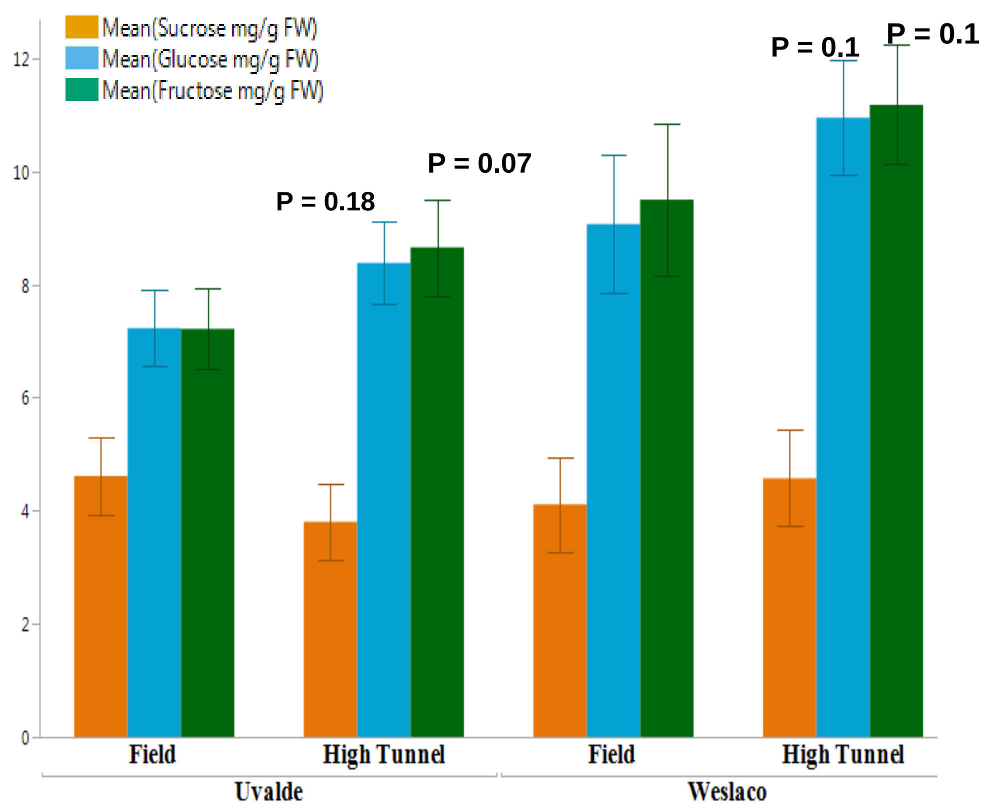
Grafting: showed a decreasing trend in Vit C production

Uvalde, Weslaco -2017

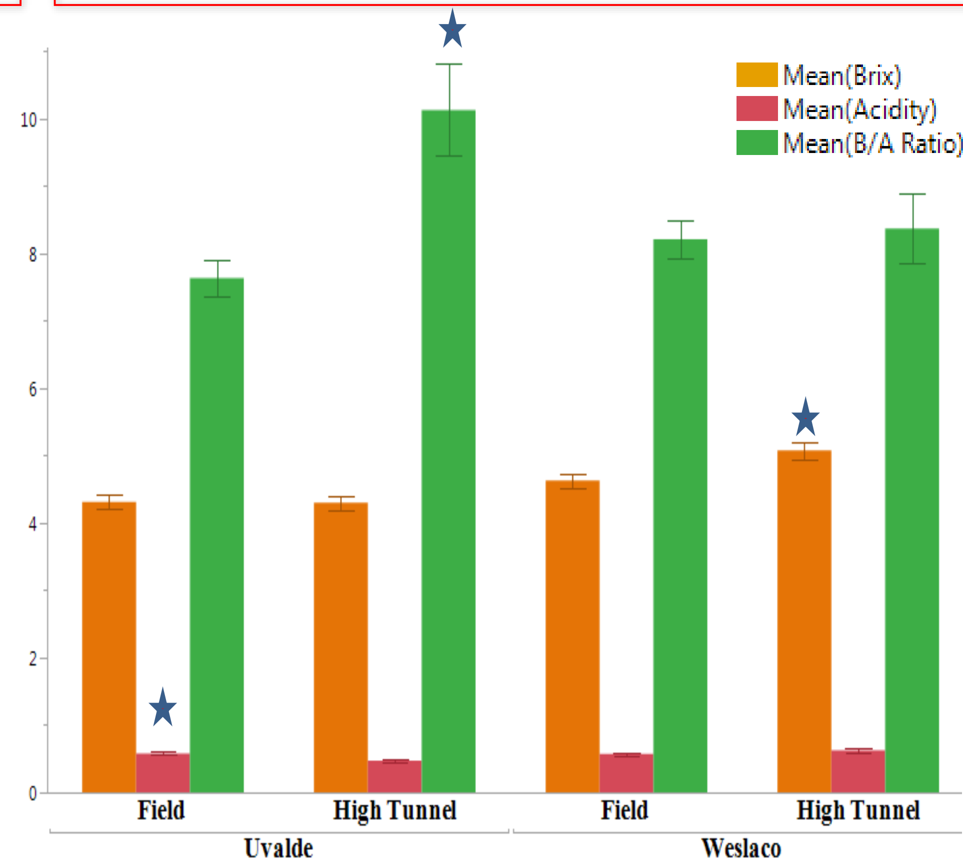


Environment: HT positively impacted fruit quality (2017)

Sugar accumulation in HT showed positive trends

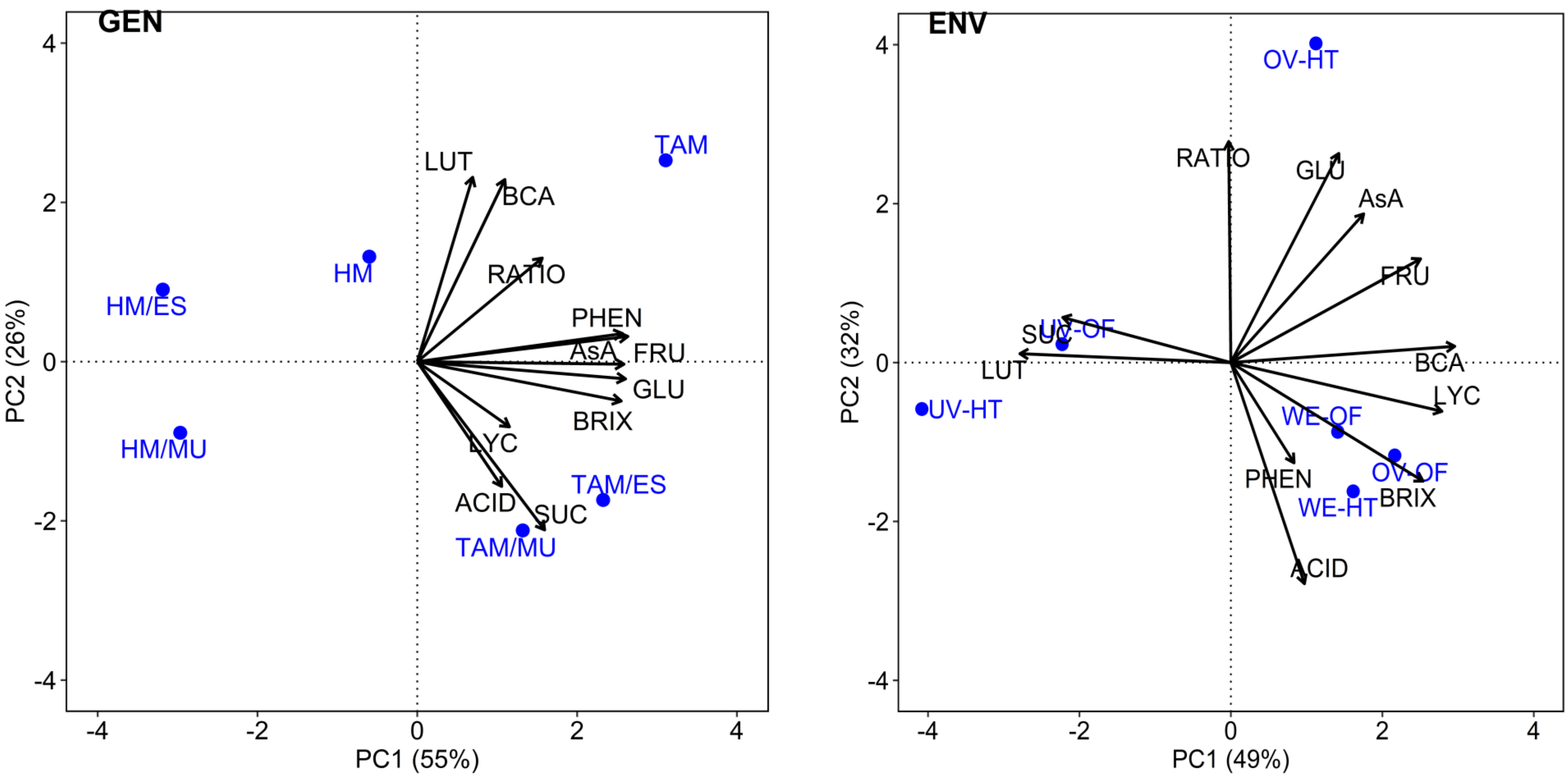


B/A accumulation in HT showed positive trends



There was a negative correlation between Yield and Quality traits for HM

2018



Djidonou, Leskovar, Joshi, Jifon, Masabni, Avila, Wallace, Crosby (to be submitted)

Summary

- Plants have evolved to produce phytonutrients as a survival mechanism.

- Improved **genetics** and **cultural strategies** applied on selected **environments** have major influence on yield and quality traits (phytonutrients, sugars, size) of fruits and vegetables.

Summary

- Deficit Irrigation can be easily applied through drip systems (low volume and high frequency of applications) ensuring optimal water and nutrient uptake and product quality.

- High N rates tend to decrease vitamin C with an increase in yield. High N rates are associated with luxuriant canopy growth that may reduce light interception through shading effects.

- Moderate salinity and soil type (clay) can enhance phytochemicals and increase fruit color, flavor and sweetness.

Summary

- Higher crop yields tend to NOT correlate with quality and nutritional traits.

- **Targeting yield and quality traits through selective varieties and designed management strategies is highly possible .**

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