Enhancing Nutritional Value of Fresh Tomato under Controlled Environments

A Summary of Collaborative Research Effort

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BIO5 The University of Arizona Institute for Collaborative Bioresearch

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CEAC Controlled Environment Agriculture Center

Research background:

Increase in competition among greenhouse tomato producers

- Increasing market of greenhouse grown tomato (~40% tomatoes in US retail stores)
- Increasing amounts of greenhouse tomatoes are imported from Mexico.
- **GH growers seek for high value cultivars.**

Fruits & Veggies "More Matters"

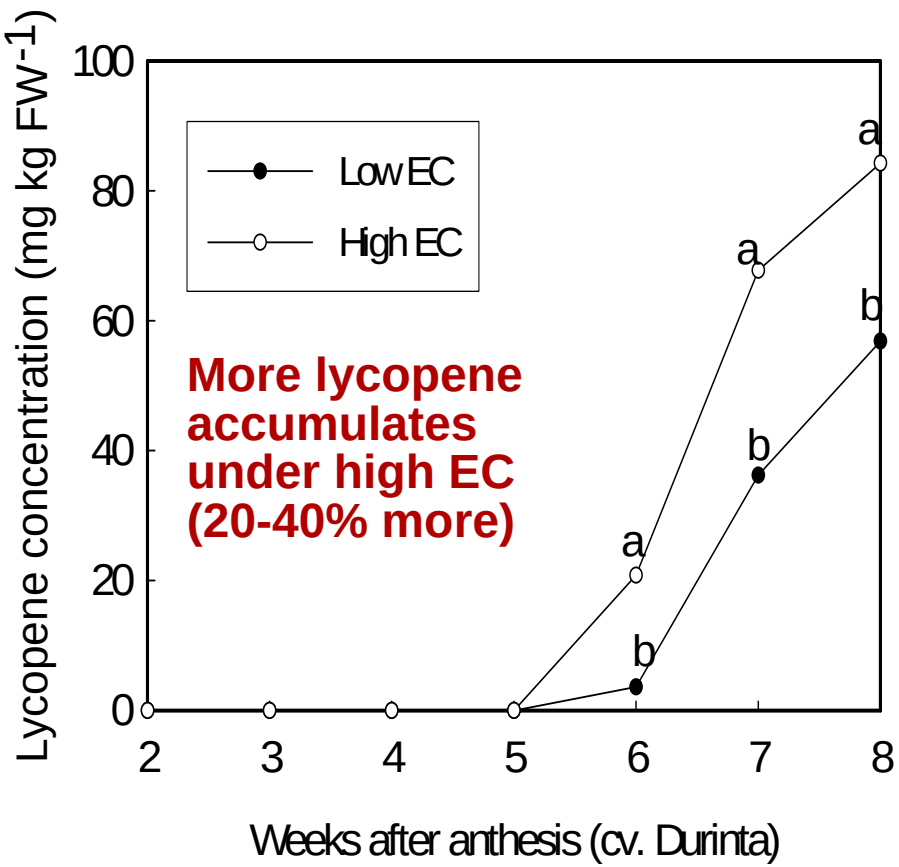
- Funded since 1991 as "5-A-Day for Better Health Program"
- Underlying idea: *Diets high in fruits and vegetables can reduce disease incidence*.
- **Does "Quality Matter"?**

Lycopene:
an antioxidant in tomato

- Lycopene is one of the most efficient singlet oxygen quenchers in the human diet.
- **Lycopene conc. in fruit varies with cultivation practice, environmental conditions, and genotypes** (15 - 90 mg/kg FW; our local survey).

Environmental factors for lycopene concentration in tomato

- Air temperature
- Light intensity
- Light quality
- Fertilization
- **Salt (EC) and water stress**



(Wu and Kubota, 2008)

Consumption study of tomato grown under high and low EC

- Research objectives
  - To establish method for **enhancing lycopene** under moderate salt stress (**high EC**) and quantify the **seasonal change** of lycopene and other antioxidants in tomato fruit.
  - To determine the effect of standard or high lycopene tomato consumption on **plasma lycopene response** as well as **oxidative stress reduction** among healthy adults.

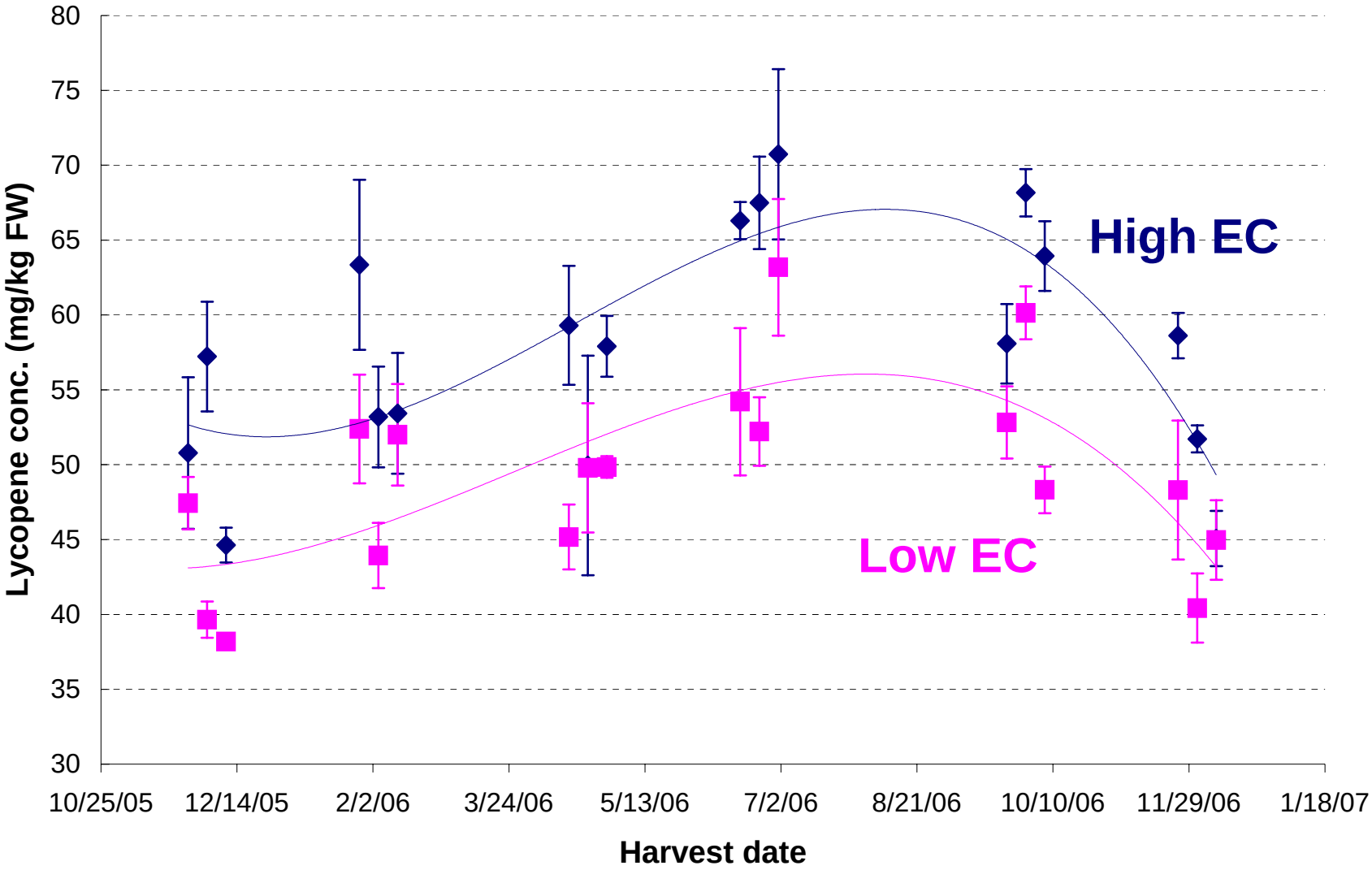
Cultural conditions

- ‘Durinta’ cluster-type tomato
- Total of 4 crops (20 months) over 2 years
- Double PE greenhouse with heating and evaporative cooling.
- Standard high-wire rockwool hydroponics
- 100 mL per irrigation (18-27 times of irrigation a day).
- Efflux EC (from the rockwool slabs) was maintained at:
  - 2.8±0.5 dS m^{-1} for Low EC
  - 7.5±0.5 dS m^{-1} for High EC (with NaCl)

Harvest and Storage Methods

- Weekly harvest; red or greater ripeness stage
- Sorted according to visual color and size
- Fruit quality analysis
  - Lycopene and Brix (weekly during intervention)
  - Vitamin C, phenolics, and carotenoid profile (twice per intervention cohort)
- 14 fruits (100 – 130 g per fruit) were delivered to each study participants after 48 hour storage at 12^{o}C
- Fruits were kept refrigerated during the week while consumed by the participants (2 fruits per day).

Lycopene concentrations of tomato fruit produced during the experiment (Crop #2-#4)



Summary of Greenhouse Environmental Conditions (Nov. 26, 2005 – Dec. 9, 2006)

Season	Daytime Air Temp (°C)	Daytime RH (%)	Daily PPF (mol/m²/d)
Spring/Summer*	23.8±2.7	66±6	26.9±3.1
Fall/Winter**	20.5±1.1	65±6	18.3±3.7
All seasons	22.0±2.6	65±6	22.0±5.5

* March 21 – September 20
** September 21 – March 20

Lycopene concentration was positively correlated with daytime air temperature and daily PPF.

(Kroggel et al. 2007)

Lycopene concentration, total soluble solids (TSS) and yield of harvested tomato fruit as affected by season and EC. (Crop #2-#4)

Season	Lycopene (mg/kg FW)		TSS (%Brix)		Yield (kg/m^2/wk)
	Low EC	High EC	Low EC	High EC	All
Spring/ Summer	49.5a	58.5a	4.3a	5.1a	1.71a
Fall/ Winter	47.2b	55.2b	4.0b	4.7b	1.06b

* March 21 – September 20, n = 37
** September 21 – March 20, n = 42

Means in the same column followed by the same letter are not significantly different at $p<0.05$.

(Kroggel et al., 2007)

Summary of tomato quality attributes under low vs. high EC (All crops #1-#4)

	Standard Low EC	High EC
Fruit size (g/fruit)[Z]	**108**	**102[NS]**
Dry matter %	**5.5[b]**	**6.6[a]**
Brix (TSS%)[Z]	**4.1[b]**	**4.9[a]** **(+20%)**
Lycopene (mg/kg FW)[Z]	**52[b]**	**63[a]** **(+21%)**
Beta carotene (mg/kg FW)[Y]	**5.9[b]**	**7.1[a]** **(+20%)**
Vitamin C (mg/kg FW)[Y]	**147[b]**	**218[a]** **(+48%)**
Total phenolics (mg/kg FW)[Y]	**330[b]**	**387[a]** **(+17%)**

[Z] Measured for fresh samples

[Y] Measured for freeze-dried samples and converted to a fresh weight basis

[NS, a, b] Non significant or significant difference at $p<0.05$.

Tomato Feeding Study 2005-2007: Randomized cross-over design (4 cohorts of 10 participants)

Screening volunteers N =40 (10 X 4 cohorts)

↓

No lycopene consumption (6 weeks)

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Consumption of high or low lycopene tomatoes (3 weeks; 2 tomatoes a day)

↓

No lycopene consumption (6 weeks)

↓

Consumption of low or high lycopene tomatoes (3 weeks; 2 tomatoes a day)

(Thomson et al., 2008)

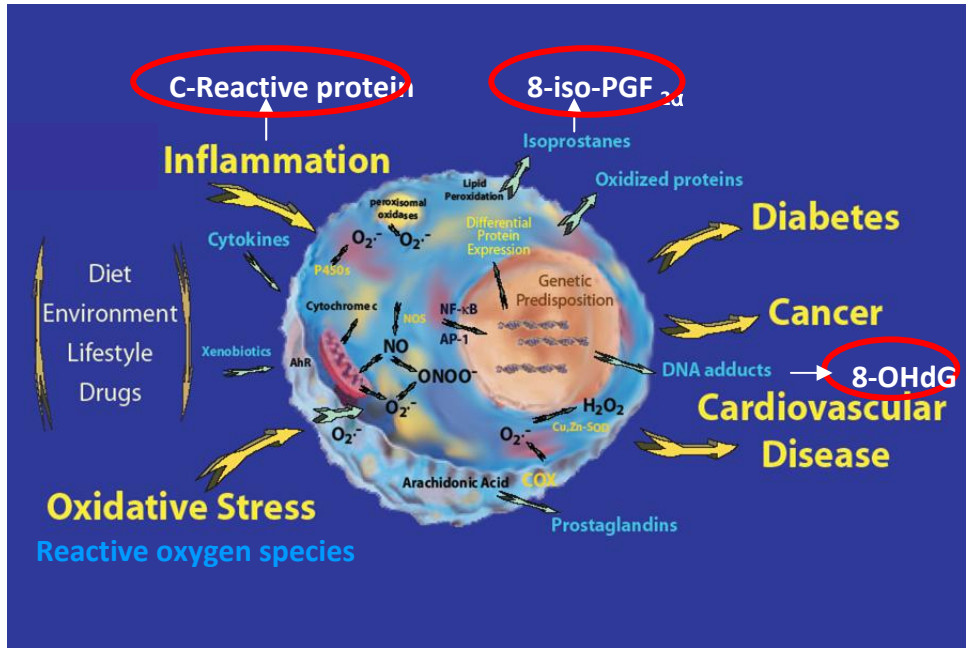
Study Population

- Healthy men and postmenopausal women
- Age : 45-65 years
- Body mass index (BMI) < 30 kg/m^2
- Good health:
  - no history of diabetes, cardiovascular, inflammatory, renal or hepatic disease, or cancer
  - No anti-inflammatory medicine
- Willing to:
  - Eat 2 fresh tomatoes a day (with 2 tbs. fat)
  - Follow a low-lycopene diet

(Thomson et al., 2008)

Study Biomarkers

- Isoprostane **8-iso-PGF$_{2\alpha}$** [the most reliable marker of **lipid peroxidation** and a standard marker of **oxidative stress**]
- **8-OHdG** (8-hydroxy-deoxyguanosine) [the most common marker of **DNA damage**]
- **C-reactive protein** [the most reliable marker of **systemic inflammation**]



(Thomson et al., 2008)

Change in Plasma Carotenoid Levels of Study Participants during Consumption of Tomato Grown under High and Low EC (μg/mL)

	High EC Tomato				Low EC Tomato				
	Pre Level	Post Level	Δ	*P*[a]	Pre Level	Post Level	Δ	*P*[a]	*High vs.Low* *P*[b]
Lycopene	0.13	0.32	0.19	0.0001	0.13	0.28	0.15	0.0001	0.05
trans-Lycopene	0.06	0.20	0.13	0.0001	0.06	0.17	0.10	0.0001	0.07
cis-Lycopene	0.07	0.13	0.06	0.0001	0.07	0.11	0.04	0.0001	0.03
α-Carotene	0.07	0.06	-0.01	0.42	0.07	0.07	-0.00	0.92	0.53
β-Carotene	0.24	0.31	0.07	0.01	0.22	0.31	0.18	0.01	0.02
Total Carotenoids	0.44	0.70	0.26	0.0001	0.42	0.65	0.23	0.0001	0.60

[a] for change from pre- to post-intervention within tomato conditions

[b] for difference in change between tomato conditions (Thomson et al., 2008)

Age and BMI Adjusted Levels of Urine Oxidative Damage Biomarkers and Blood Plasma CRP of Study Participants during Consumption of Tomato Grown under High and Low EC (ng/mg)

	HEC Tomato				LEC Tomato				
	Pre Level	**Post Level**	**Δ**	***P*[a]**	**Pre Level**	**Post Level**	**Δ**	***P*[a]**	***High vs.Low P*[b]**
8-Iso-PGF2α/ Creatinine	4.89	5.13	0.24	0.8	5.35	4.86	-0.49	0.7	0.5
8-OHdg/ Creatinine	19.69	19.33	-0.35	0.5	19.73	18.77	-0.95	0.5	0.9
CRP (mg/dL)	3.29	3.60	0.31	0.5	4.33	4.86	0.53	0.7	0.8

n=37 for CRP

[a] for change from pre- to post-intervention within tomato conditions

[b] for difference in biomarker change between tomato conditions

(Thomson et al., 2008)

Conclusion

- Tomato grown under high EC had greater antioxidants (lycopene, β-carotene, phenolics and vitamin C).
- Both EC and seasonal change in greenhouse microclimate largely affected the lycopene concentration.
- Daily intake of two fresh tomatoes resulted in significant increases in plasma lycopene.
- **The rise in lycopene was greater with the high lycopene tomato. "Quality Matters!"**
- The rise in antioxidants was not associated with a significant change/reduction in biomarkers of oxidative stress or inflammation. (*exposure, healthy adults*)

Challenges/Limitations
Future Research Opportunities

- Lycopene concentration was largely affected by change in both root-zone and aerial environments.
  - *Strategic use of acute stress to boost lycopene?*
- Small difference in ripeness stage created a large difference in lycopene concentration (difficult to detect in human eyes).
  - *-Sensor development opportunity?*
- Biomarkers of already healthy population did not respond positively to consumption of two tomatoes a day.
  - *-Dose response using unhealthy "at risk" population?*

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