Nutrient Dense Foods: Phytochemicals and Health Benefits

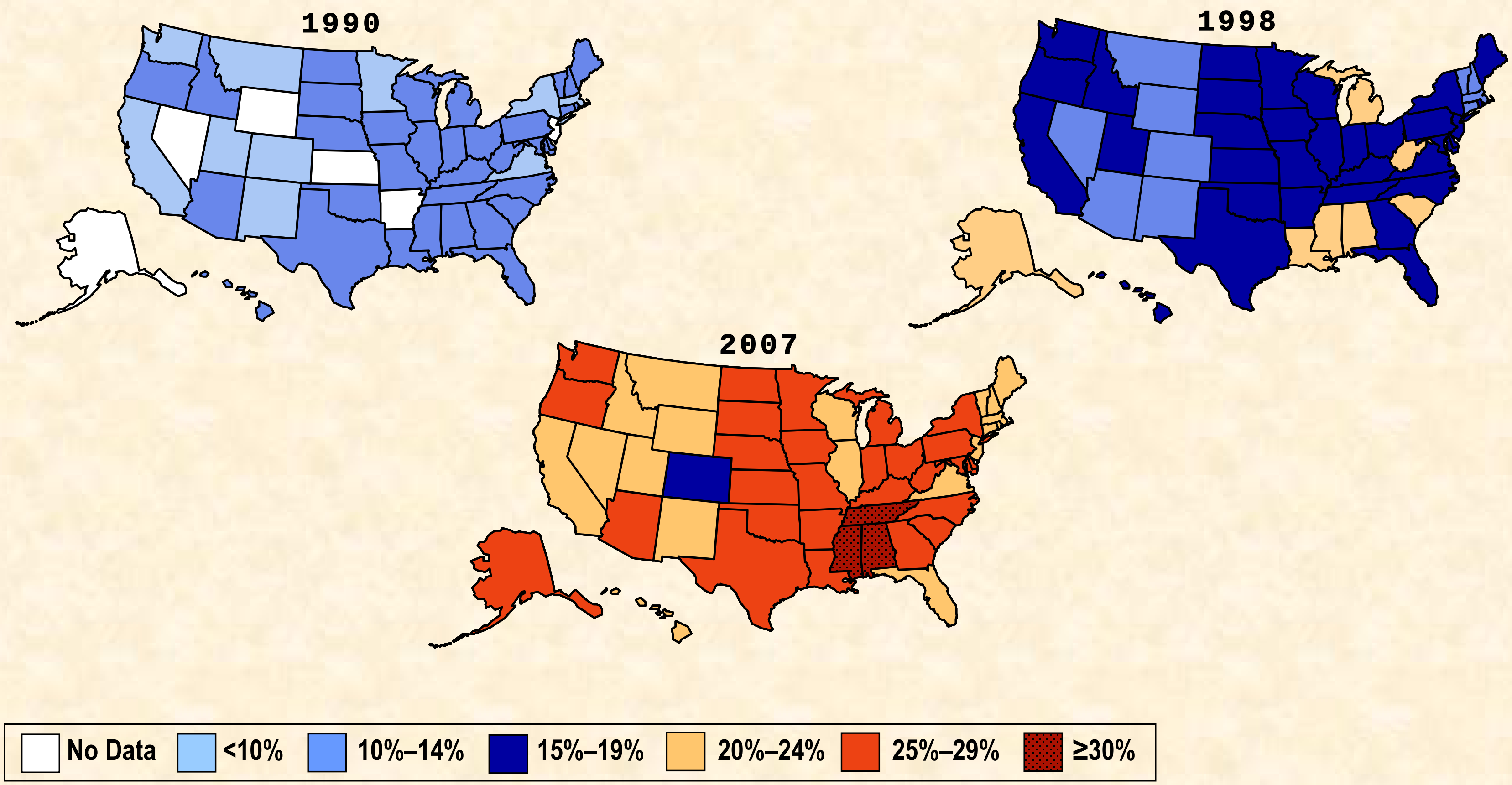
Living Soil, Food Quality, and the Future of Food
AAAS Annual Meeting, February 12, 2009

Alyson Mitchell, PhD
University of California Davis
530-752-7926
http://mitchell.ucdavis.edu

Fruit and Vegetables (F&V) in the American Diet

- Epidemiological studies indicate people who consume diets rich in F&V have a reduced risk of chronic diseases
  - stroke, type II diabetes, some cancers and potentially heart disease
- Accordingly, AHA, AICR, NIH, CDC and USDA began promoting F&V consumption more than a decade ago
  - Today USDA guidelines call for 4 fruit and 5 vegetable servings daily (USDA 2005 dietary guidelines for adults eating 2000 calorie per day)
  - Americans eat ~1.4 fruit and ~3.7 vegetable servings
- Most American's are consuming sub-optimal levels of F&V to benefit fully from the health-promoting effects of these compounds

The Obesity Epidemic



Increase the nutritional density of fruits and vegetables

BRFSS, Behavioral Risk Factor Surveillance System; http: //www.cdc.gov/brfss/

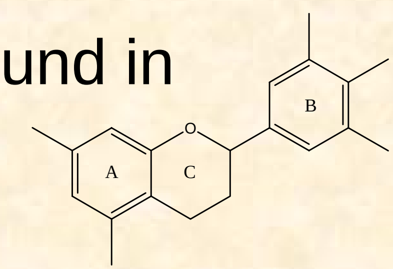
Why Focus on Fruit & Vegetables?

- Primary dietary source of vitamins, minerals, fiber and a wide array of *non-essential nutrient phytochemicals*
  - polyphenolic antioxidants (e.g. flavonoids), carotenoids (e.g. lycopenes, carotenes), isothiocyanates, etc.

- The health benefits associates with F&V are largely thought to be due to the consumption and synergistic activities of these bioactive phytochemicals

- Therefore the nutrient density of bioactives in F&V has the potential to affect susceptibility to chronic disease

- Many of the critical bioactive phytochemicals found in F&V are *Secondary Plant Metabolites* (SPMs)



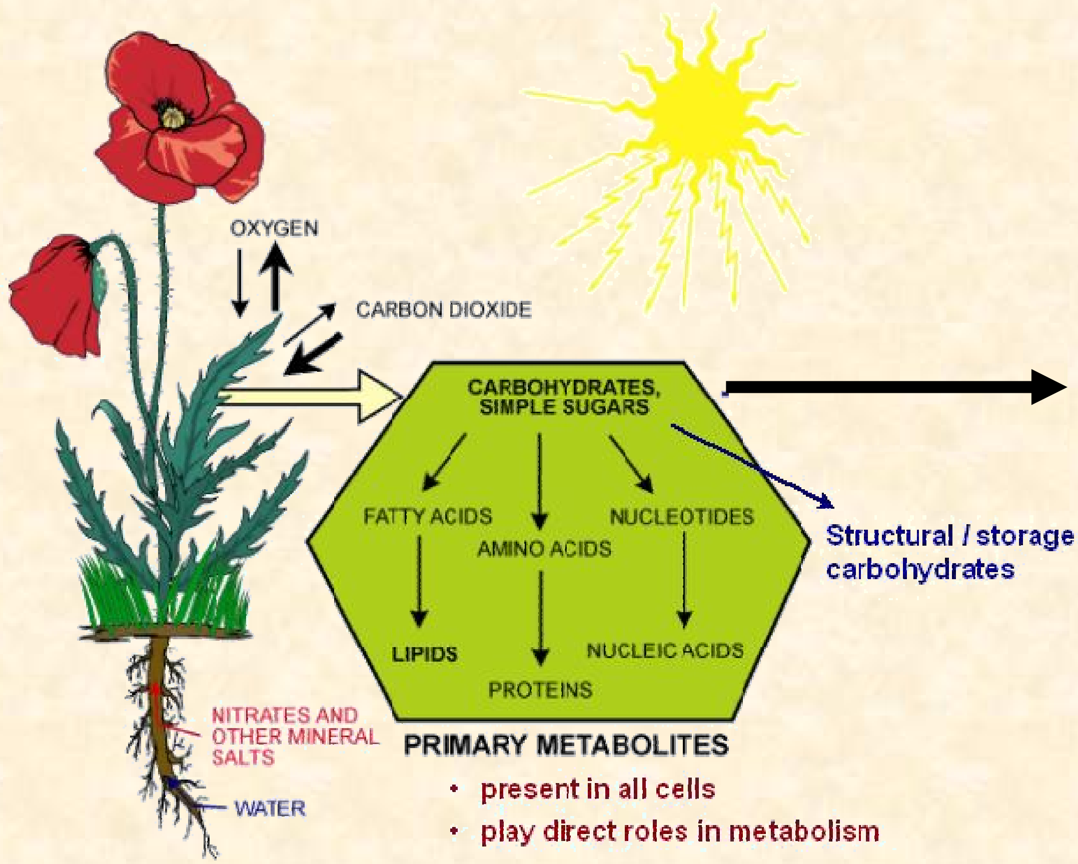
Secondary Plant Metabolites (SPMs)

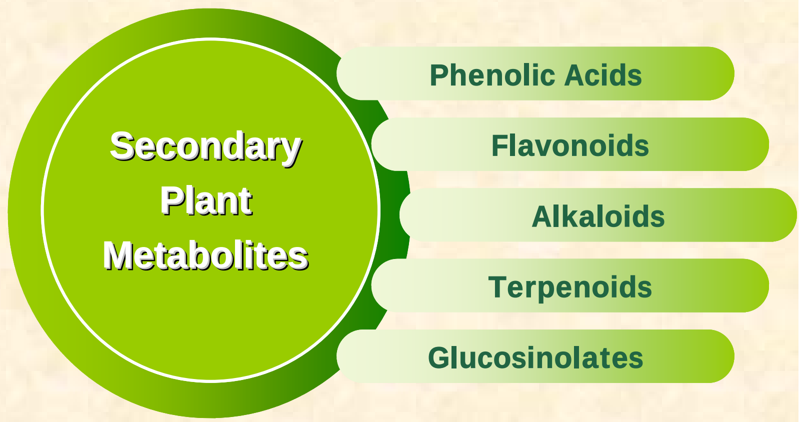
- Bioactives naturally produced by the plant usually for plant defense mechanisms
  - Many are potent antioxidants
- Synthesis is strongly influenced by genetics
  - The species and variety (cultivar) are the most important determinants of SPM expression
- Synthesis is triggered by environmental pressures
  - soil quality, nitrogen availability, geographic location, climate, pest and disease pressures, field history and UV radiation

Influenced by Agronomic Practices

- *Therefore, cultivar selection and farming systems practices have the potential to influence the nutrient density and content of bioactives in F&V*

Primary & Secondary Plant Metabolites

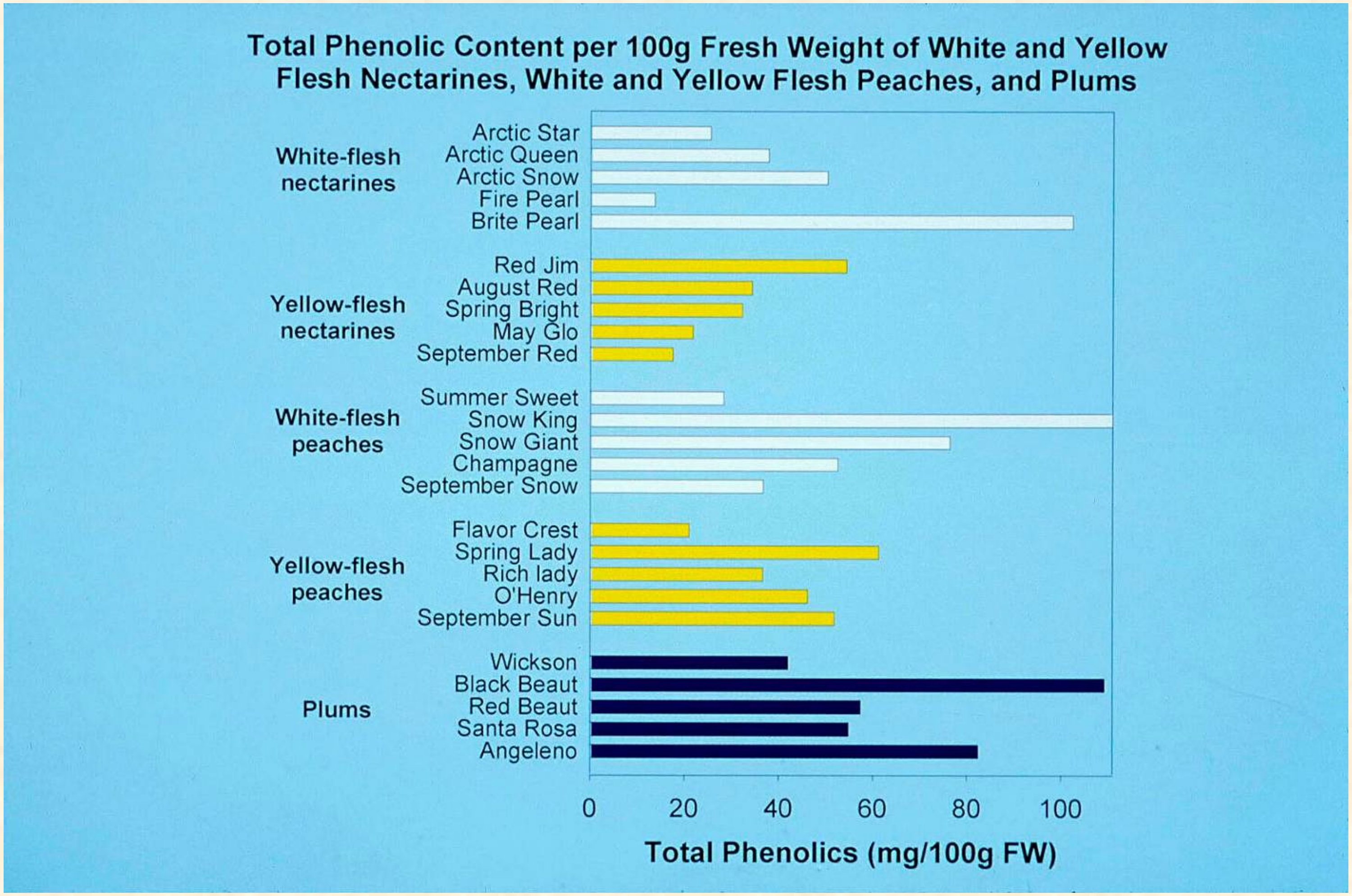




- Species and cultivar specific
- Produced in response to environmental pressure or plant stress

www.ualr.edu/botany/plantfactory.jpg

Cultivar Differences in Phenolic Antioxidants

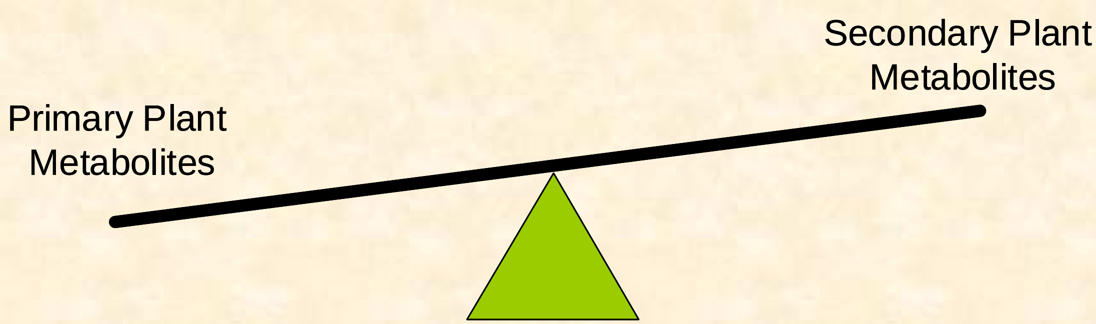


F&V cultivars selection should be based upon nutrient content and flavor as well as yield and disease resistance characteristics

Gil et al. J. Agric. Food Chem. 2002, 50, 4976-4982

The Logical Question?

- Fundamental differences between organic and conventional production systems, particularly in soil fertility management and pest control
  - It is generally agreed that these factors can affect the production of secondary plant metabolites (SPMs)
- *Do organically produced foods contain higher levels of defense-related secondary metabolites (e.g. flavonoids) as compared to conventionally produced foods?*



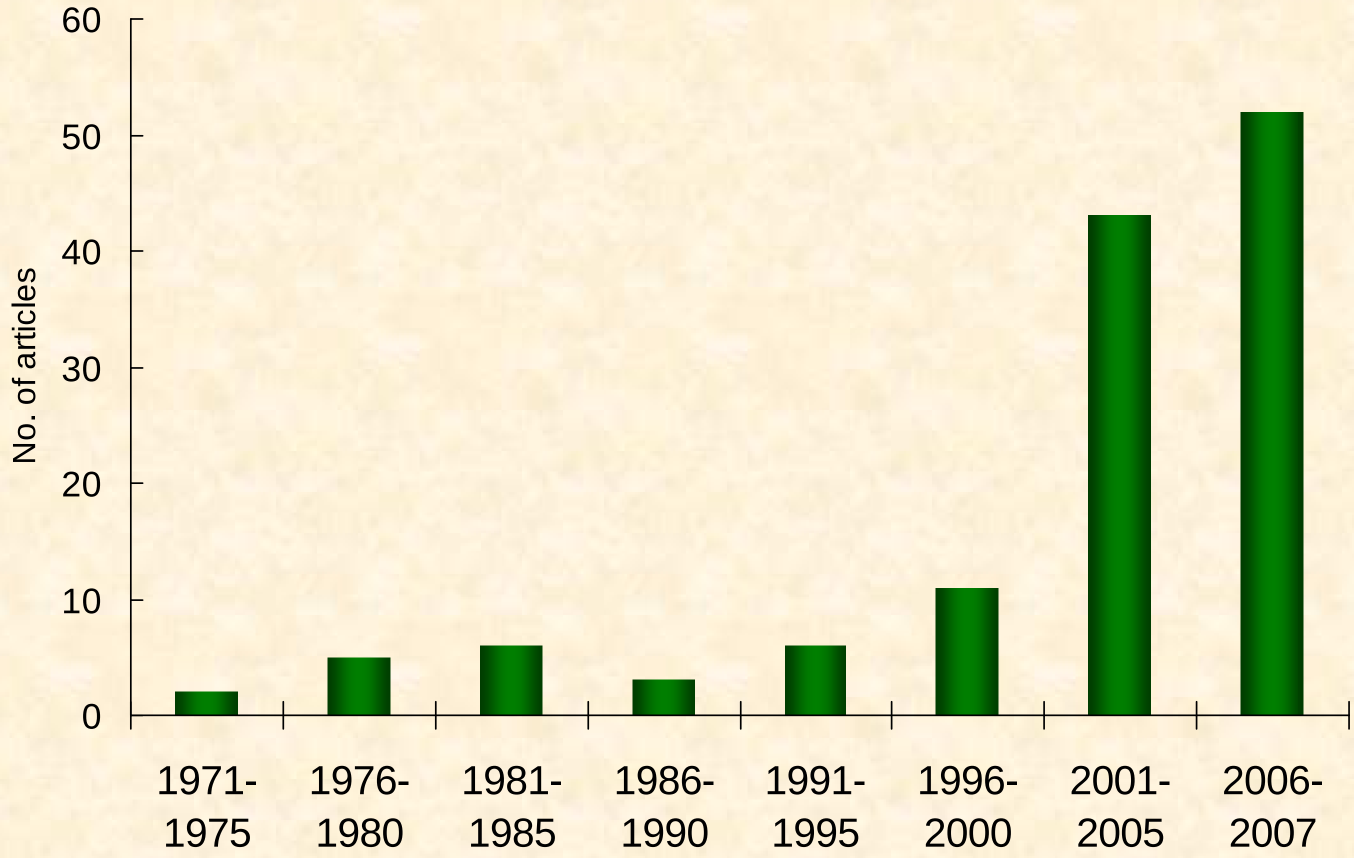
Complex Question to Address

- Comparisons of organic and conventional foods are difficult to interpret for many reasons:
  - Difficulty to selecting farms and fields that represent the cultivation practices
  - Farming systems are dynamic environments with regional variation
    - Difficulty in matching soil, irrigation, climate, insect pressures, etc
  - No definition of “conventional” farming
    - Evolved in response to technological developments in mechanization/tillage, monoculture, synthetic fertilizer, chemical pest and weed control, and breeding
    - Organic is “defined” but conditions vary dependent upon season, crop, region, pest pressures and farm philosophies

The Perception & Research

- Although the public perceives organic foods as being inherently more nutritious there is little scientific consciences to support this perception
- Reviews of the literature (prior to 2003) give mixed results and are difficult to interpret
  - Often cover large periods of time (span > 70 yrs)
  - Farming practices were not defined
    - No information on what constitutes an “organic” food
  - Lack of control in sampling, storage and analytical methods
    - Retail samples with no varietal or post-harvest control
    - Different species of plants compared
    - Different plant parts were compared (e.g. a leaf with a fruit)

Studies Comparing the Nutrient Value of Organic & Conventional Foods (1970-2007)



**Excludes: reviews, articles comparing soil, crop yield, contaminants, pesticides*

Cropping System Comparisons

Organic

- Non-synthetic Pesticides
  - Non-specific, less potent
  - Increases in pest and pathogen pressure
  - Increases in soil bacterial and fungal biomass
- Soil Fertility
  - Organic Nitrogen
  - Compost, cover crops, etc
  - Nitrogen requiring mineralization
- GDBT
  - Equilibrium between primary and secondary plant metabolism

Conventional

- Synthetic Pesticides
  - Specific, potent
  - Decreases in pest and pathogen stress
  - Decreases in soil bacterial and fungal biomass
- Soil Fertility
  - Inorganic Nitrogen
  - Synthetic fertilizers
  - Readily available NH_4+ and NO_3-
- GDBT
  - Emphasis on growth and production of primary plant metabolites

Soil Fertility
Carbon Nitrogen Balance

Nitrogen

Organic System

- Slow release of available nitrogen
- Plants grow more slowly
- Metabolism involves the balanced production of C containing compounds
  - Starch
  - Non N-containing SPMs
  - *flavonoids, vitamin C*

Conventional System

- Nitrogen surge
- Rapid growth
- Plants emphasize synthesis of primary plant metabolites that contain nitrogen
  - growth related compounds
    - *DNA, RNA, protein, alkaloids*

A Decade of Research Evaluating the Nutrient Density of Organic & Conventional Foods

I. Three-year study on fresh market (cv. Burbank) and processing tomatoes (cv. Ropreco) grown at UC Davis

II. Ten-year study of processing tomatoes grown at the Long Term Research on Agricultural Systems at UC Davis

Why Emphasize Tomatoes?

- Tomatoes are the second most consumed vegetable in North America
  - CA produced ~10 million tons of tomatoes annually (2006)
    - 90% US production
    - 30% of global production
- U.S. consumption
  - Fresh tomatoes 18.1 lb per capita (2003)
  - Tomato products 68.6 lb per capita in (2003)
- Tomatoes are a significant nutritional source of:
  - Vitamins C, A and E
  - Carotenoids (lycopene , β-carotene)
  - Flavonoids [quercetin (2000 mg/annual) and kaempferol]

ERS/USDA *http://www.ers.usda.gov/Briefing/Tomatoes/*

I. Three-Year Comparison 2002-2005

- **Fields:** **UC Davis Student Farm**
  - Matched certified organic (2002) and conventional fields
  - The fields were separated by approximately 350 feet (107 meters)
  - Water source and system were the same
  - Plants were grown using a randomized split-block design
  - Planting dates matched (green house and field)
- **Treatments:**
  - Organic plants received fertilization from cover crops and composed cow manure
  - Conventional crops received liquid fertilizer & ammonium sulfate
  - Pyrellin and permithrin were applied to conventional plots

Harvesting & Analyses

- Harvested at Commercial Maturity
  - Washed
  - Sorted by size and color
  - Sliced and vacuum packaged
  - Sub-samples were freeze-dried
  - and stored at –80 C
- The Analyses
  - Flavonoids
    - Quercetin & Kaempferol
  - Percent Soluble Solids
    - Sugars
  - Ascorbic Acid
    - Vitamin C

Tomato Flavonoids

Analysis	Year	Burbank Cultivar: Conventional		Burbank Cultivar: Organic		Burbank Cultivar: % Increase[4]	Ropreco Cultivar: Conventional		Ropreco Cultivar: Organic		Ropreco Cultivar: % Increase[4]
Quercetin	2003	68.7 ± 5.8	b	109.0 ± 27.4	a		37.7 ± 1.3	c	60.7 ± 6.4	bc	
(mg / 100g DWB[2])	2004	21.1 ± 2.8	ab	17.6 ± 4.1	b		22.1 ± 1.4	ab	25.1 ± 2.3	a	
	2005	58.4 ± 14.3		48.5 ± 11.0			47.4 ± 2.3		33.0 ± 2.7		
	Average	*49.4 ± 25.0*	a	*58.4 ± 46.5*	a	18	*35.7 ± 12.8*	b	*39.6 ± 18.7*	b	11
Quercetin	2003	3.43 ± 0.29	bc	6.30 ± 1.58	a		2.18 ± 0.08	c	4.55 ± 0.48	b	
(mg / 100g WWB[3])	2004	1.18 ± 0.15		1.12 ± 0.26			1.15 ± 0.07		1.44 ± 0.13		
	2005	3.32 ± 0.81	a	2.84 ± 0.65	ab		3.20 ± 0.16	a	2.20 ± 0.18	b	
	Average	*2.64 ± 1.27*	b	*3.42 ± 2.64*	a	**29**	*2.18 ± 1.03*	b	*2.73 ± 1.62*	b	25
Kaempferol	2003	18.8 ± 2.3		19.0 ± 5.4			15.4 ± 5.0		17.0 ± 5.7		
(mg / 100g DWB)	2004	27.0 ± 2.1	a	28.0 ± 1.9	a		21.6 ± 0.6	b	21.5 ± 0.4	b	
	2005	28.4 ± 0.7		31.9 ± 0.9			25.0 ± 2.9		28.6 ± 2.5		
	Average	*24.7 ± 5.2*	ab	*26.3 ± 6.6*	a	6	*20.7 ± 4.9*	c	*22.4 ± 5.8*	bc	8
Kaempferol	2003	0.94 ± 0.11		1.10 ± 0.31			0.89 ± 0.29		1.28 ± 0.43		
(mg / 100g WWB)	2004	1.51 ± 0.12	b	1.78 ± 0.12	a		1.12 ± 0.03	c	1.23 ± 0.02	c	
	2005	1.61 ± 0.04	b	1.87 ± 0.05	a		1.69 ± 0.20	ab	1.91 ± 0.17	a	
	Average	*1.35 ± 0.36*	bc	*1.58 ± 0.42*	a	**17**	*1.23 ± 0.41*	c	*1.47 ± 0.38*	ab	**19**

A. Chassy et al J. Agric. Food Chem. 2006, 54, 8244-8252

Soluble Solids & Ascorbic Acid

Analysis	Year	Burbank Cultivar: Conventional		Burbank Cultivar: Organic		Burbank Cultivar: % Increase[4]	Ropreco Cultivar: Conventional		Ropreco Cultivar: Organic		Ropreco Cultivar: % Increase[4]
Soluble Solids	2003	4.0 ± 0.2	b[1]	6.0 ± 0.6	a		4.4 ± 0.3	b	5.7 ± 0.5	a	
(°Brix)	2004	4.8 ± 0.2	bc	5.4 ± 0.2	a		4.5 ± 0.1	c	5.0 ± 0.4	ab	
	2005	5.2 ± 0.3	b	5.1 ± 0.4	b		5.9 ± 0.1	a	5.4 ± 0.3	ab	
	Average	*4.7 ± 0.6*	b	*5.5 ± 0.5*	a	**18**	*4.9 ± 0.8*	b	*5.4 ± 0.4*	a	**9**
Ascorbic acid	2003	13.7 ± 2.0	b	25.7 ± 7.3	a		14.2 ± 1.5	b	23.8 ± 5.6	a	
(mg / 100g WWB)	2004	16.0 ± 0.9	a	16.3 ± 1.2	a		11.2 ± 1.7	b	9.8 ± 1.3	b	
	2005	22.7 ± 1.9		24.2 ± 5.4			23.3 ± 0.8		22.1 ± 2.4		
	Average	*17.5 ± 4.7*	b	*22.1 ± 5.1*	a	**26**	*16.2 ± 6.3*	b	*18.6 ± 7.6*	b	14
Ascorbic acid	2003	275 ± 40		444 ± 126			246 ± 25		296 ± 110		
(mg / 100g DWB)	2004	288 ± 17	a	257 ± 19	ab		215 ± 33	bc	170 ± 22	c	
	2005	400 ± 33		413 ± 91			344 ± 12		330 ± 35		
	Average	*321 ± 69*	ab	*371 ± 100*	a	16	*268 ± 67*	b	*265 ± 84*	b	-1

A. Chassy et al J. Agric. Food Chem. 2006, 54, 8244-8252

II. Long Term Research on Agricultural Systems (LTRAS) Project at UC Davis

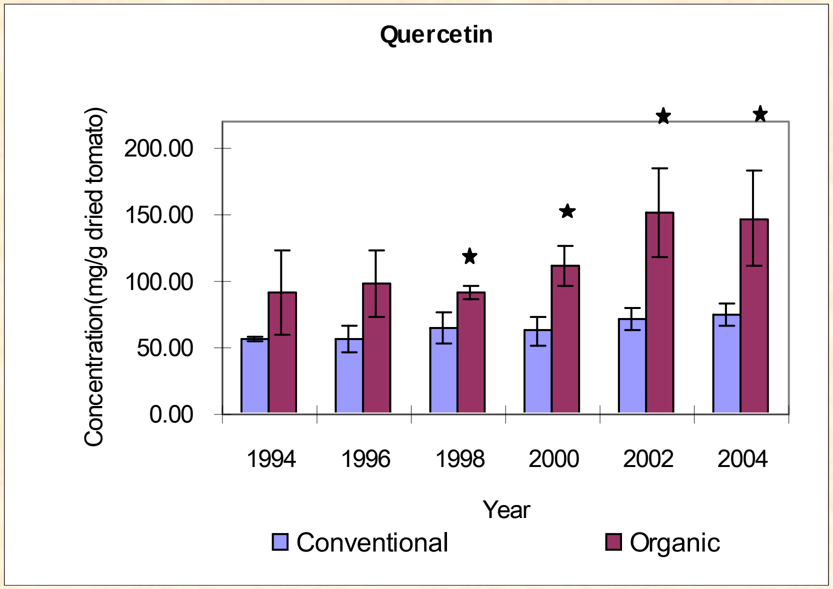
- Developed 1993 to evaluate the sustainability and environmental impact of conventional and alternative agricultural systems
- 10 cropping systems in the main experiment that differ in irrigation and fertilizer (particularly N)
  - Irrigated conventional**:** fertilized corn/tomato rotation
  - Irrigated organic**:** winter legume with compost corn/tomato rotation

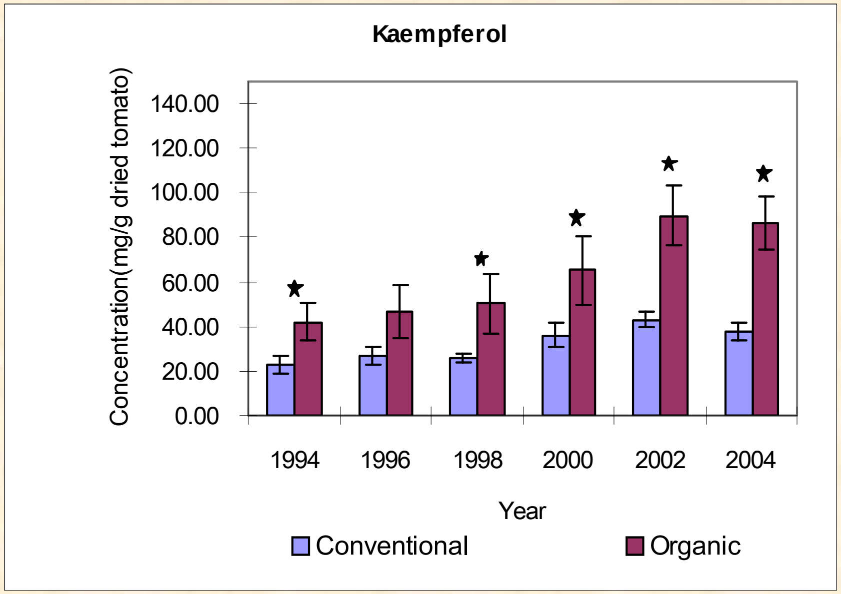
http://ltras.ucdavis.edu

The LTRAS Archive

- LTRAS is a consistently managed system
  - Limits confounding factors inherent in broad types of field studies
    - e.g. mixed field and soil histories, variability in management skill, etc.
- LTRAS tomato samples are randomly collected, air-dried and archived
  - Yield data, soil and plant nitrogen data, pest history, changes in key soil properties, such as organic matter, pH, salinity are monitored

Flavonoid Content in Haley 3155 at LTRAS 1994-2004

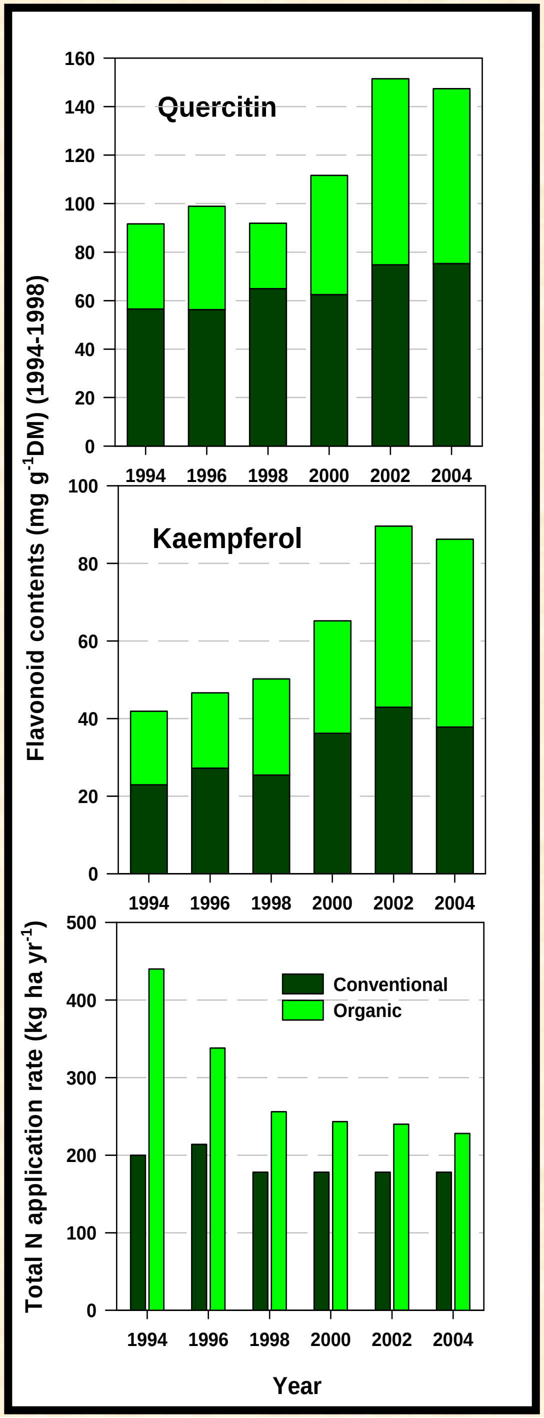




Flavonoid	Means (se) (ug g^{-1} DM)		F	p
	Conventional	**Organic**		
Quercetin	64.6 (2.49)	115.5 (8.0)	108.16	<0.0001
Naringenin	30.2 (1.57)	39.6 (1.58)	66.36	<0.0001
Kampferol	32.06 (1.94)	63.3 (5.21)	96.64	<0.0001

Influence of Nitrogen Application

- 1998: SOM appeared to reach a quantitative limit of accumulation
- At this time compost application rates were reduced from 45 Mg ha^{-1} to 18 Mg ha^{-1}
- It appears that the flavonoid content of tomatoes is related to the availability of soil nitrogen
  - Plants with limited nitrogen accumulate more flavonoids
- In organic systems N is delivered through compost which requires mineralization prior to being taken up by the plant
  - Plants grow slower
  - Equilibrium between the synthesis of primary and secondary plant metabolites



Conclusions

- More than a decade of research investigating nutritional differences between organic and conventionally grown foods indicate that agronomic practices do impact nutrient density of foods
  - Increased levels of flavonoids, vitamin C and soluble solids (sugars) in tomatoes
- The greatest influence appears to be in the relationship between soil nitrogen levels and soil nitrogen availability

Acknowledgements

- Graduate Students & Post Doctoral Scholars
  - Alexander Chassy, MS
  - Eunmi Koh, PhD
  - Katherine Meyers, PhD
  - Jaime Rudolf, PhD
  - Swarna Wimalasiri, PhD
  - Miki Heimori, PhD
  - Emilia Guchu, PhD
- Collaborators
  - Stephen Kaffka, PhD
  - Ford Dennison, PhD
  - Diane Barrett, PhD
  - Linh Bui, PhD
  - Erica Renaud, MS
  - Richard Bernard, PhD
- Funding
  - UC Division of Agriculture and Natural Resources
  - Seeds of Change/Mars Inc.