Nutrient Dense Foods: Phytochemicals and Health Benefits

Living Soil, Food Quality, and the Future of Food
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• 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

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

Influenced by Agronomic Practices
Primary & Secondary Plant Metabolites

- **Primary Metabolites**
  - Present in all cells
  - Play direct roles in metabolism

- **Secondary Plant Metabolites**
  - Species and cultivar specific
  - Produced in response to environmental pressure or plant stress

- **Phenolic Acids**
- **Flavonoids**
- **Alkaloids**
- **Terpenoids**
- **Glucosinolates**
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

• 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?
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
• 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)

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

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

Nitrogen

Conventional System

- Nitrogen surge
- Rapid growth
- Plants emphasize synthesis of primary plant metabolites that contain nitrogen
  - growth related compounds
    - DNA, RNA, protein, alkaloids
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
• 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
<table>
<thead>
<tr>
<th>Analysis</th>
<th>Burbank Cultivar</th>
<th>Ropreco Cultivar</th>
<th>% Increase&lt;sup&gt;4&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional</td>
<td>Organic</td>
<td></td>
</tr>
<tr>
<td>Quercetin (mg / 100g DWB)</td>
<td>68.7 ± 5.8 b 109.0 ± 27.4 a</td>
<td>37.7 ± 1.3 c 60.7 ± 6.4 bc</td>
<td>2003</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>49.4 ± 25.0 a 58.4 ± 46.5 a 18</td>
<td>35.7 ± 12.8 b 39.6 ± 18.7 b 11</td>
</tr>
<tr>
<td></td>
<td>Average</td>
<td>2.64 ± 1.27 a 3.42 ± 2.64 a 29</td>
<td>2.18 ± 1.03 b 2.73 ± 1.62 b 25</td>
</tr>
<tr>
<td>Kaempferol (mg / 100g DWB)</td>
<td>0.94 ± 0.11 1.10 ± 0.31</td>
<td>0.89 ± 0.29 1.28 ± 0.43</td>
<td>2003</td>
</tr>
</tbody>
</table>

### Soluble Solids & Ascorbic Acid

**Table:**

<table>
<thead>
<tr>
<th>Analysis</th>
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<th>Ropreco Cultivar</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional</td>
<td>Organic</td>
</tr>
<tr>
<td>Soluble Solids (°Brix)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>4.0 ± 0.2 b(^1)</td>
<td>6.0 ± 0.6 a</td>
</tr>
<tr>
<td></td>
<td>4.8 ± 0.2 bc</td>
<td>5.4 ± 0.2 a</td>
</tr>
<tr>
<td></td>
<td>5.2 ± 0.3 b</td>
<td>5.1 ± 0.4 b</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>4.7 ± 0.6 b</td>
<td>5.5 ± 0.5 a</td>
</tr>
<tr>
<td>Ascorbic acid (mg / 100g WWB)</td>
<td></td>
<td></td>
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<tr>
<td>2003</td>
<td>13.7 ± 2.0 b</td>
<td>25.7 ± 7.3 a</td>
</tr>
<tr>
<td></td>
<td>16.0 ± 0.9 a</td>
<td>16.3 ± 1.2 a</td>
</tr>
<tr>
<td></td>
<td>22.7 ± 1.9 a</td>
<td>24.2 ± 5.4</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>17.5 ± 4.7 b</td>
<td>22.1 ± 5.1 a</td>
</tr>
<tr>
<td>Ascorbic acid (mg / 100g DWB)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2003</td>
<td>275 ± 40 a</td>
<td>444 ± 126</td>
</tr>
<tr>
<td></td>
<td>288 ± 17 a</td>
<td>257 ± 19 ab</td>
</tr>
<tr>
<td></td>
<td>400 ± 33 a</td>
<td>413 ± 91</td>
</tr>
<tr>
<td><strong>Average</strong></td>
<td>321 ± 69 ab</td>
<td>371 ± 100 a</td>
</tr>
</tbody>
</table>

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
• 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

<table>
<thead>
<tr>
<th>Flavonoid</th>
<th>Means (se) (ug g^-1 DM)</th>
<th>F</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional</td>
<td>Organic</td>
<td></td>
</tr>
<tr>
<td>Quercetin</td>
<td>64.6 (2.49)</td>
<td>115.5 (8.0)</td>
<td>108.16</td>
</tr>
<tr>
<td>Naringenin</td>
<td>30.2 (1.57)</td>
<td>39.6 (1.58)</td>
<td>66.36</td>
</tr>
<tr>
<td>Kampferol</td>
<td>32.06 (1.94)</td>
<td>63.3 (5.21)</td>
<td>96.64</td>
</tr>
</tbody>
</table>
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
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