Breeding for Nutrition in Organic Seed Systems

Philipp Simon, Jim Myers, Walter Goldstein, Micaela Colley

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Breeding for Nutrition:
Prospects and Challenges for Plant Breeders

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Plants and People, Vegetables and Vitamins

- Domestication of plants and animals was one of the most significant human achievements
  - Modern humans are dependent on domesticated plants
- Humans domesticated crops, then crops domesticated humans
  - Jacob Bronowski

Crop Plants Feed the World
Domestication of staple food crops fed first civilizations

Rice, wheat, corn, and potatoes are major sources calories for humans today

Vegetables, fruits, and staple crops also provide vitamins and minerals

Phytonutrients

What are phytonutrients?

- Nutrients and promoters of health found in plants
  - Macronutrients (carbohydrate, oil, protein) sometimes not included in this definition
  - Vitamins, provitamins, and minerals
    - Clear function and targeted intake levels
  - Other biologically active health-enhancing compounds
    - Long list of complex molecules abundant in horticultural crops, e.g. lycopene in tomatoes, sulphorophane in broccoli, anthocyanins in strawberries, thiosulfinates in garlic & onion resveratrol in blueberries

Nutritional status of the U.S. and the Globe – Malnutrition on both sides

- Dietary Guidelines Advisory Committee (2004) identified inadequate, or shortfall, intake for at least half of the U.S. population
- Two vitamins - **A** and **C**
  - Likely vitamin **E** and **folate** also
- Three minerals - **Ca, Mg**, and **K**; also **fiber**
- Intake shortfalls for a nation with **33.8% obese** adults, **17% obese** children/adolescents
- Globally, 13% undernutrition, 30% Fe, 2% VAD
- 4% to 5% global obesity rate

In the Developing World

Nutritional diseases can be quite common - undernutrition, specific deficiencies, and obesity

Wide variation in the incidence of diseases from region to region

Can be associated with crop production differences; by region, year, etc.

Food Sources of Nutrients in the U.S. Diet

Contributions of Crop Plants to Nutrients in the U.S. Diet, 2000 (% total)

	TOTAL CONTRIBUTION FROM PLANTS	VEGETABLES & POTATOES	FRUITS	CEREALS
Carbohydrates	**** > 50%			*** > 40%
Protein	** > 30%			*
Fat	* > 20%			
Vitamin A	***	**		
Vitamin C	****	****	***	
K, Vitamin B_6	***	*		
Cu, Folate	****	*		*
Fe, Vitamins B_2, B_3	****			***
Fiber	****	**	**	**

Vegetables and fruits contribute significantly to human health

Foods Contributing to U.S. Nutrient Intake

From Simon, P.W., L. M. Pollak, B. A. Clevidence, J.M. Holden, D.B. Haytowitz. Plant breeding for human nutrition. Plant Breeding Rev.31:325-392. 2009.

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Protein	**=>30%			*
Fat	*=>20%			
Vitamin A	***	**		
Vitamin C	****	****	***	
K, Vitamin B_6	***	*		
Folate, Cu	****	*		*
Fe, Vitamins B_2, B_3	****			***
Fiber	****	**	**	**

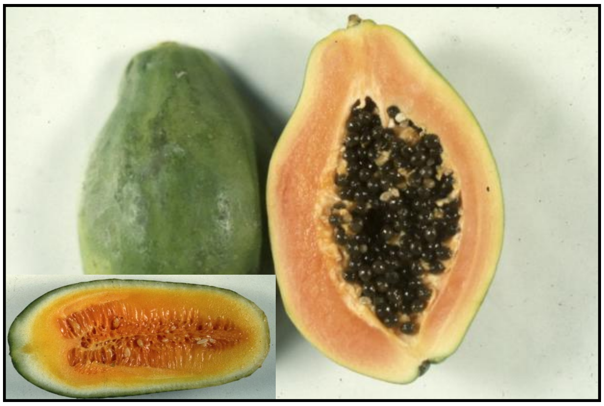


Table 7. Sources of β-carotene ranked by their relative contribution to intake of total β-carotene based on NHANES 2003-04
- all age groups

Food item	β-carotene (µg/100g)	β-carotene consumed (kg)	Total nutrient intake (%)	Cumulative %	Per capita daily consumption (g)	Per capita nutrient intake (µg)
Carrots, raw	8.285	11549	18.2	18.2	4.0	334.3
Carrots, boiled, drained	8.332	5080	8.1	26.3	1.8	147.9
Sweet potato, baked in skin	11.509	2373	5.2	31.5	0.8	95.4
Melons, cantaloupe, raw	2.02	12389	4.8	36.3	4.3	87.4
Tomatoes, red, ripe, raw	0.449	46845	4.0	40.3	16.4	73.5
Spinach, raw	5.626	3202	3.4	43.7	1.1	62.9
Sweet potato, boiled, without skin	9.444	1394	2.5	46.2	0.5	46.0
Spinach, boiled, drained	6.288	2070	2.5	48.7	0.7	45.5
Lettuce, iceberg (includes crisphead types), raw	0.299	43001	2.5	51.2	15.0	44.9
Carrots, frozen, boiled, drained	8.088	1238	1.9	53.1	0.4	35.0
Broccoli, boiled, drained	0.929	9283	1.6	54.7	3.2	30.1
Lettuce, cos or romaine, raw	3.484	2357	1.6	56.3	0.8	28.7
Sauce, pasta, spaghetti/marinara, ready-to-serve	0.324	24974	1.5	57.8	8.7	28.3
Margarine, regular, stick, composite, 80% fat, with salt	0.61	12493	1.5	59.3	4.4	26.6
Carrot juice, canned	9.303	760	1.3	60.6	0.3	24.7
Vegetables, mixed, frozen, boiled, drained	2.082	3293	1.3	61.9	1.2	23.9
Catsup	0.56	11885	1.3	63.2	4.2	23.3
Spinach, frozen, chopped or leaf, boiled, drained	7.237	878	1.2	64.4	0.3	22.2
Collards, boiled, drained, without salt	4.814	1258	1.2	65.6	0.4	21.2
Spinach, canned, drained solids	5.881	983	1.1	66.7	0.3	20.2
Watermelon, raw	0.303	17420	1.0	67.7	6.1	18.4
Collards, frozen, chopped, boiled, drained	6.818	770	1.0	68.7	0.3	18.3

Contributions of Crop Plants to Nutrients in the U.S. Diet, 2000 (% total)

	TOTAL CONTRIBUTION FROM PLANTS	VEGETABLES & POTATOES	FRUITS	CEREALS
Carbohydrates	****** =>50%**			*****=>40%**
Protein	****=>30%**			*
Fat	***=>20%**			
Vitamin A	***	**		
Vitamin C	****	****	***	
K, Vitamin B_6	***	*		
Cu, Folate	****	*		*
Fe, Vitamins B_2, B_3	****			***
Fiber	****	**	**	**

Vegetables and fruits contribute significantly to human health

Table 5. Sources of vitamin C ranked by their relative contribution to intake of total vitamin C based on NHANES 2003-04
- all age groups 2 yr and greater

Food item	Vitamin C (mg/100 g)	Vitamin C consumed (kg)	Total nutrient intake (%)	Cumulative %	Per capita daily consumption (g)	Per capita nutrient intake (mg)
Orange juice, canned, unsweetened	34.4	136756	17.9	17.9	47.8	16.4
Orange juice, frozen concentrate, unsweetened, undiluted	137.9	9530	5.0	22.8	3.3	4.6
Cranberry juice cocktail, bottled	42.3	21672	3.5	26.3	7.6	3.2
Added Vitamin C	99999.9	9	3.4	29.7	0.0	3.1
Oranges, raw, all commercial varieties	53.2	14930	3.0	32.7	5.2	2.8
Fruit punch-flavor drink, powder, without added sodium	121.9	5233	2.4	35.1	1.8	2.2
Strawberries, raw	58.8	10818	2.4	37.6	3.8	2.2
Broccoli, boiled, drained, without salt	64.9	9283	2.3	39.8	3.2	2.1
Tomatoes, red, ripe, raw	12.7	46845	2.3	42.1	16.4	2.1
Apple juice, canned or bottled, unsweetened, with added ascorbic acid	41.6	13403	2.1	44.2	4.7	1.9
Peppers, sweet, green, raw	80.4	6710	2.0	46.3	2.3	1.9
Fruit punch drink, with added nutrients, canned	29.6	18090	2.0	48.3	6.3	1.9
Melons, cantaloupe, raw	36.7	12389	1.7	50.0	4.3	1.6
Bananas, raw	8.7	50477	1.7	51.7	17.6	1.5
Peppers, hot chili, green, raw	242.5	1446	1.3	53.0	0.5	1.2
Cranberry-apple juice drink, bottled	39.5	7092	1.1	54.1	2.5	1.0

What nutrients should be targeted for genetic improvement?

- Improve well-characterized phytonutrient levels (e.g. vitamins, provitamins, minerals) ?
  - Analysis can be expensive, but data is important to consumers
- Improve less well-characterized phytonutrients ?
  - Analysis often more complicated
  - Cooperation w/ nutritionists/physicians more essential
  - Public opinion may change by the time you develop a product
- Is genetic improvement the best approach?
  - Horticultural approaches to improve garlic
  - Food scientists have also developed fortified foods

Considerations for Improving Nutritional Value of Crops: Provitamin A Carotenes

- Carotenes occur in all green leaves and are essential for photosynthesis in plants
- Some carotenes are vitamin A precursors
  - Provitamin A carotenoids
- All vitamin A ultimately comes from plants
- An essential nutrient
- Vitamin A deficiency is a global health problem
  - 100+ million deficient, several million die annually
- Little overt deficiency in the U.S. but much suboptimal intake

What can be done to make fruits and vegetables better sources of vitamin A?

- Improve the productivity of crops that provide vitamin A
  - Improve yield for growers
  - Improve postharvest longterm storage
- Identify crop varieties already in production that are better sources of vitamin A
- Genetically increase provitamin A carotene content
- Encourage consumers to increase intake
  - Flavor
  - Convenience

Crop germplasm varies widely in nutrient content

From Simon, P.W., L. M. Pollak, B. A. Clevidence, J.M. Holden, D.B. Haytowitz. Plant breeding for human nutrition. Plant Breeding Rev.31:325-392. 2009.

Table 17. Current content and range (ppm) of variation for nutritionally important carotenoids and anthocyanins in major crop sources[z]

Pigment Food	Current Content	Range	References
β-carotene			
Carrots	80	0-300	Simon and Wolff 1987; Simon et al. 1989; Simon 1990, 1992; Santos and Simon 2002, 2006; Nicolle et al. 2004; Surles et al. 2004
veet Potatoes	107	1-226	Simonne et al.1993; Laurie et al. 2004; Tunwegamire et al. 2004; Gruneberg et al. 2005; Kimura et al. 2007; Teow et al. 2007
luskmelons	0-20	0-50	Gonzalo et al. 2005; Ibdah 2006
Tomatoes	4	1-77	Lincoln et al. 1943; Tomes et al. 1953; Markovic et al. 2002; Stommel and Haynes 1994 ; Stommel et al. 2005; Rousseaux et al. 2005; Lenucci et al. 2006; Premachandra 1986
Spinach	55	9–83	Konings and Roomans 1997; Murphy and Morelock 2000
Lettuce	3-43	1-91	Kimura and Rodriguez-Amaya 2003; Mou 2005
Broccoli	4	16-91	Gross 1979;Kalia et al. 2005; Singh et al. 2005
Collards	56	44	Kopsell et al. 2007 [*B. juncea*]
Squash	2-29	1-74	Sirohi and Yayasani 2001; Pandey et al. 2002; Murkovic et al. 2002; Boiteux et al. 2007

Table 16. Current content and range (ppm) of variation for vitamin C and vitamin E in major crop sources[z]

Vitamin Food	Current Content	Range	References
Vitamin C			
Oranges	533	413-627	Dhuique-Mayer et al. 2005
Strawberries	590		Lerceteau-Kohler et al. 2004; Sato and Yamakawa 1989
Broccoli	892	222-944	Vallejo et al. 2003; Singh et al. 2004
Tomatoes	127	84-1194	Lincoln et al. 1943; Abushita et al. 2000; Bhatt et al. 2001; Markovic et al. 2002; Rousseaux et al. 2005; Lenucci et al. 2006
Apples	46	21-910	Davey et al. 2006; Sedora and Sedora 1979
Peppers	1103	151-2024	Gupta and Yadav 1984; Yadav et al. 1987; Howard et al. 2000
Muskmelons	181-369	14-431	Eitenmiller et al. 1985; Burger et al. 2006; Dhillon et al. 2007
Bananas	87	45-127	Wall 2006
Potatoes	132	110-153	Davies et al. 2002; Andre et al. 2007
Eggplants	66	10- 122	Prohens et al. 2007
Carrots	60	16-98	Nicolle et al. 2004
Squash			Sirohi and Yayasani 2001; Pandey et al. 2002
Papaya	618	190-700 DW	Selvaraj et al. 1982

able 15. Current content and range (ppm) of variation for selected minerals in major crop sources[z]

lutrient Food	Current content	Range	References
agnesium			
Dranges	100	89-33	Miller-Ihli 1996
Bananas	273	261-458	Wall 2006
Peanuts	1760	1800-1900	Pennington et al.1995
Wheat	224	200-1890	Sipos et al. 2004; Roussel et al. 2005; Oury et al. 2006
otatoes	206	153-45	Pennington et al. 2005
Maize	263	152-277	Pennington et al. 2005
Carrots	117	80-231	Nicolle et al. 2004
Apples	54	52-58	Miller-Ihli 1996; Oraguzie et al. 2003
Zinc			
Wheat	7	5-43	Oury et al. 2006
otatoes	3	2-4	Pennington et al. 1995; Andre et al. 2007
Iron			
otatoes	4	3-16	Pennington et al. 1995; Andre et al. 2007
Wheat	36	20-88	Oury et al. 2006
Beans	12	10-92	Moraghan 2004
oybean	22-44	20-97	Moraghan 2004
Rice	13	12-30	Stangoulis et al. 2005

Agronomic crops for which genetic improvement of phytonutrients is being undertaken

Breeding for Nutrient Content in Agronomic Crops

- QPM – Quality Protein Maize
  - CIMMYT since the 1970's, to improve maize lysine content
- HarvestPlus
  - High provitamin A carotenoid maize, cassava, sw. potato
  - High Fe beans, pearl millet
  - High Zn rice, wheat
- Cooking oil quality, fiber, starch quality

Horticultural crops for which genetic variation exists and improvement of phytonutrients has been undertaken

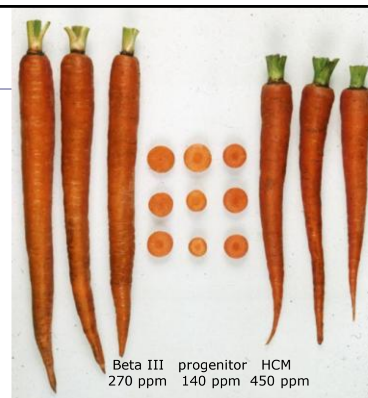
Carotene content varies among vegetable and fruit cultivars

Horticultural crops with genetics known and some breeding for essential phytonutrients

- Carotenoids: tomato, pepper, carrots, squash, pumpkin, melon, watermelon, cucumber, cauliflower, broccoli, kale, sweet potato, potato, sweet corn, citrus, mango, papaya
- Vitamin C: tomato, onion, potato, citrus, apple, strawberry
- B Vitamins: beets (folate), peas (thiamin), tomato, pepper
- Vitamin E: brassicas, carrot
- Protein: bean, potato
- Calcium: bean

An example of improving nutritional value of horticultural crops

Breeding for higher content of provitamin A carotenoids in orange carrots



Progress in Improving Carotene Content of Carrot in the U.S. Crop

- Result of classical plant breeding
- Carrot varieties of 1950's – 60 ppm
- Carrot varieties of 1970's – 90 ppm
- Carrot varieties of 1990's – 130 ppm
  - 1/2 of a carrot (50g) contains enough provitamin A to provide adult vitamin A requirements if fully absorbed
  - Concomitant flavor, convenience improvement essential to deliver higher nutritional content

U.S. Carrot and Carotene Production, 1975 ($472M, 2005$$) and 2005 ($650M)

Year	Carotene content	Per capita availability	Est. % of total vitamin A available
------	--------	-----------	-----------
1975	90	3.7 kg	14 %
2005	130	5.6 kg	21 %

Carrot Impact

One square meter of carrots (~2500) in 1 year
Enough provitamin A for 10 adults for a year

One of very few crops with increased nutritional value per unit weight, as compared to 1950 (Davis et al., 2004)

Plant breeders have made progress improving crop nutritional value in several crops

- Genetic improvement of phytonutrients content can be undertaken with simple tools for pigments
- Lab analysis necessary for most nutrients
- Growers realize no economic value from high-carotene crops
- Marketers cannot easily label high nutrient content
- Improving flavor can increase consumption, and indirectly increase nutrient intake
- Critically important to "obesity epidemic"

A team approach is essential to improve crop nutritional content

- Breeders
- Growers
- Marketers
- Nutritionists and health professionals
- Government and non-government groups
- Educators

Progress in Breeding for Crop Production
Farm Values of Nearly All Crops Have Increased

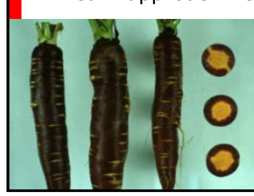
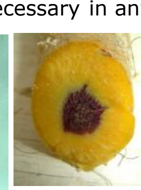
Nutritional Values of Few Crops Have Increased

Nutritious Crops Make for a Healthy Economy

- Greater consumption of healthier foods improves human health and has positive economic benefits to U.S. agriculture.
- Genetic selection for nutrients that ameliorate "obesity diseases" is expected to reduce health care costs and consequently have an economic benefit (Cordain et al. 2005).
- Healthier foods have the potential to alleviate both the incidence and severity of these diseases, as well as obesity which is a causal factor for many chronic diseases (Heber and Bowerman, 2001).
- Consumer adoption of the recommendations of the 2005 Dietary Guidelines for Americans would significantly alter food demand and production with positive economic impact (Buzby et al. 2006).
- To realize improved nutritional value of crops in the marketplace, improved economic value for the grower, and culinary quality for consumers must also be realized.

Future Issues Will Influence Progress

- What crops, nutrients, tools?
- Production, consumption, germplasm, breeding
- Value to grower, labeling
- Team approach necessary in any case


Plants and People, Vegetables and Vitamins

- Domestication of plants and animals was one of the most significant human achievements
  - Modern humans are dependent on domesticated plants
- Responsibility of agricultural scientists to increase food quantity and improve food quality
- Complex solutions requiring teamwork including international cooperation

Crop improvement is a team effort

Graduate students working on carrot, garlic, and cucumber
Postdocs & Support Scientists in particular Doug Senalik and Rob Kane
Funding

USDA,ARS	USDA, OREI	USDA, NRI	USDA, IFAFS	Seed companies
USDA, SCRI	UW Grad. School	UW CALS	Calif. Fresh Carrot Advisory Board	

http://www.ars.usda.gov/mwa/madison/vcru
Philipp.Simon@ars.usda.gov 608-262-1248

Breeding Tomatoes for increased Flavonoids

Jim Myers
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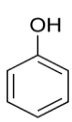
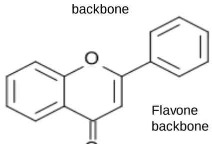
Phenolics and Flavonoids

- Phenolics
  - caffeic acids
  - chlorogenic acids
  - cinnamic acids
  - benzoic acids
- Flavonoids
  - flavones
  - flavonols
  - proanthocyanidins
  - anthocyanins



Phenol backbone



Flavone backbone

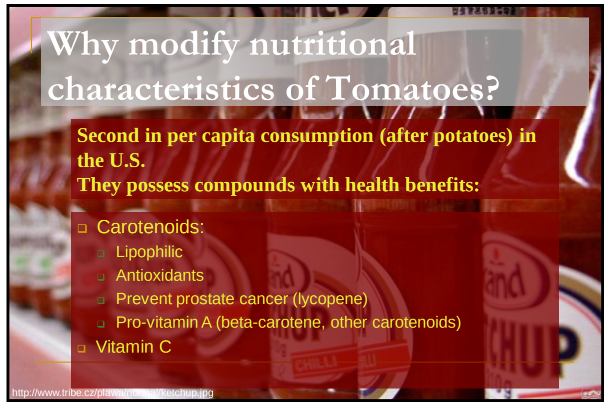
Phenolics and Flavonoids II

- Biological activity
  - Pathogen defense
  - Environmental stress
  - Feeding deterrent
  - Attractants (flowers, ripe fruit)

Relationship of Phenolics & Flavonoids & to Health

- Effects
  - Anti-allergic
  - Anti-inflammatory
  - Anti-microbial
  - Anti-cancer activity
  - Anti-oxidants
- Possible human health benefits
  - Anti-carcinogens
  - Improved cardiovascular function

New research indicates that flavonoids have only minor activity as antioxidants *in vivo* – however – they may induce other antioxidant systems. (Lotito & Frei 2006 Free Radical Biol & Med)



Why modify nutritional characteristics of Tomatoes?

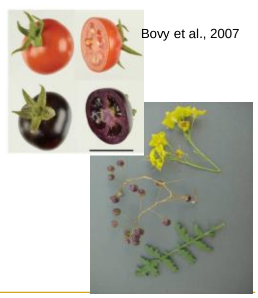
Second in per capita consumption (after potatoes) in the U.S.
They possess compounds with health benefits:

- Carotenoids:
  - Lipophilic
  - Antioxidants
  - Prevent prostate cancer (lycopene)
  - Pro-vitamin A (beta-carotene, other carotenoids)
- Vitamin C

http://www.tribe.cz/plawa/normal/ketchup.jpg

Increasing Flavonoids in Tomatoes

- Tomatoes relatively low in flavonoids
- Two approaches to increasing:
  - Transgenes
  - Introgress from related wild species

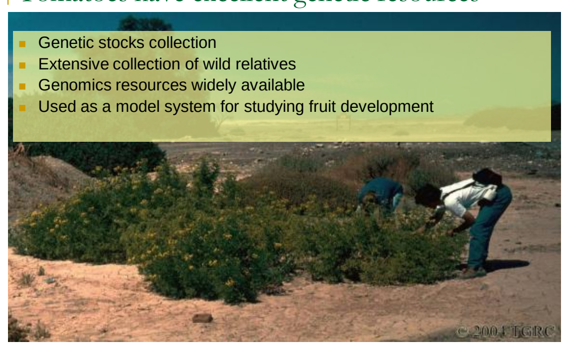


Bovy et al., 2007

Solanum peruvianum

Tomatoes have excellent genetic resources

- Genetic stocks collection
- Extensive collection of wild relatives
- Genomics resources widely available
- Used as a model system for studying fruit development



High Anthocyanin Tomatoes

What about “black” and “purple” heirloom tomatoes?

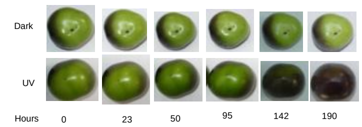
- Genotype of the “purple” tomatoes: *y or Y & gf*
- *Gf (Green flesh*) prevents complete chlorophyll breakdown, producing brown pigment

Black Krim

www.landrethseeds.com/photos/Tomato/index.html

Plant and fruit characteristics of high anthocyanin tomatoes

- Change to open plant canopy
- Foliage and stems more intensely pigmented
- Light induced expression
- Only skin deep

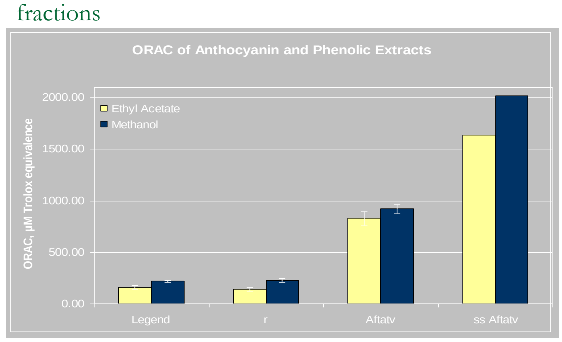


Tomato Flavonoids and Anthocyanin Quantities

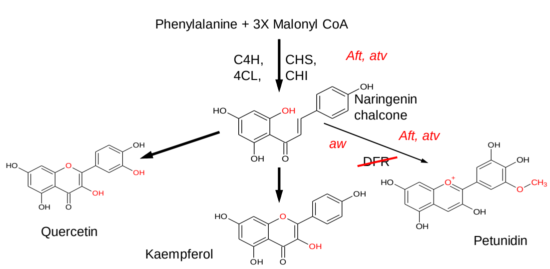
	Gallic Acid Equivalents, mg/g FW		Total Anthocyanins, mg/100gFW	
Partition	Ethyl Acetate	Methanol	Ethyl Acetate	Methanol
Legend	35.49 a	53.33 a	0 a	0 a
r	36.95 a	51.85 a	0 a	0 a
Aftatv	223.49 b	200.42 b	7.19 b	118.66 b
ss Aftatv	626.39 c	663.86 c	36.85 c	459.57 c

a-c letters indicate significant difference (P<0.05) within a column, determined by Fishers' LSD

Antioxidant Capacity of Ethyl Acetate and Methanol fractions

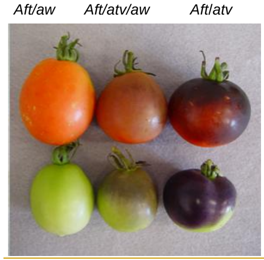


Aft/atv/aw tomatoes



Unexpected phenotype in *Aft/atv/aa* and *Aft/atv/aw*

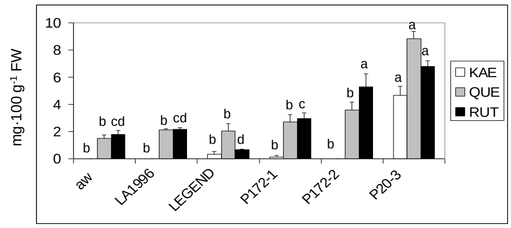
Aft/aw *Aft/atv/aw* *Aft/atv*



Aft/atv *Aft/atv/aw*

No Hcl + Hcl + Hcl No Hcl

Flavonols in *Aft/atv/aw* tomatoes (greenhouse)

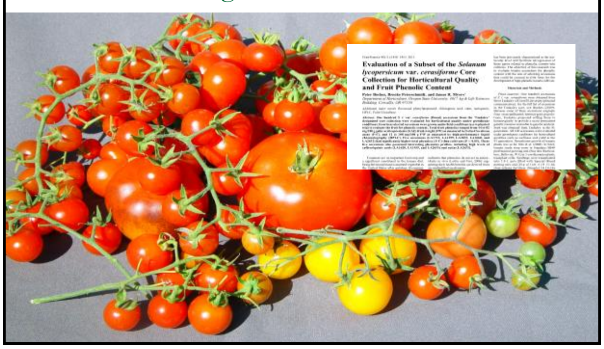


Means not sharing a letter significantly different, LSD test, p≤0.05. Error bars = one standard error, 3 biological replicates.

Fruits with anthocyanin are much more resistant to decay than normal tomato fruit

Appearance of detached fruit after 35 days in field

Need to investigate "feral" tomatoes



Breeding Corn for Nutritional Value;

Protein, Carotenoids, Taste.
What our Experience has been.

Walter Goldstein, Research Director

Mandaamin Institute

The Need for Quality as well as Quantity

- Conventional breeding has emphasized increasing grain yield.
- This caused a progressive increase in starch and decrease in the protein content of the grain.
- The protein content and quality of corn is important to produce balanced rations for organic livestock production in light of the role that corn plays in livestock feed and the high price of organic protein.
- Listening sessions with organic farmers have indicated a keen interest in improving the nutritional value of corn, including its protein content and quality, and vitamin content, as well as improving its taste.

Analysis of native corn 2011 by NIRS spectroscopy at MFAI

	no samples protein	protein	oil	starch	density	lysine	methion ine
	% of dry matter						
Hopi Flour	14	14.9	4.1	63	1.09	0.40	0.35
Hopi Mixed	4	14.2	3.6	66	1.07	0.34	0.32
Hopi Mex. June	12	12.6	5.1	67	1.24	0.36	0.27
Flour other Tribes	11	14.4	5.2	62	1.12	0.41	0.35
Corn Belt Dent	4	7.5	--	73	--	0.28	0.18

Multi-aleurone corn from the Amazon with more minerals, protein and possibly more B vitamins and phytosteroids.

Methionine and Lysine

- Methionine and lysine are generally regarded as being primary limiting amino acids for humans, hogs, poultry, and dairy cattle.
- For poultry, the sulfur-containing amino acid methionine is commonly regarded as being the first limiting amino acid for overall health and egg production, and lysine the second.
- Corn is the major ingredient of poultry food but it is naturally low in the sulfur-containing amino acids methionine, cysteine, and cystine, and in lysine.
- This deficiency is commonly made up by combining corn with soybean meal and supplementing with synthetic DL methionine.

Synthetic methionine

- Organic egg production has quadrupled since 2003.
- Neither synthetic methionine, nutrient deficiencies, nor confinement are consistent with the ideals of organic farming.
- Due to national restrictions on its use, organic poultry producers will start to reduce the use of synthetic methionine in poultry feed and replace it after 2015 (Federal Register, 2010).

Breeding High Methionine Corn

- We developed a quick, cheap, non-destructive test NIRS for measuring methionine and lysine.
- We are breeding high methionine and lysine in hard endosperm and soft endosperm breeding sources.
- Hard endosperm sources are high protein corns; methionine will be more subject to fluctuations in protein content.
- Soft endosperm corn has a higher % lysine and methionine in its protein.
- Feeding trials with broilers and layers have shown it can replace synthetic methionine.
- Some soft types (floury-2) are associated with lower seed weight and yield but others are not.
- There probably will be a yield penalty but possibly more protein harvested per hectare.

Protein and amino acid information for corn analyzed in 2007 with high performance liquid chromatography.

Component	Normal Corn	hard kernel methionine corn	floury-2 methionine corn
	-% total dry matter-		
Protein	9.5	13.1	12.8
Methionine	0.21	0.31	0.33
Total Sulfur Amino Acids	0.43	0.58	0.57
Lysine	0.30	0.36	0.46
number of samples tested	1903	28	16

Reliability: Results from 3 farms that grew the floury-2 hybrid in 2008.

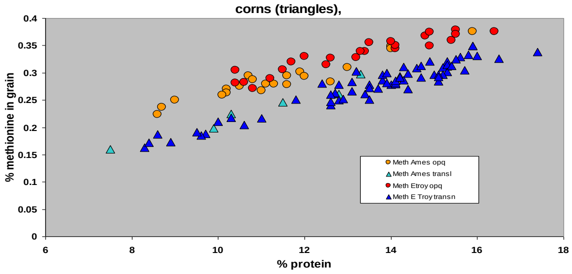
Farm	Protein %	Lysine %	Methionine %	Cysteine %	oil %
Farm 1	10.2	0.40	0.27	0.21	5.7
Farm 2	10.2	0.40	0.27	0.21	5.7
Farm 3	9.9	0.41	0.26	0.19	6.0
Average	**10.1**	**0.40**	**0.27**	**0.20**	**5.8**

Results of developing an NIRS calibration for grain amino acids:

	Range (%db)	R^2 *Determination with* Omega Spectra	Infratec Total Spectra	Protein
LYS	0.26-0.53	0.837	0.842	0.390
MET	0.14-0.39	0.746	0.730	0.542
CYS	0.14-0.37	0.783	0.787	0.797

Kovalenko et al. 2006 proposed using R^2 or RPD (Relative Predictive Determinant to test whether values are calculated values or true predicted values.

Improving Protein Quality: Corn with the new opaque trait (circles) maintains a higher % of methionine than hard kernelled high methionine corns (triangles),



Feeding trials to Chickens

- Soft-kernelled corn bred by the MFAI program replaced the need for synthetic methionine in trials with broilers by Organic Valley (Levendoski,2006) and with layers by the University of Minnesota (Jacob et al. 2008).
- Palatability of the soft kernelled cultivars in both sets of trials was very high.
- Feed had to be restricted to avoid feeding frenzies.
- In the future, larger trials may be carried out with a team of organic poultry companies called the Methionine Task Force.

Tradeoffs between protein and yield

- High methionine corns are generally high protein corns.
- Selection for high protein can easily result in reduced endosperm and seed size.
- It is possible to select for corn that produces high protein without a reduction in endosperm size.
- Select should target alterations in N physiology and greater utilization of N from soil organic matter.
- Selection on the basis of a high concentration of methionine and lysine in the grain must be coupled with estimates of yields of constituents on a per acre basis.

Goal: *cultivars should produce very high yields of protein and essential amino acids on a per acre basis and have high percentages of those constituents.*

Yields in 2009 of new hard endosperm hybrids

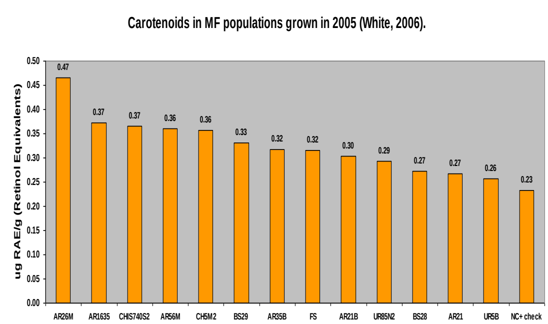
- HM hybrids were grown on 9 organic and 9 conventional sites and compared with many different normal, non-gmo hybrids.
- Relative to normal hybrids (100%) the HM hybrids in the USTN trials appeared to have averaged higher yields on organic sites (87%) than on conventional sites (81%).
- The best yielding HM hybrids on all organic sites were HM-11 and HM-2. They yielded 94% and 91% as high as the average for all the elite hybrids tested.
- The best yielding HM hybrids on conventional sites were HM-1 and HM-6 which yielded 88% as high as the average elite hybrids tested.
- The HM hybrids did not appear to differ from normal hybrids in lodging and showed a normal range in grain moisture content.

Quality 2009

- To evaluate differences in grain quality, on one site a subset of hybrids were grown next to the USTN plots and plants were self pollinated. The grain from these plants was analyzed for quality.
- The HM cultivars averaged 12.9% protein and 0.28% methionine on a total dry basis. These results are typical of results in the past.
- This is approximately 43% more protein and methionine than is generally found in normal corn hybrids in this study and others.
- Initial projections from data on one site suggest that the HM hybrids produced approximately 1/3rd more protein and methionine per acre more than did the conventional hybrids but approximately 13% less starch.

Breeding corn that has more carotenoids. These are powerful anti-oxidants and precursors for vitamin A.

They turn the yolks of eggs orange and the skin of poultry orange. Eggs get carotenoids into people!



Quality: However high it yields, someone has to eat it; they will only eat so much of it, and it may or may not taste as good as it should. Taste can raise or lower the level of enjoyment of life. We share that with our animals.

Taste Testing Corn

Taste Testing Corn Varieties Developed at Michael Fields by Independent Scoring of Corn Bread Made From a Mixture of Corn Flour, Water, Salt & Baking Soda

Individual Tester Scores

Variety ID	Sample ID	On	Bill	Alan	Stefan	Gail	Walter	Lindsay	Ave.	Std. Dev.	Variety ID	Variety	Var. Ave.
6	1	1	3.5	5	2	2	3	1	2.5	1.4	1	Nokomis Gold 2002	2.46
5	2	2	2	3	3	2	2	1	2.1	0.7	2	UR10001 MO17:MO17	2.75
4	3	1	3	2	3	2	2.5	3	2.4	0.7	3	AR16021:SO9	2.25
2	4	1	3.5	3	4	3	3.5	4	3.1	1.0	4	BS29	2.82
6	5	2	3	3	4	4	2.5	3	3.1	0.7	5	AR16021:SO8	2.50
3	6	3	2.5	2	3	2	2	2	2.4	0.5	6	BS28	2.79
5	7	2	3.5	4	4	3	2.5	1	2.9	1.1	Rating Scale		
1	8	1	3.5	4	2	2	1	1	2.1	1.2	1	Bad	
4	9	1	3.5	5	4	3	3.5	3	3.3	1.2	2	Acceptable	
1	10	3	2.5	5	3	3	1.5	2	2.9	1.1	3	Good	
3	11	2	2.5	4	2	1	2.5	1	2.1	1.0	4	Very Good	
2	12	2	2	3	3	1	3.5	2	2.4	0.9	5	Excellent	

Feeding Trials Broilers:

Floury-2 grain replaced normal corn plus synthetic methionine in feed

- **Broiler feeding trial:**
- **Organic Valley/MFAI; (Levendoski, et al):**
- **Cornish Cross Cockerells; small experiment with 3 pens.**
- **Birds fed out from when they were chicks.**
- **Three treatments: normal control, high methionine corn, potato extract.**
- **Gain, feed consumption, and feed:gain ratio were the same for control and methionine corn (2.8) but higher for potato extract (3.3).**
- **Birds with high methionine corn were more enthusiastic about the corn and had more energy. Control group was calmer.**

Feeding Trials Layers:

Floury-2 grain replaced normal corn plus synthetic methionine in feed

- Layer feeding trial:
- University of Minnesota/Organic Valley/MFAI; (Jacob, et al):
- 13 Bovan Brown pullets in 6 replicated pens.
- Birds fed out from when they were chicks.
- Gain, feed consumption were the same for control and methionine corn. Egg production was 2-5% less/pen for the high methionine corn.
- Birds with high methionine corn were more enthusiastic about the corn and luxury consumption had to be controlled.
- By the end of the trial half of the pens with control feed had been progressively disqualified because hens were eating their own eggs.

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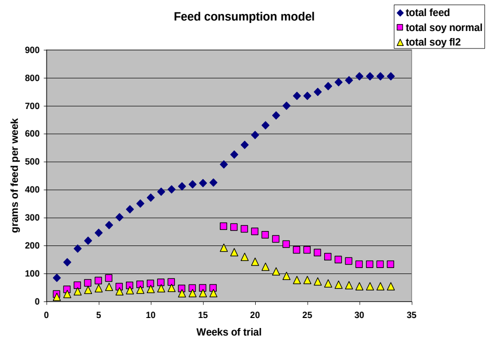

Cost Relationships for Feed

Preliminary estimates of feed requirments and cost relationships for feed.

	Normal Corn			floury 2 high meth corn		
	total feed	soy meal	corn	total feed	soy meal	corn
Pounds of feed per hen 33 weeks	37	9	28	37	5	32
% soymeal		24			13	
Costs of feed						
same cost for corn	$7.90	$3.62	$4.28	$6.86	$1.94	$4.92
at 21% higher cost for high meth corn	$7.90	$3.62	$4.28	$7.90	$1.94	$5.95

Assumptions:	cost/pound
soymeal = $800/ton	$0.40
corn = $8.5/bu	$0.15
corn = $10.29/bu	$0.18

Organic Seed Alliance
http://www.seedalliance.org/

NOVIC
http://eorganic.info/novic/

Carrot Improvement
http://eorganic.info/carrotimprovement

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Find all upcoming webinars and archived eOrganic webinars including many more recordings from the 2012 Organic Seed Growers Conference at http://www.extension.org/pages/25242

Find the slides as a pdf handouts and the recording at http://www.extension.org/pages/62564

Additional questions? Ask them at http://www.extension.org/ask

We need your feedback! Please fill out our follow-up email survey!