Breeding for Quality
(quality is color, and color is lycopene, or not…)

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Goal

(1) Discuss the possibility of multi-trait indices for quality within the context of traditional breeding and genome wide selection (gws)

(2) Discuss opportunities for new products based on real or perceived health benefits

Breeding for quality may require that we have answers to the following questions:

-What are the characteristics of quality? (sugar, color, flavor…)

-Can we measure them?

-Is there variation for the trait?

-Can objective data and trait indices help us improve quality or is quality about marketing new niches?

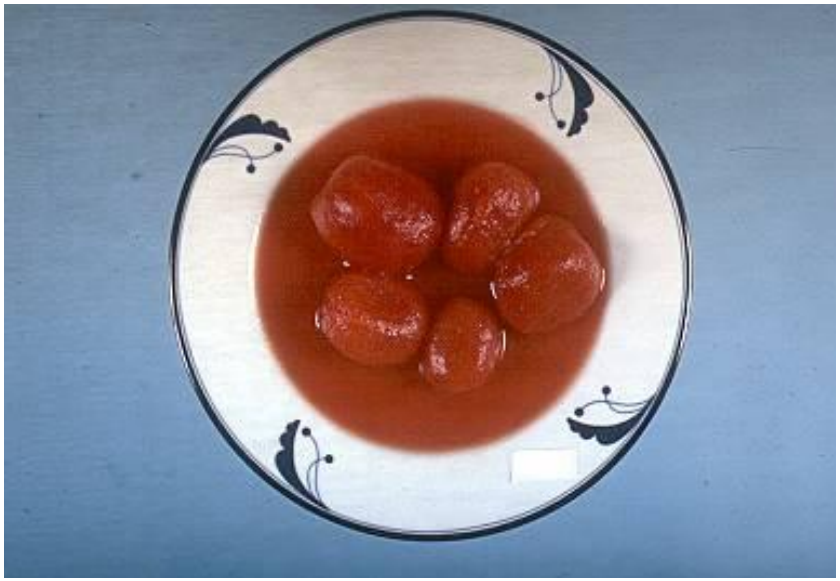
-What is the scale of the measurement ("low" is good or "high" is good)? Brix↑, L↓, Hue↓ , etc….

-How do we weigh components of quality with respect to each other?

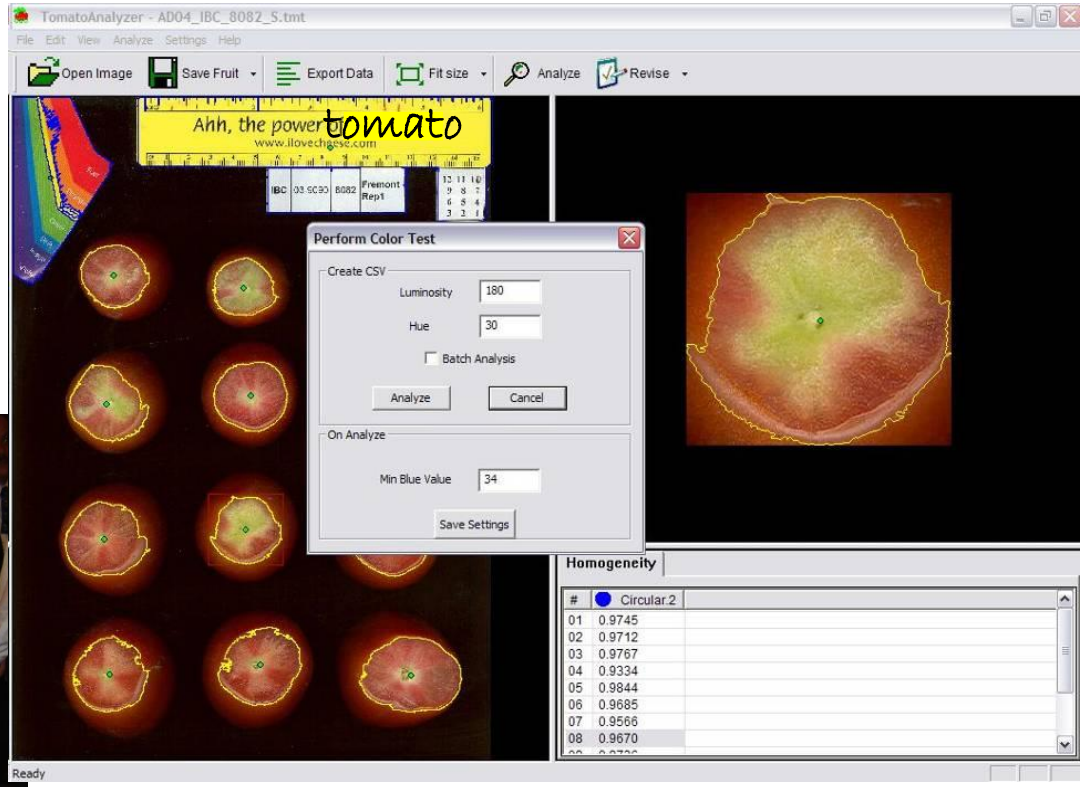
-Is there economic value and what is the market willing to pay?

Examples drawn from processing tomato breeding

Definition of quality might depend on end-use (whole-peel vs paste)



For the whole peel market, color is valued in contracts; Brix are not.

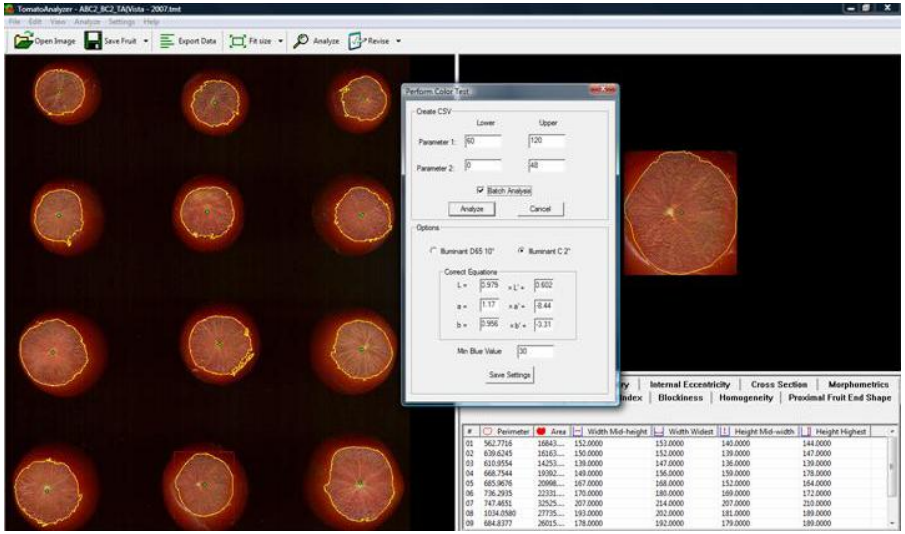


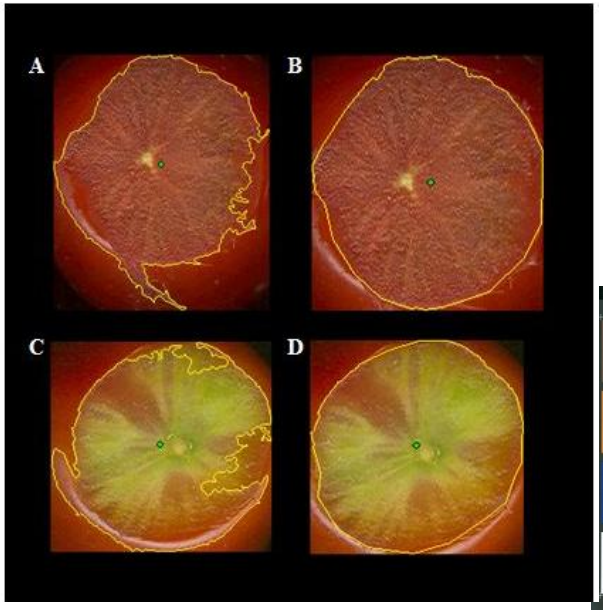
We can measure color as: L, a, b, Hue, chroma, G, R, B, luminosity, % red tissue, % yellow tissue, etc…

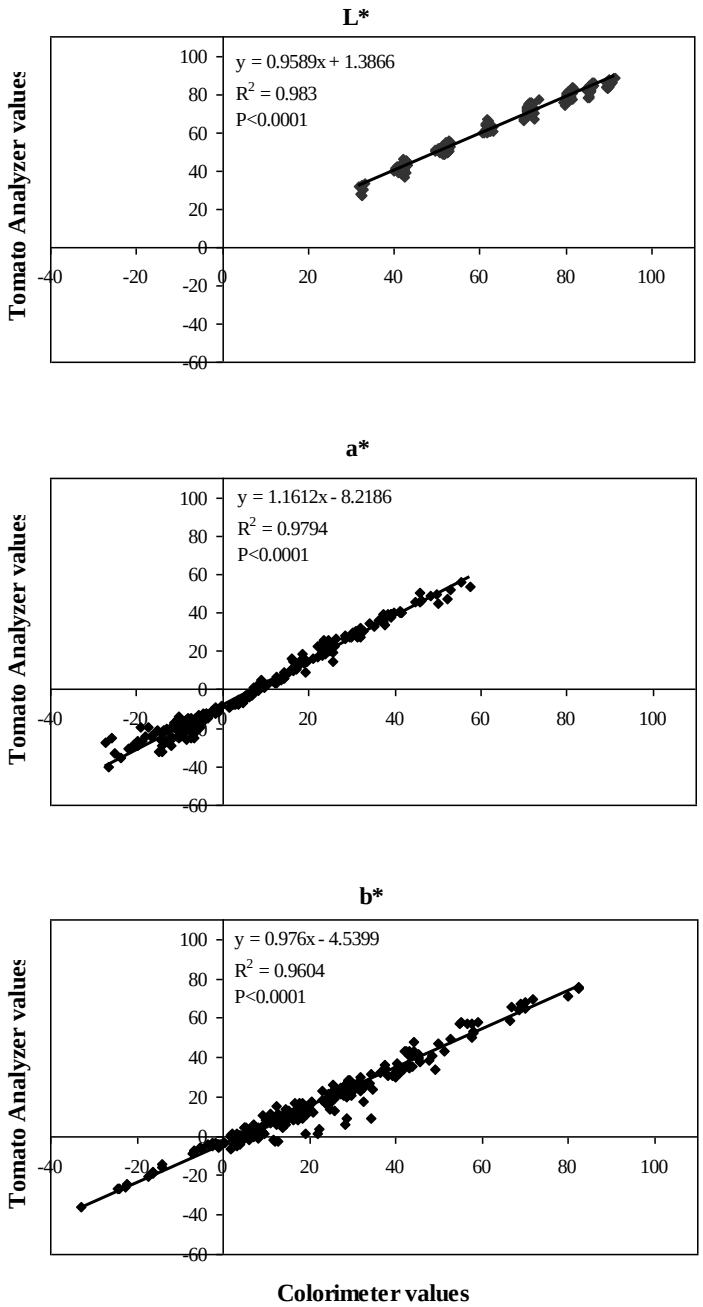
Which measurements should we select for?

Tomato Analyzer – Color Test

(Darrigues et al., *JASHS*, 2008, **133,** 579-586)





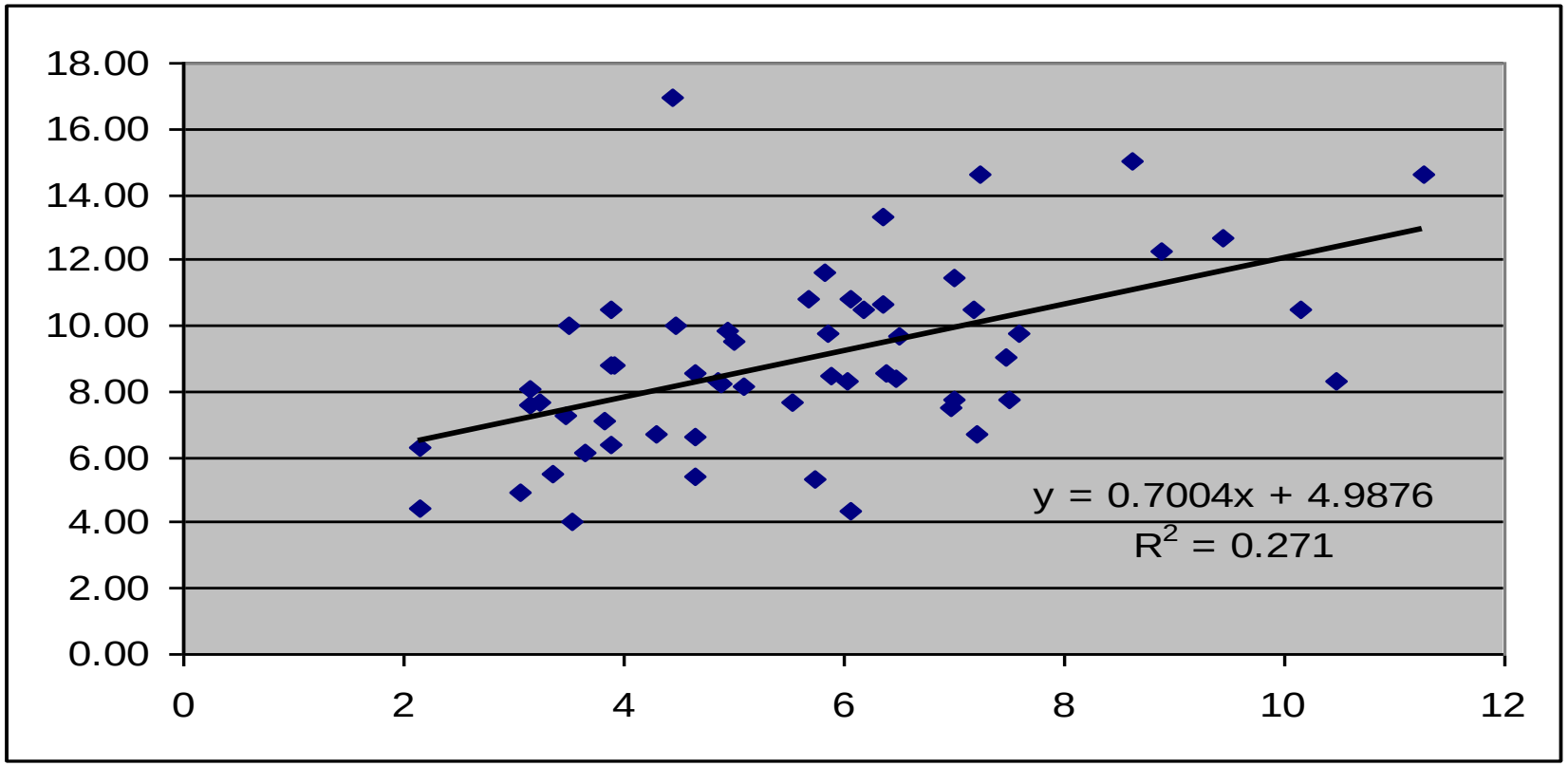


PCA and Development of Multi Trait Index

	Principal Component 1					Principal Component 2				
	BC2		BC2S4		TC19F2	BC2		BC2S4		TC19F2
	Fremont	Wooster	Fremont	Wooster	Fremont	Fremont	Wooster	Fremont	Wooster	Fremont
%YSD	0.4819	0.4535	0.4463	0.4157	-0.39377	-0.0267	-0.0911	-0.2147	-0.2896	0.301172
%RED	-0.4171	-0.4487	-0.401	-0.4371	0.444605	0.0485	-0.0451	0.1552	0.0994	-0.28885
L*	0.3731	0.338	0.3658	0.4263	0.110363	0.1677	0.0969	0.2416	0.0798	0.396884
a*	-0.3764	-0.3708	-0.3528	-0.1054	0.506258	0.4461	0.4675	0.4582	0.6575	0.156219
b*	0.2341	0.2807	0.3517	0.3974	0.190713	0.5801	0.5583	0.4777	0.3682	0.588045
Hue	0.5078	0.512	0.4609	0.4471	-0.43707	-0.0179	-0.0161	-0.159	-0.2279	0.347519
Chroma	0.0178	0.0198	0.2138	0.2923	0.389094	0.658	0.6707	0.6388	0.5293	0.421159
Proportion	0.5382	0.5283	0.6178	0.6228	0.517	0.3265	0.3138	0.2726	0.313	0.3333
Cumulative	-	-	-	-	-	0.8647	0.8422	0.8904	0.9358	0.8503

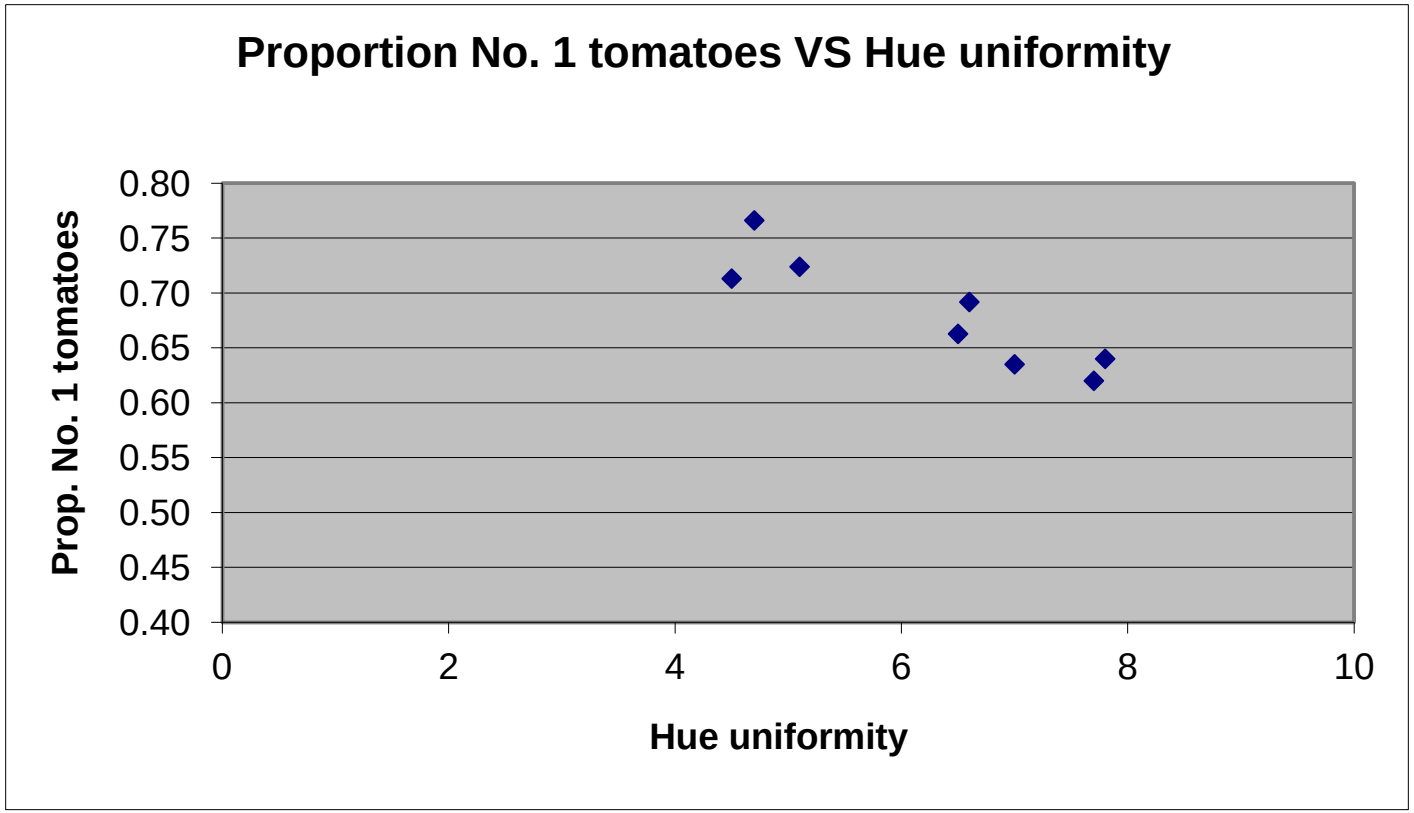
For three separate populations, PCA-1 is strongly weighted toward color uniformity and color while PCA-2 is weighted toward color intensity (Audrey Darrigues)

Equal weight to % YSD and Hue measurements (in both cases, lower is better)



There is a moderate genetic signal for measures of color uniformity (h^2 = 0.25 – 0.35)

How does our evaluation strategy compare to processor grades?



Data for 8 varieties, 2 years, 552 loads

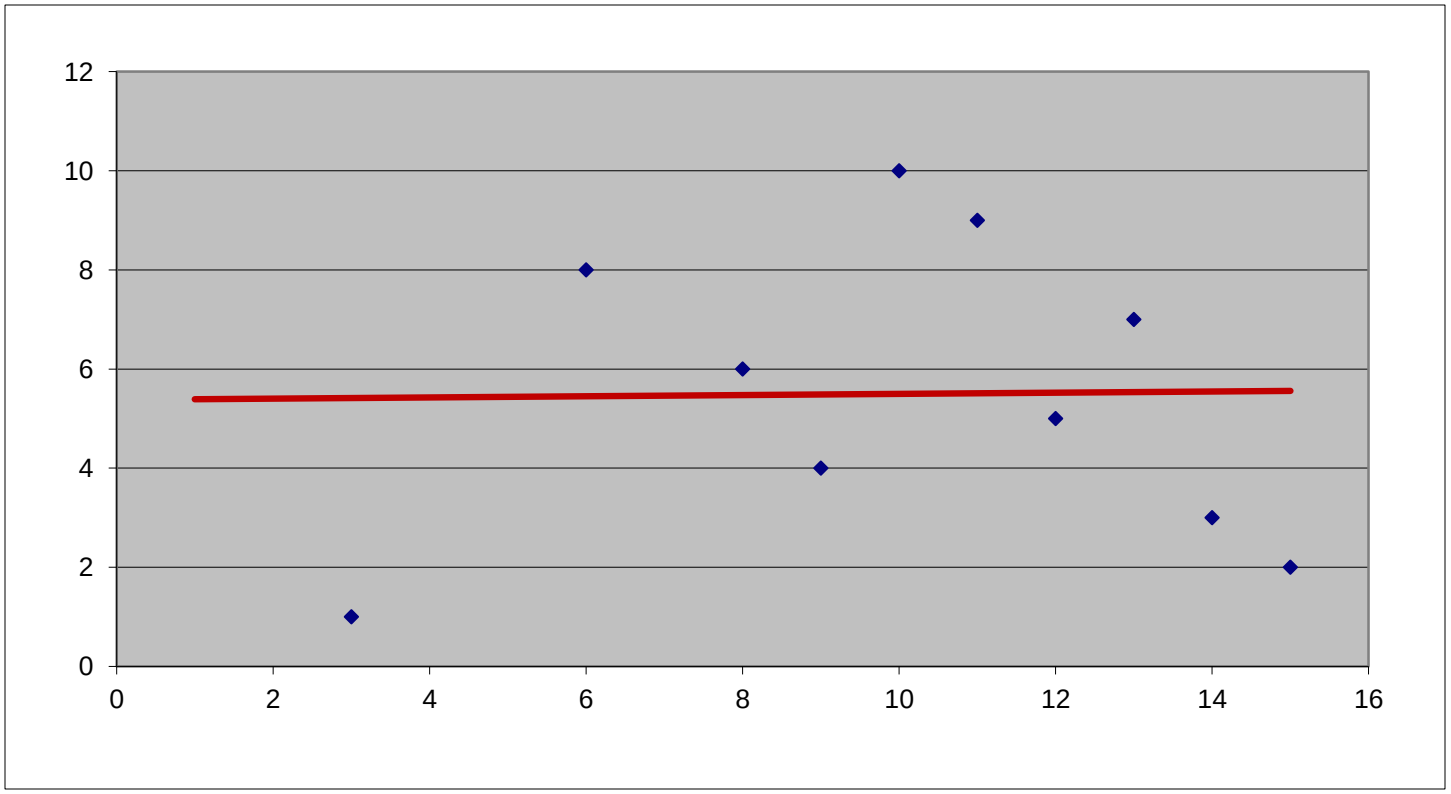
For color/color uniformity we can focus on two measures (out of ~ 11)

We weigh them equally, and scale them such that lower values are better.

A change in 2 units (50% improvement) is worth ~$60/acre (a 5% increase in yield is worth ~$150)

What about Birx^{o} ?
What about firmness ?

What about flavor?



Correlation between flavor ratings conducted between two locations during the GLVWG “Heirloom evaluations”.

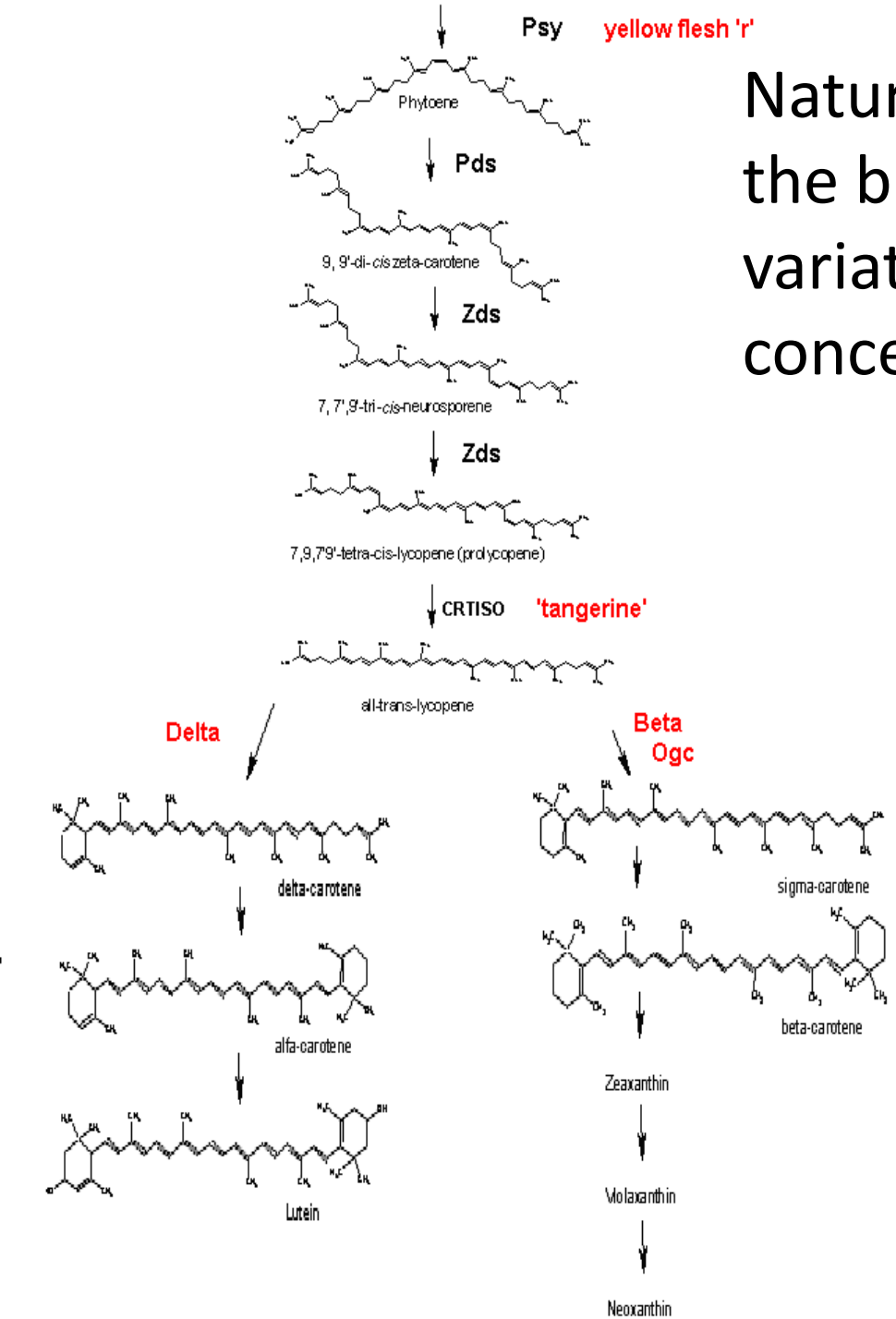
Traits for human health and nutrition

Do we know what compounds are nutrients?

(biochemical substance used by the body that must be supplied in adequate amounts and are essential for the growth of organisms)

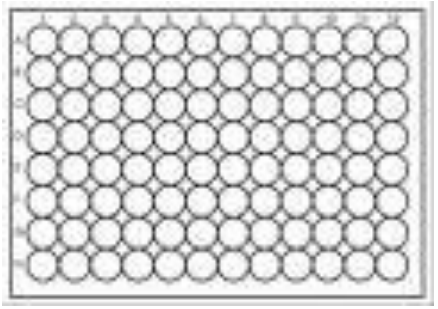
Can we measure them?

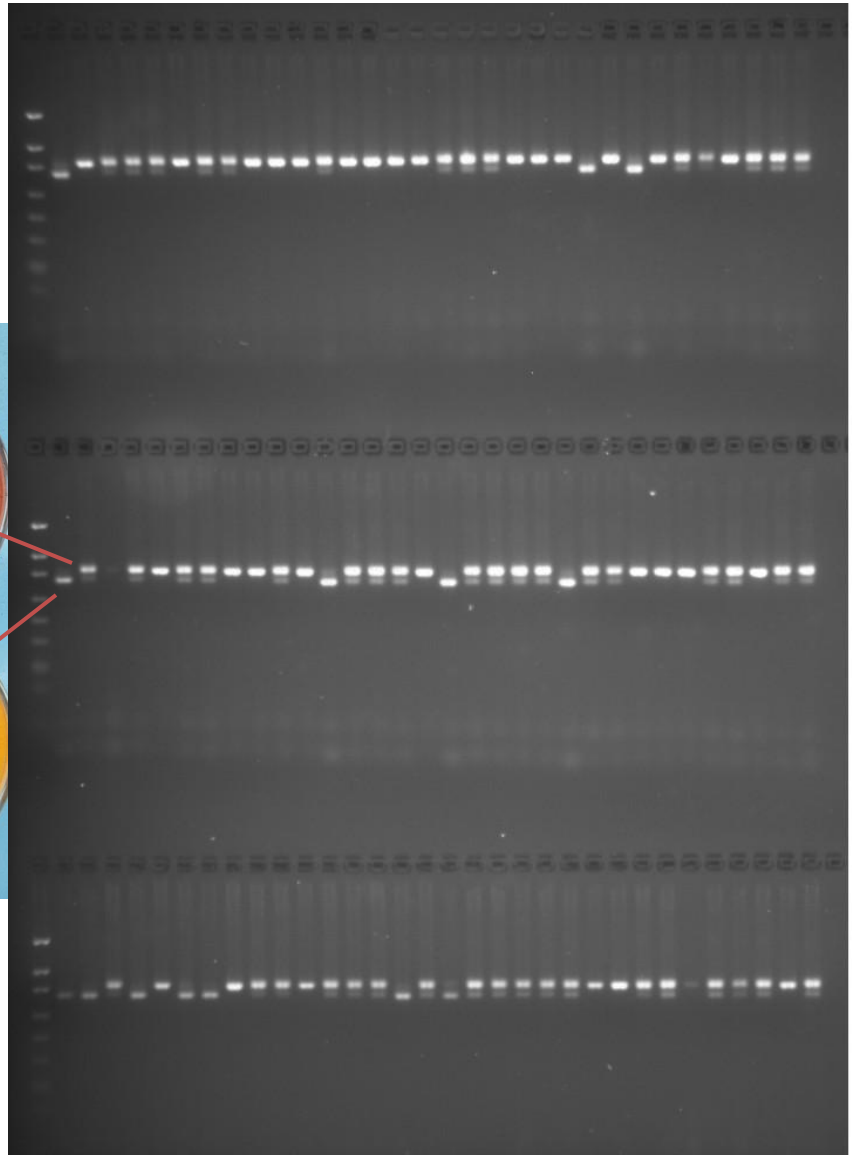
Naturally occurring variation in the biochemical pathway leads to variation in carotenoid concentration and structure



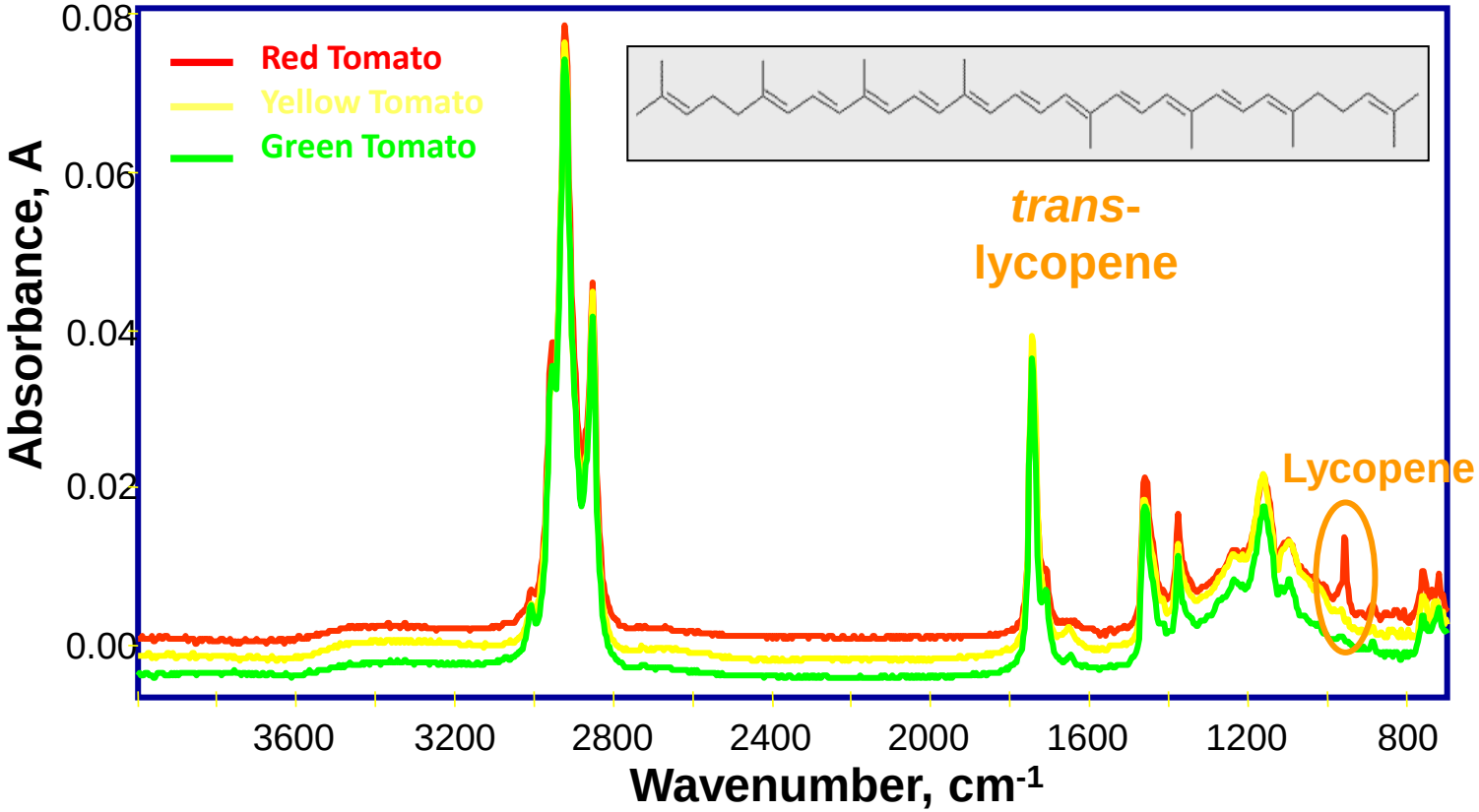
Genes in carotenoid biosynthesis pathway have been cloned and markers exist for many of the genes and alleles

Extraction of DNA

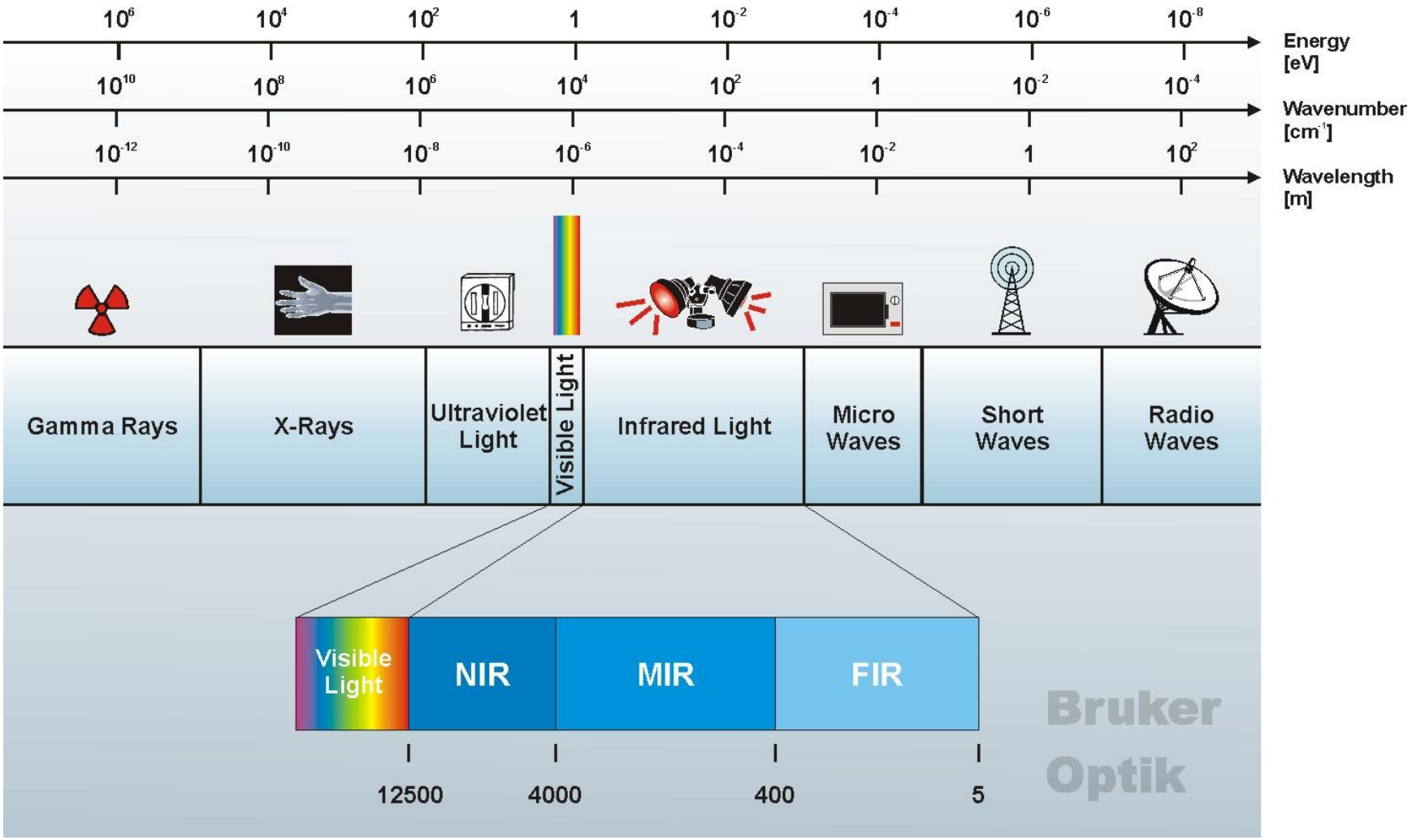




High throughput analysis of lycopene & other carotenoids using IR Spectra

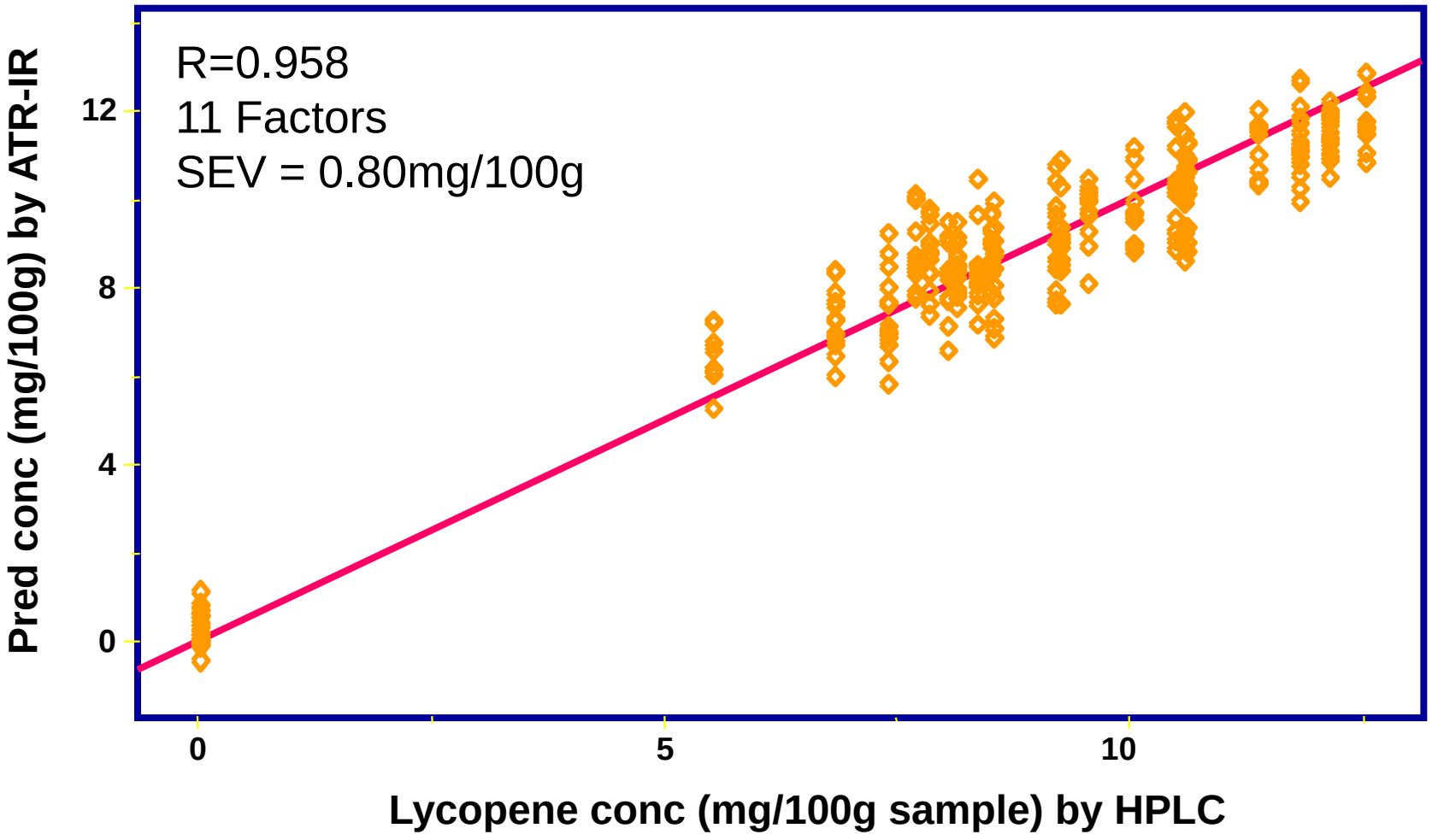


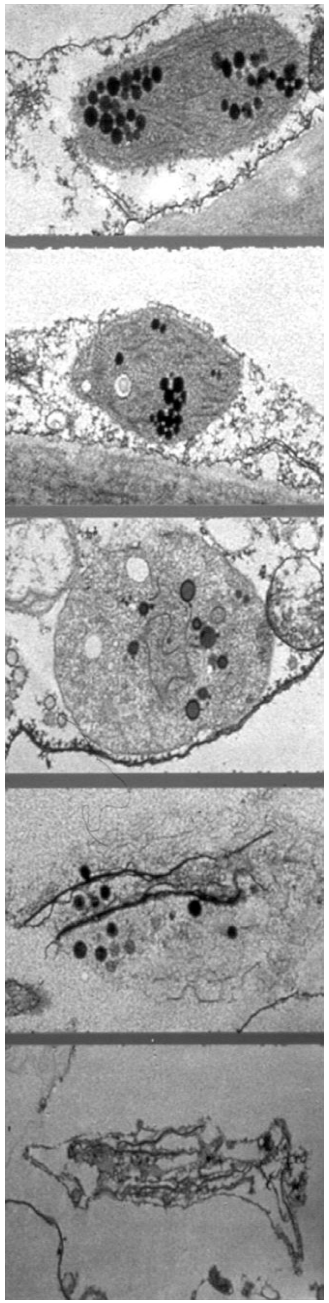
Infrared Spectroscopy



Yuwana Halim and Luis Rodriguez-Saona

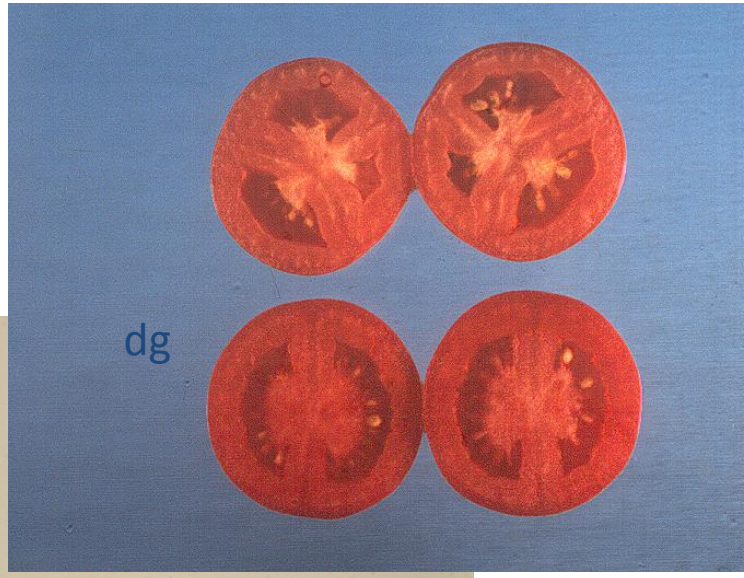
Lycopene Quantification





Genes controlling plastid density and chromoplast development affect the concentration of carotenoids

Plastid density/ structure	
Gene	**Phenotype**
hp-1	**high pigment**
hp-2(dg)	**high pigment**
gf	**green-flesh**



	Genotype						µg/g fresh weight							
Lines/Varieties	*t*	*dg*	*Beta*	*Delta*	*r*		lycopene	β-carotene	δ-carotene	tetra-*cis* lycopene	ζ-carotene	phytoene	neuro-sporene	lycopene-*cis* isomers
02-1007-3	t^{v}	*wt*	*ogc*	*wt*	*wt*		0	0	0	30.6	14.6	13.6	4.1	2.9
02-1023-1	t^{v}	*wt*	*ogc*	*wt*	*wt*		0	0	0	52.8	12.7	15.5	4.6	4.4
02-1025-1	t^{v}	*wt*	*ogc*	*wt*	*wt*		0	0	0	52.1	11.1	12	3.5	2.7
Carolina Gold	*t*	*wt*	*wt*	*wt*	*wt*		0	0	0	24.6	5.1	7.1	2.3	2
97L97	*wt*	*wt*	*Beta*	*wt*	*wt*		0	42.3	0	0	0	0	0	0
96-2472	*wt*	*wt*	*wt*	*Delta*	*wt*		15.2	0	43.5	0	0	3.1	0	0
FG99-218	*wt*	*dg*	*ogc*	*wt*	*wt*		132.7	21.7	0	0	0	0	0	0
FG03-310	t^{v}	*dg*	*ogc*	*wt*	*wt*		0	0	0	43.4	40.3	29.1	12.8	7
FG03-311	t^{v}	*dg*	*ogc*	*wt*	*wt*		0	0	0	29.6	35.1	29.1	8	4.2
FG03-301	*t*	*dg*	-	*wt*	*wt*		0	0	0	49.1	62.8	45.8	15.8	6.8
FG03-308	*wt*	*dg*	*Beta*	*wt*	*wt*		1.2	52.7	0	0	0	0	0	0
FG03-307	*wt*	*dg*	-	*Delta*	*wt*		5.1	0	45.8	0	0	0	0	0
FG03-401	*t*	*wt*	*wt*	*Delta*	*wt*		0	0	11.9	34.6	4.9	0	4.9	4.5
FG03-404	t^{v}	*wt*	-	*Delta*	*wt*		0	0	5.2	46.6	5.4	20.7	5.1	9.2
F6-232	*wt*	*wt*	*wt*	*wt*	*wt*		37.1	4.9	0	0	0	0	0	0
G1-232	*wt*	*wt*	*wt*	*wt*	*wt*		25.3	5.2	0	0	0	0	0	0
03-6336	*wt*	*wt*	*wt*	*wt*	*r*		0	0	0	0	0	0	0	0
03-7472	*wt*	*wt*	*wt*	*wt*	*r*		0	0	0	0	0	0	0	0
LSD 0.05							5.4	2.3	6.6	11.5	15	9.9	4.7	4
P-value(GLM)							<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0012

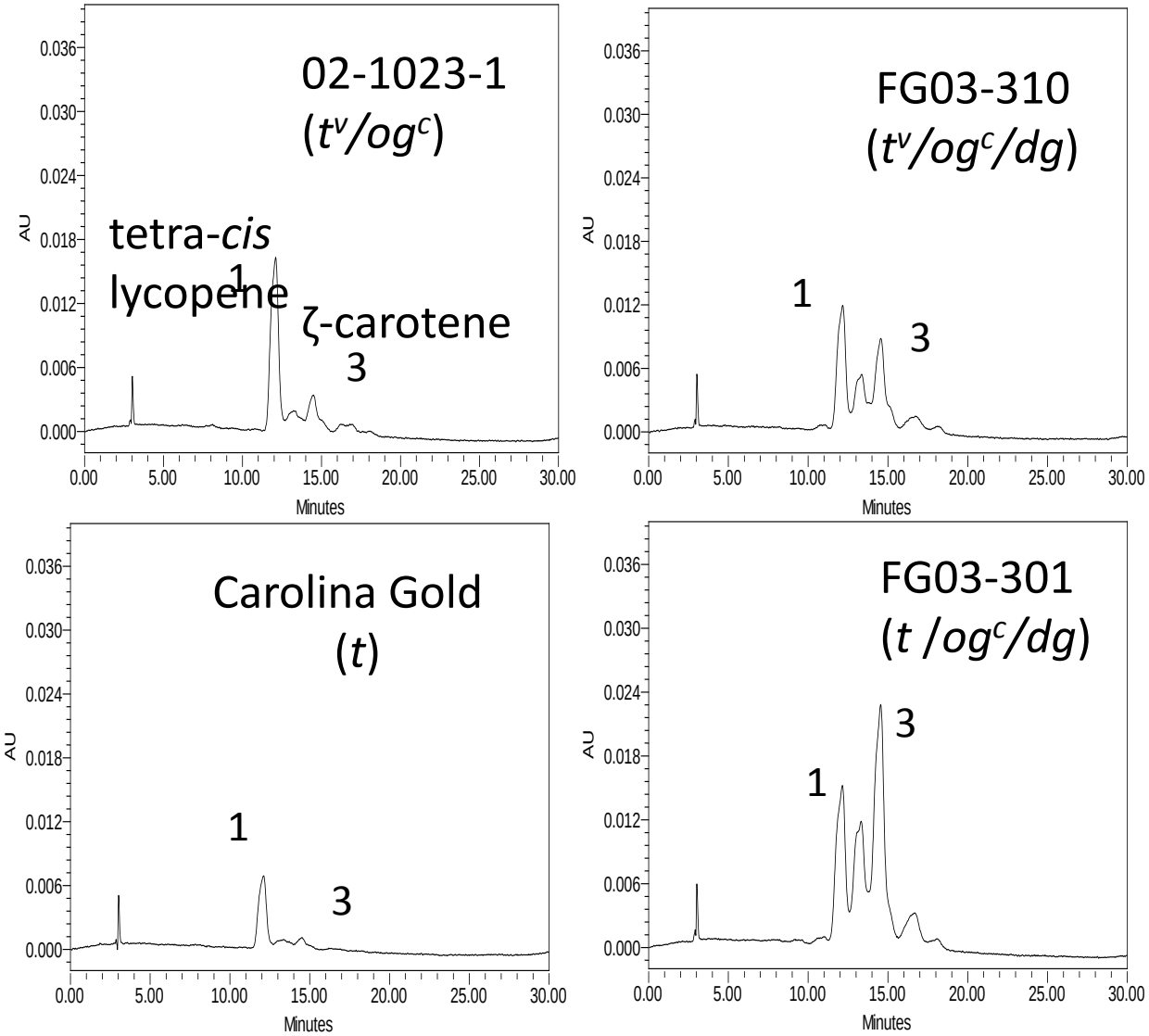
By manipulating major genes in the biochemical pathway we can obtain significant variation in carotenoid concentrations and profiles

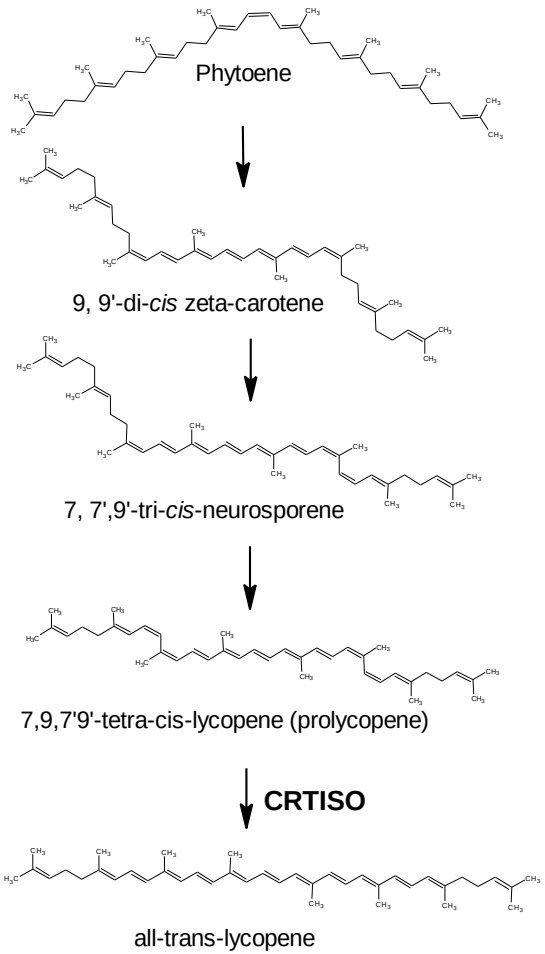
Simple genetic changes influence concentration and content of metabolite precursors in unexpected ways

	Genotype				ug/g fresh weight						
Lines/Varieties	*t*	*dg*	*ogc*		lycopene	β-carotene	tetra-*cis* lycopene	ζ-carotene	phytoene	neuro-sporene	lycopene *cis* -isomers
FG99-218	*wt*	*dg*	*ogc*		**132.7**	**21.7**	**0**	**0**	**0**	**0**	**0**
02-1007-3	t^{v}	*wt*	*ogc*		**0**	**0**	**30.6**	**14.6**	**13.6**	**4.1**	**2.9**
02-1023-1	t^{v}	*wt*	*ogc*		**0**	**0**	**52.8**	**12.7**	**15.5**	**4.6**	**4.4**
02-1025-1	t^{v}	*wt*	*ogc*		**0**	**0**	**52.1**	**11.1**	**12**	**3.5**	**2.7**
Carolina Gold	*t*	*wt*	*wt*		**0**	**0**	**24.6**	**5.1**	**7.1**	**2.3**	**2**
FG03-310	t^{v}	*dg*	*ogc*		**0**	**0**	**43.4**	**40.3**	**29.1**	**12.8**	**7**
FG03-311	t^{v}	*dg*	*ogc*		**0**	**0**	**29.6**	**35.1**	**29.1**	**8**	**4.2**
FG03-301	*t*	*dg*	*ogc*		**0**	**0**	**49.1**	**62.8**	**45.8**	**15.8**	**6.8**
LSD 0.05					**6.2**	**0.9**	**17.2**	**23.4**	**15.1**	**3.2**	**1.8**
P-value(GLM)					**<0.0001**	**<0.0001**	**0.0015**	**0.0077**	**0.0049**	**0.0001**	**0.0001**

Simple genetic changes influence concentration and content of metabolite precursors in unexpected ways

	Genotype				ug/g fresh weight						
Lines/Varieties	*t*	*dg*	*ogc*		lycopene	β-carotene	tetra-*cis* lycopene	ζ-carotene	phytoene	neuro-sporene	lycopene *cis* -isomers
FG99-218	*wt*	*dg*	*ogc*		**132.7**	**21.7**	**0**	**0**	**0**	**0**	**0**
02-1007-3	t^v	*wt*	*ogc*		**0**	**0**	**30.6**	**14.6**	**13.6**	**4.1**	**2.9**
02-1023-1	t^v	*wt*	*ogc*		**0**	**0**	**52.8**	**12.7**	**15.5**	**4.6**	**4.4**
02-1025-1	t^v	*wt*	*ogc*		**0**	**0**	**52.1**	**11.1**	**12**	**3.5**	**2.7**
Carolina Gold	*t*	*wt*	*wt*		**0**	**0**	**24.6**	**5.1**	**7.1**	**2.3**	**2**
FG03-310	t^v	*dg*	*ogc*		**0**	**0**	**43.4**	**40.3**	**29.1**	**12.8**	**7**
FG03-311	t^v	*dg*	*ogc*		**0**	**0**	**29.6**	**35.1**	**29.1**	**8**	**4.2**
FG03-301	*t*	*dg*	*ogc*		**0**	**0**	**49.1**	**62.8**	**45.8**	**15.8**	**6.8**
LSD 0.05					**6.2**	**0.9**	**17.2**	**23.4**	**15.1**	**3.2**	**1.8**
P-value(GLM)					**<0.0001**	**<0.0001**	**0.0015**	**0.0077**	**0.0049**	**0.0001**	**0.0001**

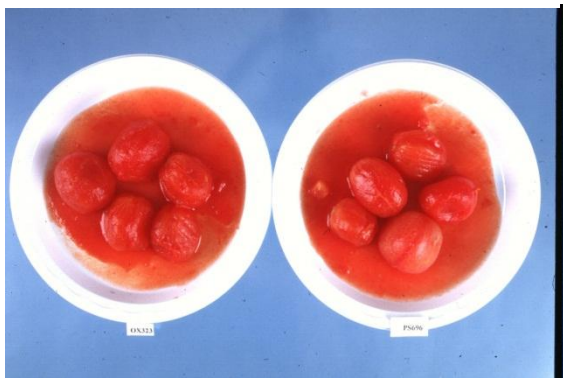


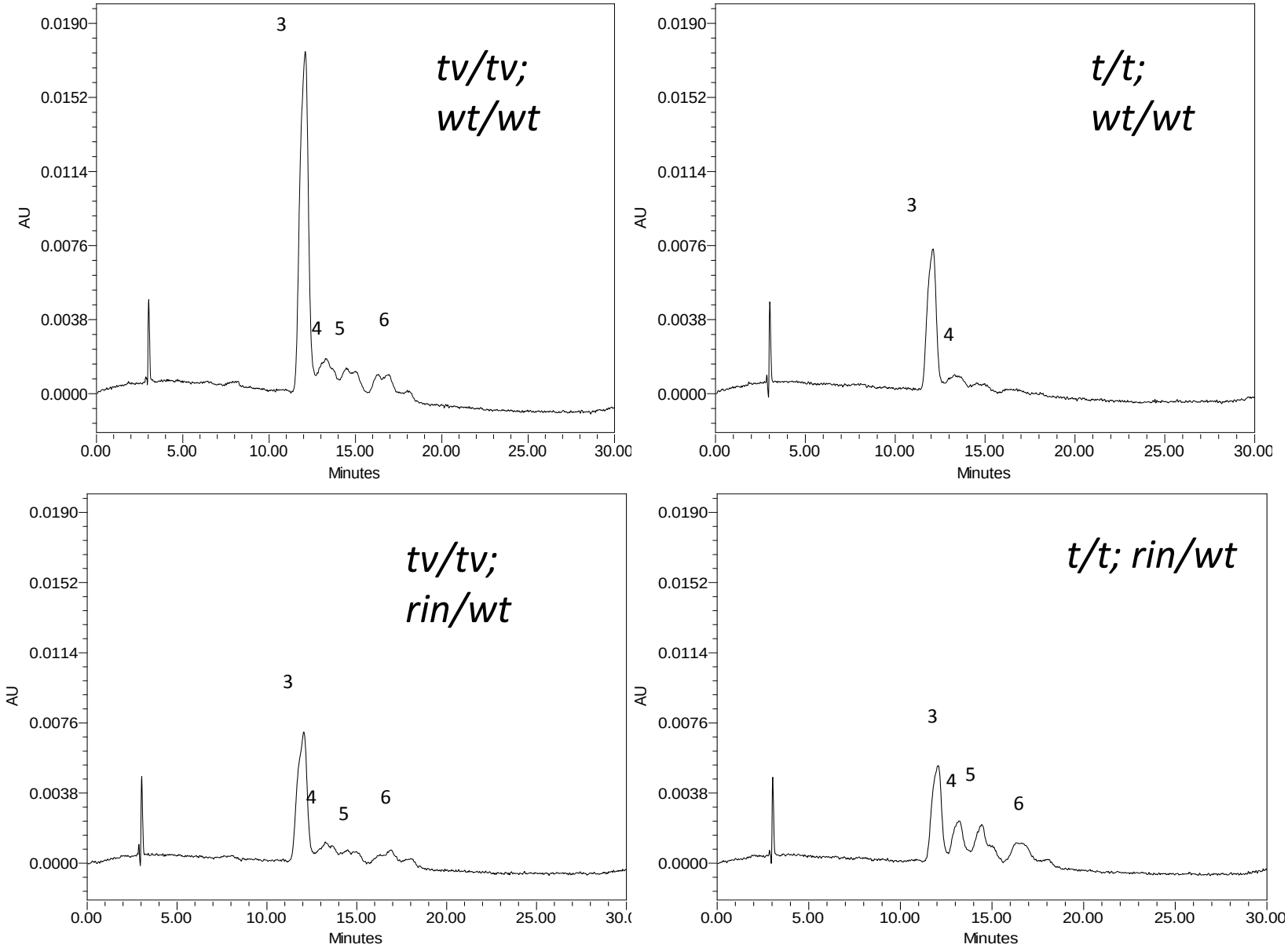


2 = phytoene 4 = neurosporene

Genetic background may influence concentration and content of target metabolites

Lines/Varieties	Genotype		µg/g fresh fruit					
	t	*rin*	tetra-*cis* lycopene	ζ-carotene	β-carotene	neuro-sporene	phytoene	*cis* -lycopene isomers
Carolina gold	*t*	*wt*	24.6	5.1	0	2.3	7.1	2
02-1007-3	t^{v}	*wt*	30.6	14.6	0	4.1	13.6	2.9
02-1023-1	t^{v}	*wt*	52.8	12.7	0	4.6	15.5	4.4
02-1025-1	t^{v}	*wt*	52.1	11.1	0	3.5	12	2.7
FG02-212	*het*	*het*	24.4	9.9	0	4.8	12.5	3.4
FG02-214	*het*	*het*	20	12.7	0	4.8	10.2	3.4
NC99471-3	*t*	*rin*	13.7	5.6	9.6	2.8	5.5	2.6
NC99471-4	*t*	*rin*	1.2	1.7	2.9	0.9	1	1.1
LSD 0.05			8.6	4.9	1.5	2.1	3.5	1.6
P-value			<0.0001	0.0027	<0.0001	0.0258	0.0002	0.0364



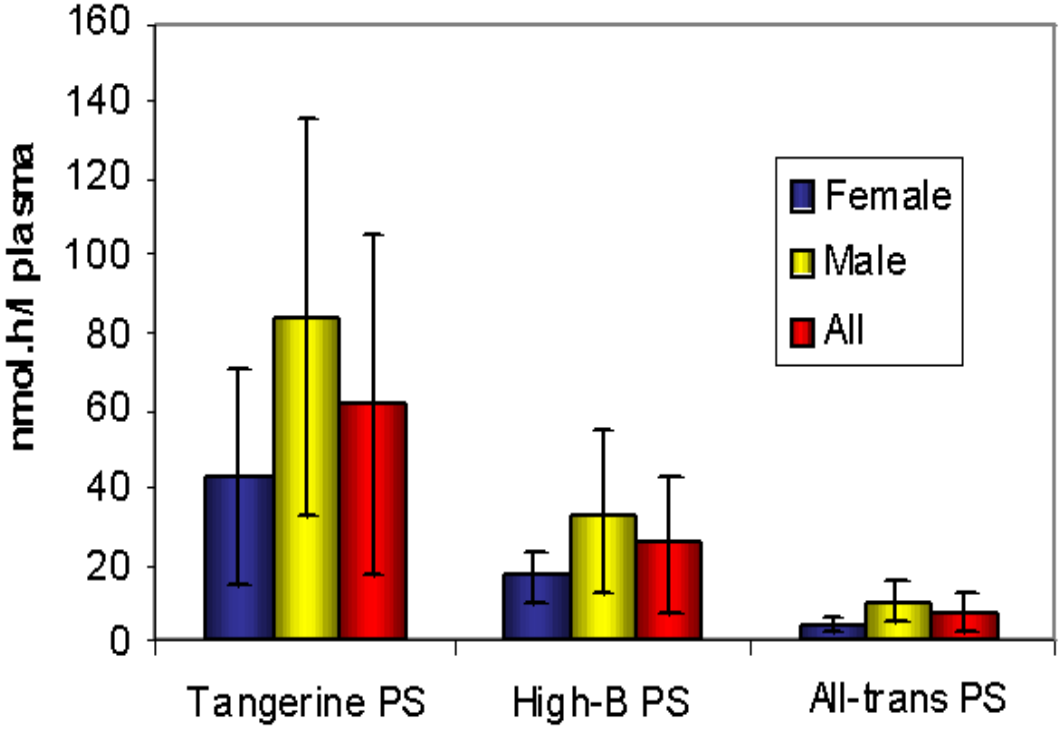


tetra-cis-lycopene (3), phytoene (4), ζ-carotene (5), & neurosporene (6)

Genetic background may influence concentration and content of target metabolites

Genotype		µg/g fresh fruit					
rin		tetra-*cis* lycopene	ζ-carotene	β-carotene	neuro-sporene	phytoene	*cis* -lycopene isomers
rin		2.9	0	8.8	0	2.2	0
het		18.4	11.8	1.2	2.8	9.4	2.3
wt		33.6	20.5	0	5.5	19.2	4.5
LSD 0.05		7.3	6.6	1.9	1.2	4.6	1
P-value		<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001

Considerations for human nutrition

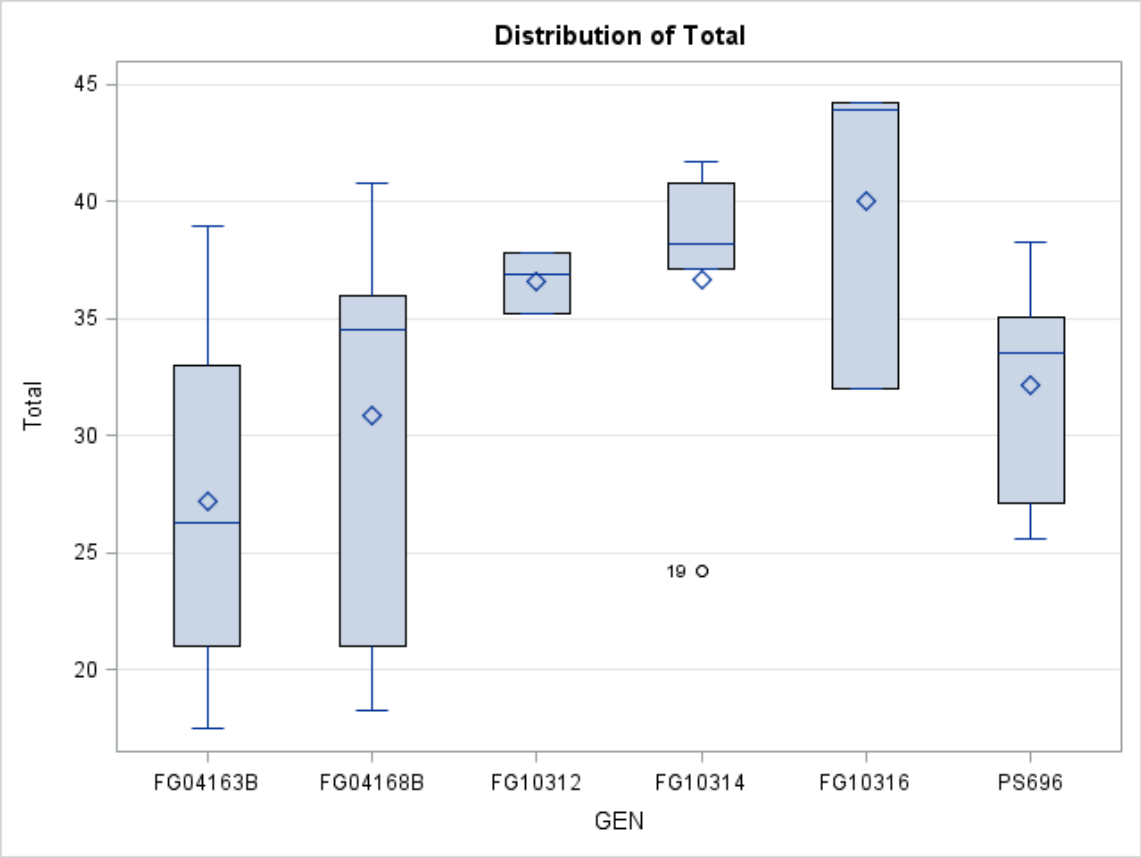


- Lycopene uptake is more efficient as part of the food matrix.
- Cis-lycopene is adsorbed more efficiently than trans-lycopene.
- High concentrations of lycopene do not increase adsorption.
- Lycopene isomers are adsorbed more efficiently by males.
- Bio-activity of cis-lycopene is unknown.

Prospects for varieties with distinct carotenoid profiles (vitamins and/or compounds with perceived health benefits)

Products based on carotenoid concentration or profile

Yield potential of cis-lycopene (tangerine) hybrids



GEN	Total LSMEAN
FG10316	38.9
FG10312	37.8
FG10314	36.7
* PS696	32.2
FG04168B	30.9
FG04163B	27.2

Source	DF	Type III SS	Mean Square	F Value	Pr > F
GEN	5	488.1607500	97.6321500	2.01	0.1233
LOC	1	33.3704167	33.3704167	0.69	0.4175
REP(LOC)	4	200.7853333	50.1963333	1.03	0.4157

A note on technology

GWS will require robust trait models. If we can't decide what we need to select for, we might find that technology is misdirecting us.

Conclusion:

Multi-trait indices can lead to improvement in specific traits

Value of quality traits remains an issue if we aim to develop robust MTI for quality

Prospects for products based on perceived health benefits exist for a focused and targetable portion of a market (i.e. niche)

Caleb Orchard, characterization of Beta-carotene material

Acknowledgments

Francis Group

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