Healthier rice: Achievements and Challenges

Christine Bergman, Ph.D., R.D.
Professor
University of Nevada Las Vegas
USA

Healthier Rice

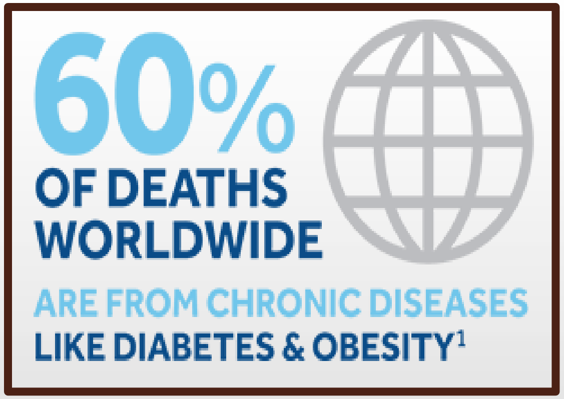
- Achievements
  - Pre-harvest management
  - Post-harvest processing
  - Traditional breeding
  - Mutation breeding
  - Genetic modification

Enhance Nutritional Properties

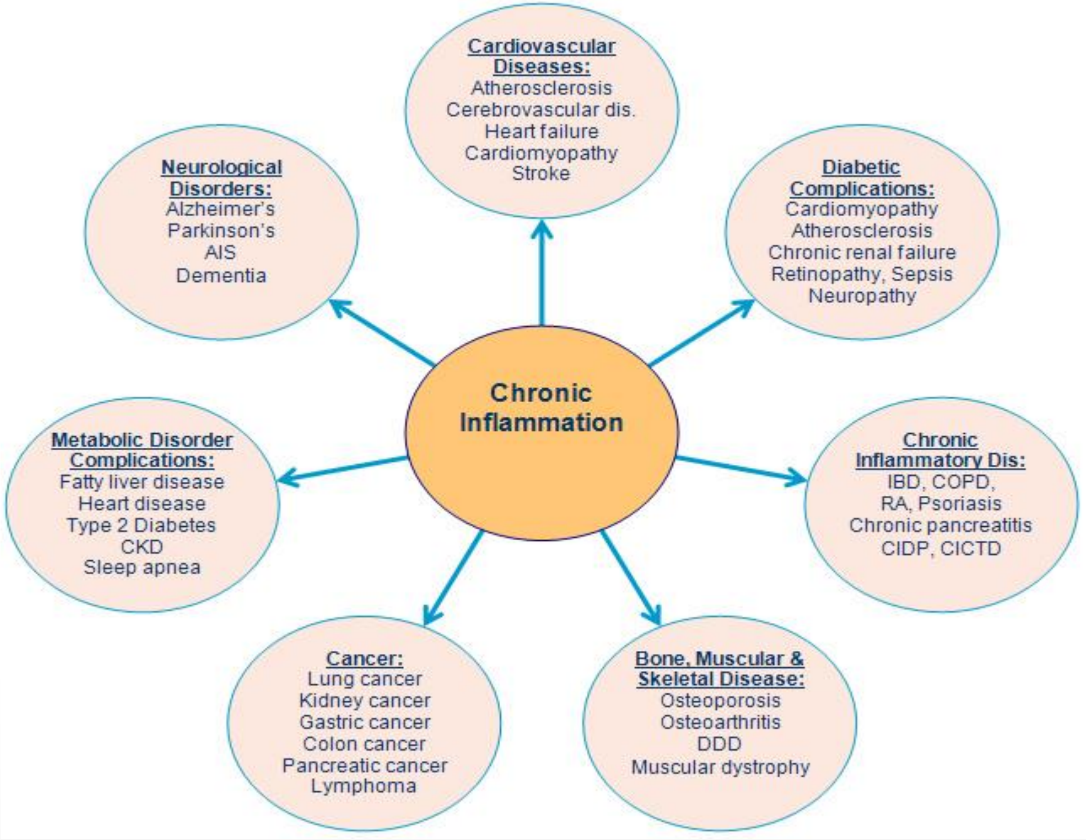
- Decrease chronic disease
- Prevent deficiency disease
- Improve well being

WHO

- **Chronic illnesses have reached global epidemic proportions**
  - Cancer
  - Heart disease
  - Diabetes
- **Cause MORE deaths than ALL other diseases combined including**
  - Malaria
  - HIV
  - Tuberculosis

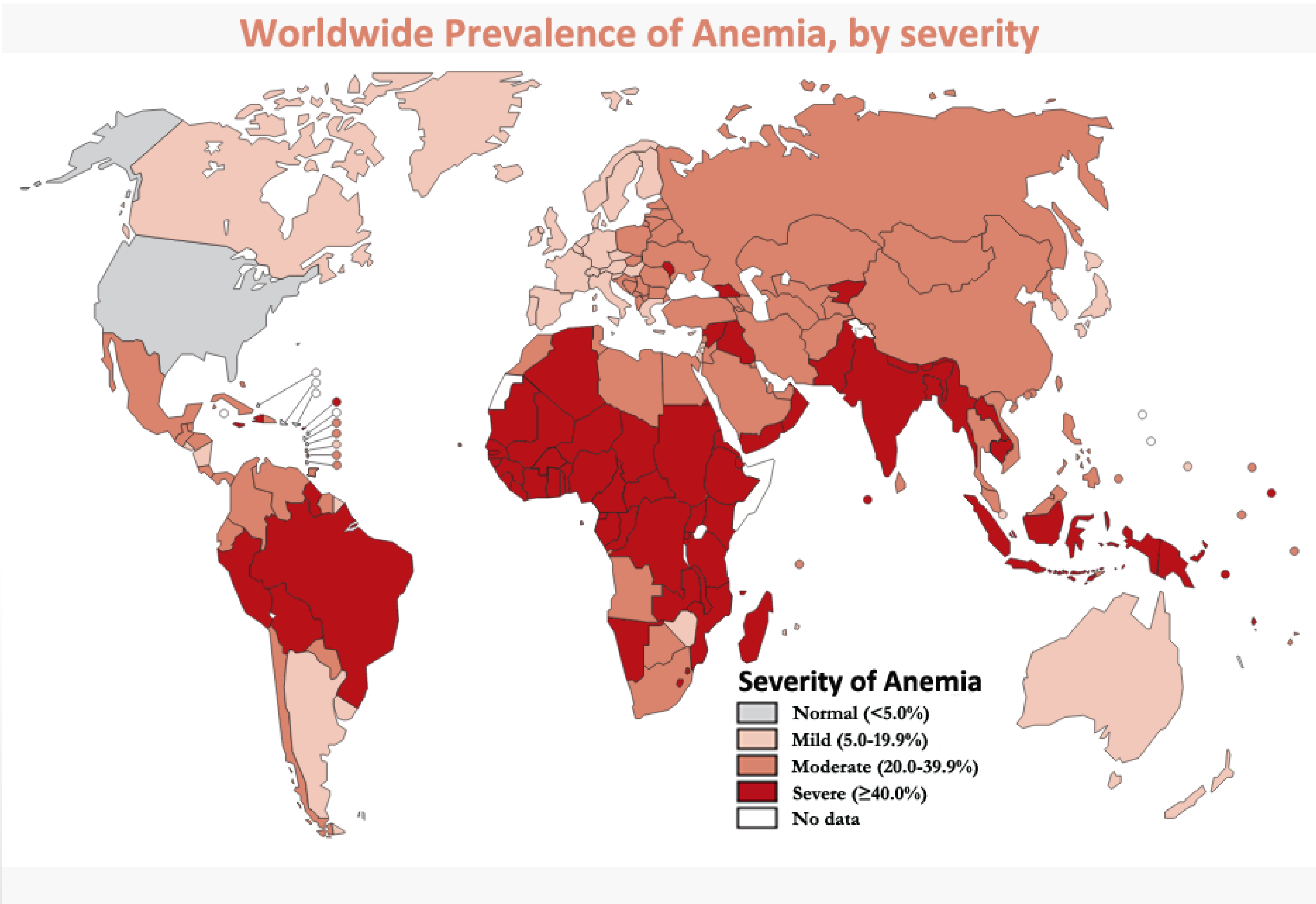


Cause or Effect?



- Diet plays a role – whole grains, fruits and vegetables, fatty fish
- Egger G. 2012. In Search of a Germ Theory Equivalent for Chronic Disease. Prev Chronic Dis 9:11.

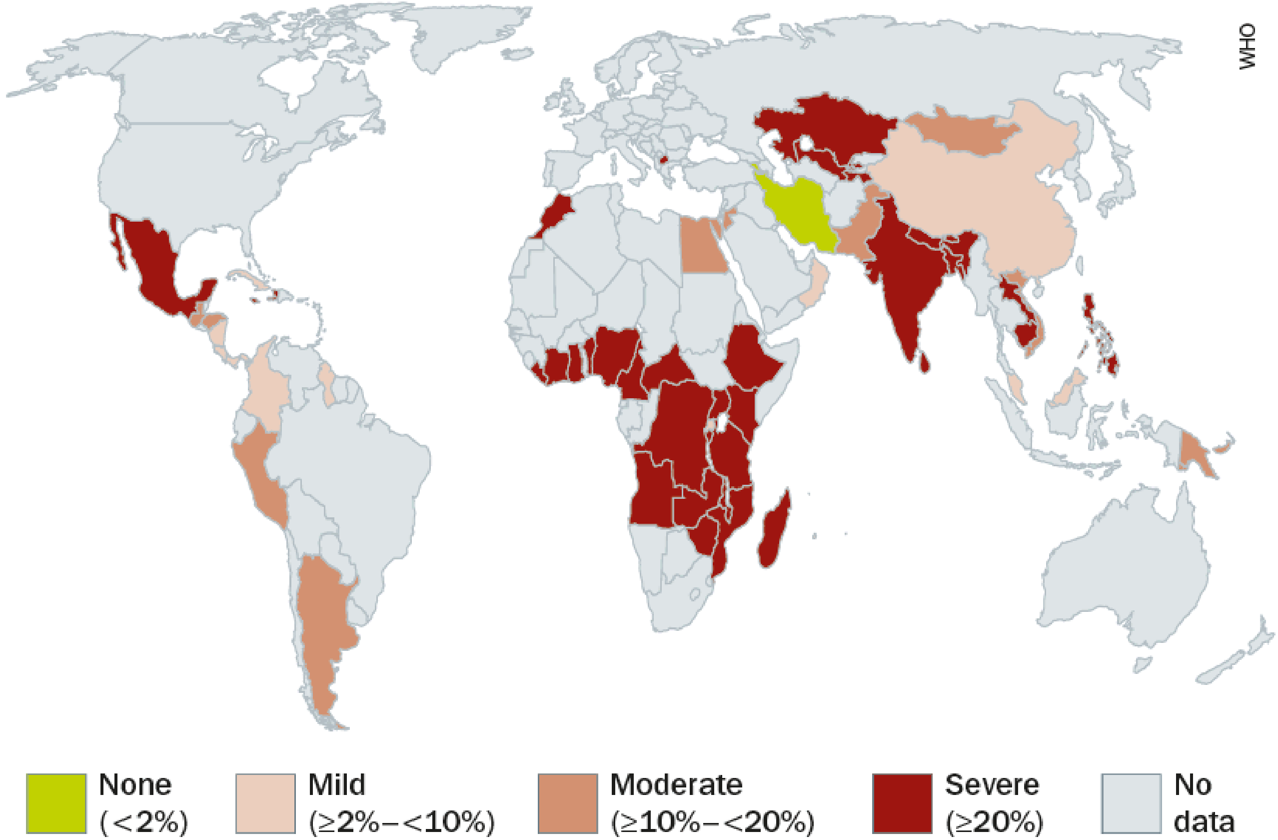
Healthier rice



WHO global estimates of anemia prevalence (2008)

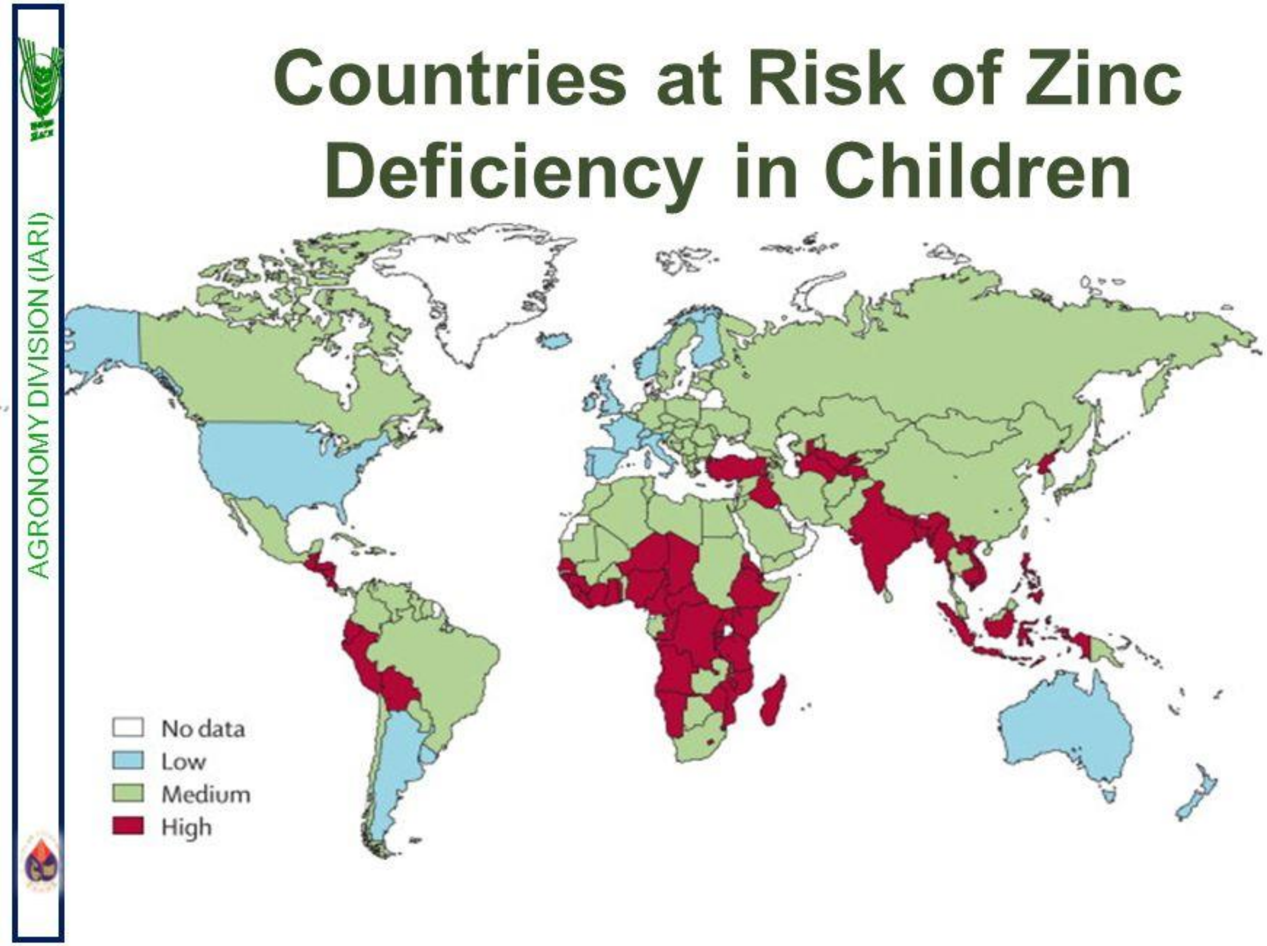
Healthier rice

Figure 1. Global extent of vitamin A deficiency as defined by prevalence of serum reinol <0.70 µmol/l in preschool children[3]



3 World Health Organization (WHO). Global prevalence of vitamin A deficiency in populations at risk 1995–2005. WHO Global Database on Vitamin A deficiency. Gen Switzerland: WHO; 2009. Available at: http://whqlibdoc.who.int/publications/2009/9789241598019_eng.pdf

Healthier Rice



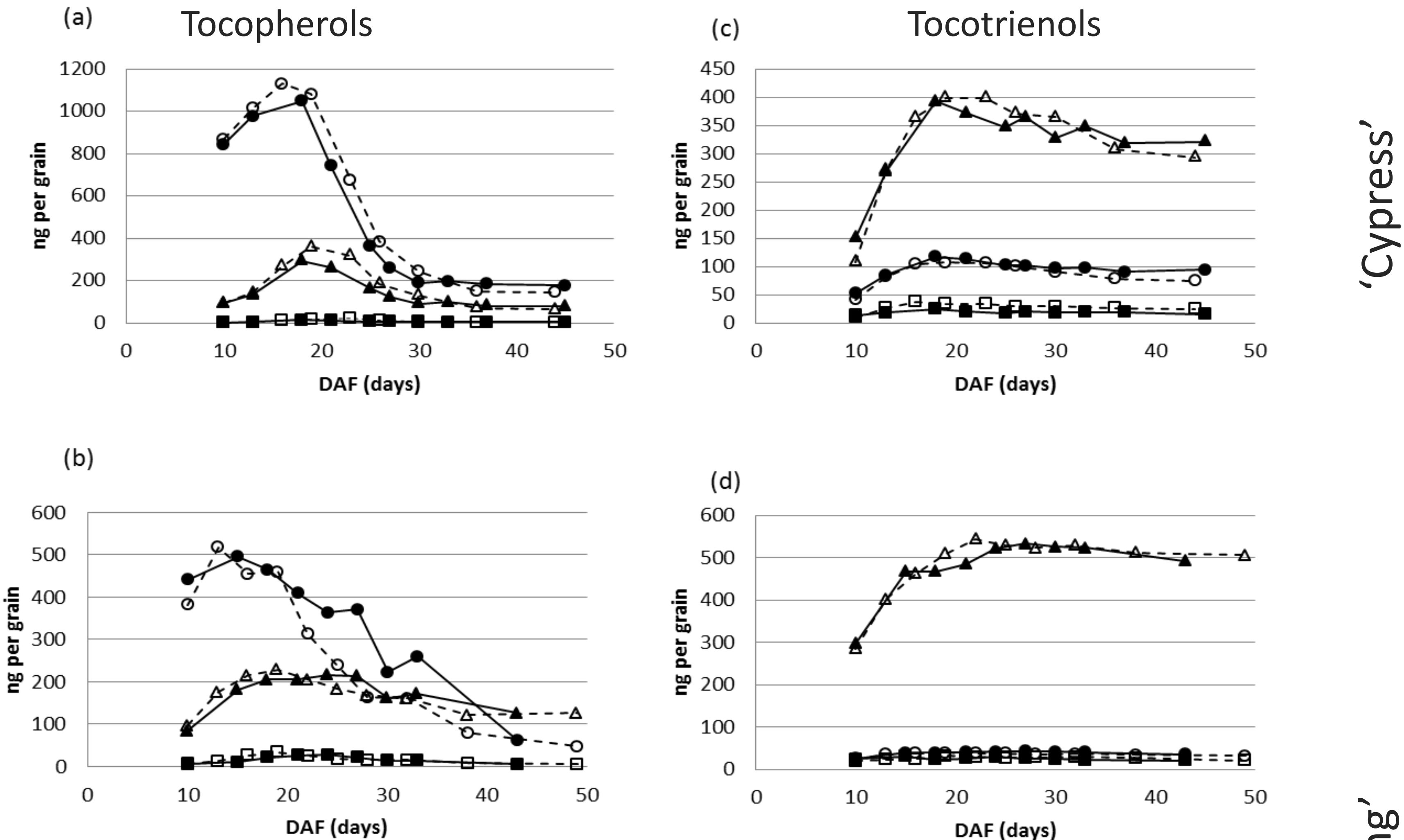
Black et al. 2008. The Lancet Maternal and Child Undernutrition Series

Pre-harvest Management

Pre-Harvest Management

Sources of Variation	$T + T_3$ [a]	Gamma-Oryzanol
Genetics (*Oryza sativa*)	3.6	2.4
Genetics (other *Oryza* species)	10.1	5.8
Growing Conditions		
Seeding Rate	No effect	No effect
Nitrogen Application	No effect	No effect
Planting Date (w/ in a Field)	1.55	1.28
Between Years	1.33	1.0

[a] Fold variation in the trait (i.e., maximum value divided by minimum value). Amount of starch in bran used to represent milling degree or the degree to which kernels broke-up during milling, thus diluting the amount of antioxidants measured.



Contents of tocopherol and tocotrienol homologues in developing grains of Cypress (a and c, respectively) and Teqing (b and d, respectively). The filled and non-filled symbols represent planting date 1 and 2, respectively. Symbols of circles, triangles and squares are α-, γ- and δ-homologues, respectively. DAF, days after flowering.

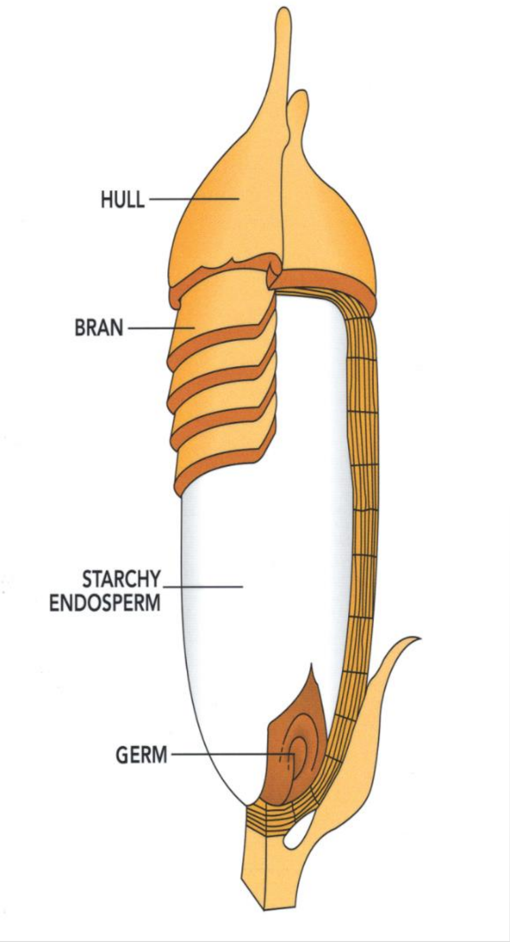
Chen and Bergman, 2005

Limitations

- There is more to know about pre-harvest effects on nutritional properties of rice
- e.g., organic production effects on mineral content
- Consumers are requiring more labeling information – difficult with variation coming from environmental effects
- Harvesting prior to maturity benefits yes but cons = different harvest and processing methods; costly.

Post-Harvest Management

- Not milled (brown)
- Under milled
- Pre-germinated Rice



Nutrient differences

	Brown Rice (one cup)	White Rice (one cup)
Calories	232	223
Protein	4.88 g	4.10 g
Carbohydrate	49.7 g	49.6 g
Fat	1.17 g	0.205 g
Dietary Fiber	3.32 g	0.74 g
Thiamin (B1)	0.176 g	0.223 g
Riboflavin (B2)	0.039 mg	0.021 mg
Niacin (B3)	2.730 mg	2.050 mg
Vitamin B6	0.294 mg	0.103 mg
Folacin	10 mcg	4.1 mcg
Vitamin E	1.4 mg	0.462 mg
Magnesium	72.2 mg	22.6 mg
Phosphorus	142 mg	57.4 mg
Potassium	137 mg	57.4 mg
Selenium	26 mg	19 mg
Zinc	1.05 mg	0.841 mg

FDA Health Claims: Brown Rice

Cardio-Disease & Some Cancers

- 1997/2008
- "Diets rich in whole grain foods and other plant foods and low in total fat, saturated fat and cholesterol may reduce the risk of heart disease and some cancers."

Type II Diabetes

- 2013
- “Whole grains may reduce the risk of type 2 diabetes, although the FDA has concluded that there is very little scientific evidence for this claim”

All rice bran isn't created equal

- Total phenolics, flavonoids and anthocyanins, and in diverse purple rice brans. More than 13-, 12-, 25- and 8-fold variations
  - Chen et al. 2017. J Cereal Science 77: 110-119
- Polyphenols reduce obesity-related oxidative stress and inflammation
  - Calcot et al. 2018. Journal of Applied Biomedicine (In press)

Whole Grain Consumption

- Indonesia, Philippines, Iran, Nigeria and a few European countries
- Brown market is projected to expand at a higher pace compared to rice market; shifting preference towards healthy eating habits
  - Diabetics
  - Fitness
  - Healthy eaters
- Increasing per capita consumption in countries where rice is not a staple expected to support the growth of the brown rice market

FMI, 2018. Brown Rice Market: Global Industry Analysis and Opportunity Assessment 2016-2026

Whole Grain Consumption

- Due to increasing demand, manufacturers are creating new brown products such as quick cooking, ready to eat and more restaurants are offering

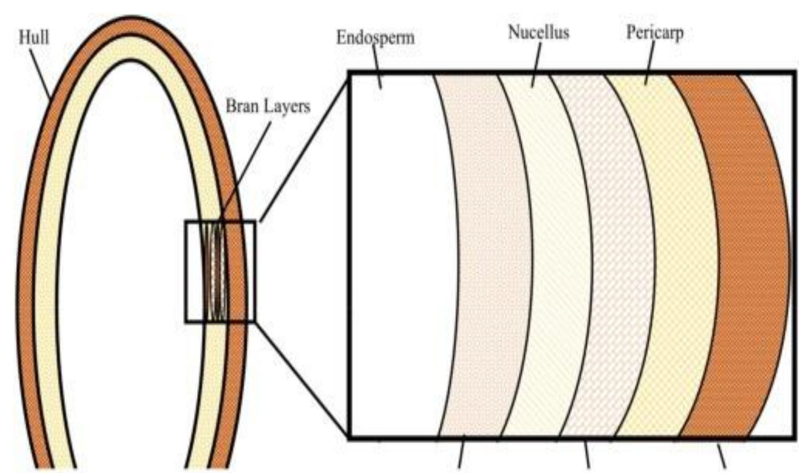
Limitations

- Consumers in less developed countries see it as poor people's food, etc.
- Developed world consumers think of it as poor tasting and don't like the texture, etc.
- More social marketing campaigns
- Teach consumers, chefs and school foodservice operators how to best prepare

Bergman et al. 2015. AACC International Abstract.

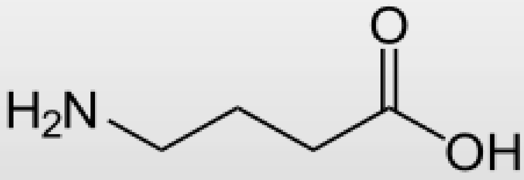
Partially Milled

- “Beige rice”
- “Gently milled”
- “Pink rice”
- Softer texture, less cooking needed
- Compromise between sensory and nutritional properties
- India – rice for diabetics
- Japan – consumers can request particular degree of milling!!!



Pre-Germinated Rice

- Whole grain rice soaked in water and allowed to begin germination
- Tremendous physicochemical changes
- “The most nutrient rice rich”
- Popularity growing in S. Korea, Japan, US
- ↓ phytic acid = ↑mineral bioavailability
- Higher levels of phytochemicals including the neurotransmitter gamma-aminobutyric acid (GABA)



Patel et al. 2011. J Food Sci Technol. 48: 661–667.
Yoto et al. 2012. Amino Acids. 43:1331-7.

Pre-Germinated Rice

- Pre-germinated rice or purified GABA
  - in-vitro (mice): High-fat diet-induced metabolic syndrome parameters improved: BP, blood glucose, serum lipid profile, inflammation indicators.
  - In-vitro (63 human, single blind, cross over): ↓ brain waves indicating stress after mental stress tasks

Yen et al. 2017. Biosci Biotechnol Biochem. 81:979-986.

Pre-Germinated Rice

Table 1A. Changes in the major phytochemical composition of Black rice during germination.

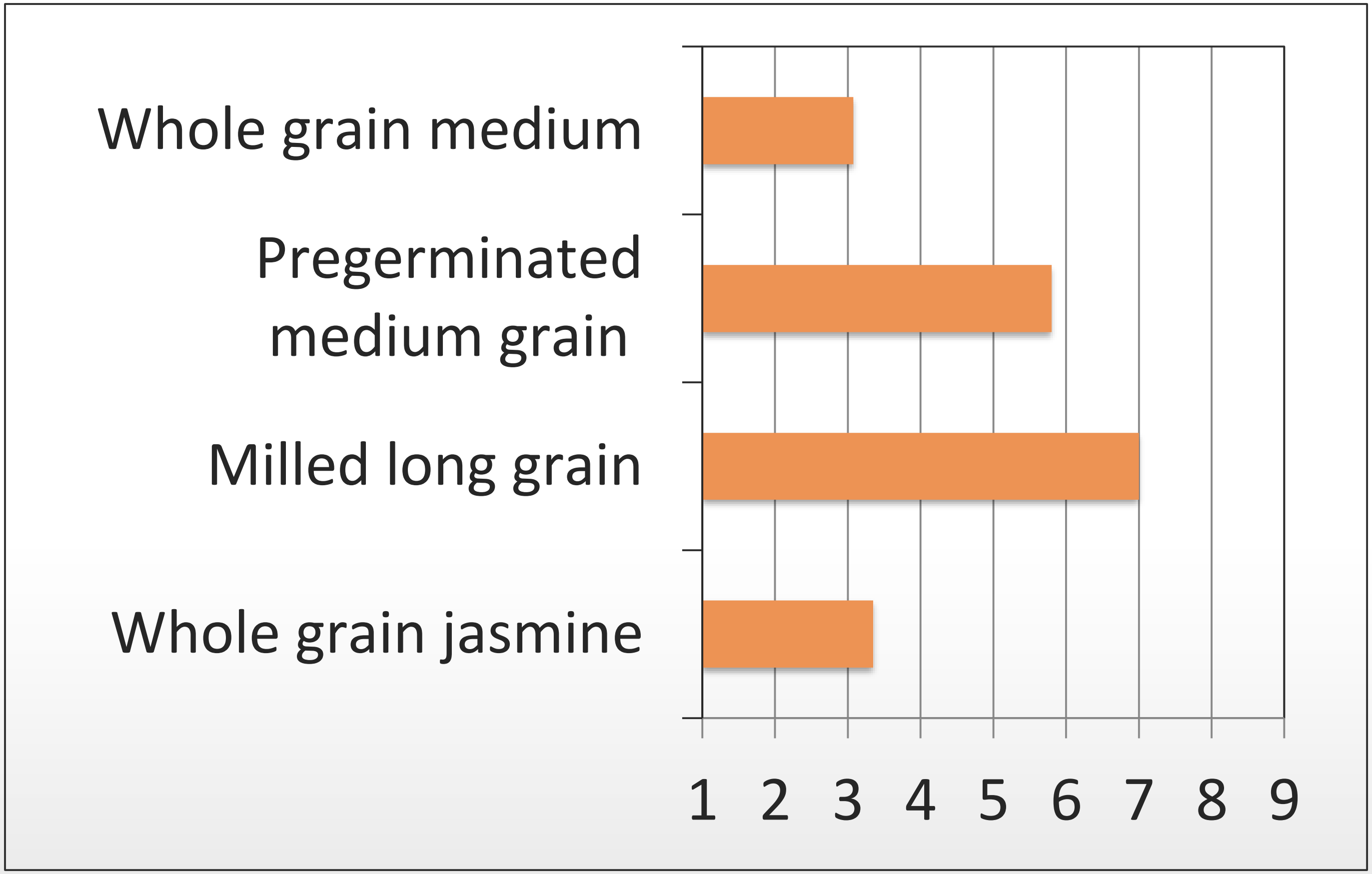
S. No.	Phytochemicals	Concentration/g of Rice (Mean ± SD)	
		Before germination	After germination
1.	*Phenolic compounds*		
	Protocatechuic acid	16.77 ± 0.85 µg	31.06 ± 1.58 µg**
	Chlorogenic acid	23.42 ± 1.78 µg	43.38 ± 2.21 µg***
	Vanillic acid	126.2 ± 6.32 µg	133.70 ± 6.82 µg*
	p-coumaric acid	54.14 ± 2.72 µg	90.27 ± 4.60 µg***
2.	*Anthocyanins*		
	Cyanidin 3-glucoside	8.12 ± 0.42 mg	15.03 ± 0.77 mg
	Peonidin 3-glucoside	276 ± 18.34 mg	311.11 ± 15.87 mg*
3.	*Tocols*		
	δ-tocotrienol	5.01 ± 0.03 µg	5.21 ± 0.27 µg
	γ-tocotrienol	11.05 ± 0.06 µg	11.82 ± 0.60 µg
4.	Gamma-Amino Butyric acid (GABA)	4.4 ± 0.23 µg	202.90 ± 4.35 µg***

$*P \leq 0.05$; $**P \leq 0.005$; $***P \leq 0.001$.

Optimized Process for GABA: 12 hr soaking, pH 7, 36 hr sprouting

Chaiyasut et al. 2017. Food Sci. Technol, Campinas, 37: 83-93

Mexican style rice – Degree of Liking



Bergman et al. 2014. AACC International Annual Meeting.

Pre-Germinated Rice

- Challenges
  - Water needed for growth
  - Energy use for drying
  - Differences in functional and sensory properties
  - GABA levels are maintained at cooler temperatures
  - Consumers need to learn about its benefits and how to prepare it

Limitations

- Studies frequently don’t control for differences in degree of milling – genotype differences can be confounded
- Brown rice is susceptible to rancidity
- Many studies focused on antioxidant activity: yet this hypothesis has yet to be well substantiated – anti-inflammatory effects are better supported but still not a strong as the “germ theory”. Is it cause or effect?
- Most traits haven’t been studied in-vivo in well designed human based clinical trials
- Those designed well are short in duration – is there a physiological adaptation unknown?

Traditional Breeding Techniques

- Compounds with the potential for enhancement
  - Fatty acid profile
  - Simple phenolics types and quantities
  - Polyphenolics types and quantities
  - Tocopherols and tocotrienols percentages and amounts
  - Gamma oryzanol compounds and amounts
  - **Resistant starch amount**

Resistant Starch

- Medical community recommending reduced CHO consumption by pre- and diabetics
- Not all starch is the same
- Resistant starch isn’t hydrolyzed in small intestine but passes to large:
  - no effect on BS
  - Increased satiety
  - ↓ risk of colon cancer
- AOAC method agrees well with RS values obtained through ileostomy studies

Resistant Starch

- 40 high amylose rice genotypes
- 1.9-fold variation in RS found
- Some had > 2 fold more RS typical US long grains
- Amylose and pasting temperature were strong predictors of resistant starch
- Cooking methods did not alter resistant starch concentrations (1:2 ratio and excel water)

Chen et al. 2017. Food Chem. 234:180-189

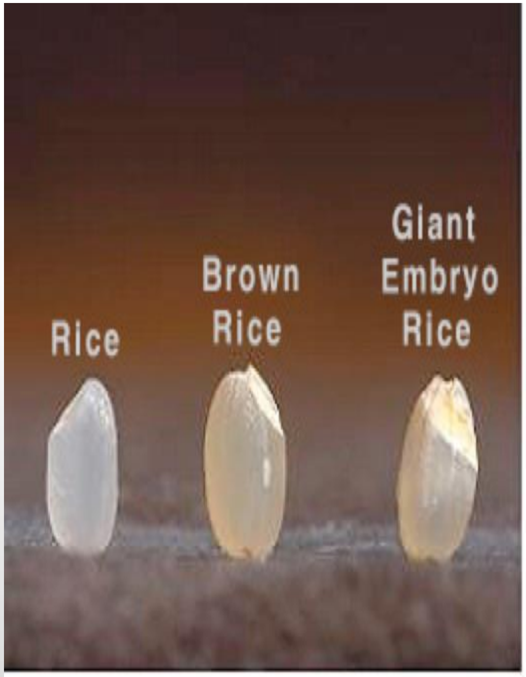
Resistant Starch

Table 1. Resistant starch concentration in cooked rice using a 1:2 (w:v) rice to water ratio and a 20-min cooking time.

SampleName[1]	COUNTRY	Structure	Apparent amylose type[2]	Viscosity type[3]	Gel temp type[4]	Viscosity_GT haplotype	Resistant starch (%)	
DALIDAO	China	IND	High	Strong	Low	Strong_Low	4.46	A
Santa Julia	Colombia	IND	High	Weak	Int	Weak_Int	4.33	AB
KN-1 B-361-BLK-2	Indonesia	IND	High	Strong	Int	Strong_Int	4.28	ABC
Ghoal Champa	Iran	IND	High	Weak	Int	Weak_Int	4.13	BCD
Tsipala 421	Madagascar	IND	High	Weak	Int	Weak_Int	4.13	BCD
Vary Vato 462	Madagascar	ADMIX_I	High	Weak	Int	Weak_Int	4.07	BCD
Jaya	India	IND	High	Strong	Low	Strong_Low	4.04	BCDE
CNTLR80076-44-1-1-1	Thailand	IND	High	Weak	Int	Weak_Int	3.96	CDEF
Rojofotsy 738	Madagascar	ADMIX_I	High	Weak	Int	Weak_Int	3.93	DEF
Sapundali Local	India	IND	High	Weak	Int	Weak_Int	3.84	DEFG
Ghati Kamma Nangarhar	Afghanistan	AUS	High	Weak	Int	Weak_Int	3.74	EFGH
EL Paso L-144	Uruguay	IND	High	Strong	Low	Strong_Low	3.73	EFGHI
ECIA76-S89-1	Cuba	IND	High	Strong/Wea	Low	Strong/Weak_Low	3.67	FGHI

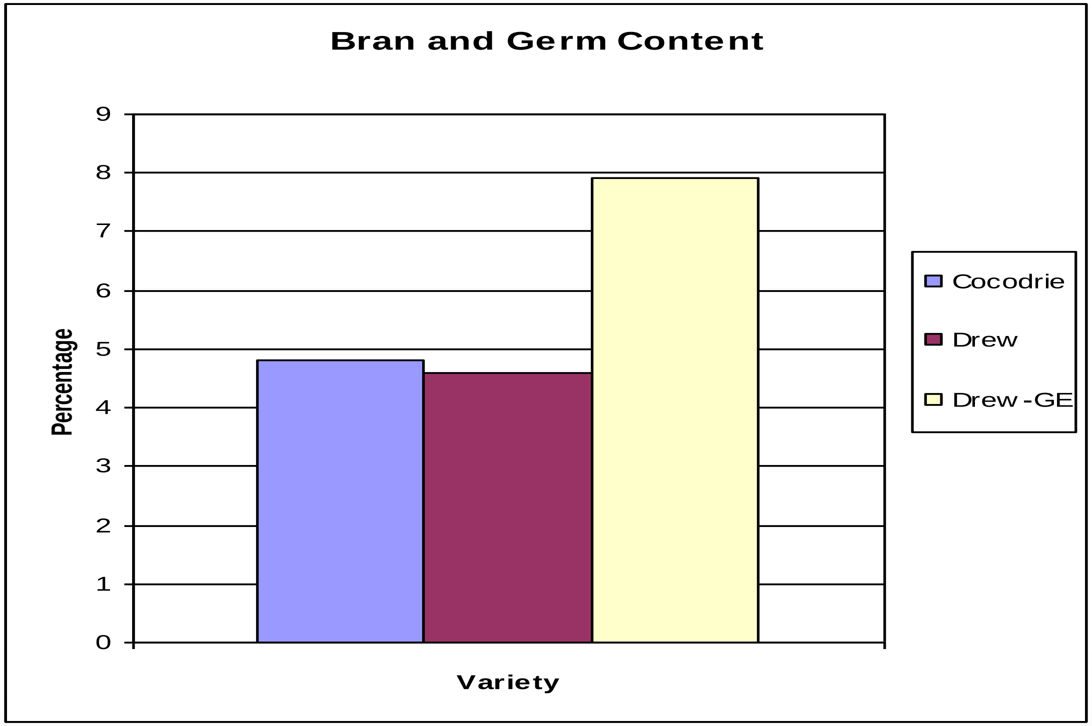
Mutation Breeding

- Gamma ray mutation
- Giant embryo mutant developed from the US cultivar Drew
- Study evaluated Drew, its mutant and 'Cocodrie'



Bergman et al. 2012. Rice Technical Working Group Abstract 4487.

Giant Embryo



- ~ 2x more bran and germ as a % of endosperm
- Closer in proportion to the amount of bran and germ in wheat

Limitations

- Agronomics need improvement
- Segregation/identity preservation techniques
- An industry partner is likely needed to support the development of nutritionally enhanced genotypes
- Such partnerships have occurred. e.g., Industry partners and the USDA
  - Quality suitable for canning and steam table stability
  - Brown rice that combined with a patented process results in quick cooking rice

Genetic Engineering

- First generation
  - Disease, insect resistance
- **Second generation**
  - **End-use and nutritional quality traits**
  - **Traits with limited potential for enhancement using genetic variation**
  - **Folate, beta carotene, Zn, Fe**
- Third generation
  - Pharmaceuticals, other industrial compounds

High Beta-Carotene Rice Update

- **Substitution Study**
  - Substitution of biofortified rice for white rice in an optimistic scenario (70% substitution)
  - would ↓ the prevalence of vitamin A inadequacy 78% in women and 71% in children in Bangladesh
  - De Moura et al. 2016. Amer J of Clinical Nutr, 104: 769–775
- **Safety trial**
  - Standard toxicology evaluation – histopathology, hematology and blood biochemistry
  - Lack of biologically meaningful unintended effects
  - Wu et al. 2017. Regulatory Toxicology and Pharmacology 88: 66-71

High Fe and Zn

- IR68144 (indica): insertion of soybean ferritin gene under the control of the endosperm specific glutelin promoter
- Increased Fe and Zn in the endosperm - only changes identified
- GRAS in the US

Table 2
Mineral content of ferritin rice and IR68144 rice.

Mineral (mg/100 g)	Brown rice			Milled rice		
	IR68144	Ferritin rice	Ref. range[b]	IR68144	Ferritin rice	Ref. range[b]
Sodium	2.65 ± 0.08	2.63 ± 0.17	2–40	1.65 ± 0.11	1.77 ± 0.05	0.6–10
Potassium	290.83 ± 6.56	289.5 ± 1.04	70–320	251.73 ± 5.24	252.8 ± 3.08	80–150
Copper	0.32 ± 0.01[a]	0.35 ± 0.004	0.1–0.7	0.29 ± 0.004	0.29 ± 0.02	0.2–0.3
Manganese	1.77 ± 0.01[a]	1.98 ± 0.05	0.2–4.2	1.22 ± 0.01	1.29 ± 0.03	0.7–2.0
Magnesium	110.5 ± 1.60	104.7 ± 1.66	20–170	[illegible] ± 1.30	83.6 ± 0.87	20–60
Iron	1.57 ± 0.02[a]	2.01 ± 0.04	0.2–6.0	0.65 ± 0.01[a]	1.6 ± 0.01	0.2–3.3
Zinc	3.01 ± 0.02[a]	3.35 ± 0.03	0.7–3.3	2.34 ± 0.06[a]	2.75 ± 0.02	0.7–2.7

Values are mean ± SEM. n = 3.
[a] IR68144 rice values were significantly different from ferritin rice at $p < 0.05$.
[b] Source: OECD (2004).

Gayen et al. 2013. Food Chemistry 138: 835–840

Limitations

- Genetics is moving faster than our understanding of health beneficial phenotypes and our ability to quantify them
  - Proteomics, metabolomics, etc.
- Understanding of rice components is ahead of our confidence in their effects on human health
- We need more clinical trials!!!

- Consumer acceptance of genetically modified rice needs to increase
- The Nobel Laureates’ (n=129) Campaign Supporting GMOs for the benefit of the developing world, specially addressing Green Parties and consumers
  - Roberts 2018. Journal of Innovation & Knowledge (In press)

Future

- With CRSPR Cas9 genome editing technology “the sky is the limit”
- Increase a trait, decrease it, or modify it
- Multi-biofortification approach more likely to occur in the future
- Geneticists, nutritionists, food scientists and public health educators must work together to create and promote *healthier rice*

Collaborators

- Ming Chen
- Anna McClung
- Shannon Pinson
- Jeff Shen
- Andrew Moreo

USDA

UNLV
UNIVERSITY OF NEVADA LAS VEGAS

FIU FLORIDA INTERNATIONAL UNIVERSITY

- Thank you conference organizers for the kind offer to come and speak with you about <u>*Healthier Rice*</u>

What will rice look like in 50 years? Similar to today.

But, hopefully, however, healthier to be able to meet the nutritional needs of our growing human population………….