"Plant Biotechnology for Sustainability and Global Economy"
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Plants for food and health: biofortification

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PlanTech

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Who am I

- Plant Biologist and Plant Geneticist
- Assistant Professor at Faculty of Biotechnology, Catholic University of Portugal
- Chief Editor of Frontiers in Plant Nutrition
- Head of the PlanTech lab

My passion: understand how nutrients are taken up or synthesized in plant foods and to understand **how we can "trick" plants into storing more of these nutrients in their edible organs.**

My "expertise"

Biofortified rice | Fe Reductase | Novel transporters | Transcriptome | Remobilization | Cultivar variability | - CO_2 + O_2 - QTLs | New Projects

1999 – 2003 – 2004 – 2006 – 2007 – 2008 – 2010 – 2012 – 2013 – 2014 – 2015 – 2016

- Genetic diversity of rice **(Breed.)**
- Fe and Zn enriched rice **(Plant Science)**
- Fe reductase in rice **(Soil Sci Plant Nut)**
- Overexpressed Fe red soybean **(Planta)**
- Genes Fe uptake accumulation **(Plant Physiol Biochem.)**
- Novel class oligopeptide transporters rice, Fe, Zn, Mn **(Rice)**
- Root transcriptome rice Fe, Zn **(J Plant Biochem Biotech)**
- Transcriptomics Fe legumes **(Food Res Int)**
- Cultivar variability **(Plant Physiol Biochem)**
- Genetic diversity**(Front Plant Sci)**
- High RH Minerals **(Front Plant Sci)**
- Morpho-physiol traits soybean **(Plant Soil)**
- Minerals bean **(Front Plant Sci)**
- Mineral partitioning remobilization (Rice)
- Protein, phytochemicals **(Food Chem, J Food Sci Technol)**
- Controlled Atmosphere (CO_2 and O_2) **(LWT-Food Sci Tech)**
- QTLs for better stomatal functioning **(Mol Breed)**

IRRI

BCM
Baylor College of Medicine

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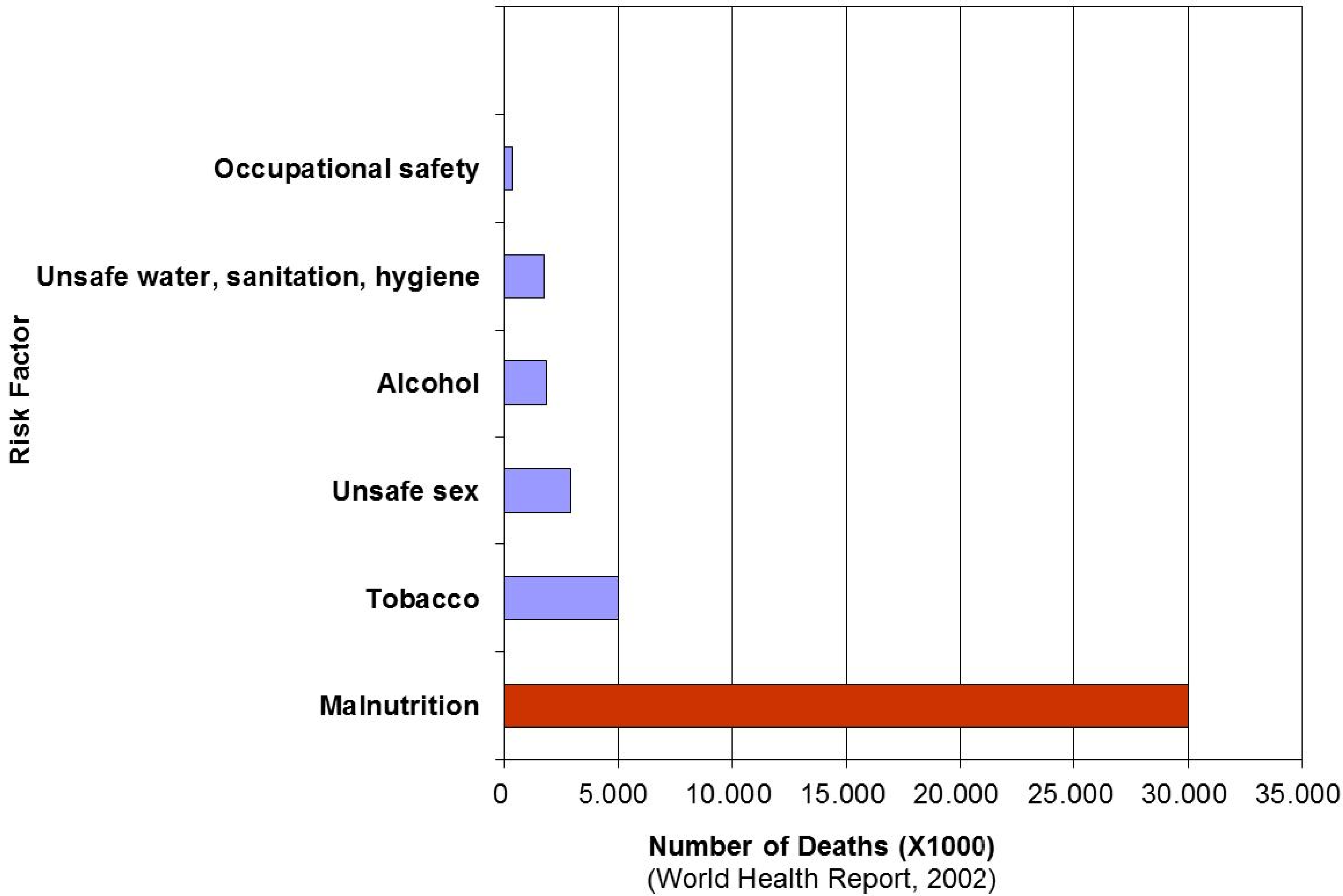
Essential nutrients for proper health

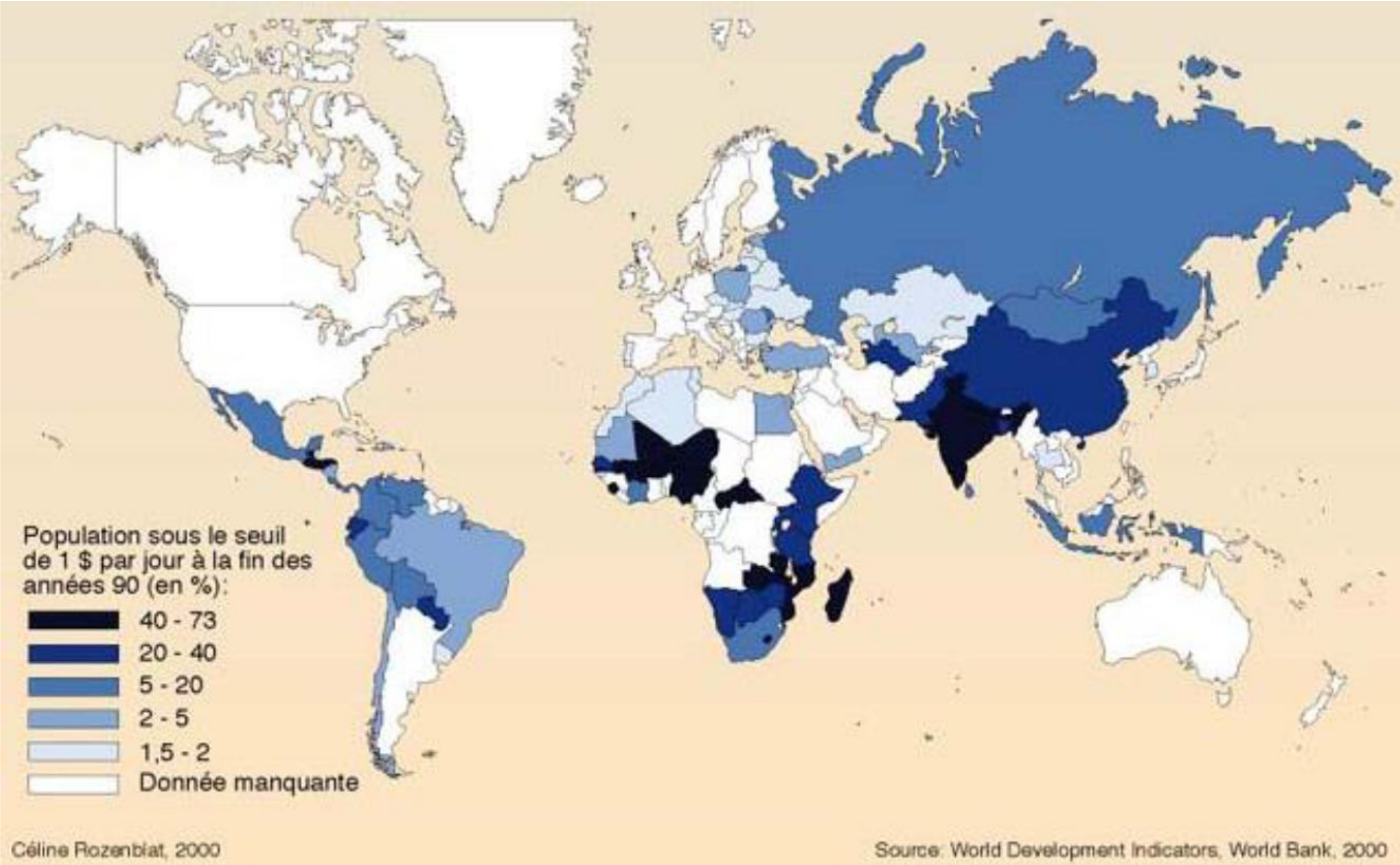
Vitamins		Minerals		
Water soluble	*Fat soluble*	*Macrominerals (100 mg or more)*	*Microminerals (<15 mg)*	*Ultra-trace minerals(µg)*
Vitamin B6	Vitamin A	P	Zn	Cu
Vitamin B_2	Vitamin D	Ca	Fe	I
Vitamin B_1	Vitamin K	Mg	S	Mo
Vitamin B_{12}-Niacin	Vitamin E		F	Se
Vitamin C			Mn	Cr
Biotin			B	B
Vitamin B_3			K	Co
Folic acid				

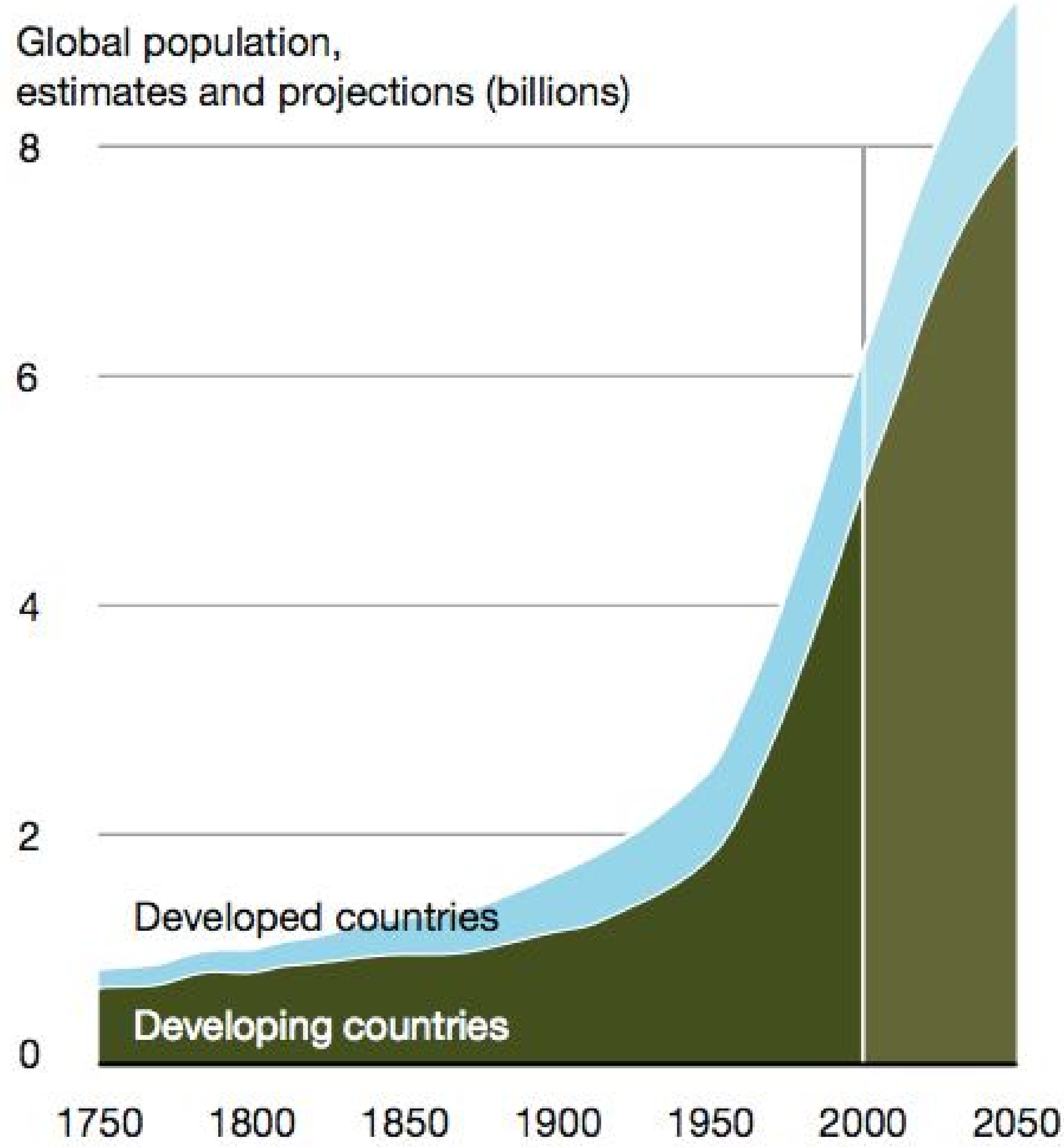
WHO Major Risk Factors



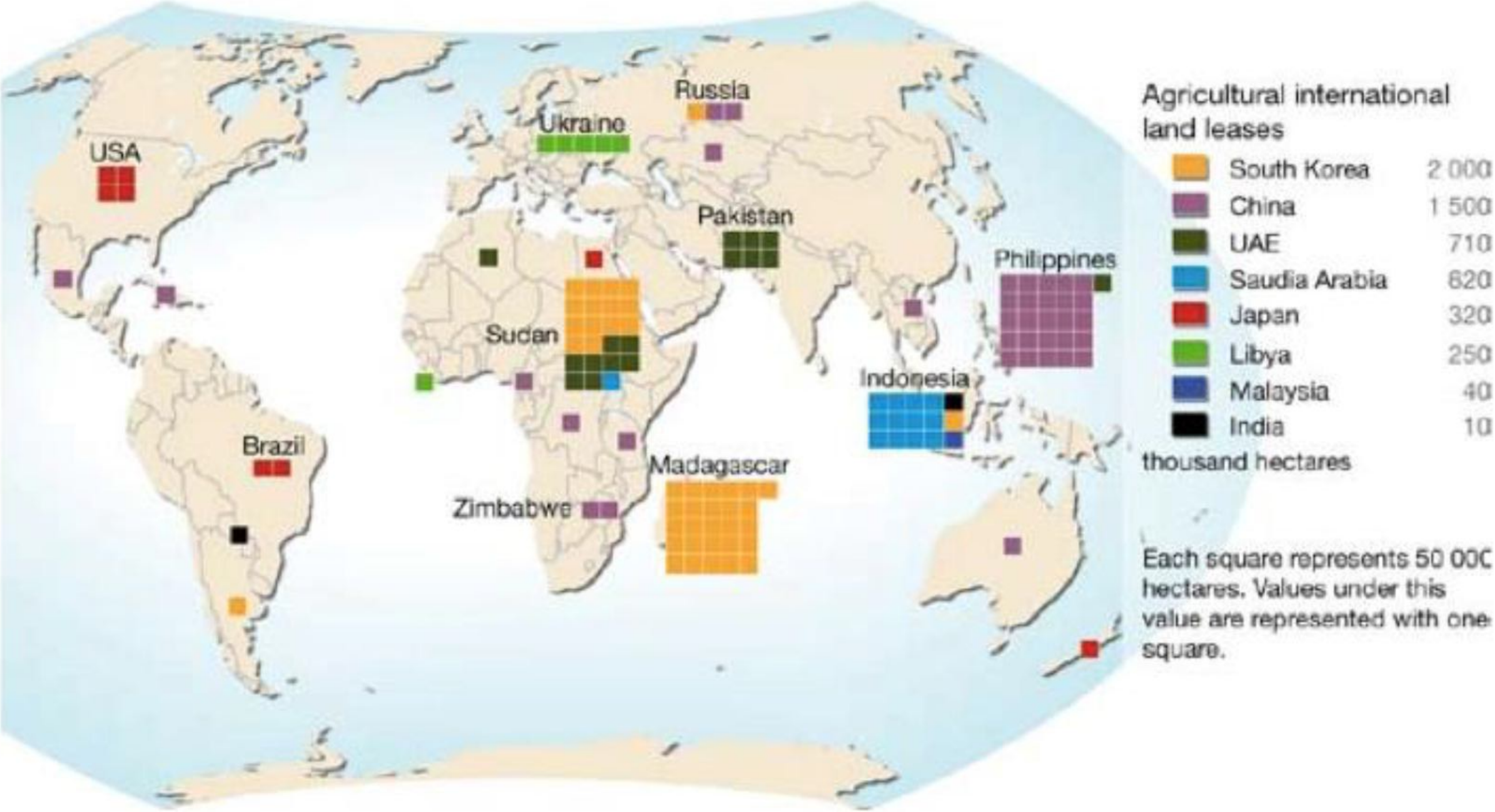
Malnourishment leads to ≈ 30 million deaths worldwide(1/s)

Poverty line: % population living with less than 1 USD per day





Fonte: FAO data and projections


Russia
Ukraine
USA
Pakistan
Philippines
Sudan
Indonesia
Brazil
Madagascar
Zimbabwe
Agricultural international land leases
South Korea 2 000
China 1 500
UAE 710
Saudia Arabia 620
Japan 320
Libya 250
Malaysia 40
India 10
thousand hectares
Each square represents 50 000 hectares. Values under this value are represented with one square.

Strategies to improve nutrition
(The World Bank)

Short routes		
• Community-based nutrition and health services (community growth promotion programs, community Integrated Management of Childhood Illnesses [C-IMCI]) • Facility-based nutrition and health services (health and nutrition services, and antenatal care) • Micronutrient supplements • Micronutrient fortification • Targeted food aid • Biofortification	• Conditional cash transfers • Microcredit cum nutrition education • Food supplementation • Micronutrient supplements • Food stamps • Targeted food aid	• Maternal nutrition, knowledge, and care-seeking during pregnancy and lactation • Infant and young child feeding • Weight control education • Hygiene education • Promoting healthy life styles (increase physical activity; consume more fruits and vegetables and less salt, sugar, and fat, and so on)

The World Bank, Directions in Development. Repositioning Nutrition as Central to Development.*A strategy for large scale action* (2006)

Biofortification

Fortification:

- Nutritional enrichment of foods during harvesting or processing

Biofortification:

- Utilization of improved varieties or improved practices that led to better uptake, partitioning or synthesis of essential nutrients during plant growth, so that the harvested products are themselves nutritionally richer

Biofortification

A sustainable strategy for nutritional enrichment!

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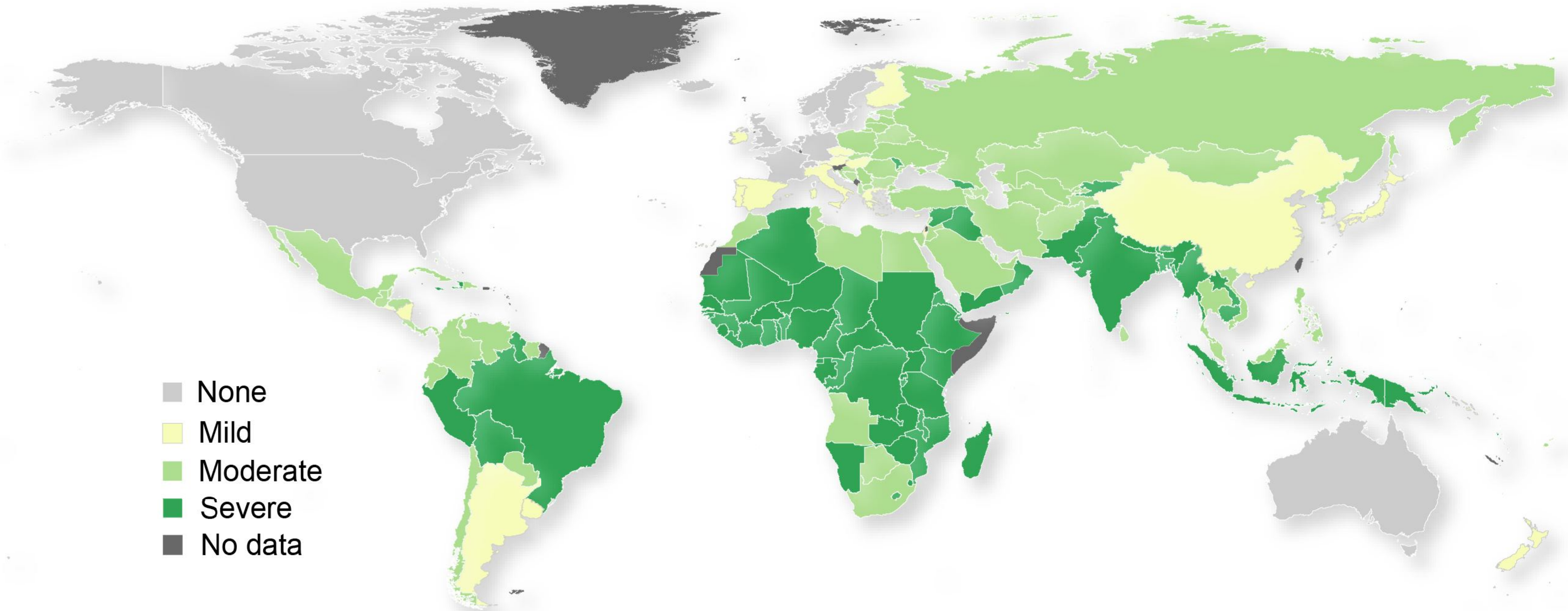
Micronutrient deficiency

Fe:	33 to 50% of population is at risk.
Zinc:	????????? (same as Fe)
Vitamin A:	250 million
Iodine:	2 billion (1/3 school age children)

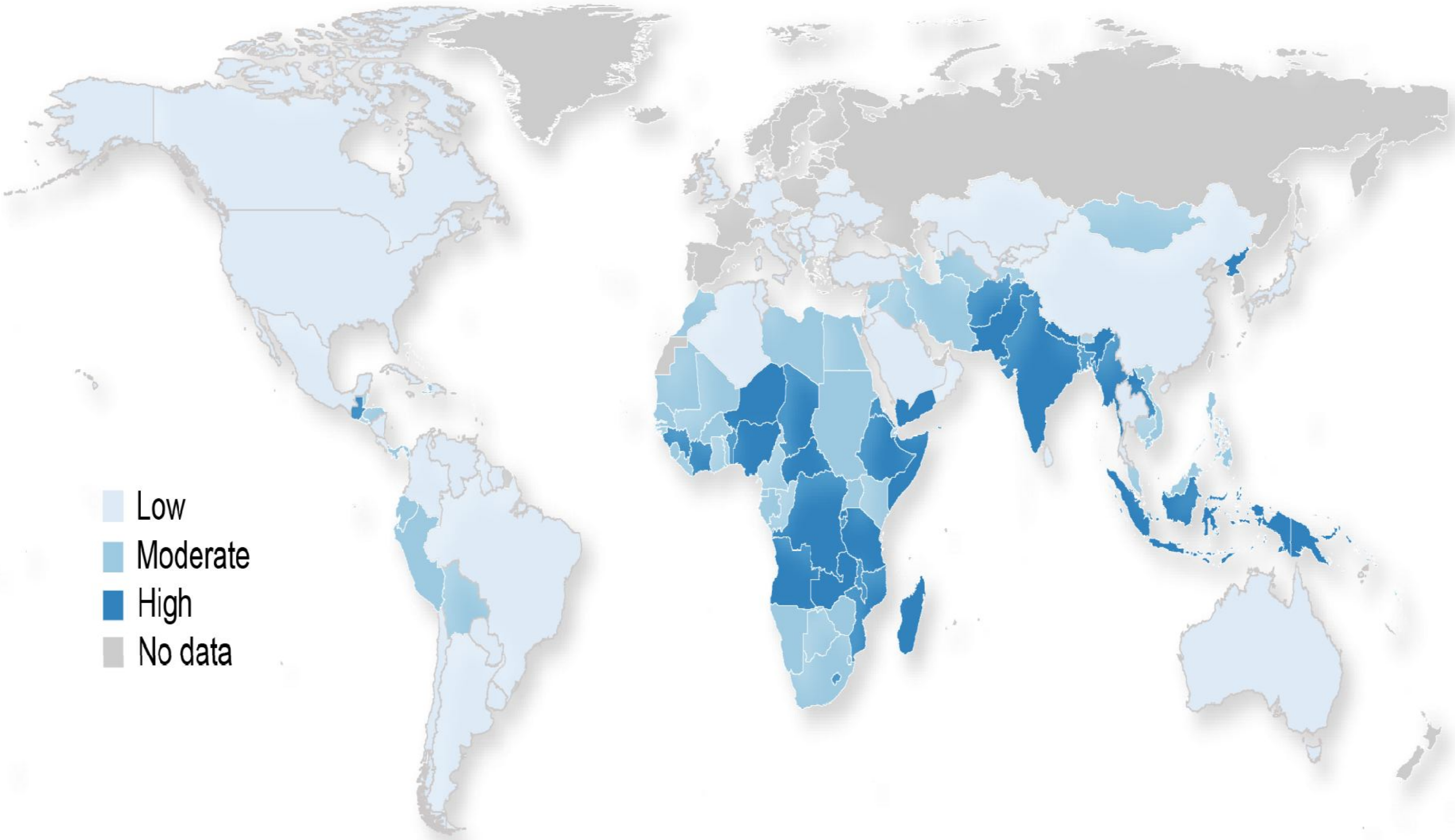
Prevalence of malnutrition: Fe



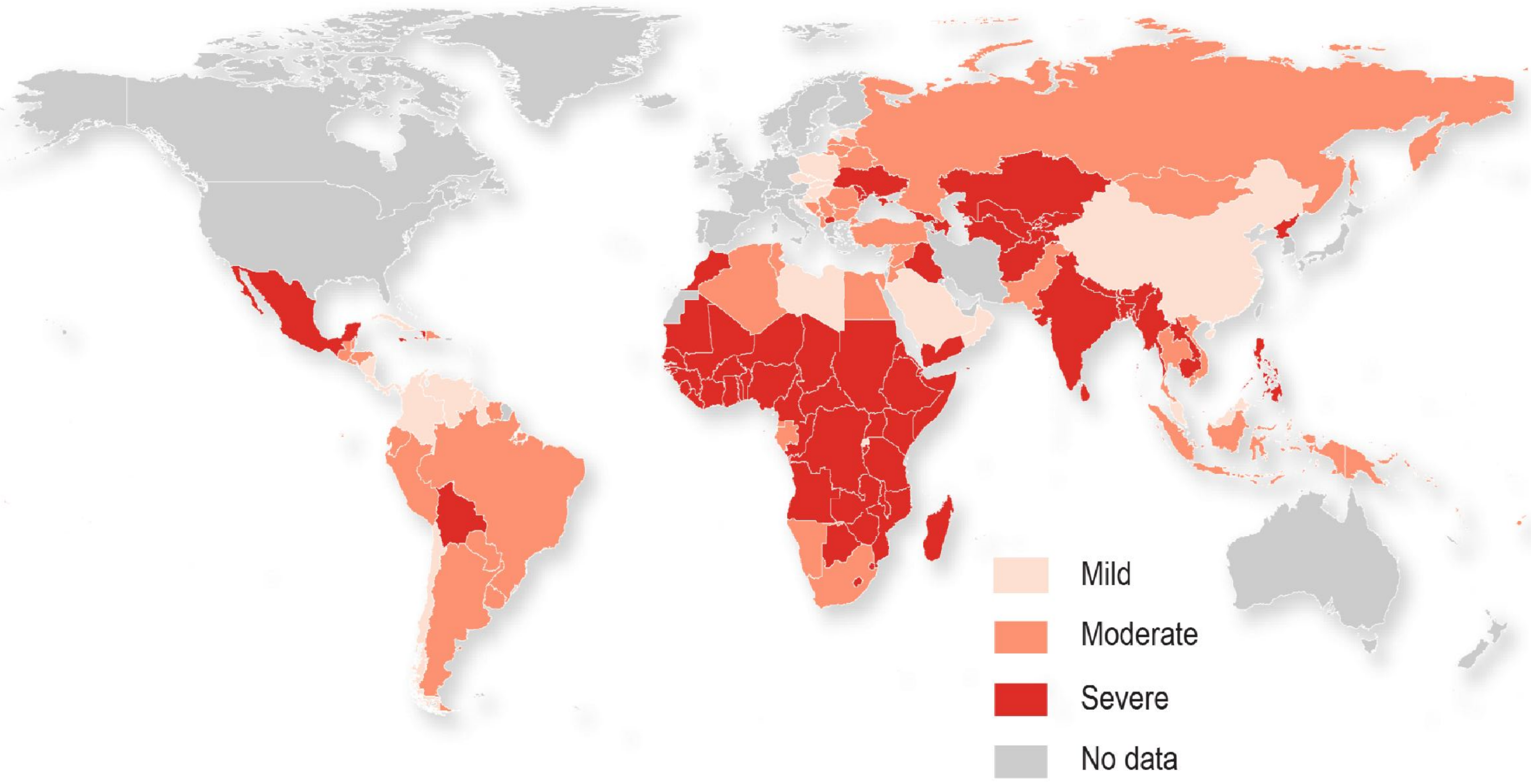
Note: Prevalence of deficiency is based on the percent of children 6–59 months of age with hemoglobin below 110g/l, and its public health significance is classified as none (<5.0%), mild (≥5.0%–<20.0%), moderate (≥20.0%–<40.0%), or severe (≥40.0%)

Source: Worldwide Prevalence of Anaemia 1993–2005: WHO Global Database of Anaemia World Health Organization, edited by Bruno de Benoist, Erin McLean, Ines Egli, and Mary Cogswell. World Health Organization, 2008. http://www.who.int/vmnis/anaemia/en/)

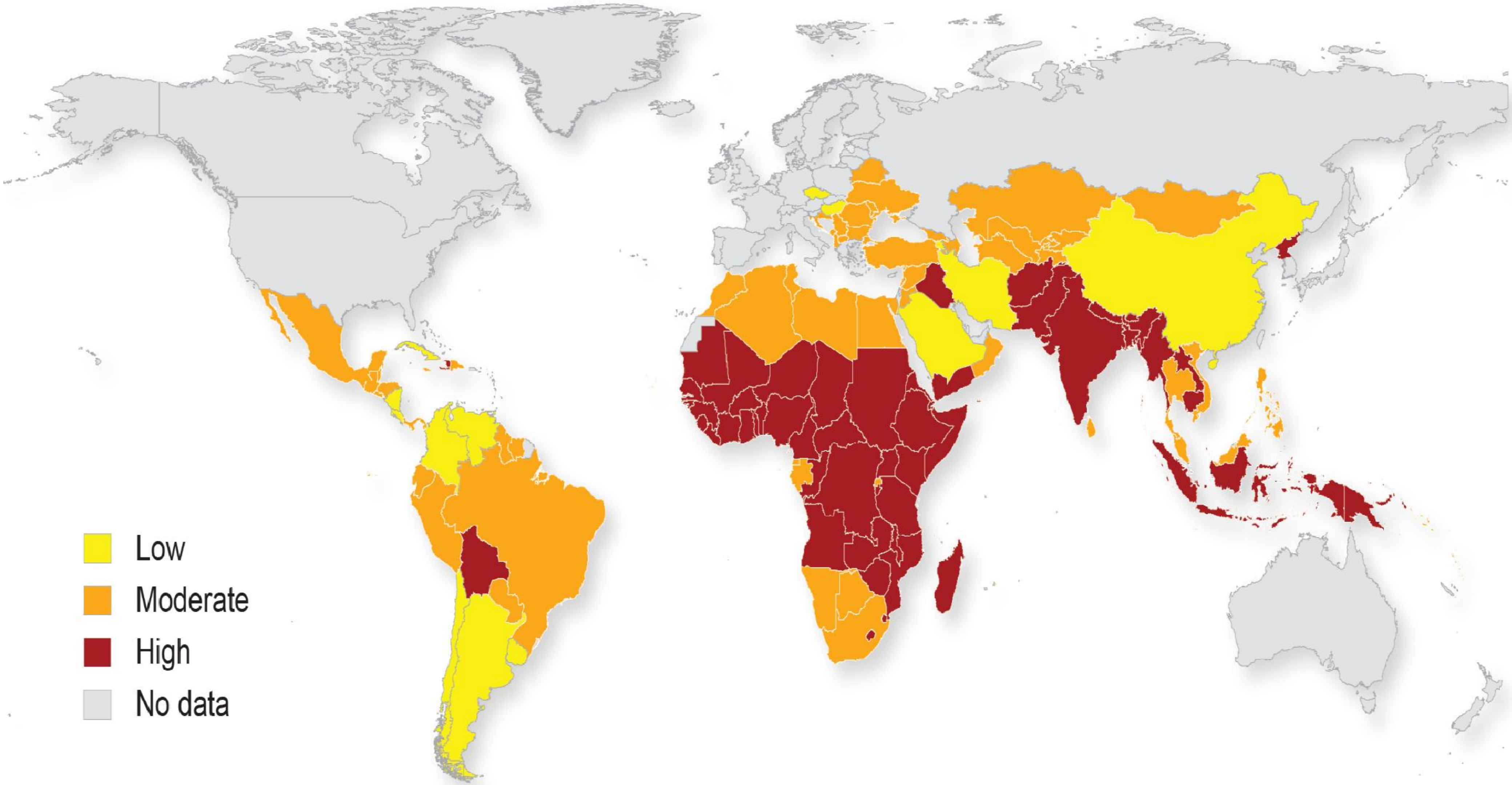
Prevalence of malnutrition: Zn



Prevalence of malnutrition: Vit A



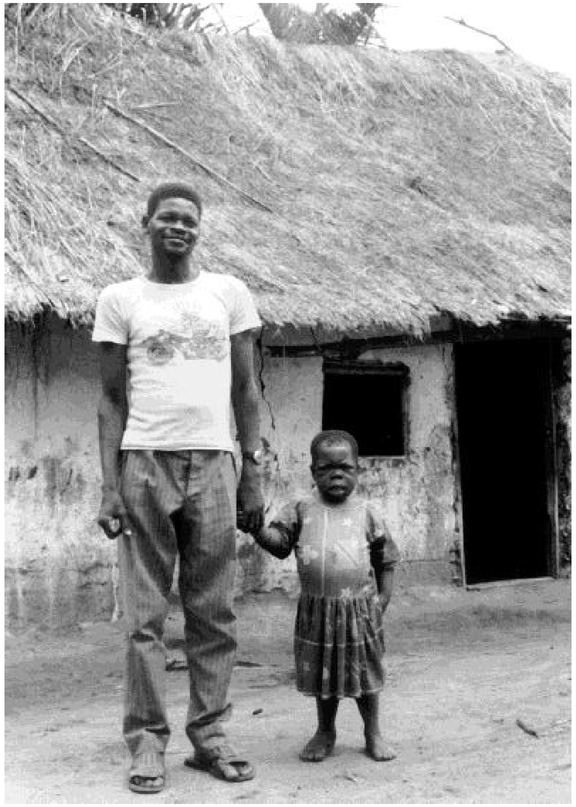
Prevalence of malnutrition: global



“Hidden hunger”

Zn

Vitamin A



Iodine

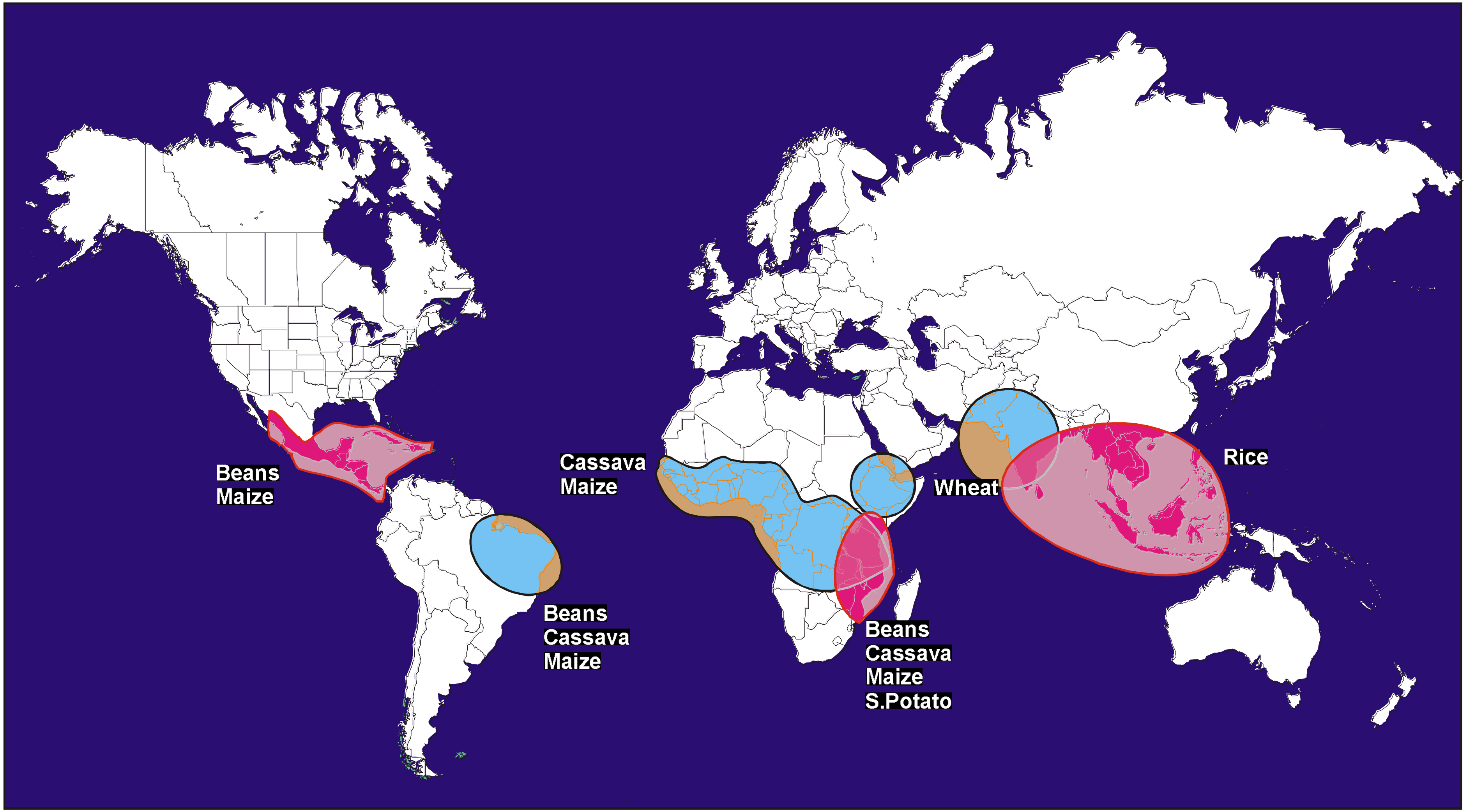
Fe

Ca

Biofortification

1. Conventional breeding
2. Genetic screening (biodiversity)
3. Bioavailability
4. Genetic engineering
5. Improved agricultural practices

Biofortification: Impact

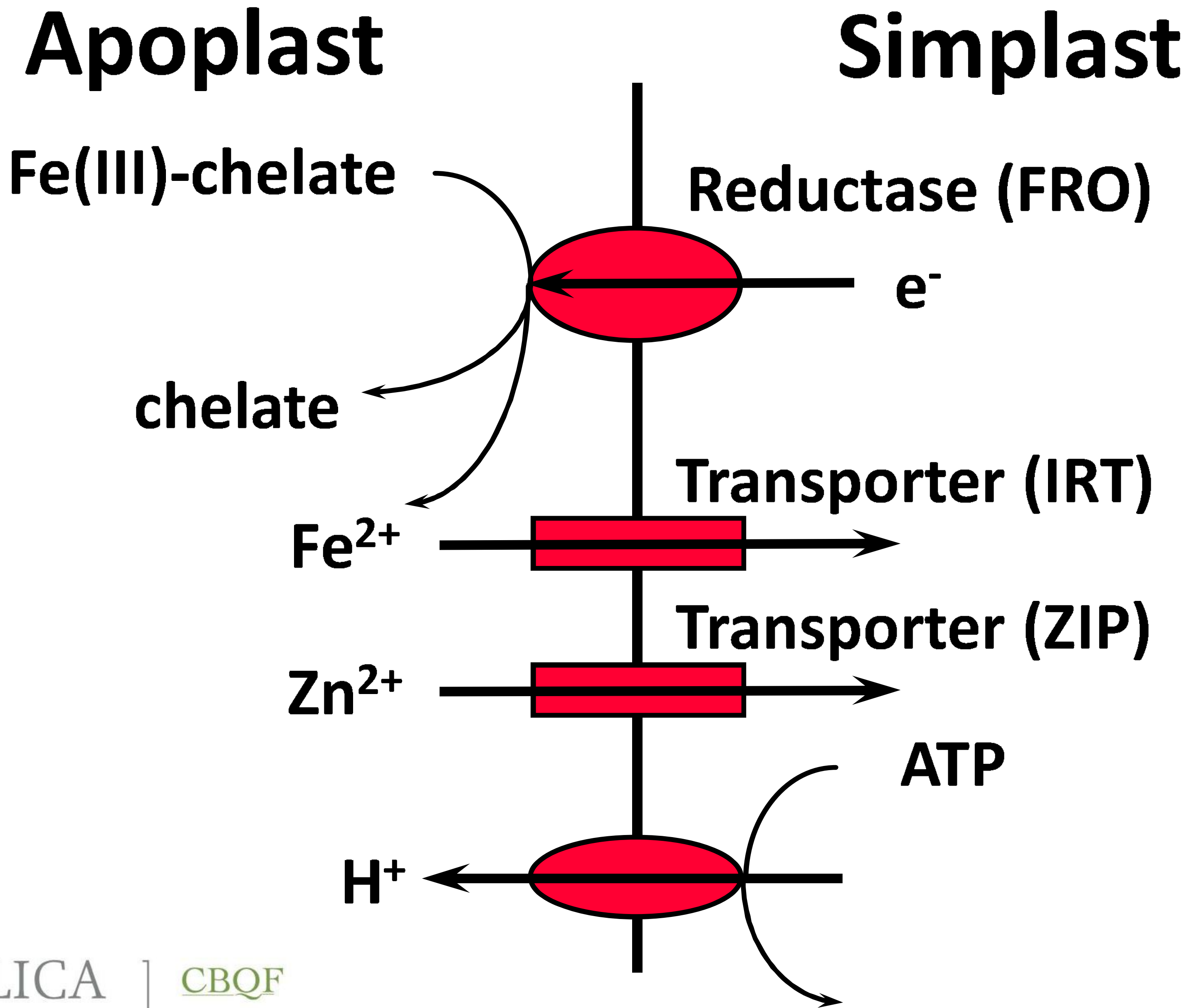


Staple foods

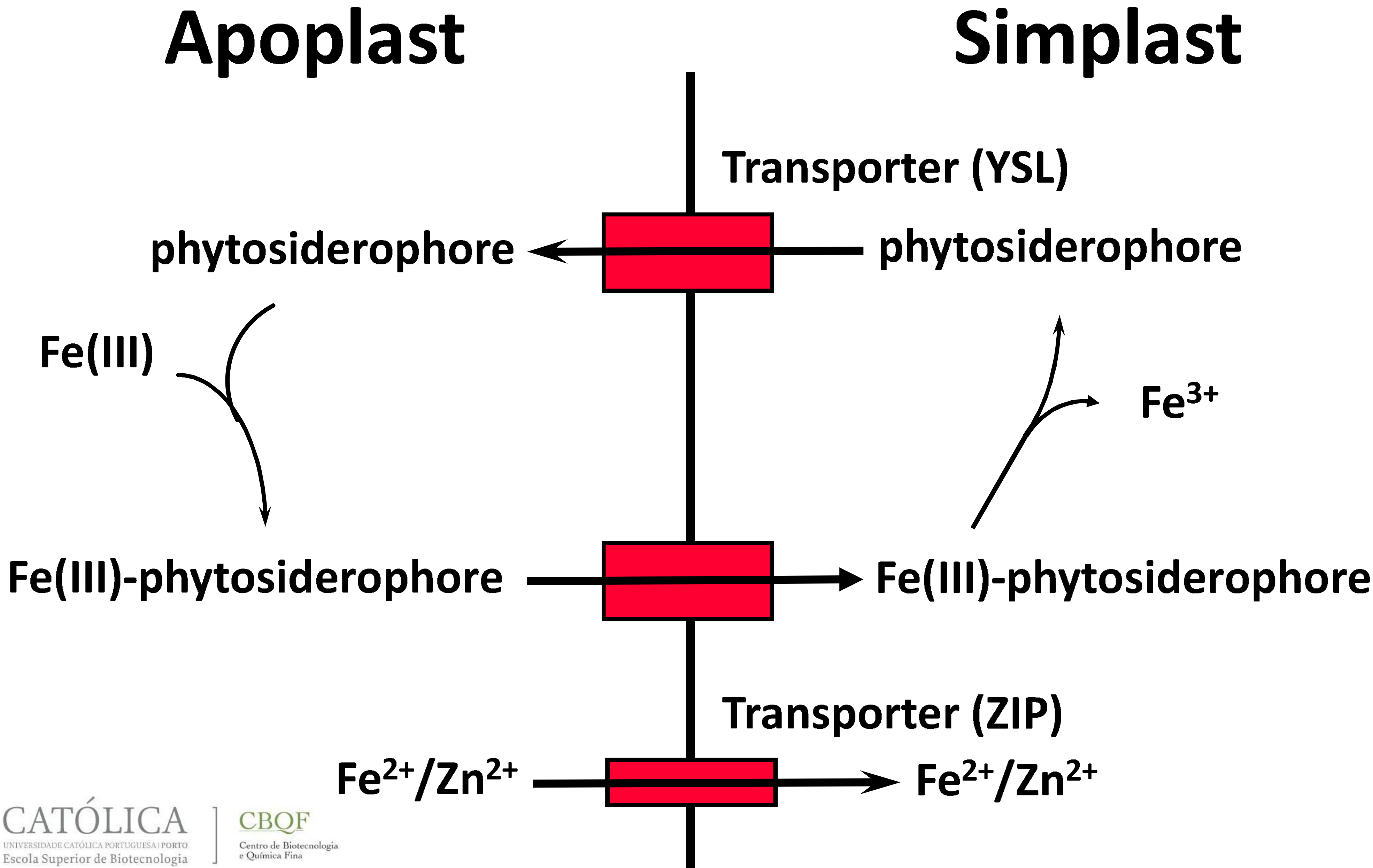
	Fe Conc. (mg/kg)	Zn Conc. (mg/kg)	Beta-carotene (mg/kg)
Brown rice	6 - 25	14 - 59	0 - 1
White rice	1 - 14	14 - 38	0
Wheat	10 - 99	8 - 177	0 - 20
Maize	10 - 63	12 - 58	0 - 10
Bean	34 - 111	21 - 54	0
Cassava	4 - 76	3 - 38	1 - 24

What are some of the metabolic processes and how can we manipulate them?

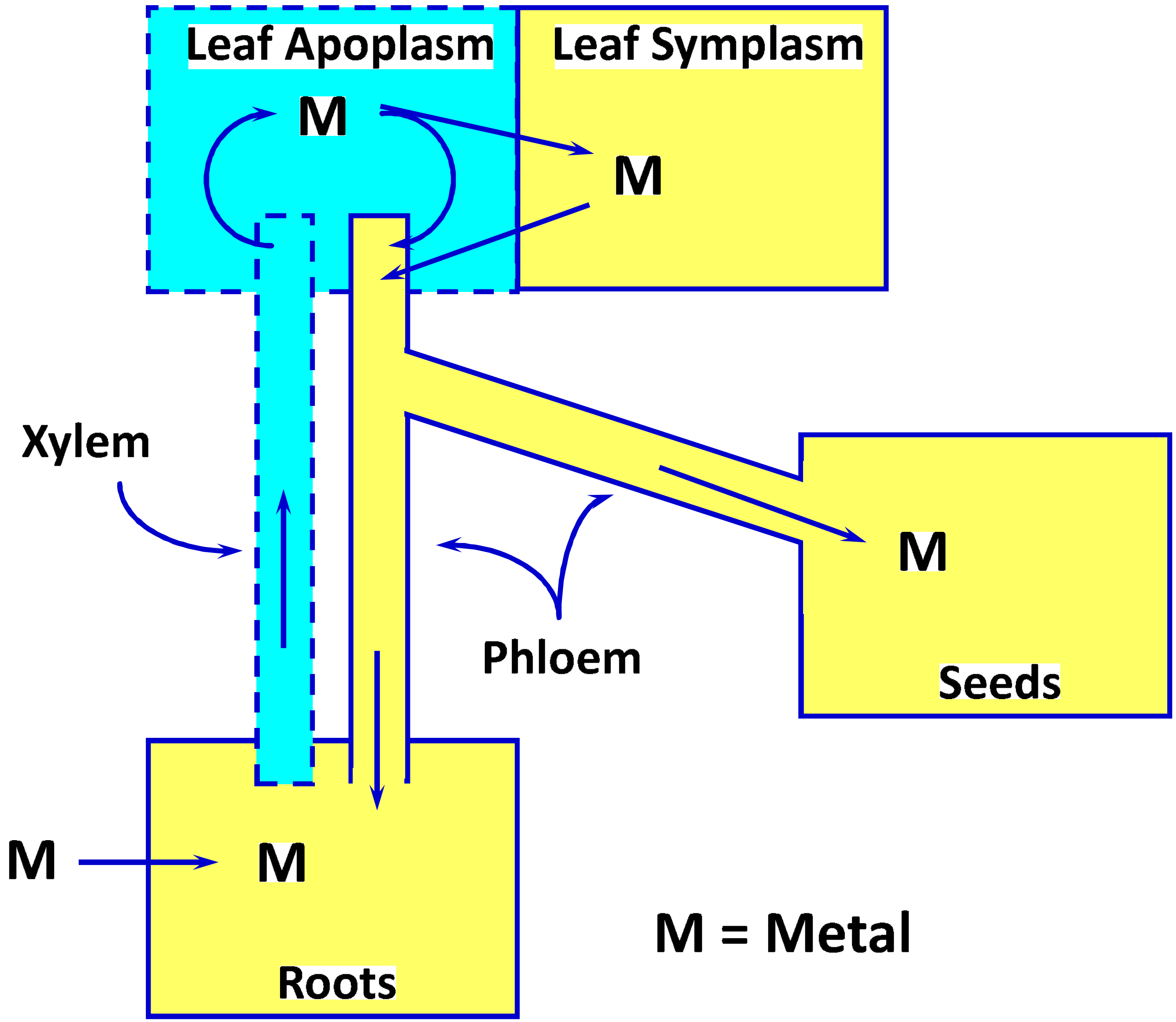
Fe acquisition (Dicot)



Fe acquisition (monocot)



Mineral transport in the plant



4. Bioavailability

- Phytate degradation (*phytase*)
- Phytate biosynthesis (*MIK*)
- Cysteine synthesis (*rgMT)*
- Vitamin synthesis (*DHAR*)
- Inulin biosynthesis (*Sac*B)

3. Seed filling

- Mineral transporters for phloem unloading (*YSL, HMA, Nramp*)
- Nutrient storage proteins (*ferritin, glutelin*)
- Valuole Fe loading (*VIT1, Nramp3, Nramp4*)

2. Shoot transport

- Mineral transporters for xylem unloading and phloem loading (FRO, *ZIP, COPT*)
- Mineral phloem mobility: increased synthesis of mineral chelators such as ITP or NA (*YSL, OPT*)

1. Root uptake and xylem loading

- Mineral transporters (*IRT, ZIP, YS, IREG, HMA, FRD3*)
- Phytosiderophore secretion (*YS, NAS*)
- Soil nutrient availability (*FRO*)
- Organic acid release(*FRD3*)

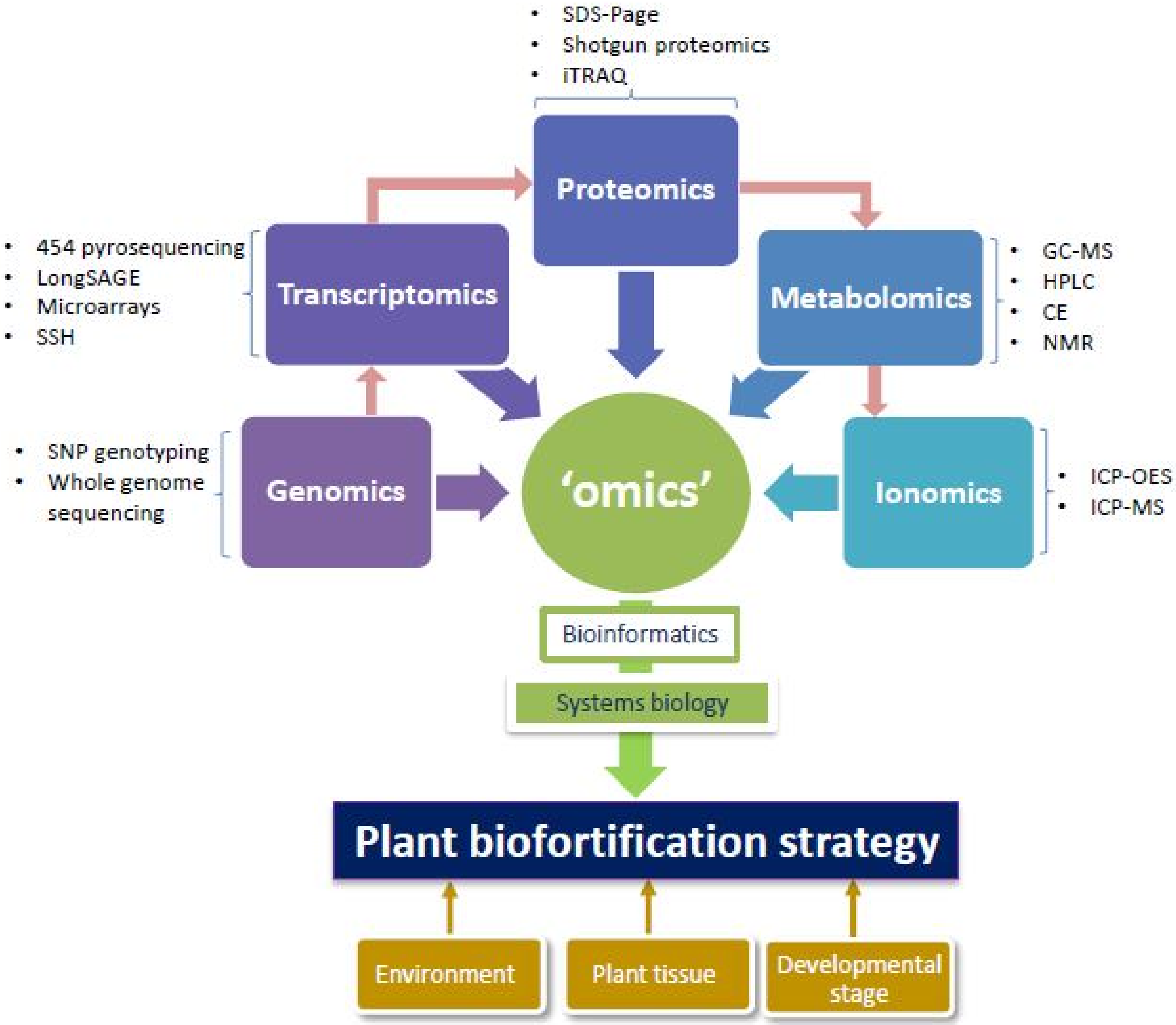
Carvalho and Vasconcelos (2013) Food Research International
http://dx.doi.org/10.1016/j.foodres.2012.12.021

Importance of bioavailability

- Bioavailable portion is as important as total amount
- Most staple foods (cereals, legumes) have low bioavailability (5% for Fe) due to antinutritional factors (phytates, poliphenols, etc)
- Example: increasing bioavailability from 5% to 30% is the same as augmenting 6x the total Fe amount

Efficient biofortification strategy:

1. Accumulation in the edible plant part
2. Maintenance of values after harvesting and storage
3. Maintenance of plant productivity
4. Improved levels of nutrient in the organism (bioavailability)
5. No adverse side effects (e.g. allergens)



Carvalho and Vasconcelos (2013) Food Research International
http://dx.doi.org/10.1016/j.foodres.2012.12.021

Biofortification examples

Crop	Improved nutritional trait	References
Rice	Beta-carotene	(Ye et al., 2000; Paine et al., 2005)
	Folate	(Storozhenko et al., 2007)
	Alpha-tocotrienol	(Zhang et al. 2012)
	Protein/amino acid	(Katsube et al., 1999; Lee et al., 2001; Tozawa et al., 2001; Lee et al., 2003; Wu et al., 2003;)
	Fatty acids	(Anai et al., 2003)
	Starch	(Terada et al., 2000, 2002; Itoh et al., 2003; Liu et al., 2003; Zhu et al., 2003; Tanaka et al., 2004; Chiang et al., 2005)
	Flavonoids	(Shin et al., 2006)
	Fe	(Goto et al., 1999; Lucca et al., 2001; Vasconcelos et al., 2003; Qu et al., 2005; Masuda et al., 2008, 2009, 2012; Ye et al., 2008; Lee and An, 2009; Lee et al., 2009, 2012; Wirth et al., 2009; Johnson et al., 2011)
	Zn	(Vasconcelos et al., 2003; Masuda et al., 2008, 2009; Lee et al., 2009; Johnson et al, 2011)
Wheat	Zn	(Cakmak et al., 2010)
	Low phytate	(Brinch-Pederson et al., 2000)
	Fe	(Borg et al., 2012)
Soybean	Fatty acids	(Chen et al., 2006; Eckert et al., 2006)
	Protein/amino acids	(Falco et al., 1995; Maughan et al., 1999; Dinkins et al., 2001; Li et al., 2005)
	Tocopherol	(Eenennaam et al., 2003; Tavva et al., 2007)
	Isoflavone	(Yu et al., 2003)
Maize	Beta-carotene	(Naqvi et al., 2009)
	Ascorbic acid	(Chen et al., 2003; Naqvi et al., 2009)
	Folate	(Naqvi et al., 2009)
	Vitamin E	(Cahoon et al., 2003)
	Protein/amino acid	(Lai and Messing, 2002; Yang et al., 2002)
	Iron	(Drakakaki et al.,2005; Aluru et al., 2011)
Potato	Anthocyanin	(Lukaszewicz et al., 2004)
	Aminoacids	(Zeh et al., 2001; Li et al., 2001)
	Carotenoids	(Ducreux et al., 2005; Diretto et al, 2006, 2007; 2006; Zain, 2010)
	Zeaxanthin	(Römer et al., 2002)
	Carbohydrate	(Schwall et al., 2000; Hellwege et al, 1997, 2000)
Cassava	Protein	(Narayanan et al., 2011; Leyva-Guerrero et al., 2012)
	Iron	(Leyva-Guerrero et al., 2012)
Canola	Fatty acids	(Dehesh et al., 1996)
	Carotenoids	(Shewmaker et al., 1999)
Lettuce	Folate	(Nunes et al., 2009)
	Resveratrol	(Liu et al., 2006)
	Iron	(Gotto et al., 2000)
Carrot	Calcium	(Park et al, 2004; Morris et al., 2008)
Tomato	Antioxidants	(Muir et al., 2001; Nigwegg et al., 2004; Giovinazzo et al. 2005; Butelli et al., 2008)
	Carotenoids	(Fraser et al., 2001, 2002; Mehta et al., 2002; Apel and Bock, 2009)
	Poliamines	(Mattoo et al., 2007)
	Folate	(Díaz de la Garza et al., 2004, 2007)
	Isoprenoids	(Enfissi et al., 2005)

Examples

- Rice (Fe e Zn)
- Rice(Vit A)
- Soybean (Fe)
- Others

Increasing Fe and Zn in transgenic rice

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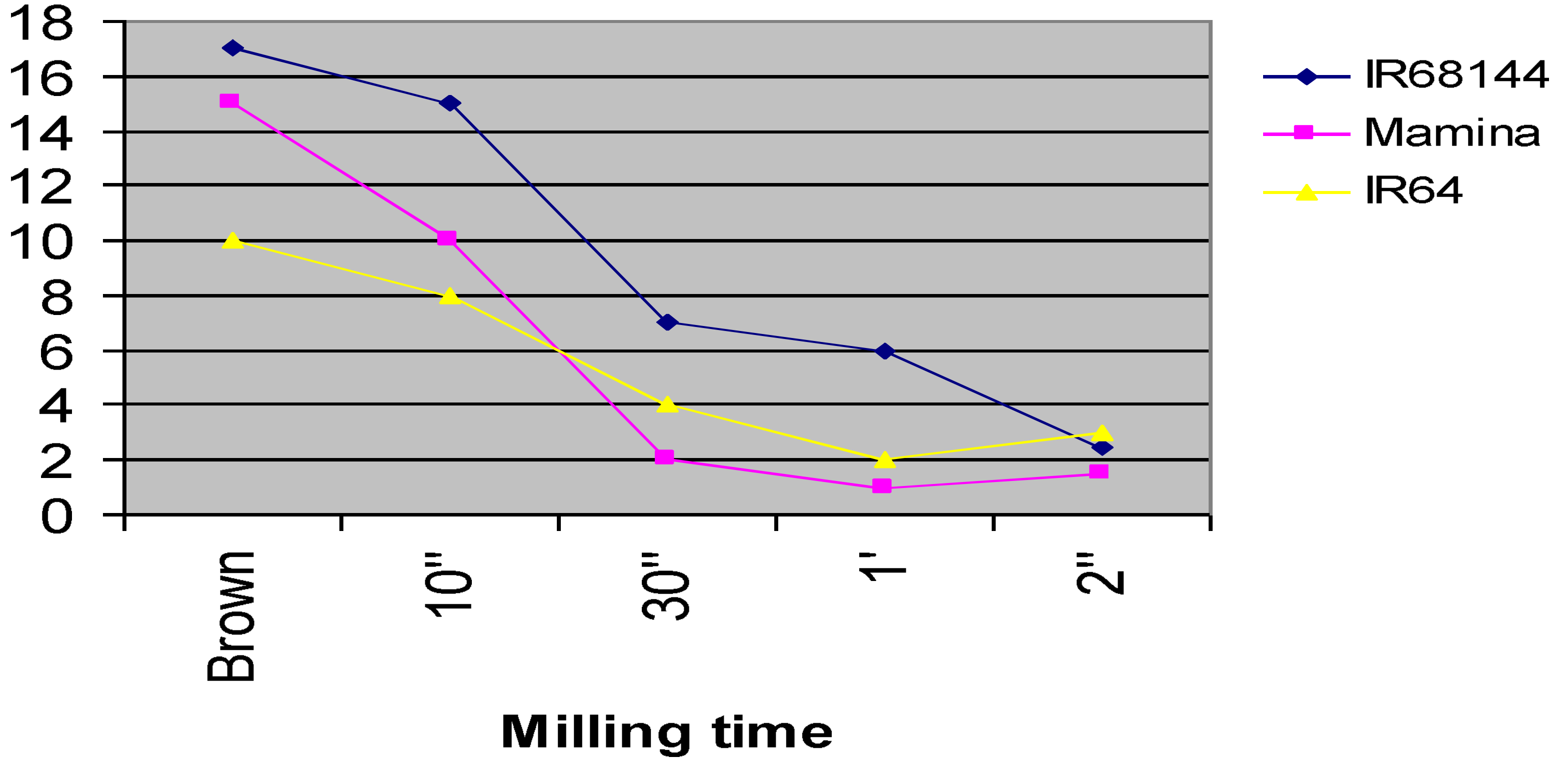
Vasconcelos et al. (2003) Plant Science 164: 371-378

Rice (*Oryza sativa* L.)

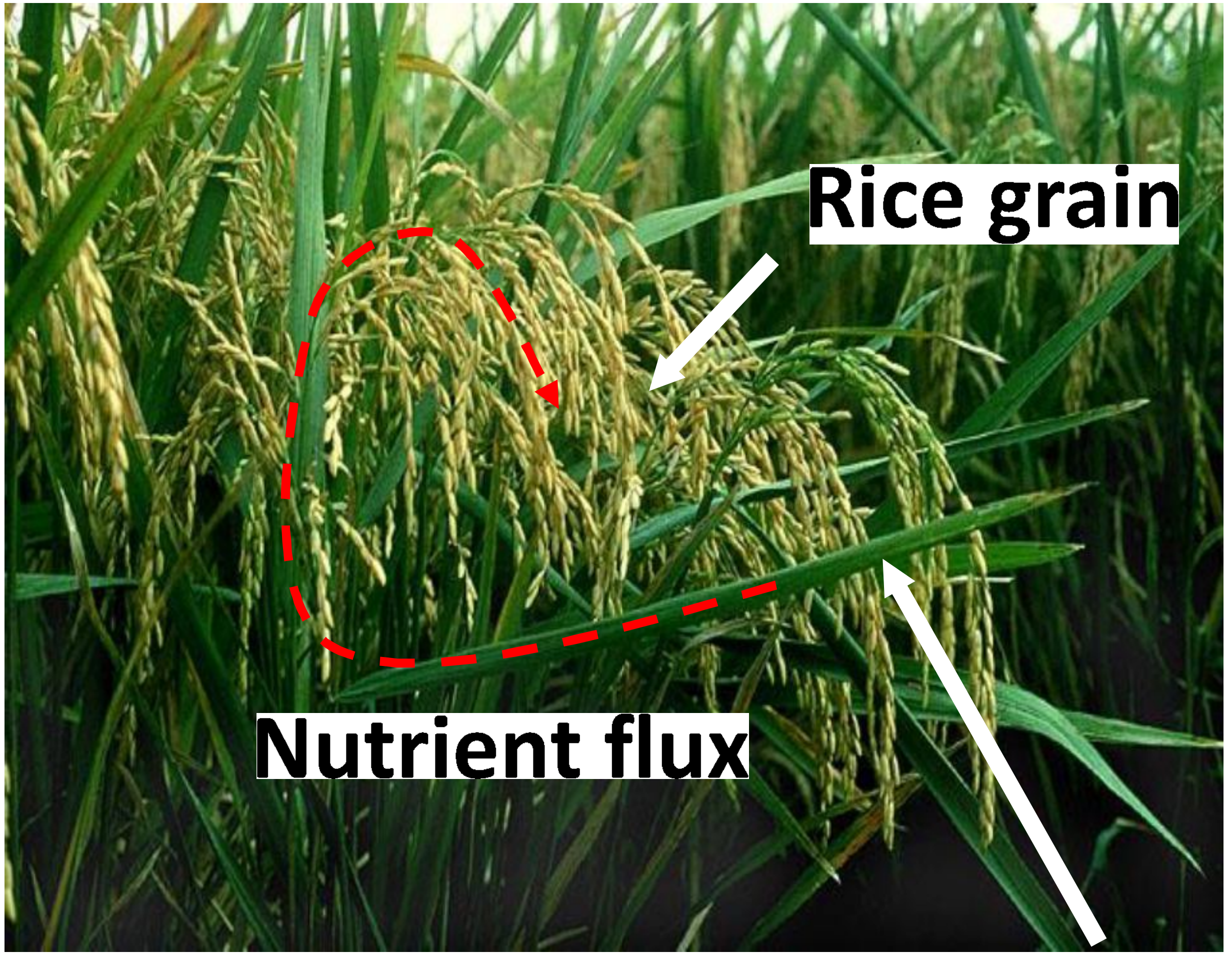
- **World´s most consumed food (2/3 of the population)**
- **Grows in many types of habitat**

The problem

- Rice is poor in Fe



Nutrient transport to the grain



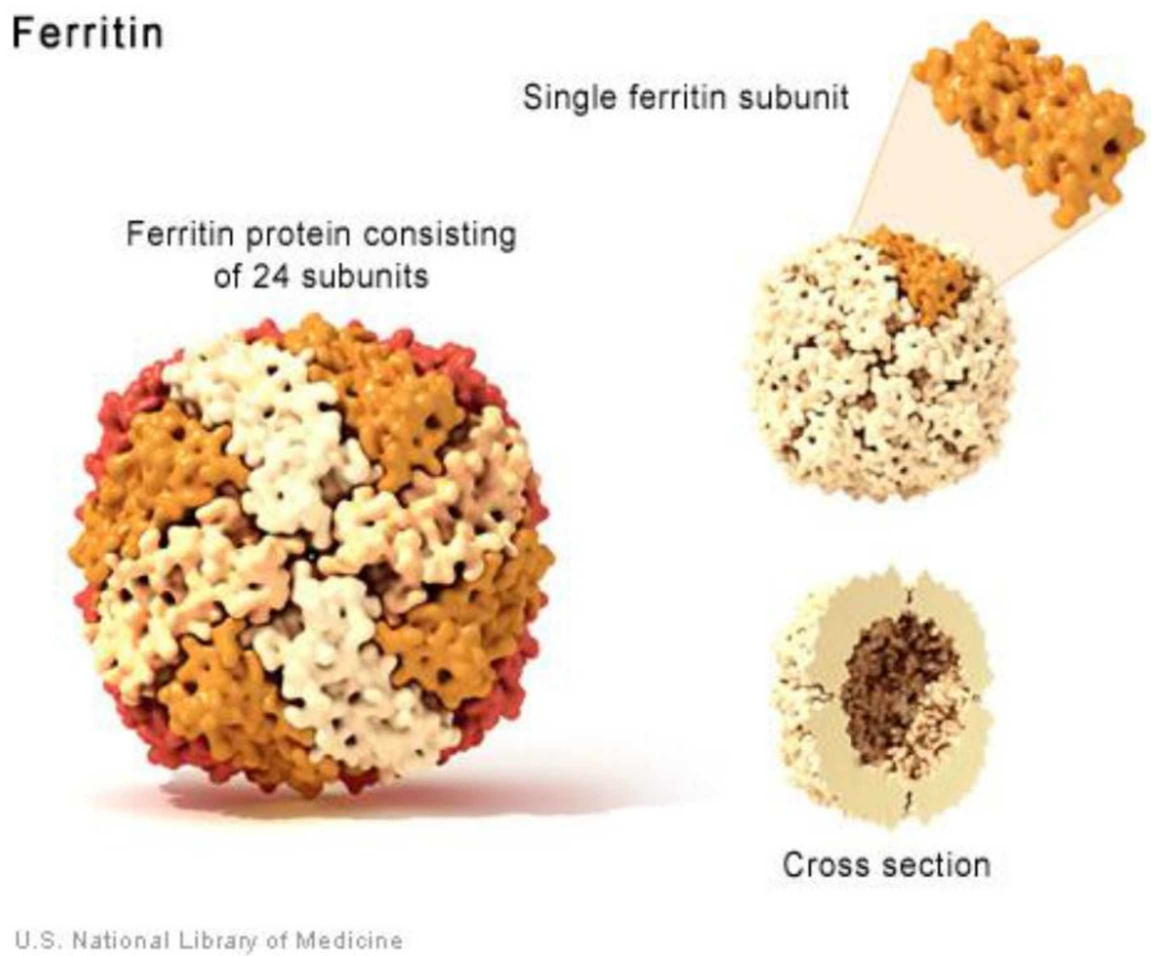
Fe is mobilized to the seeds along with sugars, amino acids and others, via phloem

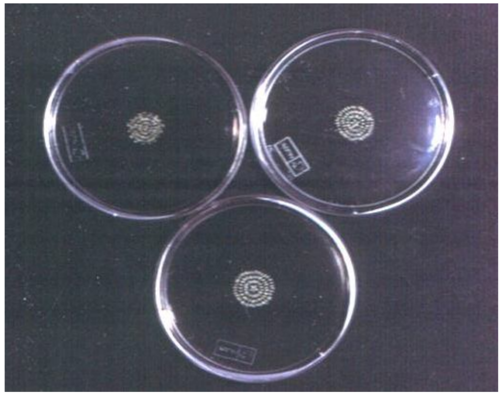
Flag leaf

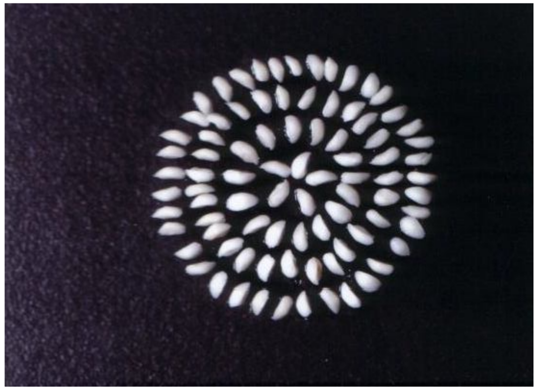
Ferritin

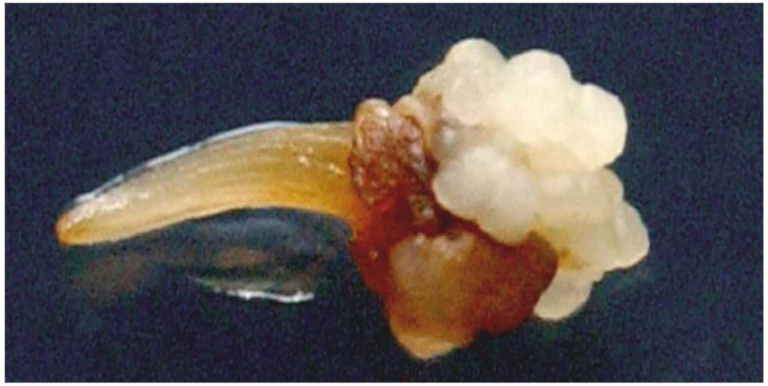
Strategy

1. Variety
2. Transformation
3. Homozigots
4. ICP

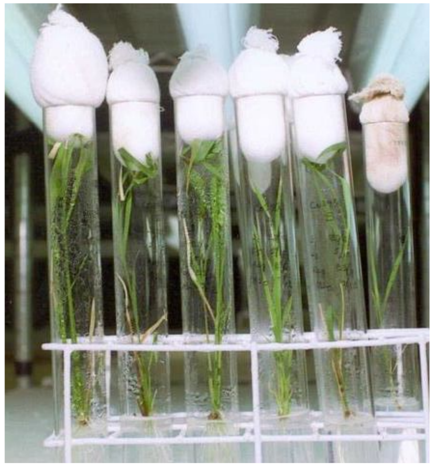






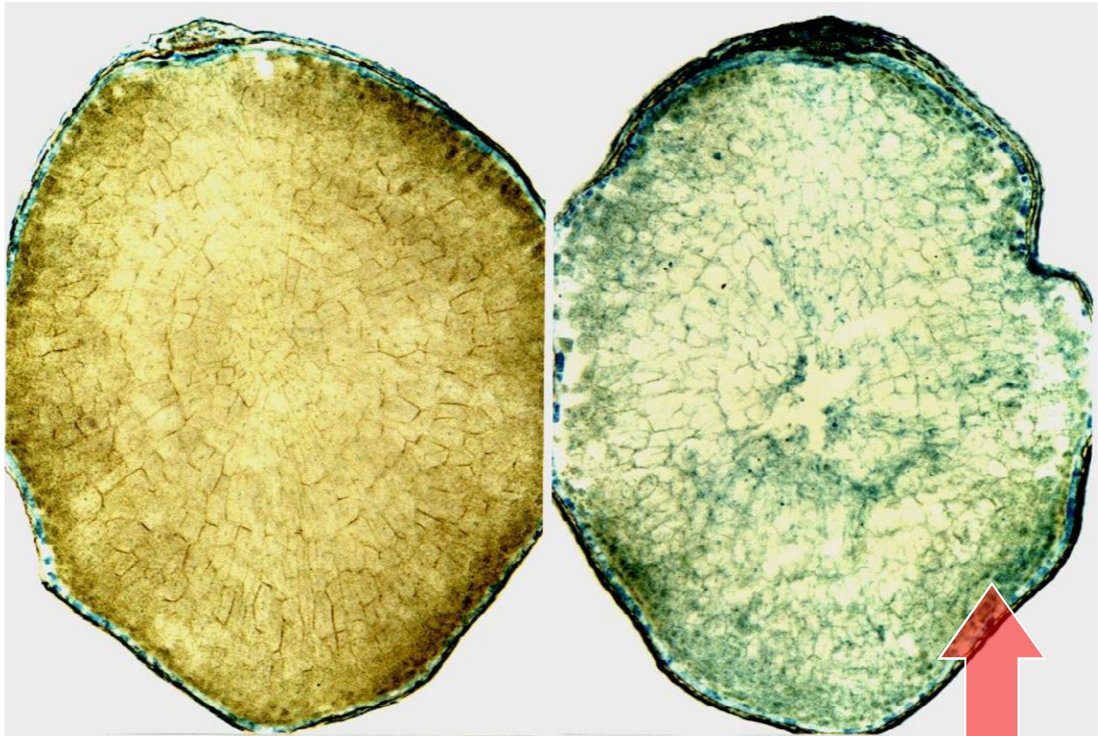


Genetic transformation

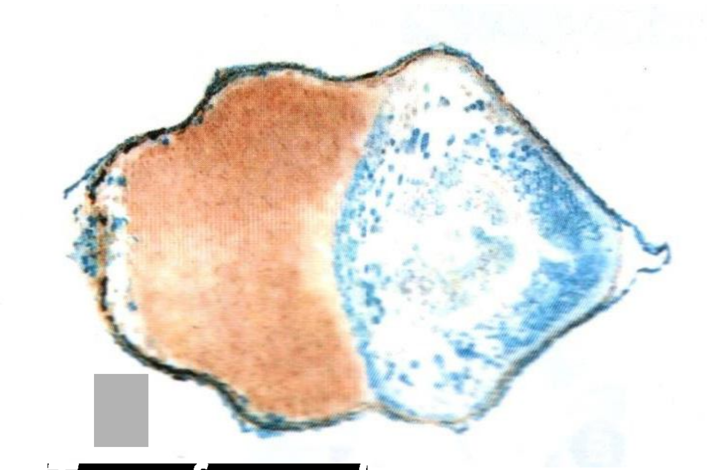


Results

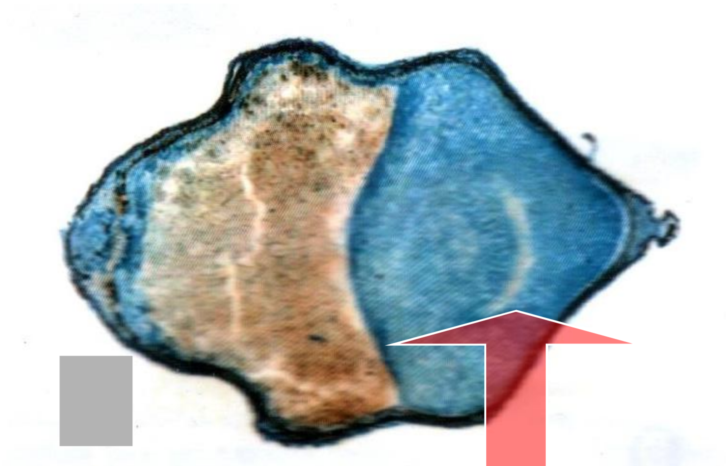
Non-transformed *Transformed*



Non-transformed



Transformed



Fe in blue

Results

- 3.7 X higher Fe and 1.4 X higher Zn, even after commercial polishing
- The Fe is bioavailable
- This material could prevent serious nutrient deficiencies

Vasconcelos, M., et al. (**2003**) Enhanced iron and zinc accumulation in transgenic rice with the *ferritin* gene. Plant Sci. 164(3): 371-378.

Mineral Biofortification in Rice: update

Table 1 | Summary of different approached undertaken for mineral biofortification of rice.

Gene	Promoter	Cultivar	Fold increase in Fe/Zn	Reference
AtNAS1+, Pvferritin+, Afphytase	CaMV 35S, Glb-1, Glb-1	*Japonica* cv. Taipei 309	6.3/1.6[1]	Wirth et al. (2009)
HvNAS1	Actin	*Japonica* cv. Tsukinohikari	3.4/2.3[2]	Masuda et al. (2009)
HvNAS1, HVNAS1+HvNAAT, IDS3	Genomic fragments	*Japonica* cv. Tsukinohikari	1.0/1.0[2], 1.1/1.1, 1.4/1.3	Masuda et al. (2008)
OsNAS1, OsNAS2, OsNAS3	CaMV 35S	*Japonica* cv. Nipponbare	2.2/1.4, 4.2/2.2, 2.2/1.4	Johnson et al. (2011)
OsNAS2	Activation tagging	*Japonica* cv. Dongjin	3/2.7	Lee et al. (2011, 2012b)
OsNAS3	Activation tagging	*Japonica* cv. Dongjin	/2.2	Lee et al. (2009b)
OsNAS1	GluB1	*Japonica* cv. Xiushui 110	1.0/1.3	Zheng et al. (2010)
SoyferH-1	Glu-B1	*Japonica* cv. Kitaake	3.0	Goto et al. (1999)
PvFerritin+ rgMT	Glb-1	*Japonica* cv. Taipei 309	2.0[3]	Lucca et al. (2001)
SoyFer	Glu-B1	*Indica* cv. IR68144	3.7/1.4	Vasconcelos et al. (2003)
SoyFer	Glu-B1; Glb-1	*Japonica* cv. Kitaake	3.0/1.1	Qu et al. (2005)
OsFer2	*OsGluA2*	Basmati rice (*Indica* cv. Pusa-Sugandh II)	2.1/1.4	Paul et al. (2012)
TOM1	CaMV 35S	*Japonica* cv. Tsukinohikari	1.2/1.6	Nozoye et al. (2011)
OsYSL2	OsSUT1	*Japonica* cv. Tsukinohikari	4.4	Ishimaru et al. (2010)
OsIRT1	Ubi	*Japonica* cv. Dongjin	1.1/1.1[3]	Lee and An (2009)
OsYSL2+, SoyFerH2+, HvNAS1	OsSUT1, Glb-1, Glb-1. Glu-B1, Act	*Japonica* cv. Tsukinohikari	6 or 4[4]/1.6	Masuda et al. (2012)

Bashir et al (2013) Frontiers in Plant Nutrition

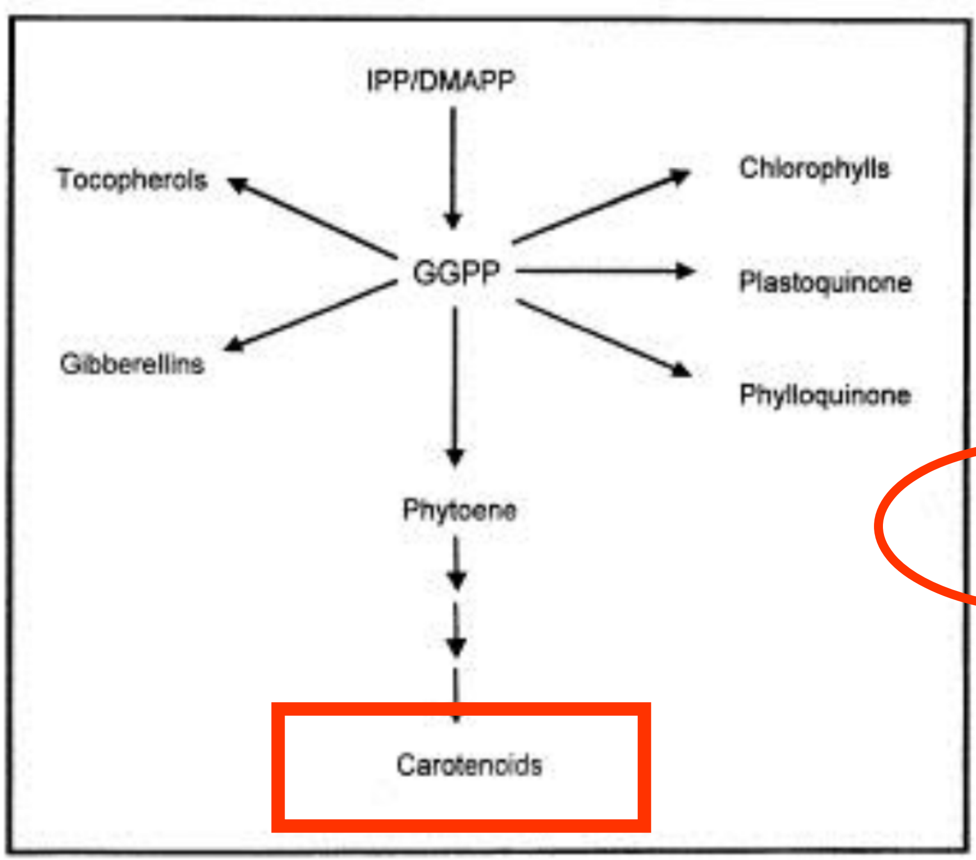
Golden rice

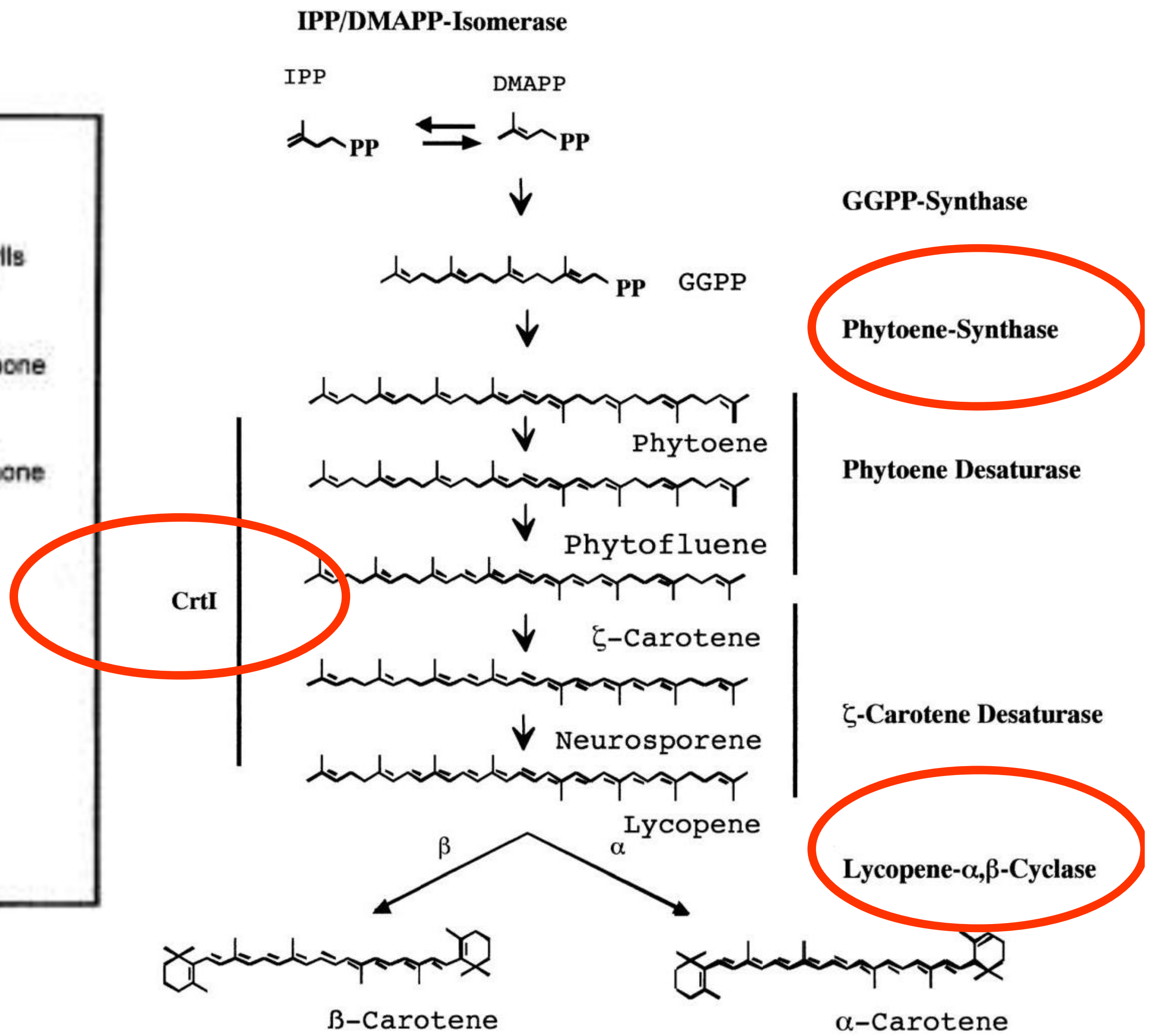
"We all require Vit A, but children are the most susceptible to deficiency. RDA for 1-3 year olds is 300 µg per day. To give half this amount would keep healthy Vit A levels in blood circulation"

Rice

- Does not produce β-carotene (provitamin A)
- The genes are in the grain, but are “turned off”
- In societies of high rice consumption, lack of Vit A is a major health problem.

Strategy

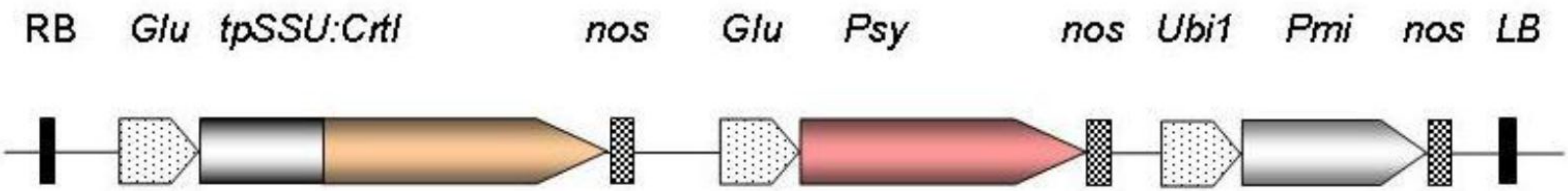

IPP/DMAPP
Tocopherols
Chlorophylls
GGPP
Plastoquinone
Gibberellins
Phylloquinone
Phytoene
Carotenoids


IPP/DMAPP-Isomerase
IPP
DMAPP
PP
PP
GGPP-Synthase
PP
GGPP
Phytoene-Synthase
Phytoene
Phytoene Desaturase
Phytofluene
CrtI
ζ-Carotene
ζ-Carotene Desaturase
Neurosporene
Lycopene
β
α
Lycopene-α,β-Cyclase
ß-Carotene
α-Carotene

Golden rice 1

1.6 µg/g

Golden rice 2 37 µg/g



✓ **72 g provides half of the RDA! ***

✓ **Rice consumption levels in target countries (100-200 g of rice per child per day).**

Golden rice to be distributed freely without associated costs

***Based on retinol equivalency ratio for β-carotene of 12:1**

http://www.goldenrice.org/index.html

Nutritional enhancement of transgenic soybean

*Vasconcelos et al., (**2006**) Planta 1432-2048*
*Vasconcelos, Clemente and Grusak (**2014**) Front. Plant Sci. 5:112. doi: 10.3389/fpls.2014.00112*

Food

- ✓ Grain
- ✓ Tofu
- ✓ Miso
- ✓ Flour
- ✓ Bread
- ✓ Candy
- ✓ Feed
- ✓ Cookies
- ✓ Pies
- ✓ Coffee
- ✓ Butter
- ✓ Milk
- ✓ Sprouts
- ✓ Oil
- ✓ (…)

Non-food

- ✓ Pencils
- ✓ Plastics
- ✓ Paints
- ✓ Fabrics
- ✓ Biodiesel
- ✓ Insecticides
- ✓ Paper
- ✓ Erasers
- ✓ Cosmetics
- ✓ Electric isolation
- ✓ Soaps
- ✓ Shampoos
- ✓ (…)

Soybean nutrition

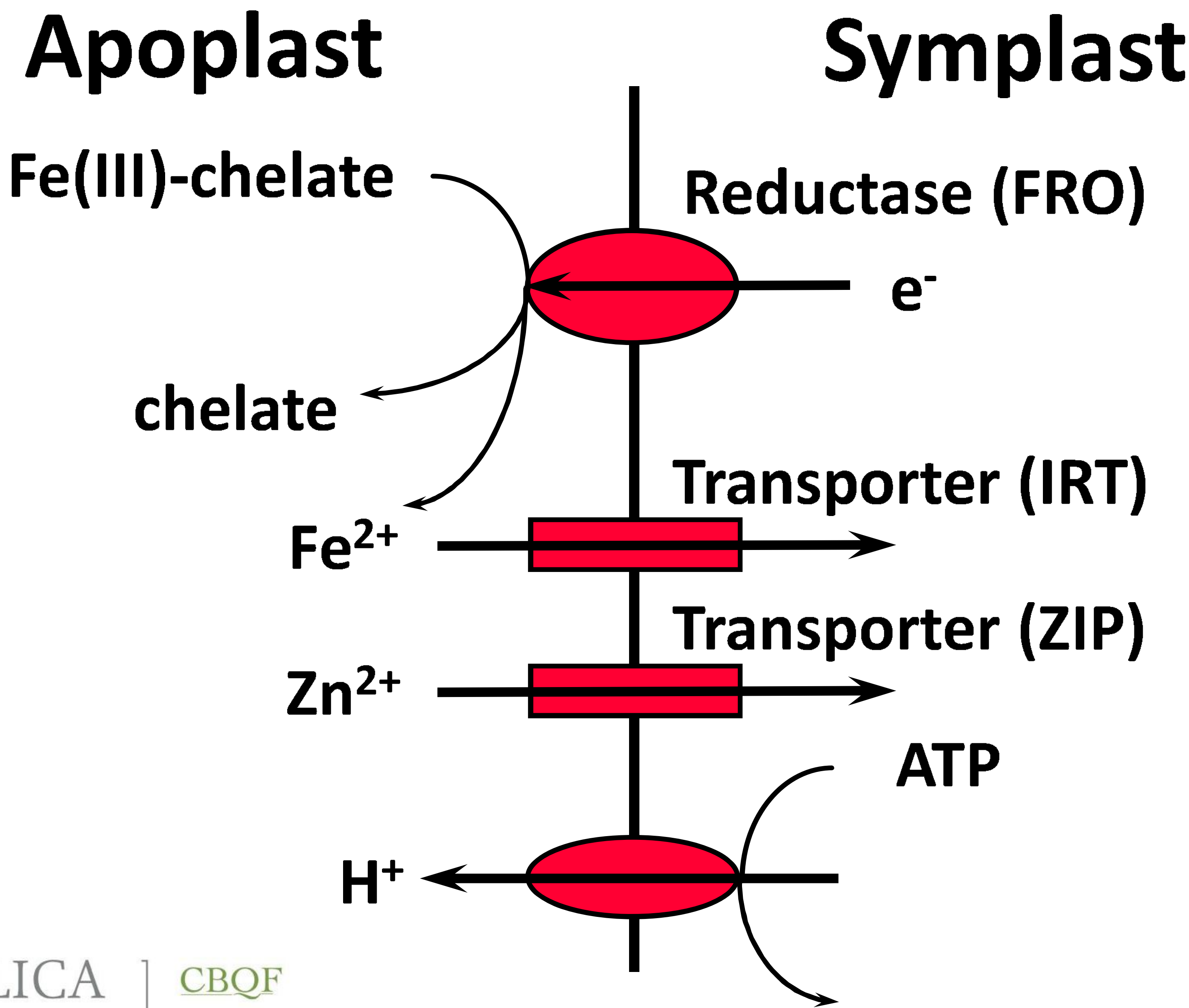
- 14% Water
- 15% HC
- 15% Fiber
- 38% Protein
- 18% Lipids

Good source of Fe, Ca, Zn, P, Mg, B, vitamins and folic acid

The problem…

1. Soybean is very susceptible to Fe deficiency (30% of world´s arable land)
2. Low Fe absorption limits Fe that goes to the grain

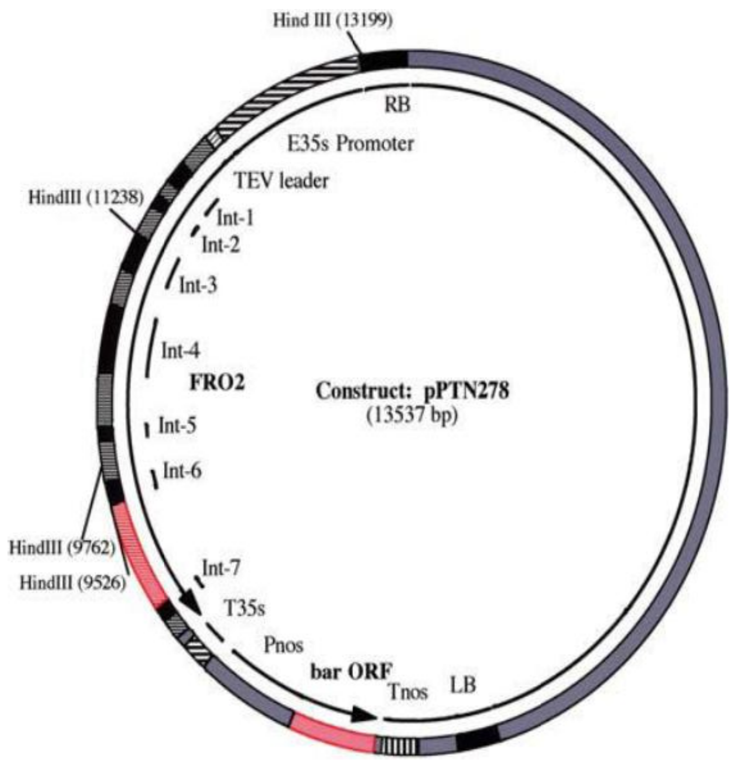
Strategy



Apoplast
Symplast
Fe(III)-chelate
Reductase (FRO)
e-
chelate
Transporter (IRT)
Fe2+
Transporter (ZIP)
Zn2+
ATP
H+

Materials

- *Agrobacterium* transformation with *AtFRO2*
- 38 transgenic lines with ***AtFRO2 (2 parental lines)***



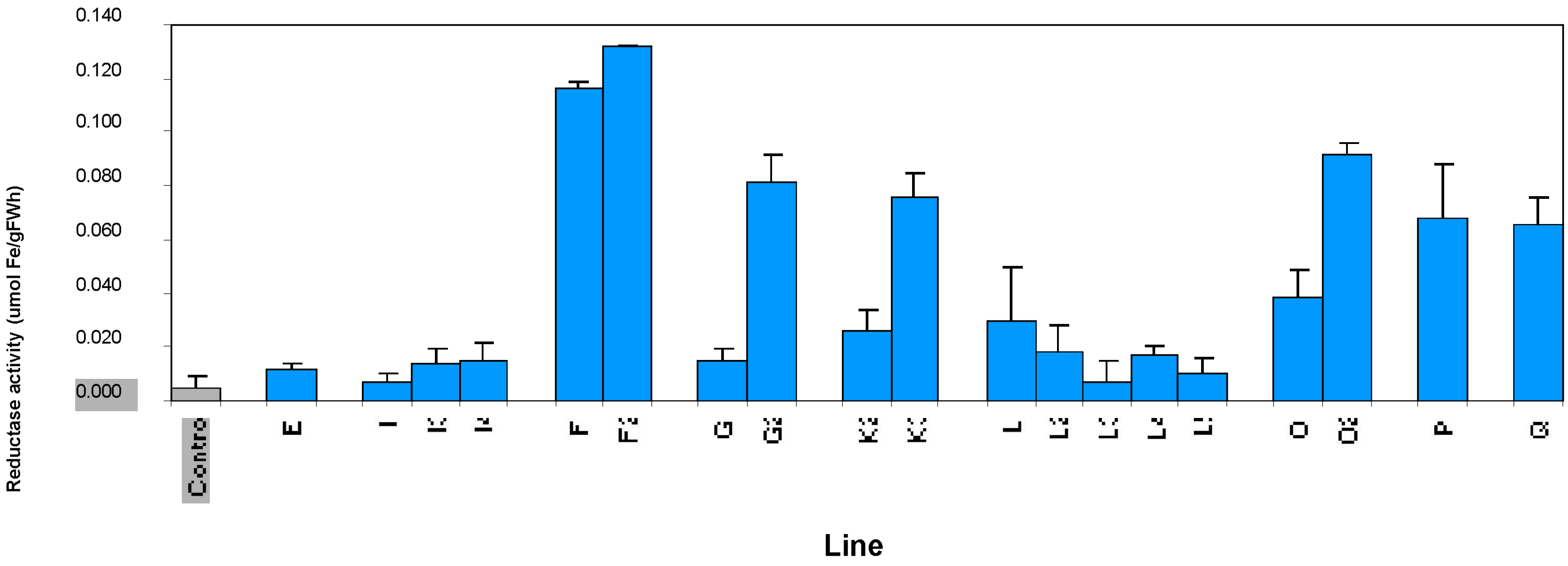
Vasconcelos *et al* Planta (2006) 224:1116–1128

Soluble assay for reductase activity

$$\text{Reductase: } \frac{\text{Av. Abs}_{535} \times \text{Vol. Sol}/1000}{0.02214 \times \text{Root FW} \times \text{Assay min}/60} = \mu\text{mol Fe/ g FW h}$$

Reductase activity ($Fe^{3+} \longrightarrow Fe^{2+}$)

23 x Higher activity!

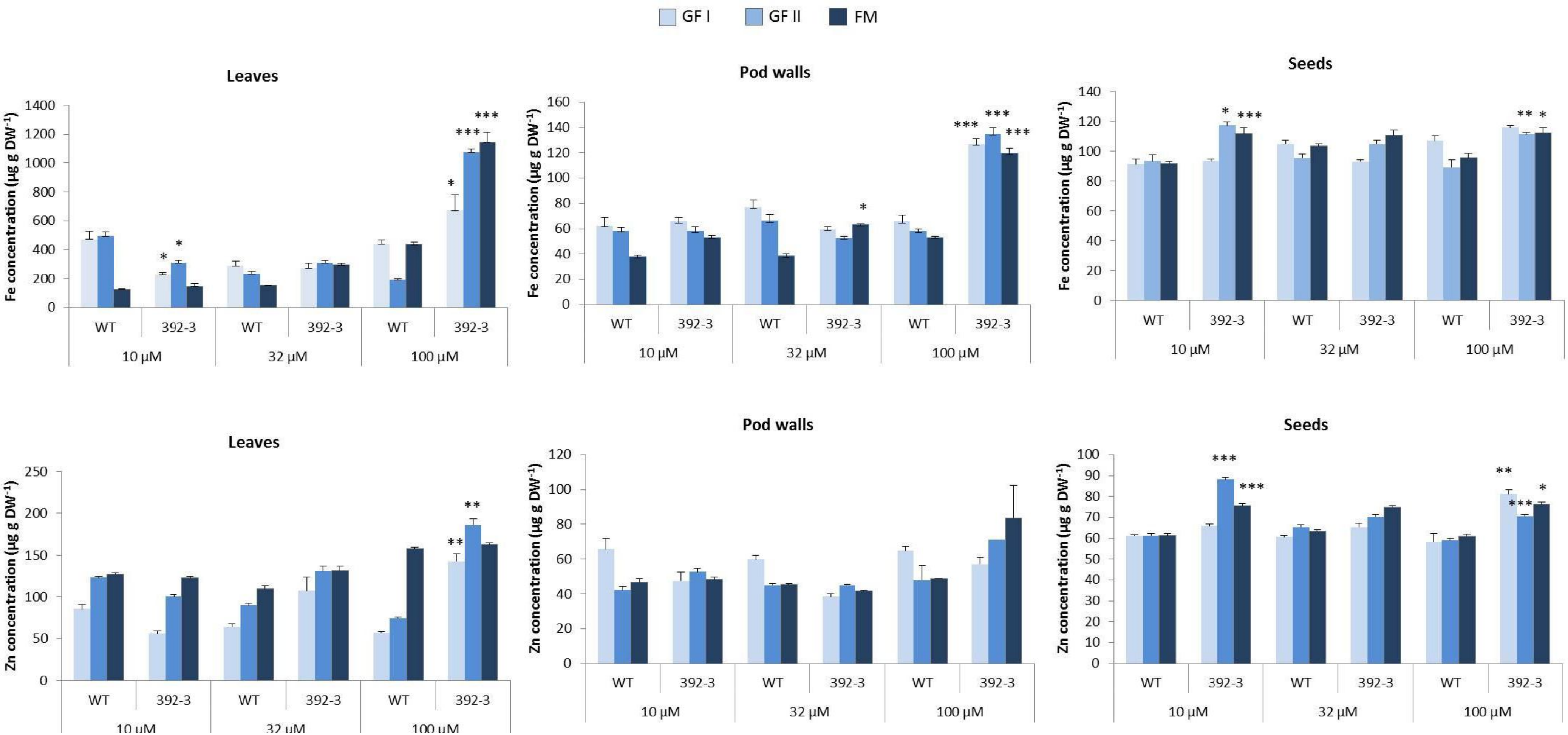


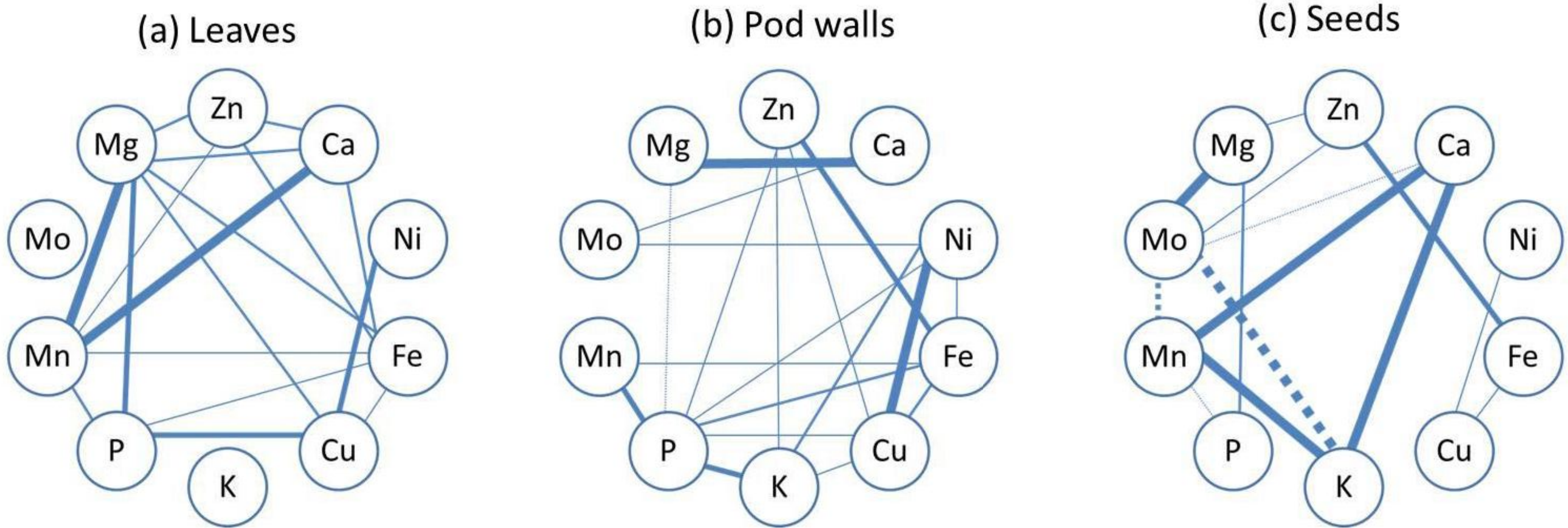
0 µM 10 µM 32 µM 100 µM

A

B

A- Control
B- 392-3

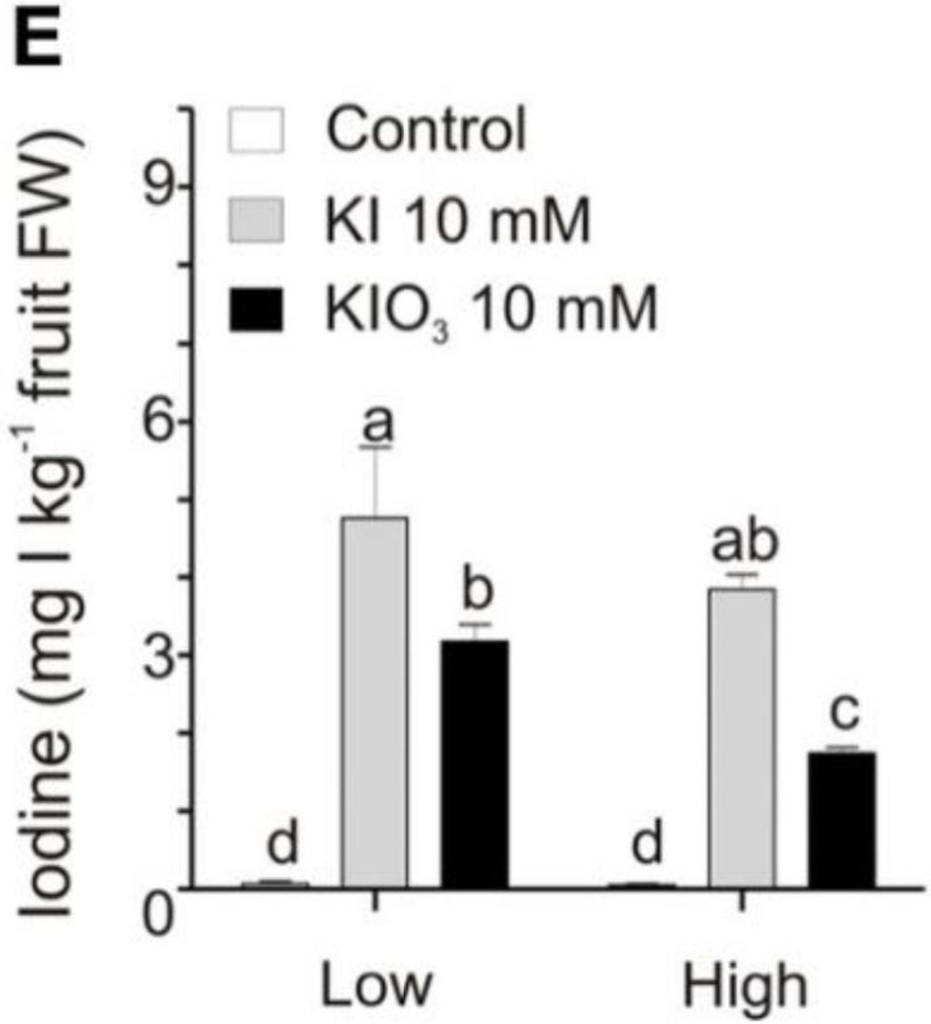

GF I
GF II
FM
Leaves
Fe concentration (µg g DW⁻¹)
Pod walls
Fe concentration (µg g DW⁻¹)
Seeds
Fe concentration (µg g DW⁻¹)
Leaves
Zn concentration (µg g DW⁻¹)
Pod walls
Zn concentration (µg g DW⁻¹)
Seeds
Zn concentration (µg g DW⁻¹)
WT
392-3
10 µM
32 µM
100 µM


(a) Leaves
(b) Pod walls
(c) Seeds
Zn
Mg
Ca
Mo
Ni
Mn
Fe
P
Cu
K

Other examples

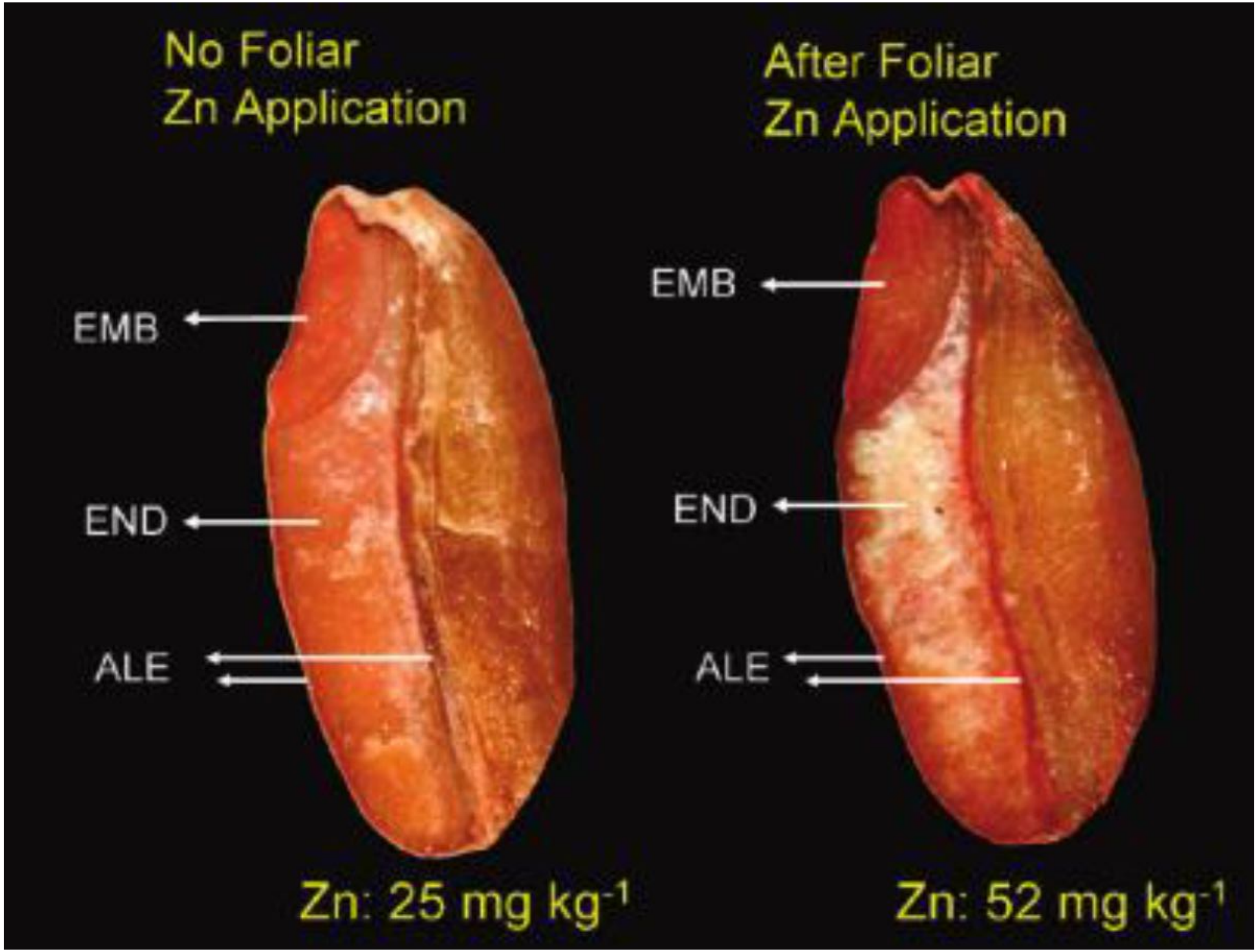
Tomato biofortified with iodine

(via soil fertilization)



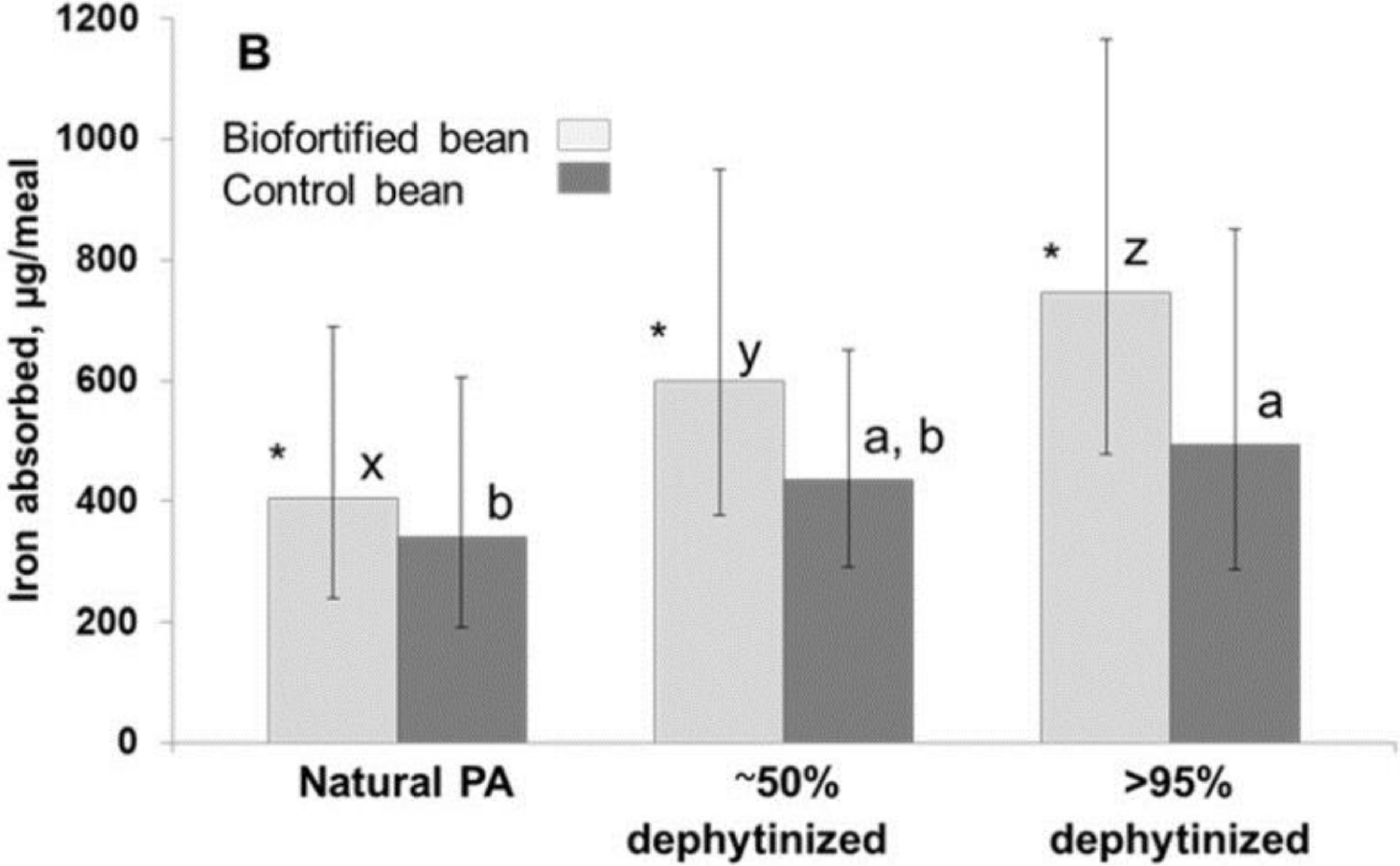
Kiferle C et al. (**2013**) Tomato fruits: a good target for iodine biofortification. Front. Plant Sci. 4:205.

Wheat with Zinc
(via foliar application)



CAKMAK et al (2010) JAFC

High iron bean
(via breeding)



Biofortified crops in the field

- Iron Beans
  - Democratic Republic of Congo
  - Rwanda
- Iron Pearl Millet
- Vitamin A Cassava
- Vitamin A Maize
- Vitamin A Sweet Potato
- Zinc Rice
- Zinc Wheat

Target Crops, Nutrients, Countries, & Release Dates

Bean	Iron	DR Congo, Rwanda	2012
Cassava	Vitamin A	DR Congo, Nigeria	2011
Maize	Vitamin A	Nigeria, Zambia	2012
Pearl Millet	Iron	India	2012
Rice	Zinc	Bangladesh, India	2013
Sweet Potato	Vitamin A	Mozambique, Uganda	2007
Wheat	Zinc	India, Pakistan	2013

Biofortified crops in the news

March 09, 2015
"Zinc-Rich Maize Can Provide Adequate Zinc for Children, Study Finds"
Chomba et al., (2015) Journal of Nutrition

December 31, 2014
"Model Vitamin A Cassava Shop Launched in Ibadan, Nigeria"

AfroPop, Rap and R&B Musicians Promote Healthier Diets—through Beans

https://www.youtube.com/watch?v=fo6449Rd3I0

Iron and Zinc

Why are they important

Plants

Fe Zn
deficiency

2 billion

63 million

C3 crops

The basis of human food and nutrition.

Major global **public health** problem.

Suffer from **Fe** and **Zn deficiency**

Loss **lives-year**

- **95%** of all plants are **C3**
- **Primary dietary source** of Fe and Zn
- Major **protein** sources

Impact of high CO_2

doi:10.1038/nature13179

Increasing CO_2 threatens human nutrition

Samuel S. Myers[1,2], Antonella Zanobetti[1], Itai Kloog[3], Peter Huybers[4], Andrew D. B. Leakey[5], Arnold J. Bloom[6], Eli Carlisle[6], Lee H. Dietterich[7], Glenn Fitzgerald[8], Toshihiro Hasegawa[9], N. Michele Holbrook[10], Randall L. Nelson[11], Michael J. Ottman[12], Victor Raboy[13], Hidemitsu Sakai[9], Karla A. Sartor[14], Joel Schwartz[1], Saman Seneweera[15], Michael Tausz[16] & Yasuhiro Usui[9]

Dietary deficiencies of zinc and iron are a substantial global public health problem. An estimated two billion people suffer these deficiencies[1], causing a loss of 63 million life-years annually[2,3]. Most of these people depend on C_3 grains and legumes as their primary dietary source of zinc and iron. Here we report that C_3 grains and legumes have lower concentrations of zinc and iron when grown under field conditions at the elevated atmospheric CO_2 concentration predicted for the middle of this century. C_3 crops other than legumes also have lower concentrations of protein, whereas C_4 crops seem to be less affected. Differences between cultivars of a single crop suggest that breeding for decreased sensitivity to atmospheric CO_2 concentration could partly address these new challenges to global health.

experiments contribute more than tenfold more data regarding both the zinc and iron content of the edible portions of crops grown under FACE conditions than is currently available in the literature. Consistent with earlier meta-analyses of other aspects of plant function under FACE conditions[14,15], we considered the response comparisons observed from different species, cultivars and stress treatments and from different years to be independent. The natural logarithm of the mean response ratio (r = response in elevated $[CO_2]$/response in ambient $[CO_2]$) was used as the metric for all analyses. Meta-analysis was used to estimate the overall effect of elevated $[CO_2]$ on the concentration of each nutrient in a particular crop and to determine the significance of this effect (see Methods).

We found that elevated $[CO_2]$ was associated with significant decreases in the concentrations of zinc and iron in all C_3 grasses and le-

! **C3 plants** will have lower **Fe**, **Zn**, **protein** in edible plant part

Global challenge

Maintain a high nutritional status

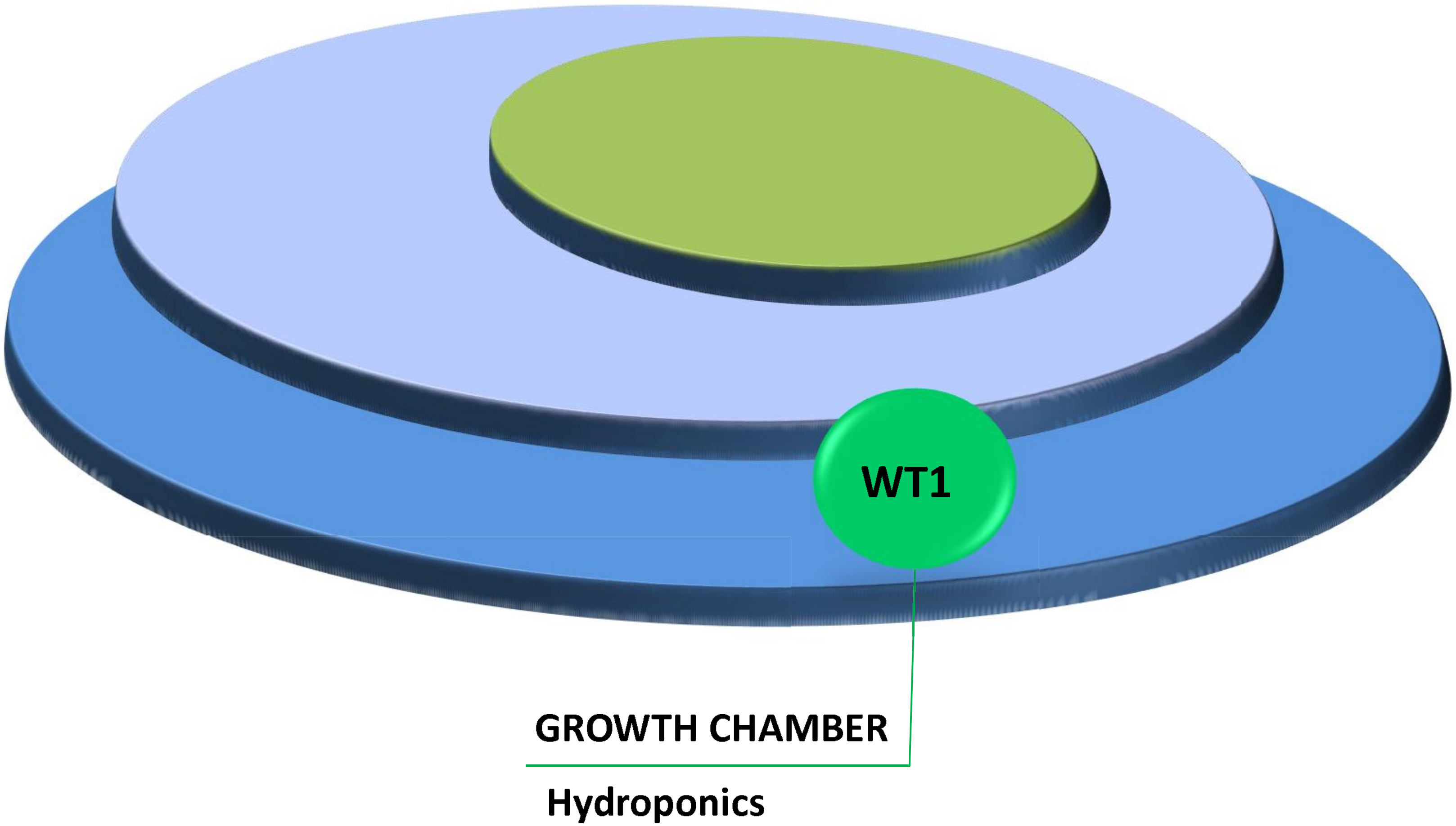
How to address this global challenge?

The necessary steps

1. Cultivars that can withstand high CO_2
2. Key traits and effectors
3. Targeted strategies
4. A nutritious food supply in the future

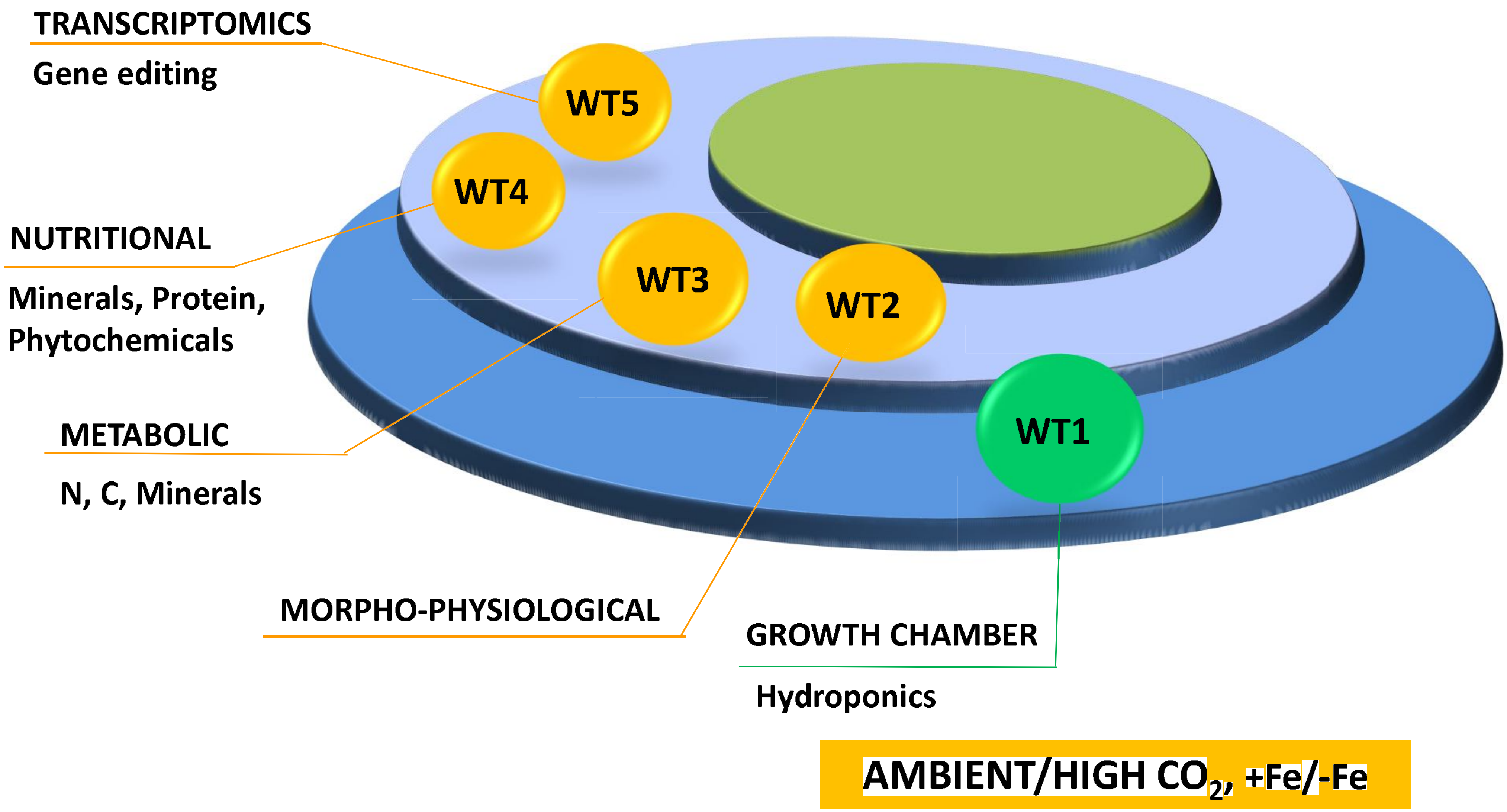
New FCT project (starts May 1st)!

NUTRI4CAST

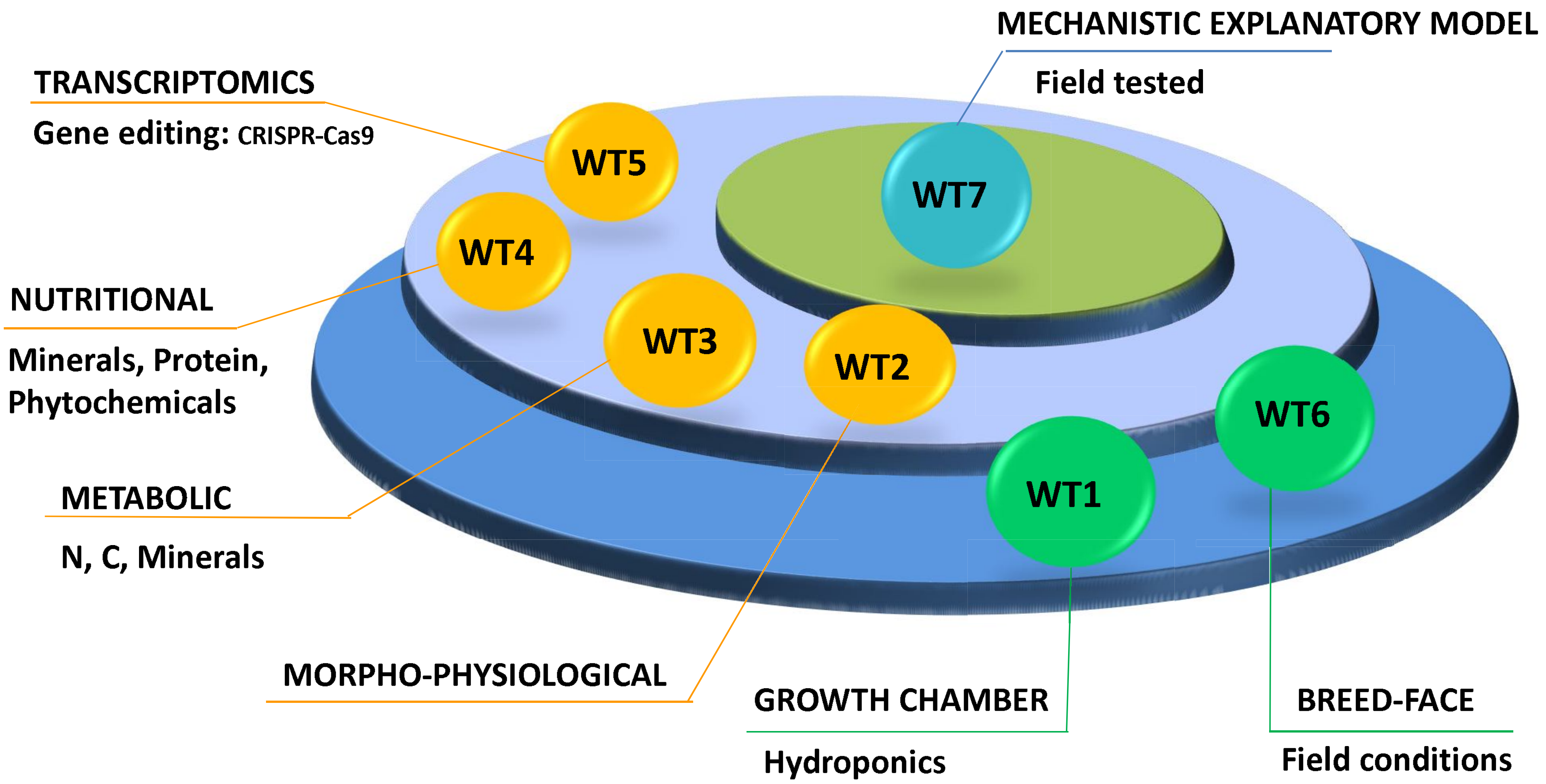


AMBIENT/HIGH CO_2, +Fe/-Fe

NUTRI4CAST

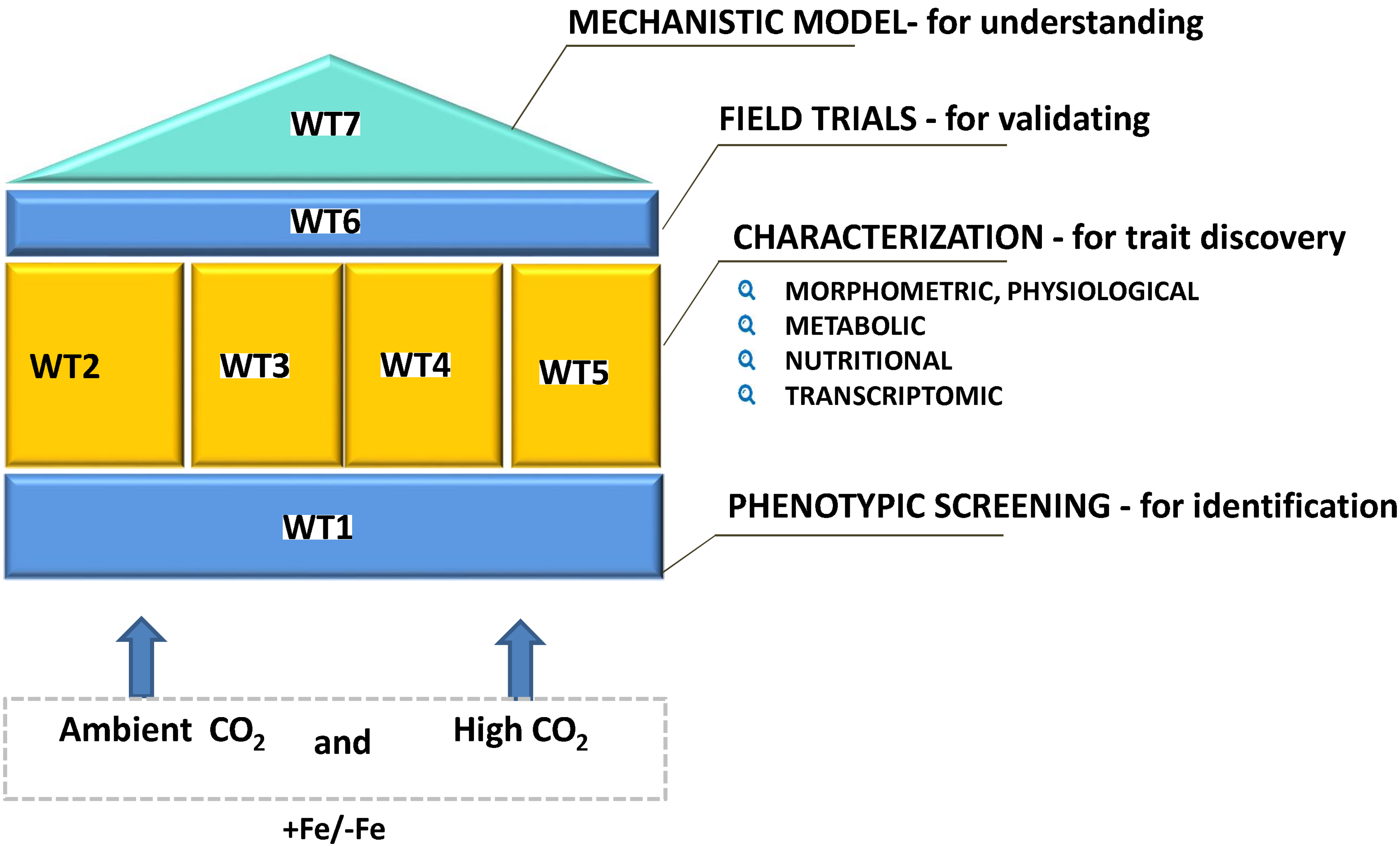

TRANSCRIPTOMICS
Gene editing
WT5
WT4
NUTRITIONAL
Minerals, Protein, Phytochemicals
WT3
WT2
METABOLIC
N, C, Minerals
WT1
MORPHO-PHYSIOLOGICAL
GROWTH CHAMBER
Hydroponics
AMBIENT/HIGH CO_2, +Fe/-Fe

CONTROL-N



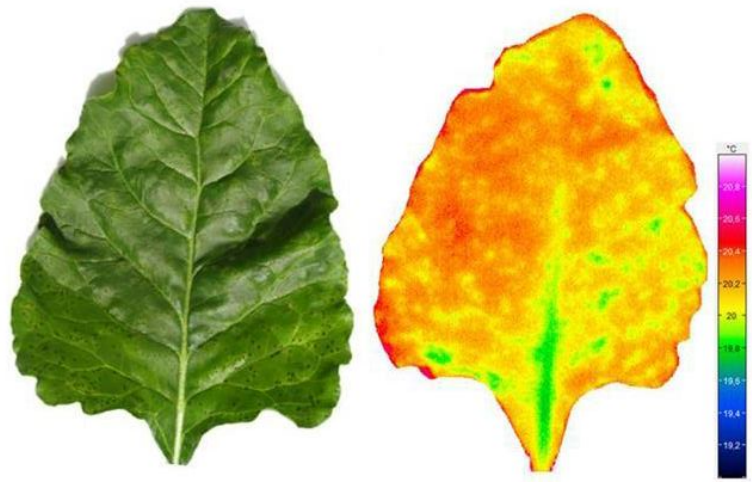
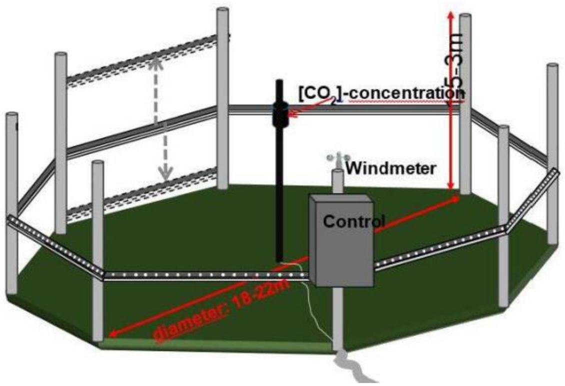
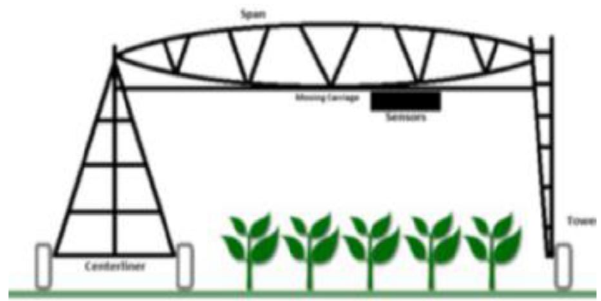
AMBIENT/HIGH CO_2, +Fe/-Fe

CONTROL-N

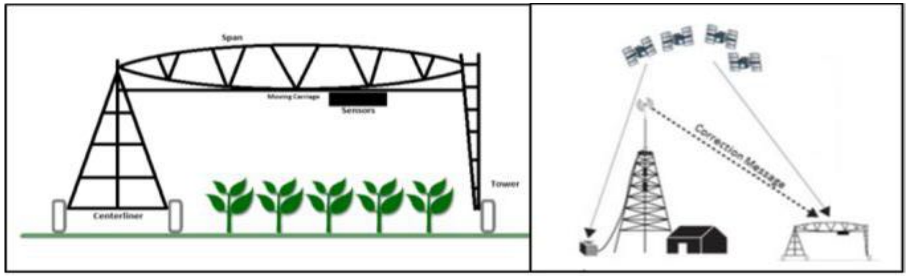

MECHANISTIC MODEL- for understanding
FIELD TRIALS - for validating
CHARACTERIZATION - for trait discovery
MORPHOMETRIC, PHYSIOLOGICAL
METABOLIC
NUTRITIONAL
TRANSCRIPTOMIC
PHENOTYPIC SCREENING - for identification
WT7
WT6
WT2
WT3
WT4
WT5
WT1
Ambient CO_2
and
High CO_2
+Fe/-Fe

High Throughput Phenotyping

Innovation

Partner	When?	What?
JÜLICH FORSCHUNGSZENTRUM	WT2 WT3 ↓ WT7	  

Milestones



Digital phenotyping

Morphometric Physiological analysis

Nutritional Metabolic analysis

Screening under controlled CO_2

Transcriptomic analysis

Breed-FACE Trial

Predictive Model

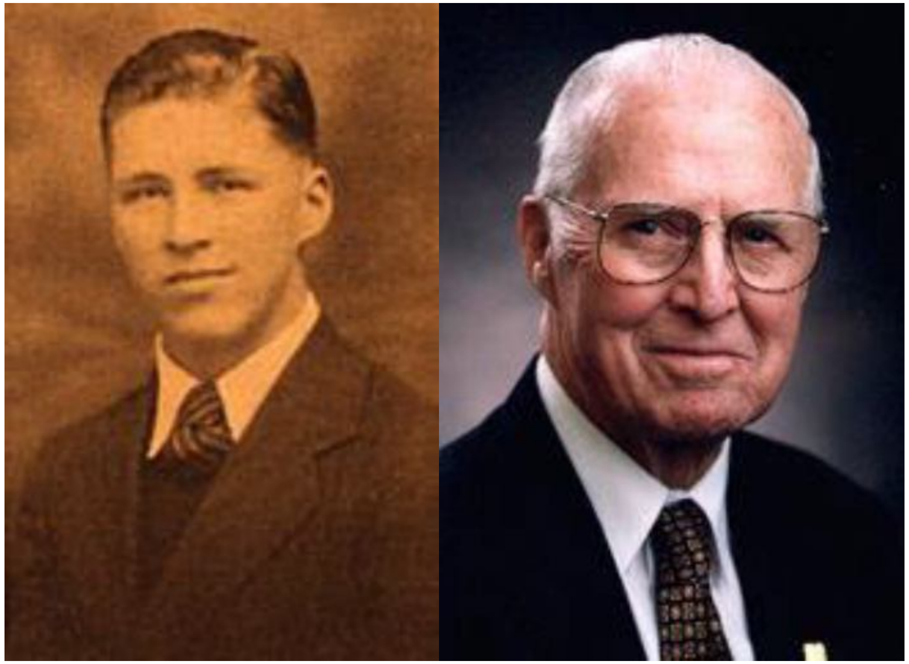
Year 1

Year 2

Year 3

Norman Borlaug

1914 –2009



"Civilization as it is known today could not have evolved, nor can ir survive, without an adequate food supply "

Thank you for your attention!

mvasconcelos@porto.ucp.pt