Picture: M. Grace

Agronomic Biofortification of Cereals with Micronutrients

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World Health Organization

Media Centre: October, 2017

- 5.6 million children under 5 years of age died in 2016.

- More than half of the early child deaths are **due to conditions that could be prevented through simple and affordable interventions.**

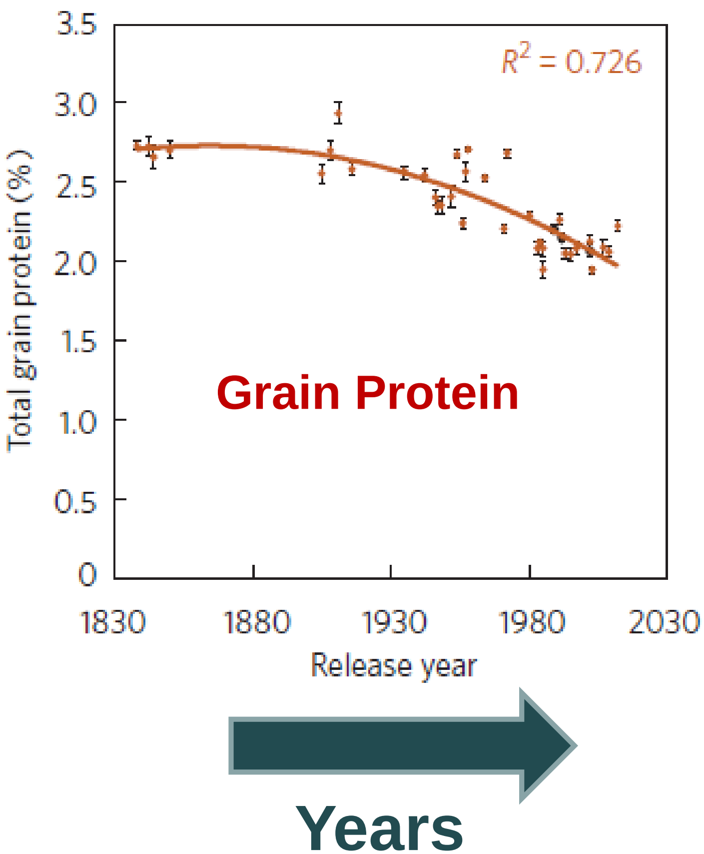
- **Malnutrition (particularly hidden hunger)** contributes to about 45% of deaths in children under 5 years of age.

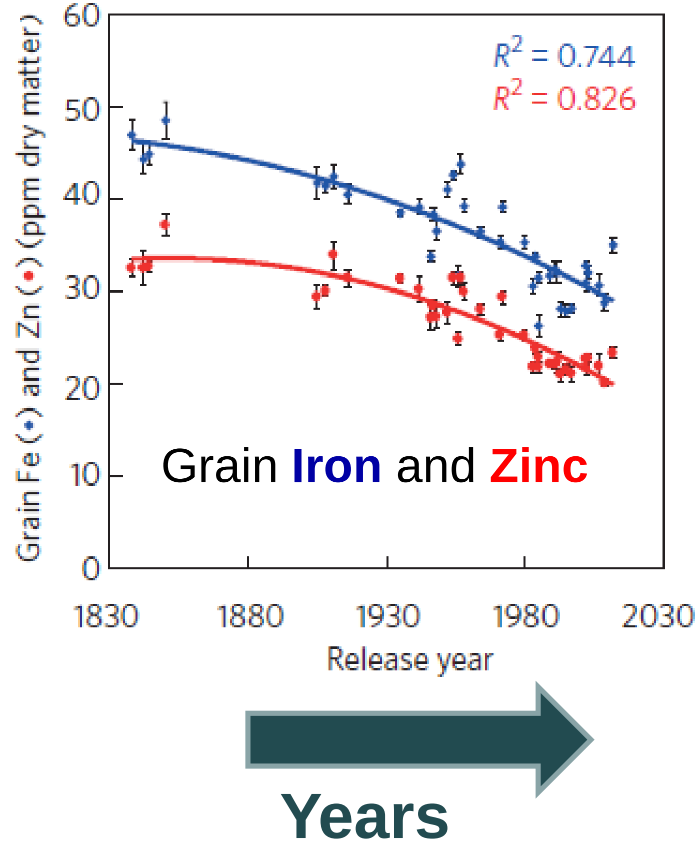
Intensification of Farming and Increases in Yield

Nutrient Depletion in Soils and Nutrient Dilution in the Harvested Products

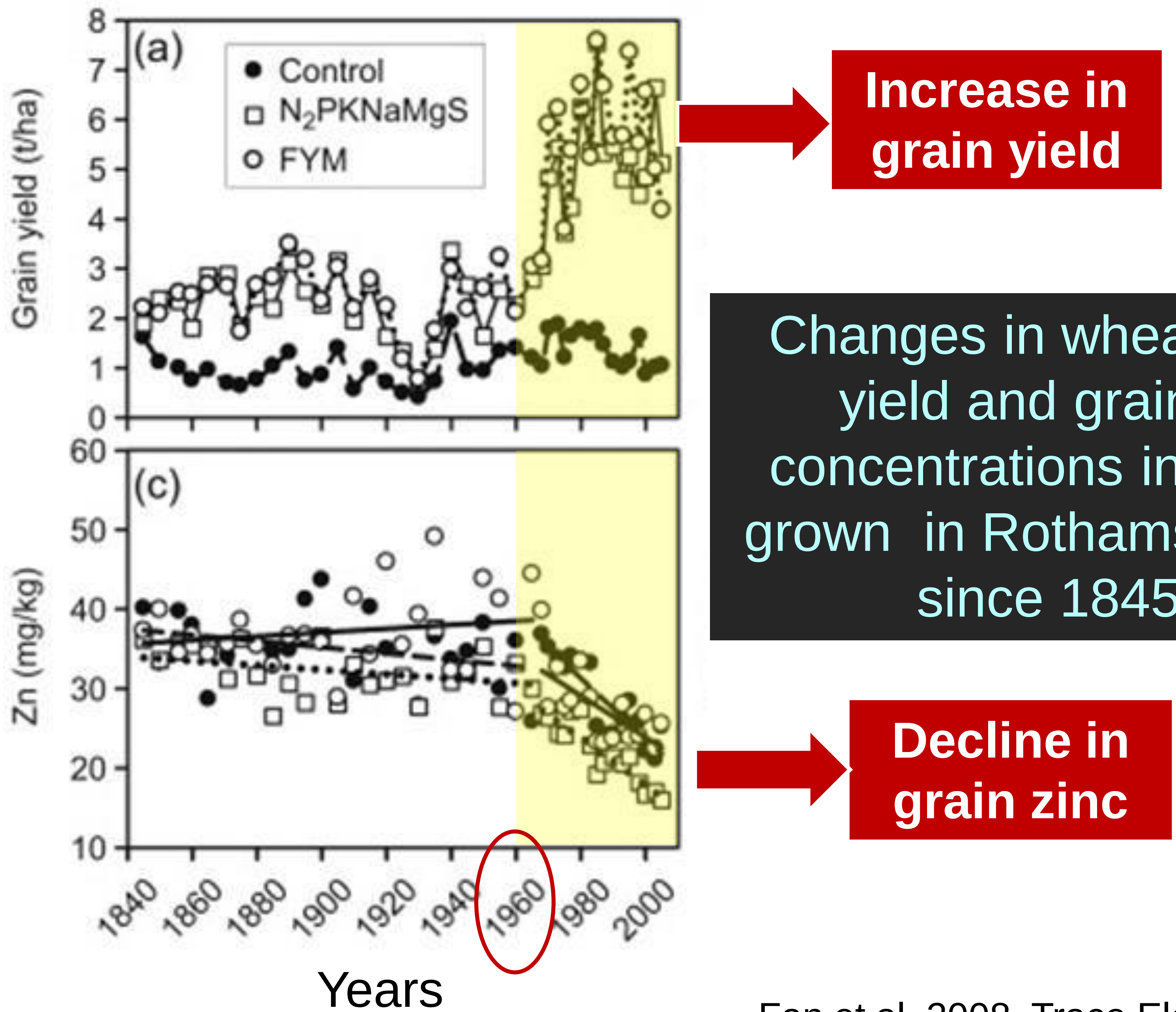
Increasing grain yield potential of new varieties results in large **dilution** of **seed-nutrients**

Historical changes in grain protein and grain zinc and iron concentrations (with increasing grain yield)





Shewry et al. 2016, Nature Plants



Changes in wheat grain yield and grain Zn concentrations in wheat grown in Rothamsted-UK since 1845.

Fan et al. 2008, Trace Elem Med Biol

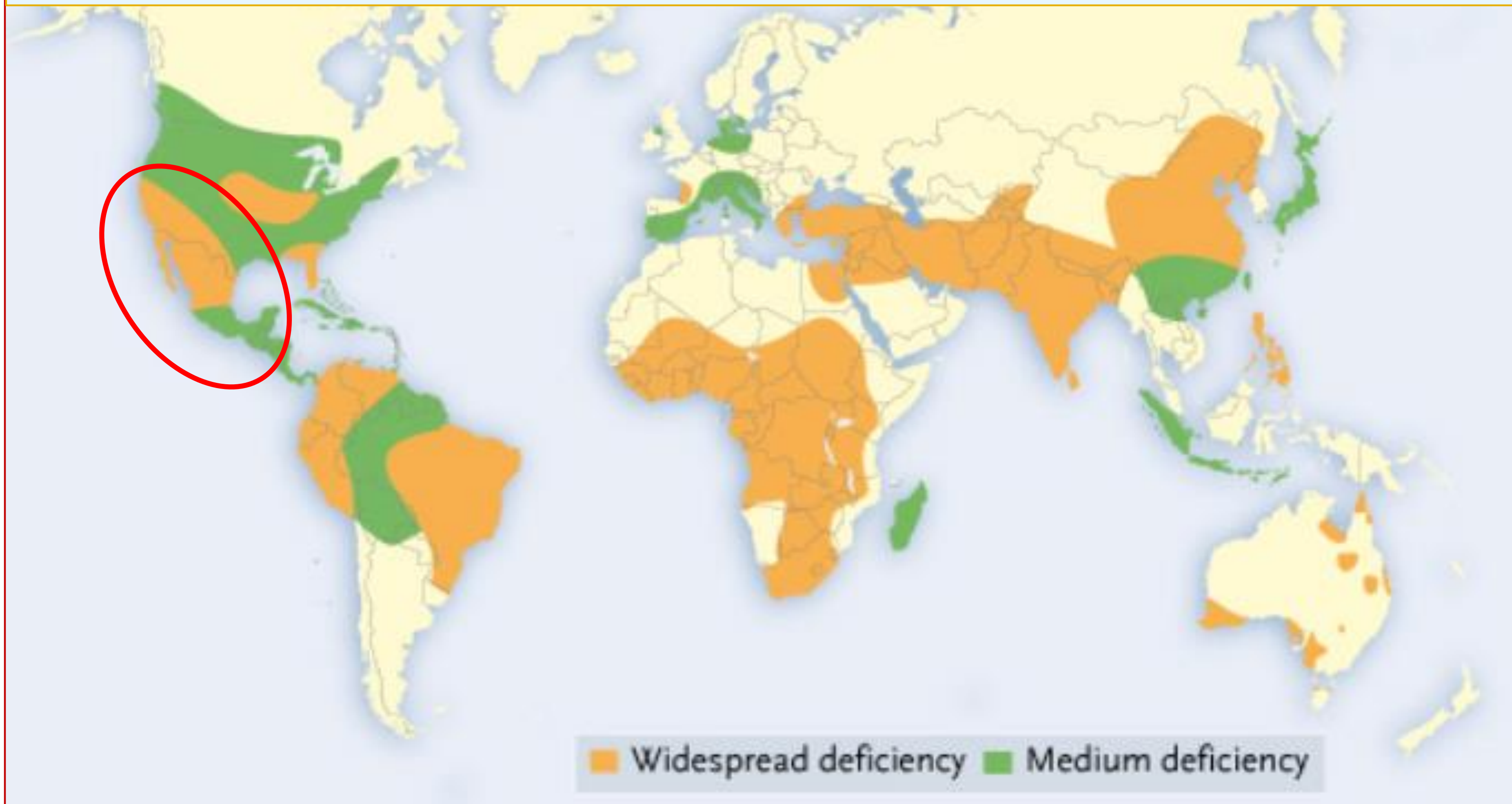
High-yielding cultivars remove high amount of nutrients from soils

Mineral nutrient	Targeted Corn Yield		
	9t	12t	15t
	Calculated Removals from Soil		
N (kg/ha)	270	330	380
P_2O_5 (kg/ha)	100	125	150
Zn (gr/ha)	340	450	560

Courtesy: Dr. V. Römheld

Global Soil Zinc Deficieny

40 % of the cultivated soils globally affected from Zn deficiency



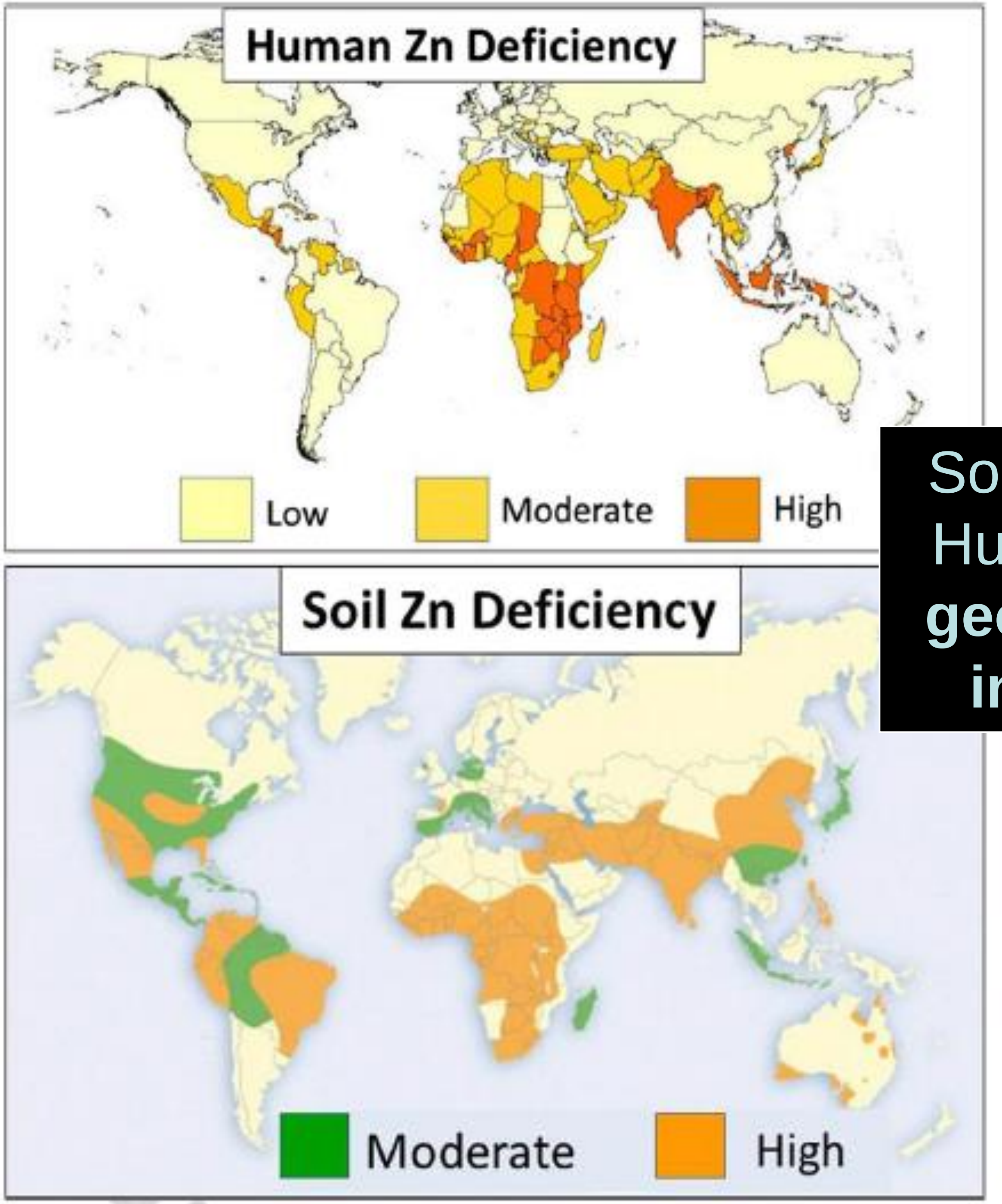
Alloway, 2007; IZA Publications

For a better zinc nutrition of human beings, cereal grains should contain around

40-60 mg Zn kg^{-1}

Current Situation: 20-30 mg kg^{-1}

Cakmak et al, 2017, Plant Soil; Cakmak and Kutman, 2017, Eur. J. Soil Sci.



Wessels et al., 2012

Soil Zn Deficiency and Human Zn Deficiency: **geographical overlap in many countries**

Cakmak et al., 2016, Plant Soil

For a better **selenium** (Se) nutrition of human beings, cereal grains should contain around

200-600 µg kg^{-1} Se

Common grain concentration of Se:

40 to 80 µg kg^{-1}

Lyons et al., 2005, Plant Soil; HarvestZinc Project

For a better iodine nutrition of human beings, cereal grains should contain at least

100-150 µg kg^{-1} iodine

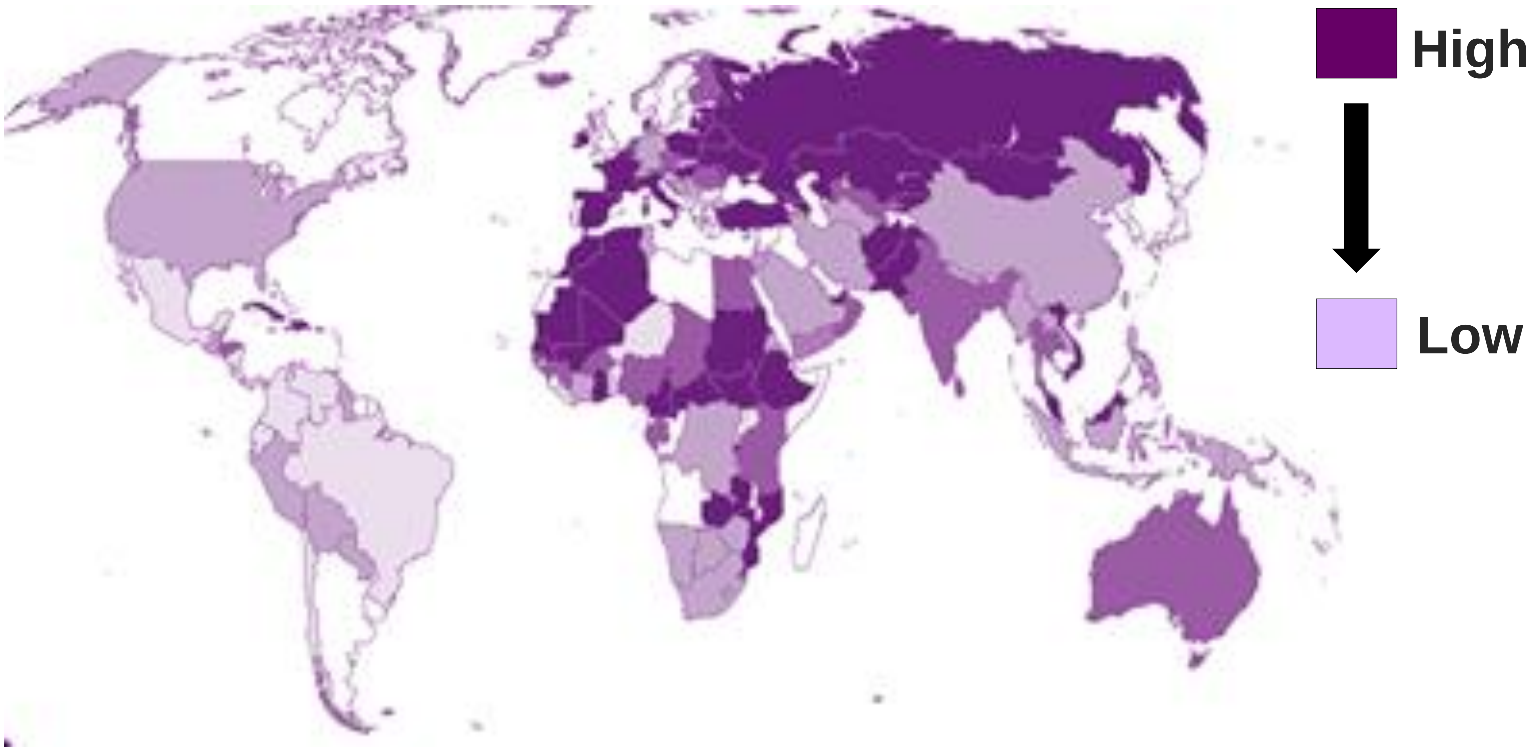


Common grain iodine conc. : **10-20 µg kg^{-1}**

HarvestZinc Project

Based on urinary iodine data collected about 1/3 of school children has insufficient iodine intake in the world

Iodine Deficiency in School Children



Average prevalence (%) per country. Based on data from: FAO, 2013. The state of food and agriculture. Food systems for better nutrition. E-ISBN 978-92 - 5-107672-9. Statistical annex p. 73-79.

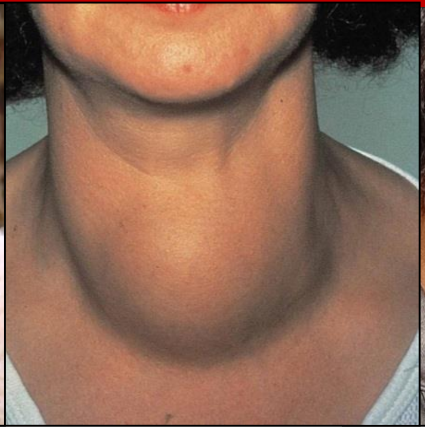
Iodine deficiency is associated with various health complications including endemic goiter, intellectual and mental impairments, growth retardation, and increased infant mortality (Zimmerman, 2009; Lazarus, 2015).

People with low iodine intake can become dull, listless and easily get tired



Iodine Deficiency Disorders: Goitre






Iodine is too low in soils and cereal grains

Cereal grains contain commonly 15 µg iodine per kg and far low to meet daily requirement of the human populations, especially in developing world where cereals are extensively consumed.

Recommended daily I-intake is 150 µg

(Swanson and Pearce, 2013, Adv. Nutr)

Solutions

- Supplementation
- Food Fortification

(may not be affordable in low income countries)

Nutritionists tend to emphasize medical approaches to solve malnutrition problems

Health comes from the farm, not from the pharmacy !

- **Agriculture is the primary source of all nutrients entering human food systems**

- **Agriculture must play an important role in fighting malnutrition**

Welch et al., 2008, FAO Publication

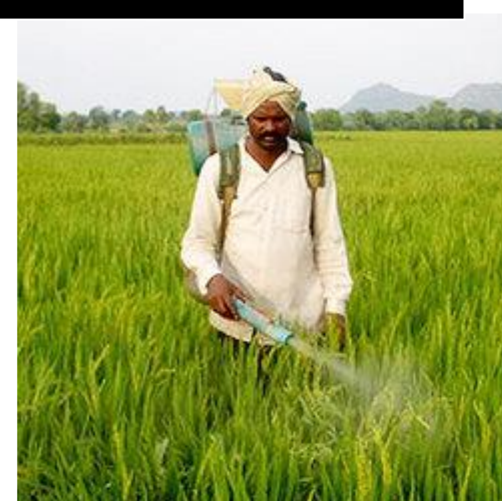
Agricultural Solutions

(Plant Breeding and Agronomy)

Plant Breeding

Plant Nutrition/Fertilizers

Complementary solutions



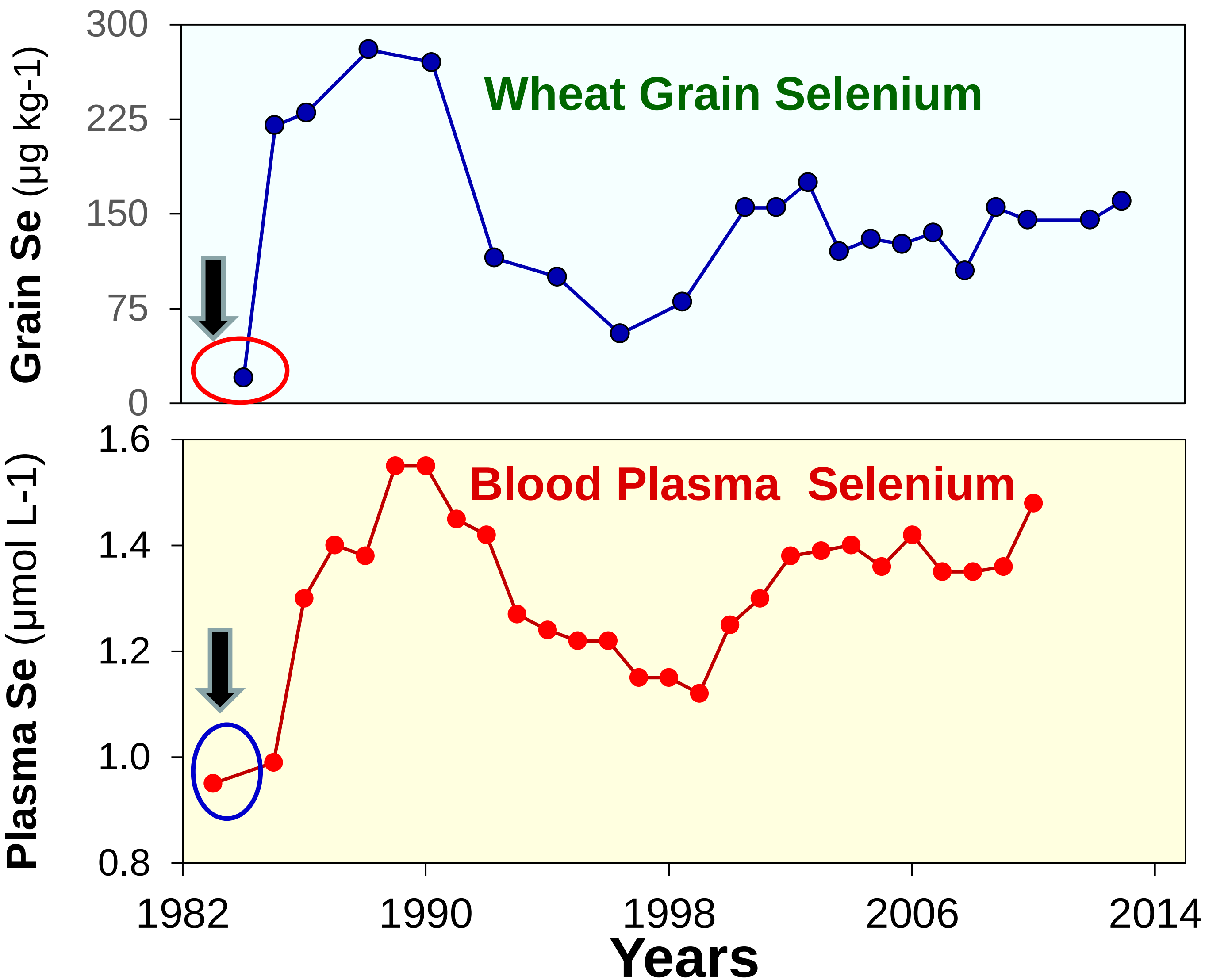
"Success Story" demonstrating key role of fertilizer strategy in fighting against micronutrient malnutrition globally

Finnish Story

Due to extremely **low selenium (Se) intake in Finland**, an official decision was made in 1984 to enrich NPK fertilizers with Se

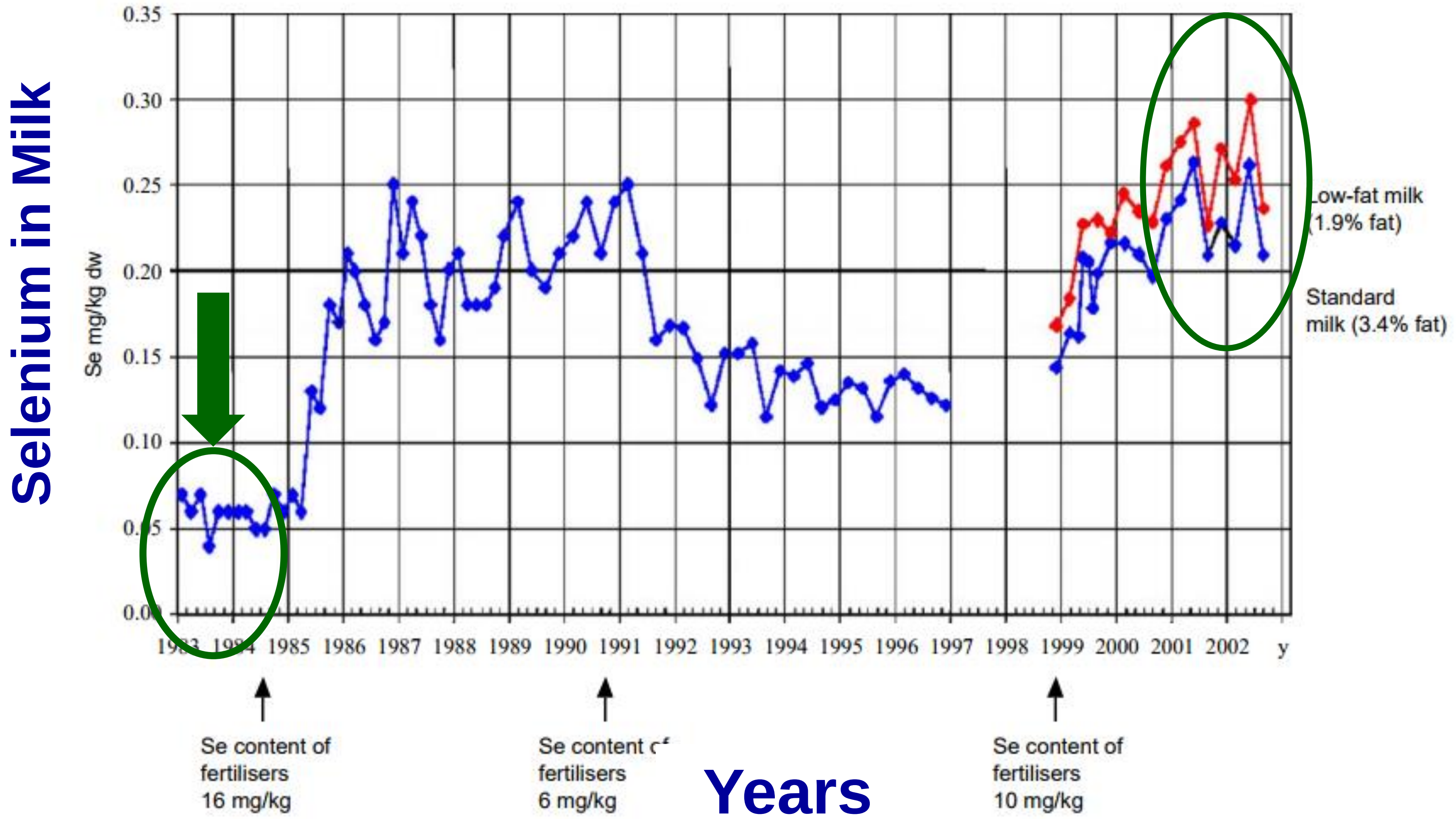
Almost all fertilizers used in Finland since 1985 contain Se. **Currently all crop fertilizers contain 15 mg Se/kg.**

Changes in grain and blood selenium since 1985 in Finland



Alfthan et al., 2015, J. Trace Elem. Med. Biol.

Changes in milk selenium concentrations in Finland during 1984–2002



Hartikainen, 2005, J. Trace Elem. Med. Biol. 18: 309–318

The amount of selenium needed per hectare very little (3-4 gram Se)

HarvestPlus-HarvestZinc Project

Zinc + Iodine Fertilizer Project

Global Zinc+Iodine Fertilizer Project

Coordinating Institution: Sabanci University

Global Zinc Fertilizer Project

HarvestZinc
exploring fertilizer use to increase zinc in cereals

2008 June- .....

Grain Zn concentration in different countries with and without foliar zinc fertilization

Country/Location	-Zn	+Zn
	mg kg^{-1}	
India		
•Varanasi	29	47
•PAU-I	25	81
•PAU-II	28	77
•PAU-III	26	61
•PAU-IV	49	65
•IARI	33	45
Kazakhstan		
•Loc-I	19	54
•Loc-II	28	73
Pakistan		
•Loc-I	27	48
•Loc-II	28	44
•Loc-III	30	40
•Loc-IV	29	60

Country/Location	-Zn	+Zn
	mg kg^{-1}	
Mexico		
•Year-I	21	45
•Year-II	36	60
Turkey		
•Konya	12	29
•Adana	32	57
•Samsun	23	49
•Eskisehir	22	43
China		
•Loc-I	28	54
•Loc-II	19	26
Australia		
•Loc-I	18	39
Germany		
•Average	20	32
Iran		
•Average	17	28
Brazil		
•Average	30	52

Zou et al., 2012 Plant Soil; www.harvestzinc.org

Grain Zn concentration in different countries with and without foliar zinc fertilization

Average Concentrations of Grain Zn

(10 Countries with 32 locations)

-Zn: 26 ppm

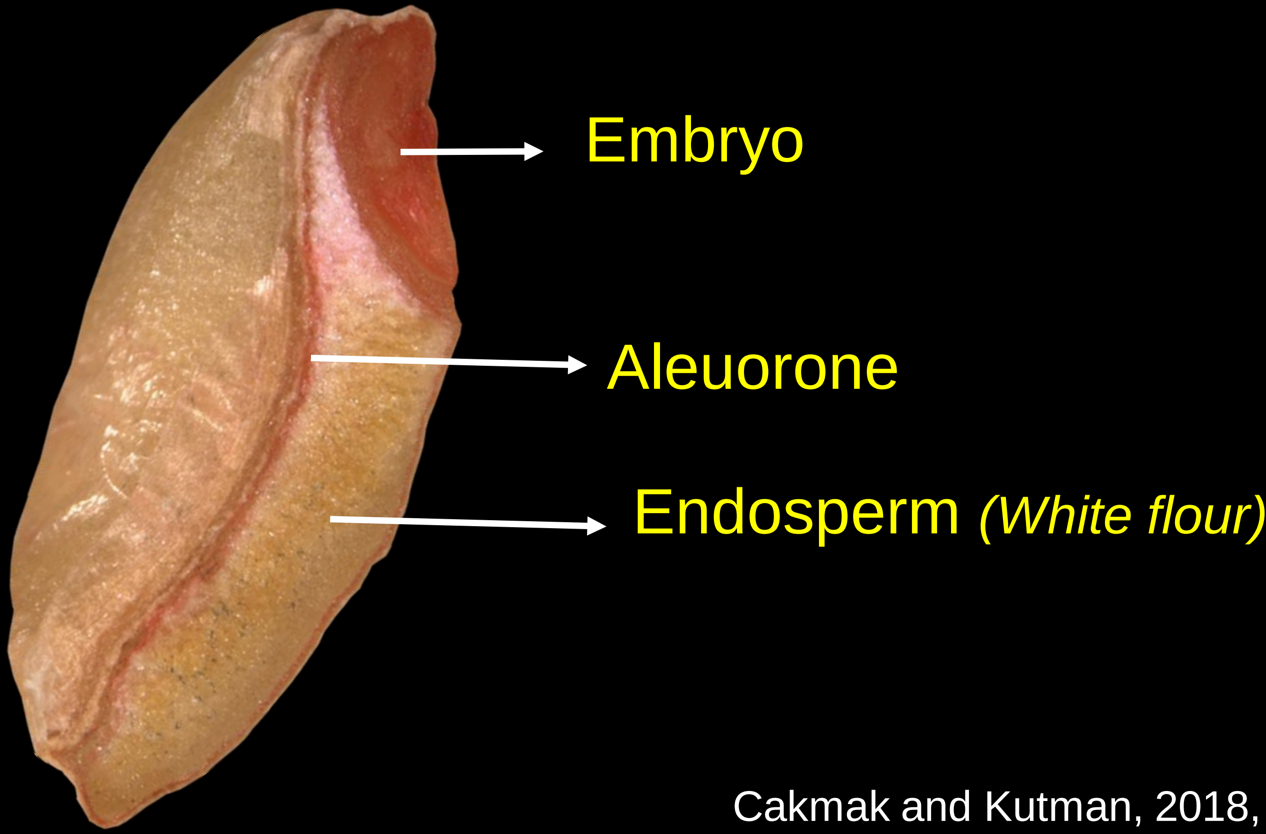
+Zn: 50 ppm

Country/Location	-Zn	+Zn
	mg kg^{-1}	
India		
•Varanasi	29	47
•PAU-I		
•PAU-II		
•PAU-III		
•PAU-IV		
•IARI		
Kazakhstan		
•Loc-I		
•Loc-II		
Pakistan		
•Loc-I		
•Loc-II	28	44
•Loc-III	30	40
•Loc-IV	29	60

Country/Location	-Zn	+Zn
	mg kg^{-1}	
Mexico		
•Year-I	21	45
•Year-II	36	60
	12	29
	32	57
	23	49
	22	43
	28	54
	19	26
	18	39
	20	32
•Average	17	28
Brazil		
•Average	30	52

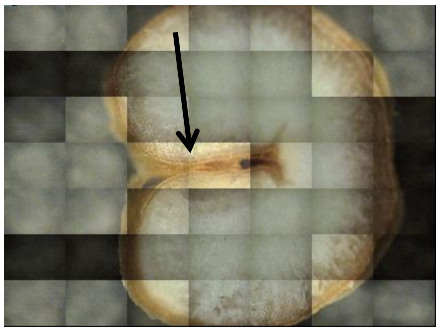
HarvestZinc Project; Zou et al., Plant Soil, 2012

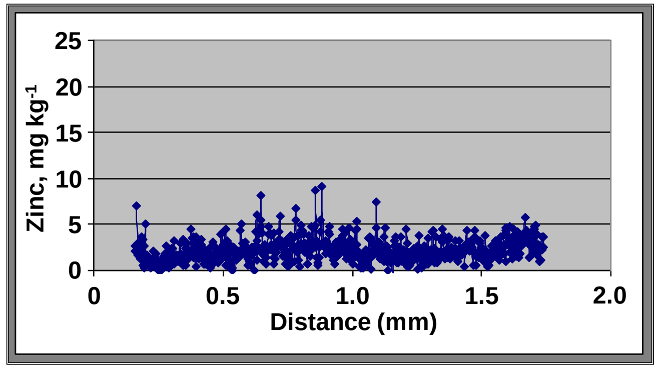
Staining and Localization of Zinc in Wheat Grain



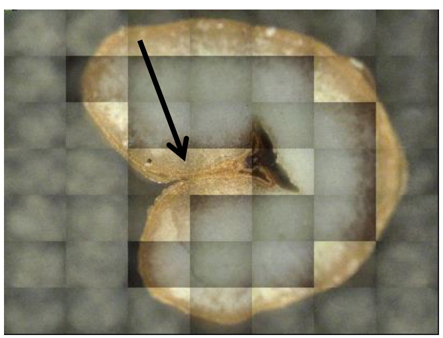
Cakmak and Kutman, 2018, Eur. J. Soil Sci.

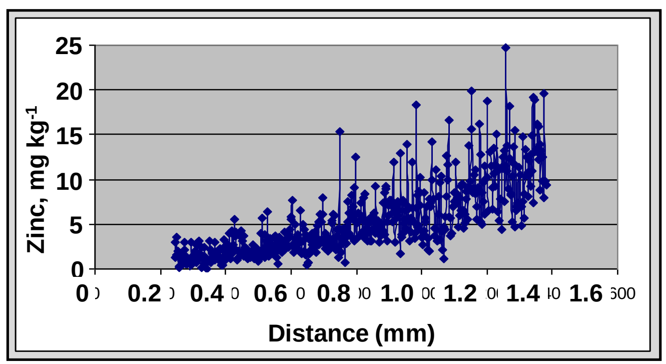
Changes in Endosperm (Flour) Zinc Concentrations
after Foliar Zinc Treatments (LA-ICP-MS measurement)





No Foliar Zn Application



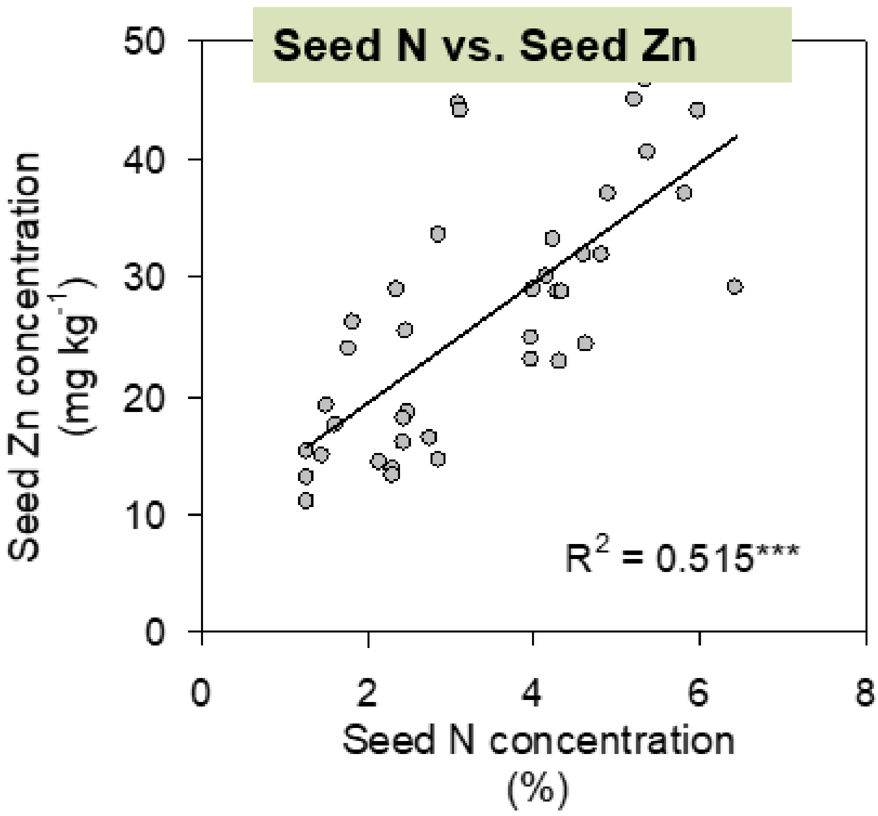


Foliar Zn Application

Cakmak et al 2010, J. Agric. Food Chem.

Nitrogen Effect

Correlations between seed Zn concentrations and seed seed N concentrations (right).

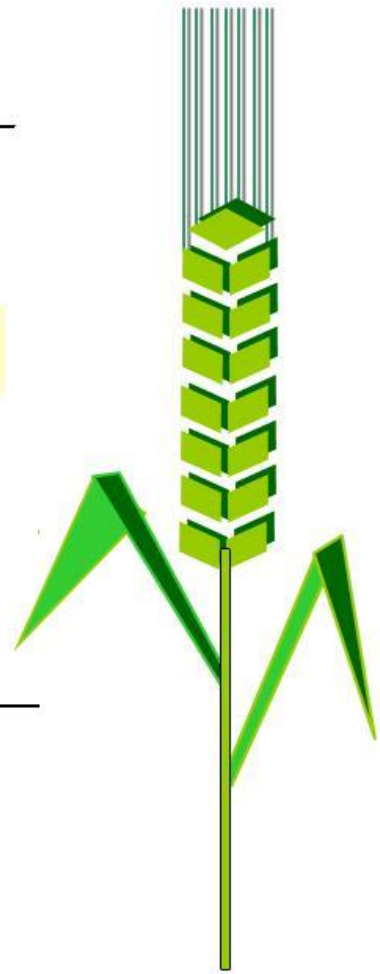


Grain samples collected from 20 dicots and 20 cereals grown in the same region and same year

Cakmak et al., 2010 Cereal Chem. 77: 10-20

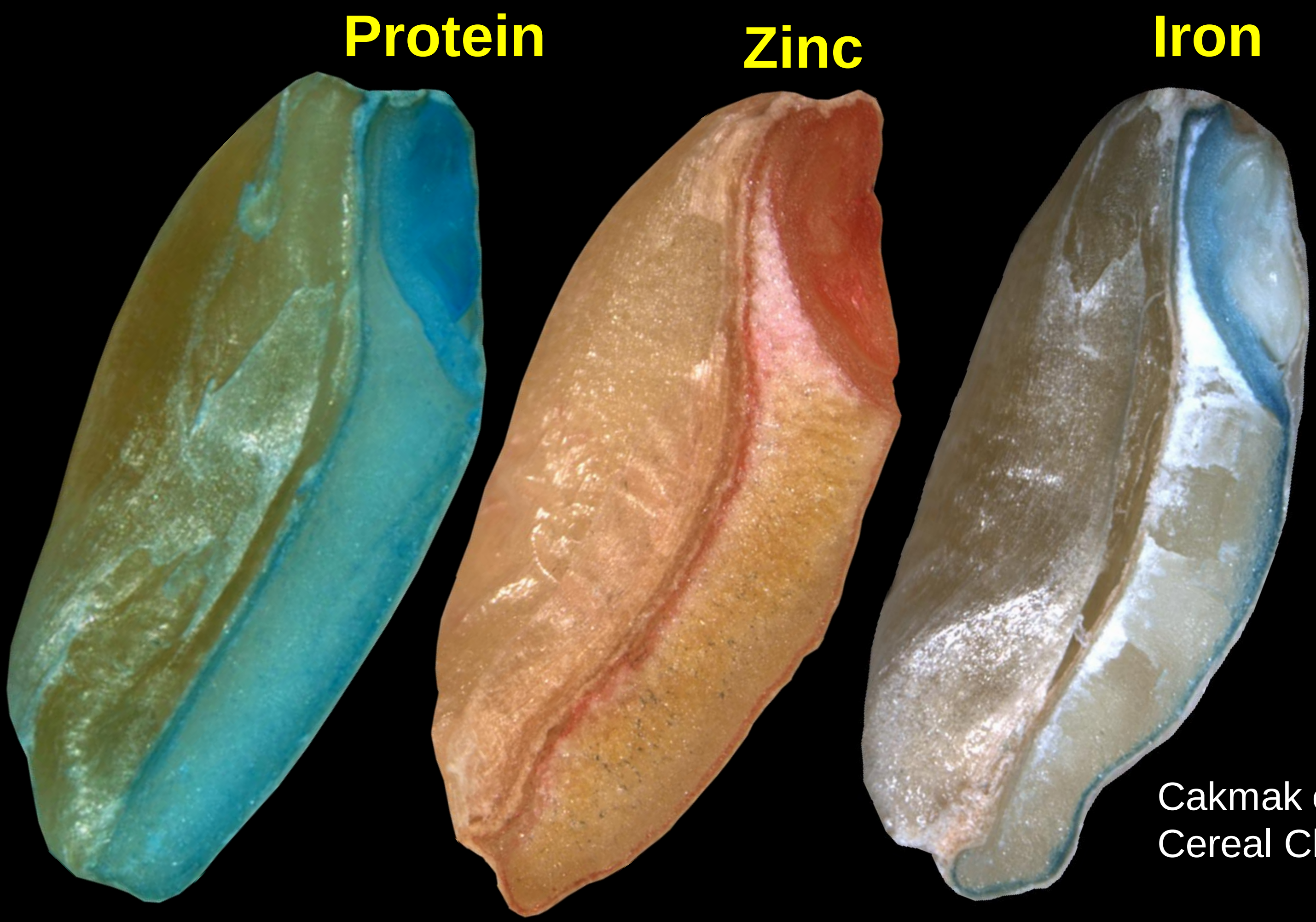
Nitrogen Dependent Zinc and Iron Partitioning (%) in Wheat Plant at Maturity

Shoot Part	IRON Low N	IRON High N	ZINC Low N	ZINC High N
Husks	9	7	10	6
Grains	38	60	59	78
Leaves	48	28	17	8
Stem	5	6	14	7



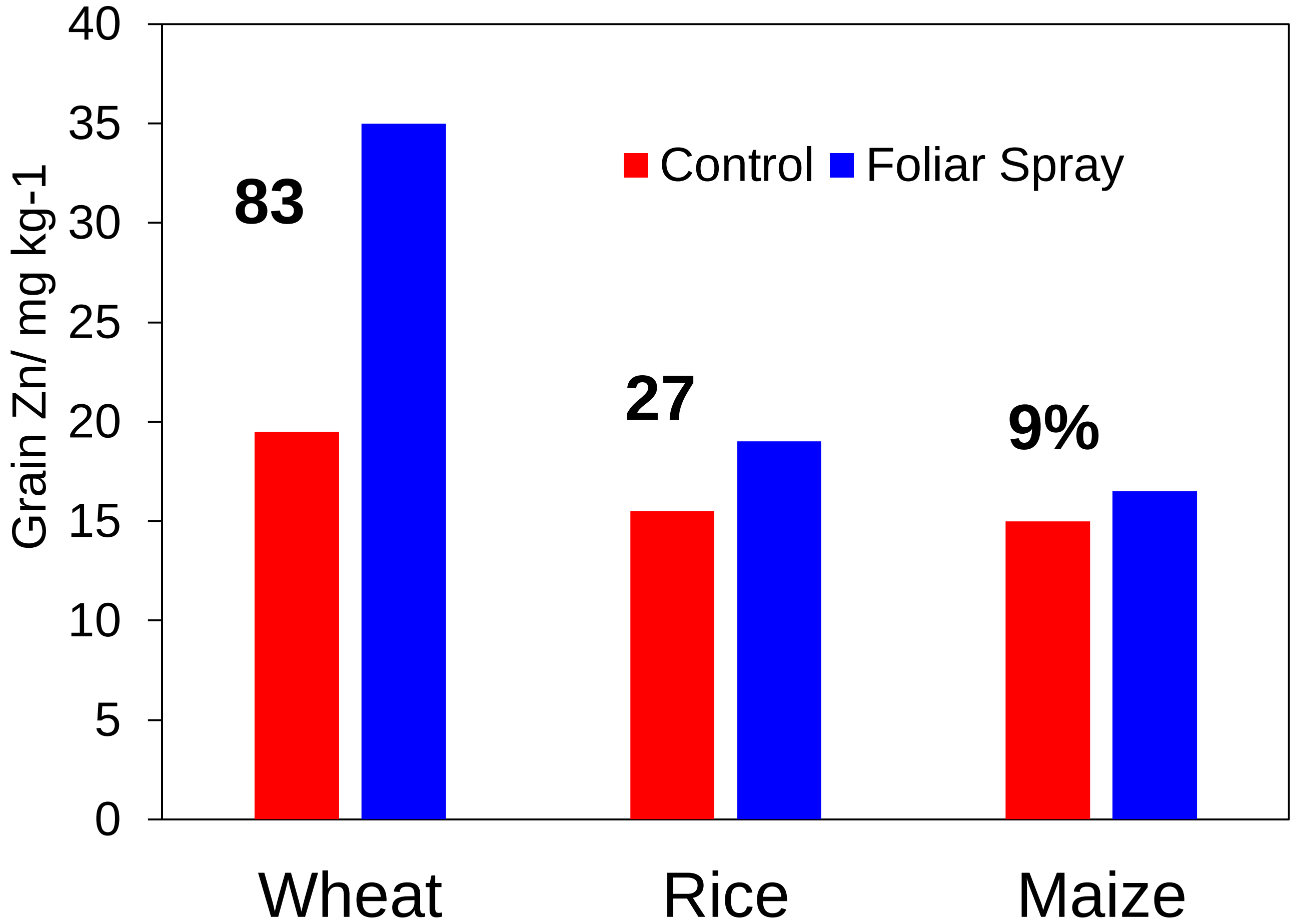
Kutman et al. 2011,
Plant and Soil

Staining and Localization of Protein, Zinc and Iron in Wheat Grain



Cakmak et al., 2010
Cereal Chem, 77: 10-20

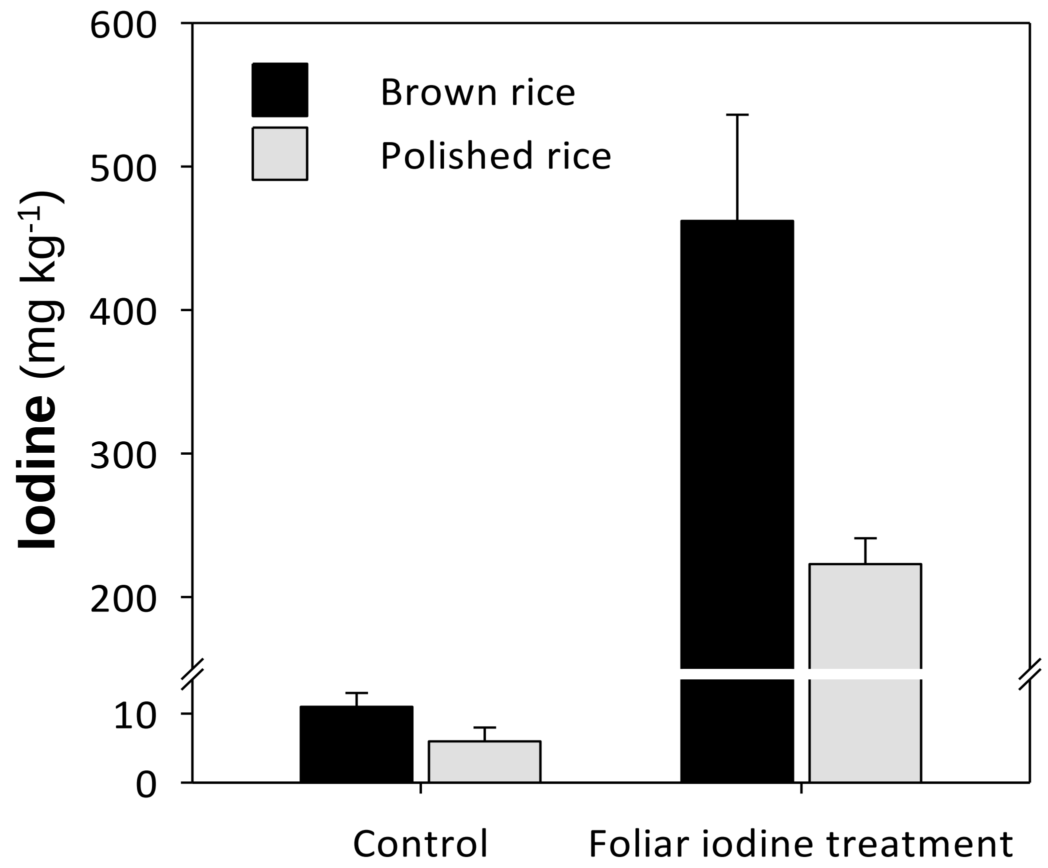
Average changes in grain Zn concentration caused by foliar Zn applications (as $ZnSO_4$) to wheat, rice and maize grown in Turkey at four locations.



Cakmak and Kutman, 2017; Eur. J. Soil Sci.

Iodine Biofortification

Iodine concentration in brown and polished rice with and without foliar iodine spray in rice in Turkey
(iodine moves also in the polished rice)



Cakmak et al, 2017, Plant and Soil

Iodine stability in agronomically-biofortified grain after food preparation

Conclusion

Targeted plant mineral nutrition is highly promising in increasing dietary concentrations of nutrients in an effective and sustainable way to contribute to human nutrition and health.

Combination of plant breeding and agronomy would create additive and synergistic impacts on grain micronutrients

"Focus on better food, not only more food"

HarvestPlus

Thank you

China Agric. Univ.

Punjab Agric Univ.

NIAB-Pakistan

Chiang Mai Univ.

Tr. Zone Agric. Inst. Turkey

Lavras Univ.-Brazil

Stellenbosch Univ. South Africa

Thank you

Grain Zn concentration of wheat grown without Zn treatment and with foliar Zn treatment alone or in combination with pesticide in 24 field experiments

			Grain Zn concentration (mg kg^{-1})			LSD (P=0.05)
			No Zn	Foliar Zn	Foliar Zn + pesticide	
India	Ludhiana	2011-12	34.6b	42.7a	39.9a	3.1
	Ludhiana	2012-13	27.2b	42.3a	43.6a	6.1
	Bathinda	2011-12	28.4b	38.2a	32.9b	3.5
	Bathinda	2012-13	25.4c	42.2a	31.7b	3.5
	Gurdaspur	2011-12	33.2b	40.3a	41.9a	2.9
	Gurdaspur	2012-13	26.2b	44.1a	40.2a	4.2
Pakistan	Faisalabad-I	2011-12	21.0b	40.9a	22.6b	4.9
	Faisalabad-II	2012-13	29.8b	36.8a	30.5b	2.9
	Muredke-I	2011-12	21.1b	34.9a	24.9b	6.1
	Kabirwala	2011-12	24.2a	26.2a	27.5a	NS
	Muredke-II	2012-13	30.4b	41.2a	41.5a	7.5
Brazil	Capão Bonito - I	2009	30.1b	50.0a	52.4a	4.8
	Capão Bonito - II	2009	29.5b	49.5a	53.5a	5.5
	Capão Bonito	2010	25.3a	42.7a	45.7a	7.5
China	Hebei-Quzhou	2011-12	32.4b	47.5a	38.5ab	10.0
	Hebei-Quzhou	2012-13	32.6b	49.2a	37.2b	8.4
	Shaanxi-Yongshou	2011-12	21.1b	40.7a	41.9a	2.0
	Shaanxi-Yongshou	2012-13	18.3b	32.5a	34.2a	6.3
Turkey	Eskisehir	2011-12	35.5a	41.9a	42.3a	NS
	Eskisehir	2012-13	30.0b	43.8a	41.8a	6.6
	Konya	2011-12	27.4b	37.2a	31.1a	6.2
	Konya	2012-13	24.8b	34.8a	32.5ab	8.0
Zambia	Chisamba	2012	31.8a	46.3a	48.3a	NS
	Chisamba	2013	33.8b	52.5a	51.8a	8.1

Ram et al., 2016, Plant and Soil

Grain Zn concentration of wheat grown without Zn treatment and with foliar Zn treatment alone or in combination with pesticide in 24 field experiments

			Grain Zn concentration (mg kg^{-1})			LSD (P=0.05)
			No Zn	Foliar Zn	Foliar Zn +	
	Konya	2012-13	24.8b	34.8a	32.5ab	8.0
Zambia	Chisamba	2012	31.8a	46.3a	48.3a	NS
	Chisamba	2013	33.8b	52.5a	51.8a	8.1

Average Concentrations of Grain Zn

(6 Countries with 24 Field Experiments)

No Zn: 28 ppm

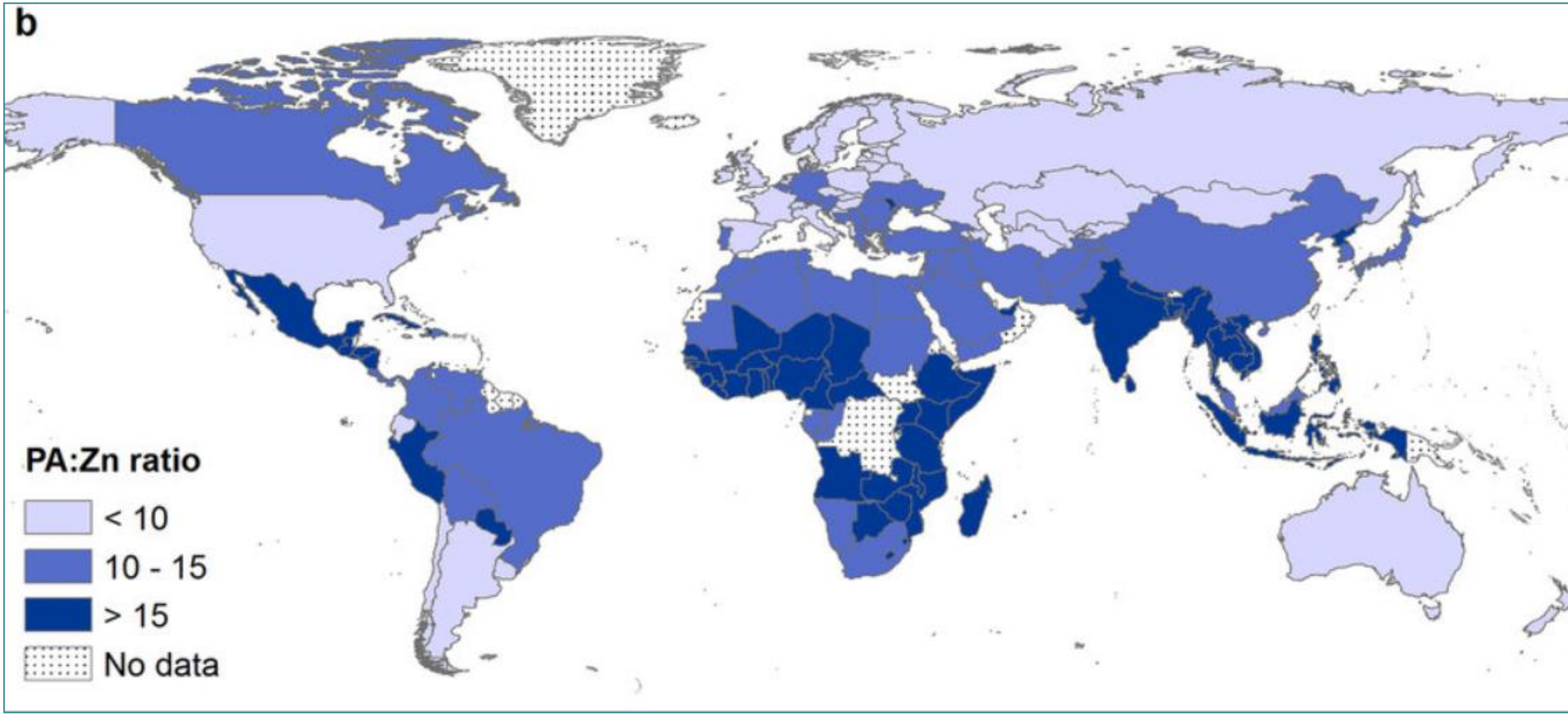
Foliar Zn: 41 ppm

Foliar Zn+Pesticide: 39 ppm

Ram et al., 2016, Plant and Soil

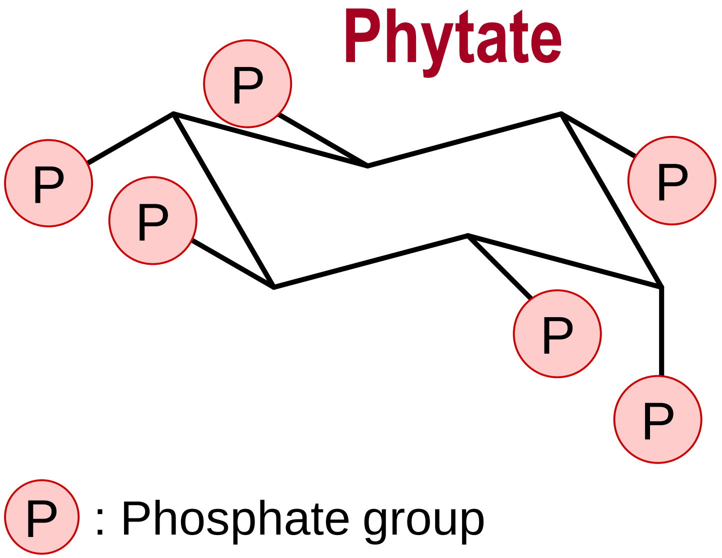
Phytate **(PA)** / Zinc **(Zn)** Molar Ratios in Diet

Higher Phytate/Zn molar ratios in food: higher risk for Zn deficiency



Kummsa et al., 2015, Scientific Reports-Nature

Phytate in grains is belived to impair Zn bioavailability and increases Zn deficiency risks in humans



- Cereal grains are rich in phytate
- Phytate forms insoluble complexes with Zn2+
- Phytate concentration is very low in endosperm

Phytate/Zn molar ratio in foods is a reliable indicator in estimating Zn bioavailability and risk for occurence of Zn deficieny in humans