Enhancing Wheat Nutritional Quality: An Atlas of QTLs for Essential Minerals from the A.E. Watkins Landrace Collection Analysis

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WGIN Stakeholders' Meeting

8th Feb 2024

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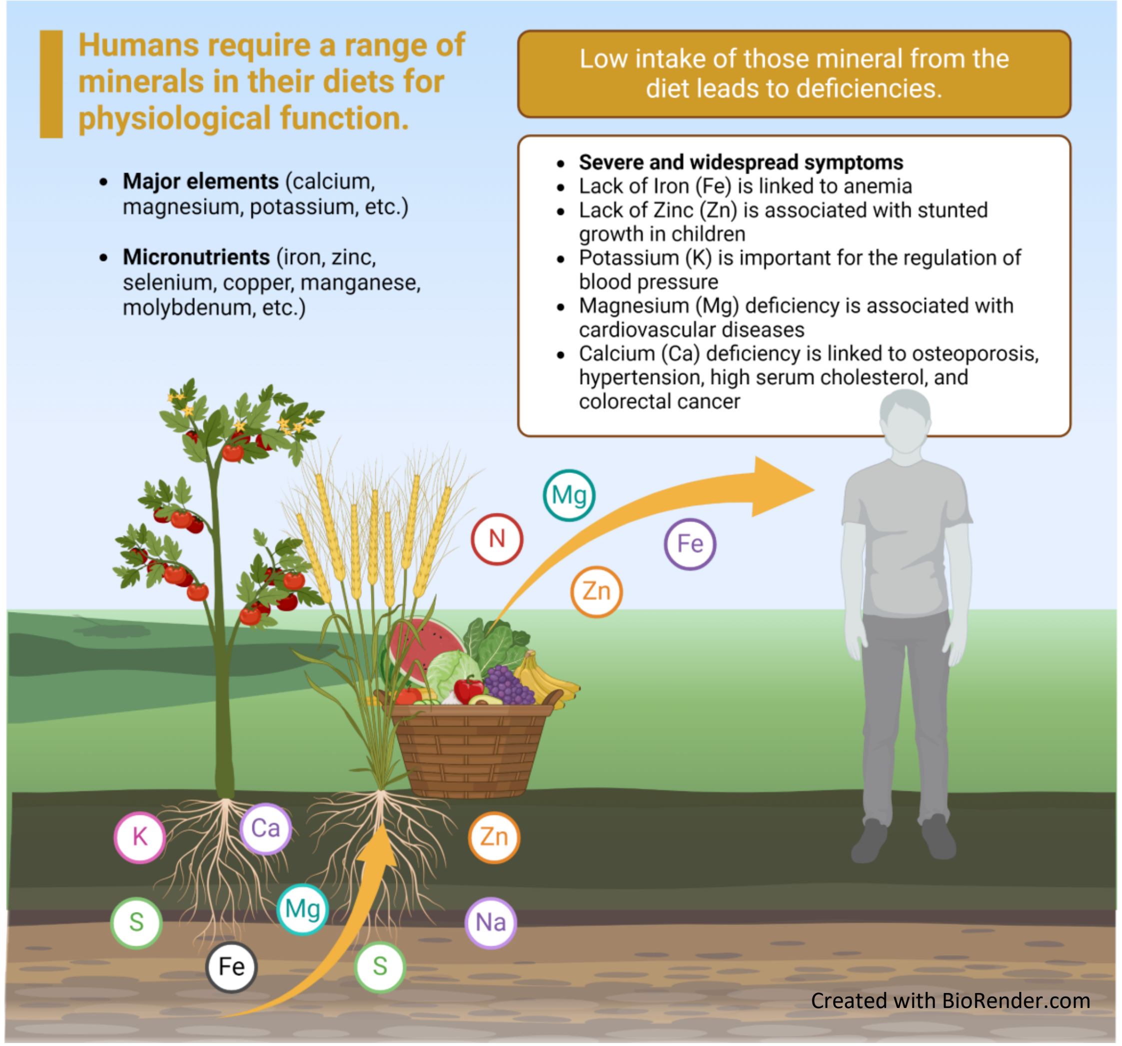
Nutrient Deficiencies



Nutrient Deficiencies – A Global Burden

- Most widespread global deficiencies include Fe and Zn, with a more severe impact in developing countries.
- According to WHO 2015, 43% of children and 29% of women suffer from anemia, and approximately half of these cases are attributed to Fe deficiency.
- Globally, over 150 million children are affected by Zn deficiency.

In the UK:

- Up to 50% of adolescent have insufficient Fe intake and around 25% of adolescents have Zn intake below the lower reference intake (Bates *et al.,* 2016).
- 27% of adult women in the UK have Fe intake below the average.
- A significant portion of adults in the UK have intakes below the recommended levels for magnesium, potassium, and selenium.

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Bridging Gaps: The Promise of Wheat Biofortification

Wheat: Most widely consumed crop

20% calories intake

- Essential Nutrients
- Dietary Fibre
- Mineral Nutrient
- Vitamins
- Phyto-chemicals
- Proteins

Up to 50% of calories in developing countries

20% of essential mineral intake in the UK

Improvement of wheat grain mineral content can have significant impact on human mineral uptake

WAYS TO INCREASE MINERAL CONTENT

Wheat Flor Fortification

Limitation: Difficult to implement and monitor in rural areas of developing countries.

Agronomic Biofortification

Application of mineral as fertiliser.
Limitation: Increased cost of crop production - problem in less developed countries.

Genetic Biofortification

Promising alternative for targeting rural populations.
Example: Development of high zinc wheat (Govindan *et al.*, 2022; Lowe *et al.*, 2022).

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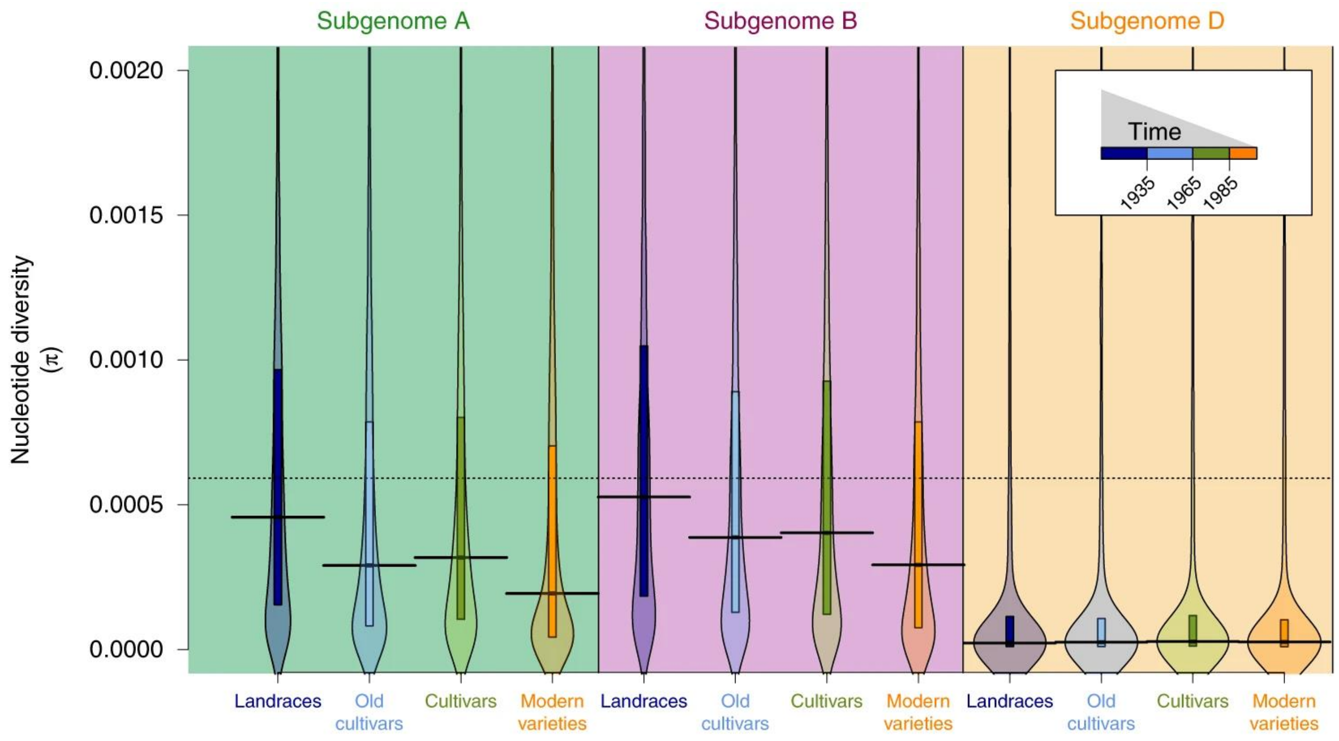
Genetic Biofortification: Looking Beyond Elite Varieties

- Successful genetic biofortification relies on the availability of genetic variation.
- Elite/modern bread wheat varieties are less genetically diverse than older cultivars and landraces.
- Elite varieties: >20% loss of nucleotide diversity (Pont *et al.* 2019).
- Older cultivars and landraces, which have been less influenced by modern breeding practices, can serve as valuable reservoirs of genetic diversity.



Obtained from Pont *et al.* 2019

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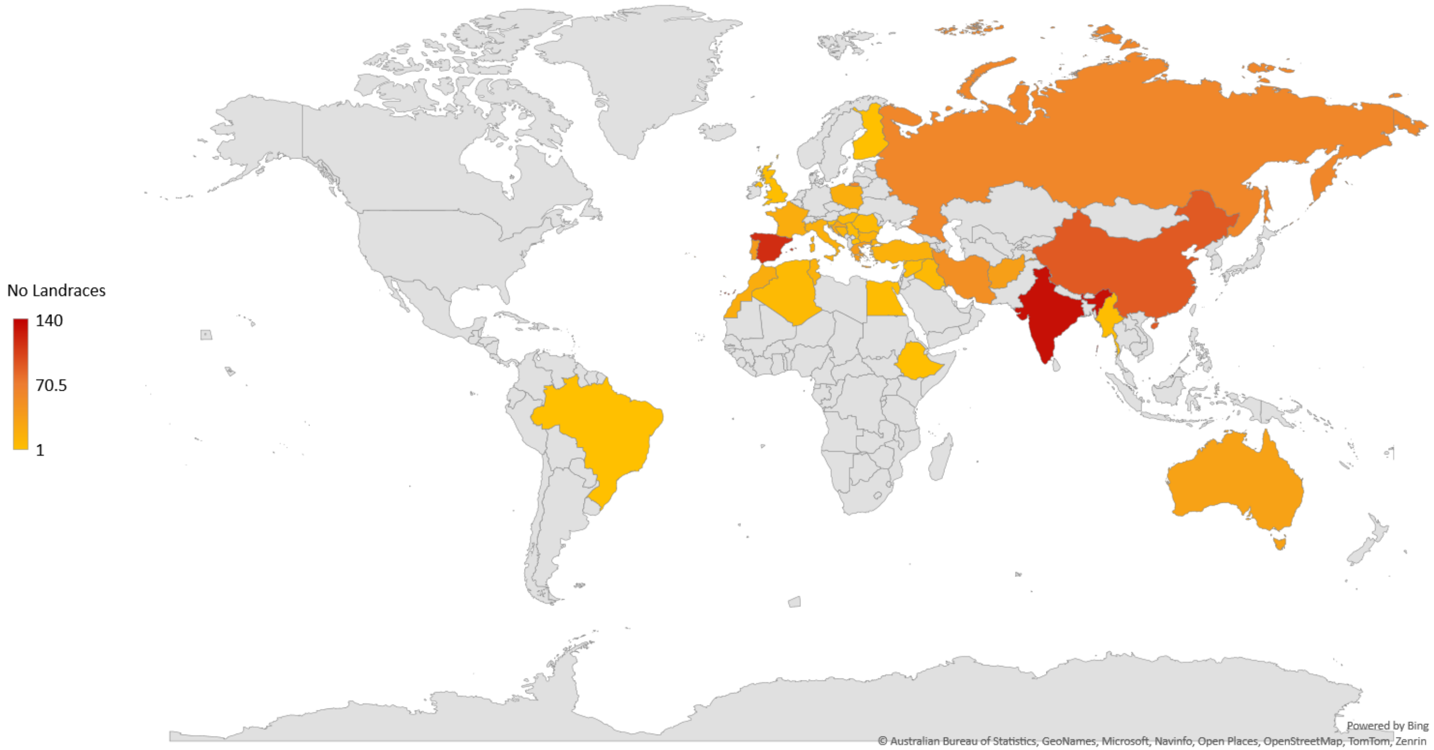
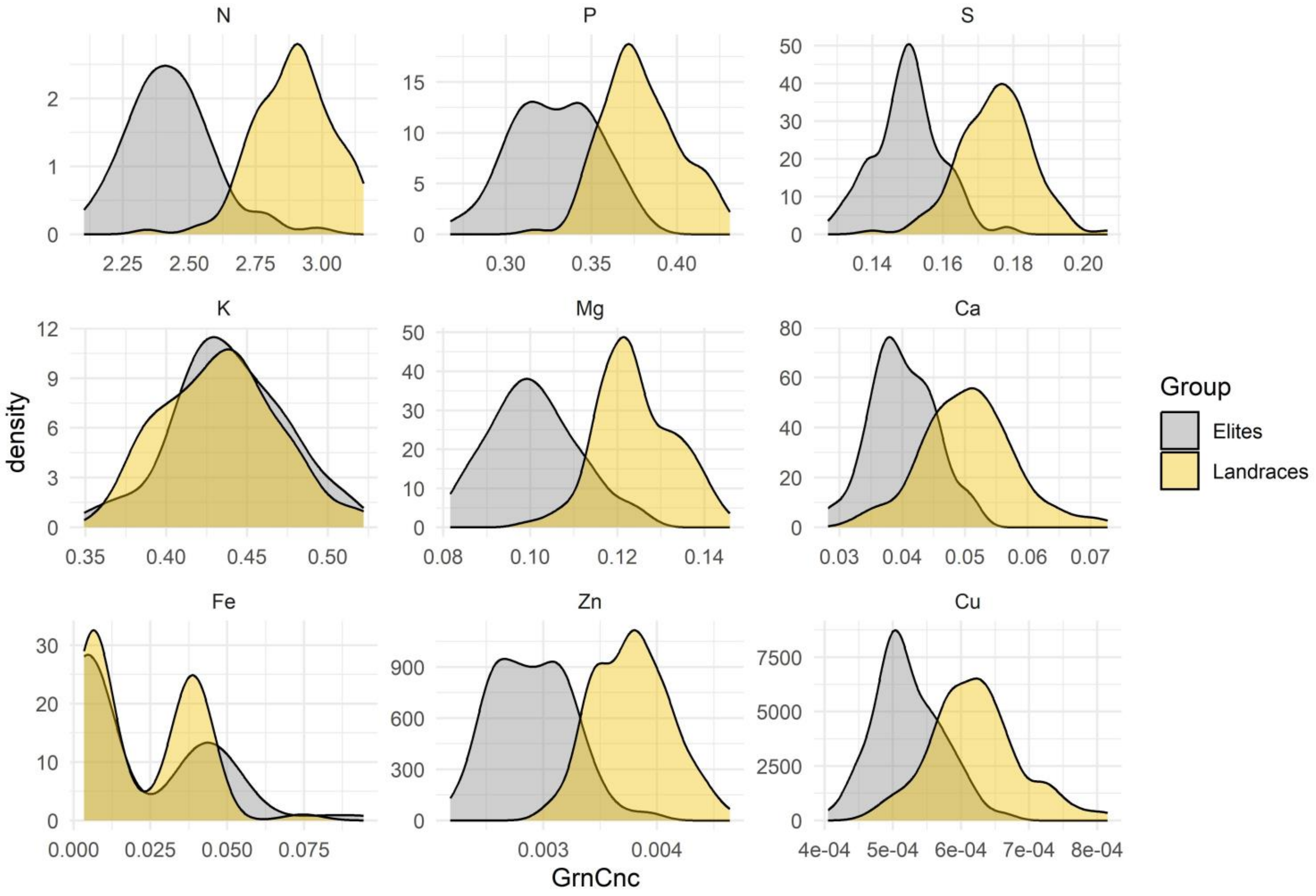
Exploiting diversity in the A.E Watkins Collection



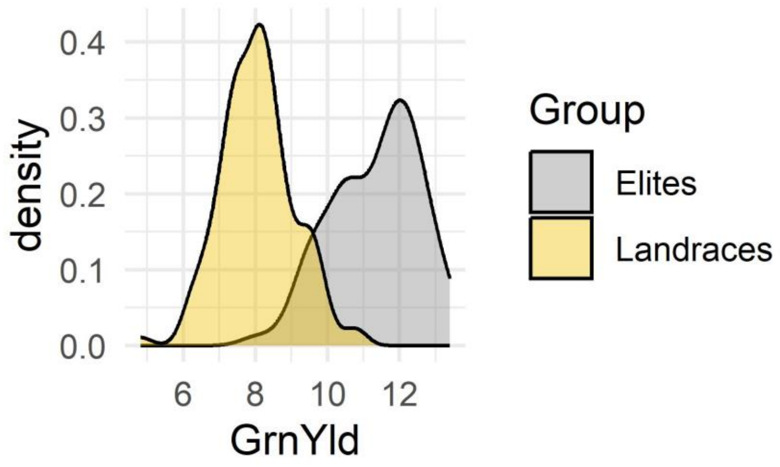
- ❑ Collection of 827 landraces collected from 32 countries in 1920s and 1930s.
- ❑ Rich genetic and phenotypic diversity.
- ❑ Main resources of UK prebreeding programs.

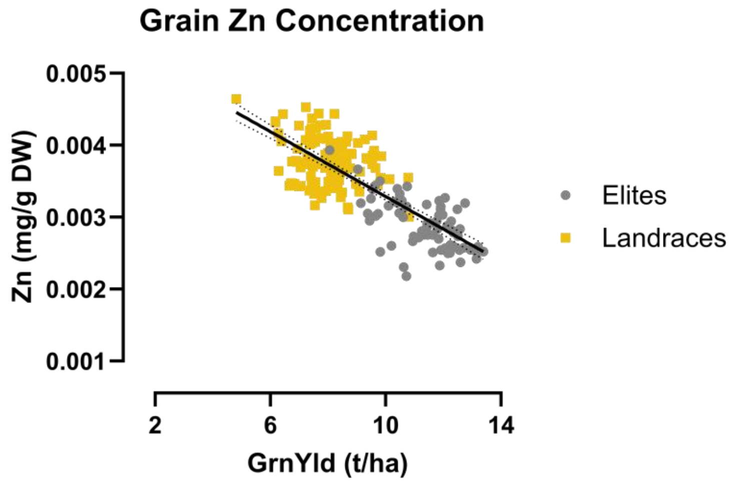
Grain Mineral Concentration in Elite Varieties and Landraces

- Wheat landraces exhibited **greater genetic diversity** in grain mineral content compared to elite varieties.
- Landraces demonstrated **higher concentrations** of most minerals in the grain.



Accounting for the Yield Dilution Effect





- However, wheat landraces are usually low yielding.
- Established concept of "yield dilution".
- Inverse correlation between concentrations of minerals in the grain and grain yield.
- Grain mineral contents were not only expressed as concentration, but also as **µg/grain**.
- **Grain mineral deviation** was also calculated: deviation from the negative regression between grain mineral concentration and yield as described by Monaghan *et al.* (2001).

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Our Approach

- Three biparental segregating populations were developed by crossing Watkins Landraces x Paragon.
- Each population: 94 F4 recombinant inbred lines.
- The 35K Axiom Wheat Breeder array was used for population ParW292 and the 44K Axiom TaNG array for the other two populations.

Watkins parent	Country of origin	Ancestral group	Selected for	Year	N Fertilization Rate (Kg/ha)
W160	Spain	C6	grain mineral content (P and Zn)	2018	200
				2019	200
				2020	200
W239	Cyprus	C6	nitrogen use efficiency (NUE)	2015	50
				2016	50, 200
				2017	50, 200
W292	Spain	C7	variation in height	2012	200
				2013	200
				2014	200

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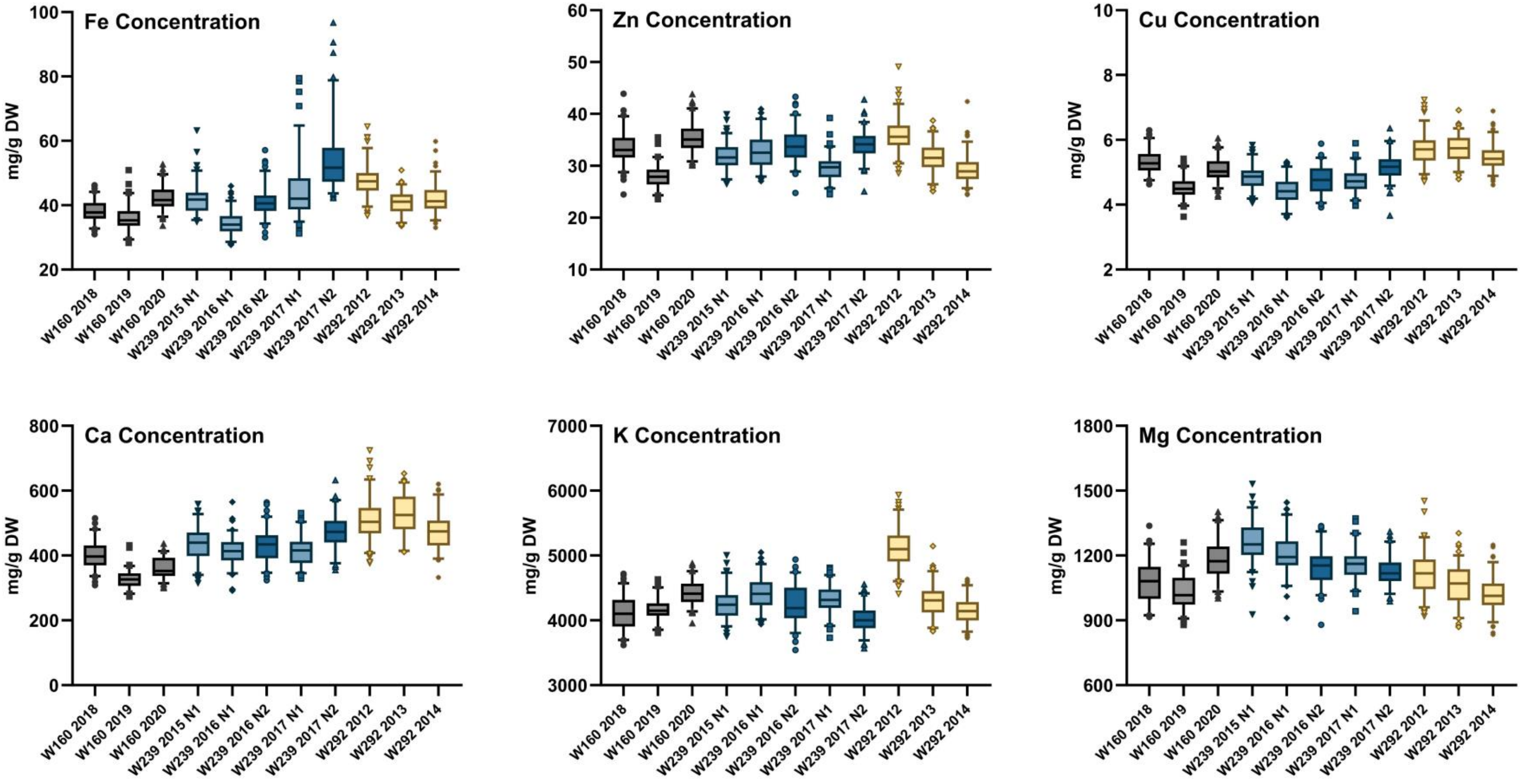
Range of Concentrations in the Populations



- ❑ Analysis of mineral content in the wholemeal flour.

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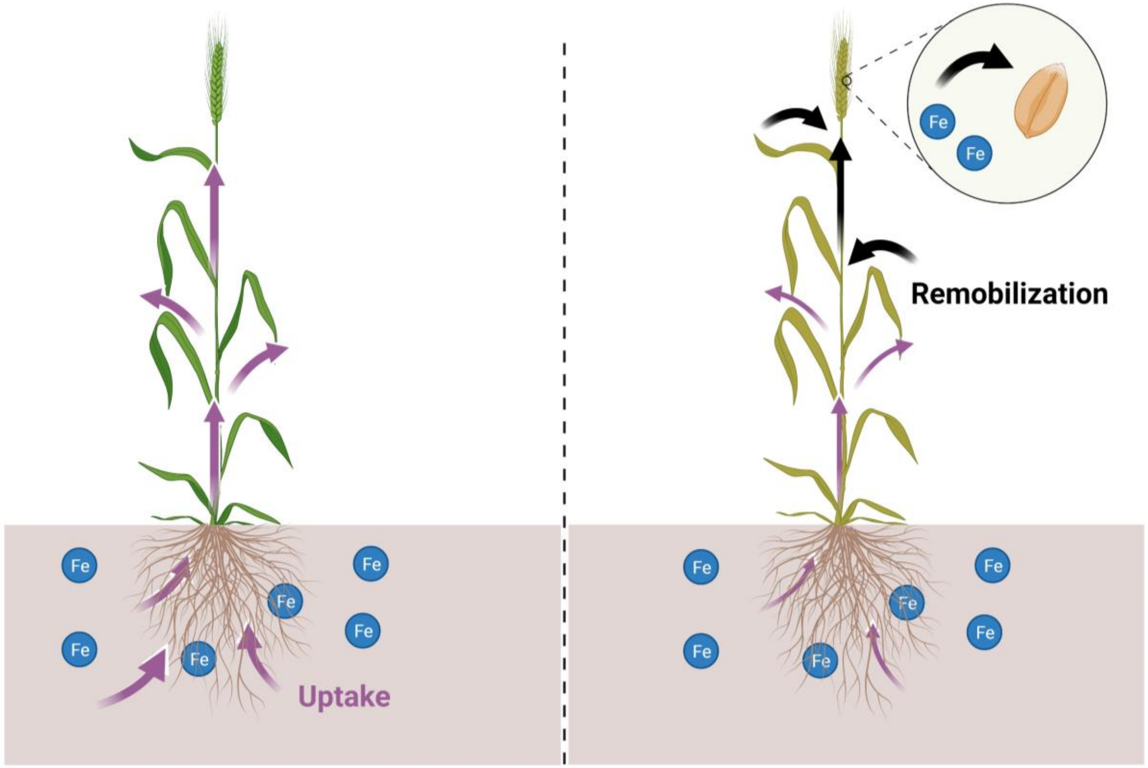
Better Mineral Uptake or Better Use?



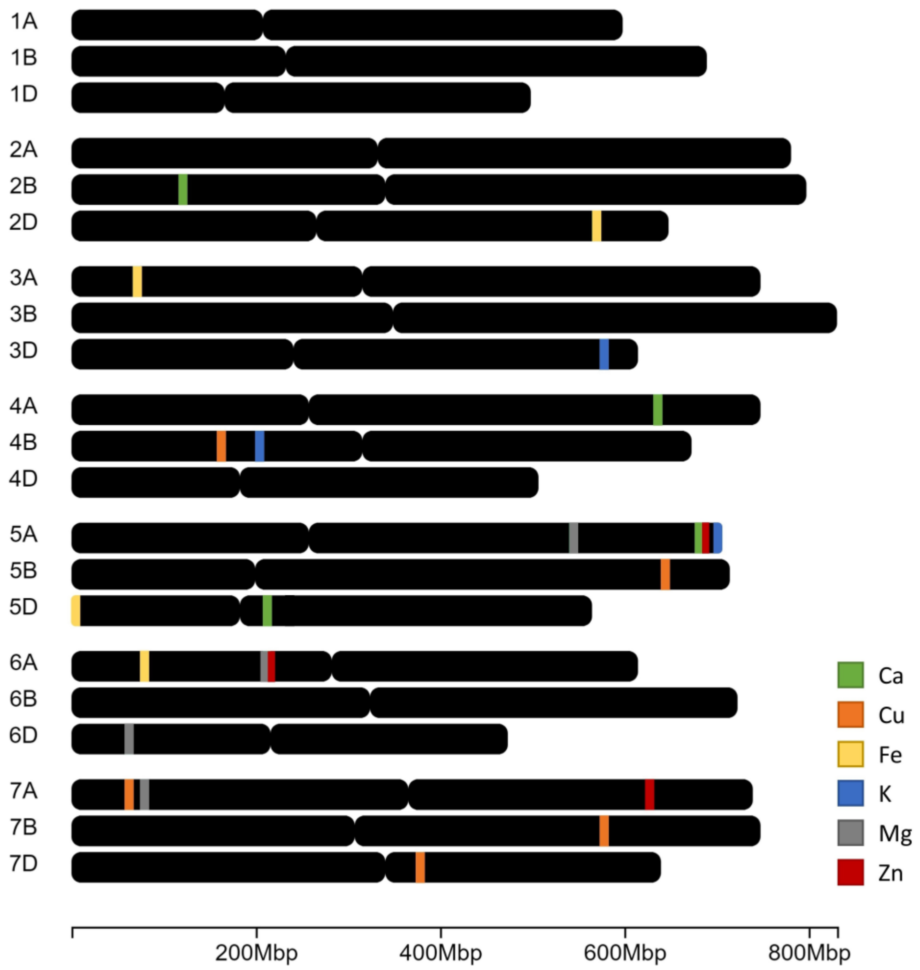
- To unravel the underlying mechanisms, the mineral content of the **straw** and the **total biomass** were also measured.
- Calculation of mineral content of the above-ground biomass and the mineral harvest index.
- The identification of co-located QTLs for the concentrations/total amounts of minerals in straw suggests a more efficient uptake of minerals by the plant.
- The absence of co-located QTLs for minerals in straw/biomass implies that the partitioning of minerals to the developing grain is more effective.

QTL Atlas of Essential Minerals

- ❑ 774 QTLs for minerals in grain, straw and calculated biomass were identified.
- ❑ Reduced to 23 strong robust QTLs for essential nutrients in grain by selecting for:
  - QTLs that were mapped in at least two sample sets.
  - with LOD* scores above 5 in at least one set.

Mineral	Chromosome	Beneficial Alleles
Calcium	2B, 4A, 5A, 5D	P, W160, W239, W292
Copper	4B, 5B, 7A, 7B, 7D	P, W239, W292
Iron	2D, 3A, 5D, 6A	W160, W239
Potassium	3D, 4B, 5A	P, W160, W239
Magnesium	5A, 6A, 6D, 7A	P, W160, W239, W292
Zinc	5A, 6A, 7A	W160, W239, W292

*LOD (logarithm of the odds)



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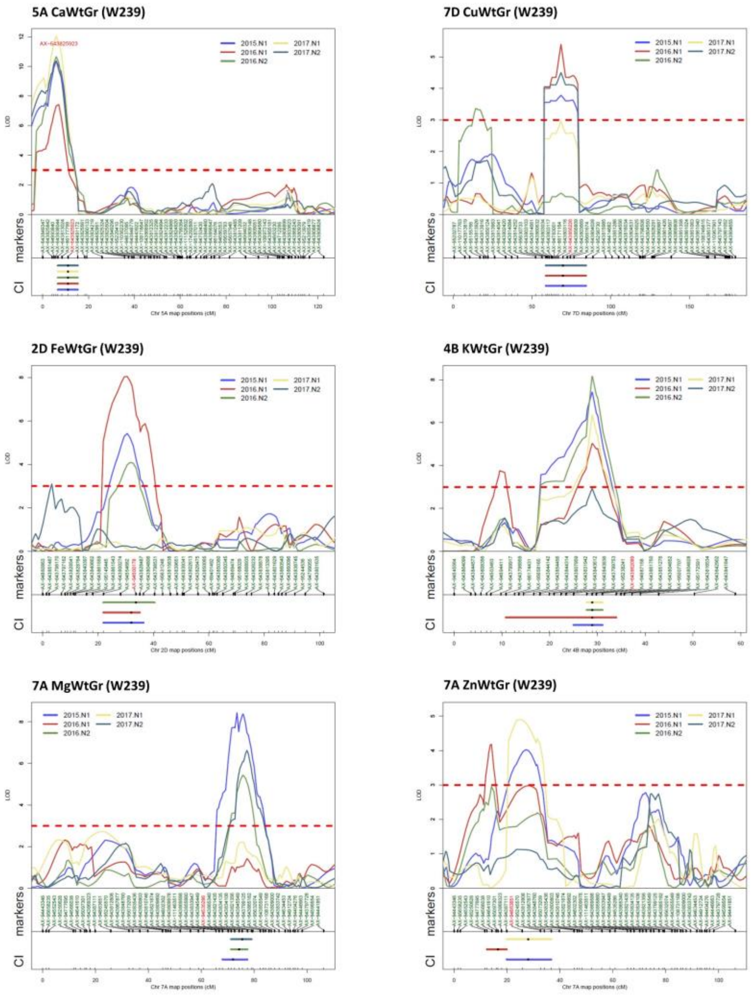
Gene Content Analysis and Genomic Comparison

- Strong QTLs were selected to determine the gene content within **5 Mb** of DNA either side of the peak marker.
- Gene Functional Annotation.
- Knetminer was used to explore any association between genes and the traits of interest (Hassani-Pak *et al.* 2021).
- Whole genome sequence data (Watseq) were used to identify functional and copy number variations between Paragon and the Watkins lines.

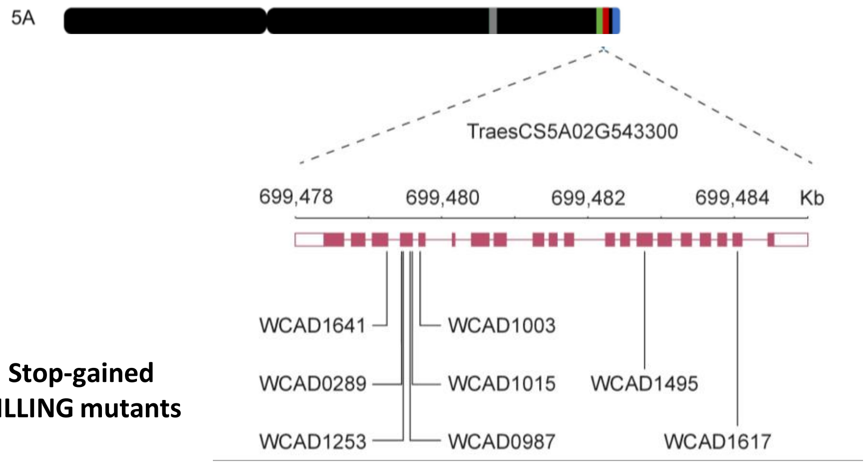
Mineral	Ca	Cu		Fe	K	Mg	Zn	
Chromosome	5A	4B	5B	2D	4B	7A	6A	7A
Gene number	127	52	102	120	29	128	40	91

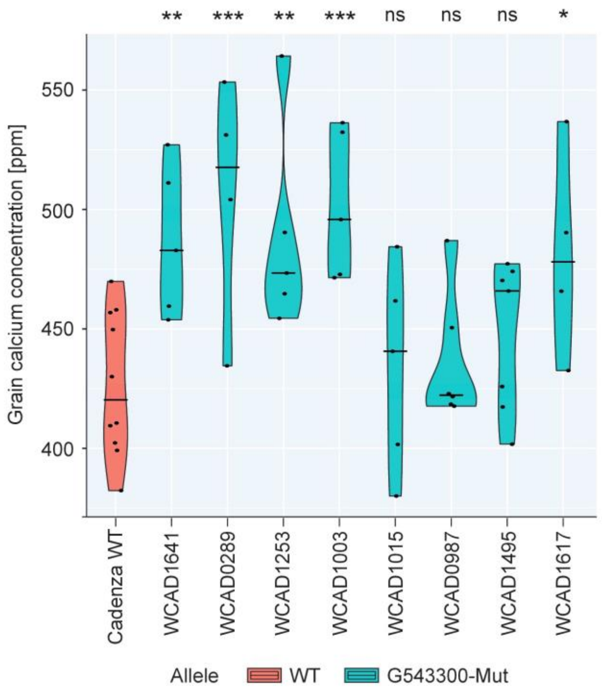


An ATPase Transporter as the Candidate Gene for Higher Ca Content

Based on the functional annotation, two candidate genes were identified in the region surrounding the 5A QTL peak:

- *TraesCS5A02G543300* which encodes a cation transporter/plasma membrane ATPase.
- *TraesCS5A02G542600* which encodes a major Facilitator Superfamily transporter.





TraesCS5A02G543300 TILLING mutants showed 10% higher Ca content in grain.

No difference in grain weight.

This suggests that *TraesCS5A02G543300* and its homoeologues could be manipulated to increase grain Ca content.

Focus on Ca-biofortified Wheat?

- ❑ Ca deficiency is a global concern, affecting up to half of the total population (Shlisky *et al.*, 2022).
- ❑ Insufficient Ca is linked to various health issues, including osteoporosis, hypertension, high serum cholesterol, colorectal cancer, and rickets (a pediatric bone disease).
- ❑ Adults aged 19 to 64 require a daily Ca intake of 700 mg.
- ❑ According to the National Diet and Nutrition Survey (NDNS), 15% of children (11-18) and 9% of women (19-74) have Ca intakes below the recommended levels.
- ❑ In the UK, adults (age 19-64) derive approximately 30% of their Ca from cereals, with around 15% coming from bread (NDNS).
- ❑ The increasing adoption of vegan diets necessitates obtaining Ca from alternative sources, such as cereals.
- ❑ In the UK, the fortification of white flour with Ca is mandatory, with an approximate content of 235-390 mg of Ca per 100 g of flour.

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Funders

Thank you for your attention!