NATIONAL ACADEMIES
Sciences Engineering Medicine

Maximizing Agriculture to Enhance Nutrient Composition to Better Fulfill Dietary Recommendations

January 30, 2024

Standing Committee on Evidence Synthesis and Communications in Diet and Chronic Disease Relationships

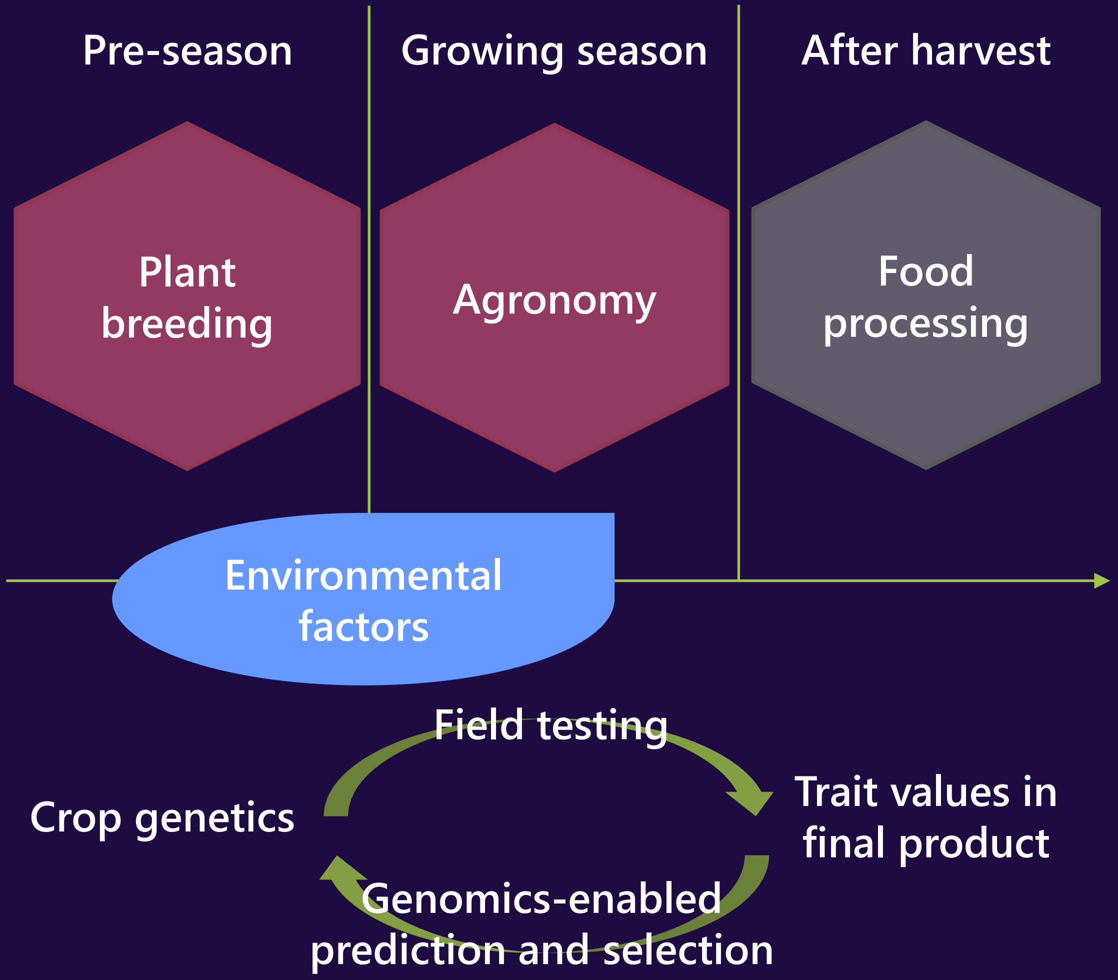
Workshop agenda, as important context for this talk

Key Question: What upstream changes in agriculture and food production can help the public better meet nutrition requirements and dietary guidelines?

- **Session 1:** What is currently known and being done around the quality of crops and animals to enhance human nutrition?
- **Session 2:** What agricultural technology and other approaches are currently being explored and developed to enhance human nutrition?
- **Session 3:** What are the multi-scale challenges and what needs to be done in agriculture moving forward to create sustainable ways of enhancing human nutrition? This session will focus on environmental challenges, socio-behavioral and cultural issues, economic issues, and human biology issues.

Topics for this talk, *with a focus on vegetables and grain legumes*

1. Overview of the plant breeding process
2. Highlighting of complementary approaches
3. Technologies that can assist biofortification
   - ❖ DNA and RNA sequence information
   - ❖ Accurate and efficient trait measurement
   - ❖ Testing of nutrient levels at time of consumption
4. Next steps for improving nutritional quality in crops, and (major caveat: *from a plant breeding perspective*) nutritional status in humans, through these approaches



Overview of the plant breeding process

- There are typically a few to several public-sector breeding programs per vegetable or legume crop in the U.S. The extent of private-sector breeding varies by the crop.
- Importance of **transdisciplinary consortia**; e.g., USDA Hatch Multi-State, USDA NIFA Specialty Crop Research Initiative, USDA NIFA AFRI Coordinated Agricultural Projects, Lettuce Genome Sequencing Consortium, LettuceKnow, FFAR Consortia, USDA ASCEND for Better Health Initiative
- Importance of germplasm banks as sources and maintainers of diverse material (Byrne et al. 2018); e.g., USDA National Plant Germplasm System, World Vegetable Center
- Importance of long-term funding for varietal development and germplasm enhancement, among other pre-breeding activities (Coe et al. 2020)

USDA NPGS Germplasm Collection Genebanks

A couple of key terms

- ***Genotype***: an individual representation of a given crop (e.g., Granny Smith or Macintosh, in apple); could be a publicly released crop variety, an unreleased ‘breeding line’, germplasm bank material, etc.

- ***Biofortification:*** the improvement of crop nutritional quality through plant breeding and/or agronomy (Bouis and Welch 2010)

- We typically aim to improve the **<u>concentration</u>** of a given nutrient, so that a consumer receives more of that nutrient in the same amount of food (and with minimized change to growers’ practices).

Credit: Sassoum Lo

Brief overview of biofortification breeding pipelines

- Hundreds to thousands of samples per year from multiple locations
- Measuring nutritional quality traits can be expensive and often requires multiple instruments/platforms
- Typically breeding for several traits simultaneously

Marketable yield

Disease and pest resistance

Tolerance to drought, heat, salinity, etc.

Resource use efficiency

Nutrient concentrations

Postharvest quality

Credit: Jonathan Berlingeri

Agronomy and food processing are complementary approaches to biofortification breeding

- While major-effect genes have been identified for certain nutritional quality traits, these (alongside agronomic) traits can be influenced by **Genotype, Environment, Management**, and their interactions (G x E x M).
- It can be challenging to improve multiple (to several) nutritional quality traits simultaneously.

Mineral nutrients <u>not</u> produced in the plant must be **taken up** from the soil and **transported** to the edible tissue

Credit to Michael Grusak; USDA ASCEND for Health Initiative, https://www.nutrition.gov/topics/ascend-better-health

Nutrients produced in the plant (such as vitamins) that are susceptible to degradation would need to be **retained** from harvest through consumption.

➢ **Agronomy and food processing could be key in maximizing crop nutritional quality, together with or separately from biofortification breeding.**

Technologies that can assist biofortification: genomics (and transcriptomics)

- Costs of obtaining **genomic information** have plummeted; these data can be used to

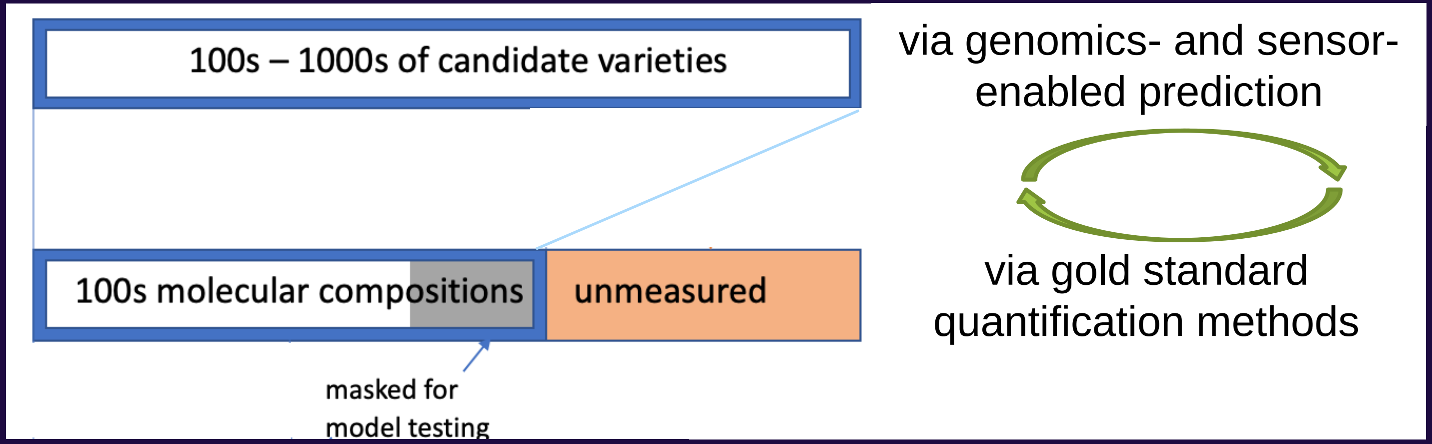
1) Identify candidate genes and genomic regions that can be used in breeding	2) Rapidly screen genotypes for whether they possess the favorable version of those genes/regions	3) Predict which genotypes have the best breeding values for priority traits

- **Transcriptomics** (RNA sequencing) can help in narrowing down regions to individual candidate genes and understanding accumulation/retention of the priority nutrients
- **Gene editing** technologies can have a complementary role; e.g., precise engineering of favorable alleles without *linkage drag*, functional validation of candidate genes, monitoring for *pleiotropy*

Linkage drag: detrimental effects on plant performance due to flanking genomic regions that accompany the favorable allele of interest (when making crosses); ***Pleiotropy:*** one gene affects multiple traits

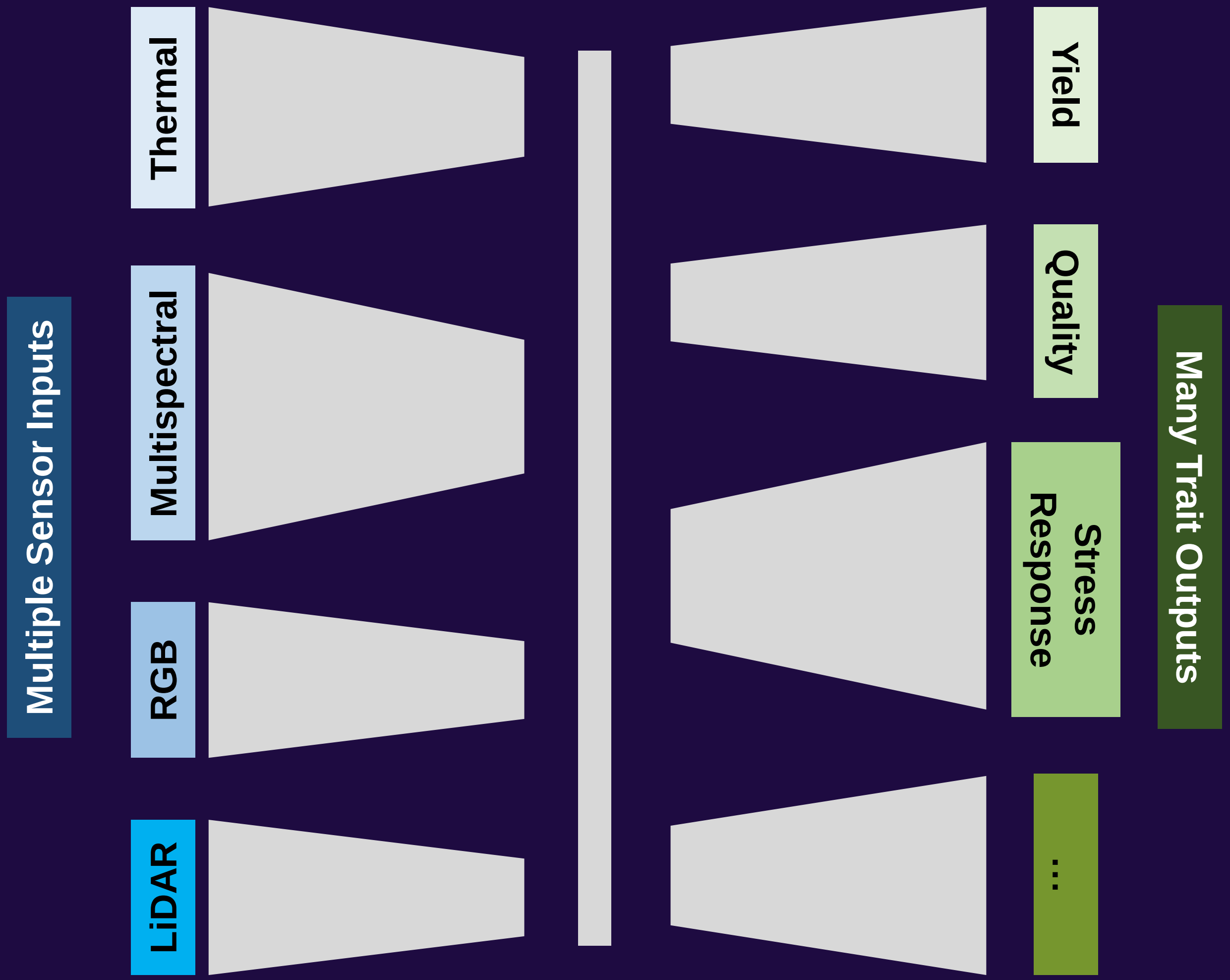
Technologies that can assist biofortification: accurate and efficient phenotyping

- Gold standard methods for quantification of these compounds have been critical. E.g.,
  - *High- or ultra-performance liquid chromatography* for vitamins and amino acids
  - *Inductively coupled plasma-mass spectrometry* for mineral nutrients (Fe, Zn, etc.)
- High-efficiency methods are more feasible for certain nutrients, and need to be routinely calibrated against gold standard methods
- Opportunities for genomics-enabled prediction, and to partner with experts in sensor technologies



Adapted from figure by Daniel Runcie

Using artificial intelligence to predict multiple traits using inputs from multiple sensors

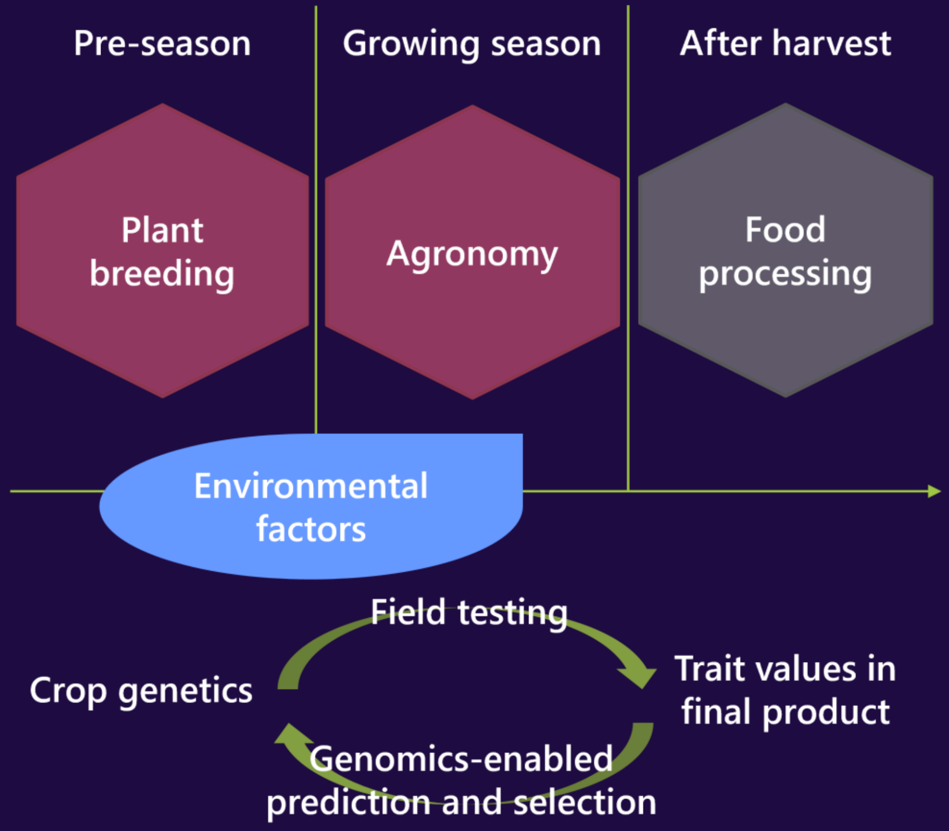


Credit for figure: Mason Earles

Raja et al. (2021), doi: 10.48550/arXiv.2112.03205

Summary: next steps for improving nutritional quality of crops through these technologies

1. Enabling cost-effective and routine integration of nutritional quality traits into breeding pipelines, for staple and specialty crops
2. Understanding the roles of these nutrients—and anti-nutrients—in plant growth and development and nature of linkages (genetic, physiological, etc.)
3. Understanding (especially repeatable) effects of environment and management, alongside genotype
4. Continued (broad and deep) collaborations with food scientists, experts in human nutrition, etc.



(Major caveat: *from a plant breeding perspective*) next steps for improving nutritional status in humans through these technologies

- Achieving target nutrient levels can take multiple cycles → speed up the breeding process
- Some crops may not have substantial natural variation for certain nutrients → multi-crop approaches and complementation with animal-sourced foods
- Evaluating the release of nutrients from food matrices and availability for absorption
- Balancing incentives for growers and processors with <u>affordability</u> of biofortified foods
- Concretely improving nutritional status may look different under <u>occasional</u> rather than staple consumption → incentivize increased consumption?
- Randomized controlled trials to understand the <u>impact</u> of a dietary intervention; models that examine 'dietary adequacy' may be a helpful intermediate

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