Harvest for Health:
Improving Wellbeing through Resilient Agriculture

Convening Event

January 31 - February 1, 2019
Washington, DC

FFAR

Wifi Network: Visitor
No password required

Introduction to FFAR

Dr. Sally Rockey
FFAR Executive Director

About FFAR

- **Nonprofit initially created through bipartisan congressional support in the 2014 Farm Bill**

- **Governed by a Board of Directors, advised by expert Councils**

- **FFAR complements the work of the USDA**

How We Work

Private-Public Partnerships

We build unique partnerships to support innovative science addressing today's food and agriculture challenges.

$385M + **$385M**

FFAR Investment | Non-Federal Match

"FFAR also brings together diverse groups that might not otherwise collaborate to solve big challenges ...the FFAR model delivers - and doubles the taxpayer's investment."

-Bob Stallman

Past President, American Farm Bureau Federation
Current FFAR Board Member

OUR VISION

We envision a world in which ever-innovating and collaborative science provides every person access to affordable, nutritious food grown on thriving farms.

The FFAR Paradigm

- **Creates novel research partnerships** across the food and agriculture sector.
- **Works nimbly** to efficiently address emerging issues in food and agriculture.
- **Leverages public dollars** with private dollars to expand research impact.
- **Fills research gaps** to ensure great science supports farms, reduces food insecurity, and supports better health.

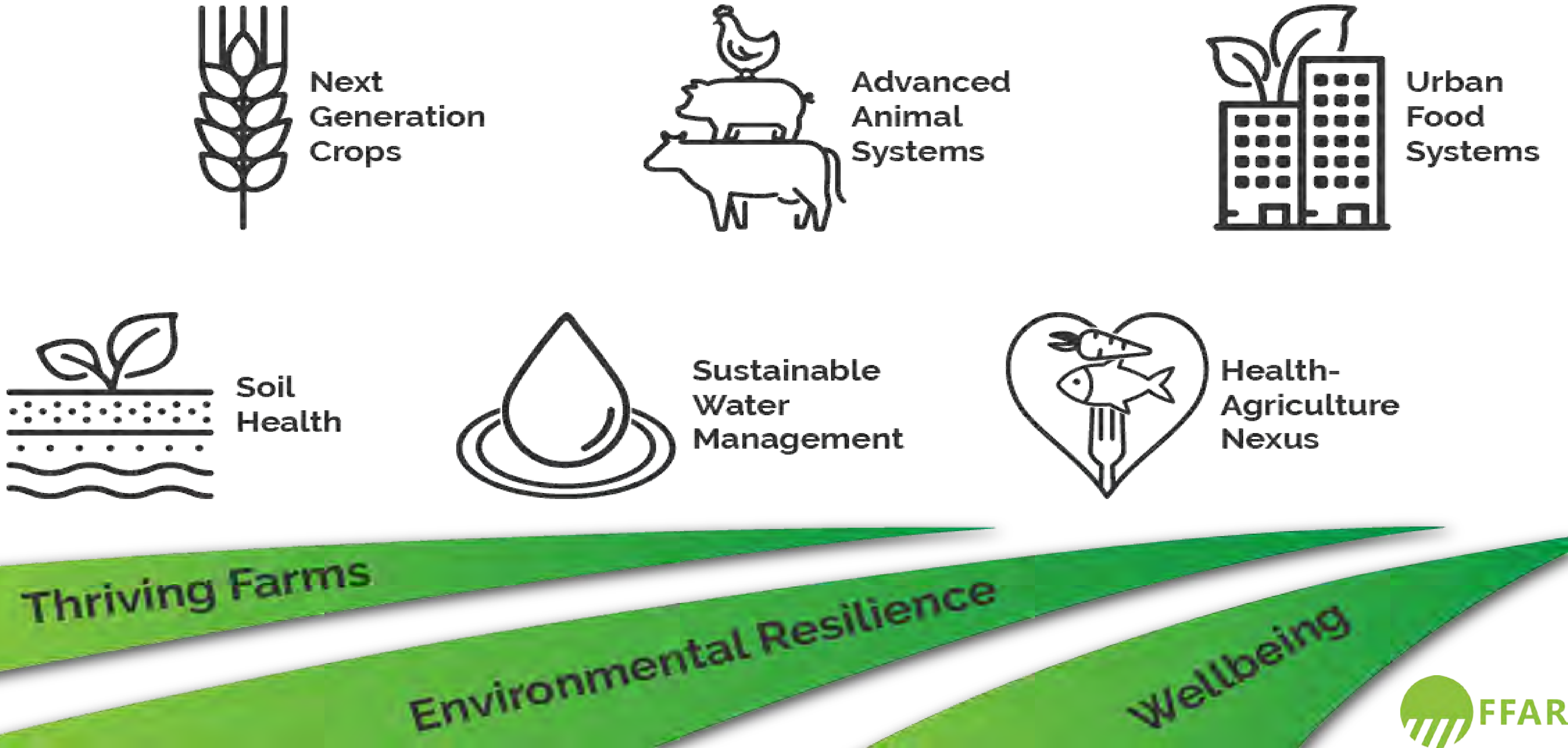
By the Numbers

99 grants awarded

1:1.25 matching ratio

$158M funding awarded or in the pipeline

FFAR 2019 CHALLENGE AREAS

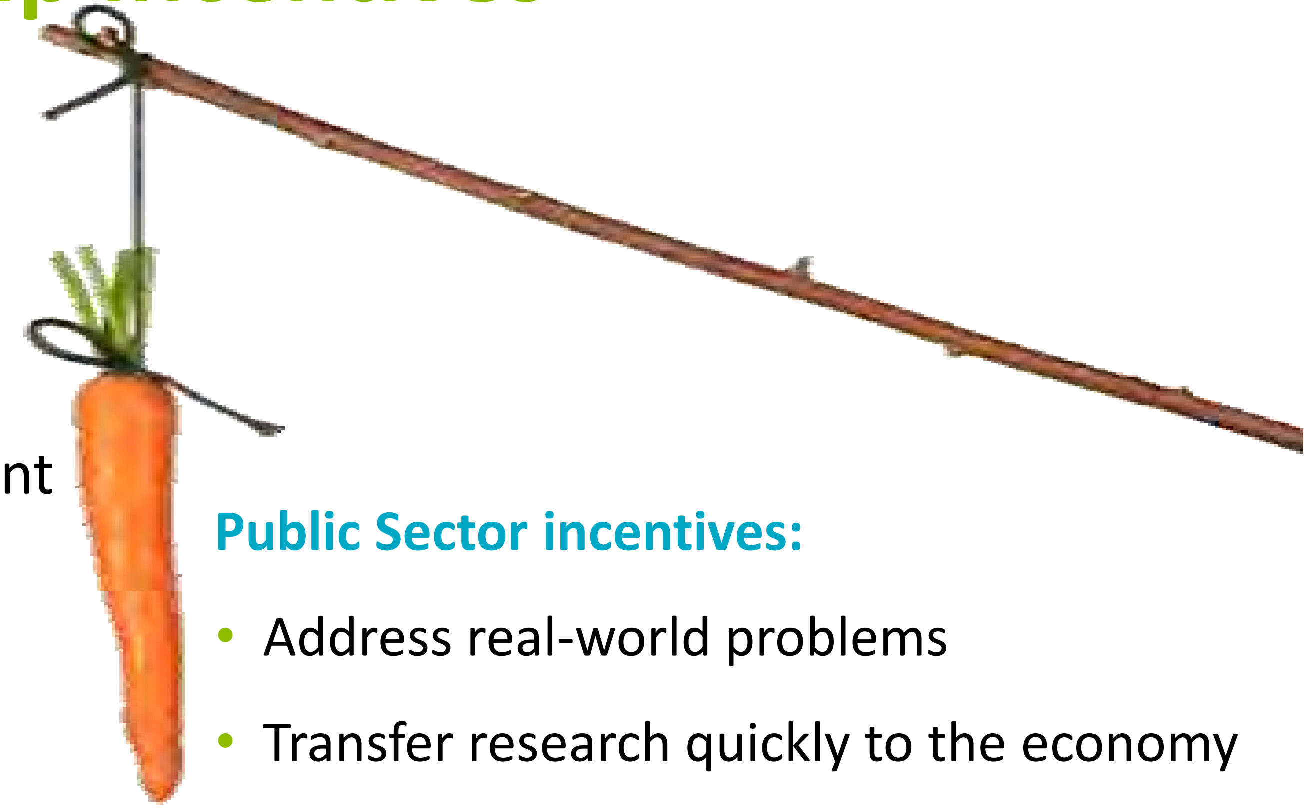


How We Work

FFAR may award funds in four ways:

- Competitive Grants
- Direct Awards
- Prizes
- Consortia

Public-Private Partnership Incentives



Private sector incentives:

- Corporate social responsibility
- Rapidly overcome obstacles to advancement
- Cost savings
- Direct access to fundamental research
- Access to academic expertise
- Cultivate future employees

Public Sector incentives:

- Address real-world problems
- Transfer research quickly to the economy
- Access to resources and data otherwise unattainable
- Access to expertise

FFAR

Industry and Foundation Partners

Over 280 distinct funding partners!

FFAR-Supported Consortia

Irrigation Innovation Consortium

- Irrigation industry, nonprofit, & academic partners

Crops of the Future Collaborative

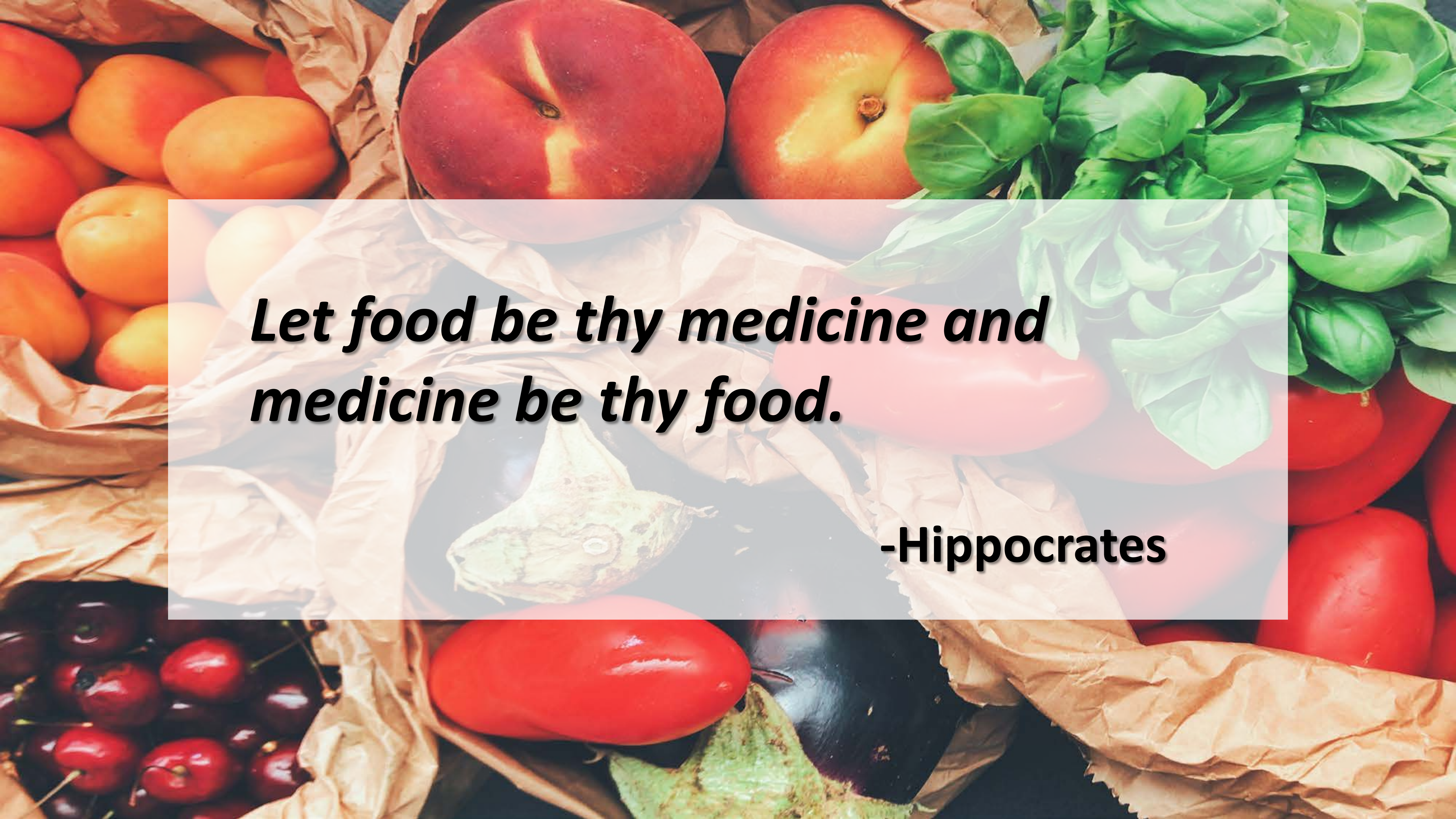
- Nonprofit research & seed company partners

Precision Indoor Plants

- Technology companies, vertical farming, & seed company partners

Antibiotic Stewardship in Animal Production

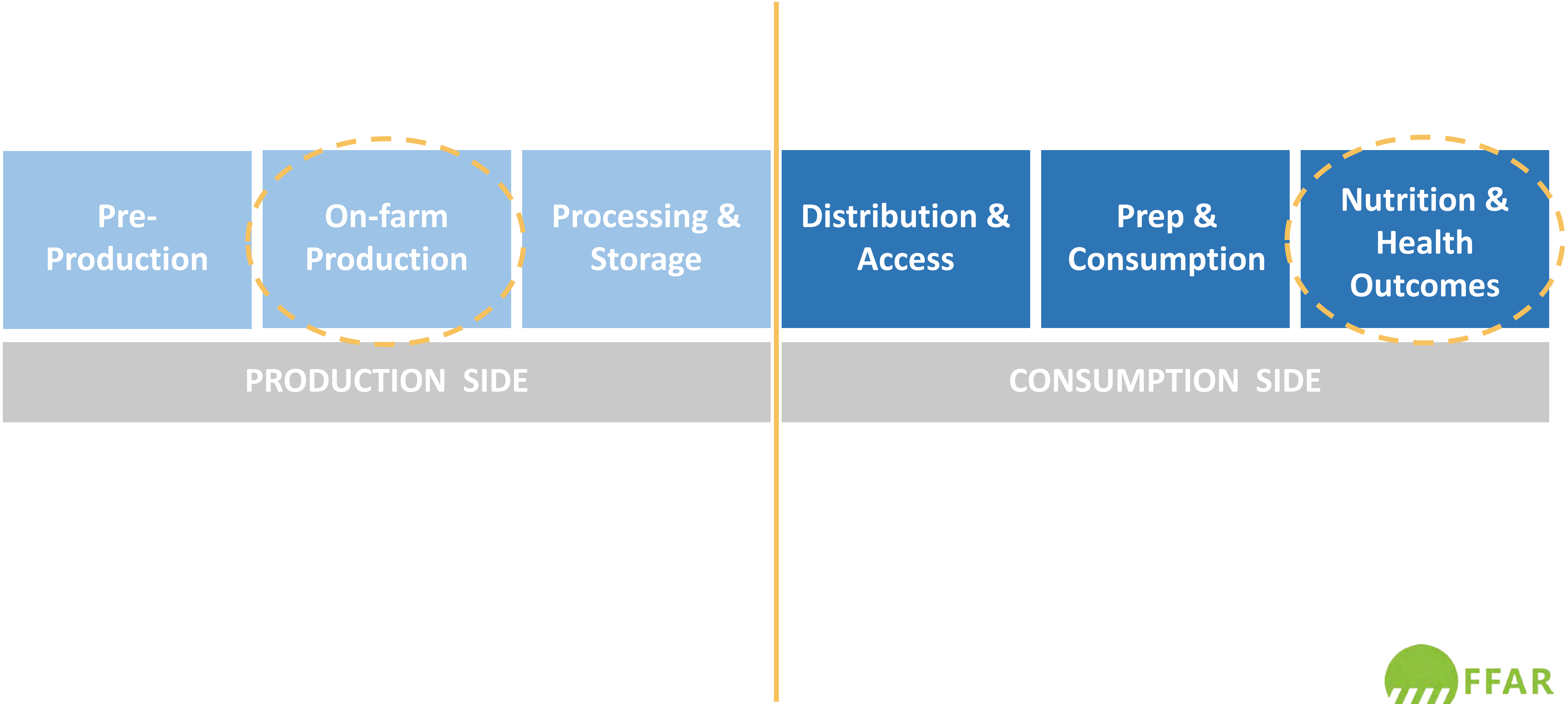
- Pharmaceutical & food processing partners



Let food be thy medicine and medicine be thy food.

-Hippocrates

How We *Usually* Study the Food System



FFAR

How We *Should* Study the Food System

Pre-Production	On-farm Production	Processing & Storage	Distribution & Access	Prep & Consumption	Nutrition & Health Outcomes

PRODUCTION SIDE

CONSUMPTION SIDE

Engage with FFAR

- Advisory council participant
- Peer reviewer
- Grant applicant
- Convening event participant
- Consortium participation
- Call us

FOSTER OUR FUTURE
cultivate. discover. grow.

February 5, 2019
Washington, DC

Interactive Food & Agriculture Research Expo

1-5 pm

- Exhibits and talks demonstrating game-changing approaches to address challenges in food and agriculture

6-9 pm

- Receptions
- Panel discussion

- Evening panel with philanthropist, business and innovator perspectives
- Moderated discussions
- VIP and general receptions

FOSTER OUR FUTURE
cultivate. discover. grow.

Thank You

Dr. Sally Rockey
Executive Director
Foundation for Food and Agriculture Research

srockey@foundationfar.org

@RockTalking

Connect with FFAR
www.foundationfar.org

@FoundationFAR

FFAR

Making Food Systems a Solution to Accommodating Healthy Eating Patterns and Reduced Risk of Diet-Related Illnesses and Human Health Disparities

Steven R. Shafer, Ph.D.
Soil Health Institute (ret.)
USDA-Agricultural Research Service (ret.)

Naomi K. Fukagawa, MD PhD
USDA ARS Beltsville Human
Nutrition Research Center

Views reflect those of the speakers and not that of the USDA, nor the US Government, nor the Soil Health Institute.

FFAR Foundation for Food and Agriculture Research

Harvest for Health: Improving Wellbeing through Resilient Agriculture

Convening Event

January 31 – February 1, 2019

The National Academy of Sciences Building
2101 Constitution Avenue, NW, Washington, D.C.

FAO's dimensions of food security

Availability of sufficient quantity and quality	Access to adequate resources to acquire (e.g., income)	Utilization of food through adequate diet, clean water, sanitation, and health care	Stability (access at all times)

About 2+ billion of 7+ billion people globally fall short of one or more

J. Otten, University of Washington

The Stage Has Been Set

- World population (7.5 billion) expected to reach 9.7 billion in 2050
- By 2030, 1 in 3 people will be city dwellers.
- By 2050, > 1 in 5 people will be over 60 yr (80% in low- & middle- income countries.)
- Colliding epidemics (ID, NCD, food security)
- Challenges for Mother Earth (natural resources, clean water) and by Mother Nature (drought, floods, rising temp & seas)

CHALLENGES AHEAD

- Impact of land use/management on food crops/nutritional quality
- Impact of land use/management on animal health and food safety
- Impact of land use/management on agroecosystem health and the food system
- Health of the community-connecting the dots between soil and food security

- Estimated total food production demand
  (www.csiro.au/Portals/Multimedia/On-the-record/Sustainable-Agriculture-Feeding-the-World.aspx)
  - 1500 – 2010: 677 x 10^{18} calories
  - 2010 – 2060: 730 x 10^{18} calories
- Science-based solutions to the dilemma
  - Put more land into agricultural production
  - Get higher yield per unit land area
    Sustainable *intensification* (FAO.org)
  - Use fewer animals
  - Waste less

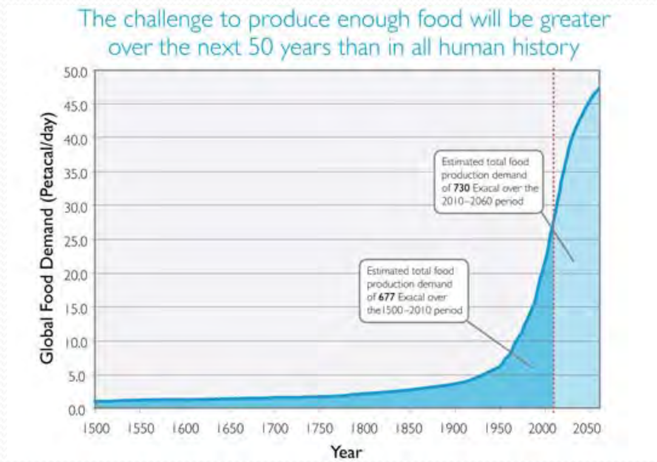
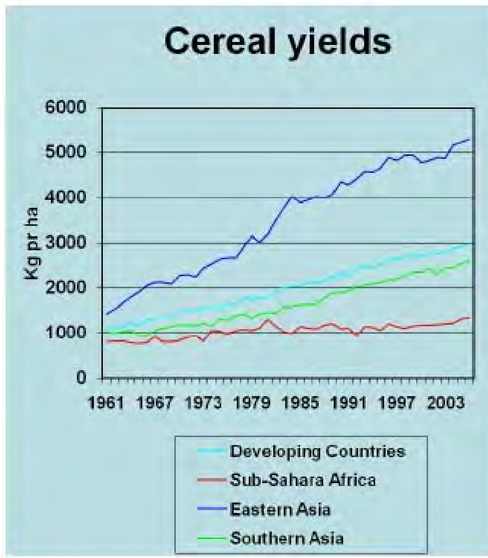


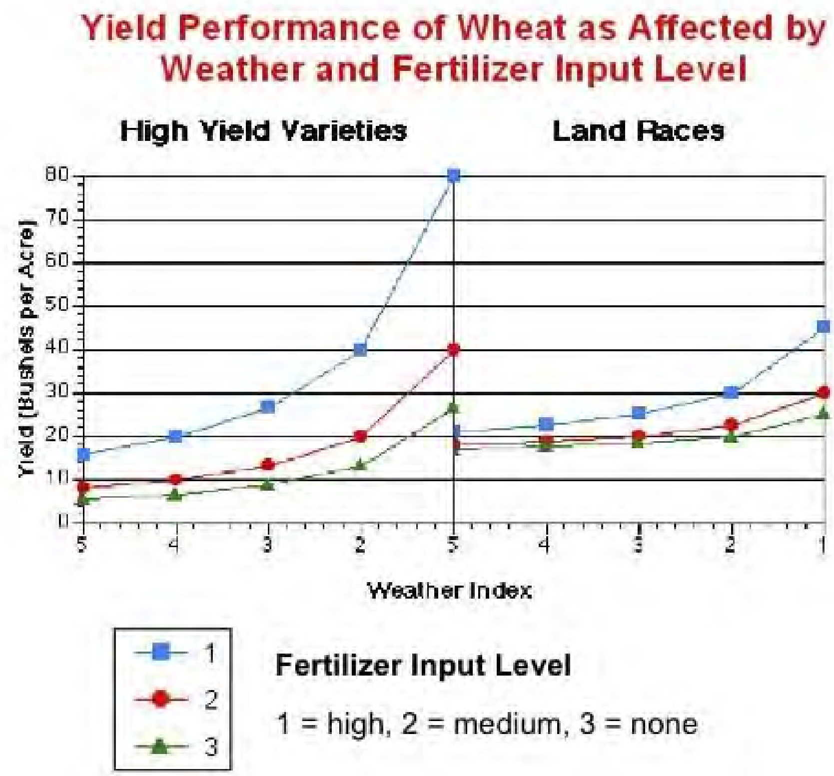
Photo credits:
http://www.prwatch.org/spin/2008/06/7424/more-you-bargained-your-chicken
http://www.dreamstime.com/royalty-free-stock-image-corn-waste-image8500156
USDA-ARS

Green revolution impacts on crop improvement

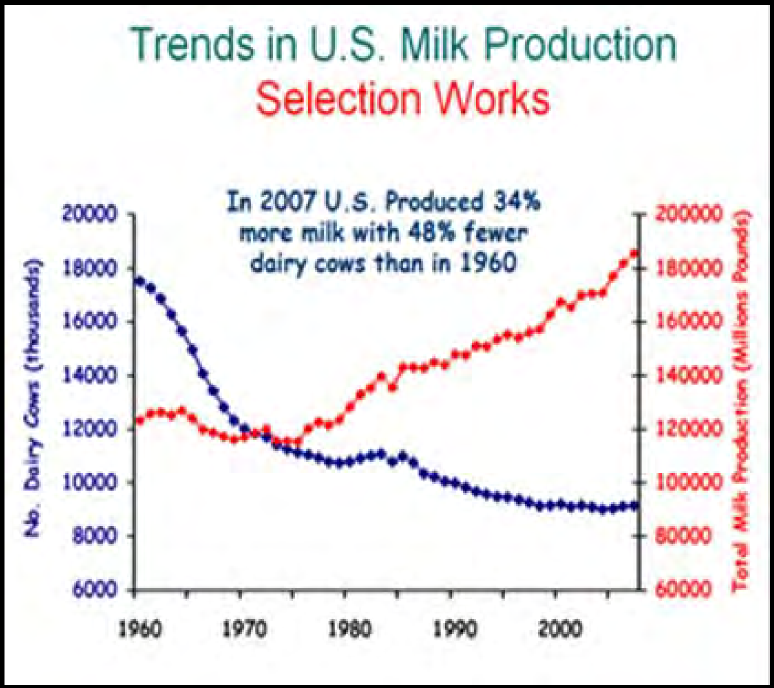
- Production
  - Cereal output in developing countries has grown 2.8 percent annually for three decades
- Productivity
  - Yields, not area, were responsible for growth
  - TFP grew along with yields



https://www.slideshare.net/PrabhuPingali/agriculture-renaissance-2010



https://paxsims.wordpress.com/2011/12/03/simulating-the-green-revolution/



ARS and industry partners have increased milk production while reducing the number of dairy cows.

- An increasing number of traits is considered in the merit index.
  - Pre 1994: milk, fat, protein
  - Now: milk, fat, protein, longevity, mastitis resistance, conformation traits, fertility, calving ease, stillbirths
  - More traits to be added
- Use genomics markers rather than pedigree analysis
  - Rapid identification of animals for breeding
  - Selection for traits that have low heritability

Journal of Food Composition and Analysis 56 (2017) 93–103

Contents lists available at ScienceDirect

Journal of Food Composition and Analysis

journal homepage: www.elsevier.com/locate/jfca

Study Review

Mineral nutrient composition of vegetables, fruits and grains: The context of reports of apparent historical declines

Robin J. Marles

Senior Scientific Advisor, Nutrition Premarket Assessment Division, Bureau of Nutritional Sciences, Food Directorate, Health Canada, 251 Sir Frederick Banting Driveway (Mail Stop 2203E), Ottawa, Ontario K1A 0K9, Canada

Marles, 2017
J. Food Composition and Analysis 56: 93-103.

- Reports of declines over decades in the nutrient content of fruits, vegetables, and grains.
- Attributed to soil mineral depletion by agricultural practices.
- Some evidence cited widely is not in the peer-reviewed literature.
- Many confounding factors, e.g.,:

- Data sources (new vs old data)	- Sample size
- Crop varieties	- Sampling method
- Geographic origin	- Laboratory methods
- Ripeness	- Statistical methods

Marles, 2017
J. Food Composition and Analysis 56: 93-103.

- Evidence that reduced nutrient content has *not* occurred comes from:
  - Archived vs contemporary soil samples
  - New vs old crop varieties grown side by side, or archived samples
  - % differences vs absolute differences
  - Great variation in nutrient content

Marles, 2017, J. Food Composition and Analysis 56:93-103. (Table 1 excerpts by SRS)

Each is < 5% of dry wt.

Each is < 0.02% of dry wt.

Table 1
Ranges of mineral nutrient content in examples of grains, vegetables and fruits.

Crop	Ca Range[a] (%)	K Range[a] (%)	Mg Range[a] (%)	P Range[a] (%)	Cu Range[a] (%)	Fe Range[a] (%)	Mn Range[a] (%)	Zn Range[a] (%)
Common bean[5] [b]	9–425 (4722%)	1300–2490 (191%)	100–326 (326%)	230–842 (366%)	<0.04–1.4 (>3500%)	3.14–12.07 (384%)	0.0009–2.63 (292,222%)	<1.89–6.24 (>330%)
Sweet potato, raw peeled[7] [b]	79.0–147.4 (187%)	724.0–1454 (201%)	73.7–87.6 (119%)	135.7–179.2 (132%)	0.5–0.7 (140%)	2.1–6.4 (305%)	1.3–2.6 (200%)	0.6–1.2 (200%)
Tomato, red ripe raw[9] [b]	145.2–181.8 (125%)	3600–4833 (134%)	116.7–206.9 (177%)	379.3–500.0 (132%)	0.67–1.07 (160%)	4.91–8.33 (170%)	1.83–2.07 (113%)	1.50–3.09 (206%)
Papaya, ripe[10] [b]	57.93–285.9 (494%)	1238–2309 (187%)	89.53–229.6 (256%)	44.76–146.8 (328%)	0.12–0.83 (692%)	0.9–14.81 (1646%)	0.081–0.24 (296%)	0.39–2.80 (718%)

Data sources: [1] Davis et al. (1984); [2] Organisation for Economic Cooperation and Development OECD (2016); [3] OECD (2002); [4] OECD (2004); [5] OECD (2015); [6] OECD (2012); [7] OECD (2010a); [8] Farnham et al. (2000); [9] OECD (2008); [10] OECD (2010b).

[a] Range units are mg/100 g dry weight; percent as maximum/minimum × 100%; n/a: not available.

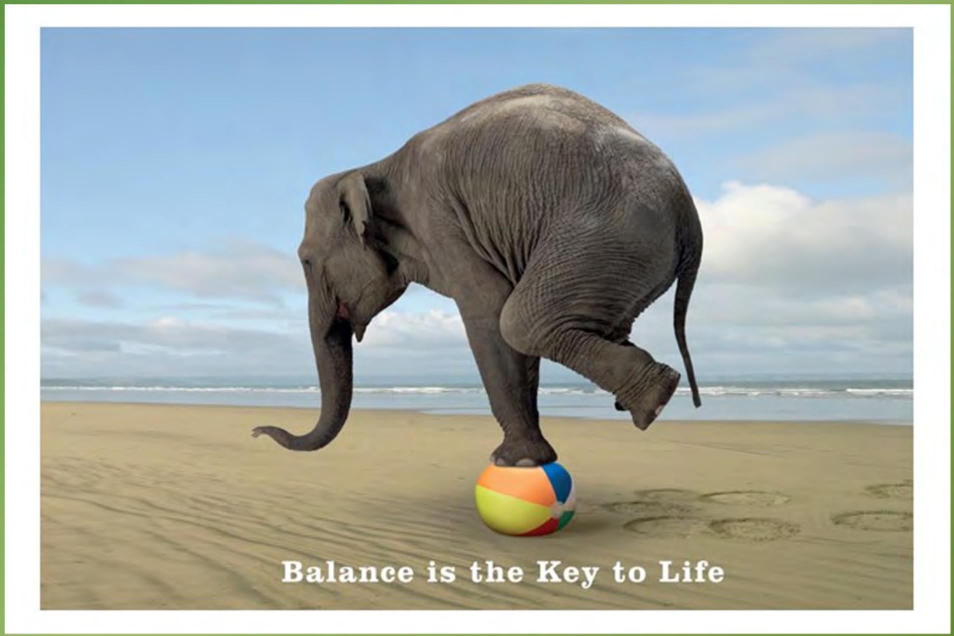
[b] *n* values are not available from OECD consensus document tables since they are compilations of published data.

ACHIEVING & MAINTAINING EQUILIBRIUM

Food Systems/Environmental Health

Food Production

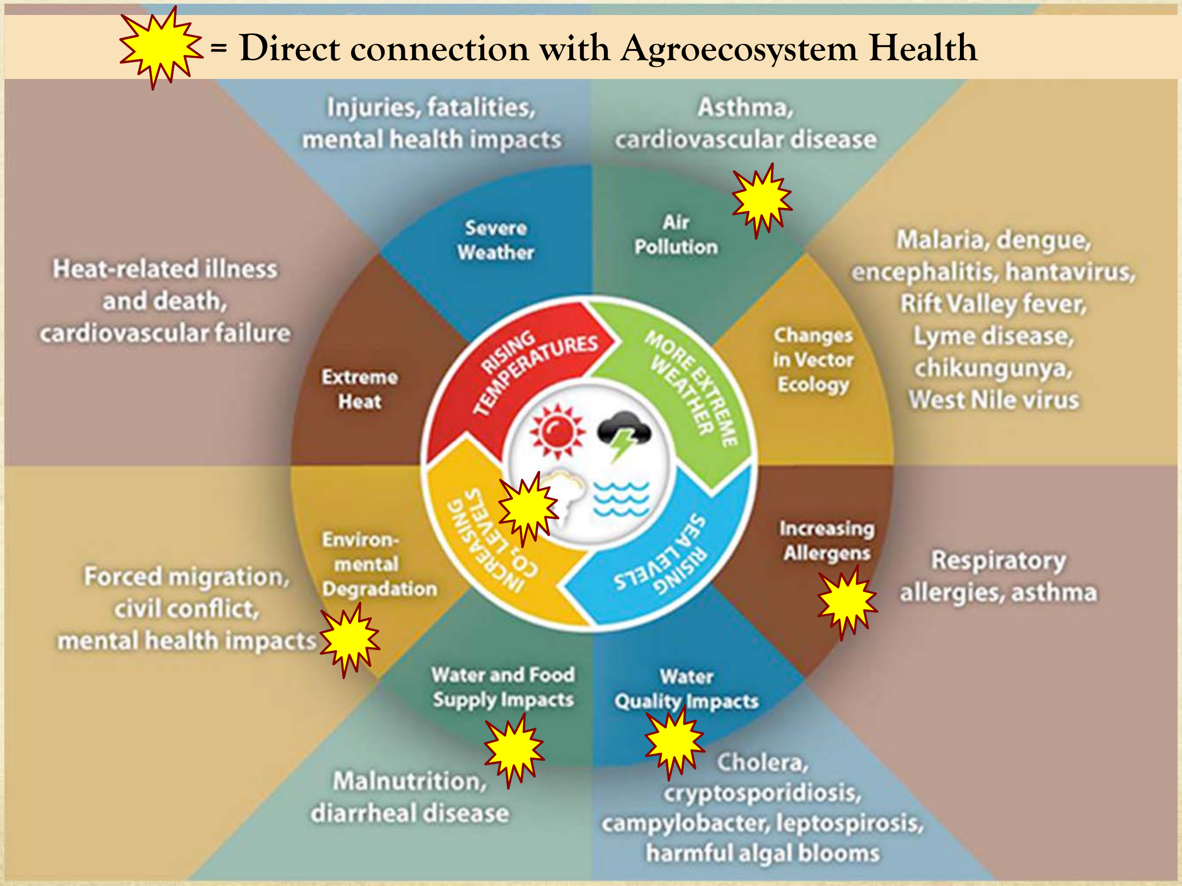
Dietary Intake



Wellness

Chronic diseases

Areas of Overlap Between Agroecosystem Health & Human Health



https://www.cdc.gov/climateandhealth/effects/default.htm

J.A. Paulson, GWU School of Medicine

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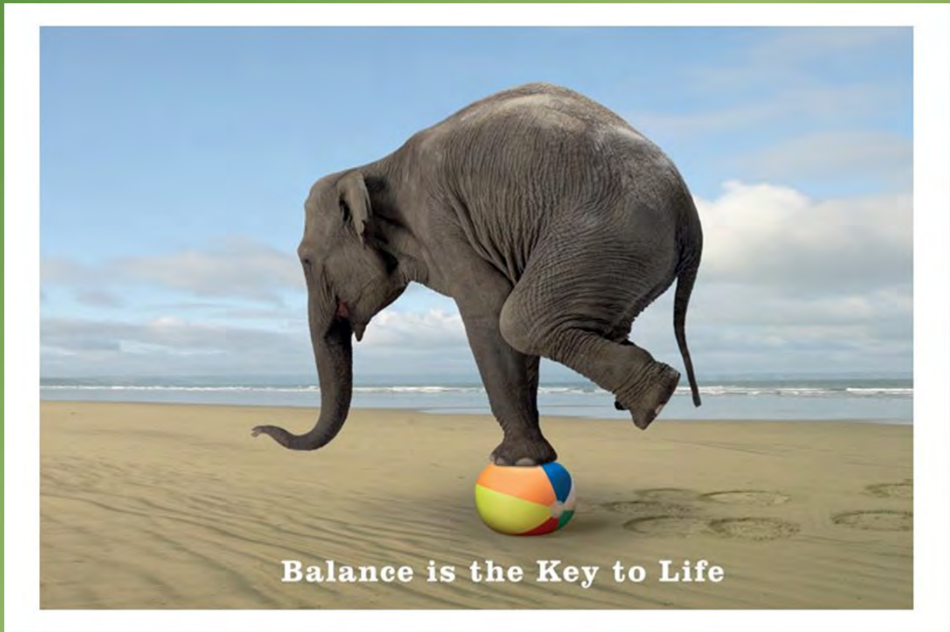


Wellness

Chronic diseases

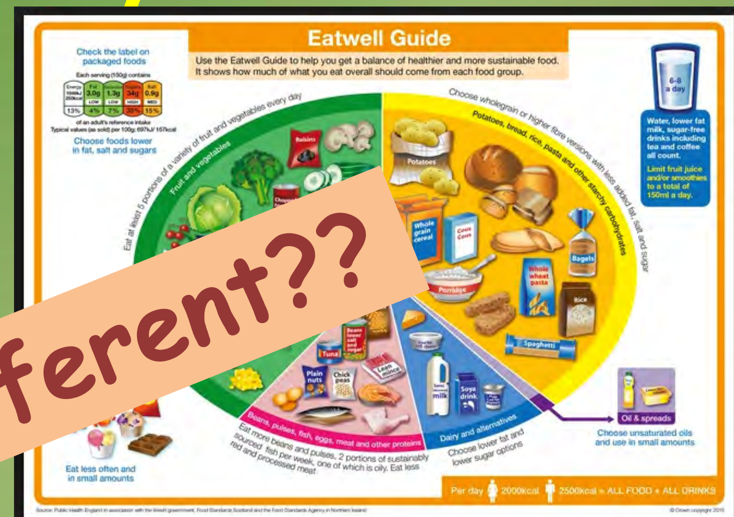
What does a "healthy" plate look like?

How do we provide it?

The "Healthy" Plate

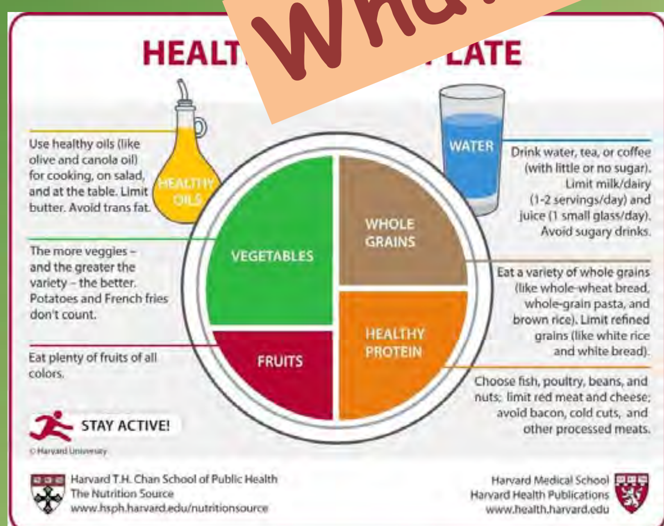
USDA

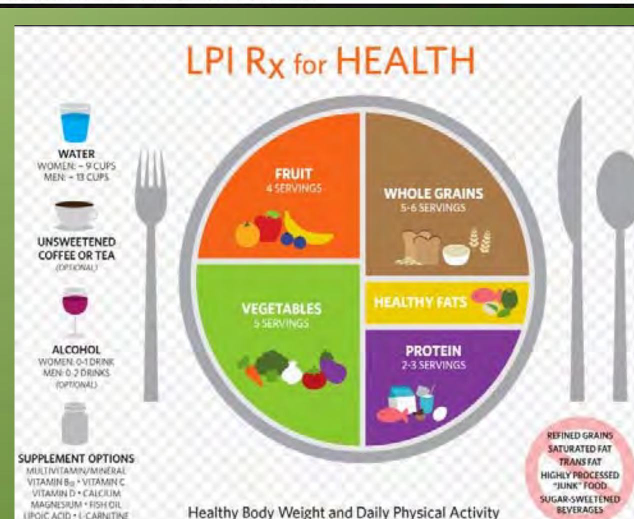
UK



What's different??

Harvard School of Public Health





Linus Pauling Institute

Marles, 2017, J. Food Composition and Analysis 56:93-103. (Table 1 excerpts by SRS)

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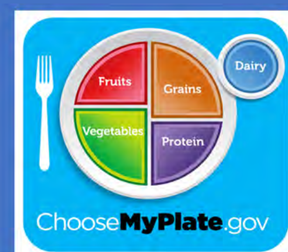
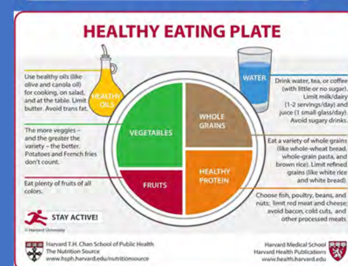
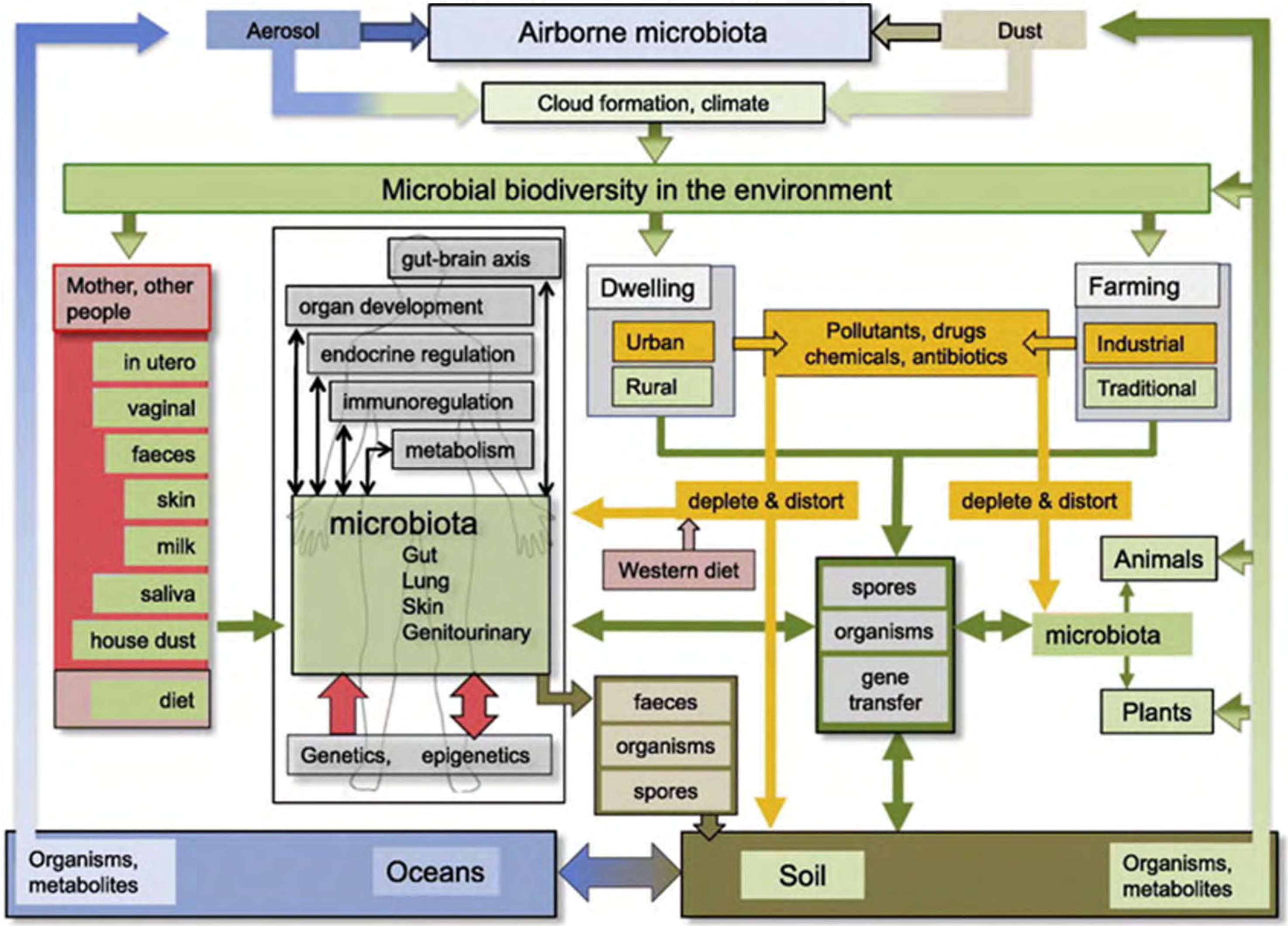
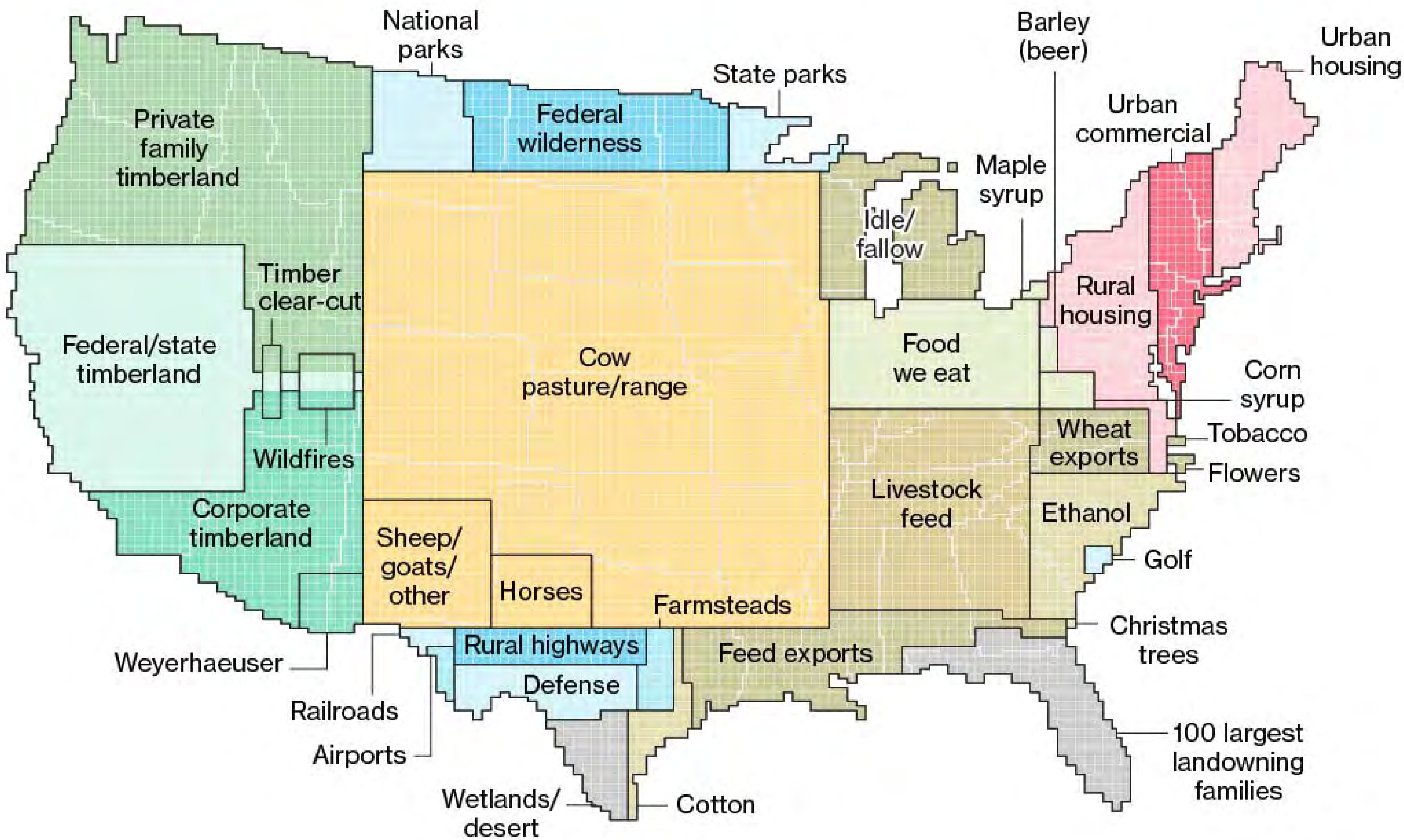


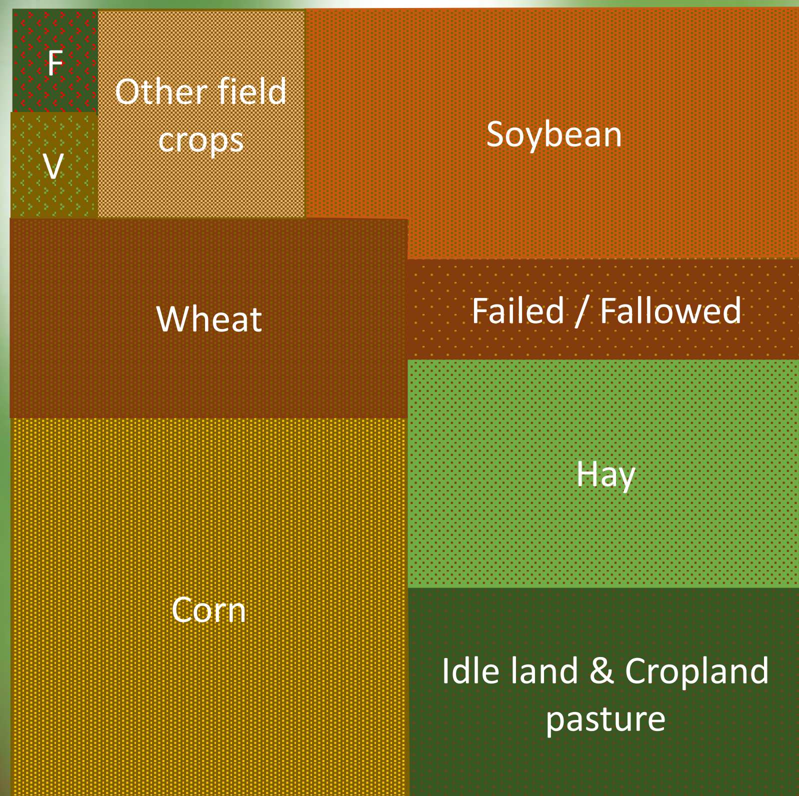




Flandroy et al., 2018, Science of the Total Environment 627: 1018-1038.

https://www.bloomberg.com/graphics/2018-us-land-use/





ary Guidelines

nclude

- Vegetables, variety
- Fruits, whole
- Grains, whole
- Dairy, low-fat
- Protein, variety

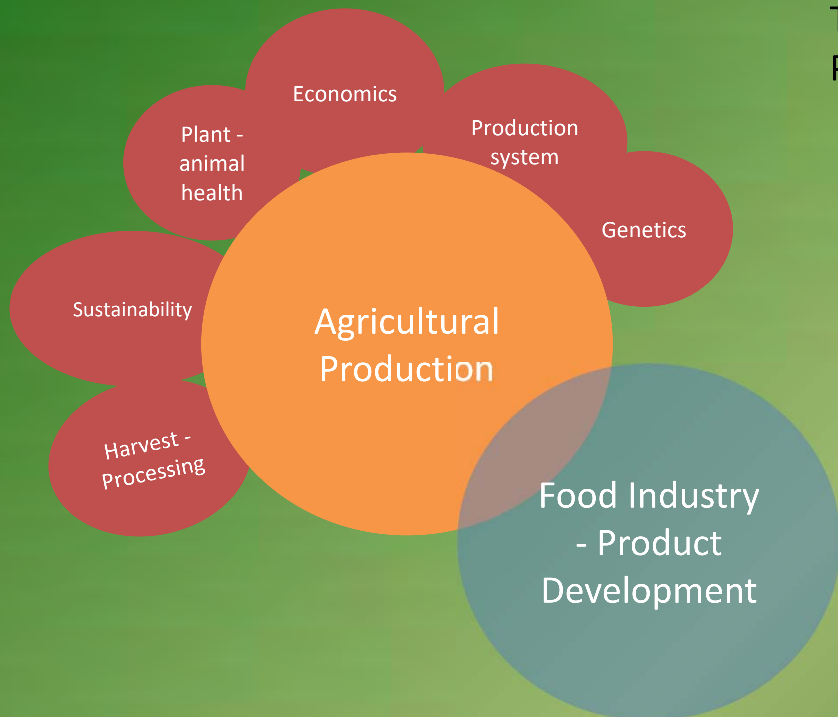
Limit

- Added sugars
- Saturated fat

How would land use patterns need to shift?

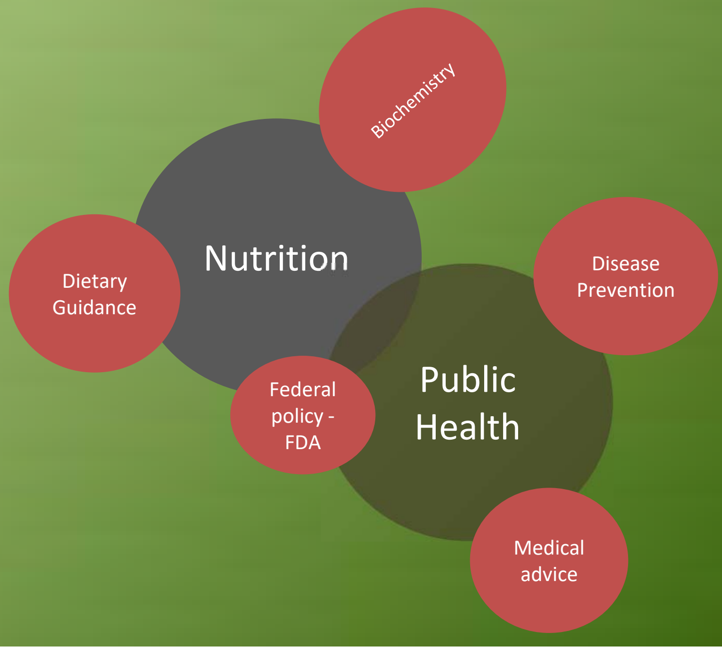
C. Peters, Tufts University

The **FOOD SUPPLY** from the
Point of view of producers/manufacturers

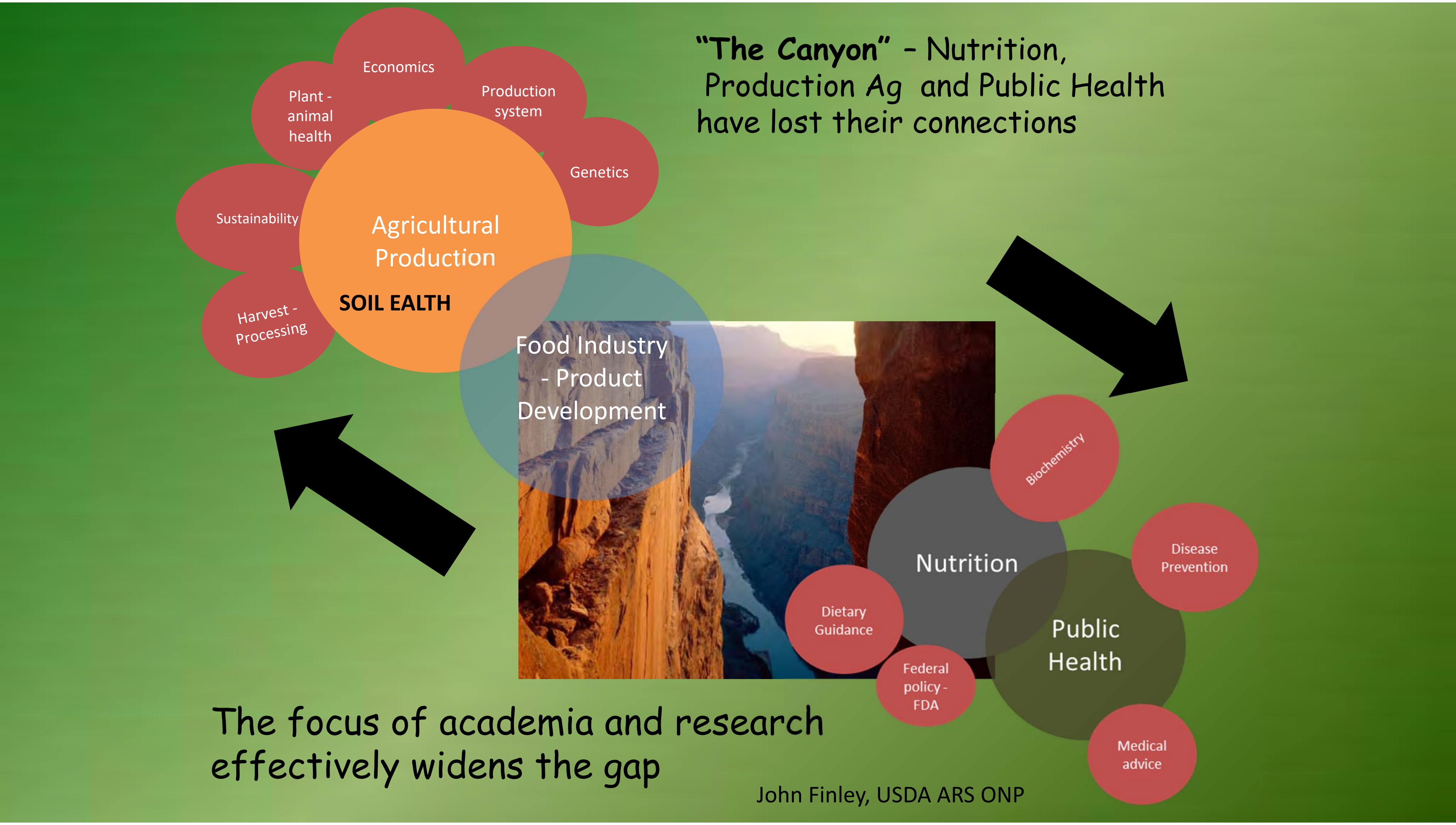


John Finley, USDA ARS ONP

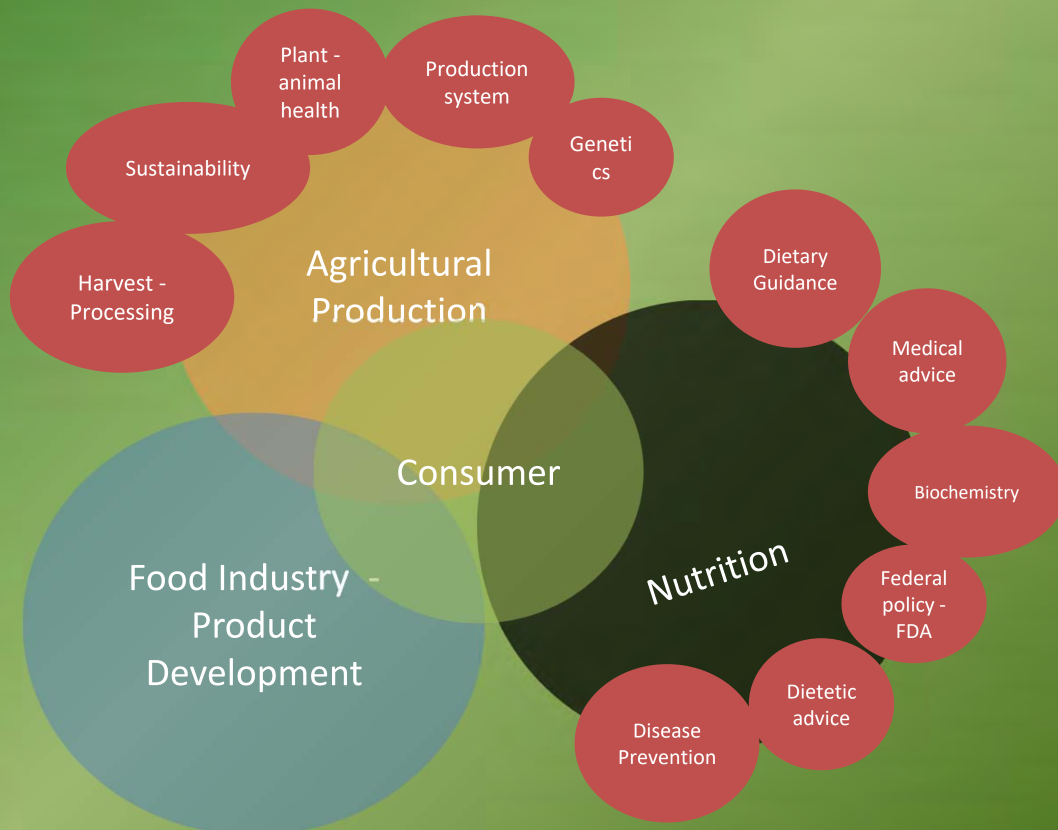
The **FOOD SUPPLY** from the
Point of view of nutrition



John Finley, USDA ARS ONP


"The Canyon" – Nutrition, Production Ag and Public Health have lost their connections
Economics
Plant - animal health
Production system
Genetics
Sustainability
Agricultural Production
SOIL EALTH
Harvest - Processing
Food Industry - Product Development
Biochemistry
Nutrition
Disease Prevention
Dietary Guidance
Public Health
Federal policy - FDA
Medical advice
The focus of academia and research effectively widens the gap
John Finley, USDA ARS ONP

Bringing it back together is the challenge….



John Finley, USDA ARS ONP

WELCOME

CONFERENCE on CONNECTIONS BETWEEN SOIL HEALTH and HUMAN HEALTH

October 16-17, 2018
Silver Spring, Maryland USA

HUMAN NUTRITION
FOOD SAFETY
FATE & TRANSPORT
MICROBIOME
COMMUNITY HEALTH

3 categories

- ***Development and Use of Transdisciplinary Research Organization and Infrastructure***
- ***Strategic Transdisciplinary Research and Outreach***
- ***Priority Transdisciplinary Research Themes***

10 Major Recommendations

Development and Use of Transdisciplinary Research Organization and Infrastructure

- **Capitalize on long-term experiment stations**…..engage the medical community and industry in tracking….. nutrients and toxins from soil to plants to humans and microbes….. and farm laborers and consumers …..
- **Develop a network of permanent research sites**….. comparison of conventional, organic, and regenerative agricultural production systems, …..urban areas and …..forests for their nutrient uptake and other properties…..
- **Create a center to quantify the positive and negative impacts of increasing soil organic matter and associated management systems across the entire agricultural value chain**….. maximize benefits and minimize adverse impacts on human health through agricultural management practices.

Strategic Transdisciplinary Research and Outreach

- **Integrate vast existing data in a summary review of SH-HH**, including gaps, knowns, unknowns, immediate actions….. Form a working group in transdisciplinary knowledge on this topic.
- **Communicate the soil health-human health relationship to all stakeholders.** Determine how to actively engage and enlist actions from farmers to deliver health soil and make it a driver in the bigger picture.

Priority Transdisciplinary Research Themes

- **Understand soil health and regenerative systems** …..impacts on environment and the global food system. Validate methods for soil health measurement …..
- **Understand the fundamental microbiome structures and functions** related to land management, soil health, and human health. Connect existing research on the human microbiome to the soil microbiome.
- **Determine how …..soil health practices can impact human wellness, economy and the environment**….. linking soil management with nutrition content of the food produced.
- **Characterize human-soil interactions** for exposure analyses, health impacts, and avenues for intervention.
- Identify specific partners to **increase and optimize bioavailability in soil health agricultural management systems** to optimize nutrients, decrease contamination and promote community well-being.


https://www.uclan.ac.uk/research/explore/groups/young_scientist_centre.php

Significant Obstacle: FUNDING

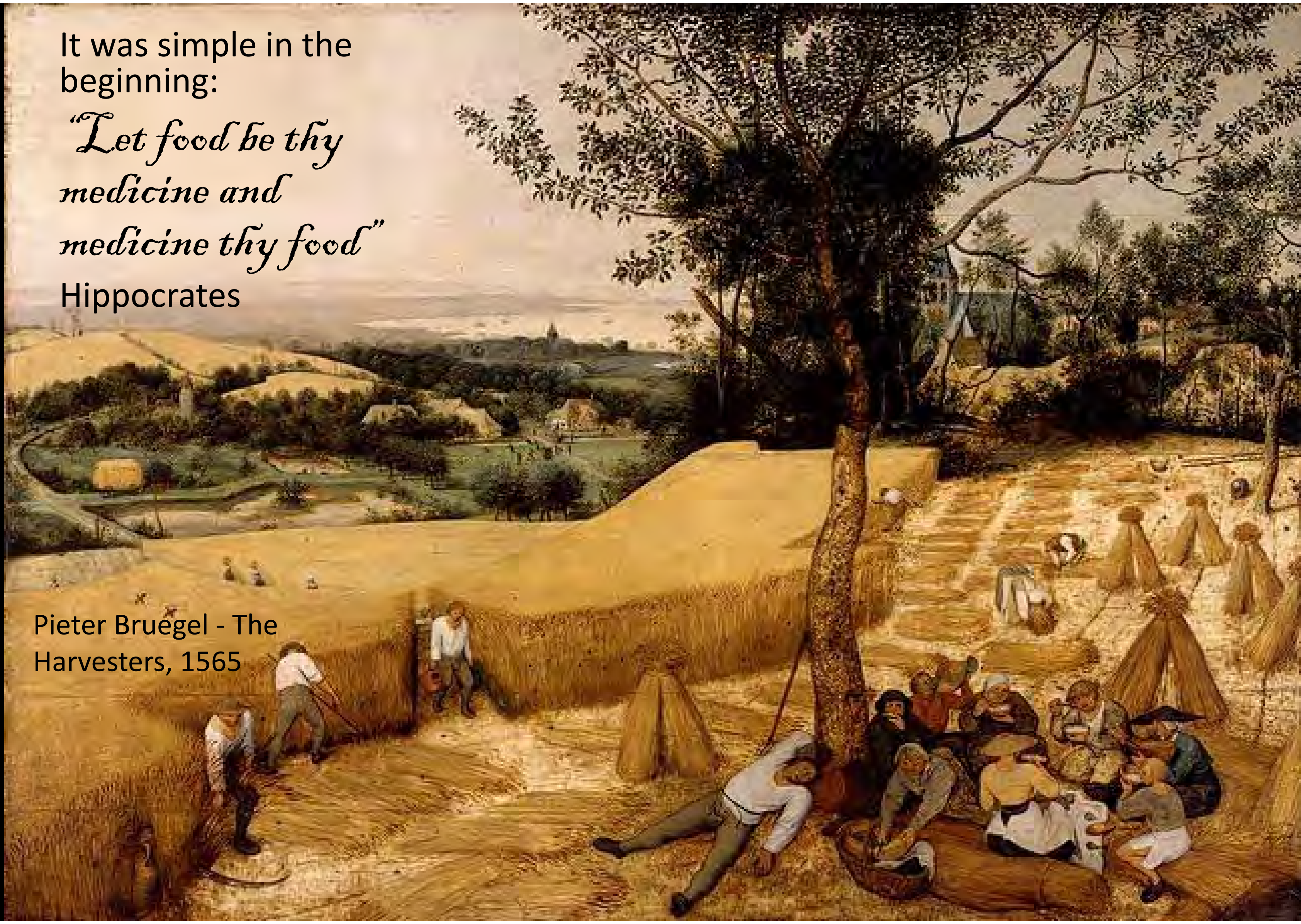
- **Authorities**
- **Availabilities**
- **Mechanisms**
- **Transdisciplinary teams**

https://nypost.com/2014/06/06/why-people-risk-their-lives-mountain-climbing/

- **Transdisciplinary teams within agencies**
  e.g., ARS Grand Challenge
- **Establishment of specific project(s) or program(s)**
- **NIH matching funds with agriculture research**

http://knowledge.wharton.upenn.edu/article/peak-performance-lessons-in-leadership-from-mountain-guides-for-business-managers/


Left
Right
Coordination among Committees authorizing and appropriating funds for research in Human Health and Agriculture



It was simple in the beginning:

"Let food be thy medicine and medicine thy food"

Hippocrates

Pieter Bruegel - The Harvesters, 1565

INNOVA MARKET INSIGHTS

TOP TEN TRENDS 2019

INNOVA MARKET INSIGHTS

1 DISCOVERY: THE ADVENTUROUS CONSUMER

Consumers are on a big and broad journey of discovery, moving out of their comfort zones to explore bolder flavors and multisensory food experiences

NEW FOOD EXPERIENCES
STORYTELLING
ETHNIC FLAVORS

2 THE PLANT KINGDOM

The plant-based market shows no signs of slowing down. Brands are greening up their portfolios to attract even the mainstream consumer

BRANDS 'GREEN-UP'
BOTANICAL FLAVORS
DEVELOPMENT OF HYBRIDS

3 ALTERNATIVES TO ALL

Consumers pay attention to health and sustainability, pushing more innovation in replacement foods and ingredients

ALTERNATIVES BRING CHOICE
SUBSTITUTE INGREDIENTS
ALTERNATIVE PROTEINS

4 GREEN APPEAL

Brands increasingly commit in market actions and innovations across both product and packaging to answer consumer expectations around sustainability

FIGHTING FOOD WASTE
COMMITTED TO SUSTAINABILITY
PACKAGING INNOVATIONS

5 SNACKING: THE DEFINITIVE OCCASION

Meeting the evolving expectations around snack products is a strong focus for innovation across all food and beverage categories

HEALTHY SNACKING
SNACK FORMAT INNOVATIONS
SNACKIFICATION

6 EATING FOR ME

Technological advances and ever expanding choice in food service and retail are enabling consumers to adopt a more individual approach to eating

INDIVIDUAL DIET NEEDS
ENDLESS CUSTOMIZATION
PERSONALIZED PACKAGING

7 A FRESH LOOK AT FIBER

Renewed interest in fiber, going beyond digestive health benefits, is driving fiber applications

GROWTH OF FIBER CLAIMS
NEWLY DISCOVERED BENEFITS
NEW FIBER APPLICATIONS

8 I FEEL GOOD

Consumers have a rising interest in the role that nutrition can play in supporting emotional and mental wellbeing

FEEL GOOD CLAIMS
SUPPORTING BRAIN HEALTH
CBD INFUSED

9 SMALL PLAYER MINDSET

Start-up companies continue to shake up the food and beverage industry, successfully competing against major players who in turn are going small in their strategy

POWER OF LOCAL
INSPIRING FOOD GIANTS
START-UP INVESTMENTS

10 CONNECTED TO THE PLATE

Advances in digital technology enable consumers to get closer to their food through greater levels of transparency and involvement

CONSUMER ENGAGEMENT
SMART LABEL
BLOCKCHAIN TECHNOLOGY

Food Trends Specialists for 25 Years.

Consumer insights slides created by the International Food Information Council (https://foodinsight.org/)

from its 2018 Food and Health Survey
https://foodinsight.org/2018-food-and-health-survey/

Mindy Hermann, MBA, RDN
mindy@hermanncomm.com

How was nutrient density increased in the food supply & the way forward

Maha Tahiri, PhD, Adjunct Professor, Tufts University

Outline

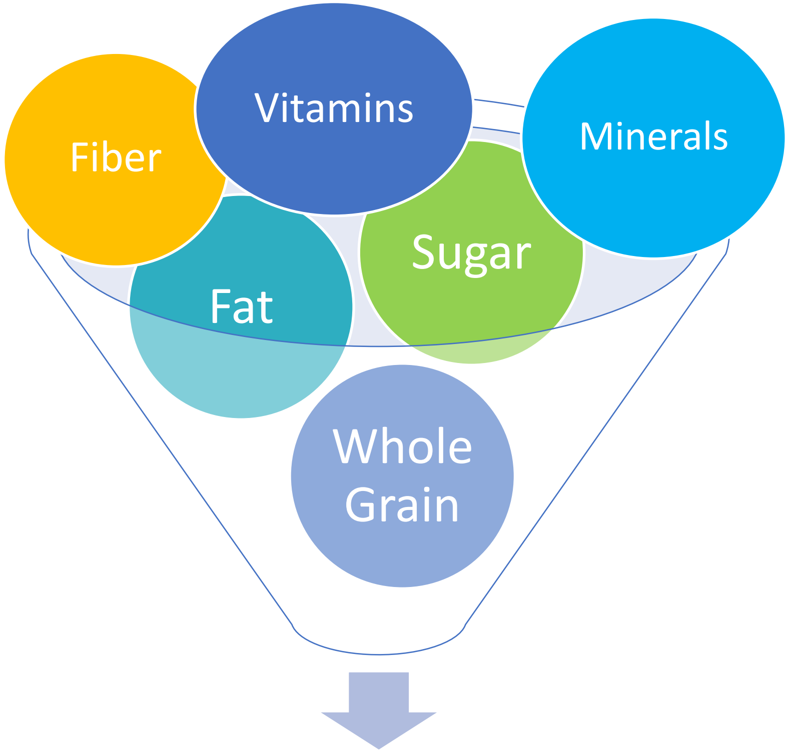
Industry efforts in increasing nutrient density

- Balance the positives and limiters
- Delivery of multiple positive nutrients nutrients
- Delivery of a positive nutrient at a large scale
- Nutrient dense food groups

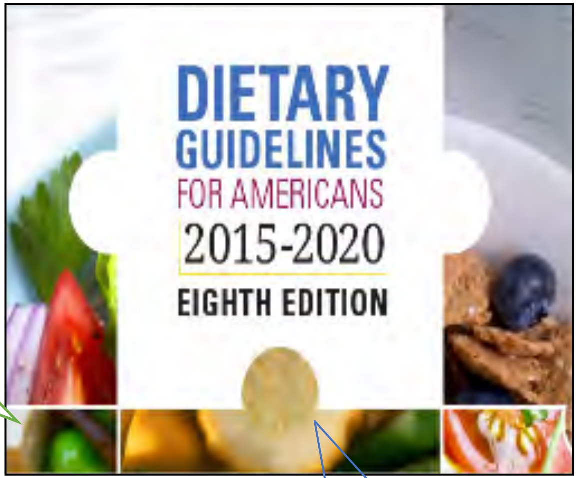
Consumer attitudes

Fortification vs biofortification

Nutrient density a more holistic approach



Nutrient Density



For example, in the dairy group, nutrient-dense choices such as fat-free milk, plain fat-free yogurt…"

Strategies to achieve higher levels of intake of vitamin D include consuming seafood and more foods ***fortified with vitamin D, especially fluid milk, soy beverage, yogurt, orange juice, and breakfast cereals***

"Those who consume all of their grains as whole grains should include some grains, such as some whole-grain ready-to-eat breakfast cereals, that have been fortified with folic acid."

Increasing the overall nutrient density of the portfolio by 2025

PEPSICO

pepsi Lay's Tropicana QUAKER G

Reduce added sugars

At least 2/3 of our global beverages portfolio volume will have **100 Calories or fewer from added sugars** per 12-oz. serving

Reduce saturated fat

At least 3/4 of our global foods portfolio volume will not exceed **1.1 grams of saturated fat** per 100 Calories

Reduce salt

At least 3/4 of our global foods portfolio volume will not exceed **1.3 milligrams of sodium** per Calorie

Offer more positive nutrition

The rate of sales growth of what we refer to as our **Everyday Nutrition products will outpace the rate of sales growth** in the balance of our product portfolio

Bringing nutrient density into the market place through product improvement

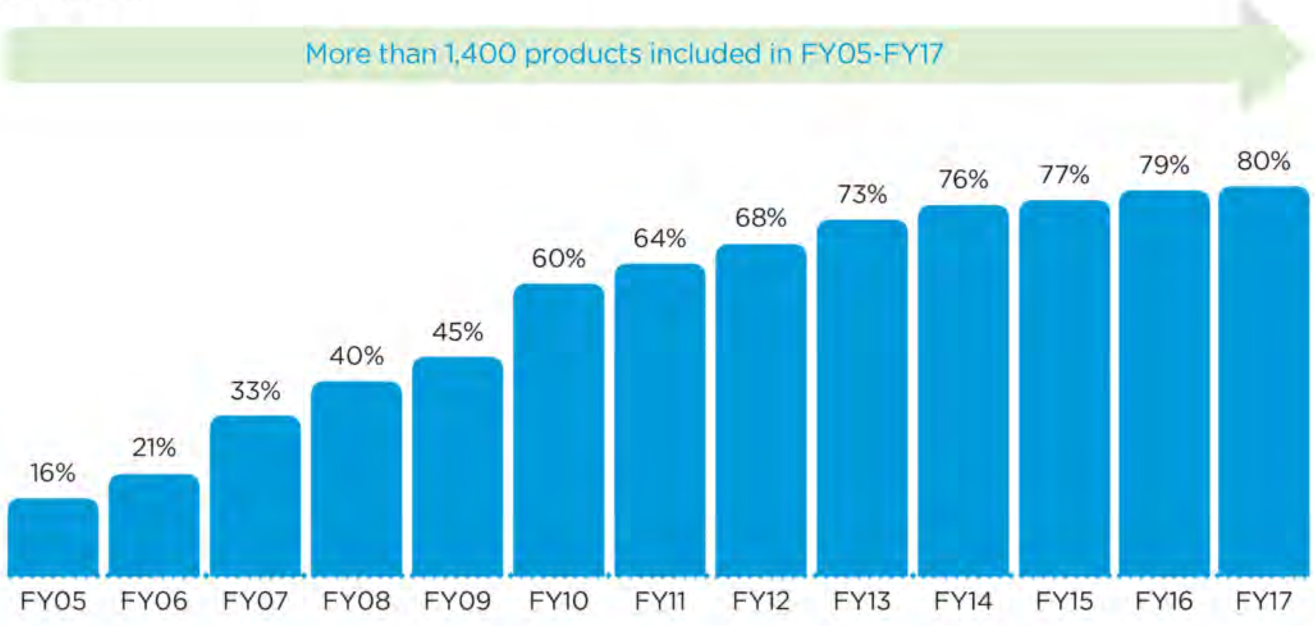
Ways in for New or Reformulated Products

- ✓ Enhance Positive Nutrition
- ✓ Reduce Limiter Nutrients
- ✓ Qualify for a Nutrient or Health Benefit Claim
- ✓ Meet: CFBAI Child Advertising criteria

U.S. Health Metric

In fiscal 2017, 80 percent of our U.S. retail sales volume was composed of products that had met Health Metric* criteria since its inception in 2005.

U.S. retail Health Metric achievement
FY05-FY17

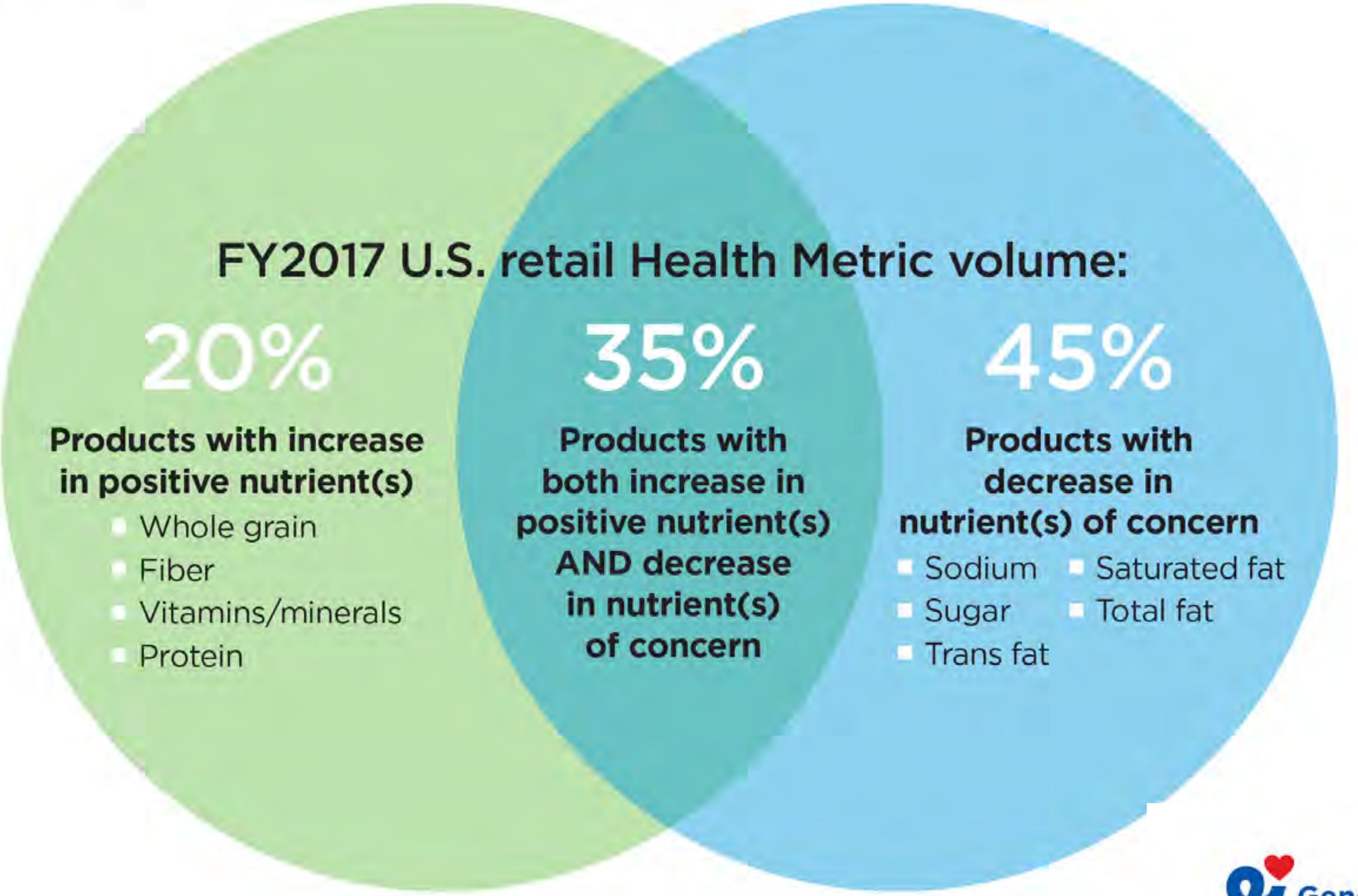


Drivers of nutritional improvements
U.S. retail sales volume FY05-FY17**

Balance the positives and limiters

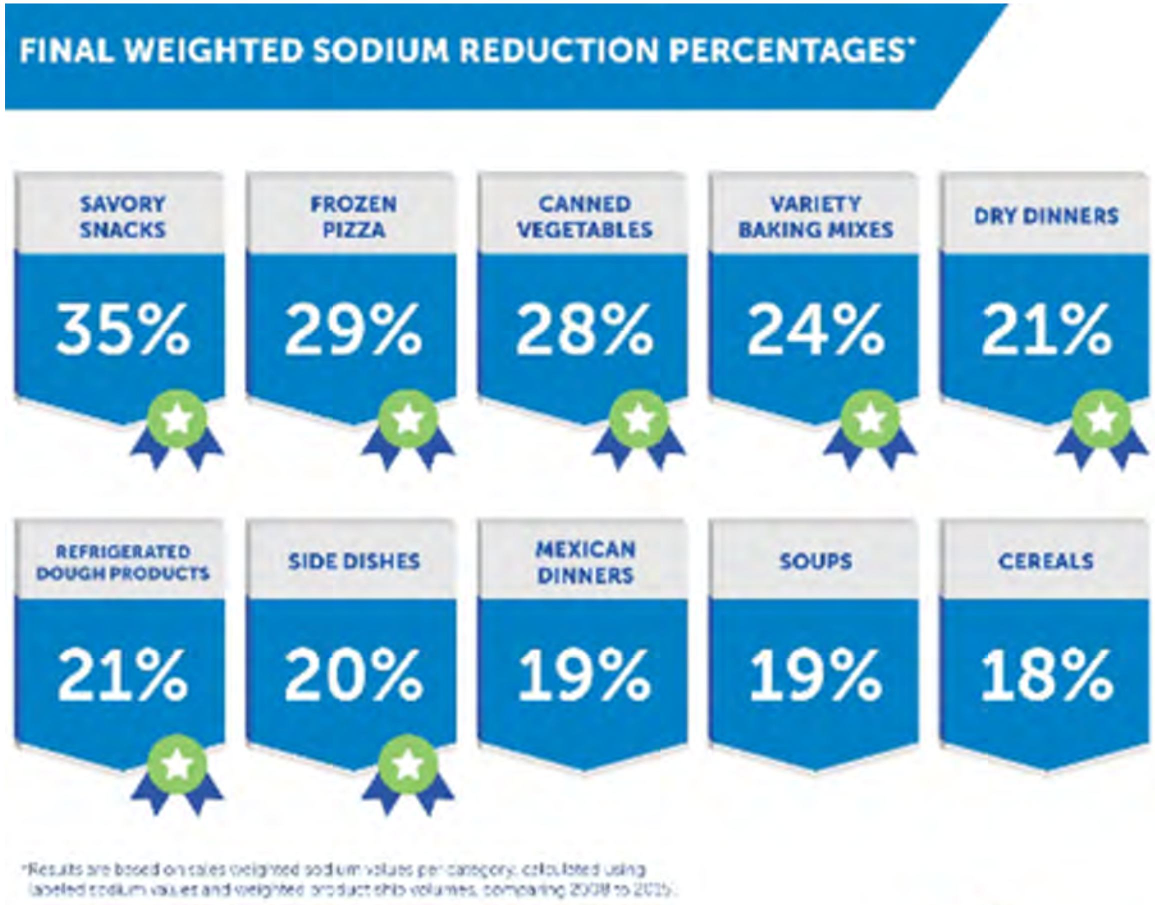
- ✓ **Increase positive nutrients**
- ✓ **Reduce Limiter Nutrients**
- ✓ **Qualify for a Nutrient or Health Benefit Claim**
- ✓ **Meet: CFBAI Child Advertising criteria**

U.S. retail sales volume FY05-FY17**



Major sodium reduction efforts and learnings

- 2010: Pledged to reduce sodium 20% in key product categories by 2015
  - ✓ Included 10 of their biggest categories
  - ✓ Used sales weighted data for baseline (2008) and to ensure biggest selling products were reduced
- 2015 results: Met or exceeded goal in 7 of 10 categories
  - ✓ Reductions from 18-35%
  - ✓ Represents >1/3 of US retail sales volume



Fortification significantly contribute to nutrients intakes

Nutrition Facts
Serving Size ¾ cup (28g)
Servings Per Container about 17

Amount Per Serving	Honey Nut Cheerios	with ½ cup skim milk
Calories	110	150
Calories from Fat	15	15
		% Daily Value**
Total Fat 1.5g*	2%	3%
Saturated Fat 0g	0%	0%
Trans Fat 0g		
Polyunsaturated Fat 0.5g		
Monounsaturated Fat 0.5g		
Cholesterol 0mg	0%	1%
Sodium 190mg	8%	11%
Potassium 115mg	3%	9%
Total Carbohydrate 22g	7%	9%
Dietary Fiber 2g	8%	8%
Soluble Fiber less than 1g		
Sugars 9g		
Other Carbohydrate 11g		
Protein 3g		
Vitamin A	10%	15%
Vitamin C	10%	10%
Calcium	10%	25%
Iron	25%	25%
Vitamin D	10%	25%
Thiamin	25%	30%
Riboflavin	25%	35%
Niacin	25%	25%
Vitamin B_6	25%	25%
Folic Acid	50%	50%
Vitamin B_{12}	25%	35%
Phosphorus	10%	20%
Magnesium	8%	10%
Zinc	25%	30%

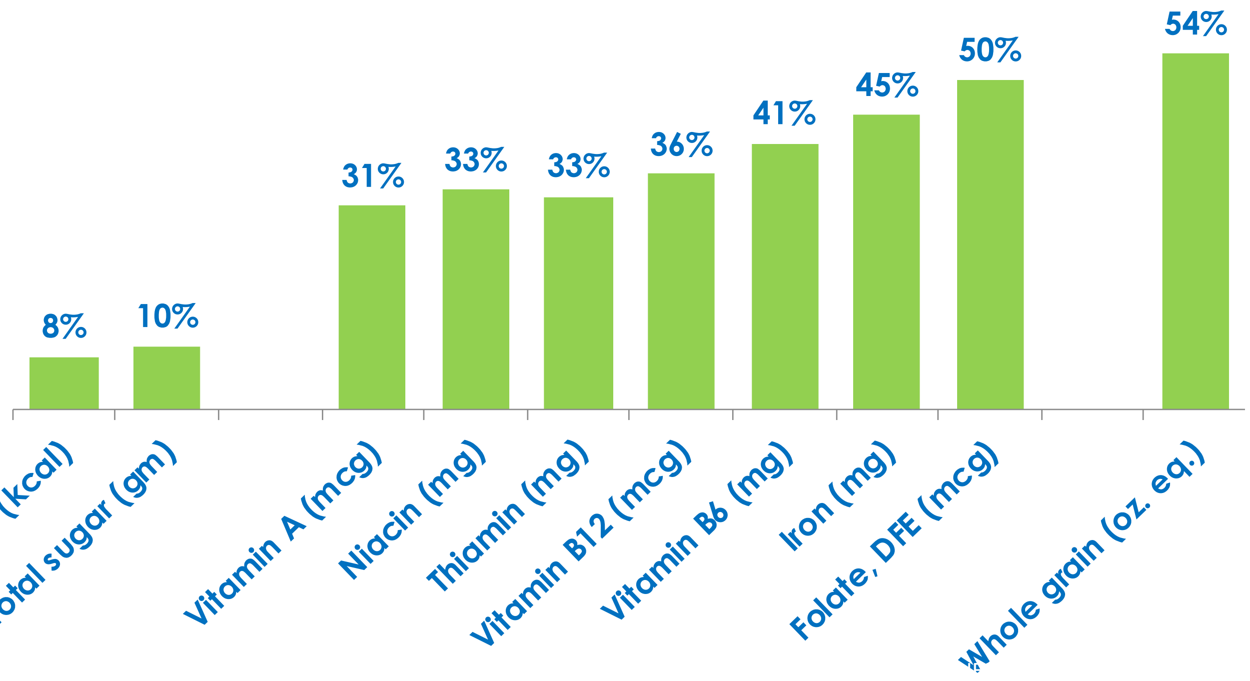
* Amount in cereal. A serving of cereal plus skim milk provides 1.5g total fat, less than 5mg cholesterol, 250mg sodium, 320mg potassium, 28g total carbohydrate (15g sugars) and 7g protein.

** Percent Daily Values are based on a 2,000 caloric diet. Your daily values may be higher or lower depending on your caloric needs:

	Calories	2,000	2,500
Total Fat	Less than	65g	80g
Sat Fat	Less than	20g	25g
Cholesterol	Less than	300mg	300mg
Sodium	Less than	2,400mg	2,400mg
Potassium		3,500mg	3,500mg
Total Carbohydrate		300g	375g
Dietary Fiber		25g	30g

Cereals fortification provides ag least 30% of total daily intake of key nutrients and whole grain in lower income children

Percent of Total Daily Intake from Cereal in Lower Income Children

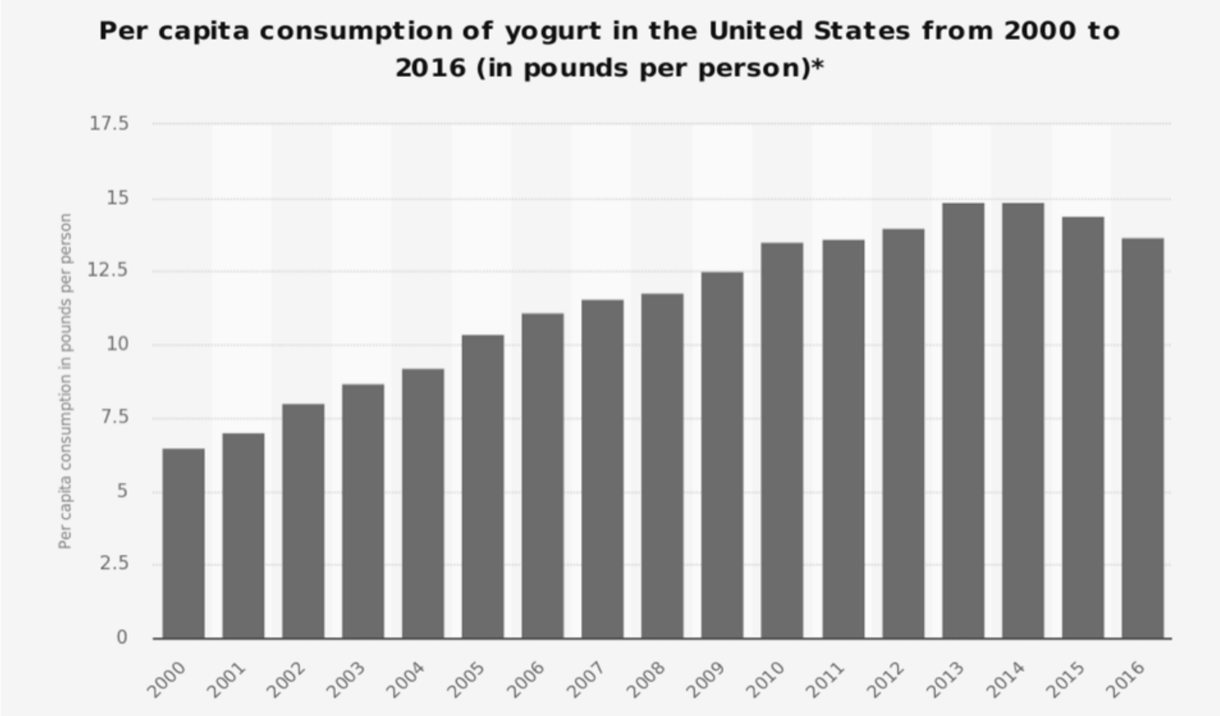


NHANES 2007-2012, ages 4-12yrs, PIR<185

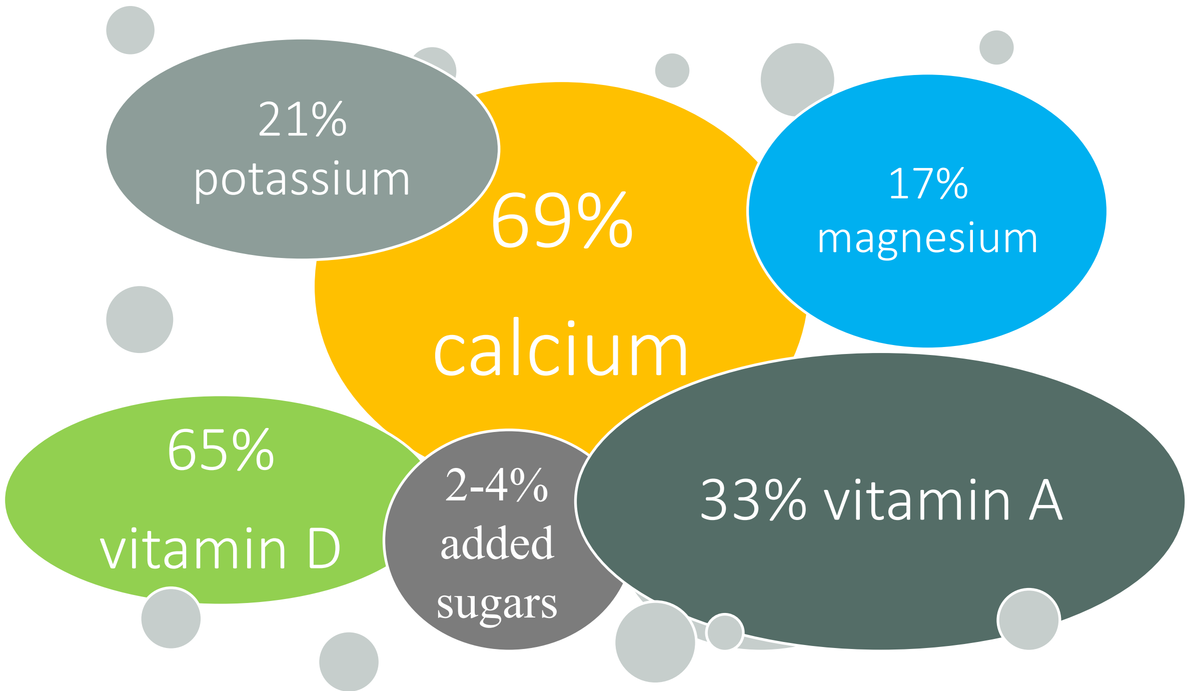
General Mills
Making Food People Love

supporting nutrient intakes

Yogurt Growth[1]



Dairy's Contributions to the U.S. Diet[3,4]



Dairy consumption has been growing over tha last decade Especially yogyrt

3. Scientific Report of the 2015 Dietary Guidelines Advisory Committee. Feb 2015. Appendix E-3.6: Dairy Group and Alternatives.
4. Drewnowski A, Rehm CD. Consumption of added sugars among US children and adults by food purchase location and food source. AM J Clin Nutr. 2014;100:901-7.

Innovations towards Nutrient-Dense Foods and Beverages

A Nutrient-Dense Innovation: Authentically Strained, High-Protein Yogurt

2X MORE
HIGH-QUALITY PROTEIN*

+ calcium

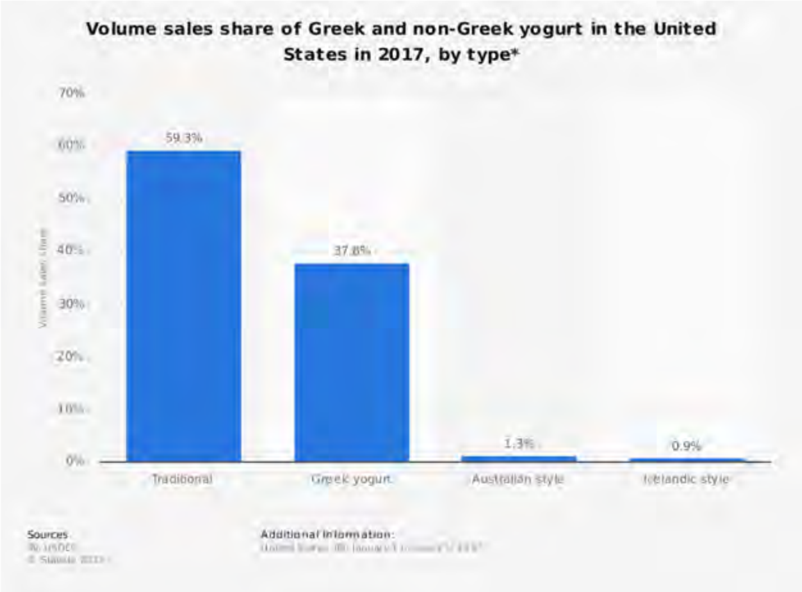
+ vitamin B12

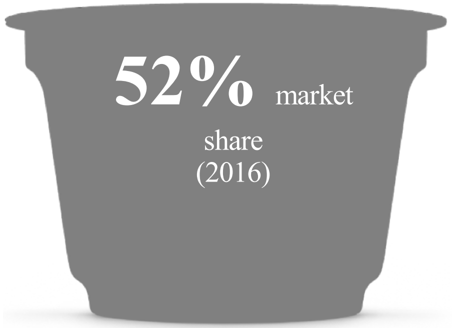
+ potassium

+ zinc

+ probiotics

+ sensible sugars to balance taste & nutrition





Chobani®

A Sponsored Satellite Program held in conjunction with
NUTRITION 2018
Where the Best in Science & Health Meet
JUNE 9-12, 2018 | HYNES CONVENTION CENTER, BOSTON, MA

Selection of nutrient dense food groups

Food Groups to Encourage are food groups that have been well-established as contributing to healthier diets. They include: fruit, vegetables, whole grains, low fat dairy, nuts, seeds and legumes.

Fruits

Tropicana Pure Premium

100% Orange Juice

In a 2,000 kcal diet, the USDA recommends consuming **2 cups-equivalent portion of fruits each day**

8oz serving of Tropicana Pure Premium is equivalent **to ½ of the USDA recommended servings of fruit for the day**

Approximately **75% of the US population consumes** less than this recommendation

Nutrition Information

Serving Size 8 fl oz

Vitamin C 120% DV	**Calories** 110
Potassium 13% DV	**Sat Fat** 0g /**Trans Fat** 0g
Folate 15% DV	**Sodium** 0mg
	Total Sugar 22g **Added Sugar** 0g

Whole Grains

Old Fashioned Quaker Oats

100% Whole Grain Oats

In a 2,000 kcal diet, the USDA recommends consuming **≥3 oz-equivalent portion of whole grains each day**

½ cup serving of 100% whole grain oats is more than **3/4 of the recommended servings for the day**

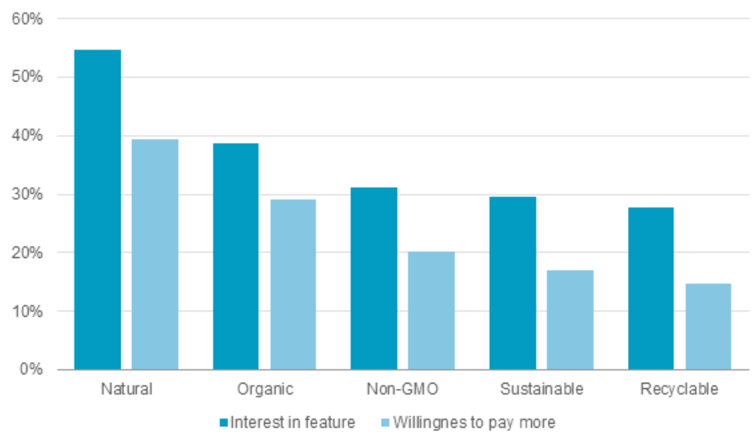
Nearly 100% of the U.S. population **consumes whole grain amounts that are below the recommended levels**

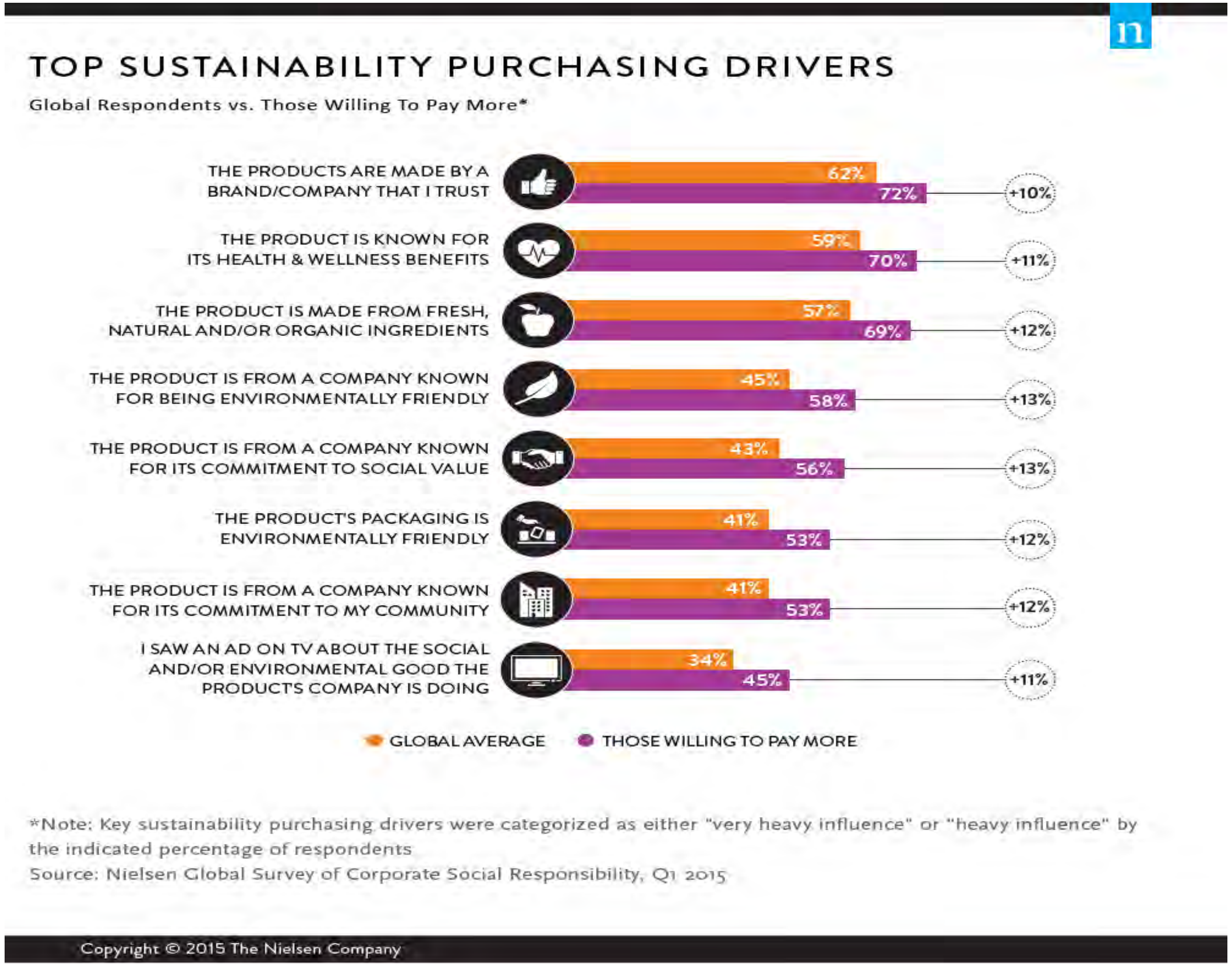
Nutrition Information

Serving Size ½ cup

Iron 8% DV	**Manganese** 70% DV	**Calories** 150
Thiamin 10% DV	**Potassium** 4% DV	**Sat Fat** 0.5g **Trans Fat** 0g
Phosphorus 15% DV	**Fiber** 4g	**Sodium** 0mg
Magnesium 10% DV	**Protein** 5g	**Total Sugar** 1g **Added Sugar** 0g

Consumers preference for natural & sustainable





With clean label now *"the most dominant trend in food and drink, many food manufacturers are moving away from fortifying foods with minerals, vitamins and other nutritious ingredients"*, says Euromonitor International.

Consumers preference for clean label & natural


Contents lists available at ScienceDirect
Trends in Food Science & Technology
journal homepage: http://www.journals.elsevier.com/trends-in-food-science-and-technology
ELSEVIER

Review

The importance of food naturalness for consumers: Results of a systematic review

Sergio Román [a], Luis Manuel Sánchez-Siles [b], Michael Siegrist [c,*]

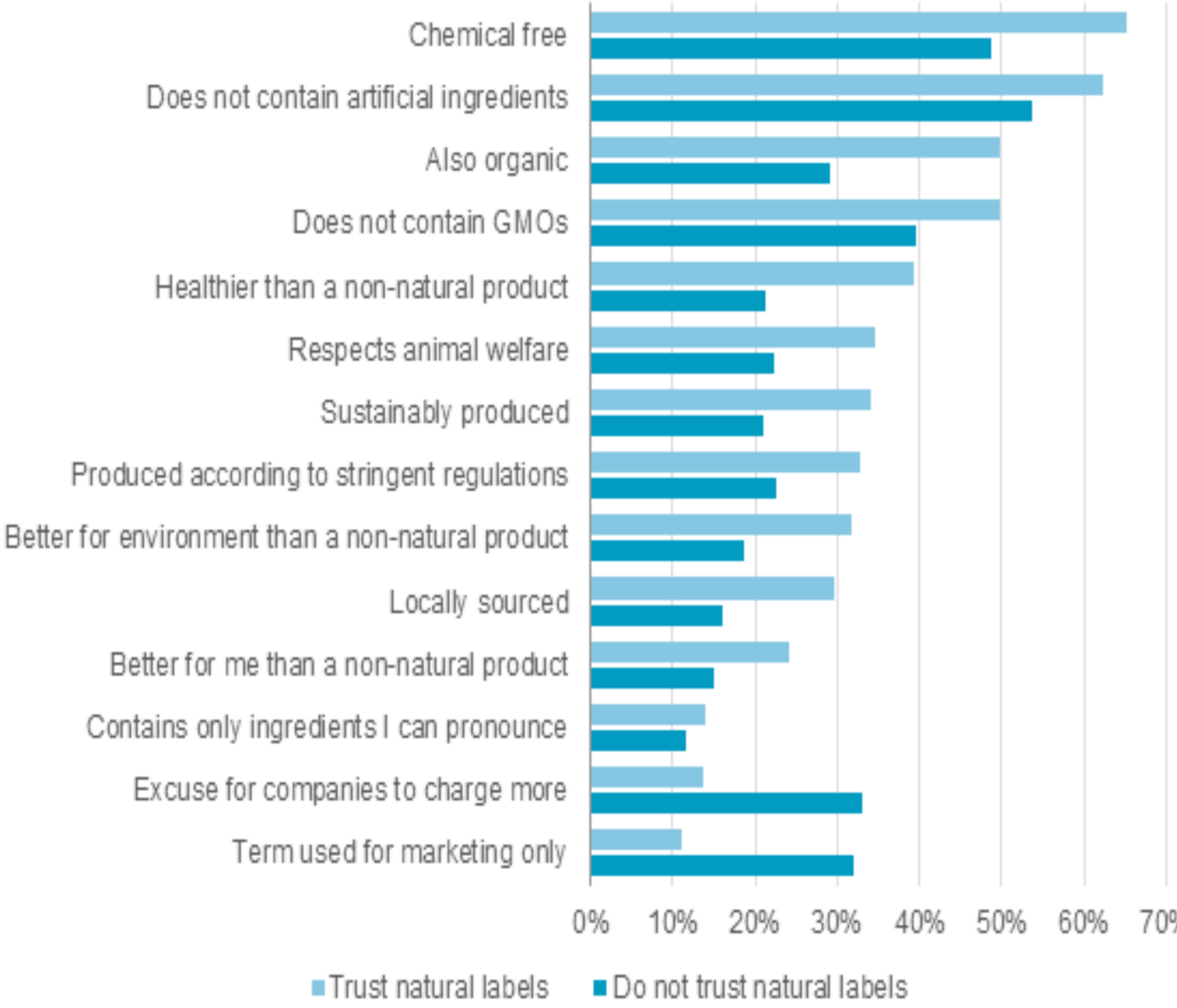
[a] Marketing Department, Facultad de Economía y Empresa, Universidad de Murcia, 30100, Murcia, Spain
[b] Research and Development Department, Hero Group, 30820 Murcia, Spain
[c] ETH Zurich, Institute for Environmental Decisions (IED), Consumer Behavior, Universitätstrasse 16, 8092 Zurich, Switzerland

Systematic review :

72 studies, 32 countries, involving more than 85000 consumers

More importance to less:

additives, preservatives, artificial colors, flavors, chemical, hormones, pesticides GMO's.



From fortification to biofortification: the issue of multiple nutrients

Nutrition Facts

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Dietary Fiber 2g	8%	8%
Soluble Fiber less than 1g		
Sugars 9g		
Other Carbohydrate 11g		
Protein 3g		
Vitamin A	10%	15%
Vitamin C	10%	10%
Calcium	10%	25%
Iron	25%	25%
Vitamin D	10%	25%
Thiamin	25%	30%
Riboflavin	25%	35%
Niacin	25%	25%
Vitamin B_6	25%	25%
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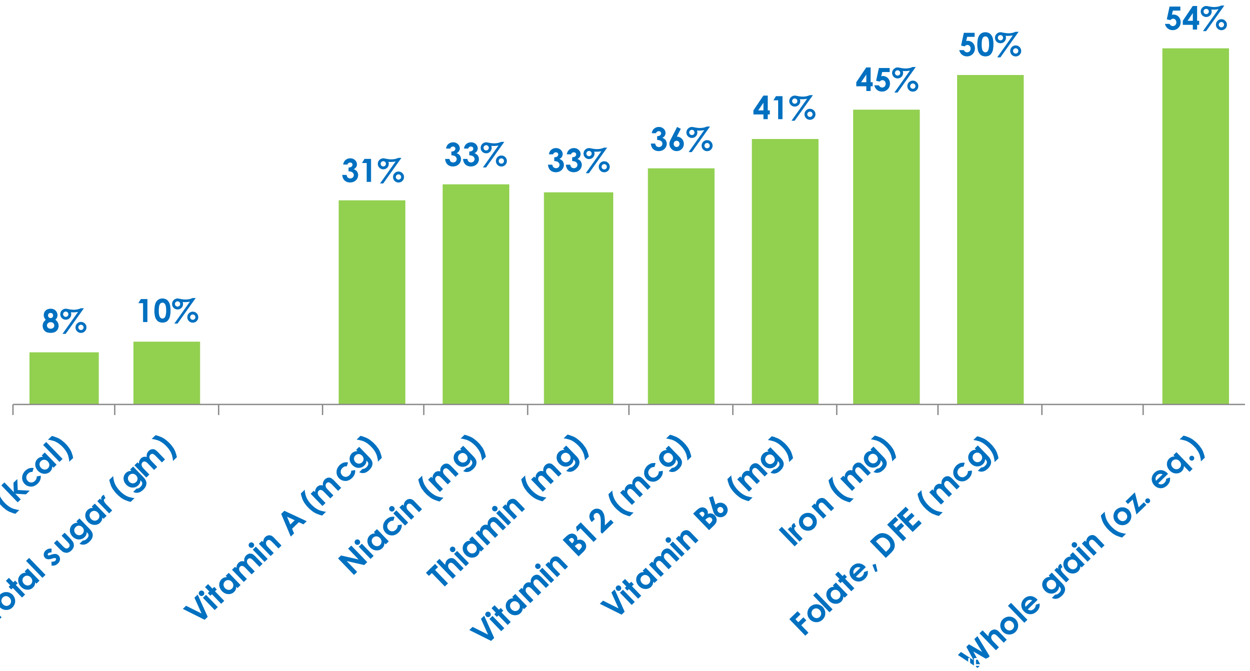


NHANES 2007-2012, ages 4-12yrs, PIR<185

From fortification to biofortification: Moroccan oat

Avena Magna: an ancient varietu of oat found in Morocco

Traditional plant breeding program to successfully domesticate the variety and preserve the nutrition attributes

↑ *2 protein content 28 to 40%

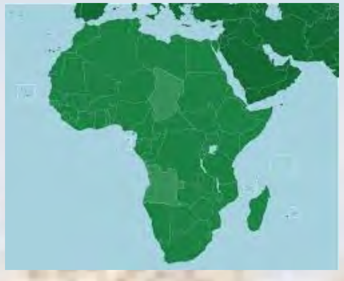
↑ Minerals & vitamins

Nutrient Density

↑ processing characteristics

↑ Agronomic Attributes

Pilots in Morocco, Ethiopia, Nigeria & Malawi



other Possible applications

Biofortification
Consideration for use in processed foods

- ✓ Nutrient concentration (higher level of priority nutrients but limited number of nutrients)
- ✓ Nutrient bioavailability (the matrix has an effect)
- ✓ Consumer acceptability (traditional breeding versus GMO)
- ✓ Impact on processing, texture etc…
- ✓ Cost

Addressing Product Reformulation through Crops Diversification:-

Emerging Nutritious Crops and Their Contribution to Future Agriculture

Dr Sean Mayes: Crops For the Future Research Centre, Malaysia
University of Nottingham, UK

Major crops have helped to secure food supplies and will continue to play a major part in any future solutions to food security

KWS wheat trials, Thriplow, UK.

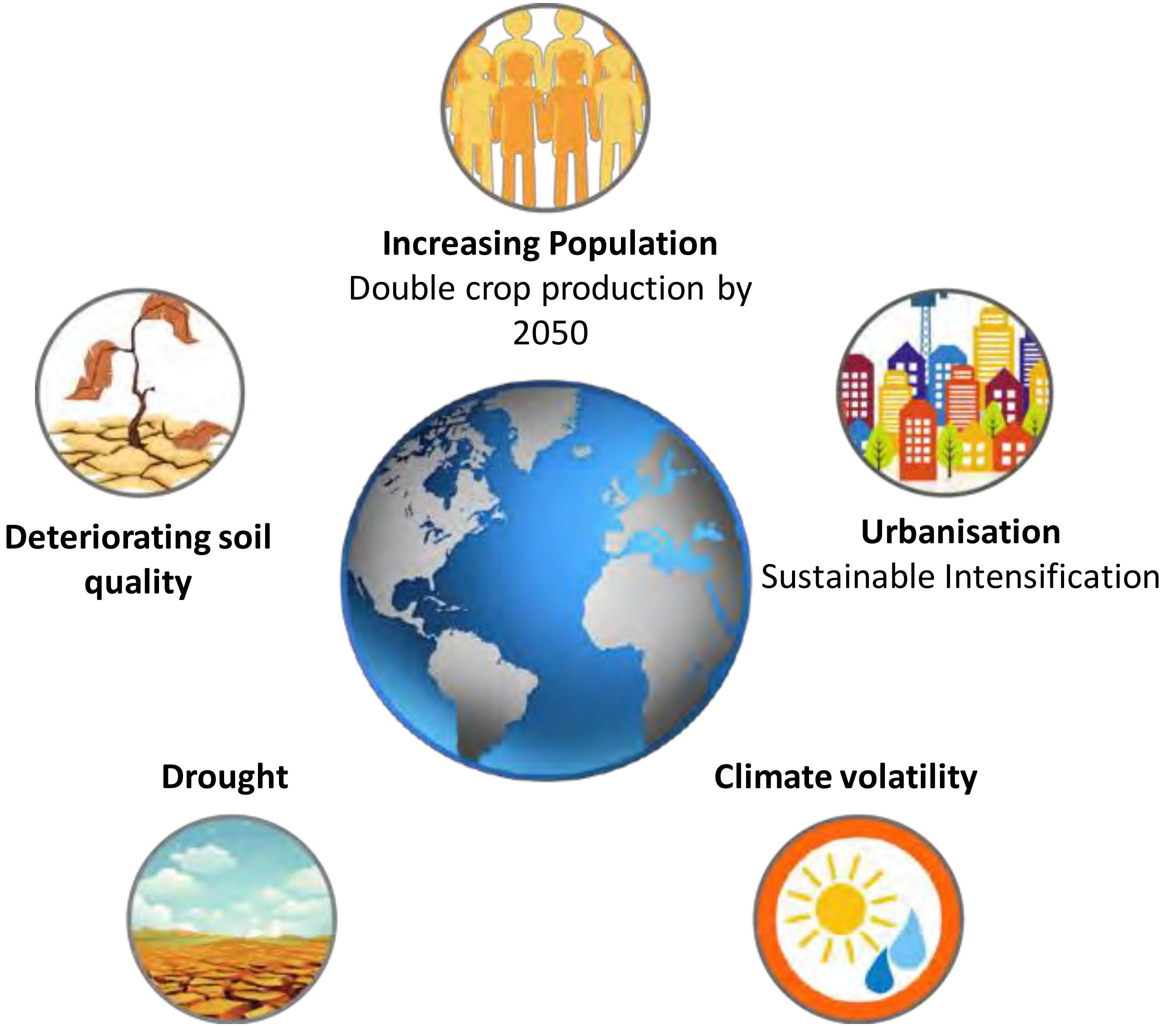
However, a major adjustment is needed to reduce the intensity of inputs in the face of climate change and improve resource use efficiency , with a focus on introduction of genes from relatives, ancestors and alien species

'Four crops to feed the world ?'

- We depend on a few crops to feed over 7 billion people

Global Challenges for Agriculture : *Food Security*

Develop or identify new varieties with improved stress tolerance and yield stability



Increasing CO_2 challenges human nutrition

Largest dataset from free-air CO_2 enrichment [FACE] experiments find that ***C_3* *crops have reduced zinc and iron levels under CO_2 levels for middle of this century***.

Myers et.al., Nature, **510**,139–142 (05 June 2014)doi:10.1038/nature13179

Bambara groundnut;
International Institute for Tropical Agriculture (IITA), Nigeria; Green World Genetics Seed; Capstone Seed

Amaranth;
World Vegetable Centre (AVRDC), Taiwan, Tanzania; East West Seed

Proso millet;
Sri Lanka, Cambridge and Nottingham University

CFF-UNMC-UoN Centre for Future Food

Understanding the mechanisms of stress resistance in underutilised crops to build future crop resilience

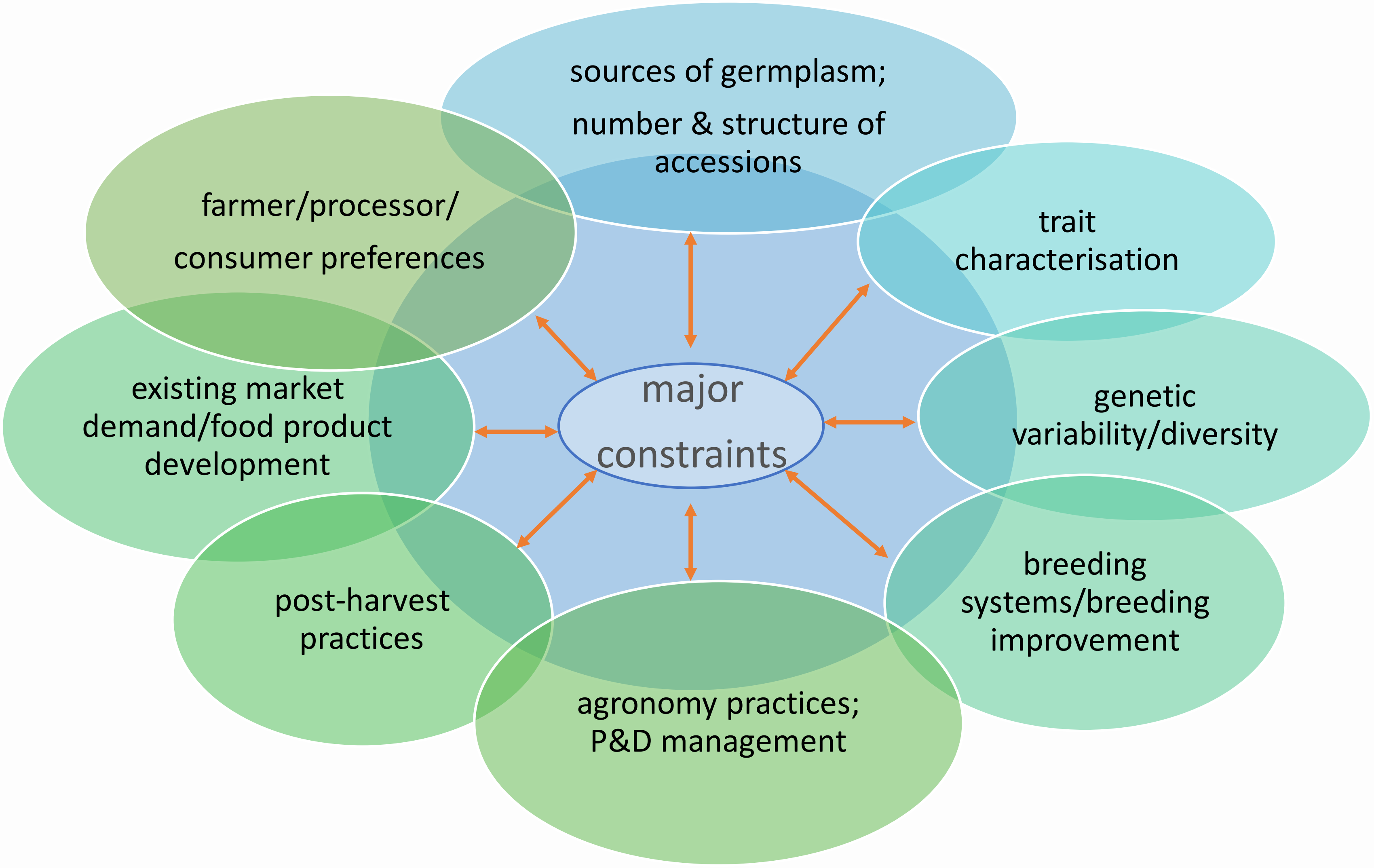
Addressing both transient and prolonged stresses

Winged bean;
East West Seeds, IITA

Foxtail millet;
McDonald Institute, Cambridge University, UK; Shanxi Agricultural University, China

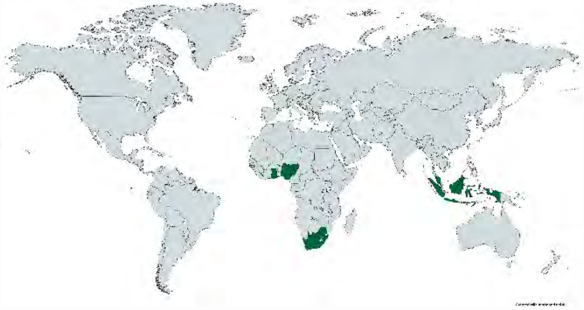
Massawe et al., 2016; Cheng et al., 2015

Some of the constraints in minor/underutilised crops



Research Value Chain approach

Germplasm development/ screening; trait of preferences



Multi-locational testing
- trait evaluation
- molecular characterisation

Gap identification
- Farmer/consumer/ processor input
- Socio-eco baseline studies
- Impact studies

- Value added product development
- Crop modelling/ prediction

Pre-breeding line development
- selection
- controlled crosses

Adzwala, *et al*., 2016a; Adzwala, *et al*., 2016b; Aliyu *et al*., 2015 & 2016; Feldman *et al*., (in press); Olayide *et al*., 2018; Halimi *et al*. (in press)

bambara groundnut (*Vigna subterranea*) – our exemplar ($2n = 2x = 22$)

Strengths:
- Drought tolerance
- Grows in semi-arid & tropical environments, marginal soil
- Nitrogen fixing
- Fast growing (4-5 months)
- 3rd most important nutrient legume in sub-Saharan Africa

Drawbacks
- Photoperiod sensitive
- Variability within landraces
- Lack of commercial varieties
- Limited markets & value added products
- P&D management

Opportunities
- Food security (alternative plant-based protein source)
- Income generation
- Product development
- Human dietary diversification
- Animal feed

Winged/goa bean (*Psophocarpus tetragonolobus*) (2*n* = 2*x* = 18)

CFF Crops For the Future

University of Nottingham UK | CHINA | MALAYSIA

Strengths:

- annual or perennial vine
- grows in hot humid tropics
- nitrogen fixing
- "*supermarket on a stalk*"*- pulse, vegetable (leaves, pods), root/tuber
- leaf & pod: rich source of vitamins, minerals, fiber
- seed "*soybean of the tropics*"** & tuber: high in protein, carbohydrate

Drawbacks

- indeterminate growth habit
- anti-nutritional factor
- photoperiod sensitive
- variability within landraces
  limited value added products
- P&D management

Opportunities

- food and nutritional security (alternative plant-based protein source)
- income generation
- product development
- human dietary diversification
- animal feed

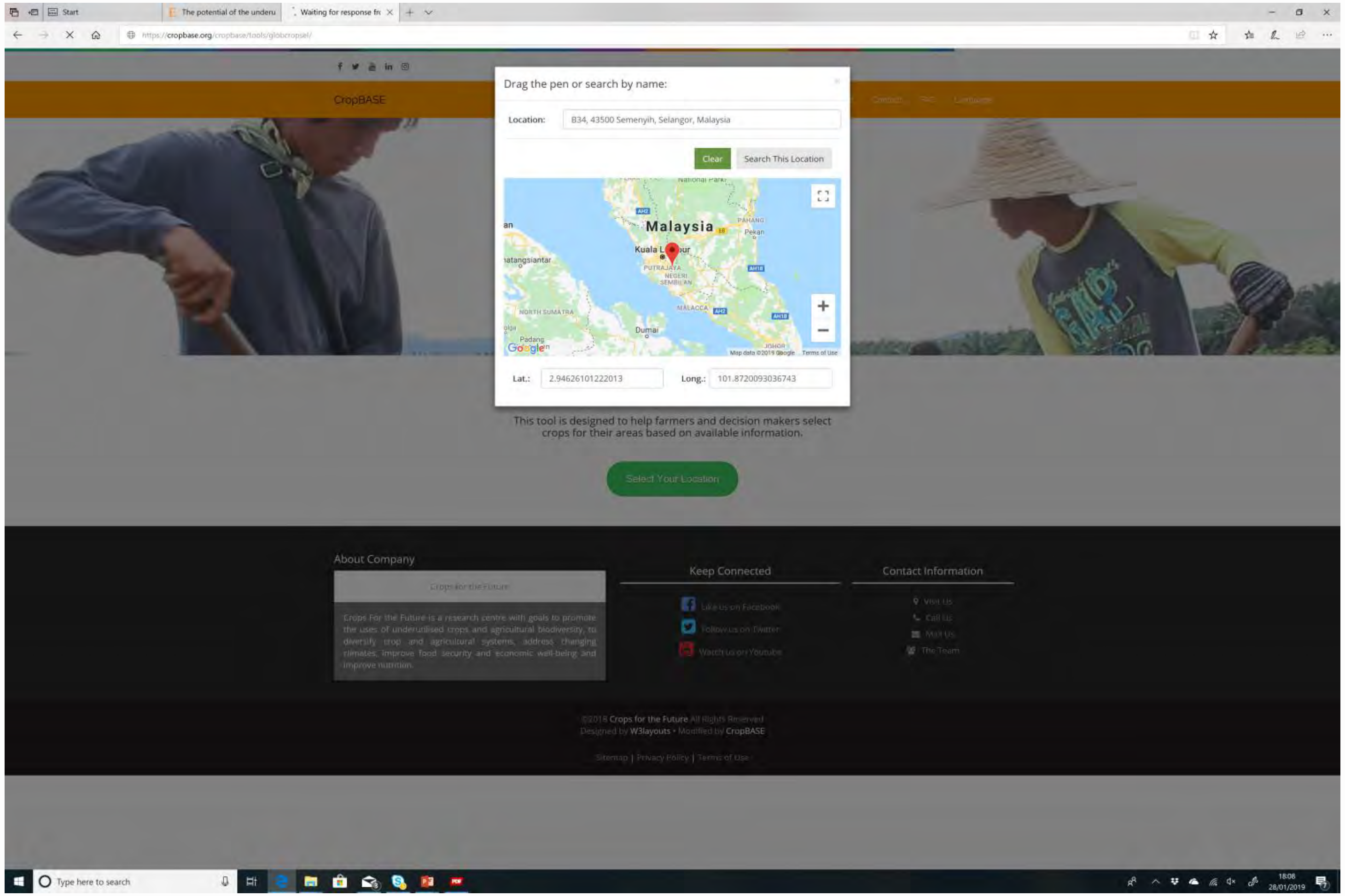
Tanzi *et al.*, manuscript in press

Amaranthus L.
- *A. tricolor* ($2n = 2x = 32$)

Strengths:
- C4 crop
- drought, heat & salinity tolerance, high water use efficiency
- grows in semi-arid & tropical regions
- mainly as leafy vegetables in SEA
- high in vitamins and minerals

Drawbacks
- photoperiod sensitive
- contain anti-nutrients: nitrate (mostly in stems) and oxalate
- limited value added products
- agronomy management

Opportunities
- Nutrition security
- Income generation
- Product development
- Human dietary diversification
- Animal feed

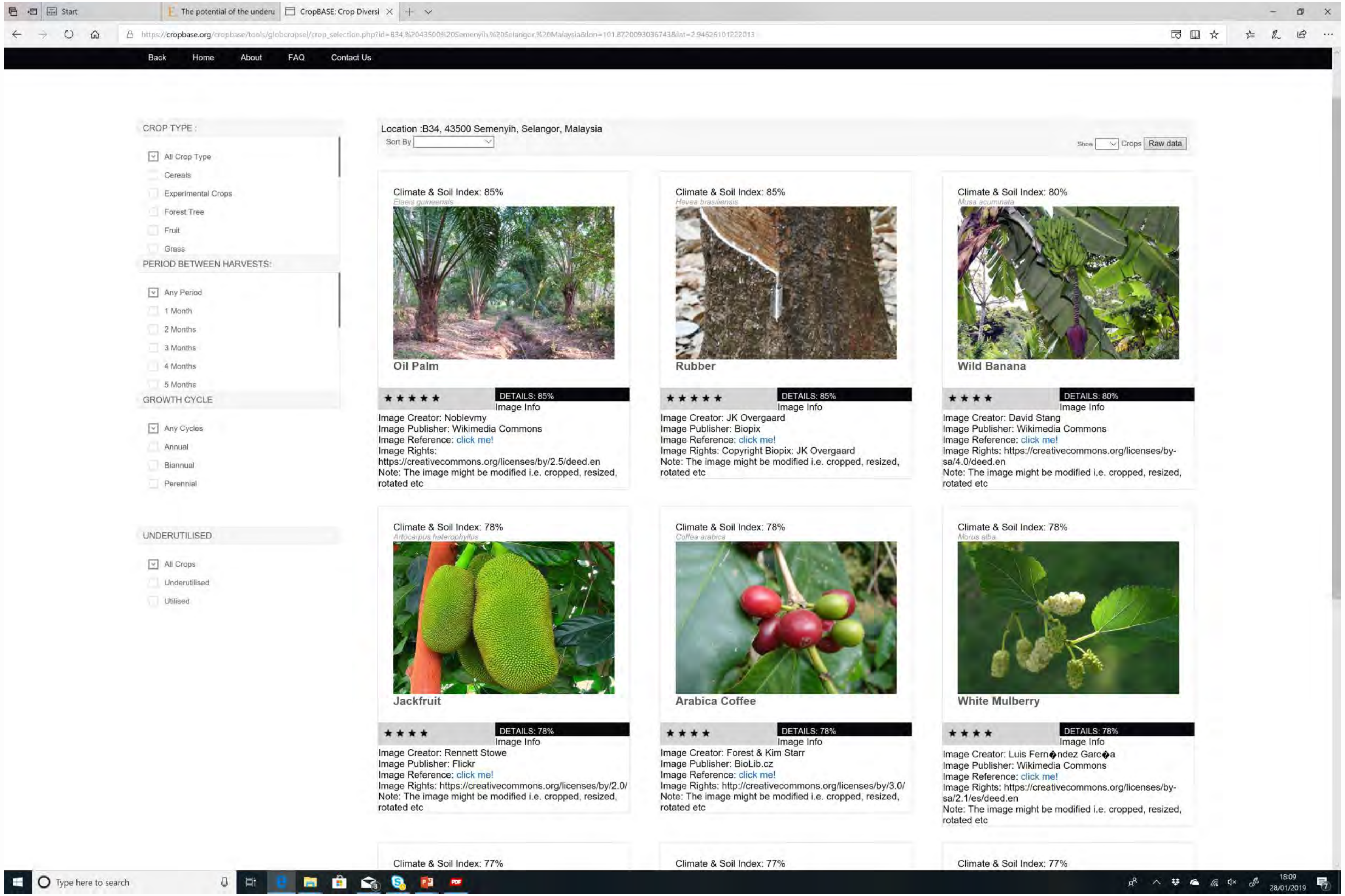


Predictive mapping: 'SelectCrop'

Allows the user to enter a location and returns crops which may grow based on climate, soils and other factors…

While at an early stage, this approach could be used to generate a crude list of options for 'new' crops.

https://cropbase.org/cropbase/tools/globcropsel/



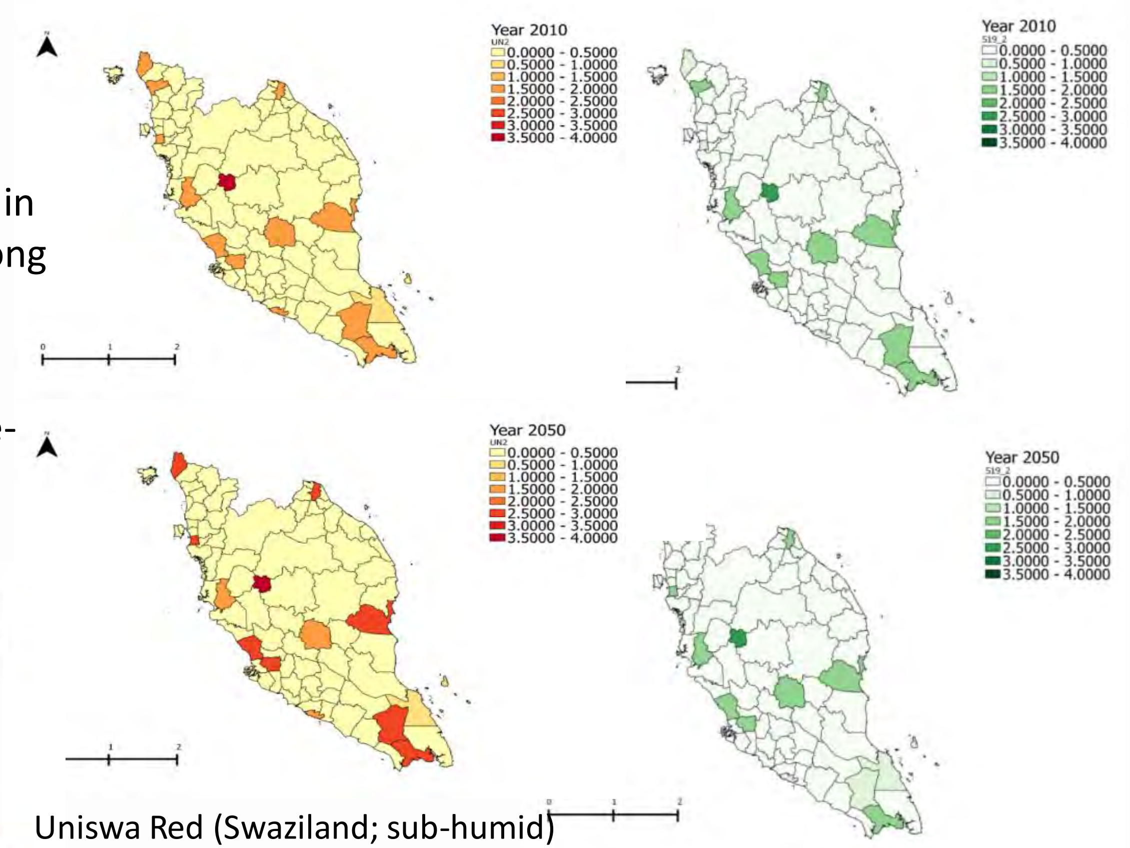
CFF
Crops For the Future

The underlying data is from the literature, but the aim is to validate this through experiments and user feedback, improving the accuracy

The underutilised crop data is an average of reports for a species.

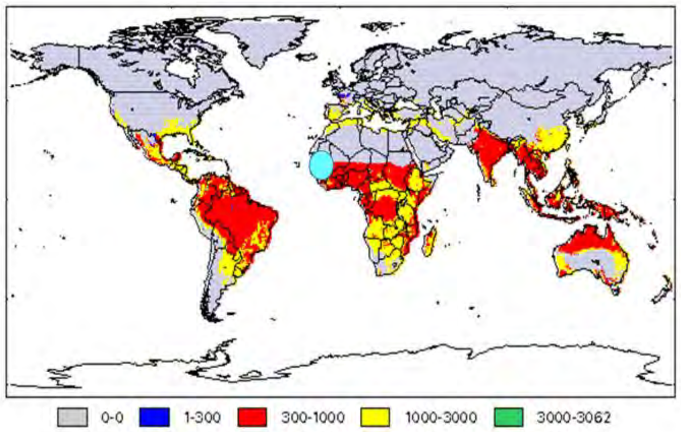
Climate and growth modelling prediction – Bambara groundnut

- Provide baseline data for future field experiments for proof of concept
- Suitability mapping and prediction of which crops could be grown now in a particular location or could be grown in the future, under Climate Change, along with potential products and markets
- Development of geospatial, genotype-anchored databases for selection potential germplasm



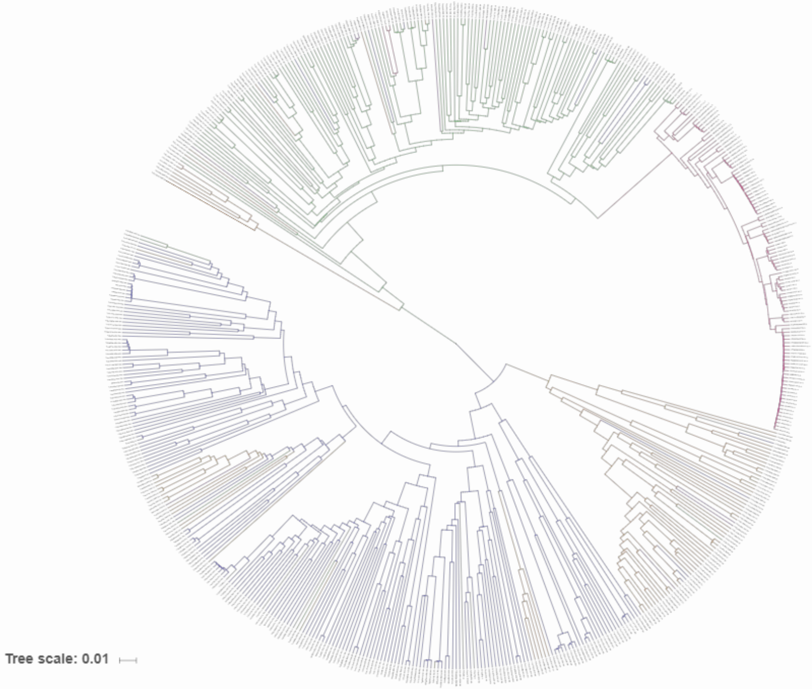
Uniswa Red (Swaziland; sub-humid)

S19-3 (Namibia; arid)



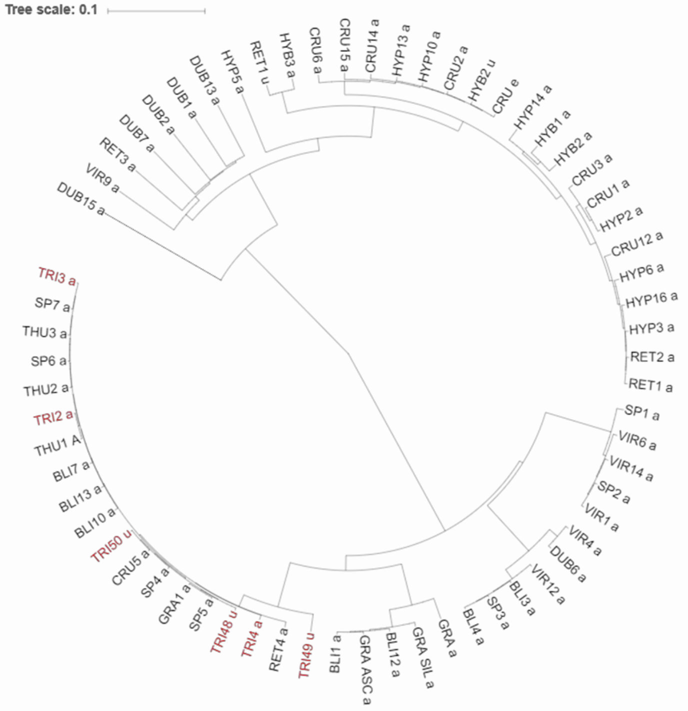
Santos et al., 2016; Leibovici et al., 2017; CropBASE

Collecting germplasm from underutilised crops to select and begin breeding



Bambara groundnut

Winged Bean



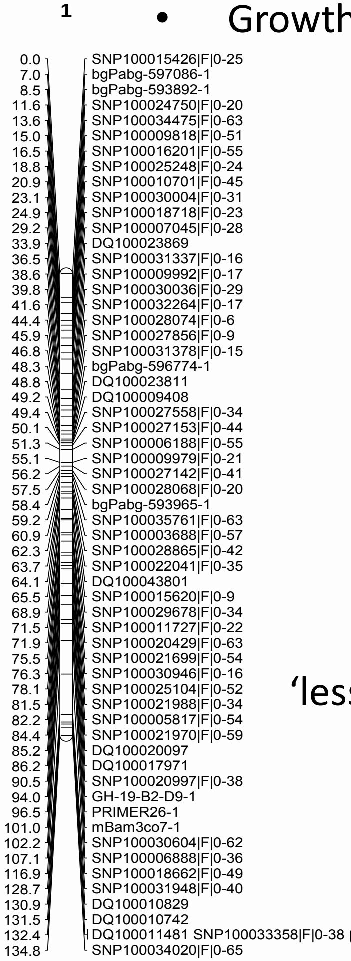
Amaranth

University of Nottingham UK | CHINA | MALAYSIA
CFF Crops For the Future

Crossing programme and marker assisted breeding

3 populations with genetic maps so far (6 crosses at F_2 and above), segregating for different traits

- Photoperiod sensitivity
- Growth habit (domesticated x domesticated)
- Growth habit (domesticated x wild)



DipC (domesticated)
'bunched'
'less-sensitive to photoperiod'

Ankpa4 (domesticated)
'sensitive to photoperiod'

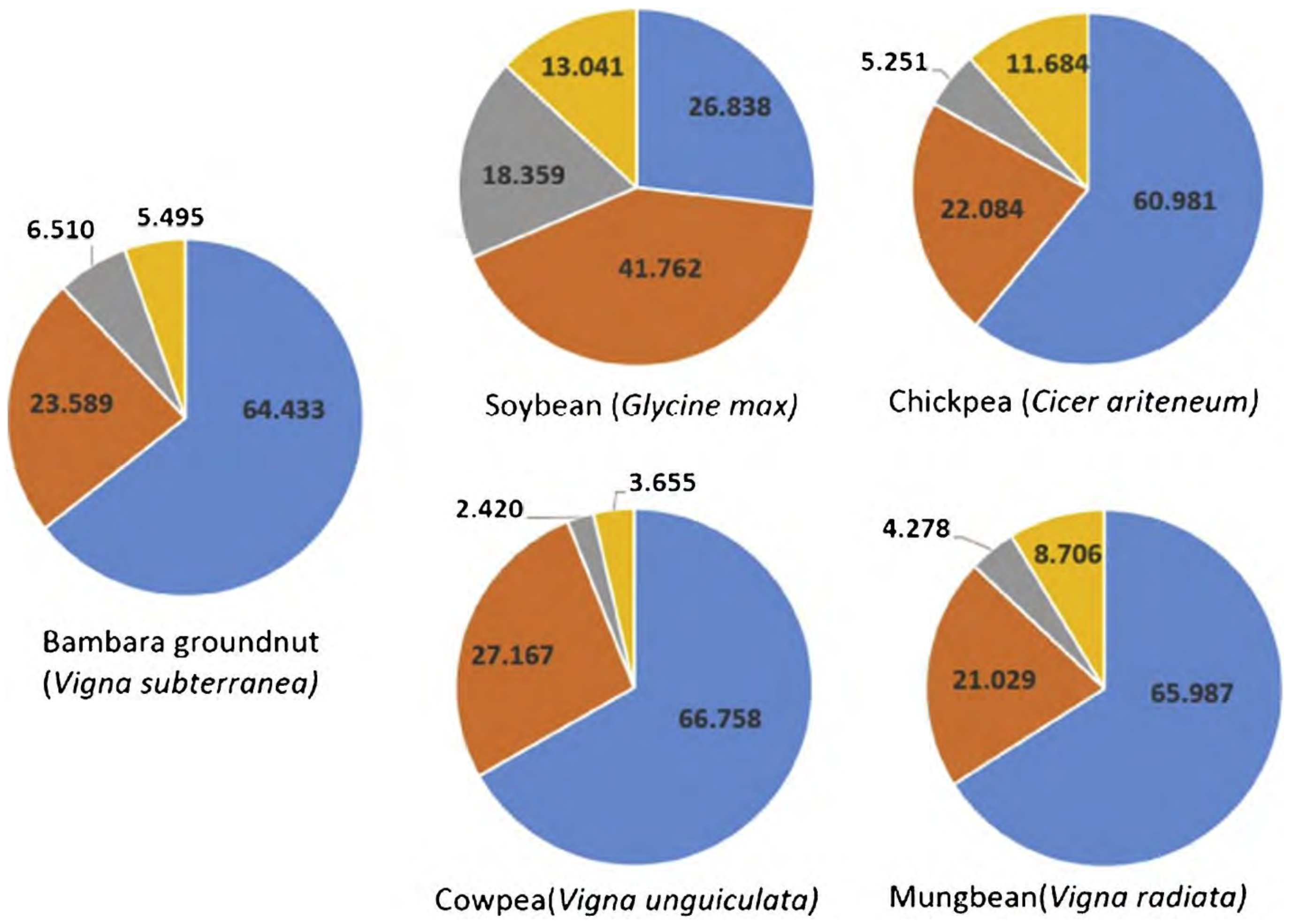
Tiga Necaru (domesticated)
'semi-spreading'

VSSP11 (wild)
'spreading' ancestor

Composite linkage groups consisting of DArT, SSR and DArTseq markers

Ahmad et al., 2016; Ho et al., 2017; Chai et al., 2017

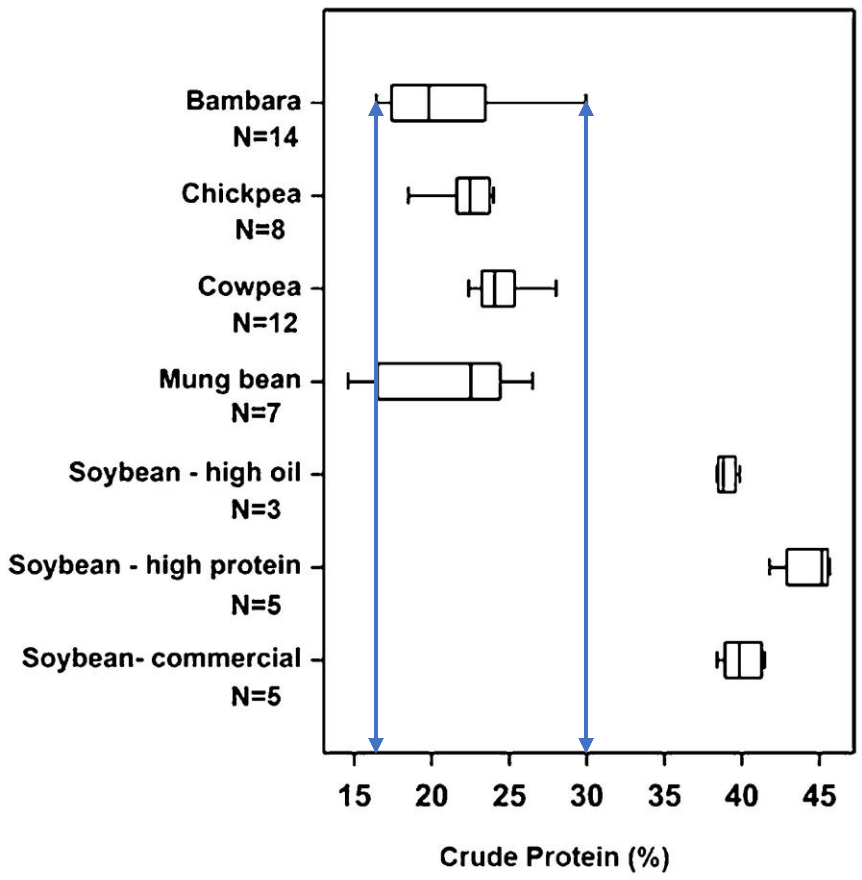
Composition and Functional Properties: An example from legumes



Blue - carbohydrate, orange - protein, grey - total fat, yellow - total dietary fibre

Razlin Azman Halimi et al. (2019) The potential of the underutilized pulse bambara groundnut (*Vigna subterranea* (L.) Verdc.) for nutritional food security Journal of Food Composition and Analysis 77: 47-59

Reported Protein Ranges for different species and amino acid composition



	Bambara groundnut[1]	Cowpea[2]	Chickpea[3]	Wheat[4]	Rice[4]
Histidine	0.59 – 4.09	2.58 – 3.92	2.73 – 3.23	1.80 – 2.00	2.20 – 2.50
Leucine	1.33–10.22	4.37 – 10.61	2.46 – 8.73	6.30 – 6.80	8.10 – 8.60
Lysine	0.99 – 8.54	5.40 – 7.54	6.63 – 7.23	1.80 – 2.30	3.30 – 4.10
Threonine	0.61– 5.22	3.01 – 5.05	2.65 – 4.08	2.40 – 3.20	3.70 – 4.10
Tryptophan	0.12 – 0.60	0.68 – 1.36	0.69 – 1.14	0.70 – 2.40	0.80 – 1.40
Valine	0.71– 6.47	4.16 – 5.06	3.16 – 4.66	3.60 – 4.90	5.80 – 6.70
Arginine	1.20 – 8.25	4.48 – 8.52	8.09– 8.95	2.80	6.40
Methionine	0.30 – 6.41	1.20 – 2.24	0.76 – 1.44	1.20 – 1.40	1.70 – 2.60
Cysteine	0.12 – 2.41	0.47 – 0.53	0.54 – 3.30	1.80	1.60
Aspartic acid	1.94 – 15.12	8.84 – 16.92	10.66 –11.31	4.20	8.80
Glutamic acid	3.21 – 21.38	16.86 – 27.62	14.84 – 17.88	31.10	15.40

Winged Bean genotypic effect – same location proximate analysis

(?; note that these are technical reps, but grown together)

	Protein		Fat		carbo		sat fat	
Genotype 1	29.2		10.6		49.7		4	
	29.1	29.2	10.1	10.6	50.1	49.6	3.6	3.9
	29.2		11		49.1		4.2	
Genotype 2	25.7		10.2		53.6		3.6	
	26.3	25.9	10.6	10.5	52.4	53.1	3.7	3.7
	25.7		10.6		53.4		3.8	
Genotype 3	33.7		9.6		45.9		3.4	
	32.9	33.3	10	9.9	46.7	46.1	3.5	3.5
	33.4		10.1		45.8		3.6	
Genotype 4	28.4		9.6		50.6		3.9	
	27.7	28.0	9.3	9.5	51.6	51.3	3.9	3.9
	28		9.6		51.6		3.8	
Genotype 5	32.1		9.3		48		3.3	
	31.8	32.0	9.5	9.3	47.7	48.0	3.3	3.3
	32		9.2		48.3		3.3	

Soybean typically has protein content of 36% and above

Bambara groundnut - same genotype – two locations in Malaysia

genotype	location	colour	protein
Songkhla1-X	CFF Terengganu	Red	15.8±0.1
Songkhla1-X	CFF FRC	Red	15.9±0.1
IPB Bam6	CFF Terengganu	Black	21.9±0.3
IPB Bam6	CFF FRC	Black	19.9±0.2
CIKUR2.1	CFF Terengganu	Black	19.5±0.1
CIKUR2.1	CFF FRC	Black	21.8±0.5

CropStore Database:

- Works at a ‘single accession’ level
- Can handle any datatype
- Provides links sequence, alignments, cross-species information
- Based on Open Data principles

- Currently being used to compile all Bambara groundnut data and extend to food composition and function data (G. King, SCU Australia)

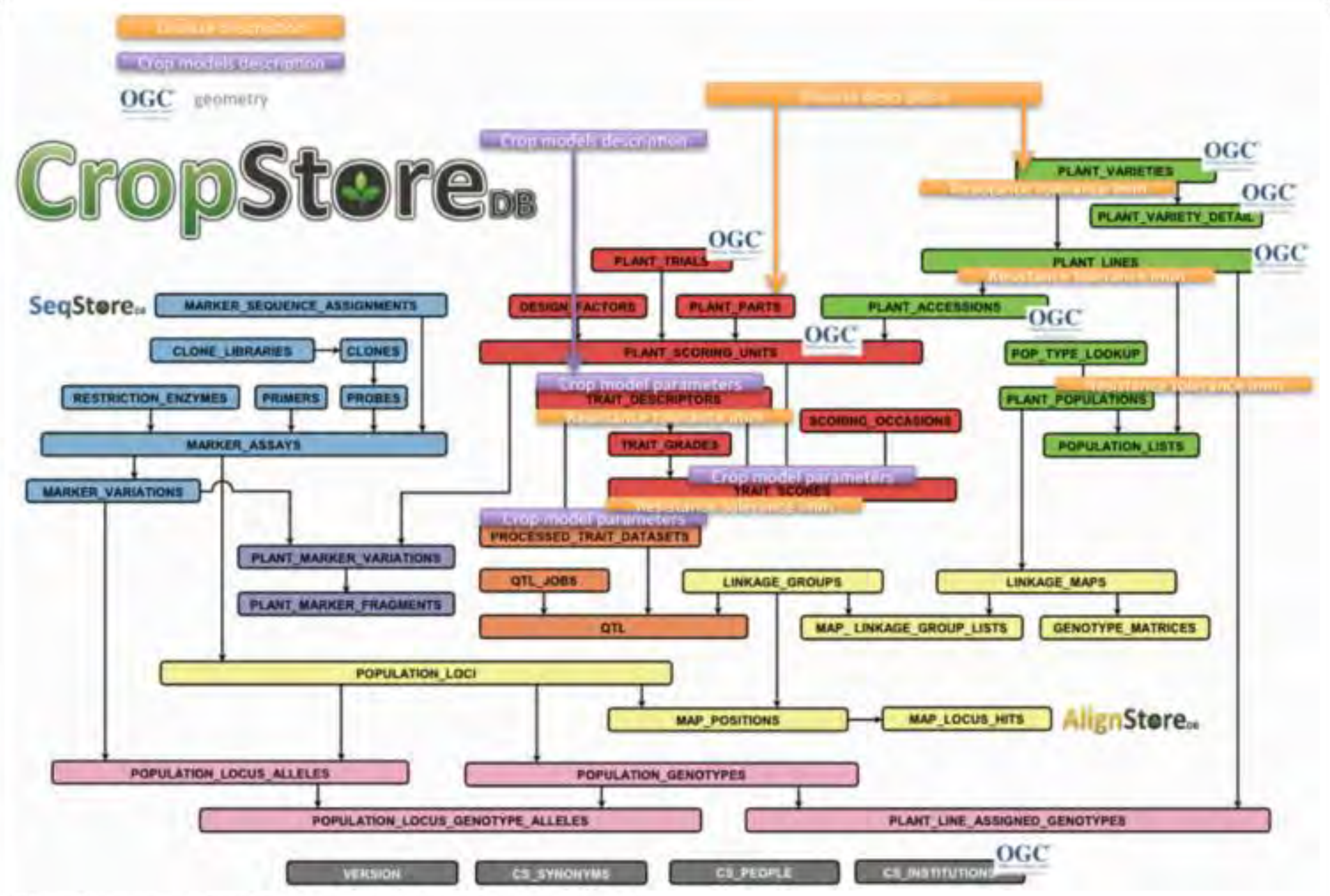


Fig. 3 The GeoGermPlasmDB schema, an evolution from CropstoreDB

Current limitations for substitution in product formulation using underutilised crops

- Current composition tables usually give an 'average' value or only single values per species/product, not the observed range

- Methodologies are variable and not always equivalent

- Descriptions often do not allow clear comparisons to be made

- The biggest problem is often that the data simply does not exist

- Developing a standard approach to composition and range for underutilised species would allow nutritionist and manufacturers to substitute components in in finished products, without effecting consumer acceptance

- Such substitutions could also increase nutrients levels or functional components

Future work

Crops For the Future

- improve draft genome with Nanopore
- to complete 100 accession x10 coverage
- to complete comparative analysis in 5 countries
- genome enabled breeding programme

- initial GWAS on drought stress
- whole genome sequence
- controlled crossing
- selection in Tanzania

Amaranth;
World Vegetable Centre (AVRDC), Taiwan, Tanzania; East West Seed

Bambara groundnut;
International Institute for Tropical Agriculture (IITA), Nigeria; Green World Genetics Seed; Capstone Seed

- to complete initial Sri Lankan diversity analysis from farmer collection
- to compared with world collections

Proso millet;
International Crops Research Institue for the Semi-Arid Tropics, Indian; Sri Lanka

Foxtail millet;
McDonald Institute, Cambridge University, UK; Shanxi Agricultural University, China

CFF
Crops For the Future
The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

CFF-UNMC Centre for Water/Heat Stress Research

Understanding the mechanisms of stress resistance in underutilised crops to build future crop resilience

Addressing both transient and prolonged stresses

Winged bean;
East West Seeds

- to complete whole genome sequence
- genotype second cross GBS
- add a further 188 to diversity analysis
- compositional analysis
- genome-enabled breeding programme

- 300 lines grown out, to genotype
- pilot work on assessment
- screening for drought, salinity and root traits

Thanks for listening!

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Genetic diversity analysis:
Niraj Shah, UoN
Rachael Symonds, Liverpool John Moore's University
Wai Kuan Ho, CFF & UNM
Rajneesh Paliwal, IITA, Nigeria

Genetic mapping & QTL
Rakhi Basu, UoN
Nariman Ahmad, UoN
Hui Hui Chai, CFF
Neil Graham, UoN
Alberto Stefano Tanzi, CFF & UNM

CropStore Database
Prof Graham King
Liliana Andres Hernandez

Sequence analysis:
Martin Blythe, DeepSeq, UoN
Joanna Moreton, ADAC, UoN
Wai Kuan Ho, CFF & UNM

Genome sequence:
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Bo Song, Beijing Genome Institute
Xin Liu, Beijing Genome Institute
Prasad Hendre, AOCC
Wai Kuan Ho, CFF & UNM
Fei Sang, DeepSeq, UoN

Single Genotype Lines:
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Katie Mayes, UoN
Luis Salazar Licea, UoN
Alberto Stefano Tanzi, CFF & UNM
Norain Jamalluddin, UNM
Zahrulakmal, CFF
Ben Faloye, IITA, Nigeria
Michael Abberton, IITA, Nigeria

DArTseq development:
Andrzej Kilian, DArT Pty Ltd., Australia

Our publications

Crops For the Future

Abberton, M., et al., (2015) Global agricultural intensification during climate change: a role for genomics. ***The Plant Biotechnology Journal*** DOI: 10.1111/pbi.12467
Adzawla, W., Donkoh. S. A., Nyarko, G., O'Reilly, P.J., Olayide, O, E., Awai, P. E. (2015) Technical efficiency of bambara groundnut production in northern Ghana. ***UDS International Journal of Development*** 2(2) 37-49.
Adzawla, W., Donkoh. S. A., Nyarko, G., O'Reilly, P.J., Olawale, O.E., Mayes, S., Aryo. F., and Azman, H.A. (2016a) Adoption of Bambara groundnut production and its effects on farmers' welfare in Northern Ghana. ***African Journal of Agricultural Research*** 11(7) 583-594
Adzawla, W., Donkoh, S.A., Nyarko, G., O'Reilly, P., Olayide, O.E and Awai, P.E (2016b) Use patterns and perceptions about the attributes of Bambara groundnut (*Vigna subterranea* (L.) Verdc.) in Northern Ghana. ***Ghana Journal of Science and Technology Development***
Ahmad, N.S., Sri Redjeki, E., Ho, W.K., Aliyu, S., Mayes, K., Massawe, F., Kilian, A. and Mayes, S. (2016) Construction of a genetic linkage map and QTL analysis in bambara groundnut. **Genome** 59(7): 459-472, 10.1139/gen-2015-0153
Aliyu,S., Massawe, F. and Mayes, S. (2016) Genetic diversity and population structure of Bambara groundnut (*Vigna subterranea* (L.) Verdc.): synopsis of the past two decades of analysis and implications for crop improvement programmes ***Genetic Resources and Crop Evolution*** 1-19
Aliyu, S, Massawe, F.J. and Mayes, S. (2015) Beyond landraces: Developing improved germplasm resources for underutilized species - a case for Bambara groundnut ***Biotechnology and Genetic Engineering Reviews***; 30:127-41
Bonthala, V.S., Mayes, K., Moreton, J., Blythe, M., Wright, V., May, S., Massawe, F., Mayes, S. and Twycross, J. (2016) Identification of gene modules associated with low temperatures response in bambara groundnut by network-based analysis. ***PLoS One*** 11(2): e0148771. doi:10.1371/journal.pone.0148771
Burgess, A.J., Retkute, R., Pound, M.P., Mayes, S. and Murchie, E.H. (2017) Image based 3D canopy reconstruction to determine potential productivity in complex multi-species crop systems. ***Annals of Botany*** mcw242. doi: 10.1093/aob/mcw242
Chang Y, Liu H, Liu M, Liao X, Sahu SK, Fu Y, Song B, Kariba R, Muthemba S, Hendre PS, Mayes S, Ho WK, Kendabie P, Wang S, Li L, Muchugi A, Jamnadass R, Lu H, Peng S, van Deynze A, Simons A, Yana-Shapiro H, Xu H, Yang H, Wang J, Liu X (2018). The draft genome of five unimproved tropical plants GigaScience; DOI: 10.1093/gigascience/giy152
Chai, H.H., Massawe, F.J. and Mayes, S. (2015) Effects of mild drought stress on the morpho-physiological characteristics of a Bambara groundnut segregating population. ***Euphytica*** DOI 10.1007/s10681-015-1581-2
Chai, H.H., Ho, W.K., Graham, N., May, S., Massawe, F. and Mayes, S. (2017) A cross-species GEM-based genetic map and QTL analysis in bambara groundnut. ***Genes***
Cheng, A., Mayes, S., Dalle, G., Demissew, S. and Massawe, F.J. (2015) Diversifying crops for food and nutrition security – a case of teff ***Biological Reviews*** doi: 10.1111/brv.12225

Feldman A, Ho WK, Massawe F, Mayes S (in press) Bambara groundnut: how could a drought-tolerant and nutritious legume improve community resilience in the face of climate change? : Atanu Sarkar et al. (Eds): **Sustainable Solutions for Food Security**, 978-3-319-77877-8.

Gregory P, Mayes S, Chai HH, Jahanshiri E, Julkifle A, Kuppusamy G, Ho WK, Tan XL, Massawe F, Suhairi T, Azam-Ali SN. Crops for The Future (CFF): Its Role in Promoting Research and Adoption of Underutilised Crops (submitted)

Halimi RA, Barkla B, Mayes S and King GJ. (in press) The potential of the underutilized pulse bambara groundnut (*Vigna subterranea* (L.) Verdc.) for nutritional food security **Journal of Food Composition and Analysis**.

Ho, W.K., Muchugi, A., Muthemba, S., Kariba, R., Mavenkeni, B.O. Hendre,P., Song, B., Deynze, A.V., Massawe, F. and Mayes, S. (2016) Use of microsatellite markers for the assessment of bambara groundnut breeding system and varietal purity for genome sequencing. ***Genome*** 59(6) 1-5

Ho, W.K., Chai, H.H., Kendabie, P., Ahmad, N.S., Jani, J., Massawe, F., Kilian, A. and Mayes, S. (2017) Integrating genetic maps in bambara groundnut [*Vigna subterranea* (L) Verdc.] and their syntenic relationships among closely related legumes. ***BMC Genomics*** 18:192.

Kendabie, K., Massawe, F. and Mayes, S. (2015) Developing genetic mapping resources from landrace-derived genotypes that differ for photoperiod sensitivity in bambara groundnut (*Vigna subterranea* L.) ***Aspects of Applied Biology*** 124, Breeding Plants to Cope with Future Climate Change pp 49 – 56

Khan, F., Azman, R., Chai, H.H., Mayes, S. and Lu, C. (2016) Genomic and transcriptomic approaches towards the genetic improvement of an underutilised crops: the case of bambara groundnut. ***African Crop Science Journal*** 24, 4, 429 - 458

Khan, F., Chai, H.H., Ajmera, I., Hodgman, C., Mayes, S. and Lu, C. (2017) Transcriptomic comparison of two Bambara groundnut landraces under drought stress. **Genes** , 8(4) :121; doi:10.3390/genes8040121

King G, Barkla B, Mayes S and Azman Halimi R. (in press) The potential of the underutilized pulse bambara groundnut (*Vigna subterranea* (L.) Verdc.) for nutritional food security. ***Journal of Food Composition and Analysis***

Mabhaudhi T, Chimonyo VGP, Hlahla S, Massawe F, Mayes S, Nhamo L and Modi AT. Prospects of orphan crops in climate change (submitted)

Mabhaudhi, T., O' Reilly P., Walker, S. and Mwale S. (2016) Opportunities for underutilised crops in Southern Africa's post-2015. ***Sustainability*** 8(4), 302.

Massawe, F.J, Mayes, S. and Cheng, A. (2016) Crop diversity – an unexploited treasure trove for food and nutrition security ***Trends in Plant Science*** 21(5): 365-368

Mayes S, Ho WK, Chai, HH, Gao X, Kundy AC, Mateva KI, Zahrulakmal M, Hahiree MKIM, Kendabie P, Licea LCS, Massawe F, Mabhaudhi T, Modi A, Berchie JN, Amoah SN, Faloye B, Olaniyi O, Abberton M, Azam-Ali, S. Bambara groundnut – an exemplar underutilised legume for resilience under climate change (submitted)

CFF Crops For the Future

Mayes, S., Ho, W.K., Kendabie, K., Chai, H.H., Aliyu, S., Feldman, A., Halimi, R.A., Massawe, F. and Azam-Ali, S (2015) Applying molecular genetics to underutilised species – problems and opportunities. ***Malaysian Applied Biotechnology*** 44(4); 1-8.

Molosiwa, O., Aliyu, S., Stadler, F., Mayes, K., Massawe, F.J., Kilian, A. and Mayes, S. (2015) SSR marker development, genetic diversity and population structure analysis of Bambara groundnut [*Vigna subterranea* (L.) Verdc.] landraces. ***Genetic Resources and Crop Evolution*** DOI 10.1007/s10722-015-0226-6

Muhammad, Y.Y., Mayes, S. and Massawe, F.J. (2015) Effects of short term water deficit stress on physiological characteristics of bambara groundnut (*Vigna subterranea* L. Verdc). ***South African Journal of Plant and Soil,*** DOI:10.1080/02571862.2015.1056847

Musa, M., Al-Shareef, I., Mayes, S., Massawe, F.J. and Singh, A. (2016) Nitrogen fixation and N-balance studies on Bambara groundnut (*Vigna subterranea* L. Verdc) landraces grown on tropical acidic soils of Malaysia. ***Communications in Soil Science and Plant Analysis*** 47:4, 533-542

Olayide OE, Donkoh SA, Ansah IGK, Adzawla W, O'Reilly PJ, Mayes S, Feldman A, Halimi RA, Nyarko G, Ilori CO, and Alabi T. (2018) Assessing socioeconomic factors influencing production and commercialisation of Bambara groundnut as an indigenous climate resilient crop in Nigeria In: ***Handbook of Climate Change Resilience*** ed W. Leal Filho; Springer Nature; https://doi.org/10.1007/978-3-319-71025-9_158-1

Santos, R., Algar, A., Field, R. and Mayes, S. (2016) Integrating GIScience and Crop Science datasets: a study involving genetic, geographic and environmental data ***PeerJ preprints***; DOI: https://doi.org/10.7287/peerj.preprints.2248v3

Tanzi, AS Eagleton GE, Ho WK, Wong QN, Mayes S and Massawe F. Winged bean (*Psophocarpus tetragonolobus* (L.) DC.) for food security: past research, and future improvement programmes (submitted)

Tanzi AS, Ho WK, Massawe F and Mayes S Development and interaction between plant architecture and yield-related traits in winged bean (*Psophocarpus tetragonolobus* (L.) D.C.) (submitted)

Wong, Q.N., Tanzi, A.S., Ho, W.K., Malla, S., Blythe, M., Karunaratne, A., Massawe, F.J. and Mayes, S. (2017) Development of gene-based SSR markers in winged bean [*Psophocarpus tetragonolobus* (L.) DC.] for diversity assessment. ***Genes*** 8, 100.

Addressing Product Reformulation through Crops Diversification: Processor/Manufacturer Considerations

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Tufts University Friedman School
of Nutrition Science & Policy

Foundation for Food and Agriculture Research

Harvest for Health: Improving Wellbeing Through Resilient Agriculture Convening Event

January 31, 2019

Washington DC

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Disclosures

Current Clients

- Bill & Melinda Gates Foundation
- Bunge
- Care4ward, LLC
- Janji, LLC
- Indigo Agriculture
- Nutrition Impact, LLC
- Pilot Lite Ventures
- Pulse Canada
- Tufts University
- WW (previously Weight Watchers)

Past Clients

- American Egg Board
- Capstone Law
- Dawn Foods
- Good Food Institute
- Q:Quest, LLC
- Sterling Rice Group
- US Dry Pea & Lentil Council / American Pulse Association

Current boards / councils

- Cornell Division of Nutrition Sciences Advisory Council
- Pulse Science Research Cluster Scientific Advisory Board, Canada (co-chair)
- Tufts Nutrition Council
- Tufts Food-Price Policy Advisory Group

Past employers (chronologically)

- University of Toronto
- Kellogg Co.
- Nestlé Canada
- Novartis, SA
- ILSI North America
- Kraft / Mondelez
- PepsiCo

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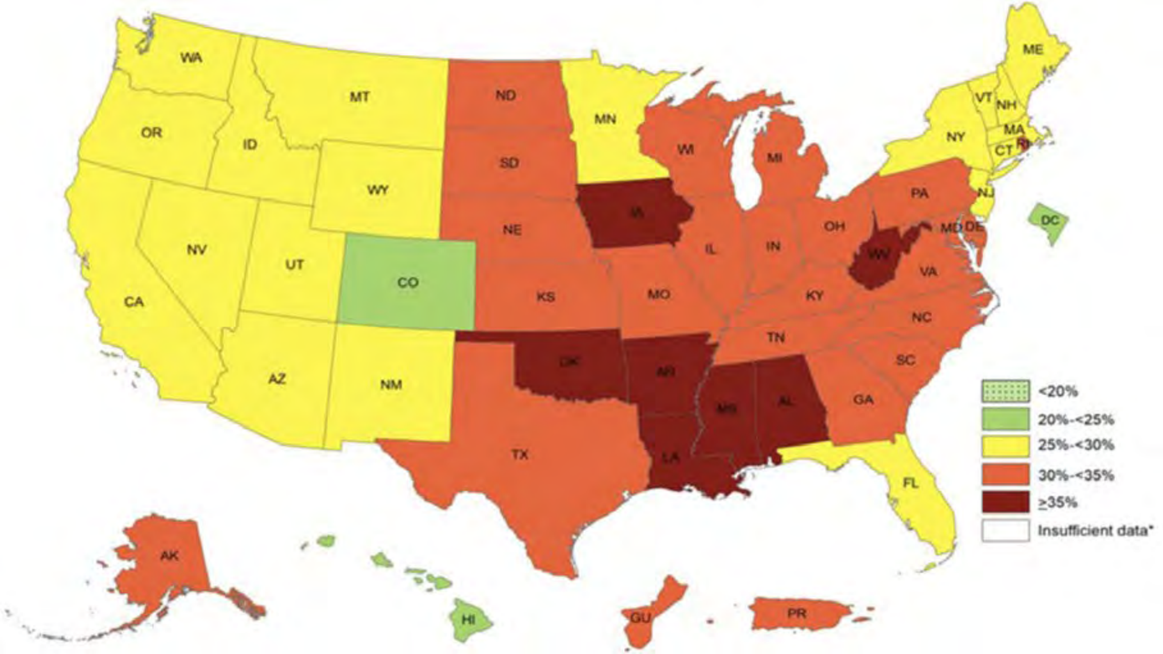
Overview

- Why Bother in the First Place?
- Seeking a Common Framework
  Bran Buds®, Quaker Oats®
- Supply consistency: It's usually more than just one ingredient
- This isn't transactional, it's not just an ingredient

Why Bother in the First Place?



U.S. Obesity Rates Are Continuing to Climb

Source: CDC, 2017

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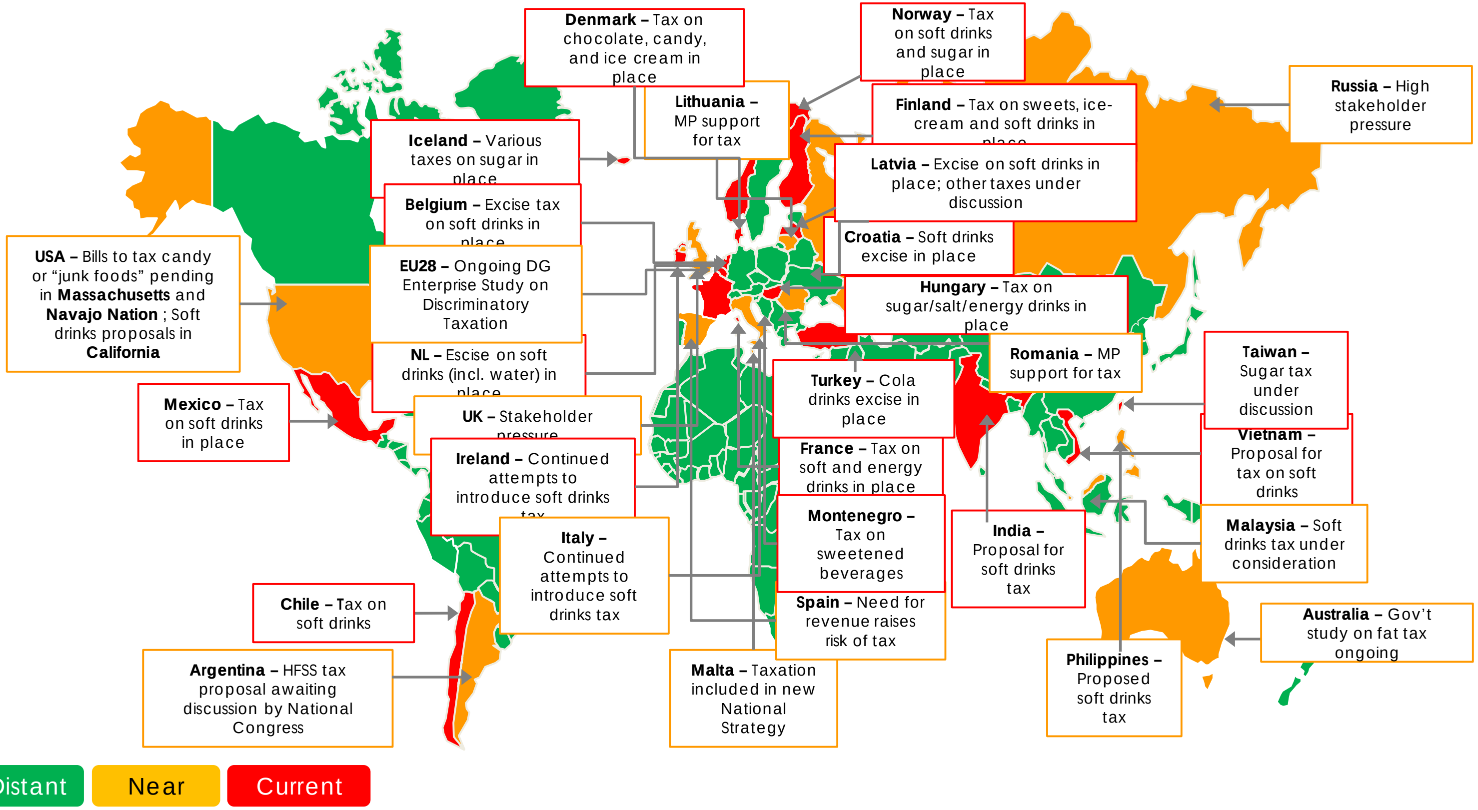
Why Bother in the First Place?



...and so why was taxation a surprise?

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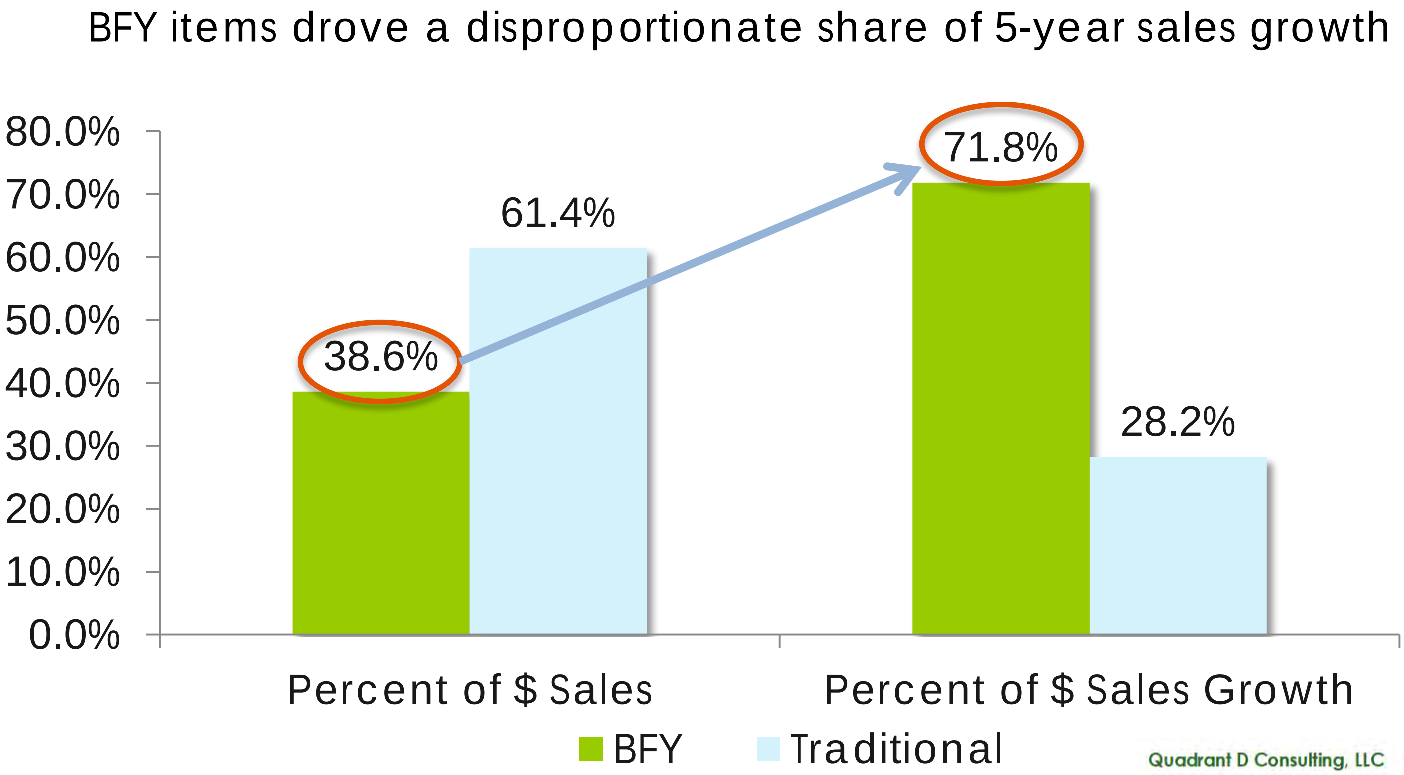
Why Bother in the First Place?



Source: Nielsen Food, Drug and Mass Merchandiser sales tracking (2007-2011)

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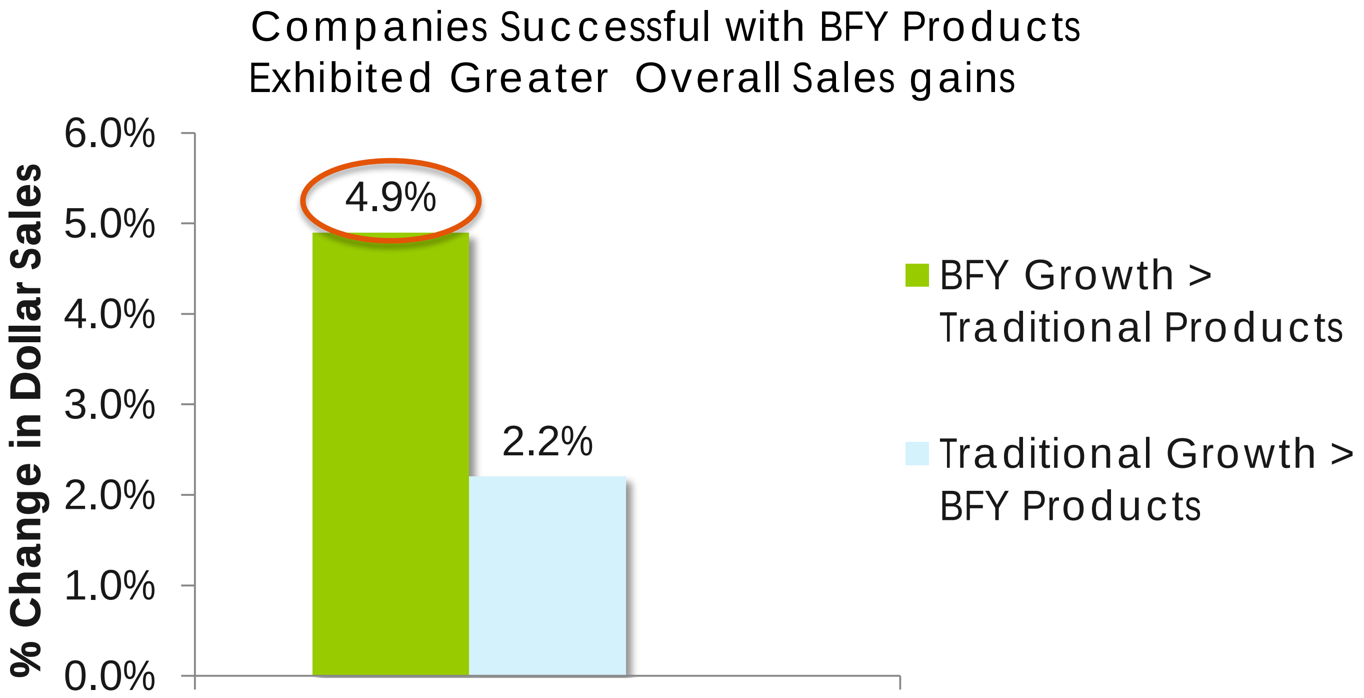
Why Bother in the First Place?



Source: Nielsen Food, Drug and Mass Merchandiser sales tracking (2007-2011)

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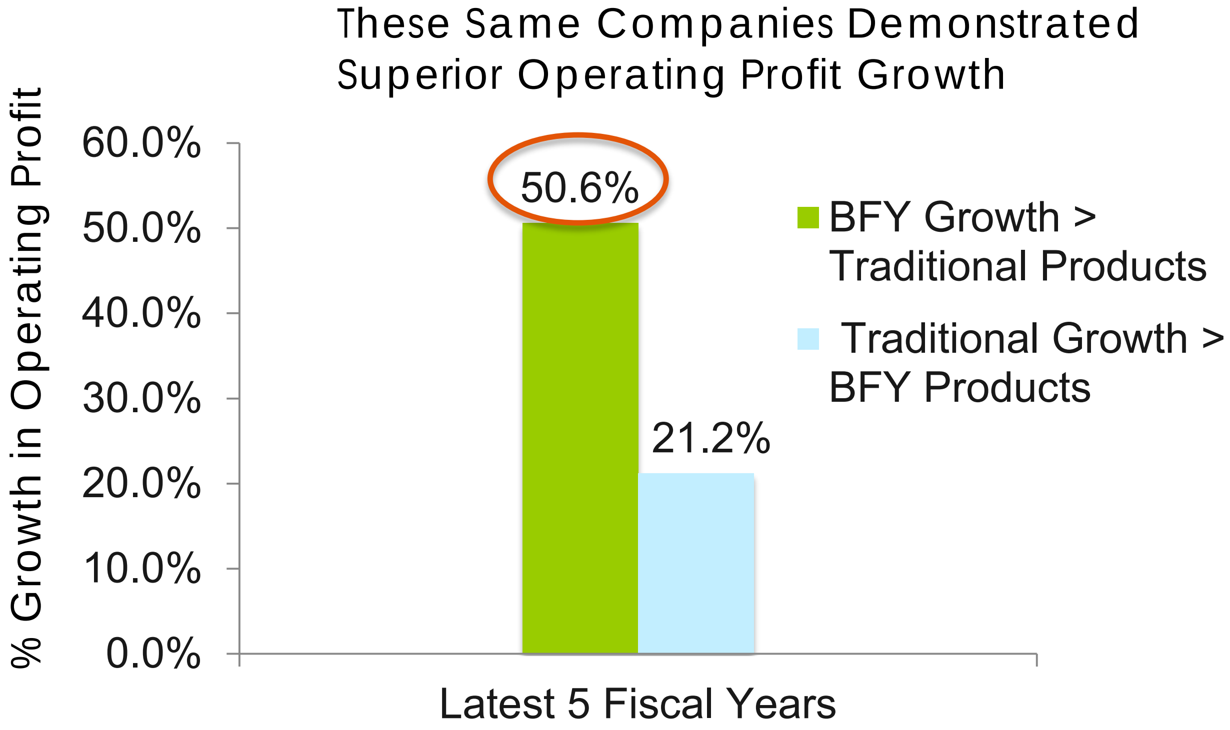
Why Bother in the First Place?



Source: Nielsen Data & Company Annual Reports (2007-2011)

Seeking a common framework: How might the Food Industry look at an ingredient?

natural

Less processed, known provenance, environmentally positive, fewer ingredients, gluten free, vegan, *etc*.

health*ier*

People have finally come to realize that food is the most important thing about health that they control

sensory

Taste is always at the top of the charts, but consumers look for new experiences with their food

functionality

It all counts for naught if we can't make it work as an ingredient

convenience

"On the Go" is more relevant than ever – but it extends into the home now too

Bran Buds® by Kellogg's® - Production Flow

- Studies demonstrated that consumption of psyllium fiber could reduce the risk of heart disease, with the claim:
  "Soluble fiber from foods such as psyllium*, as part of a diet low in saturated fat and cholesterol, may reduce the risk of heart disease. A serving of Kellogg's® Bran Buds® supplies 1.7 g of the 7g soluble fiber from psyllium husk necessary per day to have this effect."
- Kellogg's® was the only ready to eat cereal (RTEC) company to make a psyllium based food…*if only they could make it*.
- Psyllium has a relatively high amount of soluble fiber, which gels when exposed to water/steam; high pressure/high temperature steam is often used to cook grains when making RTEC, which lead to problems of flow with psyllium based RTEC.
- Eventually overcome, it was the processing patents that provided the IP protection for Kellogg's®, though the health benefits sold it.
- So, it is not just the ingredient, but also its flow during production.

* "psyllium" replaces the language in Fed Reg vol 63, no.32, "name of soluble fiber source from paragraph (c)(2)(ii) of this section and, if desired, the name of food product".

Quaker® Oats – Supply Chain Flow

- Quaker® Oats also made a heart disease risk reduction claim, based upon the ß-glucan content of oats.
- Most oats do not have sufficient ß-glucan to deliver the minimum amount required (0.75g) for the claim when considering the instant oatmeal sachet servings (25g compared to a 35g serving size from the bulk container).
- Morrison oats have a higher level of ß-glucan, but lower productivity than other oats – they are better, but more expensive.
- The solution was to blend Morrison oats with the higher productivity, lower ß-glucan content oats, to guarantee content of 0.75g.
- Morrison oats are grown (almost?) exclusively in Manitoba, Canada and depend upon Canada's highly integrated rail system for shipping…which can be impacted by the weather. Which happened in 2013.
- So, it is not just the ingredient, but also its flow through the supply chain.

Seeking a common framework: How might the Food Industry look at an ingredient?

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Supply Consistency: It's Usually More than Just One Ingredient

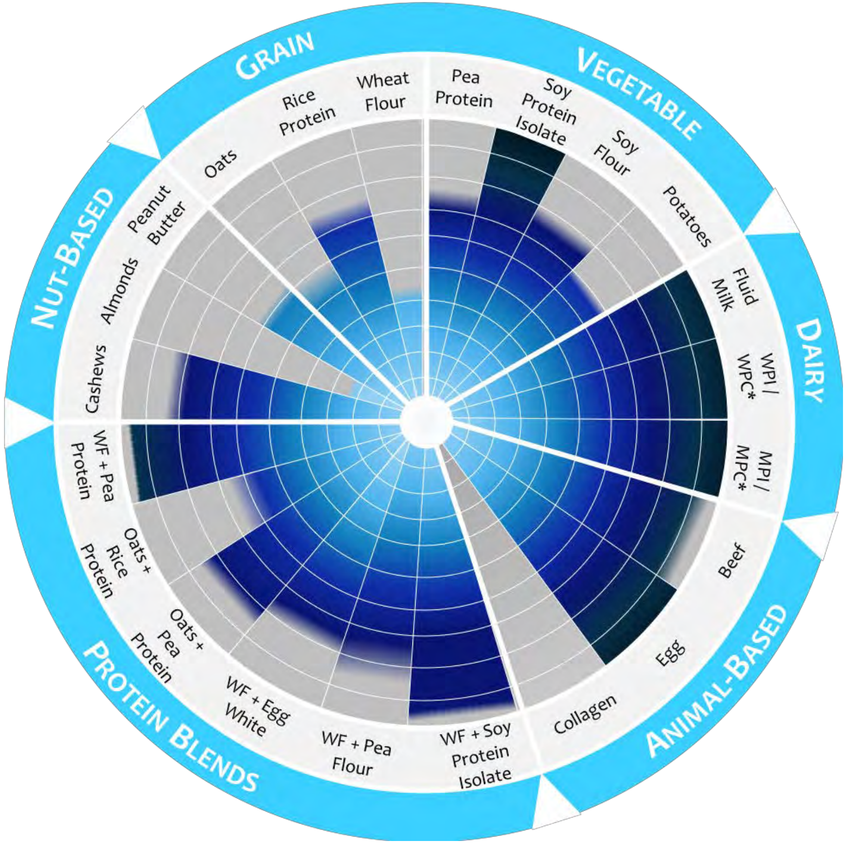
- Wheat varieties are called "soft" or "weak" if gluten content is low, and are called "hard" or "strong" if they have high gluten content.
- Hard flour, or *bread flour*, is high in gluten, with 12% to 14% gluten content, and its dough has elastic toughness that holds its shape well once baked.
- Soft flour is comparatively low in gluten and thus results in a loaf with a finer, crumbly texture. Soft flour is usually divided into cake flour, which is the lowest in gluten, and pastry flour, which has slightly more gluten than cake flour.
- Different flour functionality is achieved through blending of wheats with different "hardness", *e.g.* Hard Red Winter, Soft White Winter.

Wheat Types

(there are many cultivars for each type)

- Durum – Very hard, light-colored; high in protein, specifically, gluten protein.
- Hard Red Spring – Hard, brownish, high-protein wheat used for bread and hard baked goods.
- Hard Red Winter – Hard, brownish, high-protein wheat used for bread, hard baked goods and as an adjunct in other flours to increase protein in pastry flour for pie crusts. Some brands of unbleached all-purpose flours are commonly made from hard red winter wheat alone.
- Soft Red Winter – Soft, low-protein wheat used for cakes, pie crusts, biscuits, and muffins.
- Hard White – Hard, light-colored, opaque, chalky, medium-protein wheat planted in dry, temperate areas. Used for bread and brewing.
- Soft White – Soft, light-colored, very low protein wheat grown in temperate moist areas. Used for pie crusts and pastry.

Supply Consistency – Blends: Function & Content



Doug Bolster

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Seeking a common framework: How might the Food Industry look at an ingredient?

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It all counts for naught if we can't make it work as an ingredient

convenience

"On the Go" is more relevant than ever – but it extends into the home now too

Sometimes, the product is good but the messaging isn't

"Hint of Salt" communication maintains taste appeal

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Supply Consistency - Pulses as a crop example

- When Pulses are a key constituent in a food, the nutrition profile (*i.e.* a short-hand assessment of a food's or beverage's positive/negative contribution to the diet) of that food always improves.
- In an increasing number of countries, the nutrition profile directly impacts the level of taxation, the ability (legal or not) to advertise, and even permissible points of sale.
- Food companies and Beverage Companies are scouring the world for ingredients that are recognizable, believable, and acceptable as healthy – something Pulses might help to deliver.
- The most important challenge will be functionality, that is how do Pulses "behave" as an ingredient?
- Consistent supply (reliability and quality) and cost are important, but will not drive volume unless functionality is solved.

Supply Consistency - Pulses as a crop example

- It is not just about selling the ingredient, but helping others to understand where the opportunities lie.
- The Good Food Institute and the US Dry Pea & Lentil Council / American Pulse Association hosted a workshop on developing plant based meat analogues, with a long term goal of shifting consumption patterns – one example regularly highlighted is the “Impossible Burger”.
- Issues to be considered included:
  - Supply Chain consistency / variability
  - Technical Research Gaps
  - Consumer Research Gaps
  - Benefits innate to Pulses (*e.g.* sustainability, glycemic index, satiety)
  - Processing
- What became clear during the workshop was the opportunity of an Occasion Analogue – instead of Chicken McNuggets you might order Falafel McNuggets.

Supply Consistency - Pulses as a crop example

- Tremendous variety of pulses, often regionally or seasonally unique, with different texture, flavour, colour, and water content (to name just a few considerations), all of which affect the success of your recipe.
- For a typical snack food, production speeds are well in excess of 800 pounds of product per line per hour. A typical demand could be over 3,000 tonnes of pulses per production line, where the input ingredients are incredibly consistent month to month, year to year.
- Assurances are needed vis-à-vis agricultural practices.
- Input costs must be competitive with other commercially grown crops.

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pioneering and collaborative thought leadership in health

This Isn’t Just Transactional (Last Slide)

- I do not mean to imply that this is the only path to growth for new or different ingredients, nor am I implying that this will be easy.
- But consider a simple statistic - more than *one billion* servings of PepsiCo products are consumed every day, around the globe, about two thirds of which are food.
- In a typical potato chip factory, ~5 tonnes of potato chips can be made each week. And there are a number of such factories in the US alone. What if these incorporated some other crop, in addition to potatoes?
- But without consumer pull, there will be little appetite for change in the food industry – you need to think of the industry as a partner, not just a customer.
- Don’t try to sell your ideas to the food industry. Rather, solve their problems with you ideas.

Maintaining Bioactive Components Throughout Processing

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Presented at the Foundation For Food and Agriculture Research Harvest for Health, January 31st, 2019.

Disclosure: Mario Ferruzzi (Past 3 years)

Consulting & Board Responsibilities:

Coca Cola; Sensient Technologies; Welch's Foods

Speaker Honorarium/Travel:

Kellogg's; Tate & Lyle; Unilever

Research funding from Government/Foundations:

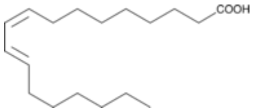
USDA; NIH; USAID; Foundation for Food & Agriculture Research

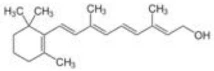
Research funding from Industry:

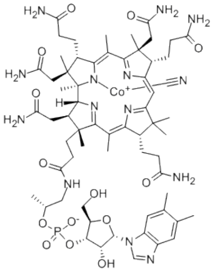
Welch's Foods; Newell Brands

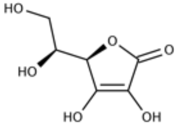
Physiological effects from food are derived from both nutrients and non-nutrients

Usda-ars









Nutrients

Macronutrients
- Protein
- Carbs
- Lipids

Micronutrients
- Vitamins
- Minerals

DRI exist

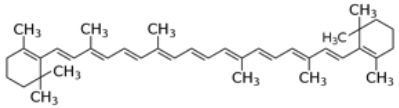
Non-Nutrients

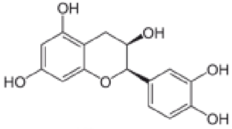
Fiber

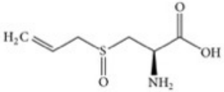
Flavor

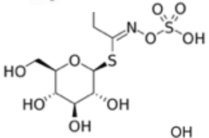
Phytochemicals
- Polyphenols
- Carotenoids
- Isothiocyanates

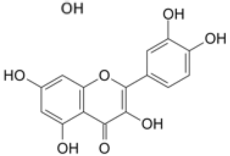
No DRI exist









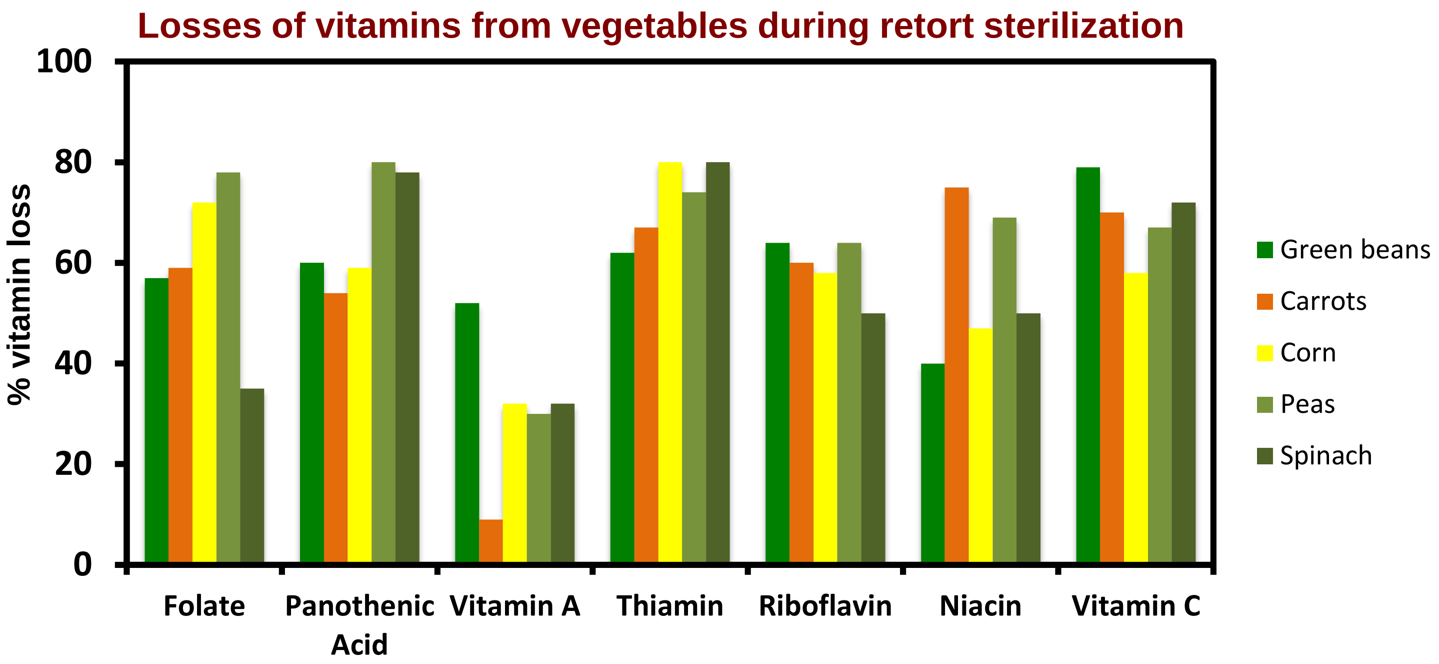


Food Processing:
Combination of multiple unit operations to generate a final product

Hot/Cold Break
Formulating
Homogenizaton
Juicing
Filling
Peeling
Heat Sterilization
Sorting
Labeling
Washing

USDA-ARS

Loss of vitamins is expected but not "total" with even with high heat treatment



***Adapted from data presented in: Gregory J. Chapter 8: Vitamins in Food Chemistry. Fennema, O. ed. CRC Press**

Recovery of plant bioactives go beyond "processing" and must consider all aspects form "seed to cell"

Raw Material → Post Harvest Handling → Ingredient Processing → Food Processing

USDA-ARS

USDA-ARS

USDA-ARS

Shelf Life

freeimages.com

In Home Prep

USDA-ARS

Consumption

ADME

toxtutor.nlm.nih.gov

Shelf Life ← In Home Prep ← Consumption ← ADME

F.A.T.-T.O.M. and stability of micronutrients and bioactives

- **Food**
  - Chemical nature of the food and or formulation factors
- **Acidity**
  - pH and stability relationships
- **Time & Temperature**
  - Post harvest handling and processing
- **Oxygen Exposure**
  - Oxidative reactions
- **Moisture**
  - Relationship between water activity and chemical reactivity

Product/Process factors that can impact stability of bioactives in food

Formulation

- Flavor Optimization
  - Sweetener, Lipid, Flavor addition
- Texture Modification
  - Carbohydrate, Protein, Lipid
  - Texturizers
- Acidification
  - Adjust processing pH
  - Alter product characteristics
- Preservatives
  - Antioxidants
  - Antimicrobials
- Color
  - NEB - Browning Reactions
  - Natural color addition

Processing

- Size Adjustment
  - Tissue disruption and homogenization
- Heat Transfer
  - Time and Temperature of process
- Mass Transfer
  - Fractionation
  - Moisture content and a_w
- Mixing
  - Air incorporation
  - Leaching

Storage/Shelf-Life

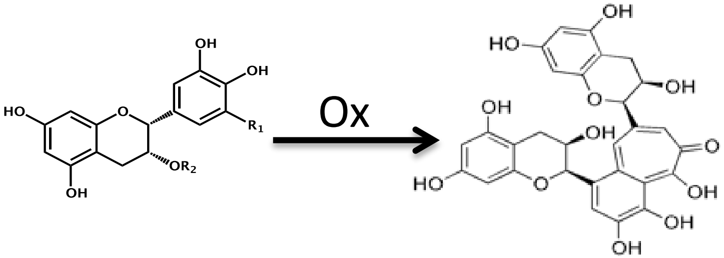
- Package
  - Material and Barrier characteristics
    - Physical
    - Moisture
    - Light
    - Oxygen
- Temperature
- Light
- Headspace
  - Residual Oxygen content

Levels and recovery of tea flavonoids from fresh brewed to RTD products

Tea Flavonoids

Epidemiological & Clinical Evidence

Cardiovascular Health



Uptontea.com

Brewed Tea

?

Ready-to-drink

"Generalized" flavan-3-ol content of consumer tea products

	Brewed Tea		RTD Tea	
mg/ 100mL	**Monomer**	**Oxidized**	**Monomer**	**Oxidized**
Green	120-180	1-25	10-30	1-10
Black	20-50	80-120	2-15	15-35

USDA Database Flavonoid Content selected foods, Release 3.1 (2014)
Peterson et al. Journal of Food Comp & Analysis 17 (2004) 397–405

Stability of flavan-3-ols in RTD tea beverages is also related to processing conditions

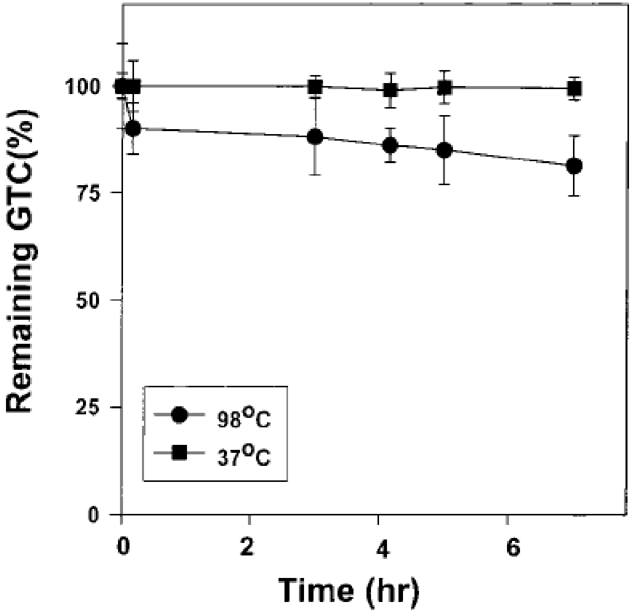


Figure 1. Stability of green tea catechins (GTC) in distilled water heated at 37 °C and 98 °C. Data are expressed as means ± SD of $n = 6$ samples.

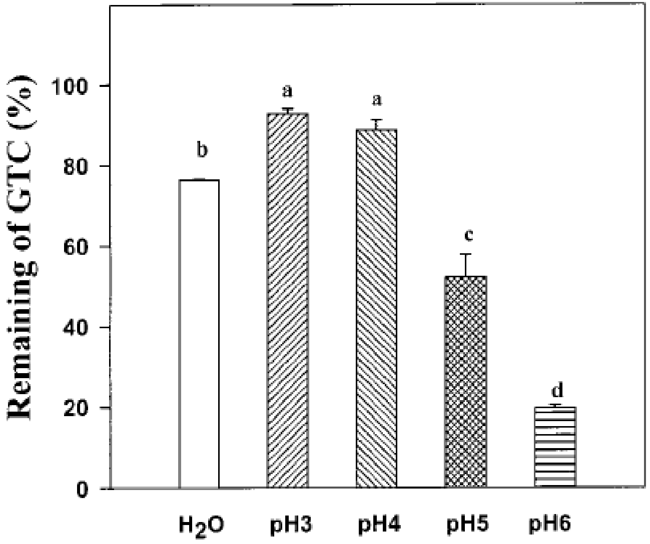


Figure 2. Stability of green tea catechins (GTC) in buffer solutions with varying pH during autoclaving at 120 °C for 20 min. Data are expressed as means ± SD of $n = 8$ samples. Means with different letters (a−d) differ significantly at $p < 0.01$.

Chen et al., (2001) J Agric Food Chem. 49:477

Consumer oat and potato products as sources of bioactive phenolics

Wholegrain oats

~100-600 mg / 100g

Wet Cooked Porridge

Puffed Cereal

Snack Bar – Flaked Oats

Potatoes

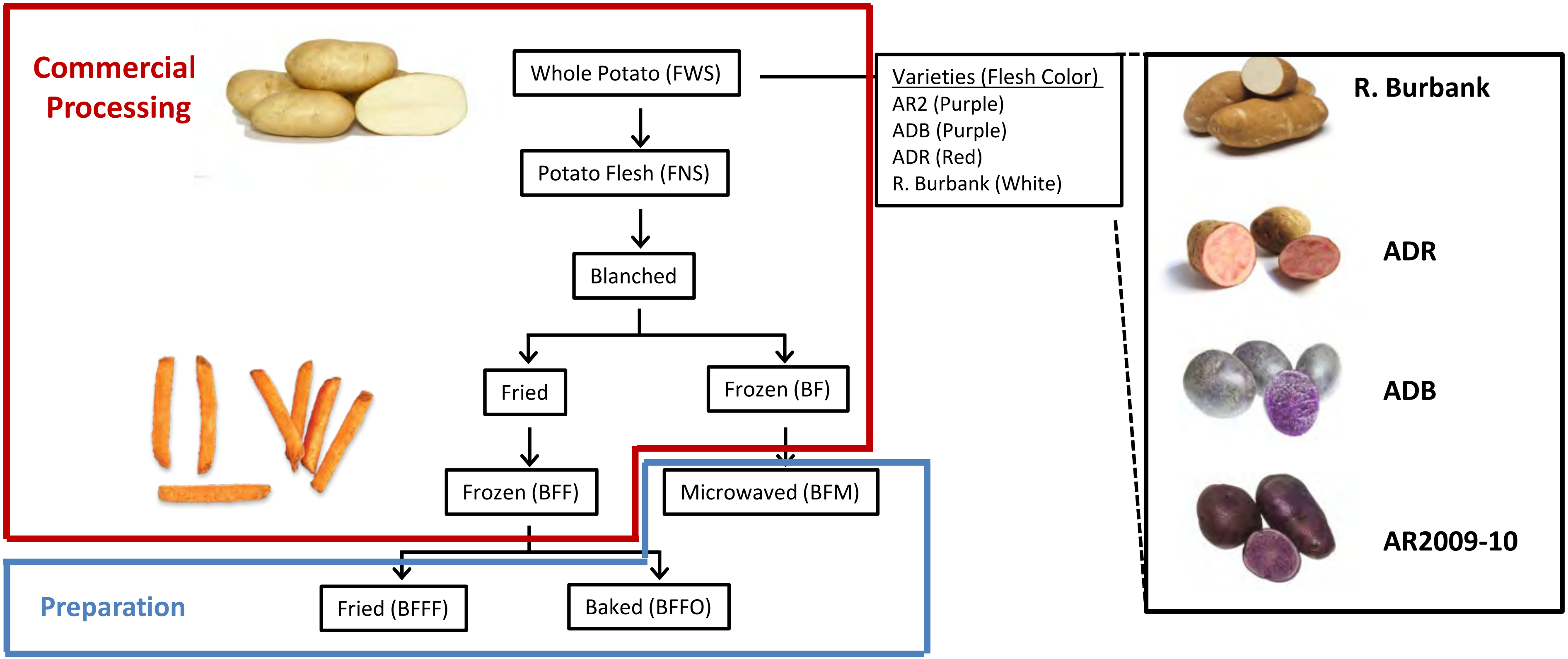
~50-200 mg / 100g

Shredded Potatoes
(Hash Browns)

Cubed Potatoes
(Home Fries)

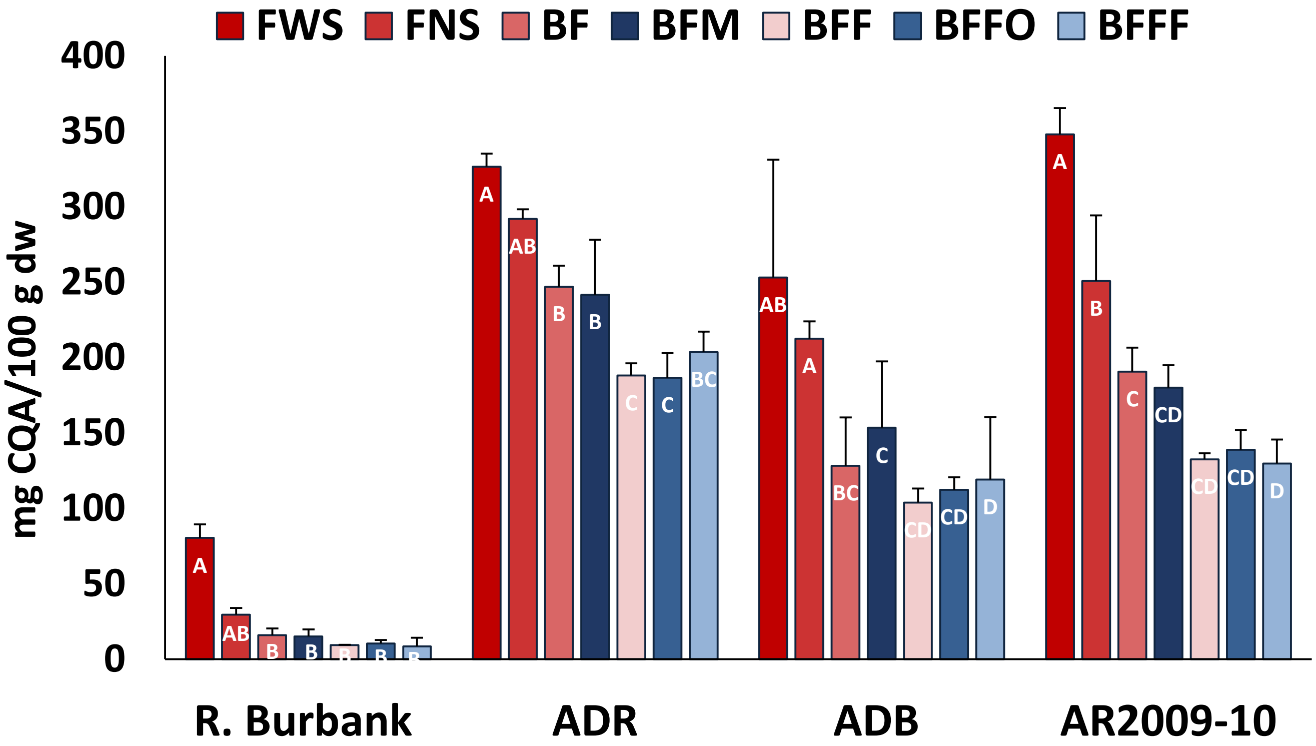
French Fries

Recovery of phenolics through the commercial potato processing chain



Furrer et al., *Food Chemistry*. 218, 47-55. **2017**.

Recovery of chlorogenic acid through the commercial French fry processing

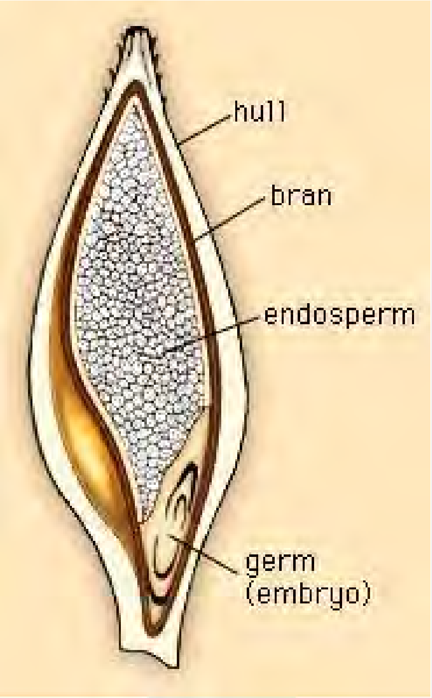


Retention

- R. Burbank: 32-55%
- ADR: 64-85%
- ADB: 49-72%
- AR2009-10: 52-76%

Furrer et al., *Food Chemistry*. 218, 47-55. **2017**.

Wholegrain oat milling and processing to flakes

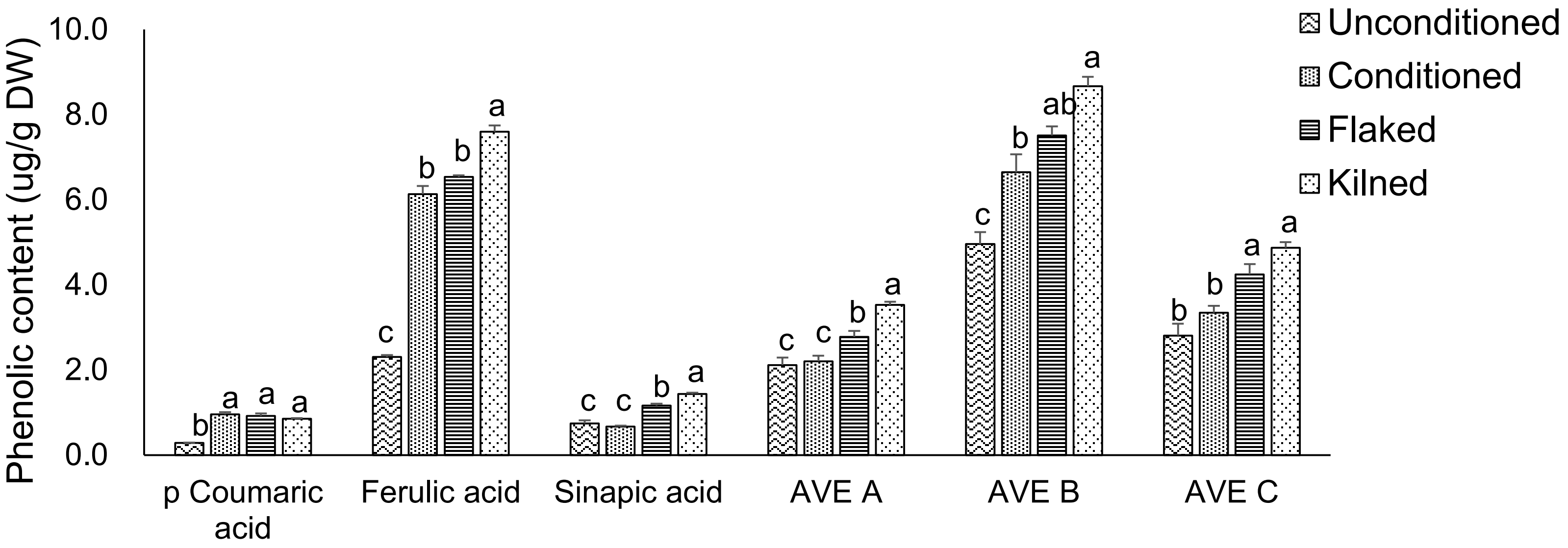


Unconditioned groat (commercial oat-1) → kilning → kilned groat → conditioning / Steaming → conditioned groat → flaking → flaked groat

Unconditioned groat (commercial oat-2) → kilning → conditioned groat → milling → oat bran; whole grain oat flour; low bran oat flour

"Commercial Oats" are commercially available blends of common oat varieties in US and Canada used in typical food processes

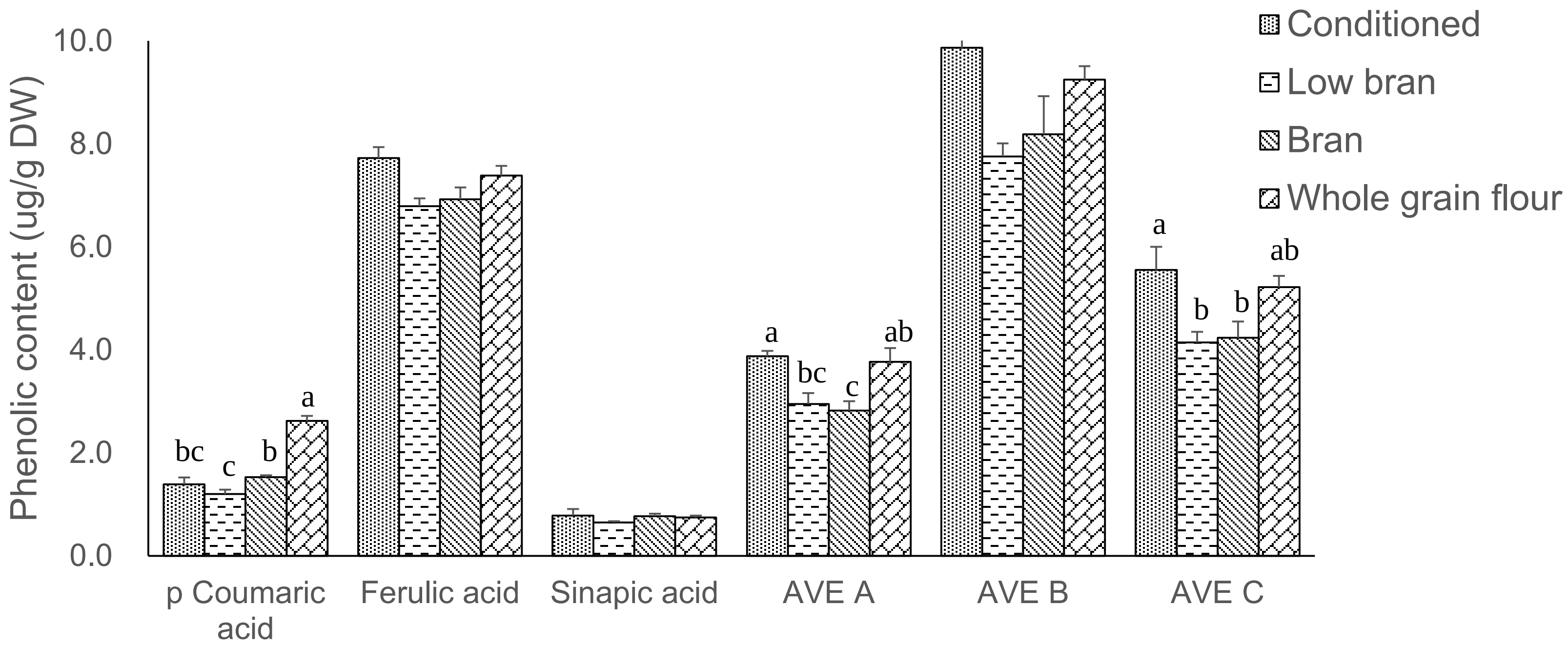
Conditioning, flaking and kilning increased free phenolic content of oats



- Hydrothermal treatment may liberate bound phenolic acids and avenanthramides from cell wall.

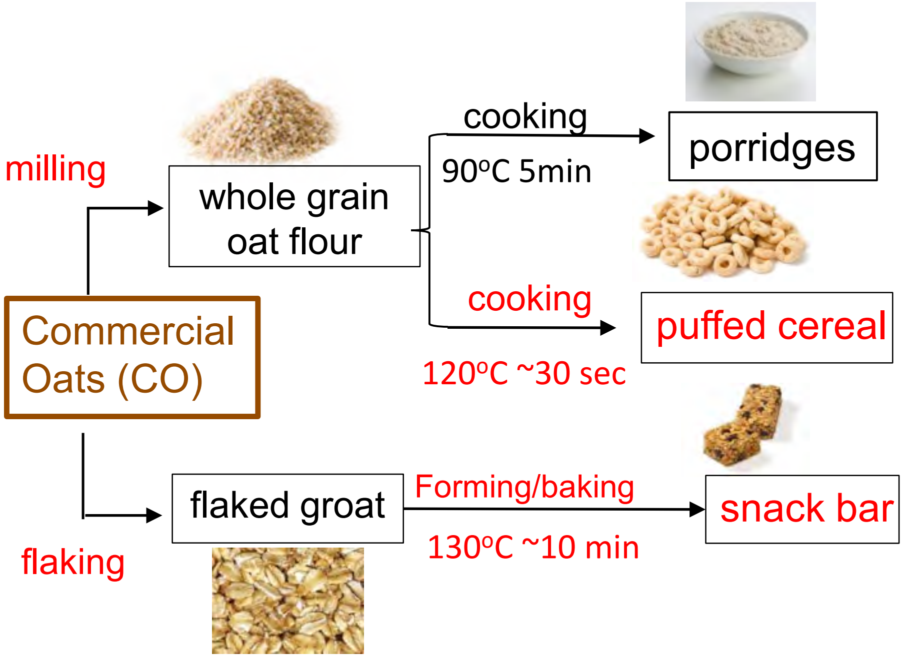
Li et al., *Food & Function*. 10;7(8):3370-81. **2016**.

Milling had minor effects on free phenolic content of commercial oat

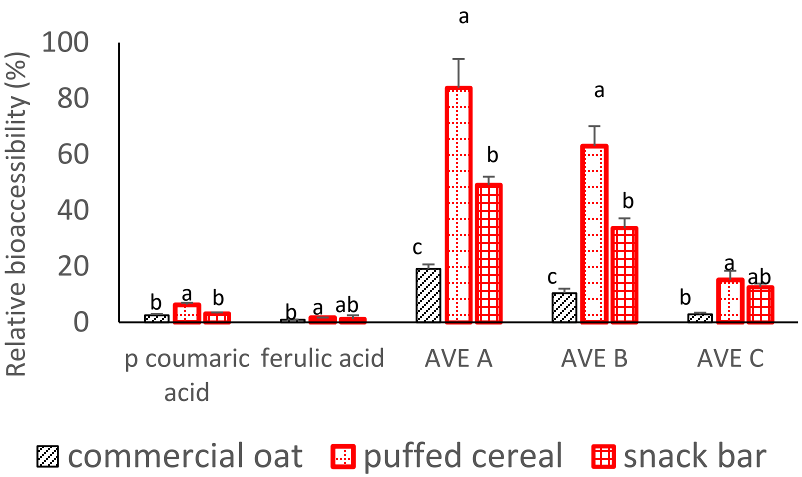


Li et al., *Food & Function*. 10;7(8):3370-81. **2016.**

Food processing impacted relative bioaccessibility, while oat variety had minor impact



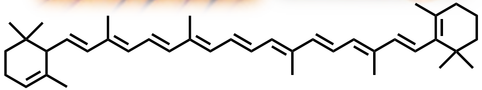
Wet-cooking v/s Ready-to-eat

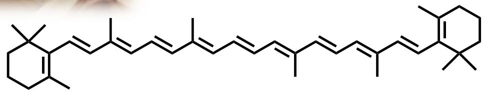


Li et al., *Food & Function*. 10;7(8):3370-81. **2016**.

Dietary Carotenoids: Lipid soluble bioactives

α & β-carotene

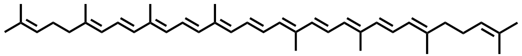




proVitamin A
Activity

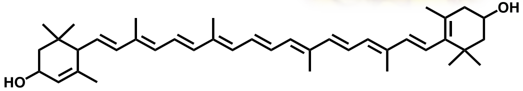
Lycopene

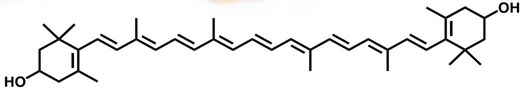
Anti-oxidant
Anti-inflammatory
Anti-cancer



Lutein & Zeaxanthin

Eye & Brain
Development
Protection

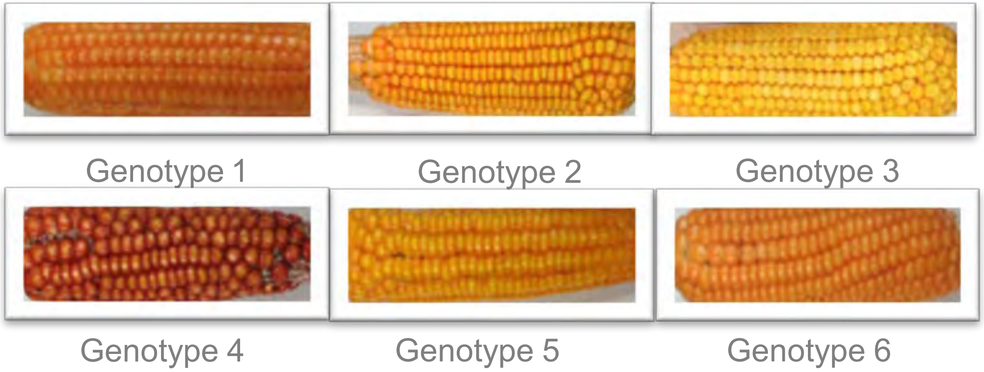




Biofortified High proVitamin A Maize Breeding Programs

PROFESSOR TORBERT'S ORANGE CORN

Dr. Torbert Rochford
Purdue University



carotenoid[b]	genotype[a]					
	1	2	3	4	5	6
all-trans-lutein	6.6 ± 0.6 bc	9.5 ± 2.3 b	14.1 ± 0.6 a	3.9 ± 0.2 c	4.7 ± 0.4 c	6.6 ± 1.1 bc
all-trans-zeaxanthin	37.5 ± 2.7 a	17.9 ± 1.5 b	3.9 ± 0.2 c	20.1 ± 0.6 b	25.9 ± 3.6 b	20.4 ± 1.8 b
α-cryptoxanthin	1.5 ± 0.1 a	1.3 ± 0.3 a	0.9 ± 0.1 a	0.9 ± 0.0 a	1.2 ± 0.1 a	1.2 ± 0.2 a
β-cryptoxanthin	3.8 ± 0.3 b	3.5 ± 0.4 b	0.7 ± 0.0 c	7.1 ± 0.4 a	4.7 ± 0.7 b	3.5 ± 0.4 b
15-*cis*-*β*-carotene	0.9 ± 0.1 b	0.8 ± 0.1 bc	1.4 ± 0.0 a	0.6 ± 0.0 cd	0.7 ± 0.1 cd	0.4 ± 0.0 d
13-*cis*-*β*-carotene	0.9 ± 0.1 a	1.1 ± 0.1 a	1.2 ± 0.1 a	0.1 ± 0.0 b	0.1 ± 0.0 b	0.1 ± 0.0 b
α-carotene	0.3 ± 0.1 a	0.5 ± 0.1 a	0.4 ± 0.0 a	0.3 ± 0.0 a	0.3 ± 0.0 a	0.3 ± 0.0 a
all-trans-*β*-carotene	4.9 ± 0.5 c	8.6 ± 1.8 b	13.1 ± 0.6 a	4.7 ± 0.2 c	3.5 ± 0.4 c	2.8 ± 0.1 c
9-*cis*-*β*-carotene	1.2 ± 0.1 bc	1.6 ± 0.2 b	2.2 ± 0.1 a	0.8 ± 0.1 cd	0.8 ± 0.1 cd	0.5 ± 0.1 d
xanthophyll	47.5 ± 2.9 a	29.9 ± 3.5 bc	19.8 ± 0.8 c	25.6 ± 0.8 bc	33.0 ± 3.9 b	30.1 ± 1.4 bc
provitamin A[c]	8.5 ± 0.1 bc	12.3 ± 0.2 ab	16.1 ± 0.1 a	9.2 ± 0.0 bcd	6.8 ± 0.1 cd	5.2 ± 0.0 d
total carotenoid content	61.1 ± 3.4 a	47.3 ± 4.2 b	39.8 ± 1.3 b	40.1 ± 1.5 b	44.2 ± 4.8 b	39.0 ± 1.4 b
dry matter (%)	66.7 ± 0.5 b	71.4 ± 0.7 a	70.9 ± 1.3 a	69.3 ± 0.3 ab	68.8 ± 0.9 ab	70.6 ± 0.9 a

Ortiz D., Rocheford T., Ferruzzi MG. (2016). *J. Agric. Food Chem*, 64, 2727-2736.

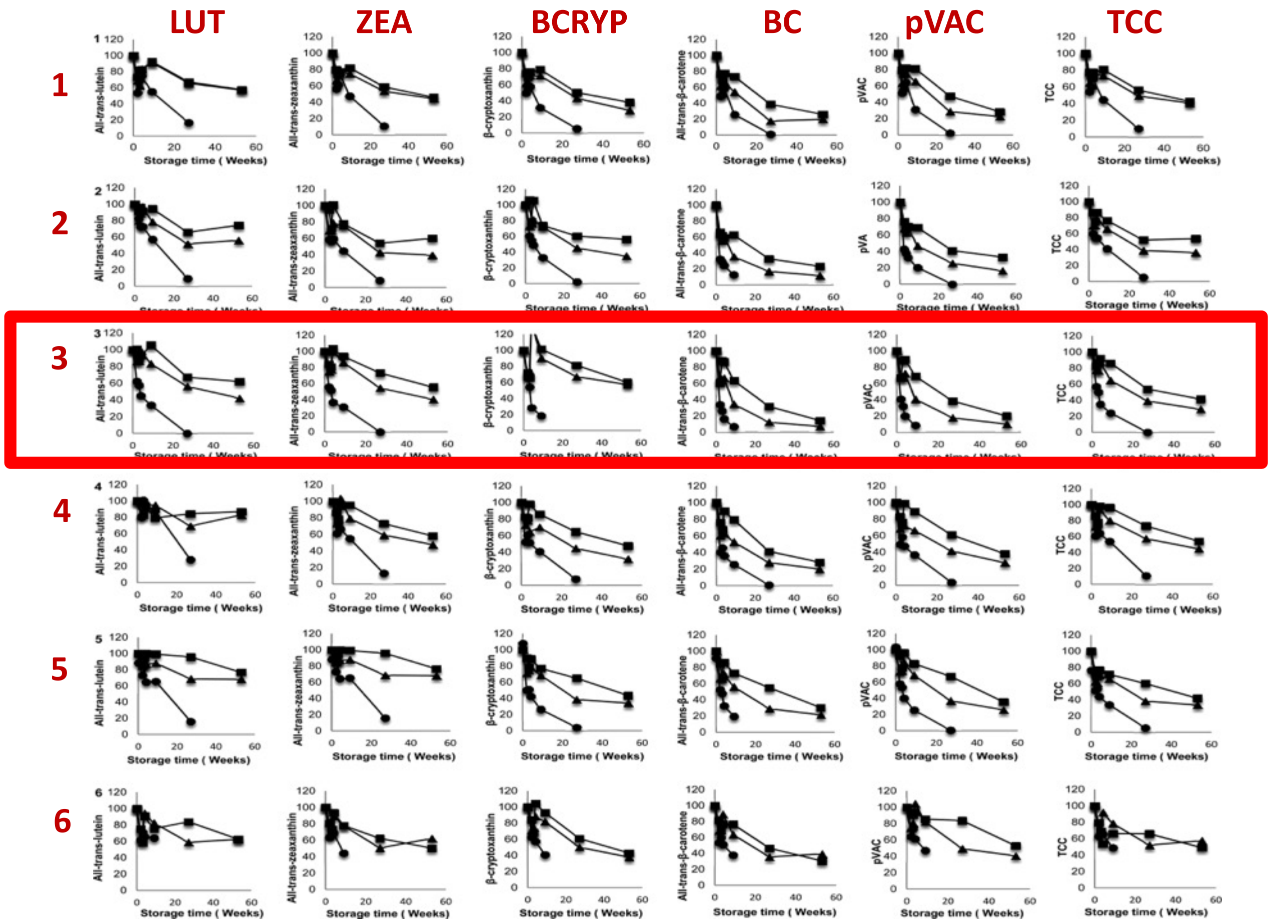
Simulating grain storage to investigate carotenoid stability

en.wikipedia.org

Storage system for stability trial

- 6 Selected Maize Genotypes
- 3 Temperatures (4, 22.5, 55°C)
- 3 aw (0.13; 0.51; 0.76)
- Time (0, 2, 3, 9, 27, 53 weeks)

Ortiz D., Rocheford T., Ferruzzi MG. (2016). *J. Agric. Food Chem*, 64, 2727-2736.



Carotenoids Retention (%) at:

(■) **4 °C,** 63.5 ± 0.72% RH;

(▲) **22 °C,** 59.14 ± 0.44% RH;

(●) **55 °C,** 50.15 ± 0.65% RH;

over **60 weeks**

Average **pVAC losses** after

3 months ~**40 %;**
6 months ~**70%**
1 year ~**80 %**

RH 59.14% and 22.5 °C

Significant Effects of :

Humidity

Temperature

Genotype

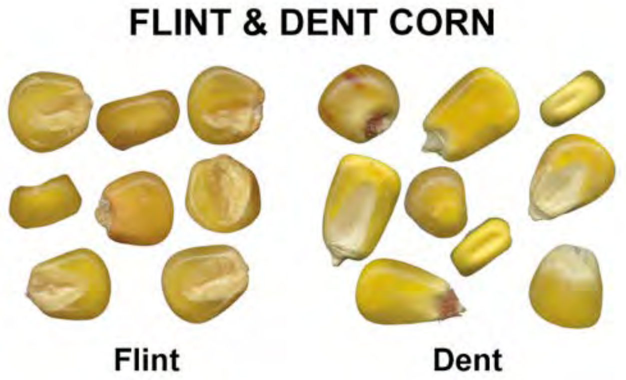
Humidity X Temperature

Ortiz D., Rocheford T., Ferruzzi MG. (2016). *J. Agric. Food Chem*, 64, 2727-2736.

Carotenoid post harvest stability influenced by kernel physical properties

kernel physical property	genotype[a] 1	2	3	4	5	6
length[b] (mm)	10.53 ± 0.2 c	12.21 ± 0.1 b	13.69 ± 0.2 a	10.57 ± 0.3 c	11.59 ± 0.2 b	9.49 ± 0.3 d
width[b] (mm)	8.51 ± 0.2 ab	8.63 ± 0.2 a	8.5 ± 0.2 ab	7.64 ± 0.3 b	8.66 ± 0.2 a	8.51 ± 0.2 ab
thickness[b] (mm)	4.82 ± 0.2 a	5.18 ± 0.2 a	4.67 ± 0.1 a	5.13 ± 0.3 a	4.82 ± 0.3 a	5.62 ± 0.2 a
geometric mean diameter[b] (mm)	7.53 ± 0.1 bc	8.13 ± 0.1 a	8.14 ± 0.1 a	7.37 ± 0.1 c	7.8 ± 0.1 ab	7.63 ± 0.1 bc
sphericity[b] ($mm\ mm^{-1}$)	0.72 ± 0.01 b	0.67 ± 0.01 bc	0.6 ± 0.01 c	0.7 ± 0.02 b	0.68 ± 0.02 b	0.81 ± 0.03 a
surface area[b] (mm^2)	178.6 ± 4.5 bc	208.12 ± 6.1 a	208.38 ± 4.4 a	170.8 ± 4.5 c	191.9 ± 6.5 ab	182.9 ± 3.0 bc
bulk density[c] (kg/m^3)	964.7 ± 1.5 b	943.6 ± 2.0 c	887.5 ± 1.6 d	981.3 ± 2.4 a	984.2 ± 1.0 a	982.4 ± 1.8 a
mass of 1000 kernels[d] (g)	281.1 ± 6.1 d	348.6 ± 3.3 b	381.8 ± 2.43 a	305.4 ± 3.3 c	291.7 ± 1.0 cd	294.7 ± 2.8 cd
single-kernel mass (g)[d]	0.28 ± 0.0 d	0.35 ± 0.0 b	0.38 ± 0.00 a	0.31 ± 0.00 c	0.29 ± 0.00 cd	0.3 ± 0.00 cd
kernel volume[d] (mm^3)	291.6 ± 6.2 d	367.8 ± 3.8 b	430.6 ± 2.4 a	312.5 ± 3.5 c	296.3 ± 0.9 cd	299.7 ± 3.8 cd
true density[d] (kg/m^3)	1233.6 ± 10.6 ab	1187.9 ± 1.0 bc	1169.4 ± 17.3 c	1262.6 ± 6.2 a	1257.4 ± 17.3 a	1265.8 ± 17.1 a
porosity[d] (%)	21.8 ± 0.6 ab	20.2 ± 0.1 b	24.1 ± 1.2 a	22.6 ± 0.3 ab	21.7 ± 1.0 ab	
L/W[b]	1.2 ± 0.0 bc	1.4 ± 0.0 ab	1.6 ± 0.1 a	1.4 ± 0.1 b	1.3 ± 0.0 b	
L/T[b]	2.2 ± 0.1 bc	2.4 ± 0.1 ab	3.0 ± 0.1 a	2.2 ± 0.1 b	2.5 ± 0.1 b	
L/Dg[b]	1.4 ± 0.0 b	1.5 ± 0.0 b	1.7 ± 0.0 a	1.4 ± 0.0 b	1.5 ± 0.0 b	

[a]Different letters within a row indicate significant difference according to Tukey's HSD test ($P < 0.05$). [b]Mean ± SEM; $n = 15$. [c]M
[d]Mean ± SEM; $n = 3$.

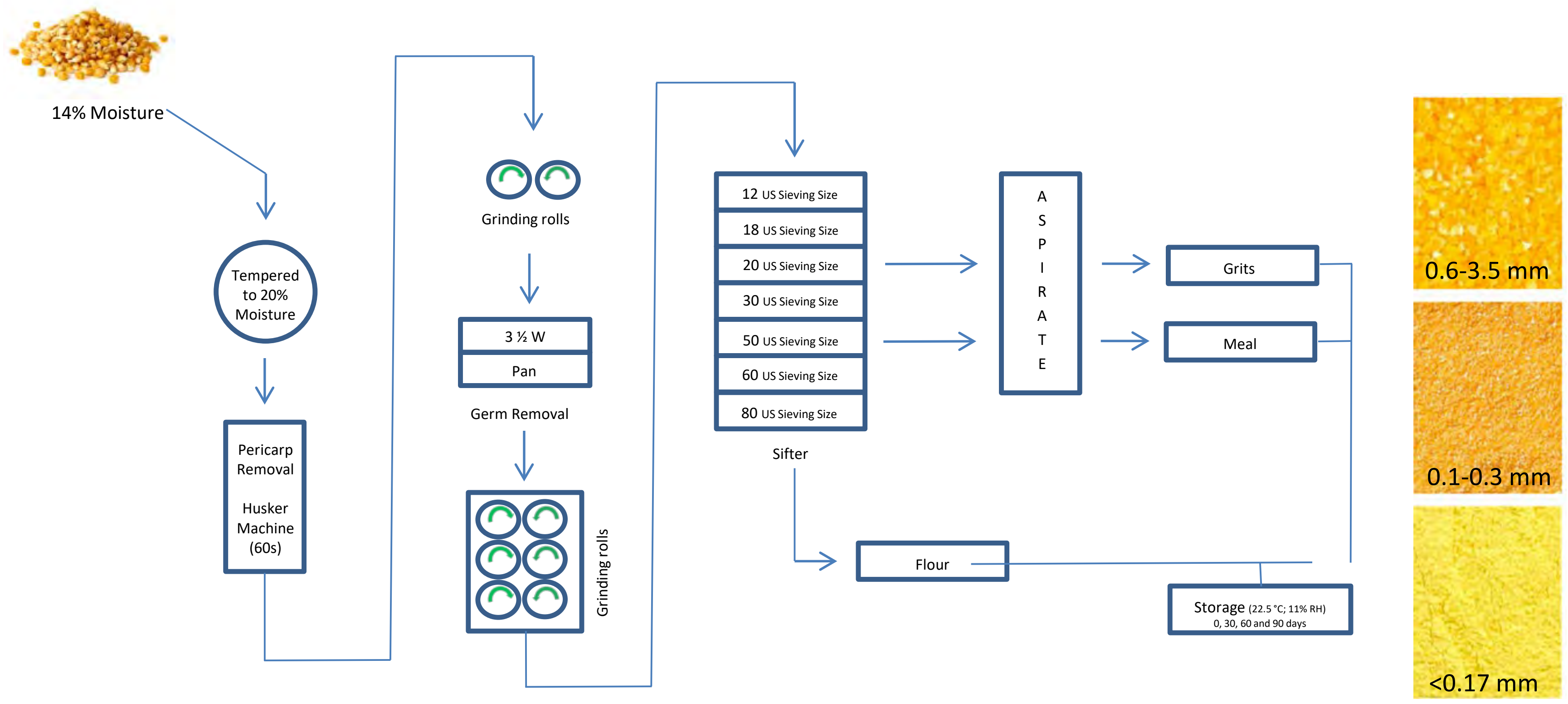


Genotype 3 is dent corn, more oblong, resulting in less dense packing of the kernels and potentially allowing more air accumulation in the void space between kernels compared with the other genotypes.

Ortiz D., Rocheford T., Ferruzzi MG. (2016). *J. Agric. Food Chem*, 64, 2727-2736.

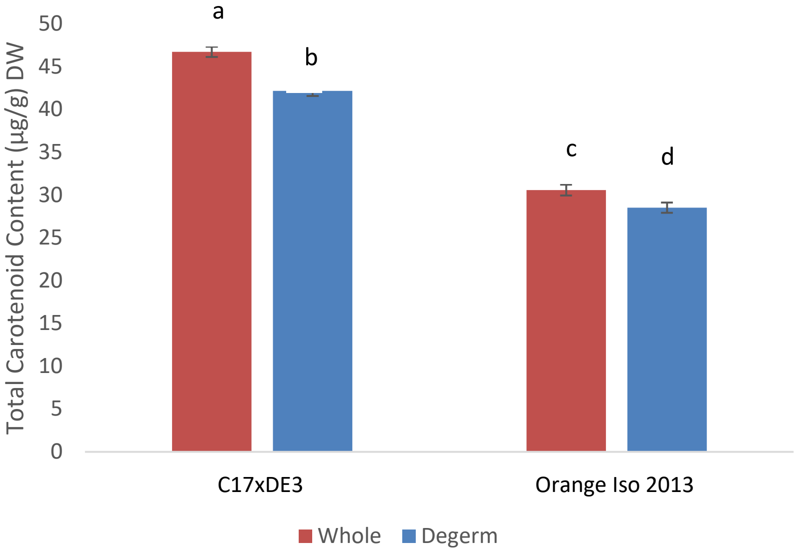
www.ams.usda.gov

Maize Dry-Milling Processing and Storage

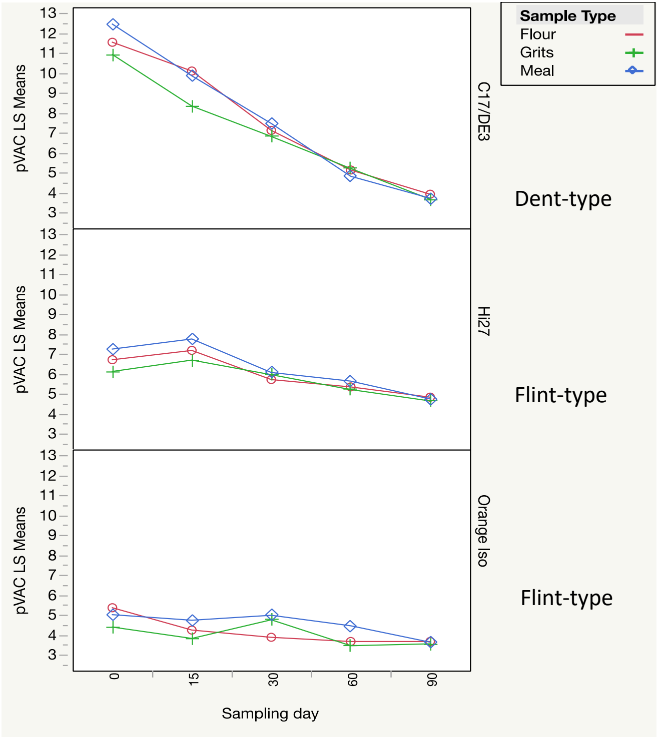


Effect of Dry-Milling on Carotenoid Levels and Stability in Biofortified Maize

Impact of Pericarp and Germ removal



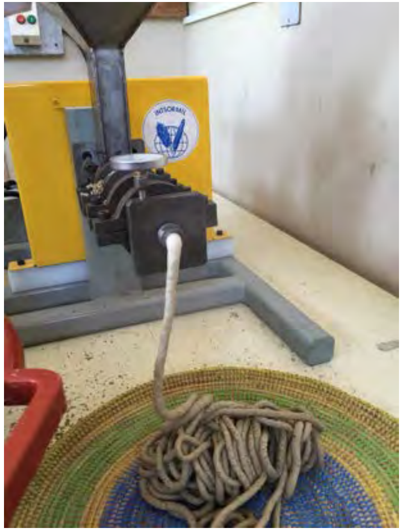
Provitamin A Carotenoid Content



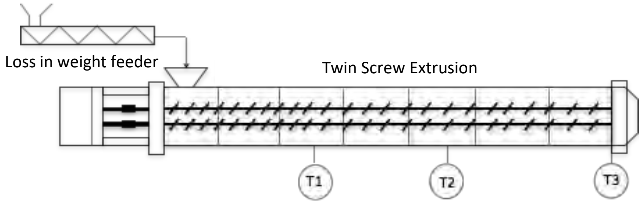
Flint type ~28% pVAC loss after 90-days storage
Dent type ~68% pVAC loss after 90-days storage

Ortiz D et al. Journal of Agricultural and Food Chemistry. 2018 Mar 15;66(18):4683-91.

Maize Extrusion Cooking Processing to instantize/functionalize maize flour results in variable recovery of carotenoids



Maize grits



- Extrusion Moisture Levels: 25%, 30%, 35%
- Screw Speed: 150 rpm, 225 rpm, 300 rpm
- T1 = 120 °C, T2 = 140 °C, T3 = 160 °C

	moisture (%)		
screw speed (rpm)	25	30	35
Total Carotenoid Content (% retention)			
150	71.7 ± 2.8 c	81 ± 9.7 b	94.3 ± 2.3 a
225	71.3 ± 5.3 c	75.9 ± 7.8 bc	65.1 ± 2.4 c
300	76.3 ± 5.1 bc	86.9 ± 6.6 b	74.1 ± 4.4 bc
Provitamin Carotenoid Content[c] (% retention)			
150	70.9 ± 2.3 c	84.2 ± 7.2 b	93.5 ± 2.4 a
225	72 ± 7.2 c	74.9 ± 6.9 bc	70.3 ± 2.3 c
300	81.8 ± 5.5 bc	85.2 ± 4.8 b	74.8 ± 6.1 bc

Precooked “Instant” Maize Flour

Biofortified Cassava

(*Manihot esculanta*, Crantz)

Centro Internacional de Agricultura Tropical
International Center for Tropical Agriculture
Consultative Group on International Agricultural Research

Biofortified Cassava Roots (CIAT Cali, Columbia)

SM 3762-15 SM 3767-84 SM 3758-43 SM 3757-75 SM 3774-21

GM 5212-6 GM 5194-13 GM 5194-5 GM 4414-5 GM 4571-3

Photo taken by Ingrid Aragon in the Experimental fields at CIAT

Semi-Industrial Production of Unfermented and Fermented Cassava Flours

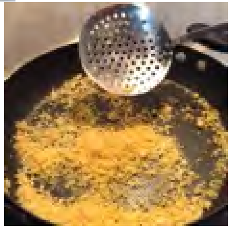
Cassava Root
↓
Peeling
↓
Washing

Grating (pellet)
↓
Drying
40 °C, 2d
↓
Milling
↓
Sieving
30 mesh
↓
Unfermented Flour (UF)*

Grating (dough)*
↓
Pressing
↓
Spontaneous Fermentation*,
~30 °C, 2d

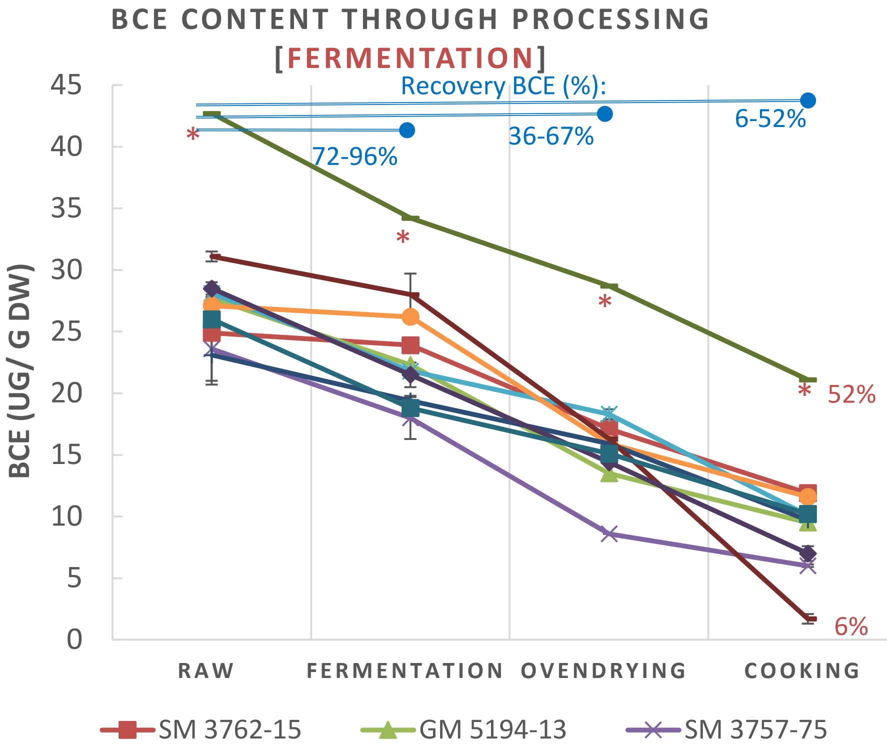
Drying
40 °C, 2d
↓
Milling
↓
Sieving
30 mesh
↓
Fermented Flour (F)*

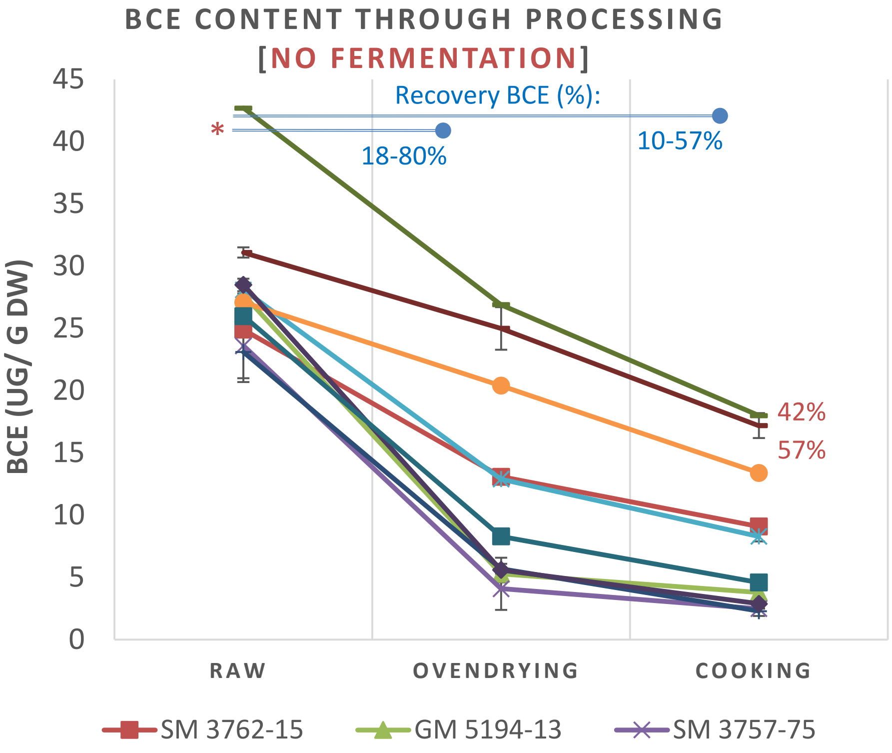
Toasting
150 °C, 15-20 min
↓
Milling
↓
Sieving
30 mesh
↓
Gari Flour*



Aragón IJ, Ceballos H, Dufour D, Ferruzzi MG. Food & function. 2018;9(9):4822-35.

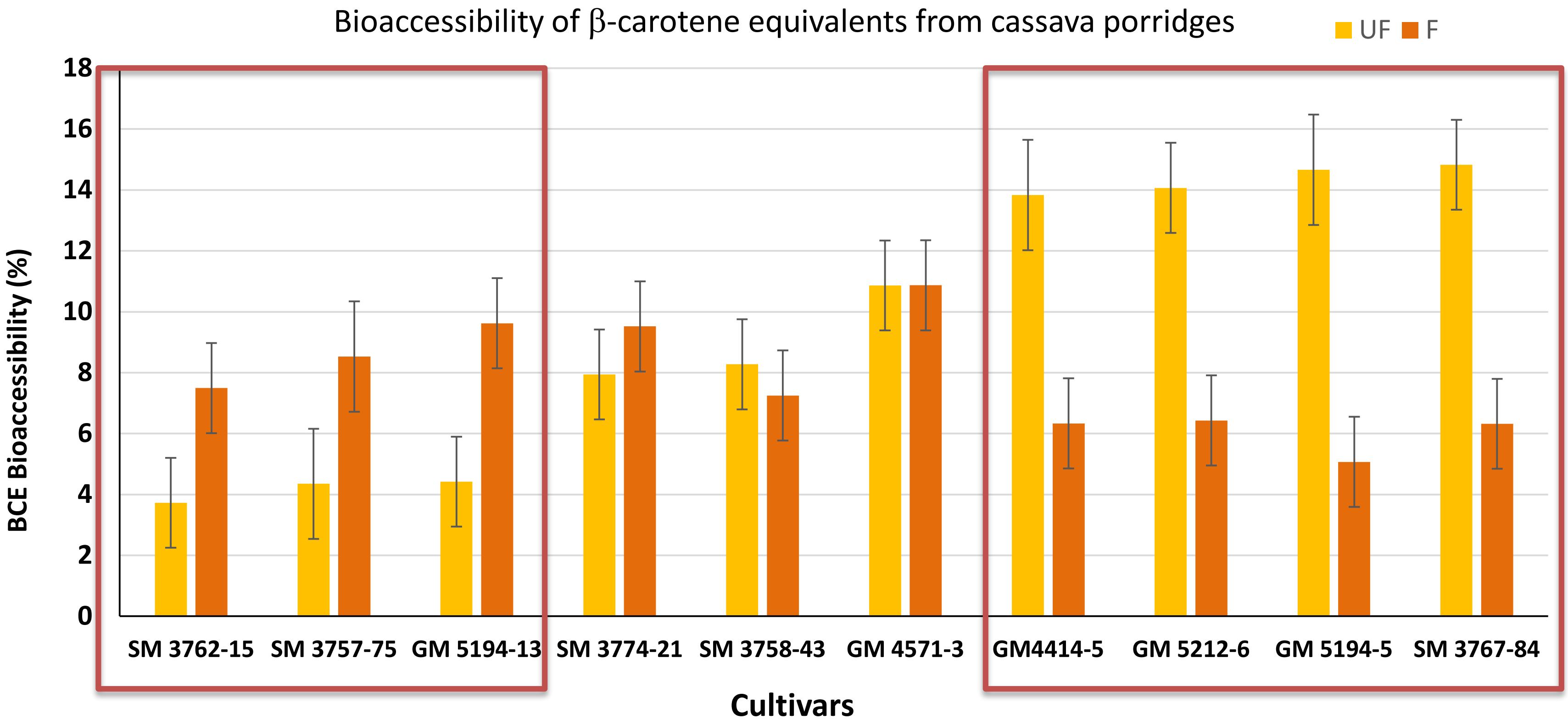
Degradation of provitamin A carotenoids in biofortified cassava from harvest to final preparation





Aragón IJ, Ceballos H, Dufour D, Ferruzzi MG. Food & function. 2018;9(9):4822-35.

Screening to biofortified cassava genotype to identify appropriate process and genotypes (G x P) for maximizing nutrient delivery



Aragón IJ, Ceballos H, Dufour D, Ferruzzi MG. Food & function. 2018;9(9):4822-35.

Some Final Thoughts…

- Bioactive levels are only one factor to consider in delivery of these compounds to consumers
- Bioactives have varied sensitivities to post-harvest and food processes which must be assessed individually
- Advances in breeding and genetics should consider potential interactions with processing (G x P) as a way to optimize potential impacts of micronutrients/bioactives
    - Stability/Recovery
    - Bioavailability/Efficacy

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Min Li, Ph.D

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USAID Feed the Future Food Processing Innovation Lab

NC Research Campus

NC STATE UNIVERSITY

NC STATE UNIVERSITY

Plants for Human Health

INSTITUTE

HarvestPlus
Better Crops • Better Nutrition

Scaling up Agricultural Production of Nutritious and Emerging Crops: Lessons Learned from Biofortification

Howarth Bouis
Founding Director, HarvestPlus
February 1, 2019

HarvestPlus c/o IFPRI
2033 K Street, NW • Washington, DC 20006-1002 USA
Tel: 202-862-5600 • Fax: 202-467-4439
HarvestPlus@cgiar.org • www.HarvestPlus.org

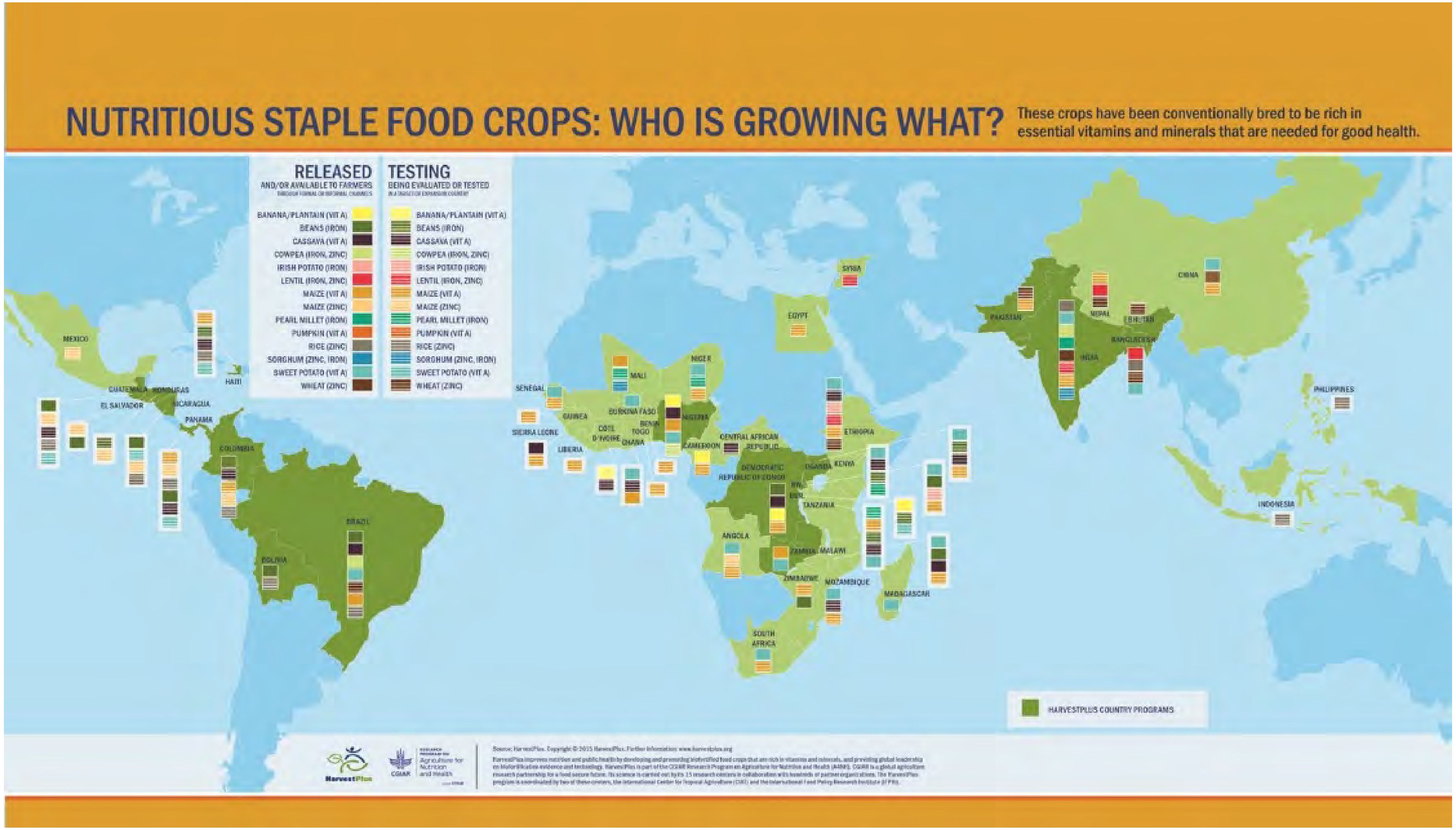
CGIAR

Cost-effective: central one time investment

Biofortified crops released in **30 countries**

In-testing in another **25 countries**

>150 Varieties Released Across 12 crops



Nutritious crops released in 30 countries; in testing in another 25

Nutrition Contribution

- Biofortified crops, as consumed, provide ***an extra*** 40% of estimated average requirement each day – substituting one-for-one the biofortified variety for the existing non-biofortified variety.

Functional Outcomes

- Efficacy trials with provitamin A, iron, and zinc biofortified crops have also shown improved functional outcomes:
  - Improved cognitive function (iron)
  - Better work performance (iron)
  - Reduced morbidity (zinc and provitamin A)
  - Better sight adaptation to darkness (provitamin A)

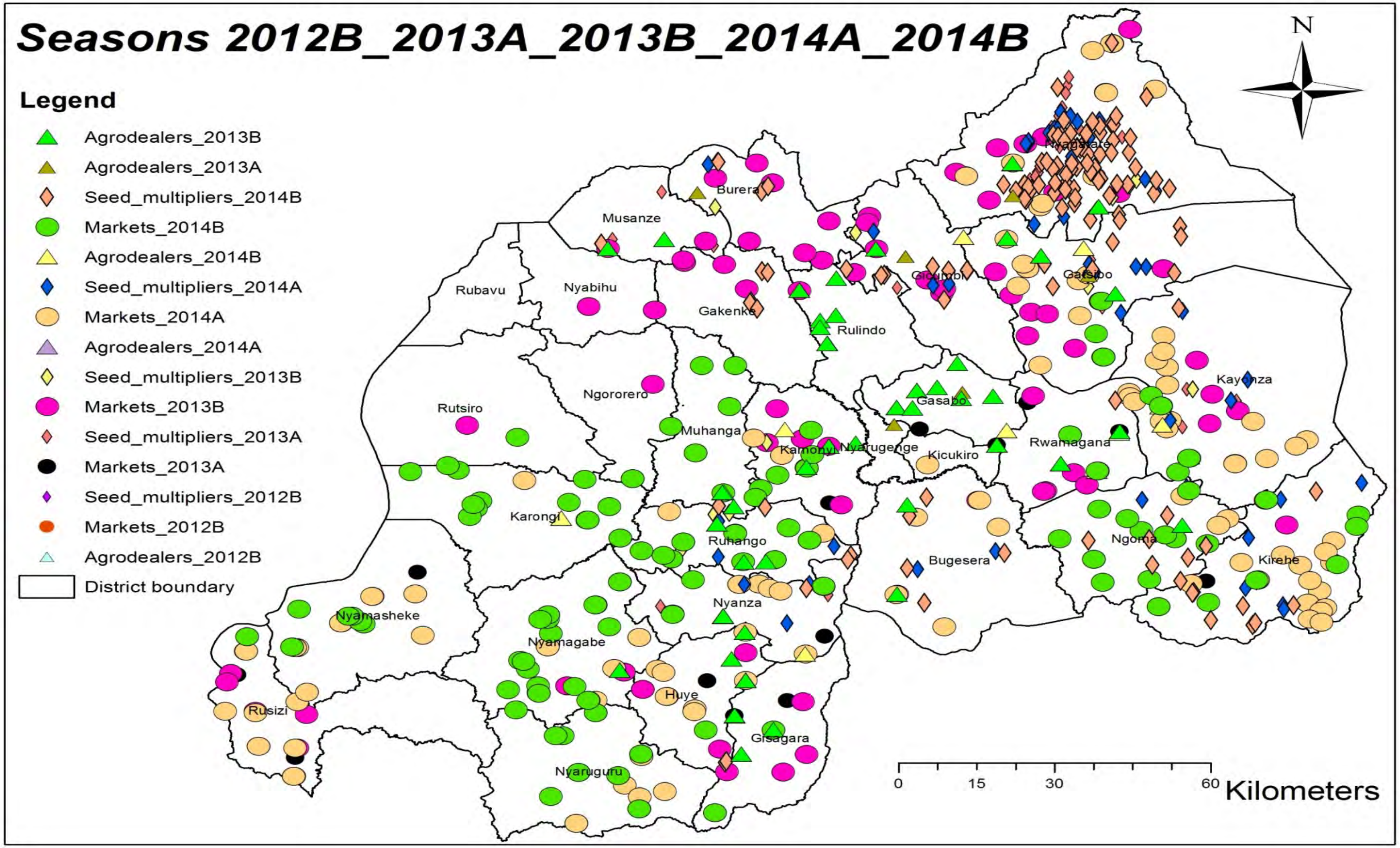
Ten Bean Varieties Released in Rwanda

AGRONOMIC PROPERTIES OF IRON BEAN

Names	Pictures	Type	Yield potential	Adaptation	Iron content	Maturity
RWV 3316		Climber	4 t/ha	High altitude	91,6ppm	110 Days
RWV 3006		Climber	3.8 t/ha	High altitude	91,7ppm	110 Days
MAC 44		Climber	3.5 t/ha	Mid to low altitude	78 ppm	87 Days
RWR 2245		Bush	2.5 t/ha	Mid to low altitude	75 ppm	87 Days
RWR 2154		Bush	2.5 t/ha	Mid to low altitude	75 ppm	87 Days
RWV 1129		Climber	3.5 t/ha	Mid to high altitude	81 ppm	110 Days
Cab2		Climber	3 t/ha	High altitude	94,8 ppm	115 Days
RWV 3317		Climber	4 t/ha	High altitude	74 ppm	110 Days
RWV 2887		Climber	3.5 t/ha	Mid to high altitude	93,7 ppm	106 Days
MAC 42		Climber	3.5 t/ha	Mid to high altitude	91 ppm	81 Days

www.rab.gov.rw - P.O.Box 5016 Rwanda - Toll free: 4675   www.HarvestPlus.org - P.O.Box 1269 Rwanda. - Tel: + 250 786 779 738

Rwanda: Location of combined activities in 2014



Results Of Nationally Representative Farm Survey

Rwanda 2015 Season B Bean Production	
Percentage of Farmers Planting Iron Beans At Least Once	30%
Iron Beans As Percentage of Total Bean Production	12%
Yield Advantage of Climbing Iron Beans	+22%
Yield Advantage of Bush Iron Beans	+17%
Added Value of Production of Climbing Iron Beans	+$78/hectare
Added Value of Production of Bush Iron Beans	+$57/hectare

Mainstreaming Through Key Stakeholders

- Public agricultural research (CGIAR, NARS)
- Seed companies (SeedCo in Africa)
- International financial institutions (World Bank, IFAD)
- Multi-lateral agencies (World Food Program, Codex)
- National governments (Brazil, China, India)
- International NGOs (World Vision)

Lessons Learned: Across All Crops

- High yield (high profit) is essential and ensures:
  - price for consumers that is equal to non-biofortified variety
  - farmer interest, the potential for adoption/acceptance
- Superior yield can be an key driver of rapid scale up
- The need to invest to multiply initial seed quantity to jump start the process of farmer adoption (e.g. demonstration plots)
- Small seed and food companies will be the initial investors; large companies are risk averse and will wait for small companies to become successful before becoming engaged
- Inform/engage a wide range of stakeholders across multiple sectors about your plans and activities.

Lessons Learned: Across All Crops

- Agricultural interventions are sustainable and can be highly cost-effective. However, donors/investors have to be committed for the long-term as farmer adoption/crop production/consumer behavior change builds slowly in the initial stages. This takes even longer if agricultural research is required initially.
- Types of seeds:
  - ***Hybrids***, easiest to get the private seed companies involved
  - ***Self-pollinated,*** varies as to involvement of private seed companies
  - ***Vegetatively propagated***, relatively difficult to get private sector involved because of the need to replant vines/stalks quickly; transport over long distances is not feasible.

Lessons Learned: Iron and Zinc Crops

- Because these minerals are invisible and tasteless, the easiest (although long-term) strategy is to gradually over time account for a very high percentage of total supply:
  - This can be accomplished through “mainstreaming” of mineral density in public and private agricultural research
  - Ultimately, government regulations should require that all approved releases of crops should have minimum (and high) mineral densities
    - The first example of this are such regulations for iron pearl millet in India

Lessons Learned: Iron and Zinc Crops

- Development and adoption of mineral dense crops can be accelerated through "institutional" demand
  - For example, the government in India could give priority to purchase of zinc rice and zinc wheat for its many food subsidy programs
  - This would require an inexpensive and quick method for testing that grain delivered is high in iron and zinc.
- A complementary or alternative strategy in the initial stages of scale up, may be to establish a commercial value chain for "identity-preserved" iron and zinc foods.
  - If identity preservation and/or advertising involve significant costs, then commercial products would not be affordable by the poor.

Lessons Learned: Provitamin A Crops

- A separate value chain needs to be established for the provitamin A products because of the change in color; building consumer demand is essential
- Yellow/orange color is not a barrier to adoption (where a white color is the norm) – as long as consumers (especially mothers) have the information:
  - that the color change is due to the provitamin A content
  - about the benefits (especially to her children) of avoiding vitamin A deficiency
- There is a taste change, but consumers overwhelmingly like the taste.

Lessons Learned: Provitamin A Crops

- In building demand, a key factor, of course, is to convey this information at low cost:
  - the ambition is that when a critical mass of consumers eat the provitamin crops on a regular basis, then information is passed on from consumer to consumer and demand "goes viral."
    - The value proposition is for the same price, protect your family from vitamin A deficiency
  - radio programming has been effective, using "soap operas"
  - village theater and feature-length movies have been tried
  - a government/industry campaign to "eat orange" is an interesting, but as yet untried idea.

Harvest for Health: Improving Wellbeing through Resilient Agriculture

Washington DC, USA

31 January - 1 February, 2019

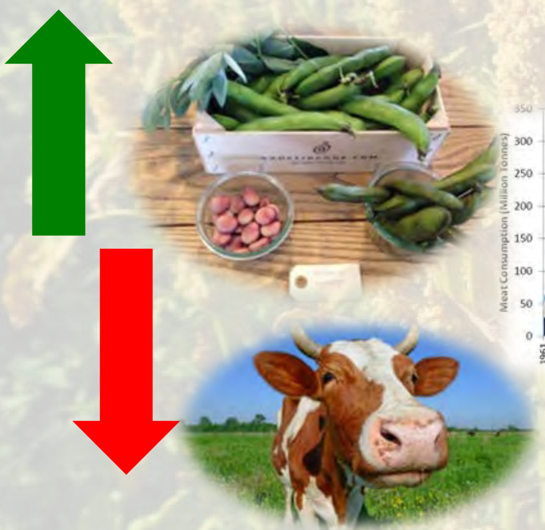
Lessons learned from quinoa

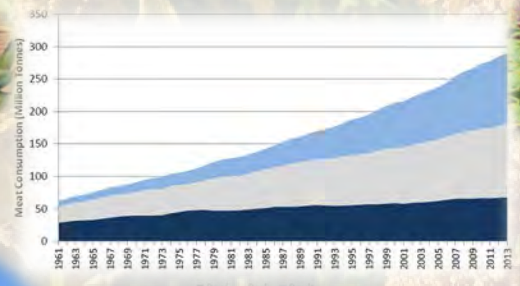
Sven-Erik Jacobsen

info@quinoaquality.com

Boost bio-economy

Improve food security and human health

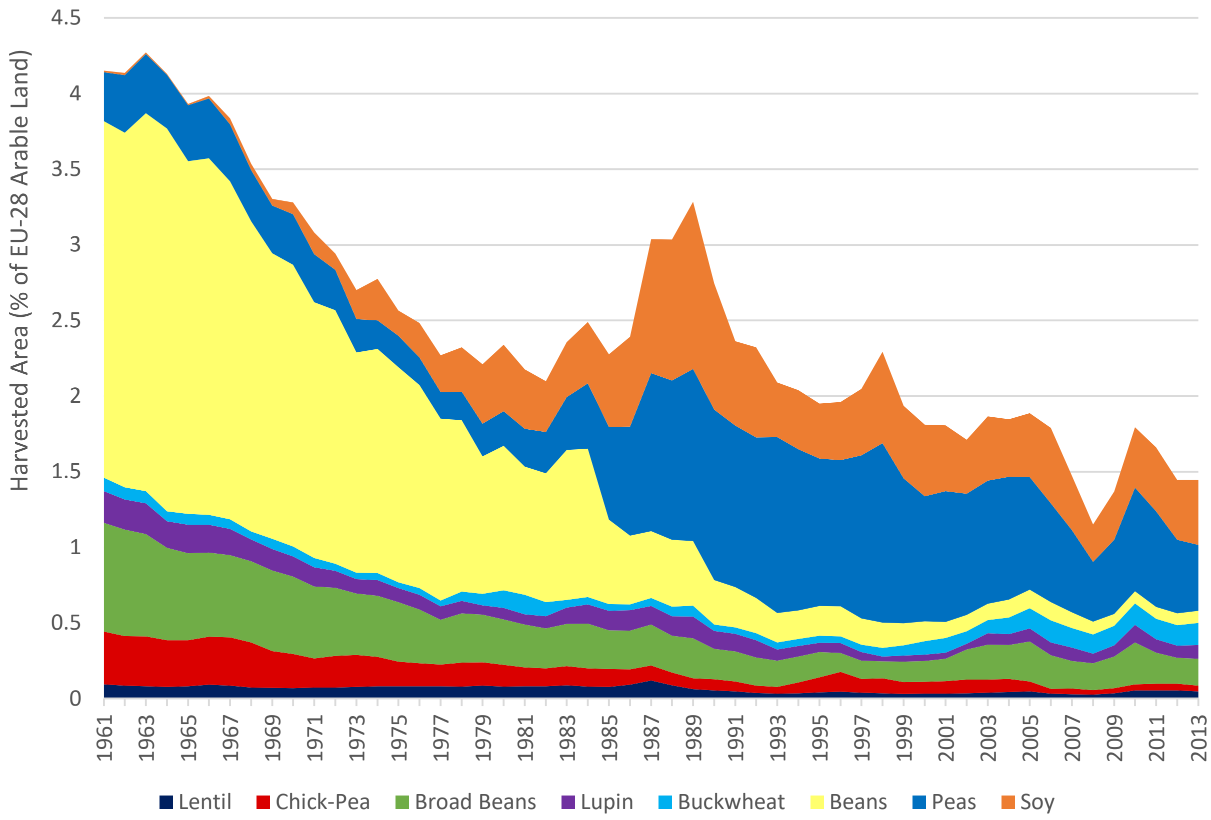




Ensure sustainability

Sven-Erik Jacobsen, PLEN

EU protein production



This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 635727.

www.protein2food.eu

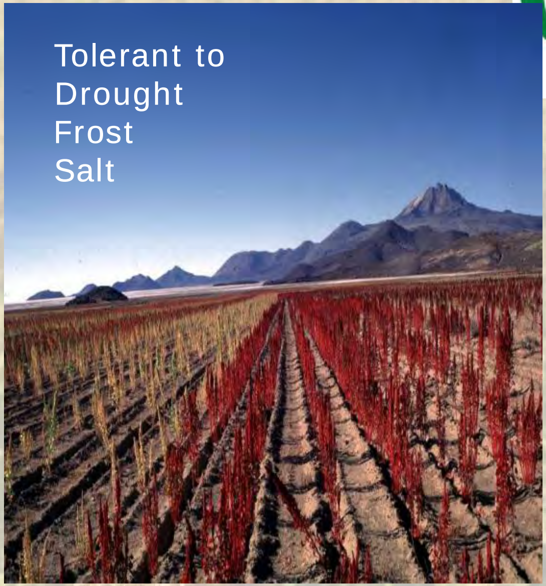
PIONEERING CROPS FOR FUTURE GENERATIONS

PROTEIN 2FOOD

Nutritional value

High protein quality
High protein content (12-20%)
High vitamin content (A, B2, E)
High mineral content (Ca, Mg, Fe, Zn)

Cultivation

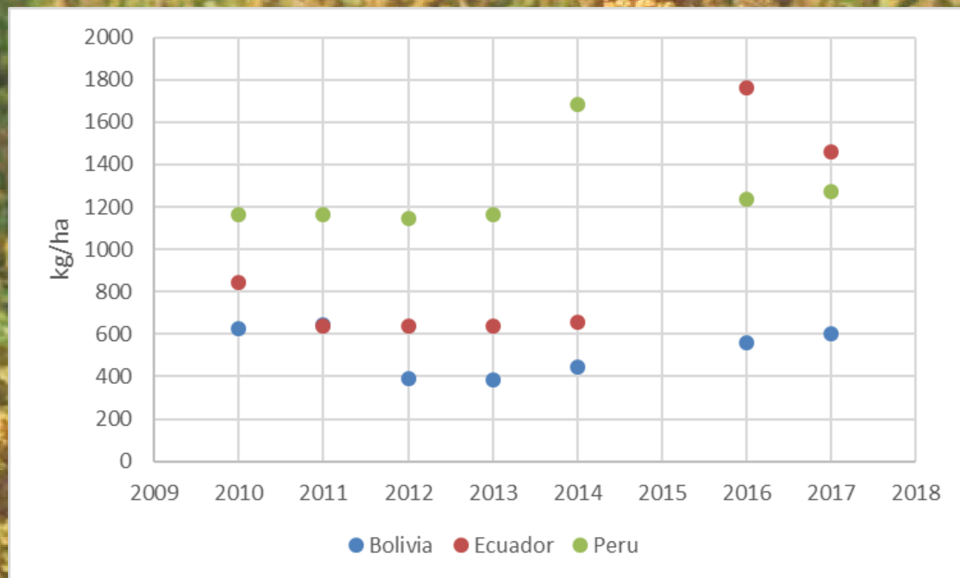


Tolerant to
Drought
Frost
Salt

Market


Area (thousand ha)
0
20
40
60
80
100
120
140
160
180
1961
1963
1965
1967
1969
1971
1973
1975
1977
1979
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
2013
2015
Bolivia
Peru
Ecuador
ha
0
20000
40000
60000
80000
100000
120000
140000
160000
180000
200000
2009
2010
2011
2012
2013
2014
2015
2016
2017
Aksetitel
Bolivia
Ecuador
Peru

Yield


kg/ha
2000
1800
1600
1400
1200
1000
800
600
400
200
0
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
Bolivia
Ecuador
Peru

Bolivia - Altiplano S (Salinas)

Countries with quinoa trials

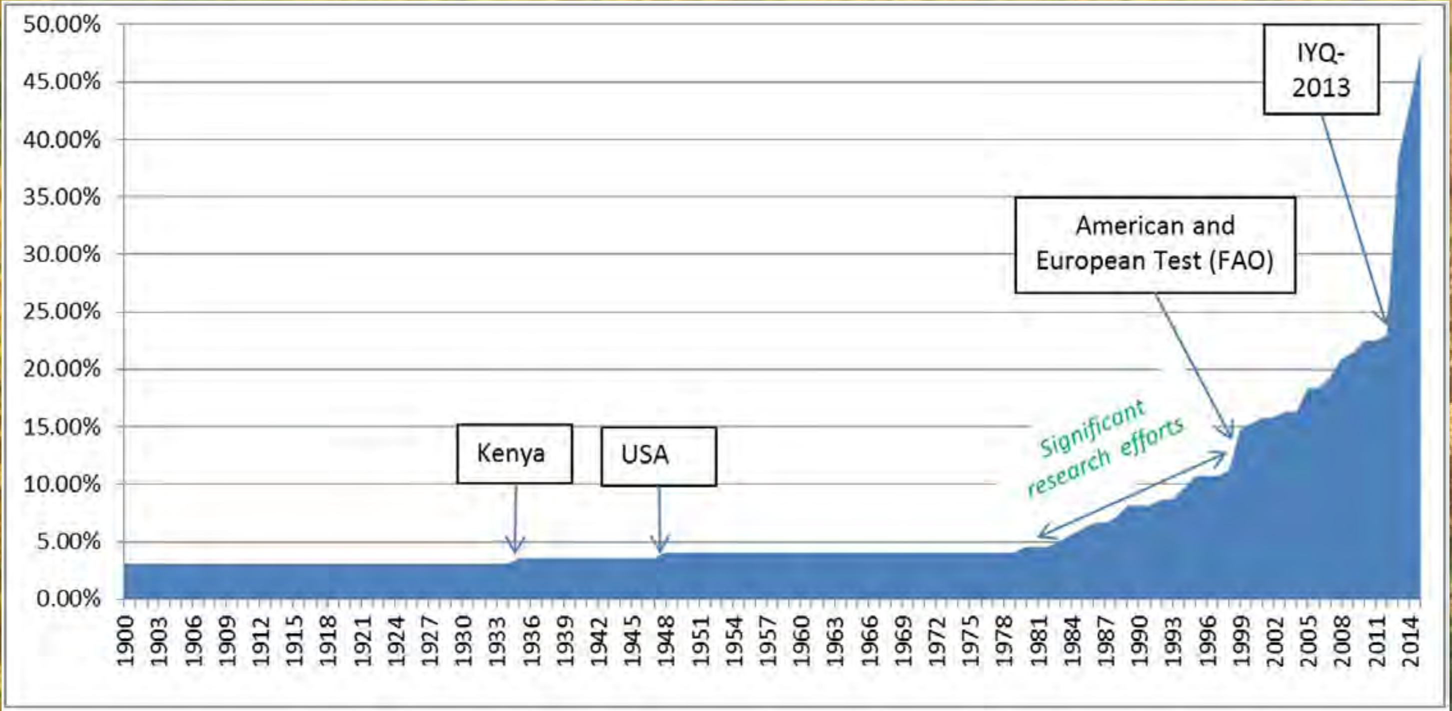


FIGURE 1 | Percentage of UN countries with quinoa experimentation or cultivation (1900–2015) (Bazile et al., 2016)

Registered European cultivars

TABLE 1 Registered European quinoa cultivars

Cultivar	Origin	Registration	Expiration	Breeder	Note
Carmen	Netherlands	2/5/1997	1/5/2022	PRI[a]	
Atlas		19/10/1999	18/10/2024	PRI	Sweet
Pasto		31/1/2005	30/1/2030	PRI	Sweet
Riobamba		31/1/2005	30/1/2030	PRI	Sweet
Red Carina		31/1/2005	30/1/2030	CPRO-DLO[b]	
Puno	Denmark	14/12/2009	31/12/2034	Quinoa Quality[c]	
Titicaca		14/12/2009	31/12/2034	Quinoa Quality	
Vikinga		15/12/2015	31/12/2040	Quinoa Quality	Sweet
Jessie	France	9/12/2013	31/12/2038	AbbottAgra[d]	Sweet

[a]PRI, Plant Research International of Wageningen University and Research Centre, The Netherlands.
[b]CPRO-DLO: CPRO—Centrum voor Plantenveredelings-en Reproduktieonderzoek (CPRO-DLO), P.O. Box 16, 6700 AA Wageningen, The Netherlands.
[c]Quinoa Quality: Quinoa Quality, Teglvaerksvej 10, DK-4420 Regstrup, Denmark.
[d]AbbottAgra, Loire-Anjou-Touraine Natural Regional Park, Les Cossonnières, 49160 Longué-Jumelles, France.

Commercial quinoa in Europe

Area, ha

- South America
  - Peru, Bolivia
  - 60000, 120000

- Europe
  - FR, ES, IT, DE, DK, NL, BE, SE, UK
  - 6500 ha

- China
  - 6000 ha

- **Total: 192500 ha**

Price and market

- Farmer:
  - Conventional 1 USD/kg
  - Organic 2 USD/kg

- Alternatives
  - Cereals 0.1-0.3 USD/kg

- Yield
  - Cereals 5 – 7 t/ha
  - Quinoa 1 – 3 t/ha

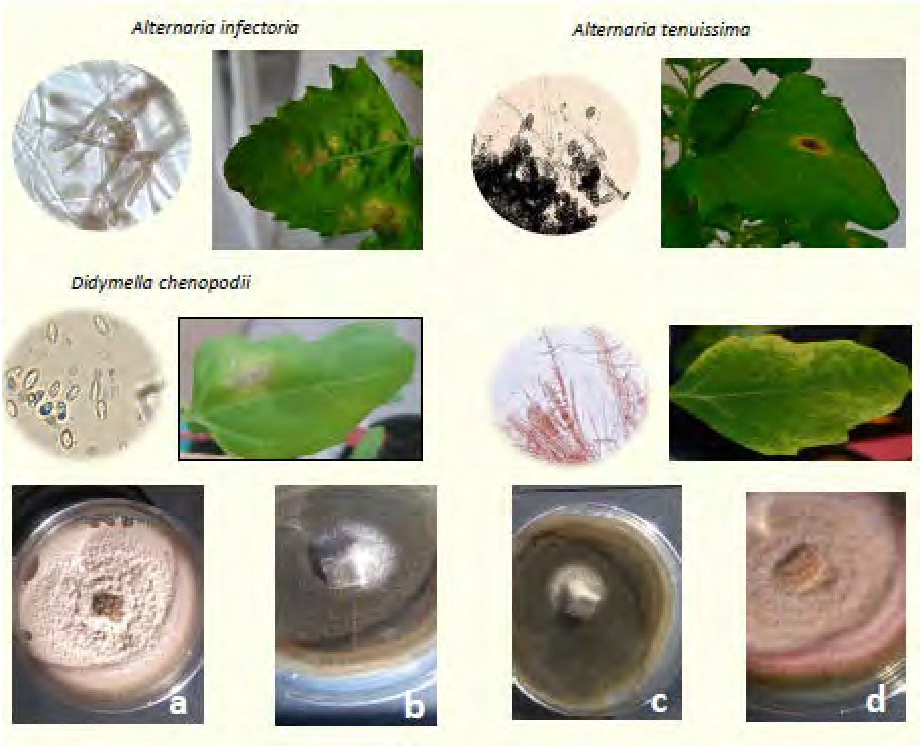
Quinoa in Denmark

Bedformer

Pneumatic single seed sowing machine

Diseases

- Peronospora variabilis
- Alternaria infectoria
- A. tenuissima
- Didymella chenopodii
- Epicoccum nigrum

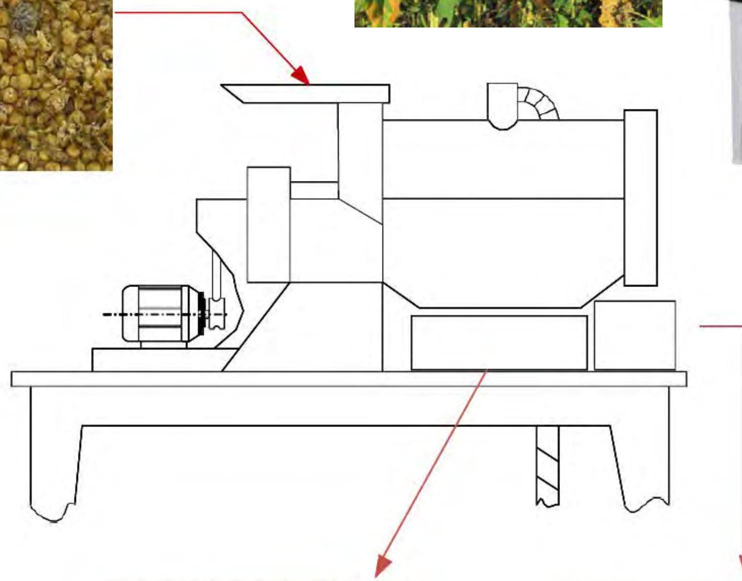


Pests

- Black aphid (Aphis fabae)
- Green aphid (Aphis pomi)
- Lepidoptera - Moth (Scrobipalpa atriplicella)
- Tortoise beetle (Cassida nebulosa)
- Altica sp.
- Sugarbeet weevil (Conorrhynchus (Cleonus) mendicus Gyll.)
- Lygus bugs
- Chenopodium-specific moths

Dehulling

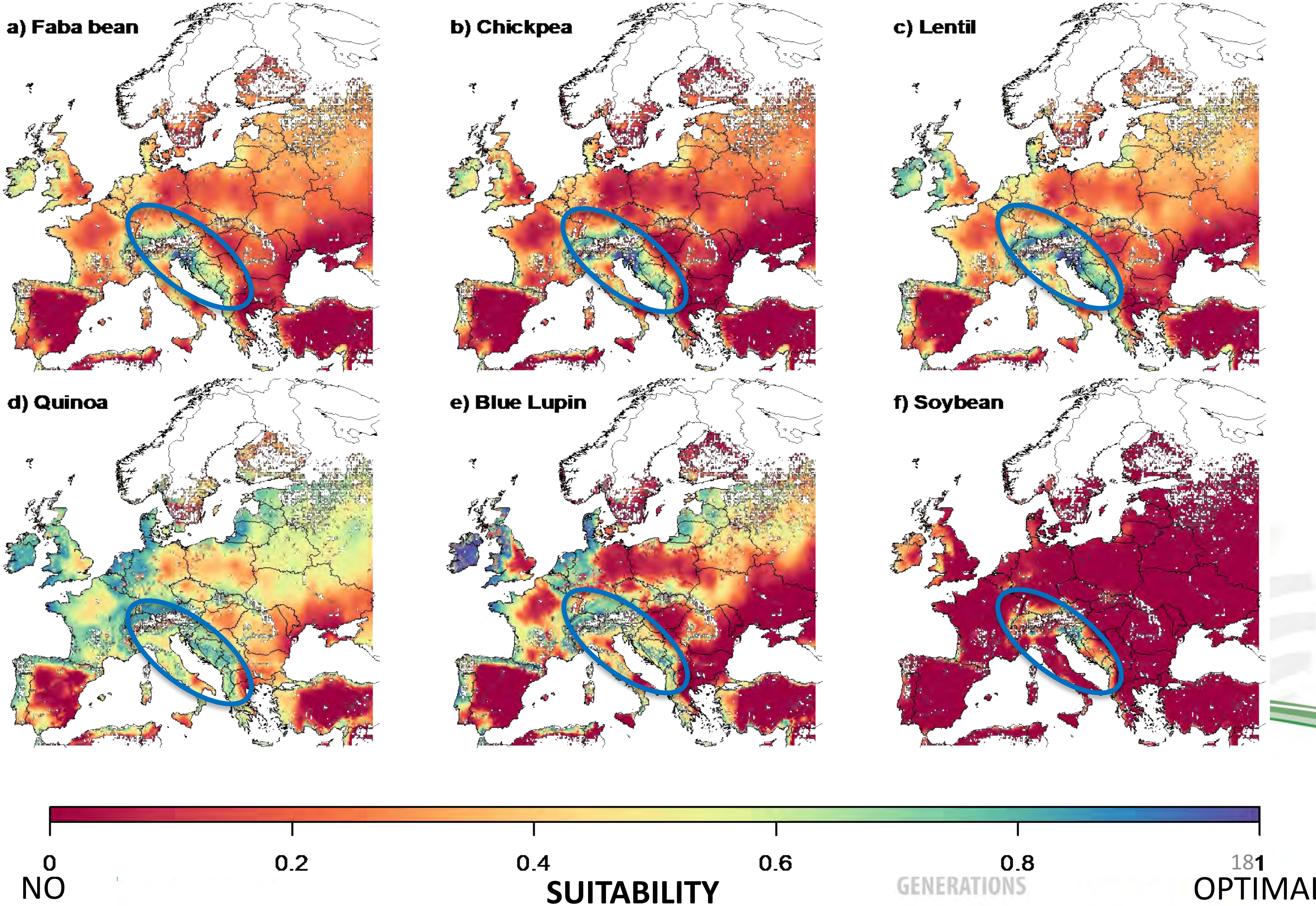
Incoming quinoa with saponin



Product removed from the quinoa surface incl. saponin

Peeled quinoa

EU Protein crop suitability under CC



GENERATIONS

Meat reducers (65%)

Meat lovers 35%, meat avoiders 5%)

- Age 18-35
- Urban
- Low score in neophobia

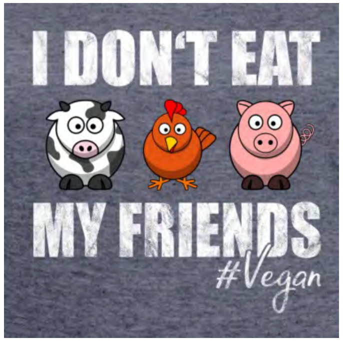


Table I What was your motivation for not eating meat at least once a week? n=28	%
Environmental concerns	78%
Animal well-being	41%
I don't need it	30%
Health	22%
Financial	11%
Variation	7%

With what did you replace the meat with those days	%
Fish/ Sea fruits	54%
Pulses	50%
Dairy (Cheese/cream)	46%
Meat substitutes (Very similar to meat)	32%
Nuts	29%
Mushrooms	25%
Not similar to meat (vegetable burger)	21%
Quinoa, Bulgur or Amaranth	14%
Traditional (tofu, tempeh)	11%
Nothing	7%
Seeds	4%

Products tested (scale 1-7)

		Tasty	Familiar	Easy to prepare	Recom
1.	Quinoa burgers	6,0	2,8	6,5	5,9
2.	Lupi love spread curry	5,9	1,9	6,8	5,7
3.	Fava bean snack	5,8	2,0	6,5	5,3
4.	Quinotto	5,8	3,2	6,0	5,4
5.	Vegetarian chicken	5,6	4,8	6,5	5,8
6.	Protein enriched bread	5,6	1,9	6,8	5,5
7.	Chickpea curry in a bag	5,4	2,1	6,8	4,9
8.	Lupin beans in glass	4,9	1,5	6,5	5,1
9.	Lupin Tempeh	4,5	2,6	6,1	4,6
10.	Protein enriched pasta	4,3	2,0	5,9	3,9
11.	Lupin beans chopped	3,4	1,3	3,9	3,2

Sven-Erik Jacobsen, PLEN

Horizon 2020 research and innovation programme under

Hvordan ændrer vi forbrugsvaner?

Quinoa at various occasions

Saison

Knabstrup

Årstiderne

Washington

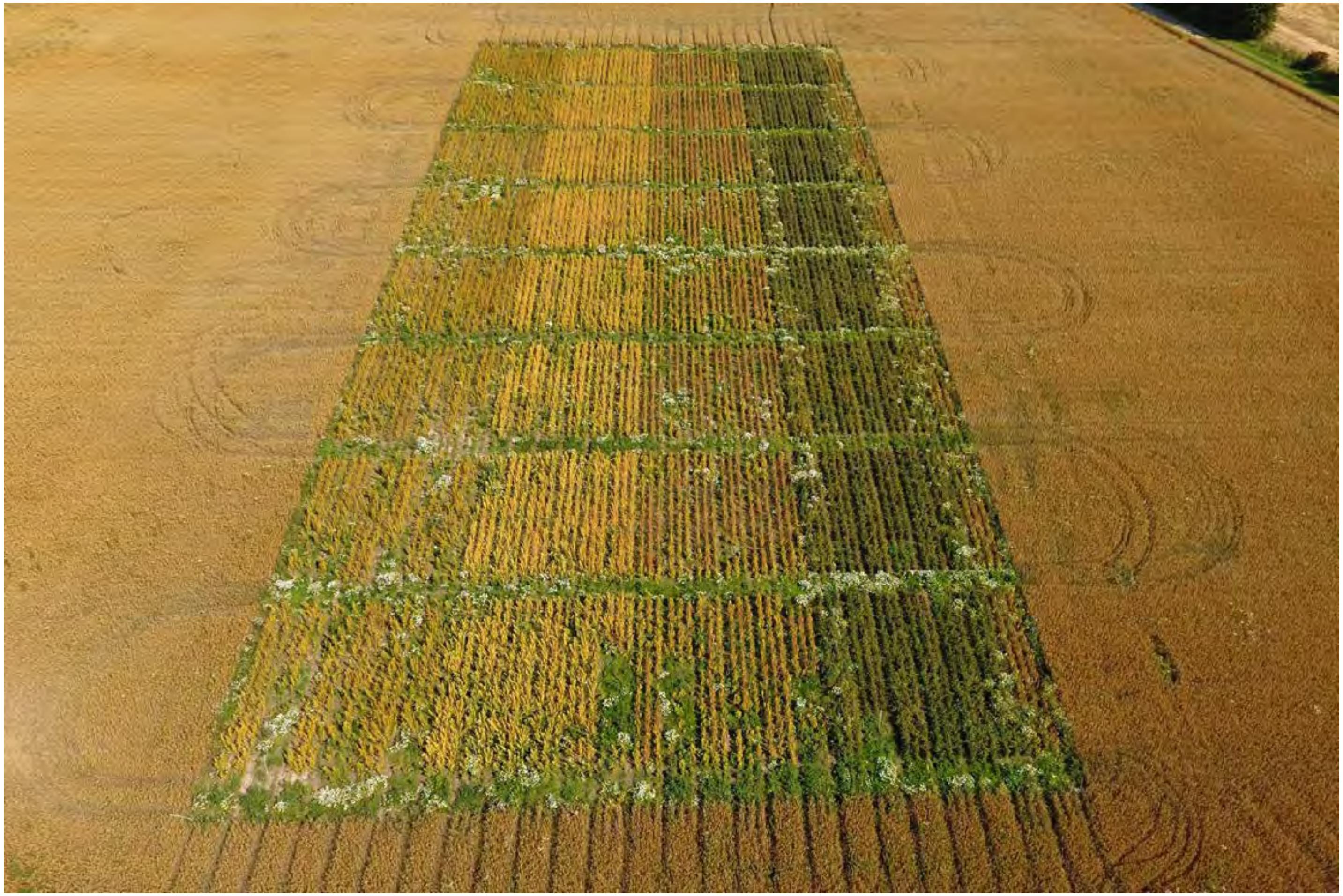

NATURLI'
HAKKET
100% PLANTEBASERET
400G


Kick-Ass
VEGAN
Curry Burgers

Conclusion

- *New genetic material*
- *Increase agrobiodiversity*
- *Decrease the focus on monocrops*
- *Develop new food products*
- *Improve cropping systems and technology*

Thanks



Lessons learned from Bambara groundnut

Dr Sean Mayes

Bambara groundnut;
International Institute for Tropical Agriculture (IITA), Nigeria; Green World Genetics Seed; Capstone Seed

Amaranth;
World Vegetable Centre (AVRDC), Taiwan, Tanzania; East West Seed

Moringa;
World Agroforestry Centre, Kenya

CFF-UNMC Centre for Water/Heat Stress Research

Understanding the mechanisms of stress resistance in underutilised crops to build future crop resilience

Addressing both transient and prolonged stresses

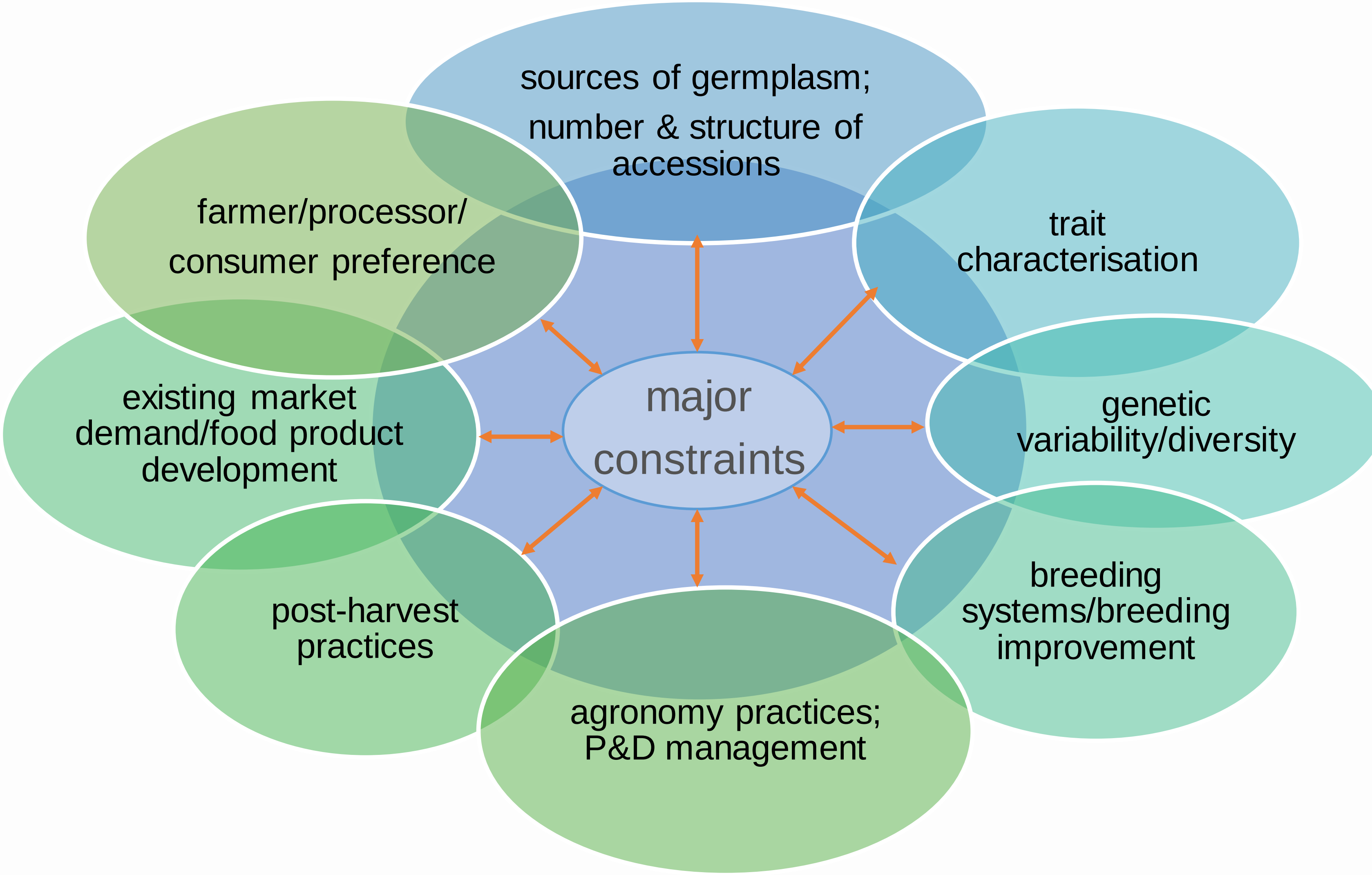
Tef?;
Ethiopia,
University of Addis Ababa

Proso millet;
Sabaragamuwa Uni of Sri Lanka

Other millets such as Foxtail

Massawe et al., 2016; Cheng et al., 2015

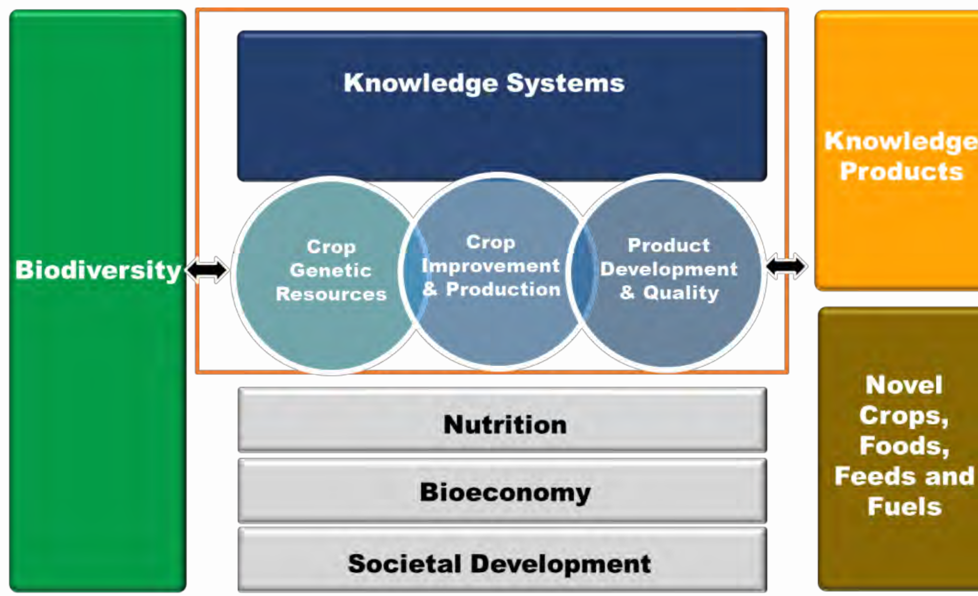
Some of the constraints in underutilised crops/species:



CFF Research Strategy

CFF HQ – Near Kuala Lumpur, Malaysia

Research Strategy and approach



Exemplar: bambara groundnut (*Vigna subterranea*)

Strengths:

- Drought tolerance
- Grows in semi-arid & tropical environments, marginal soils
- Nitrogen fixing
- Fast growing (4-5 months)
- 3rd most important nutrient legume in sub-Saharan Africa
- A potential model for underutilised legume approaches

Drawbacks

✖ Photoperiod sensitive
✖ Variability within landraces
✖ Lack of commercial varieties
✖ Limited markets & value added products
✖ P&D management

Opportunities

- Food security
- Income generation
- Product development
- Human dietary diversification
- Animal feed

Building on existing knowledge – a new crop for Europe, an ancient crop for Africa and a recent crop for South East Asia…

Nottingham, UK, 2012

Europe:
- Testing a new crop for S. Europe
- Semi-arid agriculture
- Food and feed

…Learning from the current farmers, processors and end users

Africa:
- Food & nutritional security
- Small-scale farmers

Gabarone, Botswana, 2009

Research into common constraints, leading to benefits for all Regions

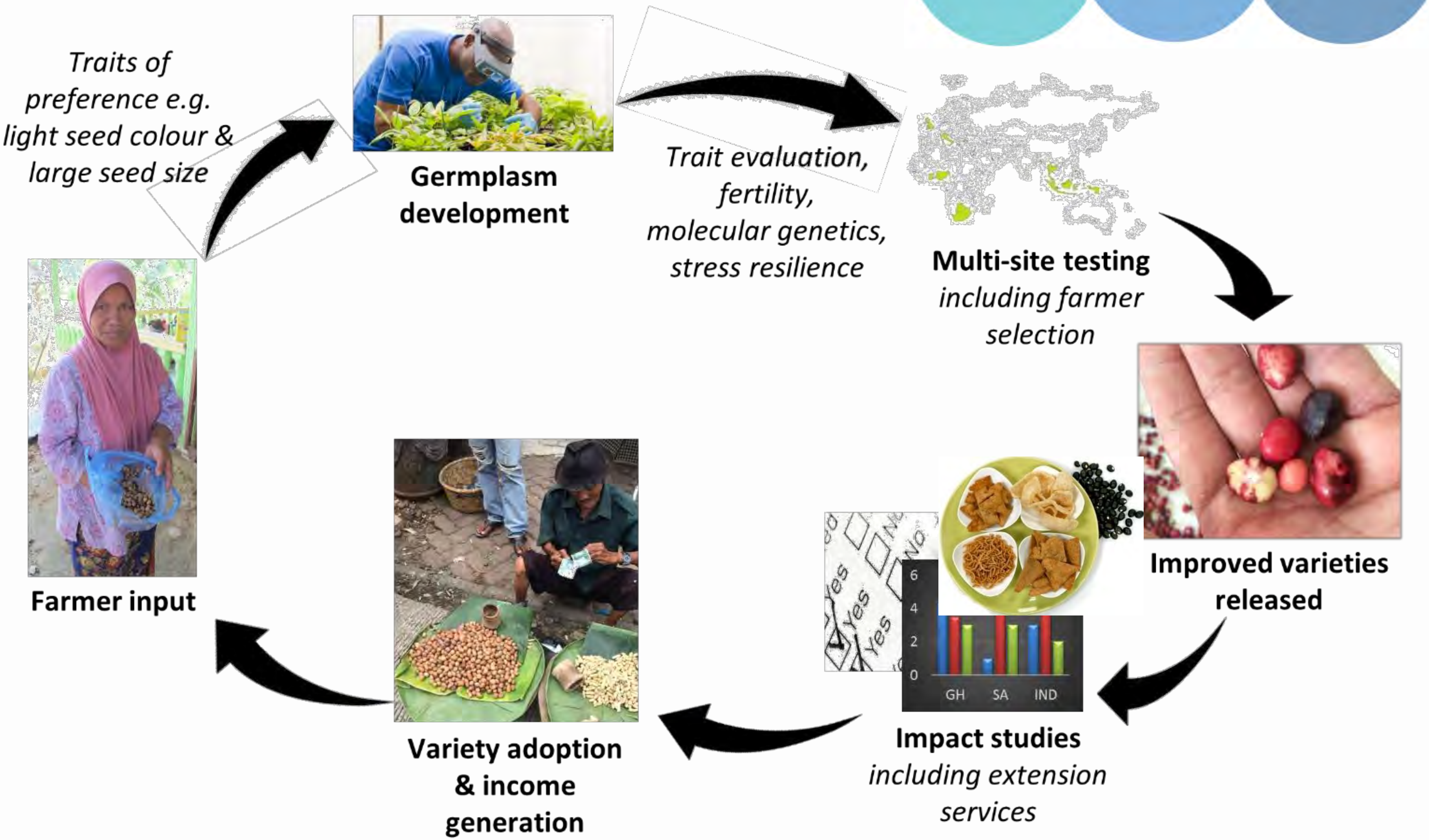
South East Asia
- Cash crop
- Value added products

Malang, Indonesia, 2010

Chai et al., 2015; Musa et al., 2016; Musa et al., submitted to Scientifica

Research Value Chain approach

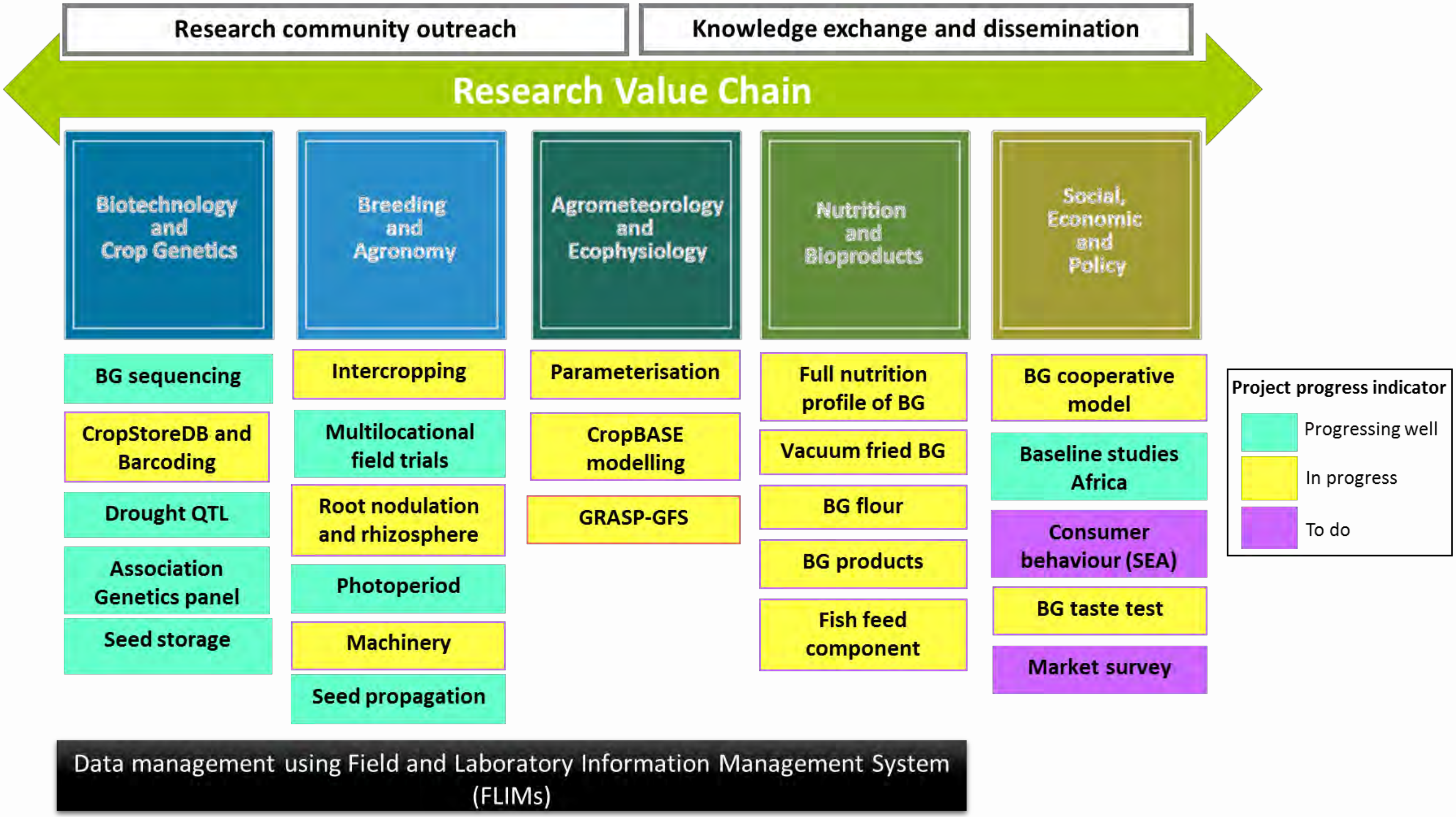
bambara groundnut as an exemplar



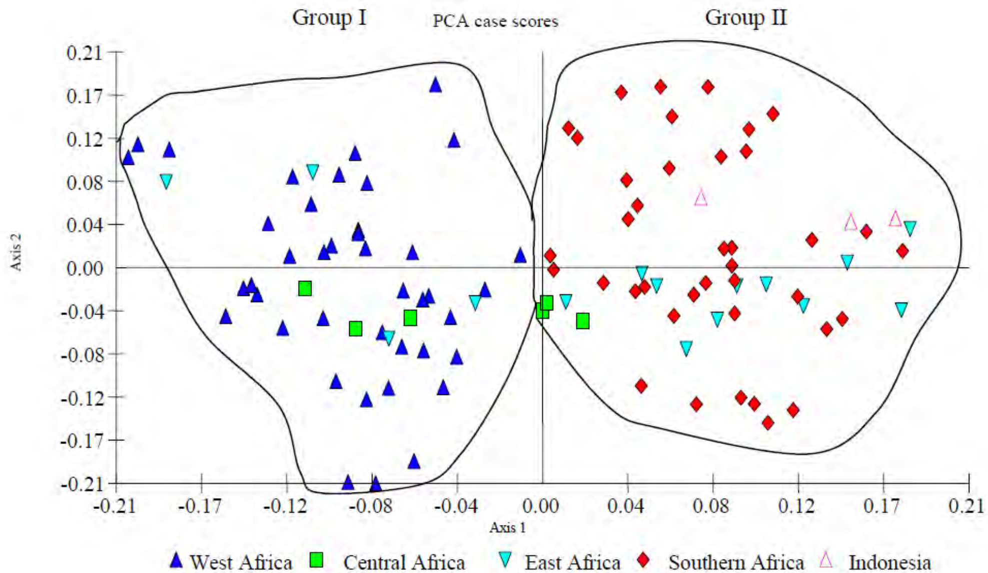
Adzwala, et al., 2016a; Adzwala, et al., 2016b; Aliyu et al., 2015 & 2016

BamYIELD

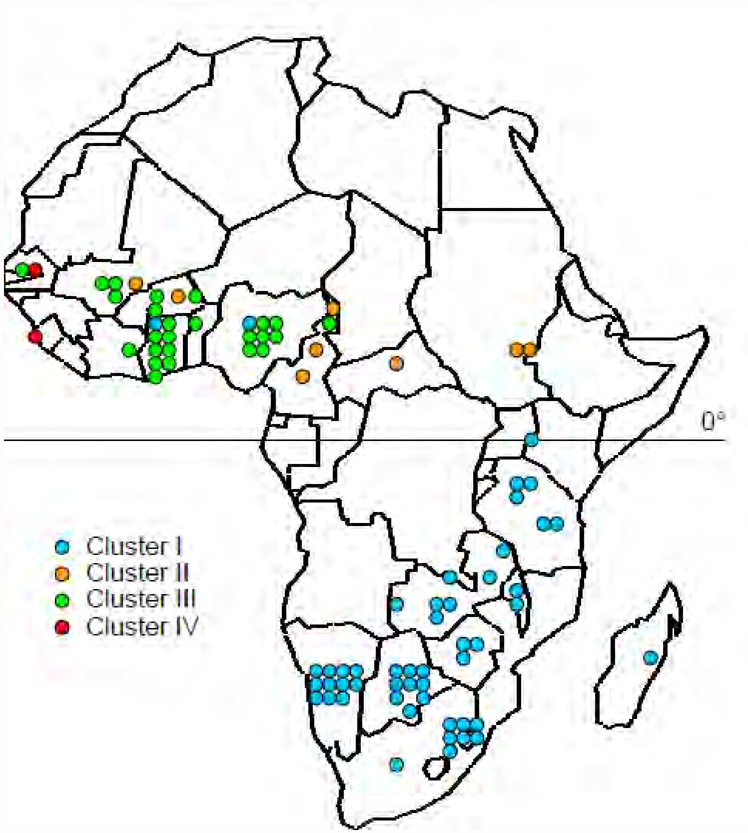
BamNetwork – www.bambaragroundnut.org



Diversity of germplasm



SSR-based genetic diversity analysis (PCA)



DArT microarray analysis

Clear differentiation between West and South+East African accessions

Molosiwa et al., 2015; Aliyu et al., 2015

Breeding & agronomy:
Structured germplasm development

core germplasm

Name	Origin
Ankpa4	Nigeria
DipC	Botswana
DodR	Tanzania
Getso	Nigeria
Gresik	Indonesia
IITA-686	Tanzania
LunT	Sierra Leone
S19-3	Namibia
Tiga Necaru	Mali
Uniswa Red	Swaziland

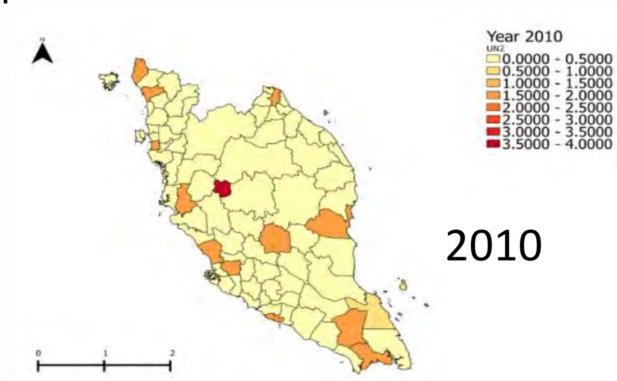
controlled crosses from core parents

Cross	Generation
Ankpa4 x IITA-686 (& reciprocal)	F_2/F_3
S19-3 x Ankpa4	F_3/F_4
DipC x Ankpa4	F_2/F_3
IITA-686 x LunT	F_2
Ankpa4 x DodR	F_1
Uniswa Red X Getso	F_1
Uniswa Red x DodR	F_1
S19-3 x Getso	F_1
S19-3 x Ankpa4	F_1
Ankap4 x DipC (& reciprocal)	F_1

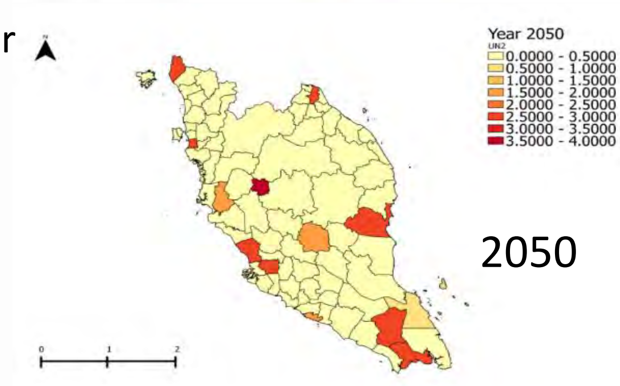
Association Panel:
420 genotype lines from genebank, farmers, researchers, UoN materials
Small seed numbers, test of GbS marker panel for seed coat colour (end-2017)

Climate and growth modelling prediction

- Provide baseline data for future field experiments for proof of concept
- Suitability mapping and prediction of which crops could be grown now in a particular location or could be grown in the future, under Climate Change, along with potential products and markets
- Development of geospatial, genotype-anchored databases for selection potential germplasm



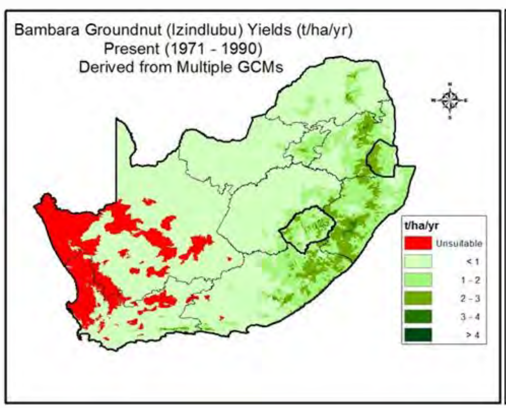
2010



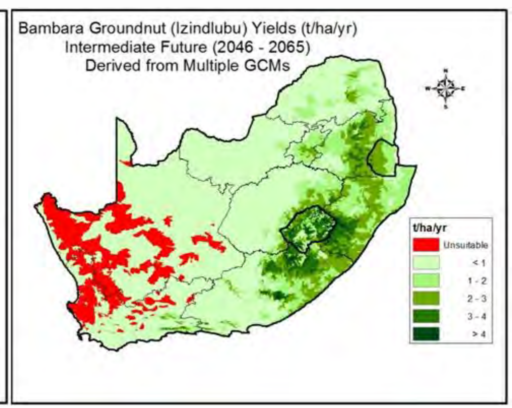
2050

Uniswa Red (Swaziland; sub-humid)

MALAYSIA



Yields 1971-1990



Yields 2046-2065

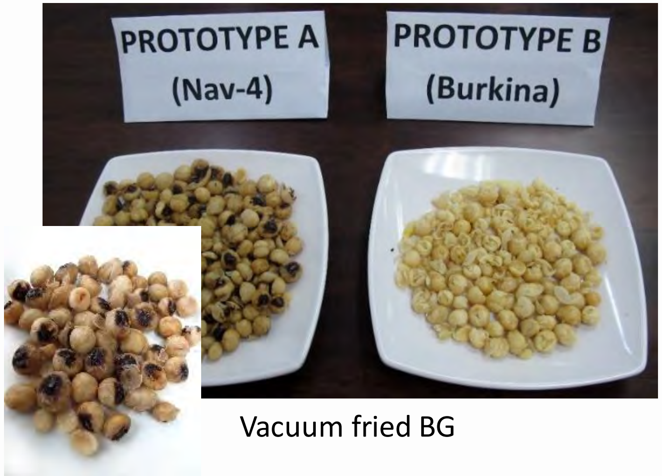
Jozini;

SOUTH AFRICA

Santos et al., 2016; Leibovici et al., 2017; CropBASE (unpublished); T. Mabhaudhi, R.P. Kunz and R.E. Schulze (unpublished)

Nutrition content and food product development

‘Boiled’ snack in Kedah & Thailand



Vacuum fried BG

BG biscotti

BG patty burger bun

‘Fried’ snack in Indonesia

Pandan/red BG drinks - in collaboration with a local snack company

BG tortilla chips (with rice flour, 90% BG), Keropok (with tapioca and rice flour, 20% BG), BG tortilla chips (with tapioca flour, 90% BG) and murukku (with rice flour, 50% BG)

Social, Economics and Policy

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- Improving livelihood of local communities

1) Value Chain research in Indonesia

- Assessment of co-operative model set up for BG cultivation, and production of raw material for direct commissioning of processing by the farmers, socio-economic impact on local community

2) End user research in Africa

- Acceptance of local community towards BG as a crop, and as a food source (Ghana, Nigeria and Tanzania)
- Understanding consumption, utilisation, marketing constraints

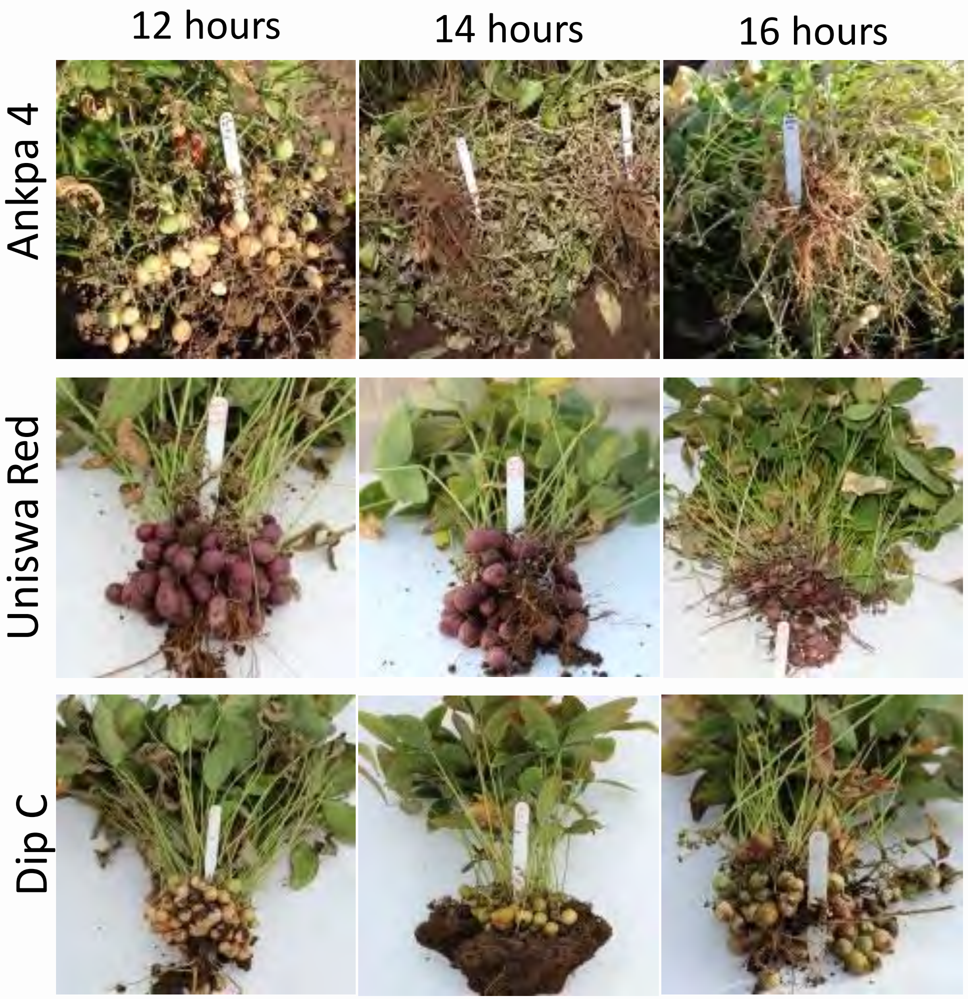
BamNetwork

Adwala et al., 2015, 2016a and 2016b (Ghana); Mabhaudhi et al. 2016 (Southern Africa);
Sri Redjeki et al. (manuscript in prep) (Indonesia)

Problem traits: photoperiod sensitivity

Differences in yield formation at three daylengths

Crops For the Future



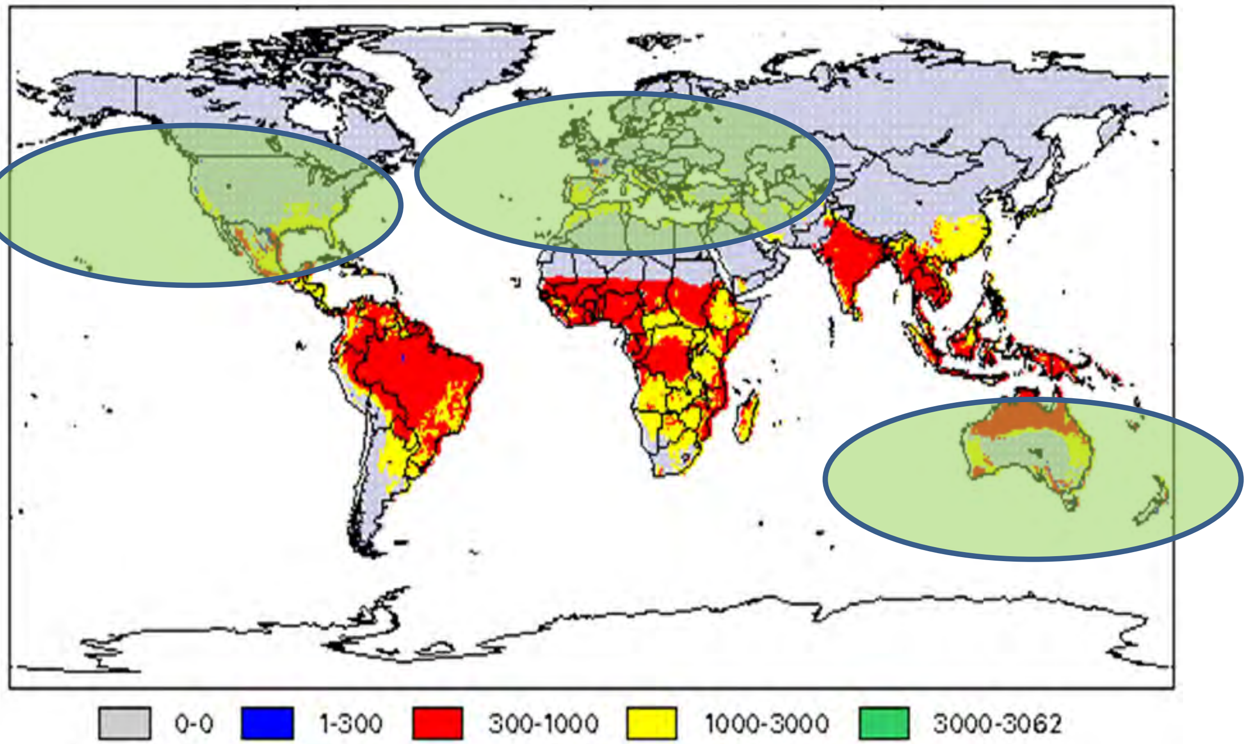
- <u>Qualitative short day:</u>
  Ankpa 4
- <u>Quantitative short day:</u>
  Tiga Necaru, Lun T, Getso and Gresik
- <u>Quantitative long day:</u>
  IITA-686 and DodR
- <u>Less-sensitive types:</u>
  Dip C, Uniswa Red and S19-3

Material supplied to KwaZulu-Natal Uni (SA), Acacia for All (Tunisia), Kirkhouse Trust and 4 ITPGRFA partners

Continued/supported by RPA-AFS C2C (Zoe Wilson)

Kendabie et al., 2015

The potential importance of reduced photoperiod



Crop suitability mapping exercise; DFID 2003

-Potential to stabilise yields, where planting always follows rains
-Potential as a new protein source in new environments

Translation: mobilising diversity

FAO-ITPGRFA (2016-2019): Looking at drought tolerance and cookability in the global germplasm
A West Africa - Southeast Asia collaboration (Ghana, Nigeria, Indonesia and Malaysia)

- developing pre-breeding materials with partners at field sites, in parallel with local germplasm

Ho et al., 2016

“Genetic and trait characterisation of farmer and genebank sources of Bambara groundnut for the development of drought tolerant lines in sub-Saharan Africa and Southeast Asia”

CFF Crops For the Future

CFF Crops For the Future

Malaysia

Ghana

CSIR — Council for Scientific and Industrial Research • Ghana •

Institut Pertanian Bogor

Indonesia

Nigeria

IITA Transforming African Agriculture

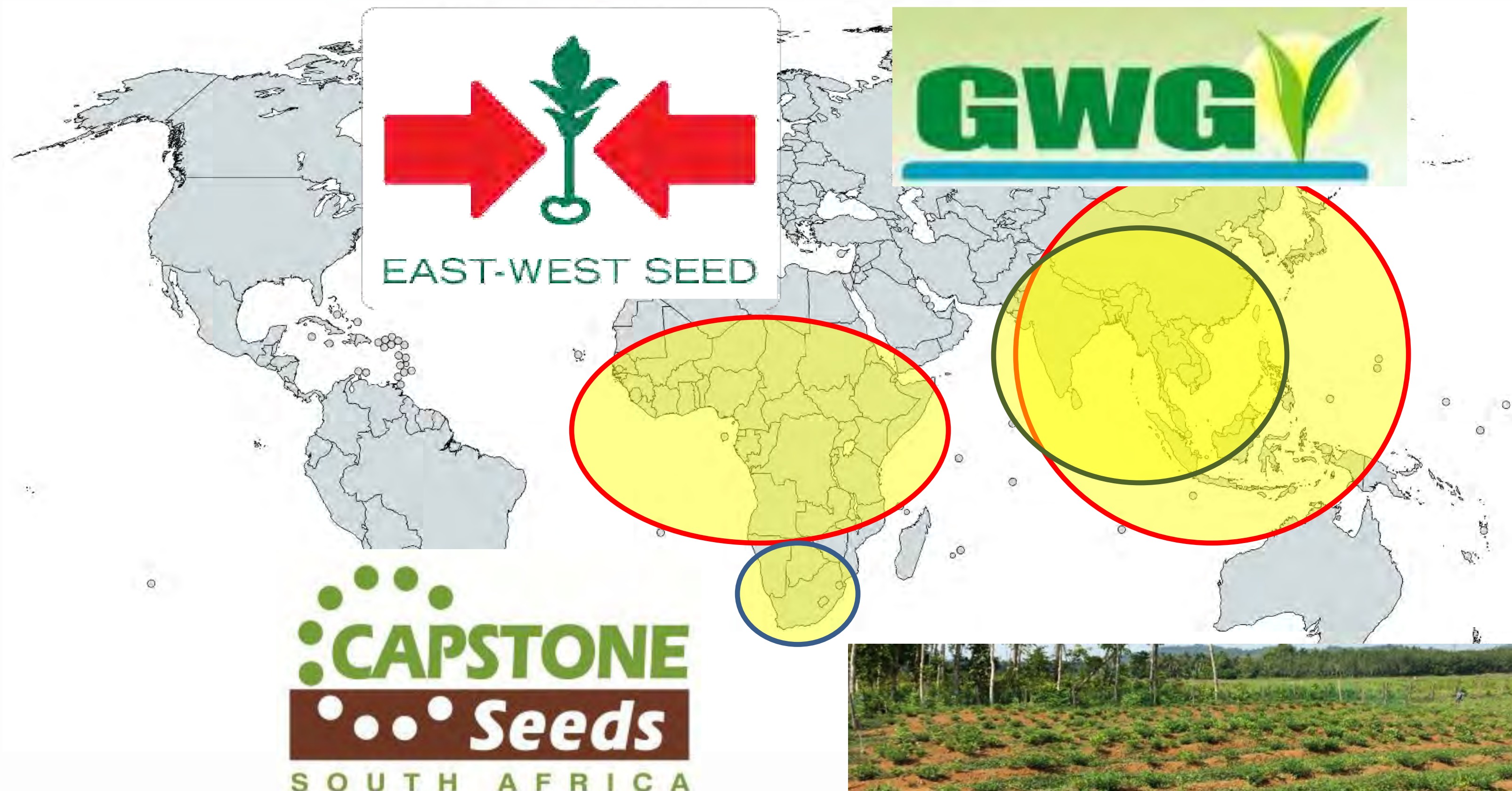
Benefit Sharing Fund; ITPGRFA; R3, W3; 2016 -2019

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

CFF Crops For the Future

Demand-led application

Global potential to commercialise underutilised crops



Seed companies (with formal agreements) to develop pipelines for our pre-breeding lines of underutilised crops through to seed available to farmers

Contract farming with a local subsistence farmer at Kedah, Malaysia (next to a rubber plantation plot)

Delivery from breeding to farmers

Crop Genetic Resources | Crop Improvement & Production | Product Development & Quality

<u>Germplasm screening</u>:
eg. photoperiod sensitivity - could be effecting yield and preventing growth in North Africa & Southern Mediterranean

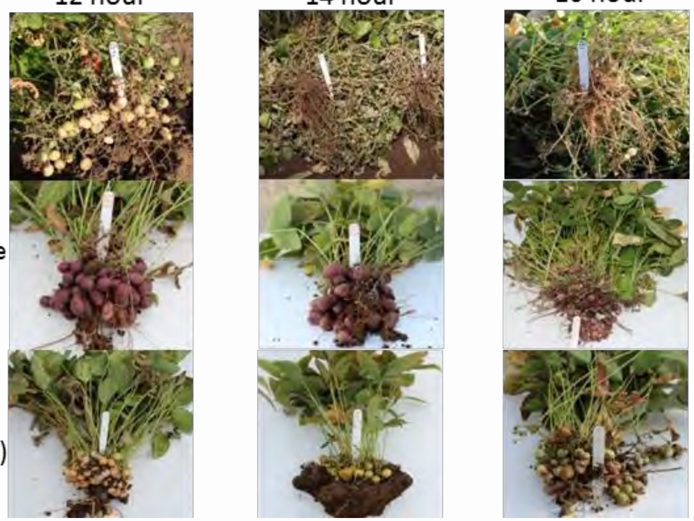
Imposed day length

12 hour | 14 hour | 16 hour

(1) qualitative short-day type

(2) quantitative short-day type

(3) Insensitive (?)



Other traits under analysis: drought tolerance, morphology, hard-to-cook

Sponsored seed provision for poor farmers

Commercial sales for cash farmers

With seed companies

• Malaysia • South Africa • Tanzania

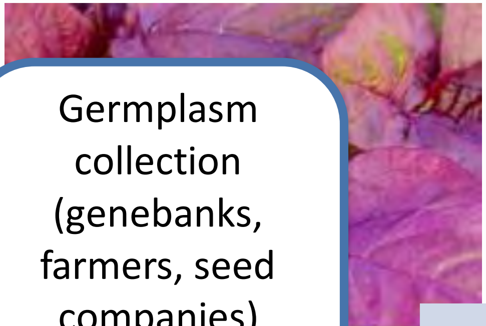
3. Field/farmer evaluation

2. Line purification / improved varieties

1. controlled field environments

Genetic analysis & introgression of climate resilience traits into locally adapted germplasm in CE chambers

Translating to other crops…



Germplasm collection (genebanks, farmers, seed companies)

Phenotypic characterization

Line purification / multiplication

Winged bean (*Psophocarpus tetragonolobus*)

Proso millet (*Panicum miliaceum*)

<u>Genotyping characterisation (GbS & SSR)</u>

- Core set development

- in-breeding/heterozygosity assessment

-diversity/population analysis

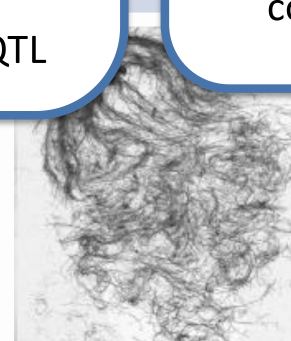
-genetic mapping & QTL

Further characterisation

eg. defined abiotic stress screening,

nutrient uptake/ composition analysis

Field evaluation – potential improved varieties



Leafy Amaranths (esp. *Amaranthus tricolor*)

Wong et al., 2017; Jamalluddin et al. (manuscript in prep)

Current bottlenecks:

1. Significant interest from large food companies, but no offers to assist with the cost of scaling

2. Lack of detailed understanding of genetic x environment effects on composition and functional properties

Theme 1: Genetic Resources and field studies	Theme 2: Crop Improvement and production	Theme 3: Product development and quality	Theme 4: Knowledge Systems
Bamyield — Genome sequence 100 lines reseq; FRC/GWG Trials	Acacia for All; 50 lines (Tunisia)	BAMPRO(2018-2020) 2.4 M MYR; C2C (£55K) FoodPlus; FishPlus ASSESSCROP (750K MYR)	Bamyield; CropBase SCU-CropStore – PhD, MSc DivSeek
ITPGRFA Nigeria, Ghana, Indonesia, Malaysia; common 12 and Associational Panel with IITA; 4 PhD $500K; 2016 - 2019		MSc Seed imbibition	ITPGRFA Surveys – Nigeria, Ghana, Indonesia $500K; 2016 - 2019
Beacon Future Food - Bambreed Major targets : photoperiod requirement, Hard-to-Cook, registration £1.8M – 2018-2013		SCU- Nutritional pipeline for BG; 2016-2020 - PhD; UoN – Processing; meal worms – 2 PhDs; 2018-21	Beacon Future Food – Bambreed £1.8M – 2018-2013
Plant Breeders w/o Borders Crossing training for farmers – new lines (€300K – 2018-2022; Bayer)	RSA Fellowship – field assessment in UKZN; 2018-19; IAA –UoN; 2018 Strigolactones –UoAmsterdam	Monash hard-to-cook	Plant Breeders w/o Borders Community-led breeding(€300K – 2018-2022; Bayer)
IAA-Adelaide-UoN Aerial remote sensing PhD 2018-21	UNMC funded PhDs -drought; in shade house; in Tanzania		C2C – UK tasting (£50K)
	UoN PhDs -drought assessment FutureCrop		Newton LINKs workshop – UoN-ICRAF-UKZN UK-Kenya-South Africa 9th – 15th July 2018
Kirkhouse Trust –Stress Tolerant Orphan Legumes Comparative testing of 4 legumes; 52 lines of BG Burkino Faso, Tanzania; no cost; 2017-2020			

June 2018 onwards:

- Modification of peanut planting and harvesting machinery
- Sheller development begins
- Development of projects in Kedah state and on a demonstration farm in Malaysia producing 'simple' snack products
- **Development of a dedicated breeding programme for high value ingredients –scale to 1000 hectares in three years**

Conclusion:

Ideally, the products from an underutilised crop need to be high value to subsidise the cost of upscaling from experimental to production

Beacons of Excellence

Crops For the Future

Future Food

Addressing food security for a changing world

bambara groundnut: focus on generating improved varieties with reduced photoperiod sensitivity and hard-to-cook traits; CFF-UNMC based subproject (£1.8M over 5 years) of the main Beacon led by Prof David Salt (approx. £24M over 5 years); start January 2018

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European Framework Programmes
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CFF, Malaysia
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Kirkhouse Trust
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UoN RPA-AFS; C2C project

Genetic diversity analysis:
Florian Stadler, TUM, Germany
Odireleng Molosiwa, UoN

Genetic mapping, QTL & eQTL:
Rakhi Basu, UoN
Nariman Ahmad, UoN
Hui Hui Chai, UoN
Neil Graham, UoN
John Peter Hammond, Reading Uni, UK

Sequence analysis:
Martin Blythe, Deep Seq, UoN
Joanna Moreton, ADAC, UoN
Wai Kuan Ho, CFF

Genome sequence:
Beijing Genome Institute
AOCC; Wai Kuan Ho

Single Genotype Lines:
Presidor Kendabie
Katie Mayes

DArTseq development:
Andrzej Kilian, DArT Pty Ltd., Australia

Gene Networks:
Suresh Bonthala, UoN
Faraz Khan, UoN
Jamie Twycross, UoN
Chungui Lu, NTU

CropStore Database
Prof Graham King

Crop Yield Mapping
Prof Asha Karunaratne

Geospatial, UoN
Didier Leibovici
Suchith Anand
Roberto Santos

University of Nottingham
UK | CHINA | MALAYSIA

CFF
Crops For the Future

Our publications

Abberton, M., et al., (2015) Global agricultural intensification during climate change: a role for genomics. ***The Plant Biotechnology Journal*** DOI: 10.1111/pbi.12467

Adzawla, W., Donkoh. S. A., Nyarko, G., O'Reilly, P.J., Olayide, O, E., Awai, P. E. (2015) Technical efficiency of bambara groundnut production in northern Ghana. ***UDS International Journal of Development*** 2(2) 37-49.

Adzawla, W., Donkoh. S. A., Nyarko, G., O'Reilly, P.J., Olawale, O.E., Mayes, S., Aryo. F., and Azman, H.A. (2016a) Adoption of Bambara groundnut production and its effects on farmers' welfare in Northern Ghana. ***African Journal of Agricultural Research*** 11(7) 583-594

Adzawla, W., Donkoh, S.A., Nyarko, G., O'Reilly, P., Olayide, O.E and Awai, P.E (2016b) Use patterns and perceptions about the attributes of Bambara groundnut (*Vigna subterranea* (L.) Verdc.) in Northern Ghana. ***Ghana Journal of Science and Technology Development***

Ahmad, N.S., Sri Redjeki, E., Ho, W.K., Aliyu, S., Mayes, K., Massawe, F., Kilian, A. and Mayes, S. (2016) Construction of a genetic linkage map and QTL analysis in bambara groundnut. **Genome** 59(7): 459-472, 10.1139/gen-2015-0153

Aliyu,S., Massawe, F. and Mayes, S. (2016) Genetic diversity and population structure of Bambara groundnut (*Vigna subterranea* (L.) Verdc.): synopsis of the past two decades of analysis and implications for crop improvement programmes ***Genetic Resources and Crop Evolution*** 1-19

Aliyu, S, Massawe, F.J. and Mayes, S. (2015) Beyond landraces: Developing improved germplasm resources for underutilized species - a case for Bambara groundnut ***Biotechnology and Genetic Engineering Reviews***; 30:127-41

Bonthala, V.S., Mayes, K., Moreton, J., Blythe, M., Wright, V., May, S., Massawe, F., Mayes, S. and Twycross, J. (2016) Identification of gene modules associated with low temperatures response in bambara groundnut by network-based analysis. ***PLoS One*** 11(2): e0148771. doi:10.1371/journal.pone.0148771

Burgess, A.J., Retkute, R., Pound, M.P., Mayes, S. and Murchie, E.H. (2017) Image based 3D canopy reconstruction to determine potential productivity in complex multi-species crop systems. ***Annals of Botany*** mcw242. doi: 10.1093/aob/mcw242

Chai, H.H., Massawe, F.J. and Mayes, S. (2015) Effects of mild drought stress on the morpho-physiological characteristics of a Bambara groundnut segregating population. ***Euphytica*** DOI 10.1007/s10681-015-1581-2

Chai, H.H., Ho, W.K., Graham, N., May, S., Massawe, F. and Mayes, S. (2017) A cross-species GEM-based genetic map and QTL analysis in bambara groundnut. ***Genes***

Cheng, A., Mayes, S., Dalle, G., Demissew, S. and Massawe, F.J. (2015) Diversifying crops for food and nutrition security – a case of teff ***Biological Reviews*** doi: 10.1111/brv.12225

Ho, W.K., Muchugi, A., Muthemba, S., Kariba, R., Mavenkeni, B.O. Hendre,P., Song, B., Deynze, A.V., Massawe, F. and Mayes, S. (2016) Use of microsatellite markers for the assessment of bambara groundnut breeding system and varietal purity for genome sequencing. ***Genome*** 59(6) 1-5

Ho, W.K., Chai, H.H., Kendabie, P., Ahmad, N.S., Jani, J., Massawe, F., Kilian, A. and Mayes, S. (2017) Integrating genetic maps in bambara groundnut [*Vigna subterranea* (L) Verdc.] and their syntenic relationships among closely related legumes. ***BMC Genomics*** 18:192.
Kendabie, K., Massawe, F. and Mayes, S. (2015) Developing genetic mapping resources from landrace-derived genotypes that differ for photoperiod sensitivity in bambara groundnut (*Vigna subterranea* L.) ***Aspects of Applied Biology*** 124, Breeding Plants to Cope with Future Climate Change pp 49 – 56
Khan, F., Azman, R., Chai, H.H., Mayes, S. and Lu, C. (2016) Genomic and transcriptomic approaches towards the genetic improvement of an underutilised crops: the case of bambara groundnut. ***African Crop Science Journal*** 24, 4, 429 - 458
Khan, F., Chai, H.H., Ajmera, I., Hodgman, C., Mayes, S. and Lu, C. (2017) Transcriptomic comparison of two Bambara groundnut landraces under drought stress.
Mabhaudhi, T., O' Reilly P., Walker, S. and Mwale S. (2016) Opportunities for underutilised crops in Southern Africa's post-2015. ***Sustainability*** 8(4), 302.
Massawe, F.J, Mayes, S. and Cheng, A. (2016) Crop diversity – an unexploited treasure trove for food and nutrition security ***Trends in Plant Science*** 21(5): 365-368
Mayes, S., Ho, W.K., Kendabie, K., Chai, H.H., Aliyu, S., Feldman, A., Halimi, R.A., Massawe, F. and Azam-Ali, S (2015) Applying molecular genetics to underutilised species – problems and opportunities. ***Malaysian Applied Biotechnology*** 44(4); 1-8.
Molosiwa, O., Aliyu, S., Stadler, F., Mayes, K., Massawe, F.J., Kilian, A. and Mayes, S. (2015) SSR marker development, genetic diversity and population structure analysis of Bambara groundnut [*Vigna subterranea* (L.) Verdc.] landraces. ***Genetic Resources and Crop Evolution*** DOI 10.1007/s10722-015-0226-6
Muhammad, Y.Y., Mayes, S. and Massawe, F.J. (2015) Effects of short term water deficit stress on physiological characteristics of bambara groundnut (*Vigna subterranea* L. Verdc). ***South African Journal of Plant and Soil*** DOI:10.1080/02571862.2015.1056847
Musa, M., Al-Shareef, I., Mayes, S., Massawe, F.J. and Singh, A. (2016) Nitrogen fixation and N-balance studies on Bambara groundnut (*Vigna subterranea* L. Verdc) landraces grown on tropical acidic soils of Malaysia. ***Communications in Soil Science and Plant Analysis*** 47:4, 533-542
Santos, R., Algar, A., Field, R. and Mayes, S. (2016) Integrating GIScience and Crop Science datasets: a study involving genetic, geographic and environmental data ***PeerJ preprints***; DOI: https://doi.org/10.7287/peerj.preprints.2248v3
Wong, Q.N., Tanzi, A.S., Ho, W.K., Malla, S., Blythe, M., Karunaratne, A., Massawe, F.J. and Mayes, S. (2017) Development of gene-based SSR markers in winged bean [*Psophocarpus tetragonolobus* (L.) DC.] for diversity assessment. ***Genes*** 8, 100.

Harvest for Health: Improving Wellbeing through Resilient Agriculture
Farmer Considerations

Foundation for Food and Agriculture Research

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Kevin Murphy

Associate Professor of International Seed and Cropping Systems

Dept. of Crop and Soil Sciences, Washington State University

January 31, 2019

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January 31, 2019

Crop and Nutritional Diversity within our Sustainable Seed Systems Lab

Quinoa EPB Projects

United States
Barley, Quinoa, Proso Millet, Spelt, Buckwheat, Perennial Grains

PERSPECTIVE ARTICLE

Front. Plant Sci., 09 May 2016 | https://doi.org/10.3389/fpls.2016.00608

Development of a Worldwide Consortium on Evolutionary Participatory Breeding in Quinoa

Kevin M. Murphy[1*], **Didier Bazile**[2], **Julianne Kellogg**[1] and **Maryam Rahmanian**[3]

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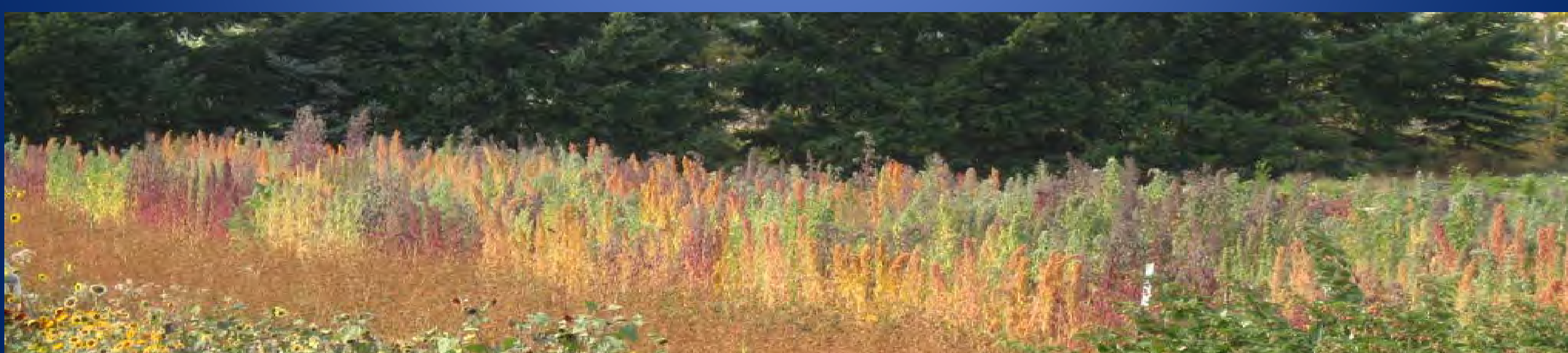
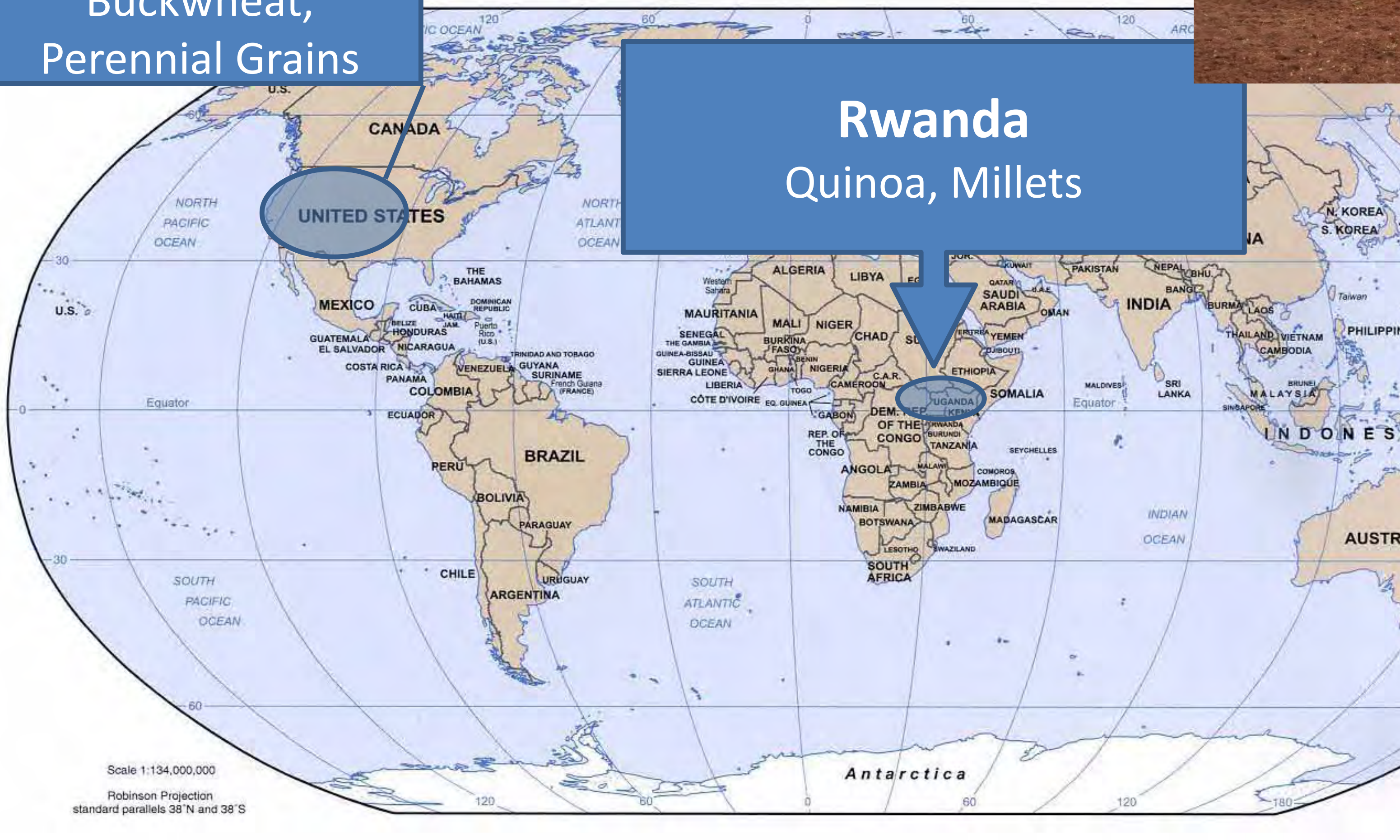


Quinoa EPB Projects

United States
Barley, Quinoa, Proso Millet, Spelt, Buckwheat, Perennial Grains

Rwanda
Quinoa, Millets



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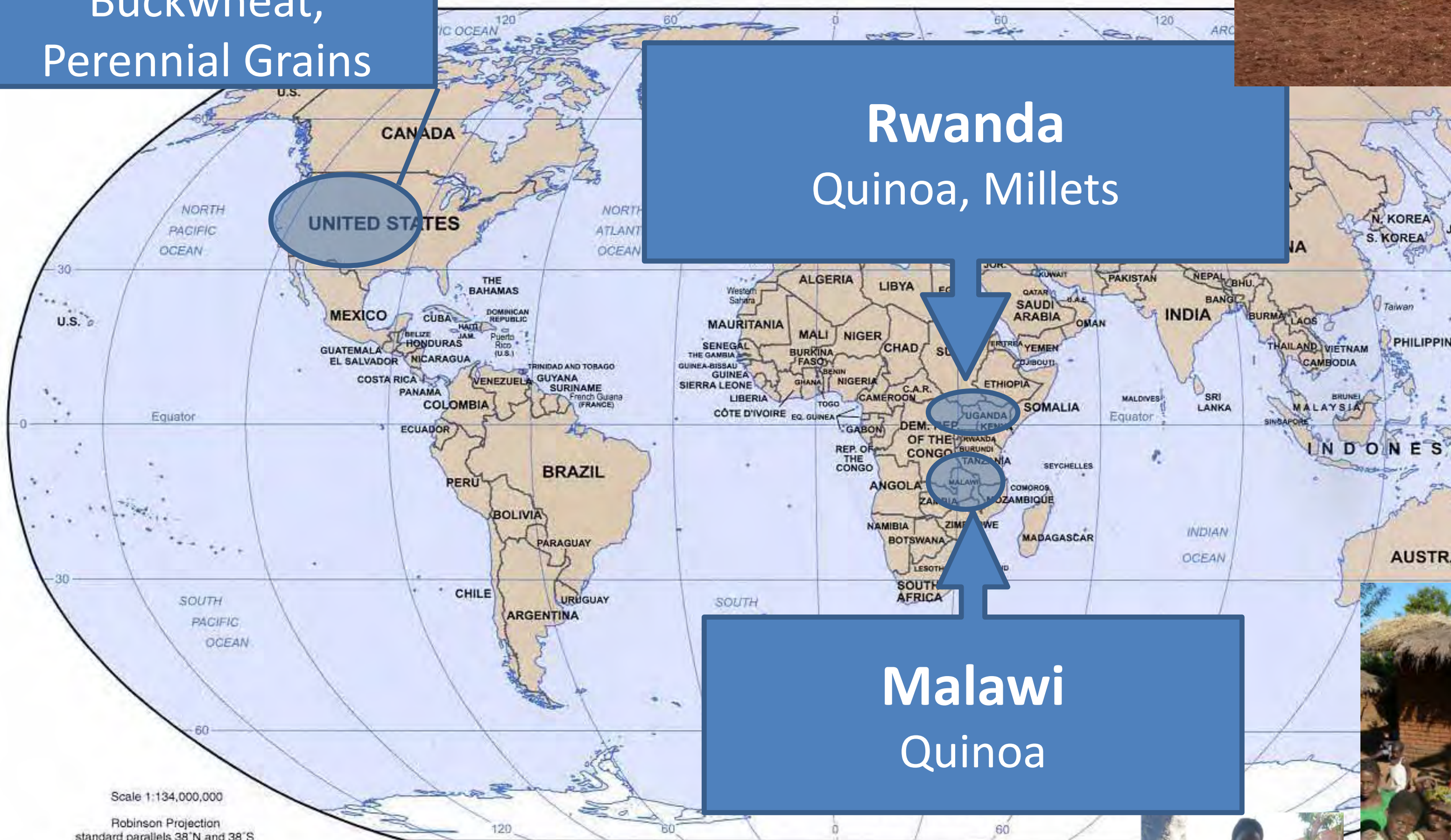
Barley, Quinoa, Proso Millet, Spelt, Buckwheat, Perennial Grains

Rwanda
Quinoa, Millets

Malawi
Quinoa



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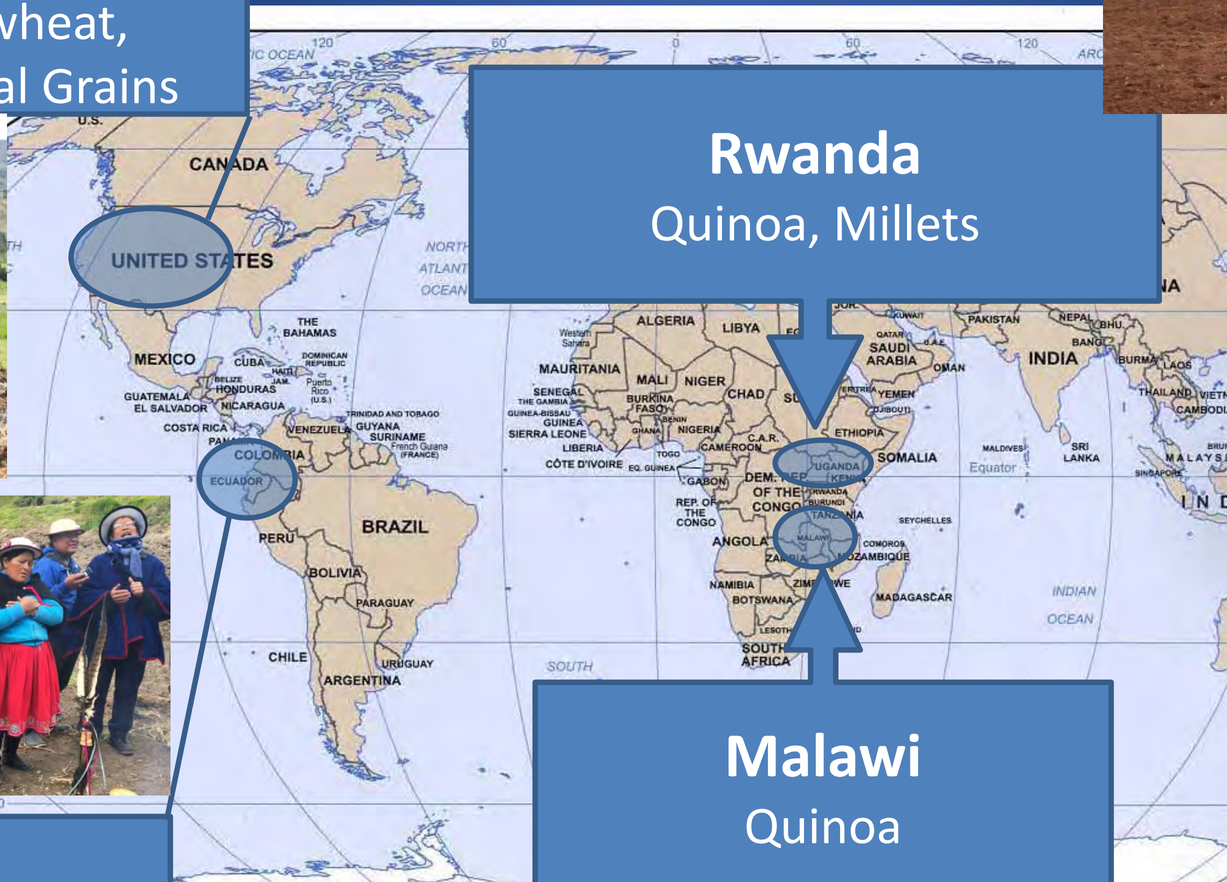


Rwanda
Quinoa, Millets

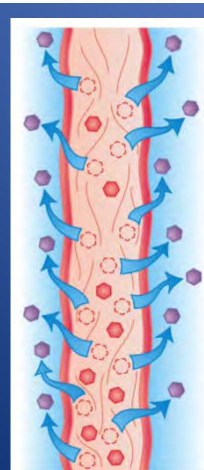
Malawi
Quinoa

Ecuador
Quinoa, Barley

Considerations

- How do farmers get rewarded for improving the nutritional content of food?
  - Input required (cost related to soil prep, fertilizers, water, level of mechanization, environmental sustainability)
  - Output (yield, resilience, nutrient content)

Healthy Foods from Soils to Society



Elson S. Floyd
College of Medicine
WASHINGTON STATE UNIVERSITY

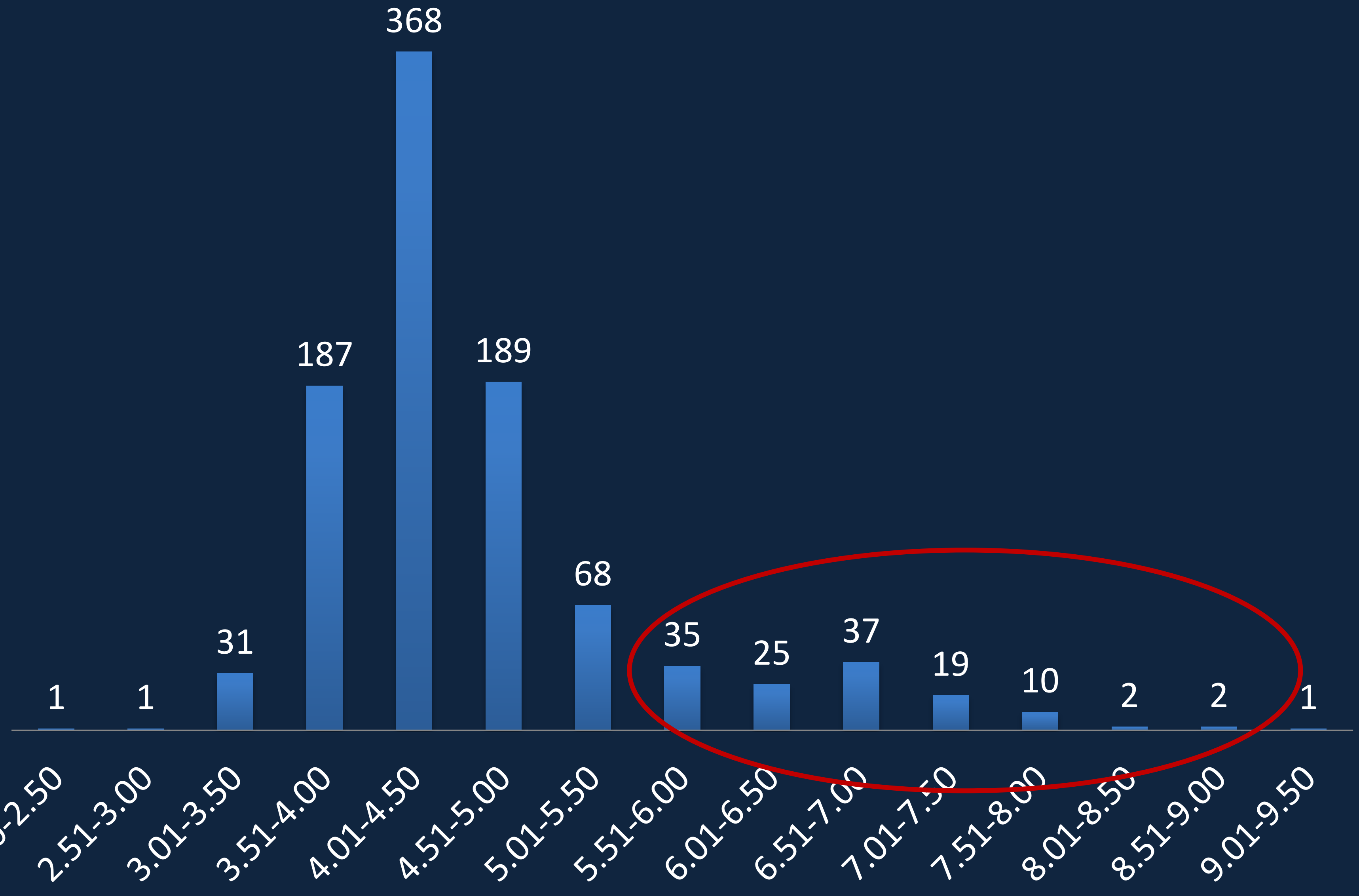
Decrease in Crop Nutritional Value

Mineral concentration in historical and modern Wheat varieties

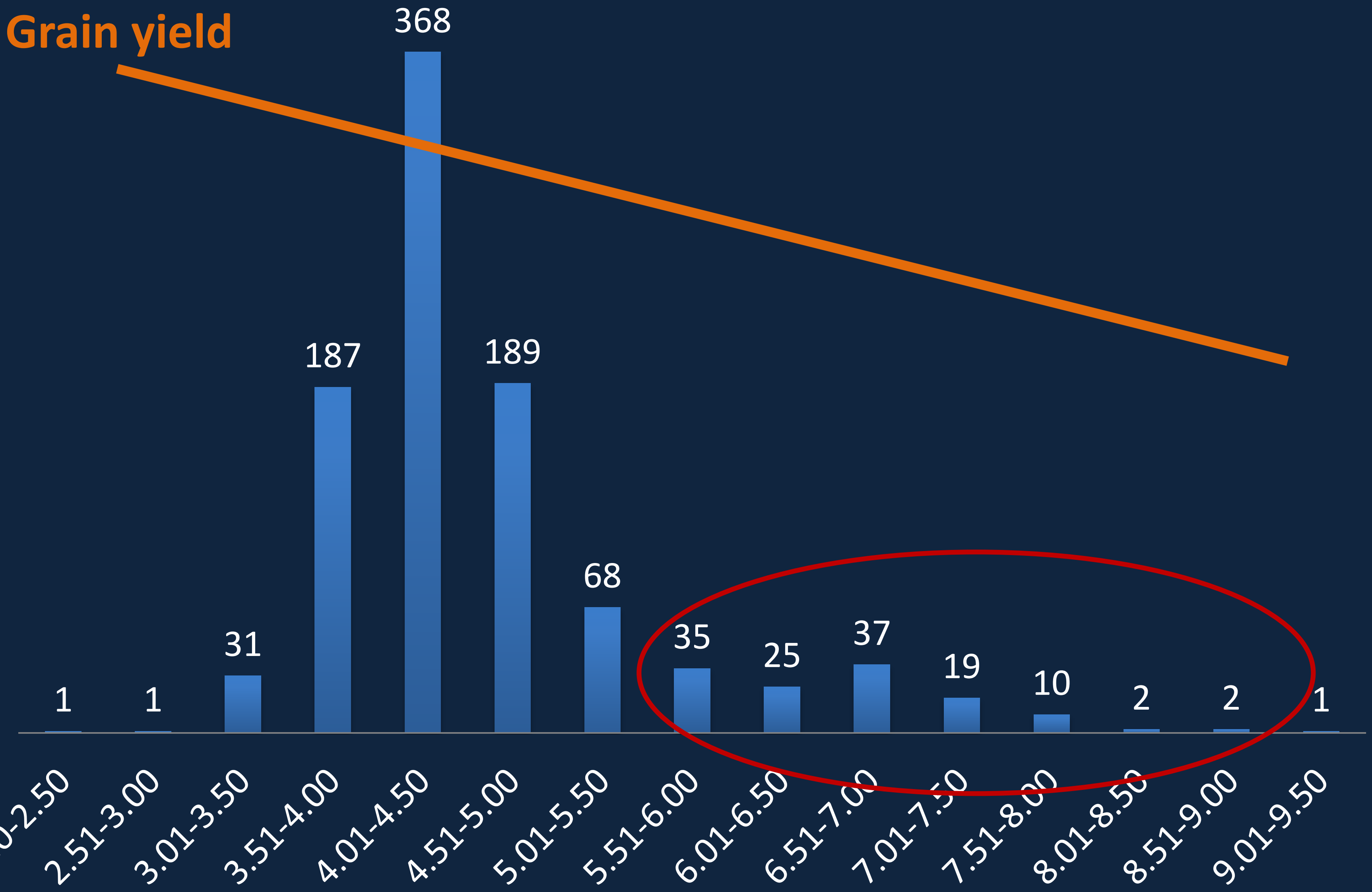
Mineral	*Mineral Concentration*		
	Historical (1842-1965)	Modern (2003)	% Change
Ca	421	398	- 6
Cu	4.76	4.10	- 16 ***
Fe	36	32	- 11 **
Mg	1403	1308	- 7 ***
Mn	50	46	- 7 *
P	3797	3492	- 9 ***
Se	16.2	10.8	- 50 *
Zn	34	27	- 25 ***

Murphy et al. 2008

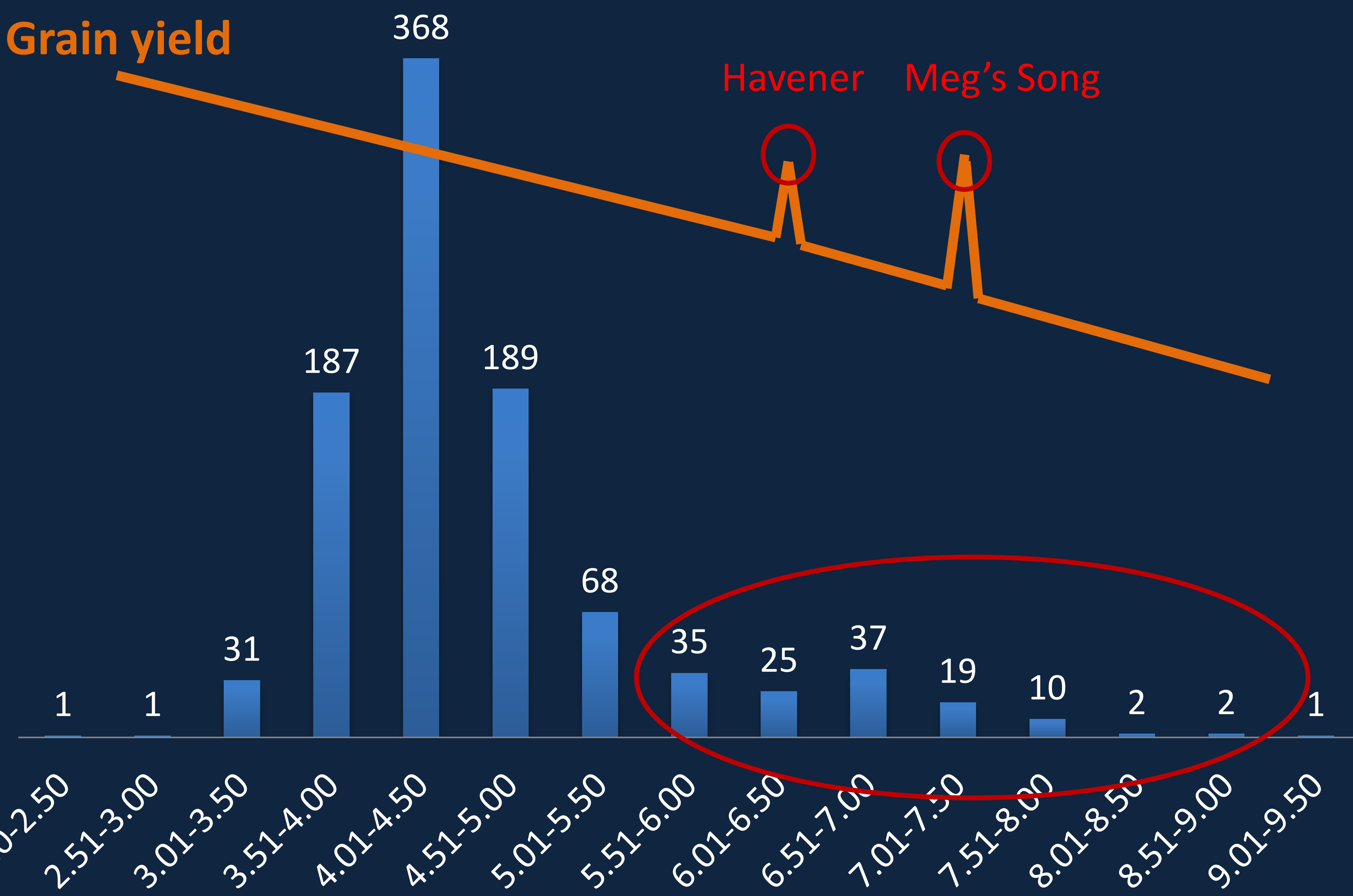
β-glucan content of 976 barley breeding lines



β-glucan content of 976 barley breeding lines



β-glucan content of 976 barley breeding lines



Meg’s Song

Understand Genotype x Environment (GxE) Interactions for β-Glucan

How does environment play a role in β-glucan content?

Can we identify stable varieties across contrasting environments?

8 locations, 2 years (2017-2018), 18 entries

Halle Choi, MS student

Effect of Nitrogen and Seeding Rate on β-glucan Content and Yield in Barley GxExM (Management)

- 3 years (2016-2018), 2 locations (Genesse, ID and Almota, WA)
- 5 nitrogen rates
- 3 seeding rates
- 2 varieties

Cedric Habiyaremye, PhD student

Naked Food Barley Quality

Buck Havener Meg's Song

Cardiovascular Benefits of high β-glucan Barley

Collaboration with the WSU College of Medicine to conduct human clinical trials using Meg's Song barley, a low β-glucan variety, and a wheat check.

Key biomarkers related to cardiovascular health will be evaluated after a six-month study.

Julianne Kellogg, PhD student

Demand for Healthy Food

Awareness of Options

Demand for Healthy Food

Awareness of Options

1510


Butternut Squash Frittata P. 89
Natural Wine Is Good for You, Right? P. 82
Salsa Verde Smash Burgers P. 72
Coconut Chia Breakfast Bowls P. 62
bon appétit
Starting with DANIELA SOTO-INNES, the fresh new face of Mexican cooking P. 52
THE HEALTHYiSH ISSUE
21 people who are already making us feel way, way better about 2019
FEBRUARY 2019
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Butternut Squash Frittata P. 89
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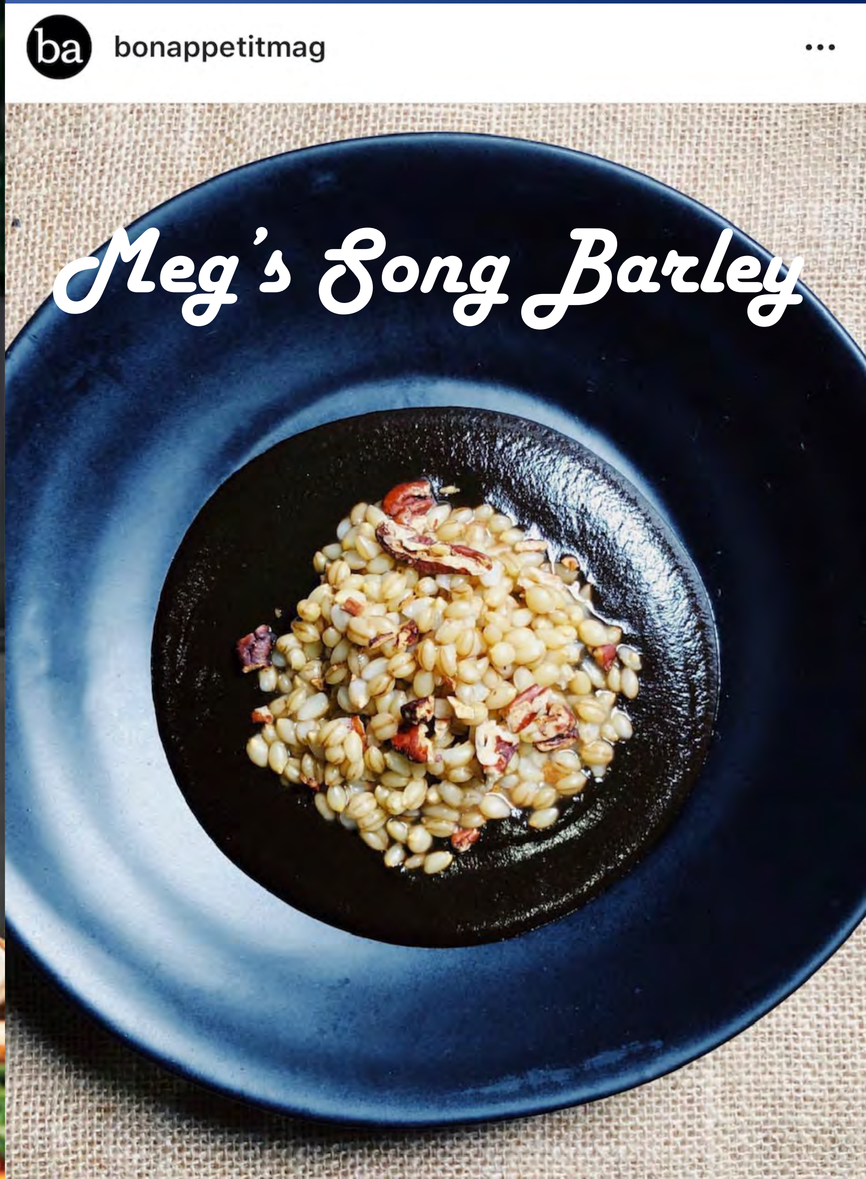
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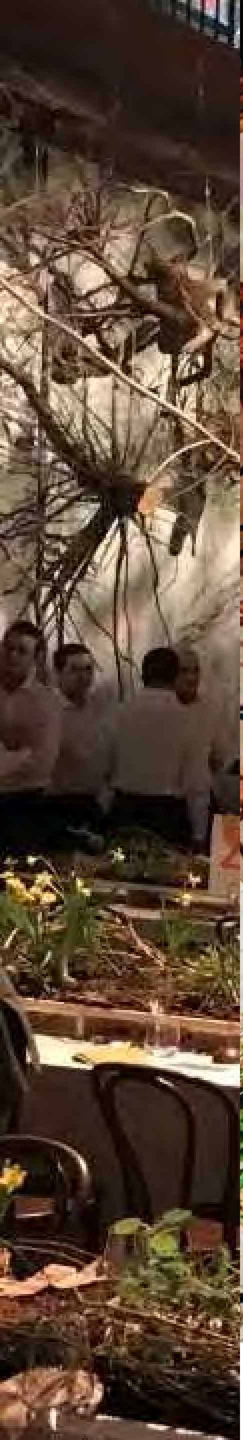



chefdanbarber

ROW 7 x NYC

JANUARY 29, 2019

898 SQUASH

Dan Barber

BADGER FLAME BEETS

ROASTED, PICKLED, FERMENTED

Jean-Georges Vongerichten

BADGER FLAME BEETS

EGG YOLK, ELDERFLOWER

Christian Puglisi

GOISOT, BOURGOGNE ALIGOTÉ 2017

UPSTATE ABUNDANCE POTATOES

BEESWAX, THISTLE OIL, BUCKWHEAT

Heinz Reitbauer

HABANADA PEPPER

RED LENTIL KÖFTE, FETA

Ana Sortun

EXPERIMENTAL OATS

CARROTS, LEMON, CHILI

Dan Kluger

VALDESIL, 'SOBRE LÍAS' GODELLO, VALDEORRAS 2016

A TASTE OF WHEAT: OLD AND NEW

EINKORN SOURDOUGH, BARBER WHEAT SOURDOUGH

Pam Yung

MEG'S SONG BARLEY

MOLE NEGRO, PECANS

Daniela Soto-Innes

ROBIN'S KOGINUT SQUASH

MORCILLA, QUINOA, APPLES

Daniel Humm

RODANO, CHIANTI CLASSICO 2015

NAKED SPELT

SPELT ICE CREAM, BRIOCHE CROUTONS, BITTER ALMOND, SPELT ASH CONE

Alex Stupak

#R7XNYC

ROW 7

898 SQUASH
Breeder: Michael Mazourek, Cornell University
Bred to reimagine the workaday butternut, packing concentrated flavor and beta-carotene into a squash that fits in your hand.

BADGER FLAME BEET
Breeder: Irwin Goldman, University of Wisconsin–Madison
Bred for a lower concentration of geosmin—the organic compound that gives beets their polarizing earthy flavor—resulting in an exceptionally sweet, mild beet that can (and should) be eaten raw.

BARBER WHEAT
Breeder: Steve Jones, The Bread Lab, Washington State University
Bred for a less bitter bran—the outer layer of the grain discarded in the industrial milling process—to be better suited for whole grain baking.

EXPERIMENTAL OATS
Breeder: Michael McMullen, North Dakota State University
Bred to boost oats' natural oil content for better nutrition and flavor.

HABANADA PEPPER
Breeder: Michael Mazourek, Cornell University
Bred to express the melon-like sweetness and aroma of the famous habanero, minus the burn.

MEG'S SONG BARLEY
Breeder: Kevin Murphy, Washington State University
Bred to redeem barley as a true culinary crop: hulless, high in beta glucan content and memorably delicious.

NAKED SPELT
Breeder: Kevin Murphy, Washington State University
Bred to make spelt more accessible and delicious—the first hulless spelt ever developed.

ROBIN'S KOGINUT SQUASH
Breeder: Michael Mazourek, Cornell University
Bred for sweetness, smooth texture, storability and a built-in ripeness indicator to ensure each squash is picked for peak flavor and nutrition. (Think: vine-ripened squash.)

UPSTATE ABUNDANCE POTATO
Breeder: Walter De Jong, Cornell University
Bred to produce an abundance of naturally creamy, nutty and buttery potatoes—so there's no need to add actual butter.

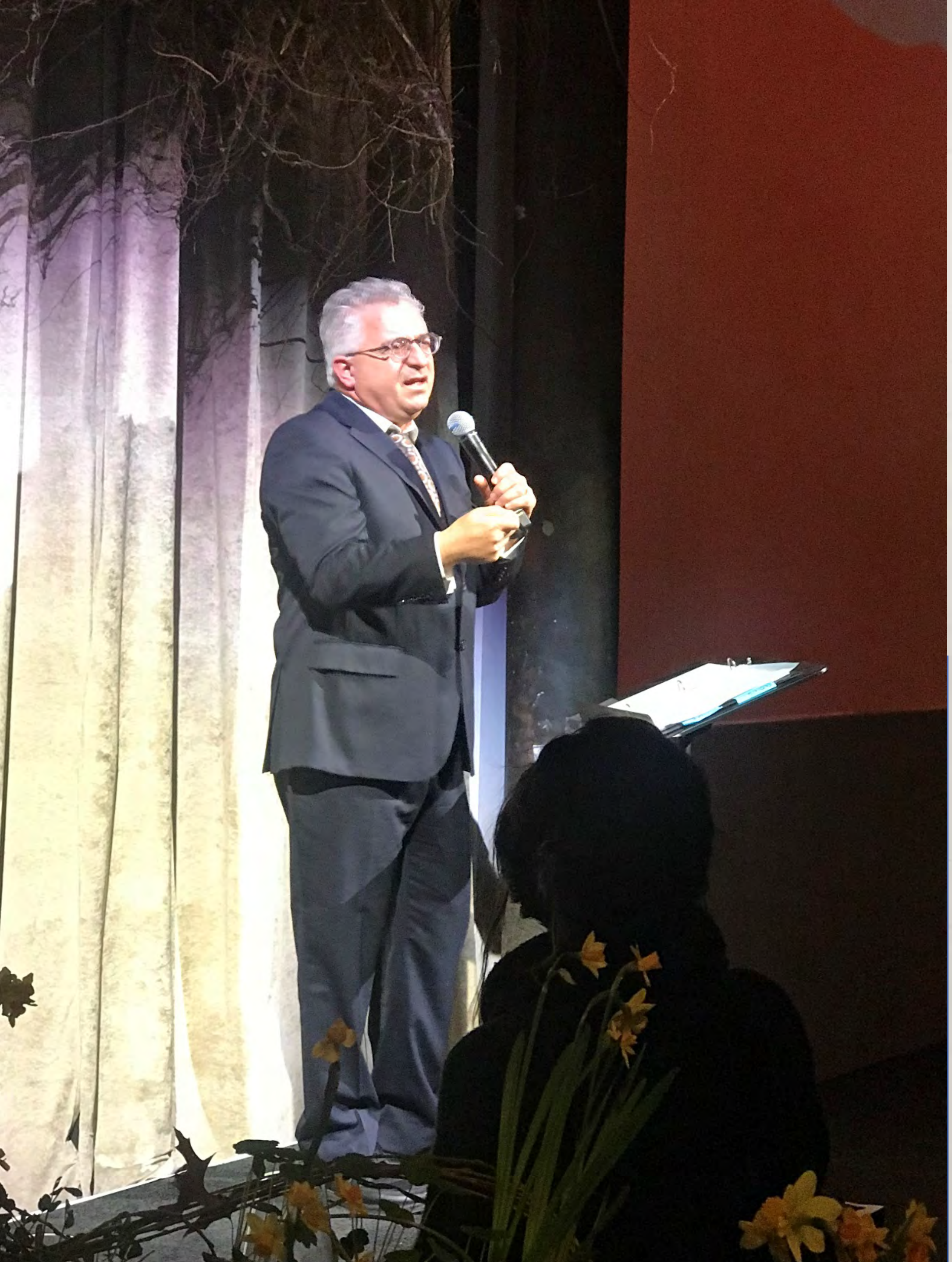
JANUARY 29, 2019

ROW 7 X NYC


309,000


Koginut Squash


Habanada Pepper

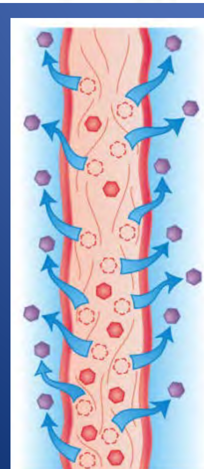


Badger Flame Beet

Elwha River Spelt


2.2M

Healthy Foods from Soils to Society



Elson S. Floyd
College of Medicine
WASHINGTON STATE UNIVERSITY

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- Robert Nilan Endowment
- Washington Wheat Foundation
- Western Sustainable Agricultural Research and Education
- American Malting Barley Association
- United States Department of Agriculture
- Lundberg Family Farm
- Clif Bar Foundation

Breeding Objectives

- Seed yield
- Heat tolerance
- Drought tolerance
- Salinity tolerance
- Resistance to downy mildew
- Pre-harvest sprouting resistance
- Saponin content
- Early maturity
- Photoperiodism
- End-use quality

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Acknowledgments

Lab Members

- Dr. Dan Packer
- Dr. Leonardo Hinojosa
- Cedric Habiyaremye
- Halle Choi
- Julianne Kellogg
- Adam Peterson
- Max Wood
- Dr. Janet Matanguihan

Perten Instruments

Ryan Bishop

SUSTAINABLE SEED SYSTEMS LAB

Breeding for Diversity at Washington State University

Grant Number ञ़ज़झ़ढ़घ़ड़झ़ट़ज़ज़फ़ड़त़ज़त़