Breeding for Nutritional and Rotational Diversity in Dryland Cereal and Seed Crops in the Palouse Prairie Ecosystem of the Pacific Northwest

Texas A&M Plant Breeding Symposium 2016

Kevin Murphy

www.sustainableseedsystems.org

Take Six of These and Call Me in the Morning

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RANGE
OLYMPIC
MTNS
WASHINGTON
PALOUSE
COLUMBIA
BASIN
CASCADE
Washington State Land Cover and Relief
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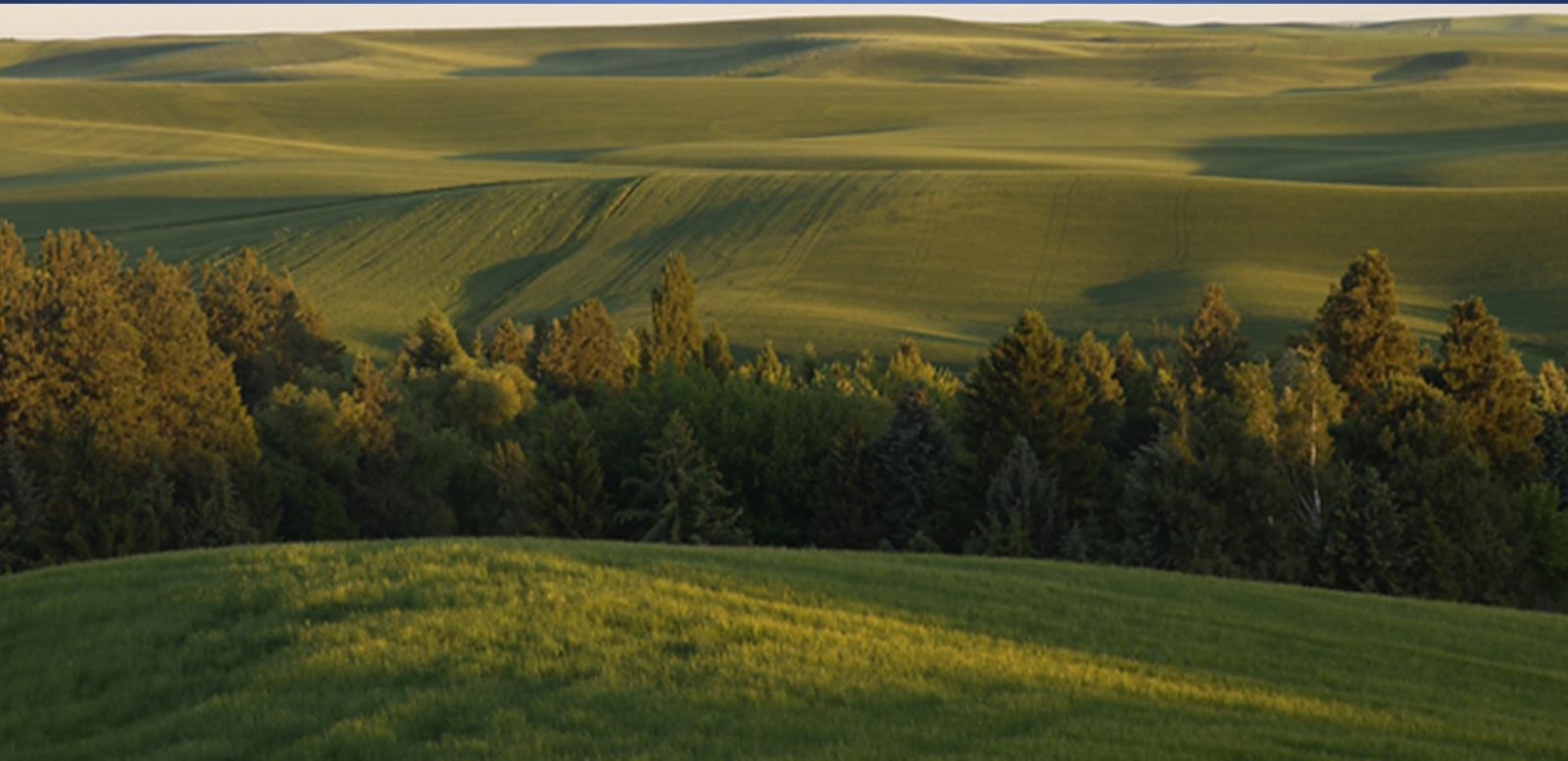
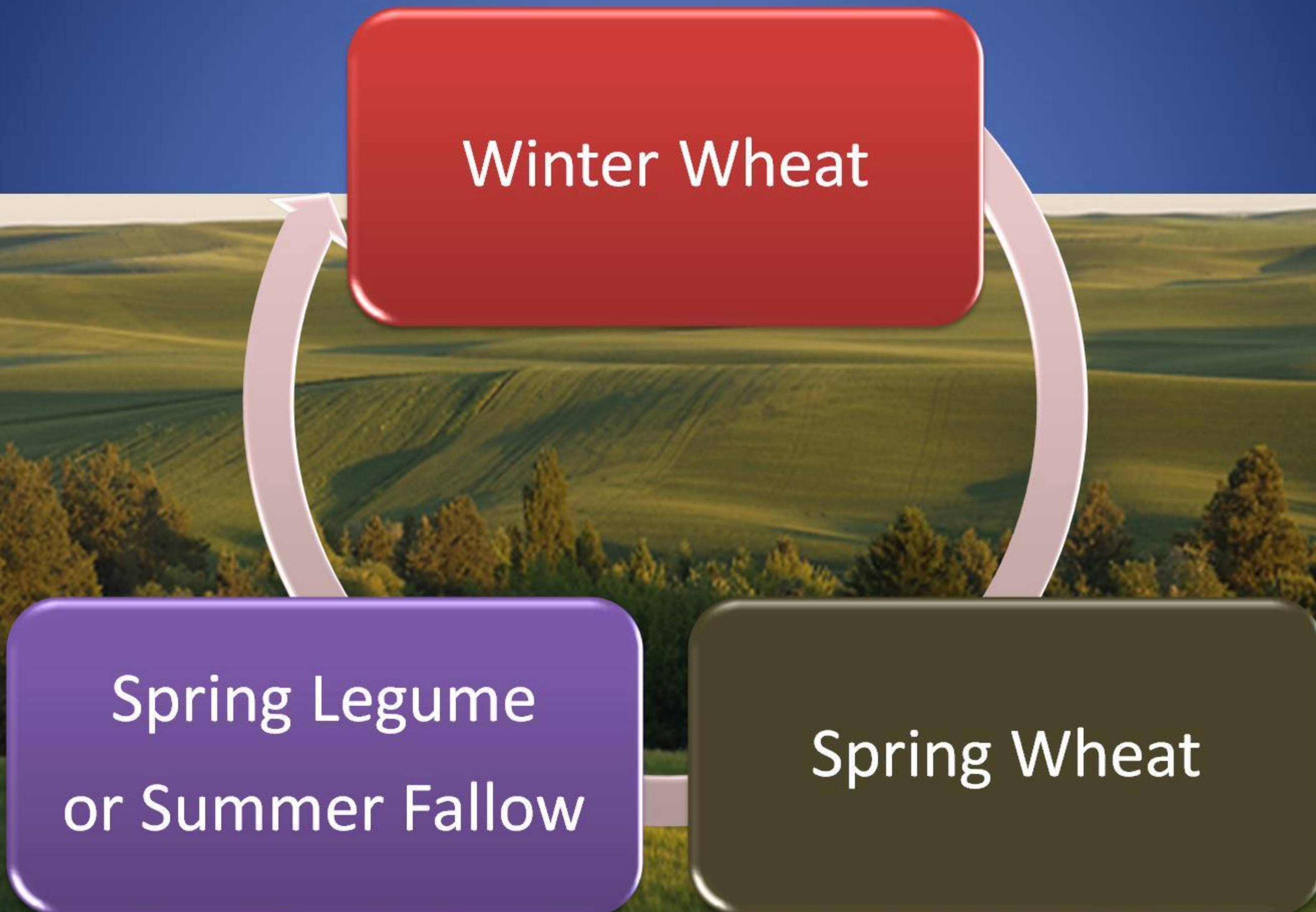
Breeding within a System

Crop Diversity



Breeding within a System



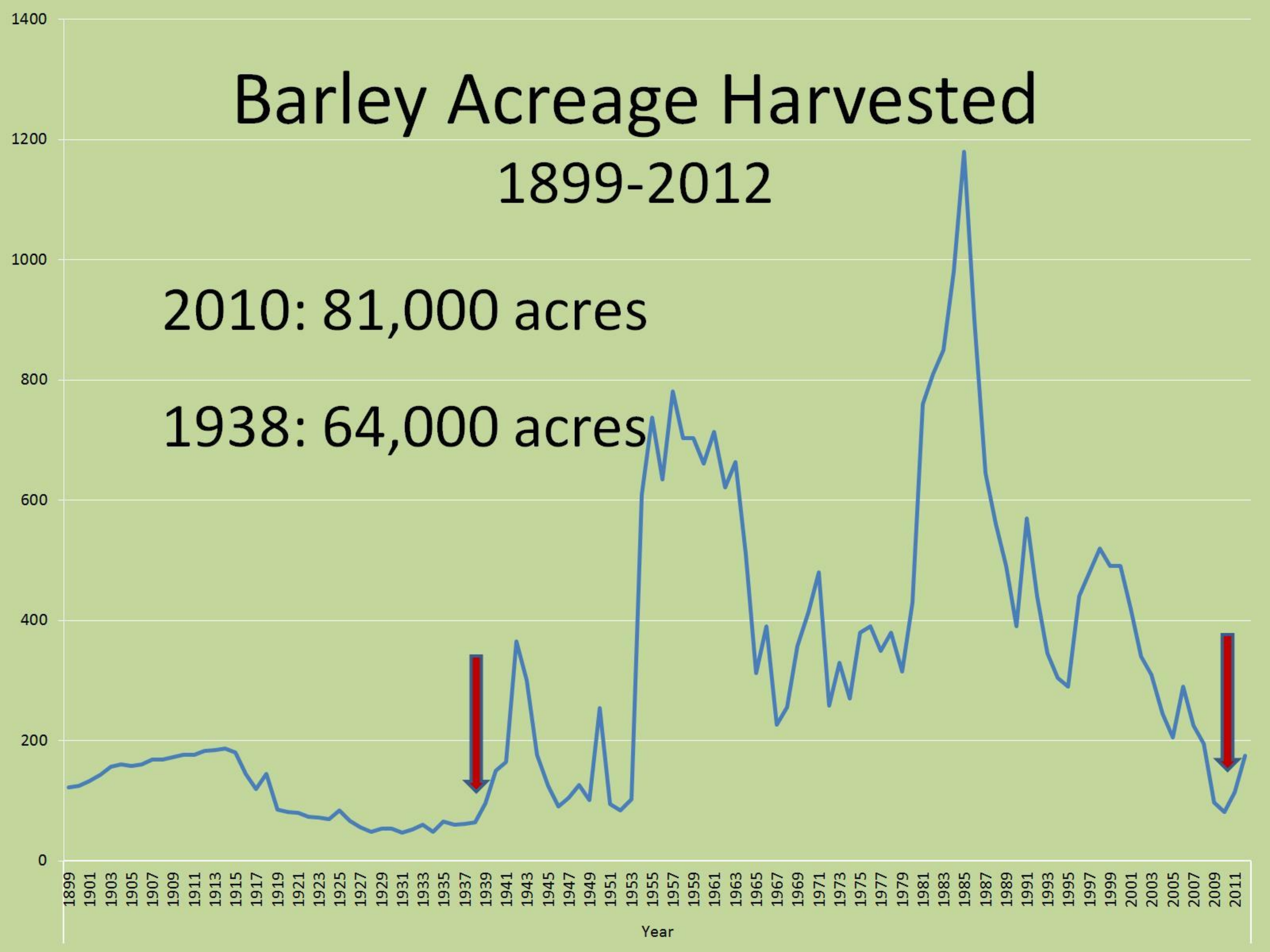
Breeding for Diversity

Intraspecific diversity

Interspecific diversity

Crop Diversity within our Breeding Program 5 years ago

Barley


Barley Acreage Harvested
1899-2012
2010: 81,000 acres
1938: 64,000 acres
1400
1200
1000
800
600
400
200
0
Year

Crop Diversity within our Breeding Program Today

Crop Diversity within our Breeding Program Today


CS
CS + 4E

Mineral Concentration in Spring Wheat

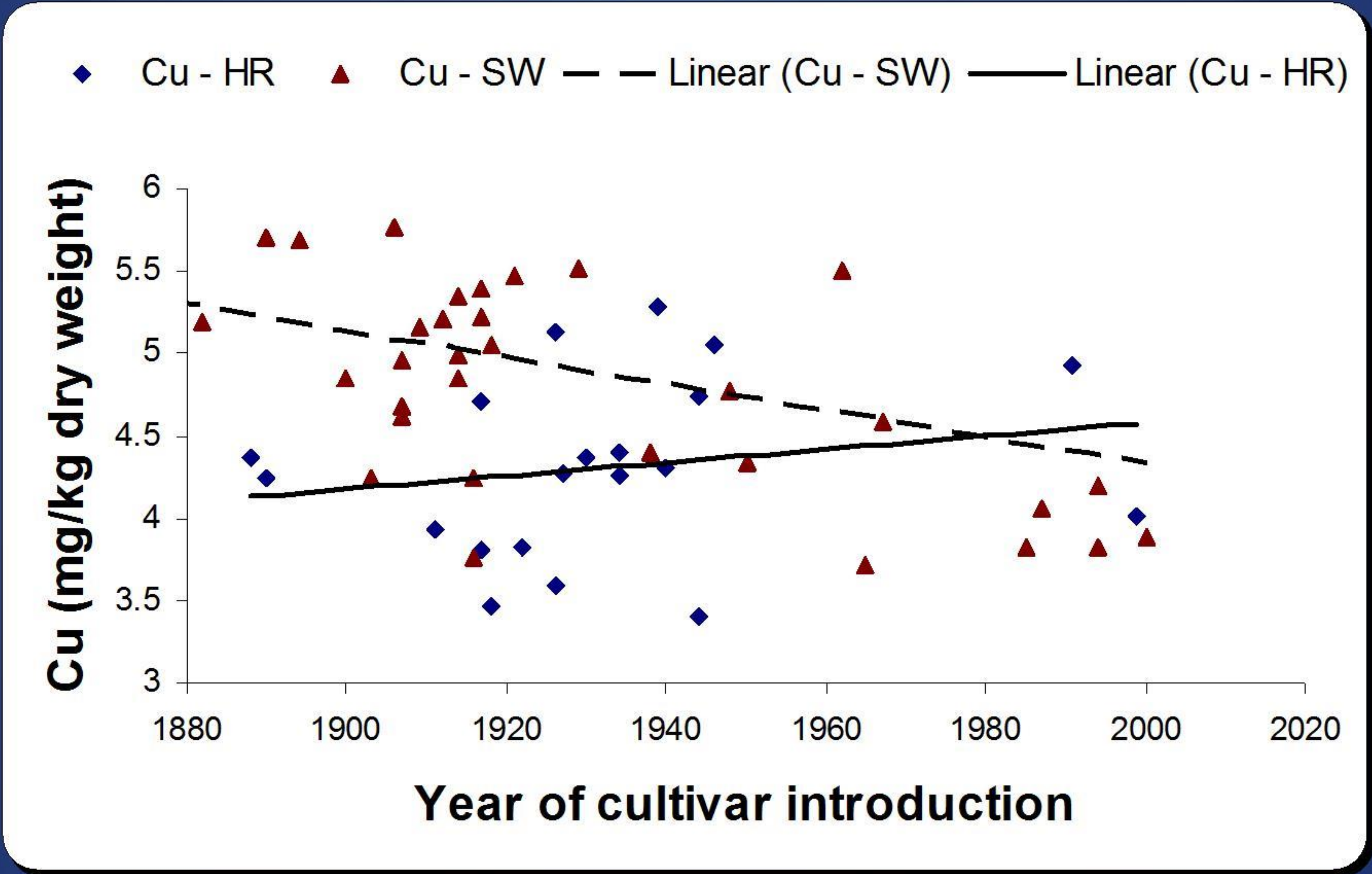
- Has mineral nutrient density increased or decreased over time in wheat varieties?
- Is there a yield – mineral nutrient concentration trade-off?

Mineral concentration in historical and modern wheat varieties

Mineral	*Mineral Concentration* Historical (1842-1965)	Modern (2003)	% Change	Grain Yield/Mineral Correlation
Ca	421	398	- 6	-0.41 ***
Cu	4.76	4.10	- 16 ***	-0.17 ***
Fe	36	32	- 11 **	0.05 ns
Mg	1403	1308	- 7 ***	-0.35 ***
Mn	50	46	- 7 *	-0.17 **
P	3797	3492	- 9 ***	-0.25 ***
Se	16.2	10.8	- 50 *	-0.38 ***
Zn	34	27	- 25 ***	-0.06 ns

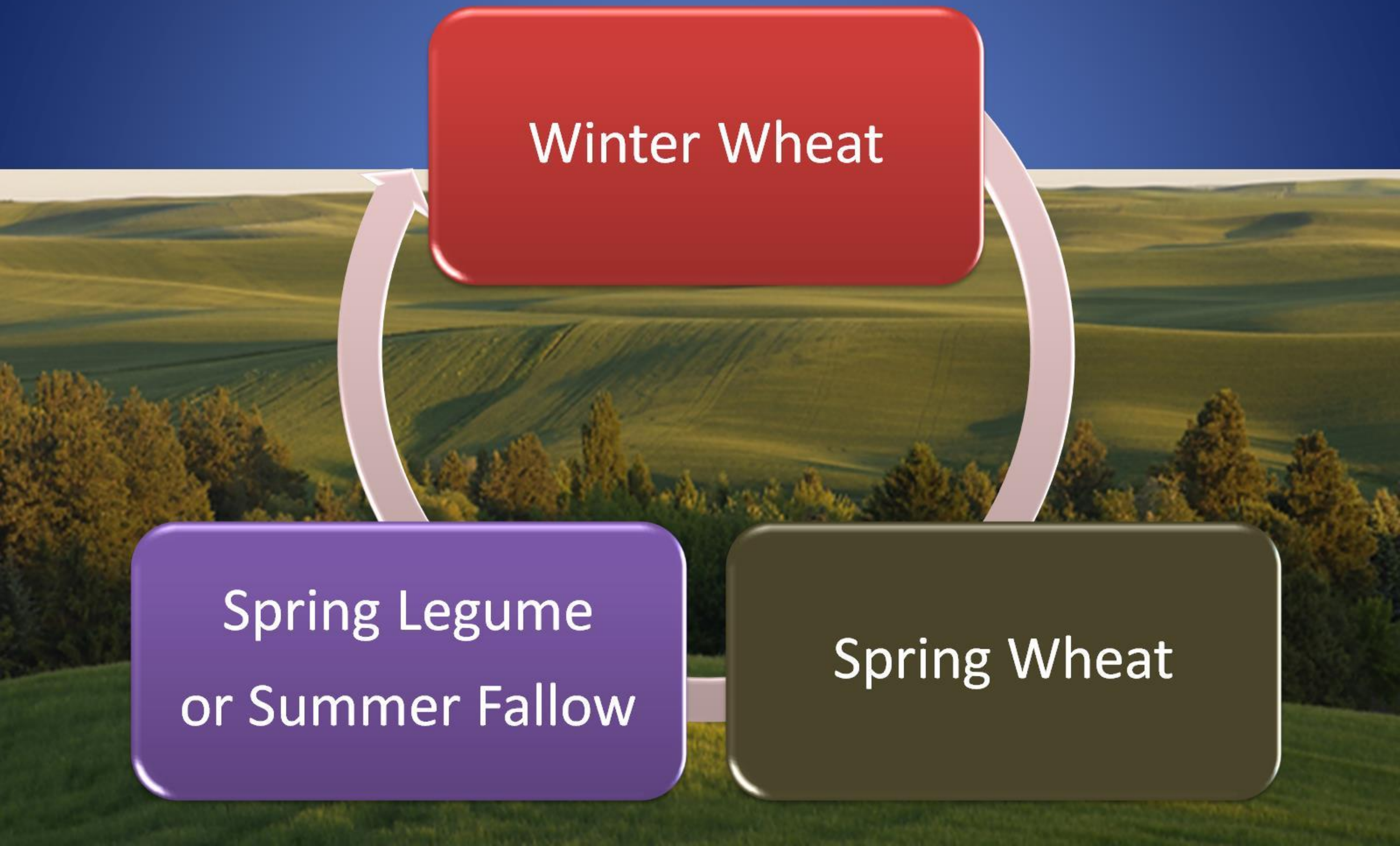
Mineral content is given in mg/kg dry weight ± standard error for all minerals except Se, which is given in ug/kg. *, **, ***: $P < 0.05$, 0.01 and 0.0001, respectively. Ns = not significant.

Genetic Variation / Trade-off

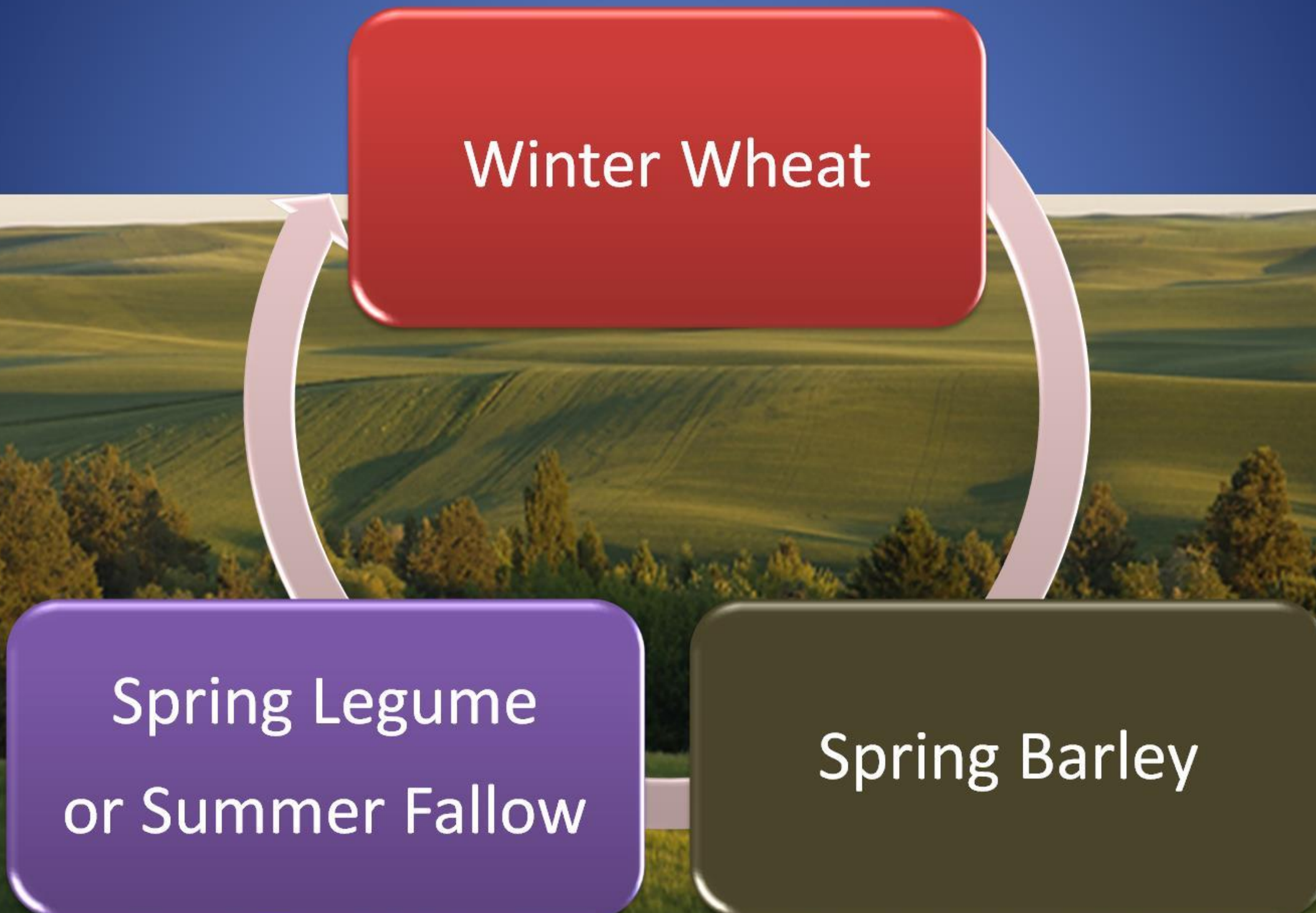


Murphy et al. (2008) *Euphytica*

Breeding within a System



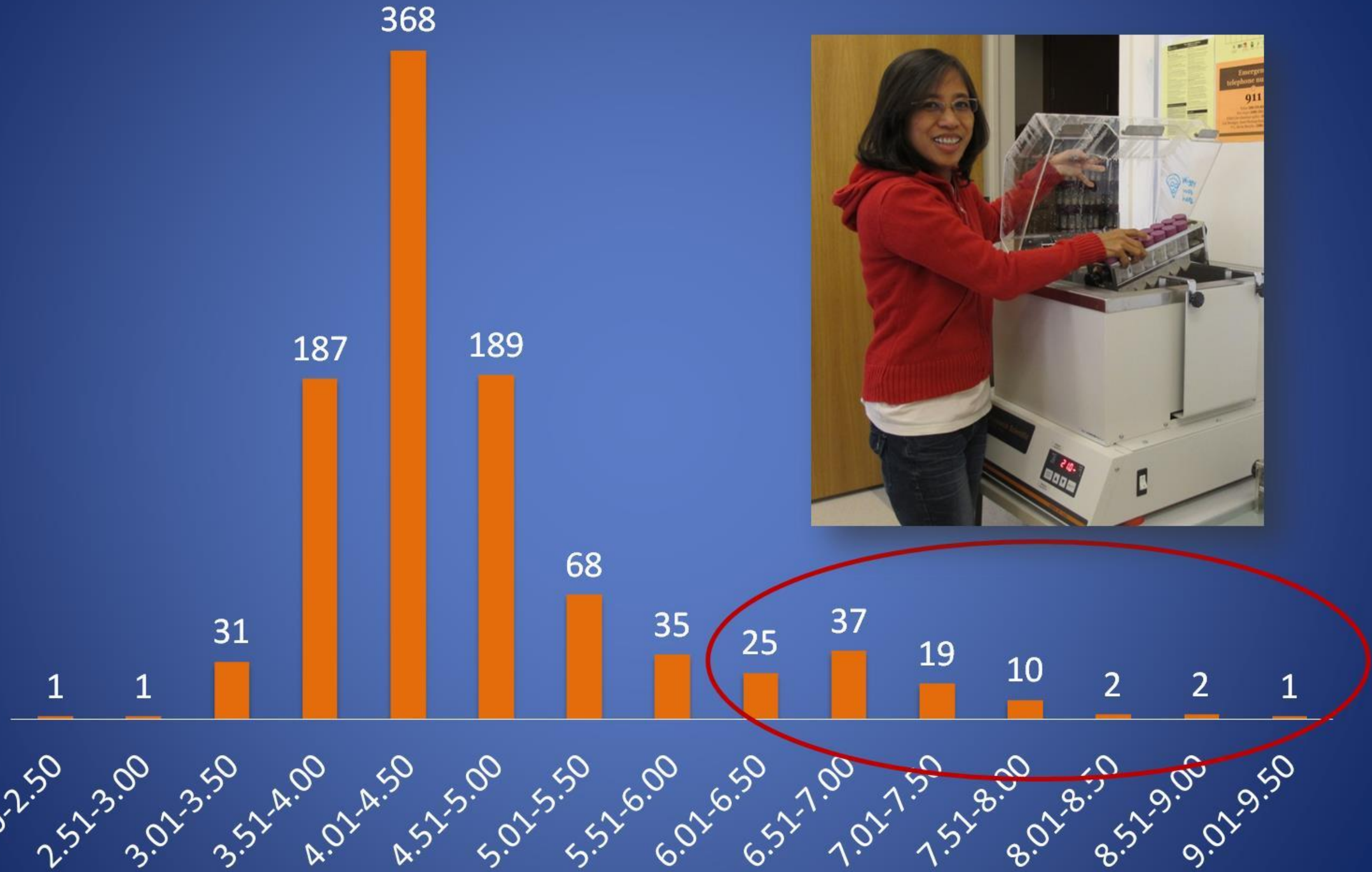
Breeding within a System



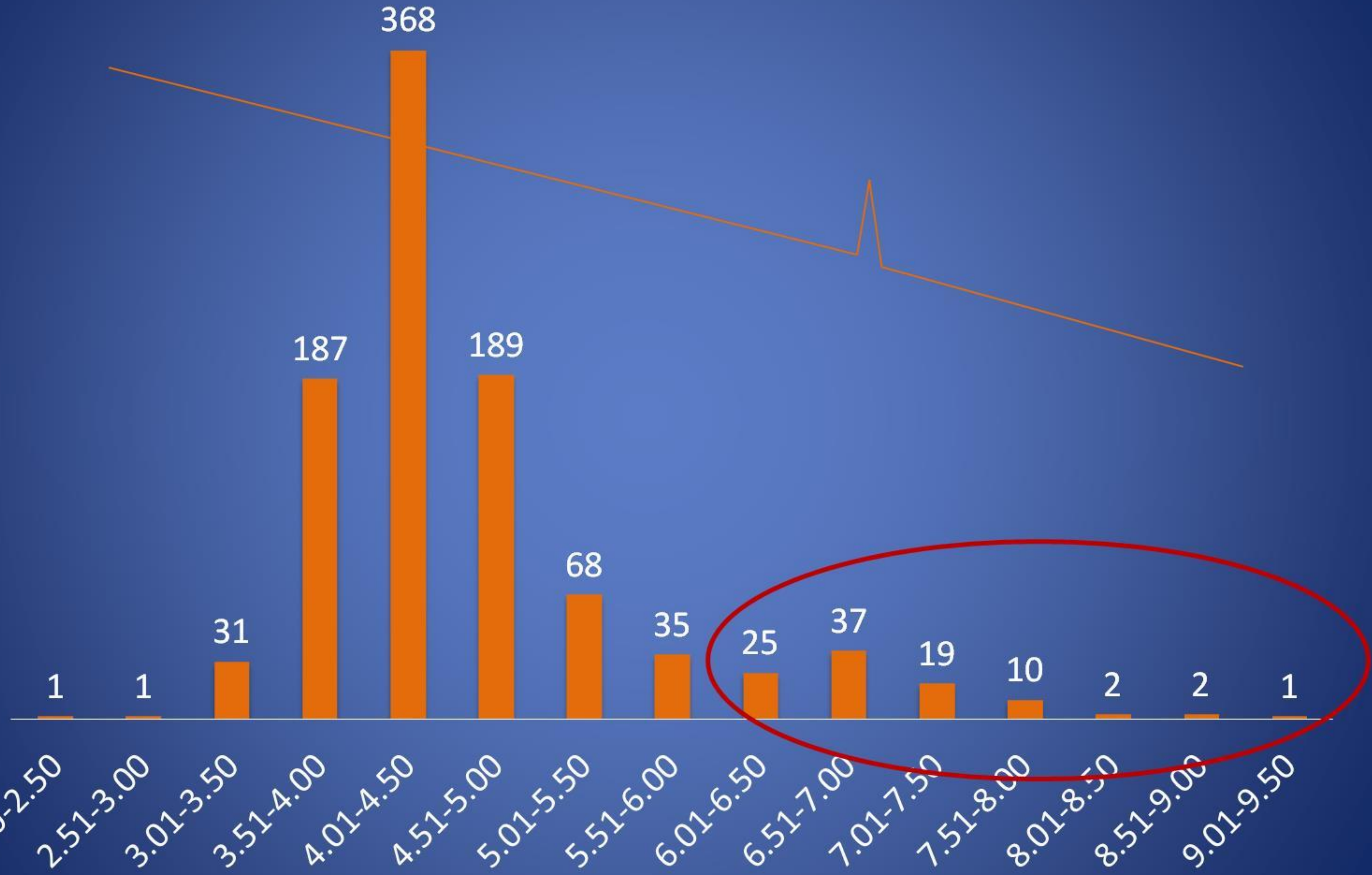
Hulless (Naked) Food Barley

- Hulless barley has greater value for human consumption because key vitamins and minerals are not lost in pearling
- Non-starch polysaccarides of the barley kernel are β –glucan, arabinoxylans, and cellulose
- Comprise 75% of the cell wall
- β –glucan reduces the risk of heart disease and diabetes in humans

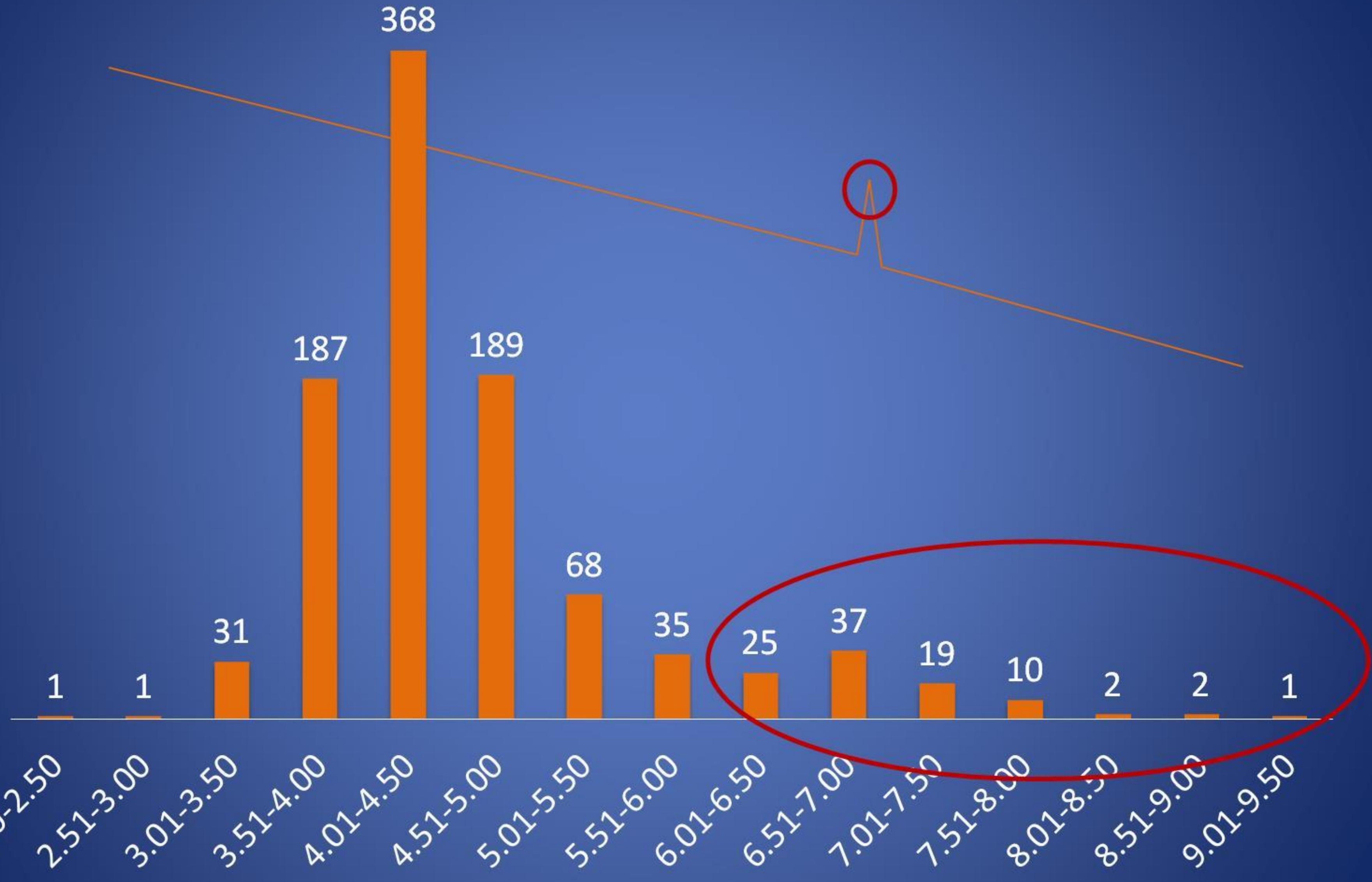
β-glucan content of 976 barley breeding lines



β-glucan content of 976 barley breeding lines



β-glucan content of 976 barley breeding lines



New food Barley Variety

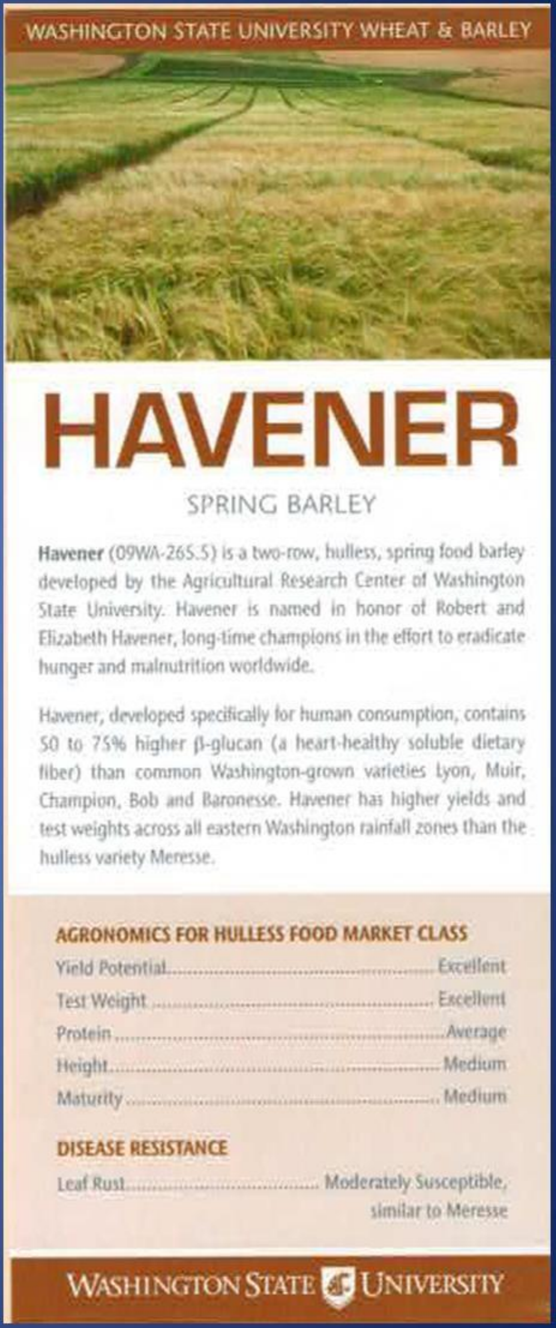
- Havener:
  - 2-row, hulless spring barley
  - Specifically selected for human consumption




Havener: 2-row hulless food barley

Variety	2013-2015 7 location years (Fairfield, Farmington, Pullman)		2012-2014 (Pullman)
	Grain yield Lbs/a	Test Weight Lbs/bu	B-glucan %
Havener	**3824**	**57.8**	**6.18**
Meresse	3399	54.8	6.05
LSD (0.10)	224	0.7	na

Feed barley % β-glucan: Baronesse = 3.80; Lyon = 3.98; Muir = 3.52


WASHINGTON STATE UNIVERSITY WHEAT & BARLEY

HAVENER

SPRING BARLEY

Havener (09WA-265.5) is a two-row, hulless, spring food barley developed by the Agricultural Research Center of Washington State University. Havener is named in honor of Robert and Elizabeth Havener, long-time champions in the effort to eradicate hunger and malnutrition worldwide.

Havener, developed specifically for human consumption, contains 50 to 75% higher β-glucan (a heart-healthy soluble dietary fiber) than common Washington-grown varieties Lyon, Muir, Champion, Bob and Baronesse. Havener has higher yields and test weights across all eastern Washington rainfall zones than the hulless variety Meresse.

AGRONOMICS FOR HULLESS FOOD MARKET CLASS

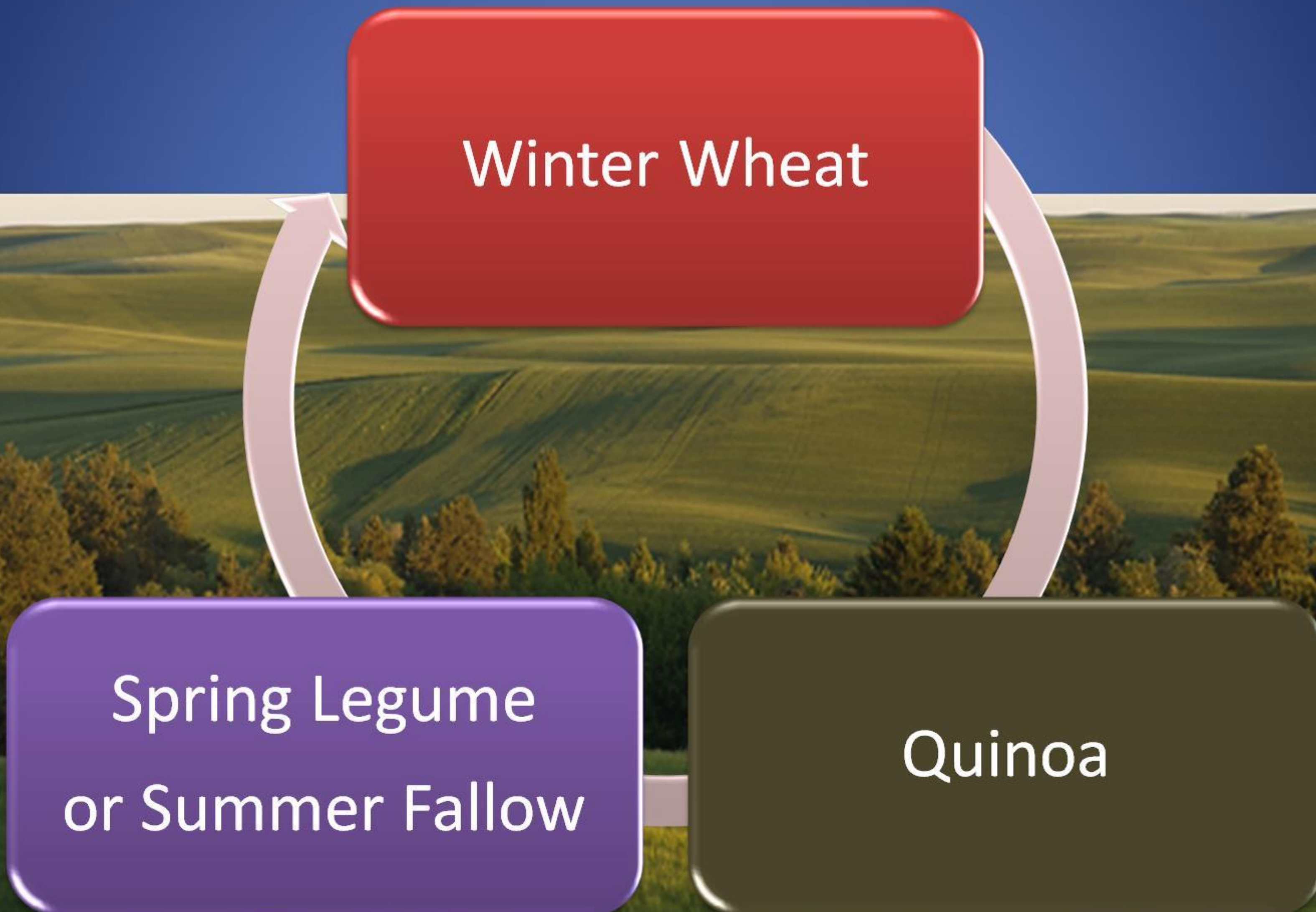
Yield Potential........Excellent
Test Weight........Excellent
Protein........Average
Height........Medium
Maturity........Medium

DISEASE RESISTANCE

Leaf Rust........Moderately Susceptible, similar to Meresse

WASHINGTON STATE UNIVERSITY

Breeding within a System



Breeding Objectives

- Seed yield
- Heat tolerance
- Resistance to downy mildew
- Low saponin content
- Drought tolerance
- Early maturity
- Pre-harvest sprouting resistance
- Nutritional value and flavor
- Photoperiodism
- Salinity Tolerance

Nutritional value of quinoa

- Excellent source of protein – contains high levels of 10 essential amino acids
- High concentrations of Ca, Mg, Fe, Cu and Zn
- Rich in beta carotene, niacin, riboflavin, Vitamin A, B2 and E
- High in Essential Fatty Acids, particularly linoleic acid

(Vega-Galvez et al., 2010, J Sci Food Agric)

Quinoa Hybridization

Peterson et al., 2015. *Sustainability*

Hermaphrodite flower: typically found on terminal position of flower cluster; contain a single pistil usually surrounded by 5 anthers

Female flower is shown with sepals removed

Inflorescence color was used as a dominant morphological marker in a cross between Temuco (**female**, **left**) and Bio-bio (**male**, **center**). F_1 (**right**) exhibit the dominant pink inflorescence color, as well as leaf morphology intermediate to both parents

Variety Trials

Variety	Seed Yield (#/a)		
	Chimacum, WA		
Titicaca	3438		
Kaslaea	2904		
QQ74	2679		
KU-2	2424		
Isluga	2368		
Linares	2316		
Puno	2260		
NL-6	1952		
Oro de Valle	1875		
QuF9P1-20	1844		
CO 407 Dave	1843		

Variety	Seed Yield (#/a)		
	Chimacum, WA	Pullman, WA	
Titicaca	3438	1298	
Kaslaea	2904	647	
QQ74	2679	437	
KU-2	2424	781	
Isluga	2368	411	
Linares	2316	393	
Puno	2260	563	
NL-6	1952	935	
Oro de Valle	1875	423	
QuF9P1-20	1844	523	
CO 407 Dave	1843	503	

Variety	Seed Yield (#/a)		
	Chimacum, WA	Pullman, WA	Lewiston, ID
Titicaca	3438	1298	0
Kaslaea	2904	647	0
QQ74	2679	437	0
KU-2	2424	781	0
Isluga	2368	411	0
Linares	2316	393	0
Puno	2260	563	0
NL-6	1952	935	0
Oro de Valle	1875	423	0
QuF9P1-20	1844	523	0
CO 407 Dave	1843	503	0

Variety	Seed Yield (#/a)		
	Chimacum, WA No heat stress	Pullman, WA Moderate heat stress	Lewiston, ID High heat stress
Titicaca	3438	1298	0
Kaslaea	2904	647	0
QQ74	2679	437	0
KU-2	2424	781	0
Isluga	2368	411	0
Linares	2316	393	0
Puno	2260	563	0
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Oro de Valle	1875	423	0
QuF9P1-20	1844	523	0
CO 407 Dave	1843	503	0

Breeding Material & Strategies

Breeding Material & Strategies

- Pedigree breeding, derived from
  - BYU: 800 F_6 to F_9 recombinant inbred lines (RILs)
  - WSU: 2000 F_5 RILs; 100s F_2 to F_4 RILs
- Participatory breeding
  - Evolutionary participatory breeding
  - 10 WSU populations grown in bulk on farmers fields
  - Farmer positive and negative selection
- Introgression from wild *Chenopodium* spp.

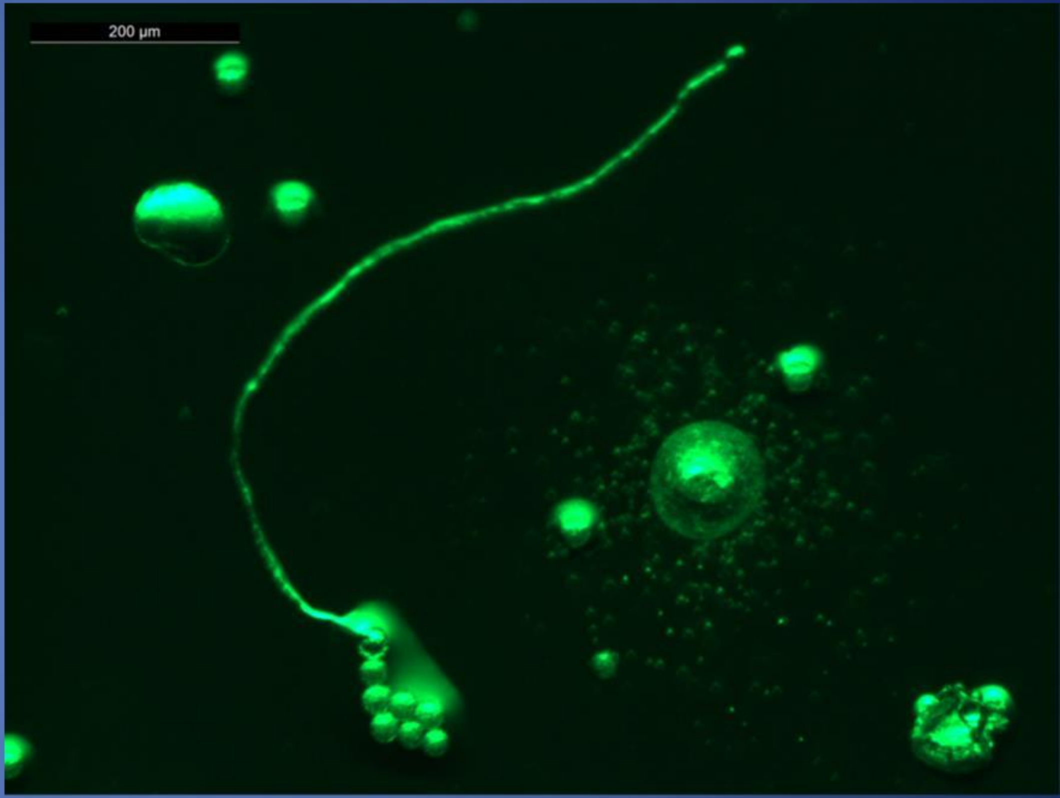
Introgression of heat tolerance from *C. berlandieri*

PI 29773: collected in New Mexico by Rick Jellen (photo: D. Brenner)

Rick Jellen, BYU

David Brenner, USDA

Introgression of heat tolerance from *C. berlandieri*



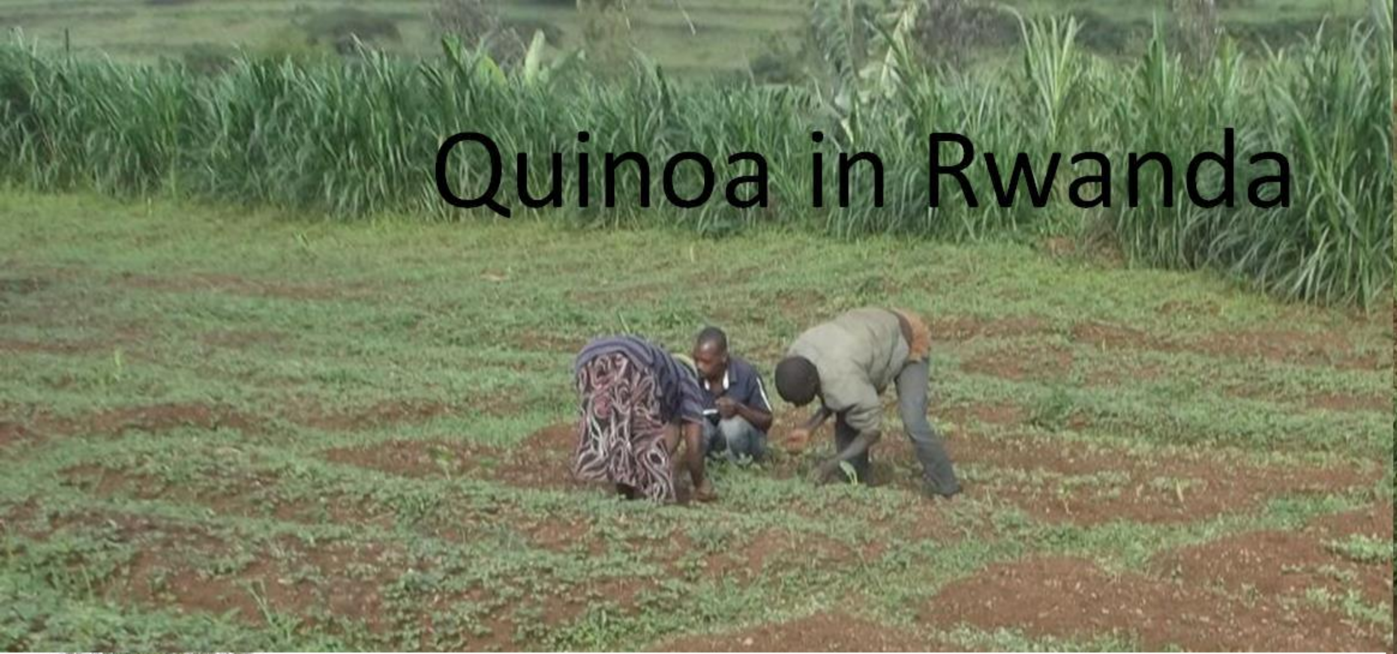
QQ74 x PI 29773 F_1 plant

Photos: L. Hinojosa

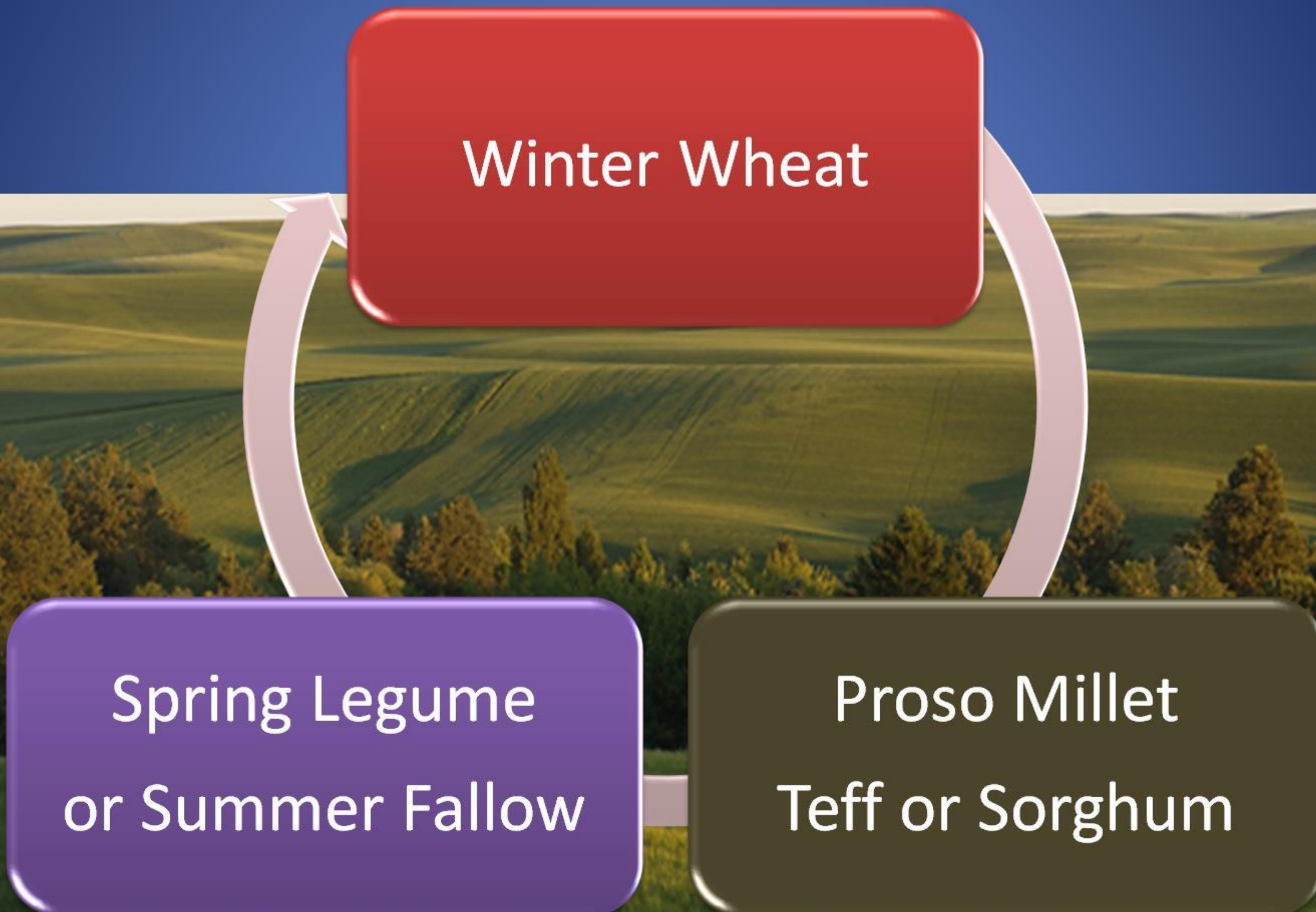
Nutritional Value of Quinoa: Bioactive Compounds & Micronutrients

Quinoa in Malawi

Quinoa in Rwanda

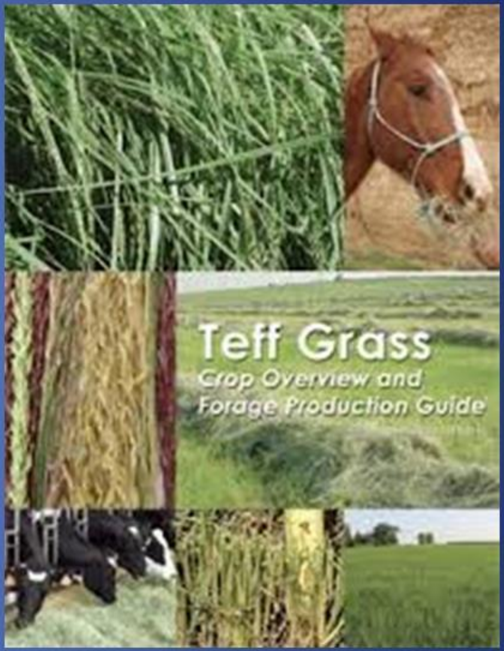


Breeding within a System



C_4 rotation crops - Grasses

- Teff (*Eragrostis tef*)
  - Heat tolerant
  - Short season, late planting used for spring weed control
  - Not susceptible to same diseases as wheat and barley
  - Grown in the U.S. as an alternative forage crop as well as for seed
  - **High protein and iron, and high in 8 essential amino acids**



Proso millet (*Panicum miliaceum*)

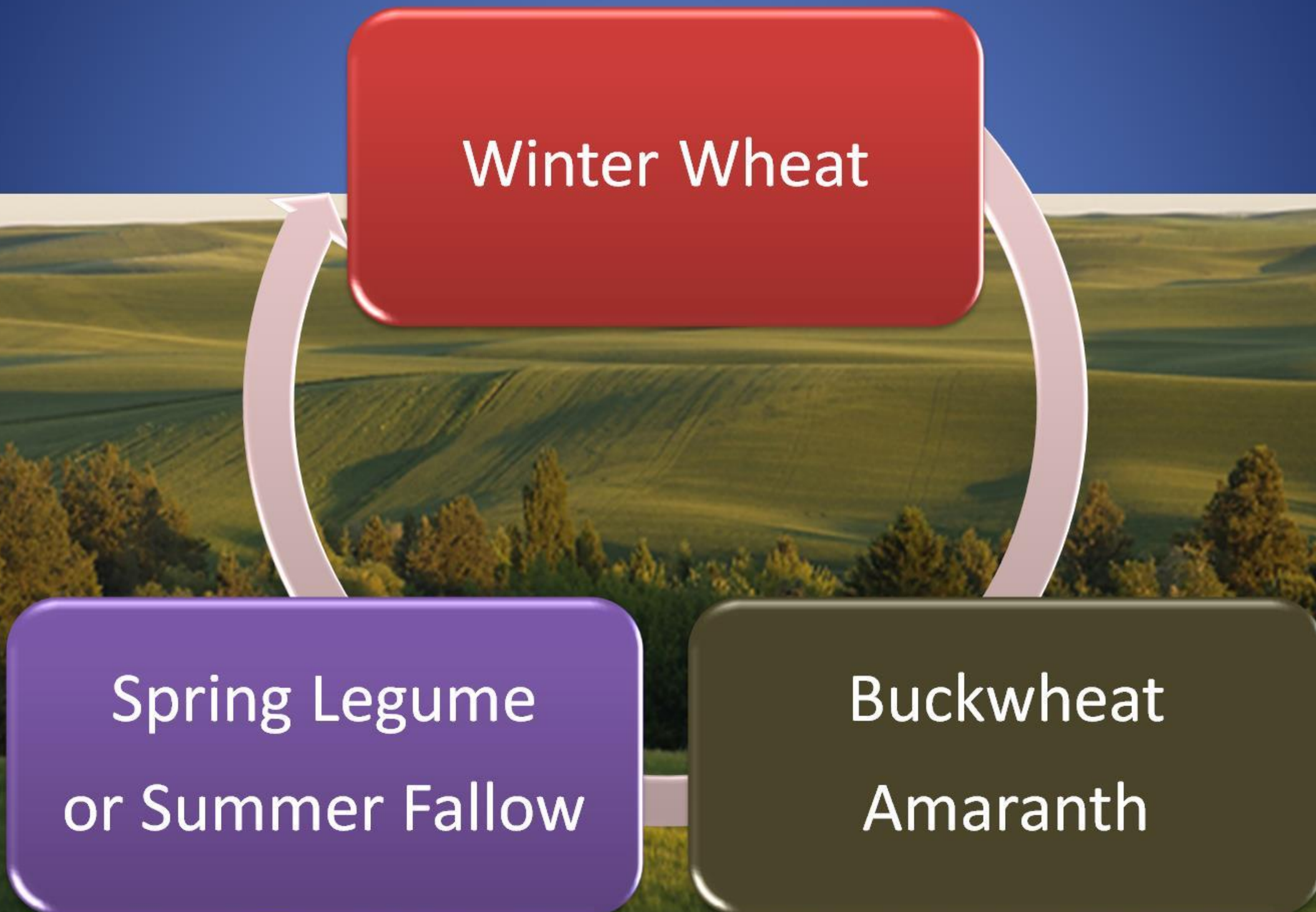
- Five main types or species of millet grown around the world; proso millet is the primary millet grown as a grain in the U.S.
- Matures in 60 to 80 days after seeding
- Heat tolerant

http://www.npr.org/blogs/thesalt/2013/10/02/227889550/can-millet-take-on-quinoa-first-itll-need-a-makeover

Nutritional Benefits of Millet

- **All millet species high in phenolic compounds and antioxidant activity**
- **Gluten free**
- **Along with buckwheat and sorghum, millet is used as the base malt ingredient in gluten free beer**

Breeding within a System



Buckwheat (*Fagopyrum esculentum*)

- High in lysine and arginine
- Richer source of Mn, Zn, K, P, Cu, Mg than cereals
- High levels of vitamins of B1 and B2
- Only source of dietary rutin among cereals and pseudocereals (strong antioxidant capacity)

Variation for Phenolics in Buckwheat

- Strong correlation (*r*2 = 0.99, *P* < 0.002) between antioxidant capacities and total phenolics content of buckwheat seeds (Holasova et al. 2002) .

TABLE III

Free, Bound, and Total Phenolics Contents in Buckwheat Groats and Husks[z]

	Groats			Husks		
Cultivar	**Free Phenolics**	**Bound Phenolics**	**Total Phenolics**	**Free Phenolics**	**Bound Phenolics**	**Total Phenolics**
VNS	4.9e	2.4cd	7.3e	23.8f	9.6g	33.4h
Gv228	4.9e	2.5bc	7.4e	22.3g	15.0d	37.3g
Co903	5.3de	2.6b	7.8d	31.0c	23.9b	54.9b
Gv-Manor	5.6bcd	2.4cd	8.0d	24.3ef	13.5e	37.9g
Co901	4.5f	2.3d	6.8f	32.8b	17.2c	50.0c
Gv-Manisoba	5.5cd	2.5bc	8.0d	24.6e	15.1d	39.7f
Commercial	5.7bc	2.5b	8.3c	25.4d	17.0c	42.4e
Co902	5.4cd	2.4bc	7.9d	32.6b	26.1a	58.6a
Nikko	6.0b	2.4bc	8.4b	34.2a	12.5f	46.7d
Ta-1	17.1a	3.6a	20.7a	25.7d	6.7h	32.4i

[z] Expressed as milligrams of gallic acid equivalent per gram of dry sample (mg of GA/g). Each value is expressed as mean (*n* = 2). Mean values with different letters within a column are significantly different (*P* < 0.05).

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Lu et al. Cereal Chemistry 2013

Rotation Benefits of Buckwheat

- Breaks up cereal diseases, insect pests, and weeds
- Short season, early maturity
- Excellent pollinator crop
- Buckwheat has been shown to be highly efficient in taking up P compared to spring wheat
- Total P uptake by buckwheat was nearly 10-fold higher than that of spring wheat
- Buckwheat may be included in crop rotation systems to activate P sources in soils

Zhu et al., Plant and Soil 2002

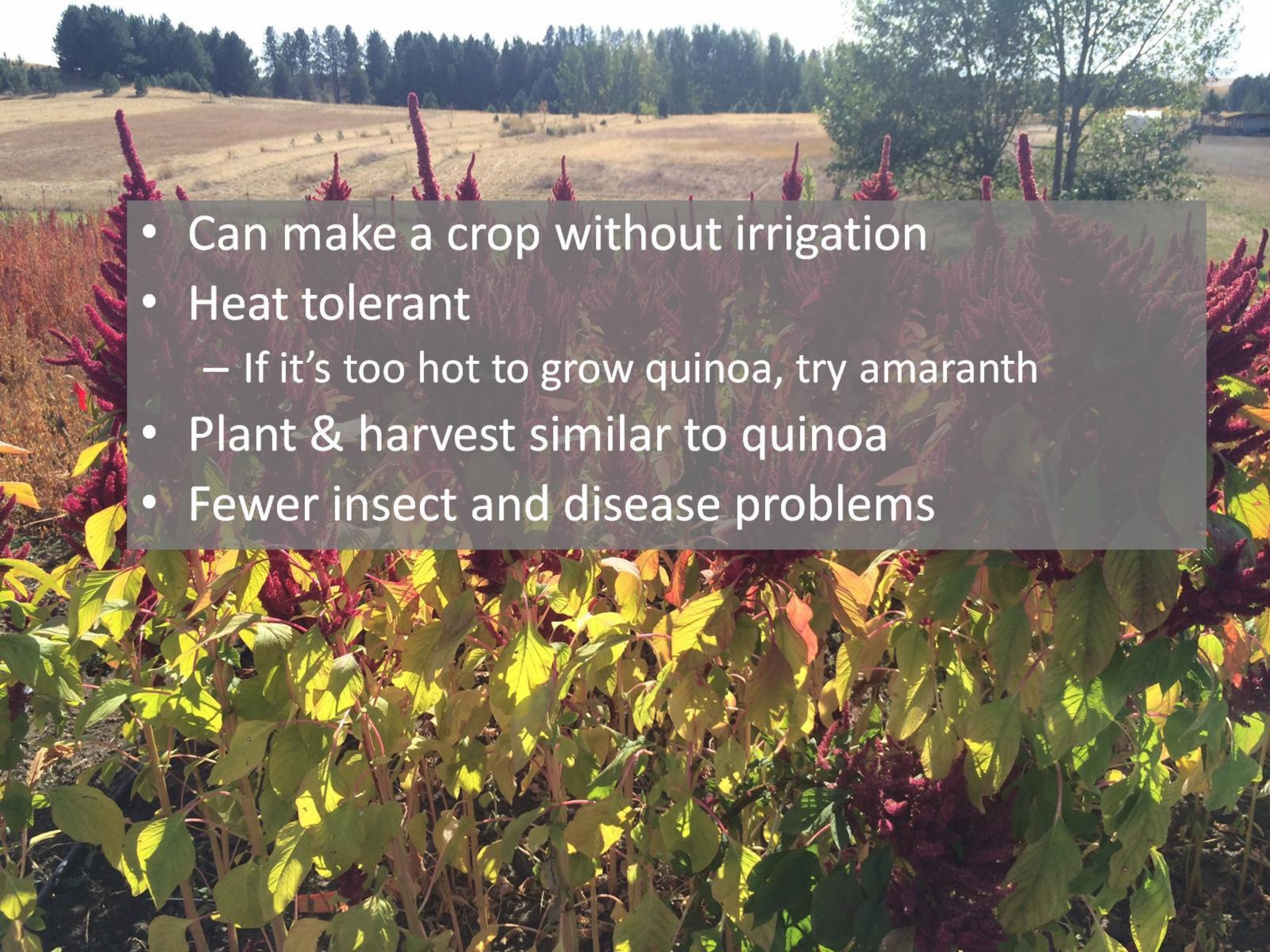
Buckwheat Variety Development

Devyatka buckwheat variety at maturity/new WSU EFOF

- 'Devyatka' x 'Dikul'
- Early Flowering
- Early Maturity
- Determinate variety
- High yielding

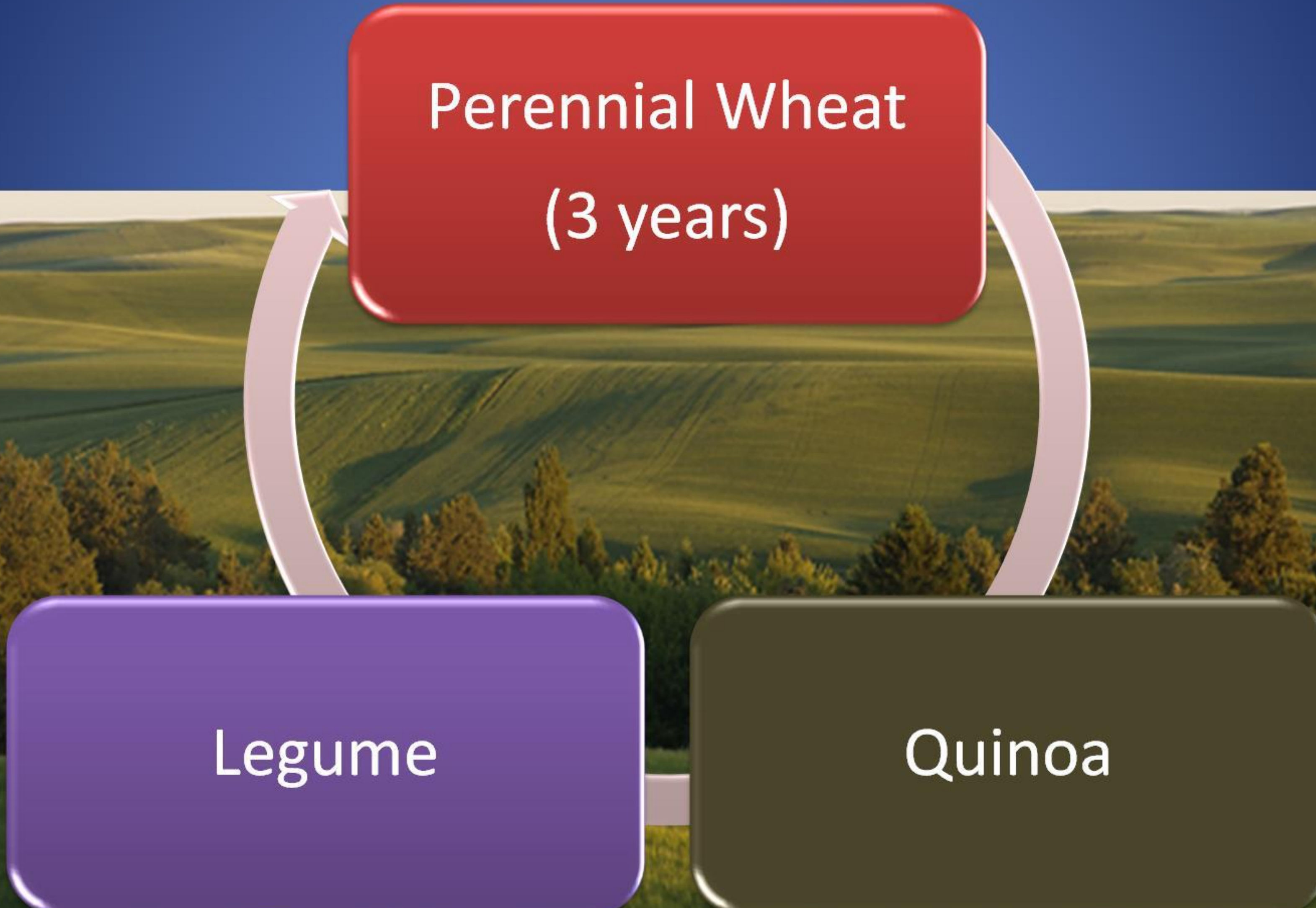
Amaranth (*Amaranthus* spp.)

- Has been cultivated as a grain for over 8000 years; Staple food of the Aztecs
- Today it is grown around the world, especially in African nations, and in Nepal and India
- High protein, and high in lysine, an amino acid which is often limited in other grains
- Gluten-free



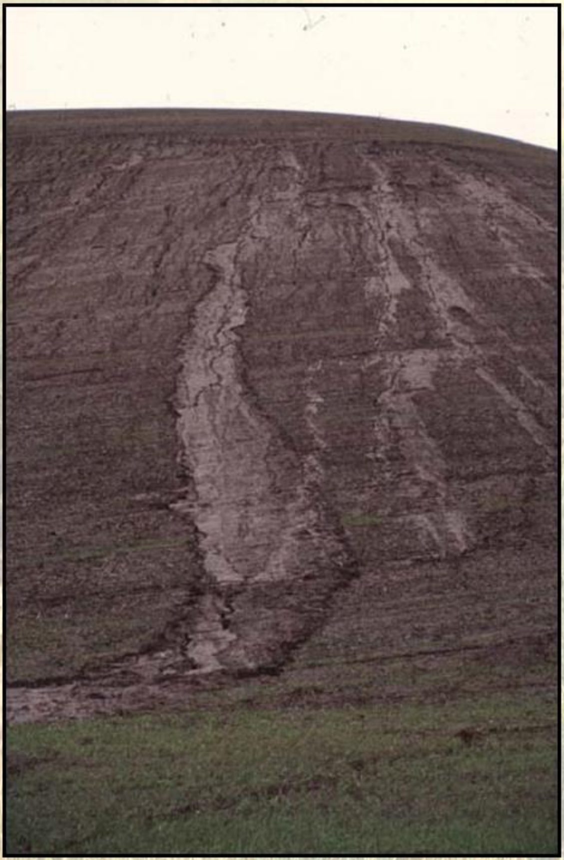
- Can make a crop without irrigation
- Heat tolerant
  - If it’s too hot to grow quinoa, try amaranth
- Plant & harvest similar to quinoa
- Fewer insect and disease problems

Breeding within a System or Redefining the System ?

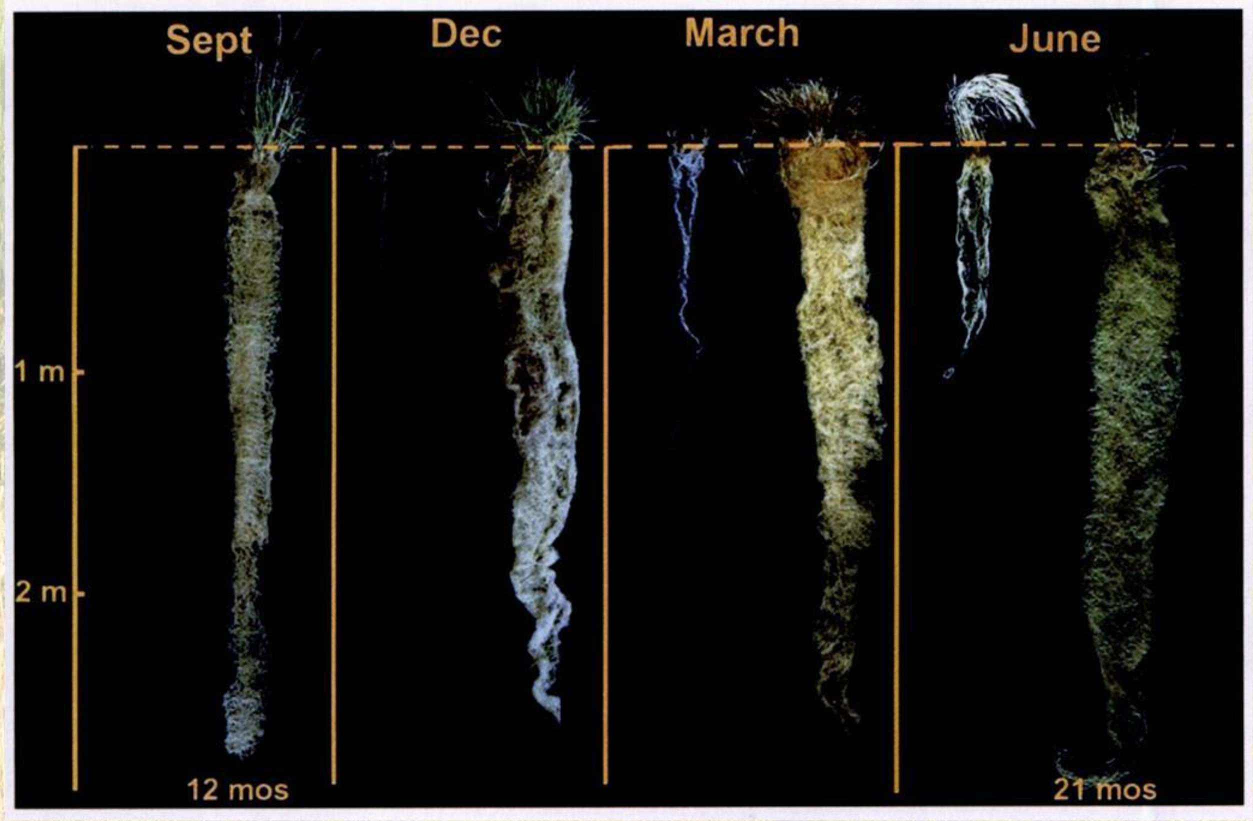


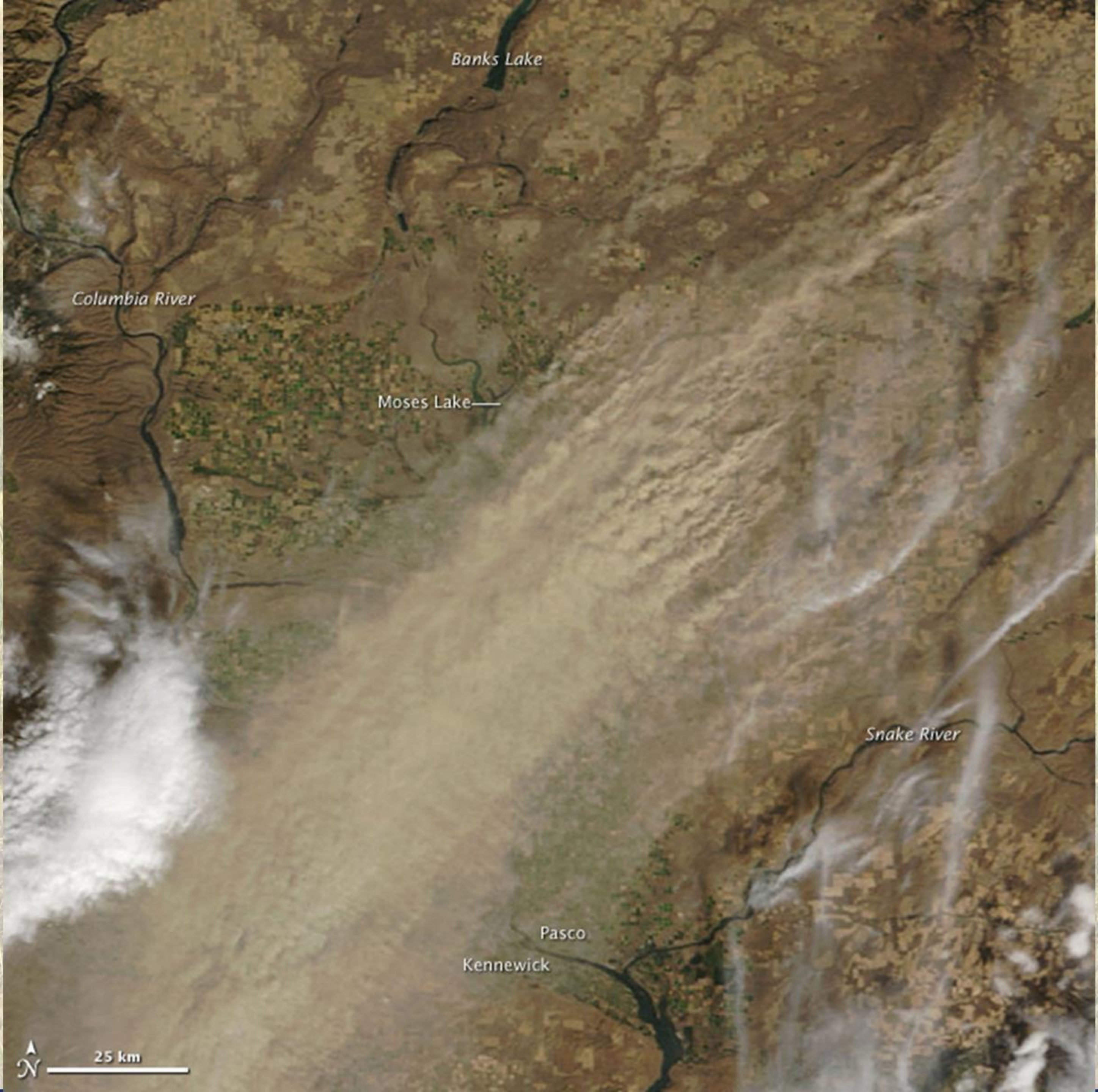
Perennial Wheat: Challenges and Opportunities

Soil Erosion



Perennial crop more than 50 x more effective than annual crops in maintaining topsoil (Gantzer et al. 1990)




Banks Lake
Columbia River
Moses Lake
Snake River
Pasco
Kennewick
N
25 km

Two Complementary Approaches to Breeding Perennial Grains

Direct Domestication

- Selection within species for higher yields, bigger seed, high threshability and non-shattering seed

Land Institute cultivar ‘Kernza™’

Two Complementary Approaches to Breeding Perennial Grains

Wide Hybridization

Crossing perennial wheatgrass species to annual wheat cultivars

Hybridization is difficult due to differences in ploidy level and problems with chromosome pairing

Progeny looks more like wheat

Breeding approaches

Wide hybridization

- Annual crops supply genes for domestication and high yield
- Perennial relatives supply genes for regrowth and disease resistance

Th. elongatum (2n=2X=14) x *T. aestivum* (2n=6X=42) 'Madsen'

Challenges

- Unequal chromosome number
- Sterility
- Deleterious genes / linkage drag

Breeding approaches

Wide hybridization

- Annual crops supply genes for domestication and high yield
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Challenges

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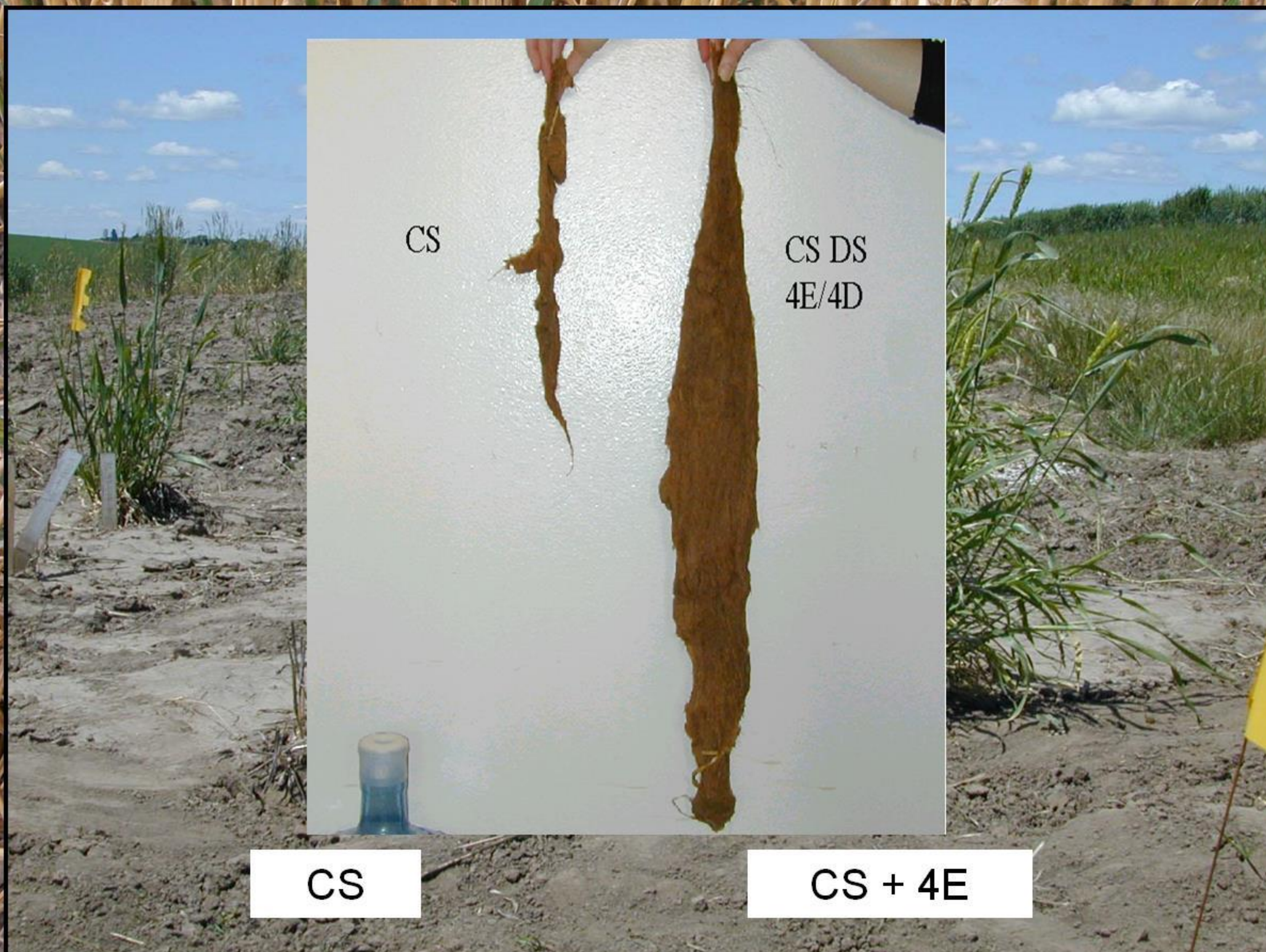
Regrowth after Harvest

Regrowth

Regrowth after Harvest

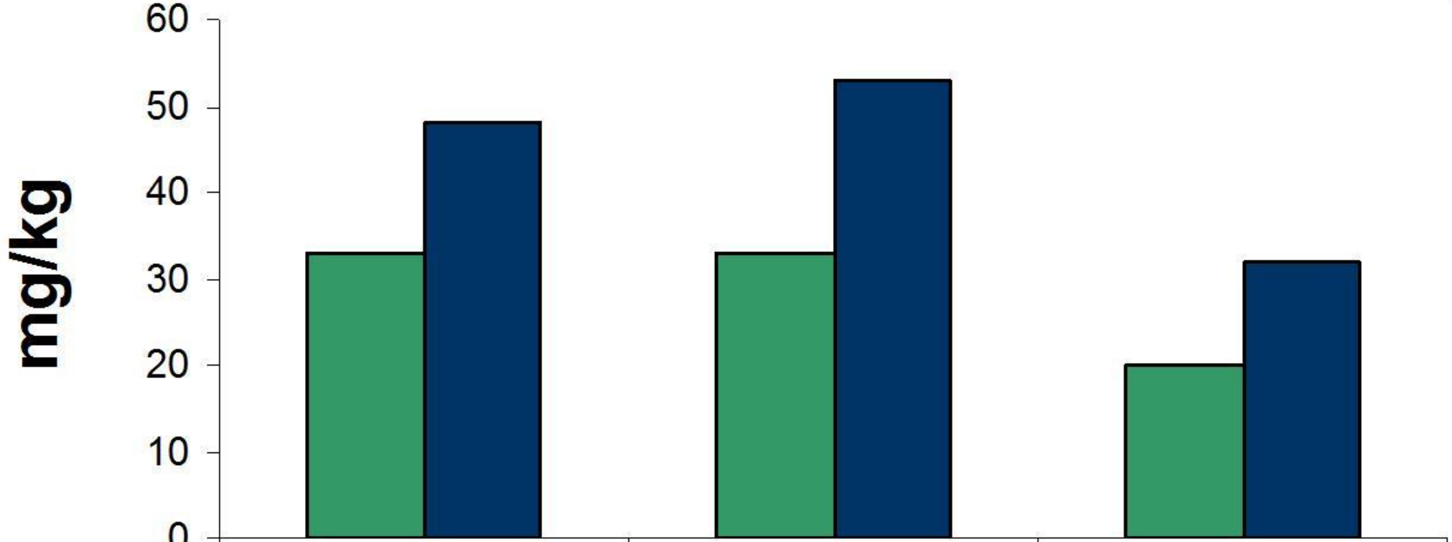


Mineral Concentration

Aegilops tauschii shown to have higher mineral concentration than hexaploid wheat (Ortiz-Monasterio & Graham, 2000)

Synthetic hexaploids (*Triticum durum* x *Ae. tauschii*) have 25 to 30% higher mineral concentration for Fe, Mn, Mg, P and Zn (Calderini & Ortiz-Monasterio, 2003)

Nutritional Value of Perennial vs Annual Wheat



	Fe	Mn	Zn
Annual	33	33	20.1
Perennial	48	53	32

Micronutrients

3 Locations (P=0.05)

Seed Quality

PW has lower test weight, single kernel hardness, and seed size, but higher protein than AW

VARIETY	Test Weight (#/bu)	Kernel Hardness	Seed Size (mm)	Protein (%)
BAUERMEISTER	60.2	70.3	2.25	11.56
FINLEY	62.7	71.2	2.42	12.40
PF4R1-0008	56.0	71.0	1.74	14.02
PF4R1-0014	56.3	50.1	1.59	14.94
PF4R1-0019	57.9	61.0	1.66	14.79
PF4R1-0021	54.6	45.0	1.78	16.47
PF3R1-0030	55.5	52.9	1.66	15.16

Final Thoughts

- Our strategy is to work closely with farmers to determine how best to diversify the existing wheat-based rotation in the Palouse
- All regionally novel crops should fill an agronomic need and marketing opportunity
- Each crop in a rotation, from wheat to buckwheat to quinoa, would ideally have a regional breeding program which targets nutritional, agronomic and quality trait improvement simultaneously

Final Thoughts

- As part of our lab at WSU, we are developing a high-throughput nutritional phenotyping service center
- Targeting β-glucan content, micronutrient concentration, protein content, amino acid composition, etc. to serve a wide range of locally relevant crop species
- This should help fill the early to mid generation selection gap for nutritional and/or heart healthy traits of interest

Thank you for the invitation and for your attention!

Sustainable Seed Systems Lab

www.sustainableseedsystems.org