The National Association of Plant Breeders in partnership with the Plant Breeding Coordinating Committee and The Plant Breeding Genomics Community of Practice presents

How to breed new plant varieties: imagining and engineering crops

Kevin Murphy

Dept of Crop and Soil Sciences

Washington State University

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Keen on Quinoa Breeding

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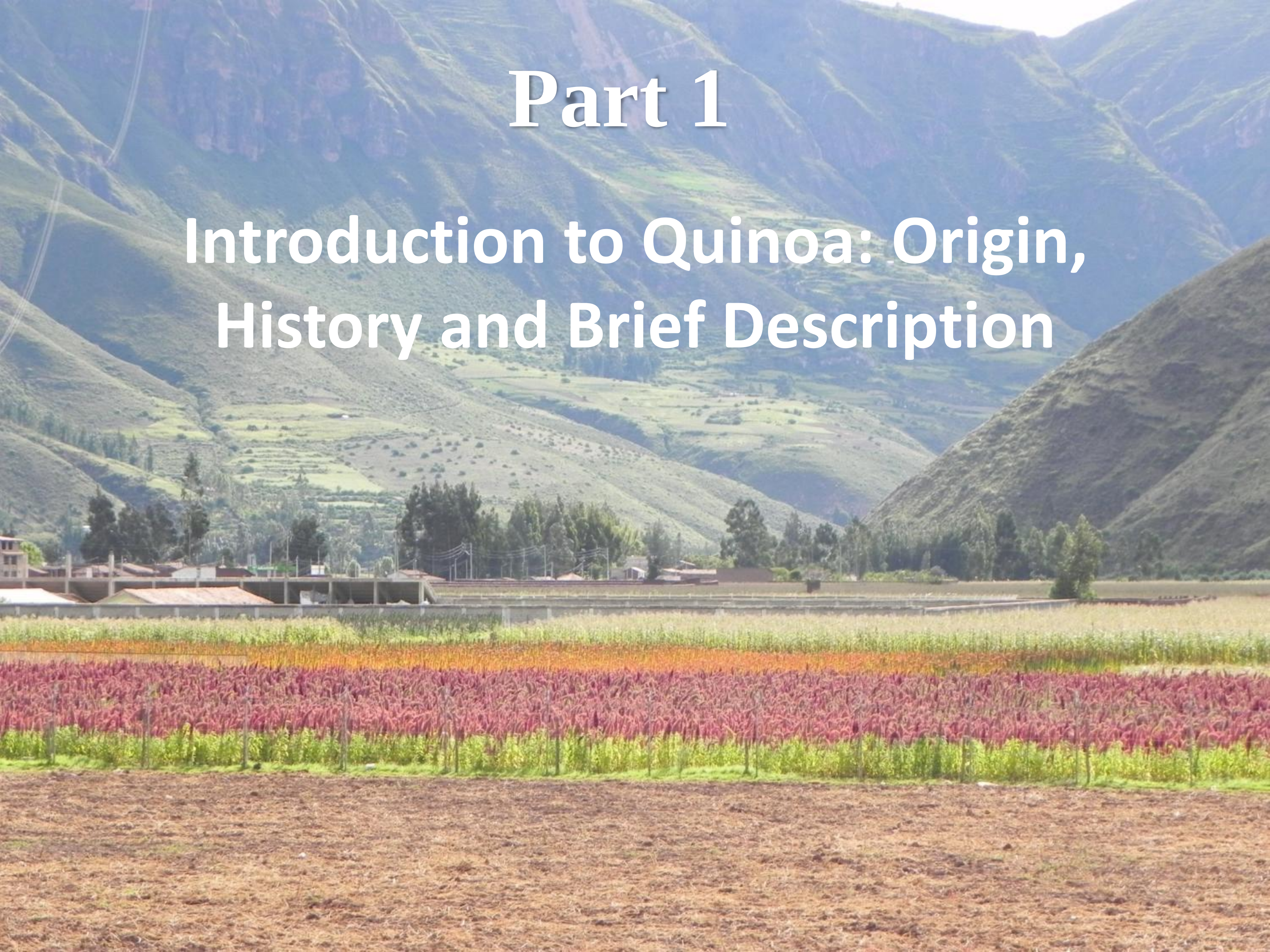
Today’s Topics

- Introduction to Quinoa: Origin, History and Brief Description
- Quinoa Botany and Genetics
- WSU Quinoa Breeding Program: Traits of Interest and Selection Strategies

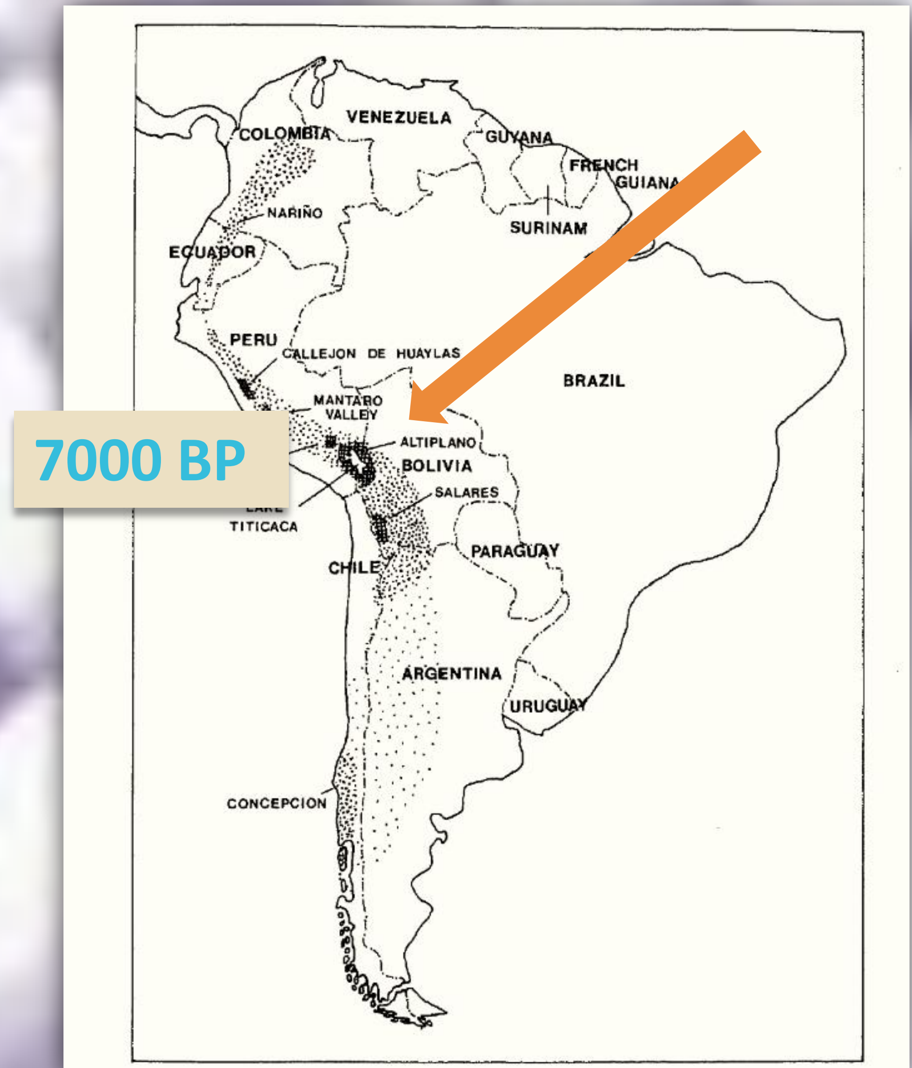


Part 1

Introduction to Quinoa: Origin, History and Brief Description

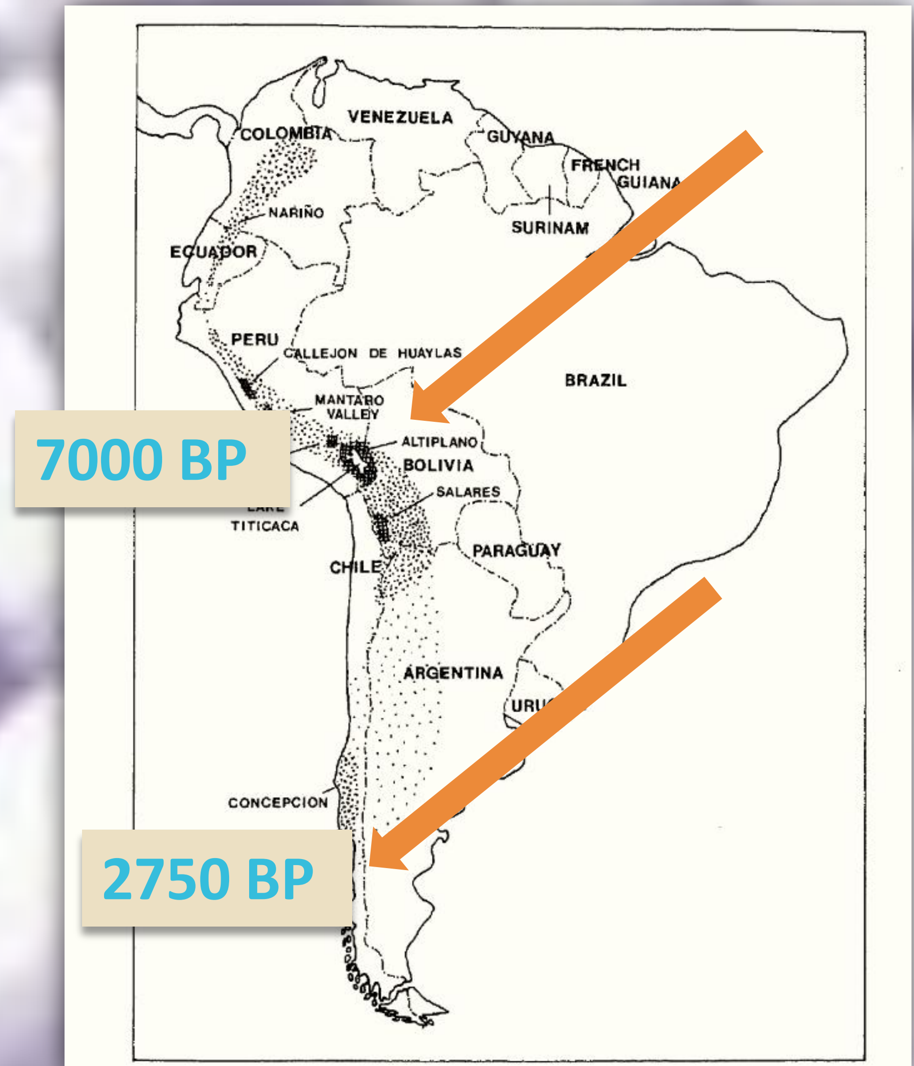
Quinoa: Origin & History

- Center of origin: Lake Titicaca in Peru and Bolivia
- Evidence of cultivation as early as **7000 BP**



Quinoa: Origin & History

- Center of origin: Lake Titicaca in Peru and Bolivia
- Evidence of cultivation as early as **7000 BP**
- From there, it spread north and southward along trade routes and via animal migration
- Cultivated in Chile by **2750 BP**

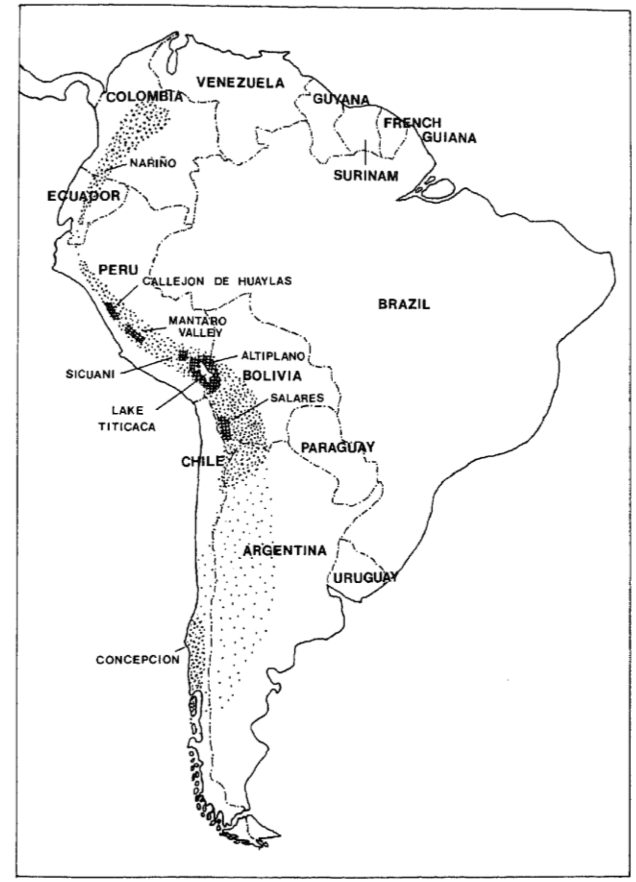


Origin and History

- After the conquest of the Inca Empire, cultivation of quinoa was discouraged, and largely replaced by introduced crops from Europe, including barley and wheat
- Quinoa cultivation was reduced to harsh, marginal environments and isolated areas

Five major groups

- **Sea-level:** South-Central Chile, altitude < 500m
- **Valley:** Andean Valleys, altitude range of 2000 to 4000m
- **Subtropical:** Bolivian Yungas, altitude range of 2500-3000m
- **Salar:** Bolivian Salares, altitude approximately 3700-3800m
- **Altiplano:** Lake Titicaca, 3500 to 4000m



Risi and Galway, 1984

For more information: Didier Bazille, webinar ‘The Genetic Diversity of *Chenopodium quinoa* and its Global Expansion’ https://www.youtube.com/watch?v=s1LTtAEcWXQ&feature=c4-overview&list=UUNlwP-FG1Ylbk4ic-MVhGYw

Adaptation

- Grown over a wide range of latitudes (2°N to 42 °S) in South America – a range of over 3,000 miles
- Wide range in altitude – from sea level to 14,000 ft
- Wide range in annual precipitation (6 inches to over 110 inches)
- Drought tolerant, grows in a wide range of pH soils, frost tolerant

For more information: Sven-Erik Jacobsen, webinar 'What is the global potential of quinoa?'
https://www.youtube.com/watch?v=3GVvtKhHbG8&feature=youtu.be

Nutritional value of quinoa

- Excellent source of protein
  - Common range 12-18% (7 to 22% reported)
  - 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
- Due to its high starch content (51 to 61%), it can be used similarly to cereals in flour production
- Gluten-free

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

Salinity Tolerance

Halophyte - capable of tolerating higher soil salinity while maintaining high yields

- Saline Soils > 4 dS/m
- High yields up to 20 dS/m
- 60% of normal from 20-40 dS/m
- Sea water – 55 dS/m

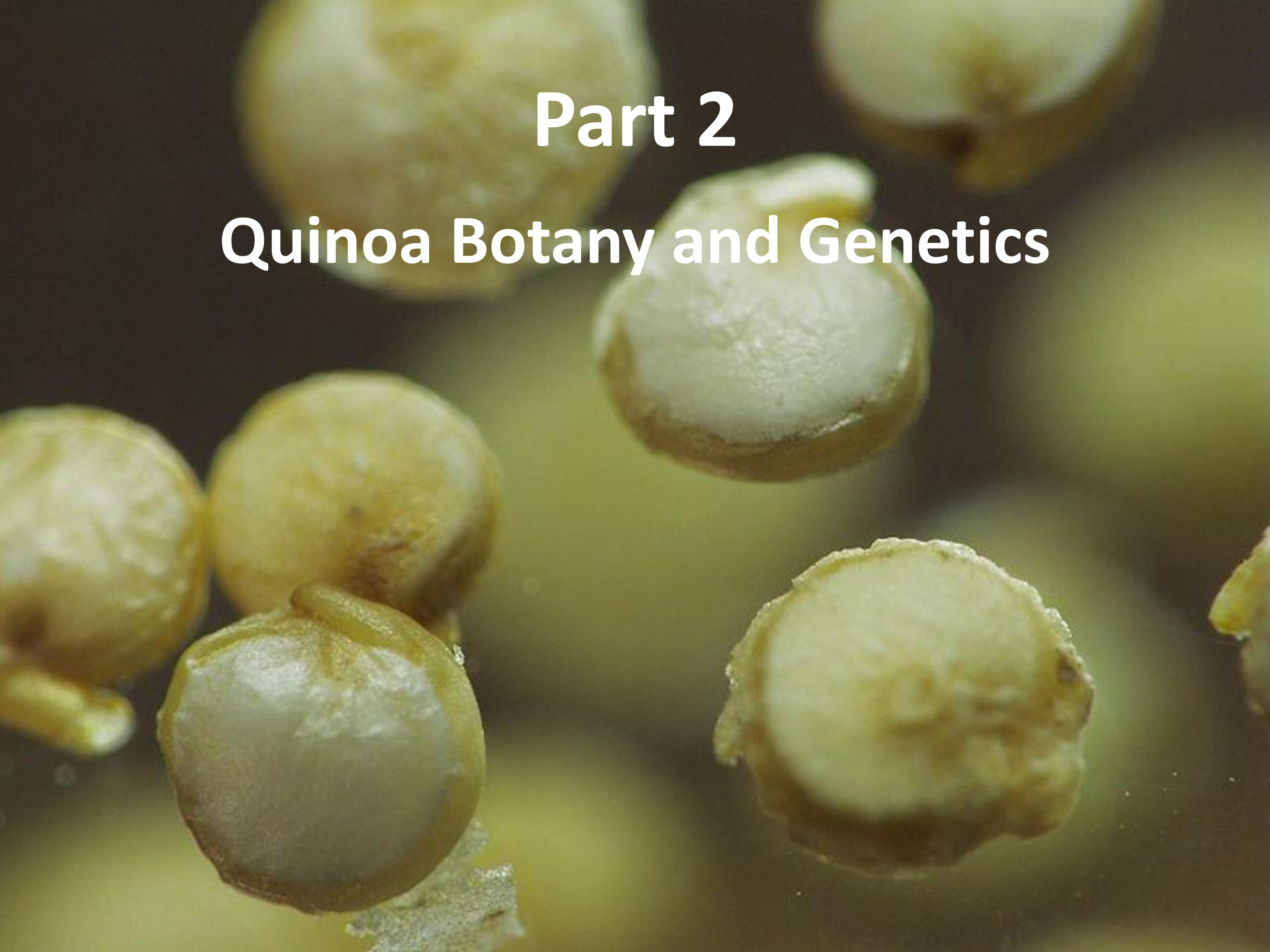
dS/m = deciSiemens per meter (measurement of electrical conductivity)

http://jeb.co.in/journal_issues/201109_sep11/paper_22.pdf

Soil Salinity – Symptoms in Wheat

Part 2

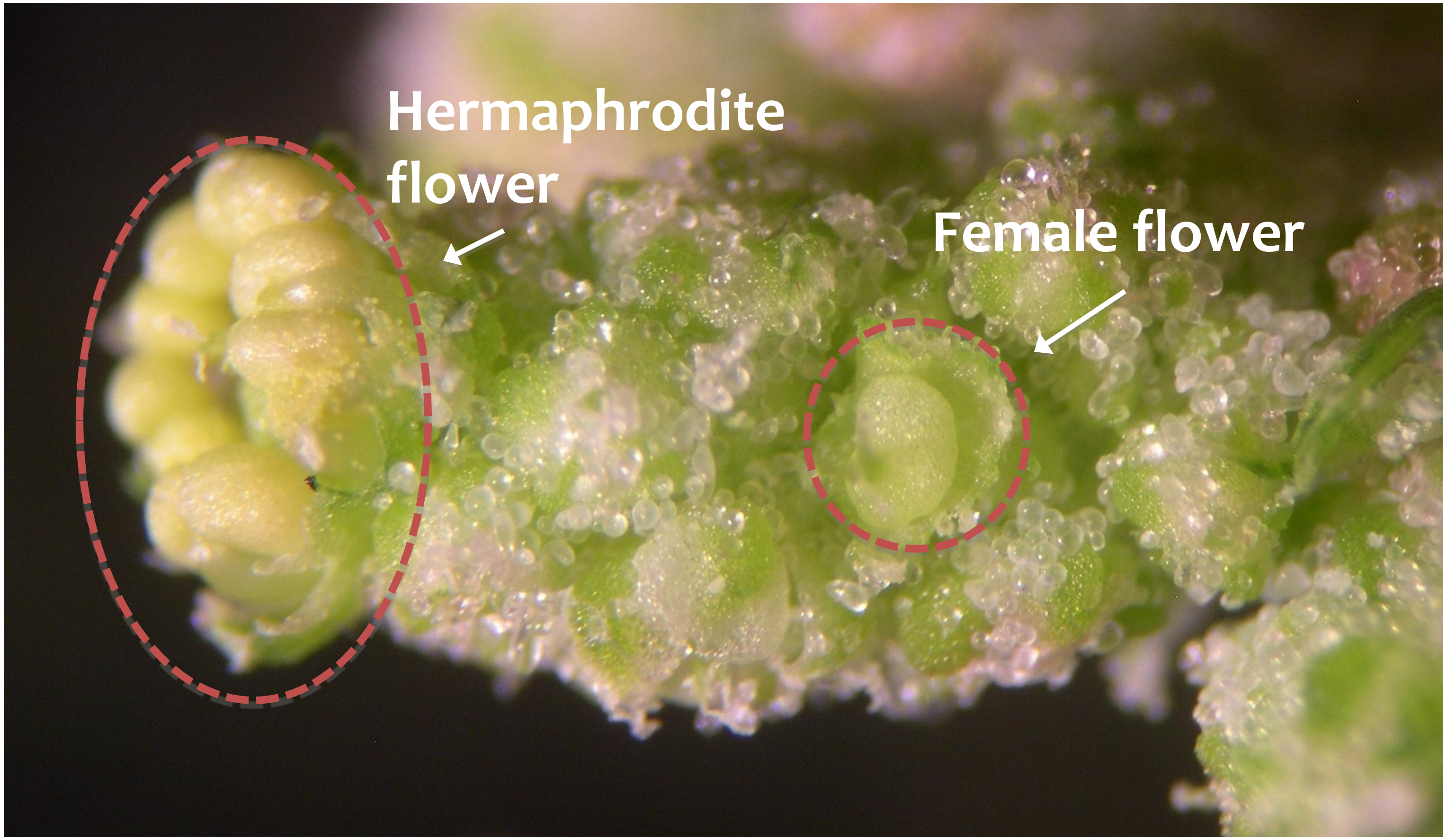
Quinoa Botany and Genetics



Quinoa (*Chenopodium quinoa*)Botany

- Member of Amaranthaceae Family, grown primarily for its seed
- Pseudocereal – not a true ‘grain’
- Related to: Beets (*Beta vulgaris*), spinach (*Spinacia olereaceae*), Common lambsquarters (*C. album* & *C. berlandieri*)
- Gynomonoecious (i.e., female and perfect flowers are present on the same individual)

Gynomonoecious



Large, terminal hermaphrodite flower on end with sepals removed, making yellow anthers visible. In the middle of the flower cluster, a much smaller female flower with removed sepals is visible. (Adam Peterson, photo)

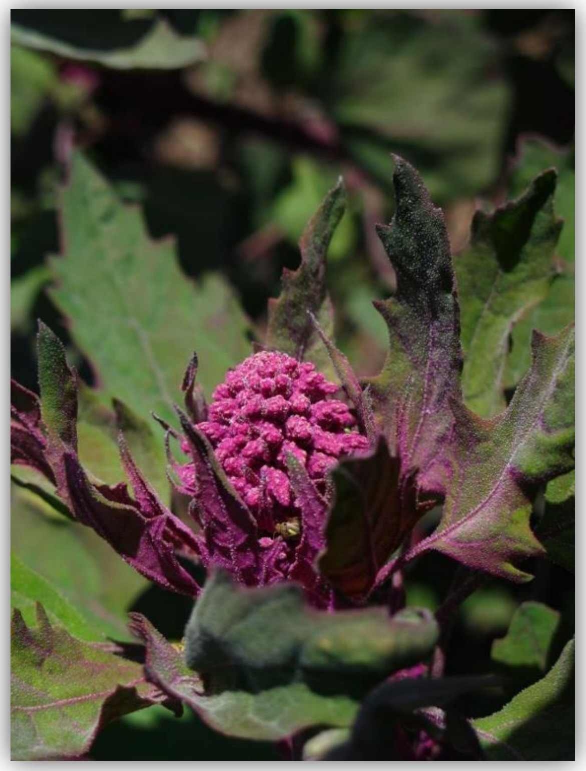
Cross Pollination

- Varying rates of natural hybridization from 10 to 17% (Masterbroek et al., 2001; Spehar and Santos, 2005)
- Flowers are grouped together to form a primary panicle; however there is often profuse branching

Cross section of a quinoa inflorescence. Stigmas are visible as 'hairs' emerging from flowers. Yellow, dehisced anthers are also visible on many of the terminal flowers. (Adam Peterson, photo)

Quinoa Genetics

- Facultative autogamous annual
- Allopolyploid; Base chromosome number of $x = 9$; $2n = 4x = 36$
- Primarily disomic inheritance; some tetrasomic segregation occurs for quantitative traits



For more information: Jeff Maughan, webinar 'Genomic resources for *Chenopodium quinoa*'
https://www.youtube.com/watch?v=QiLyzYxed9Y&feature=youtu.be

Related species

- *Chenopodium album* (common lambsquarters)
  - Allohexaploid ($2n = 6x = 54$)
  - Considered a ‘weed’ in most of the US
  - Lacks domestication traits found in quinoa (shattering, hard seed coat)
  - Commonly cultivated in northern India and Pakistan as a leafy green

C. album

Related species

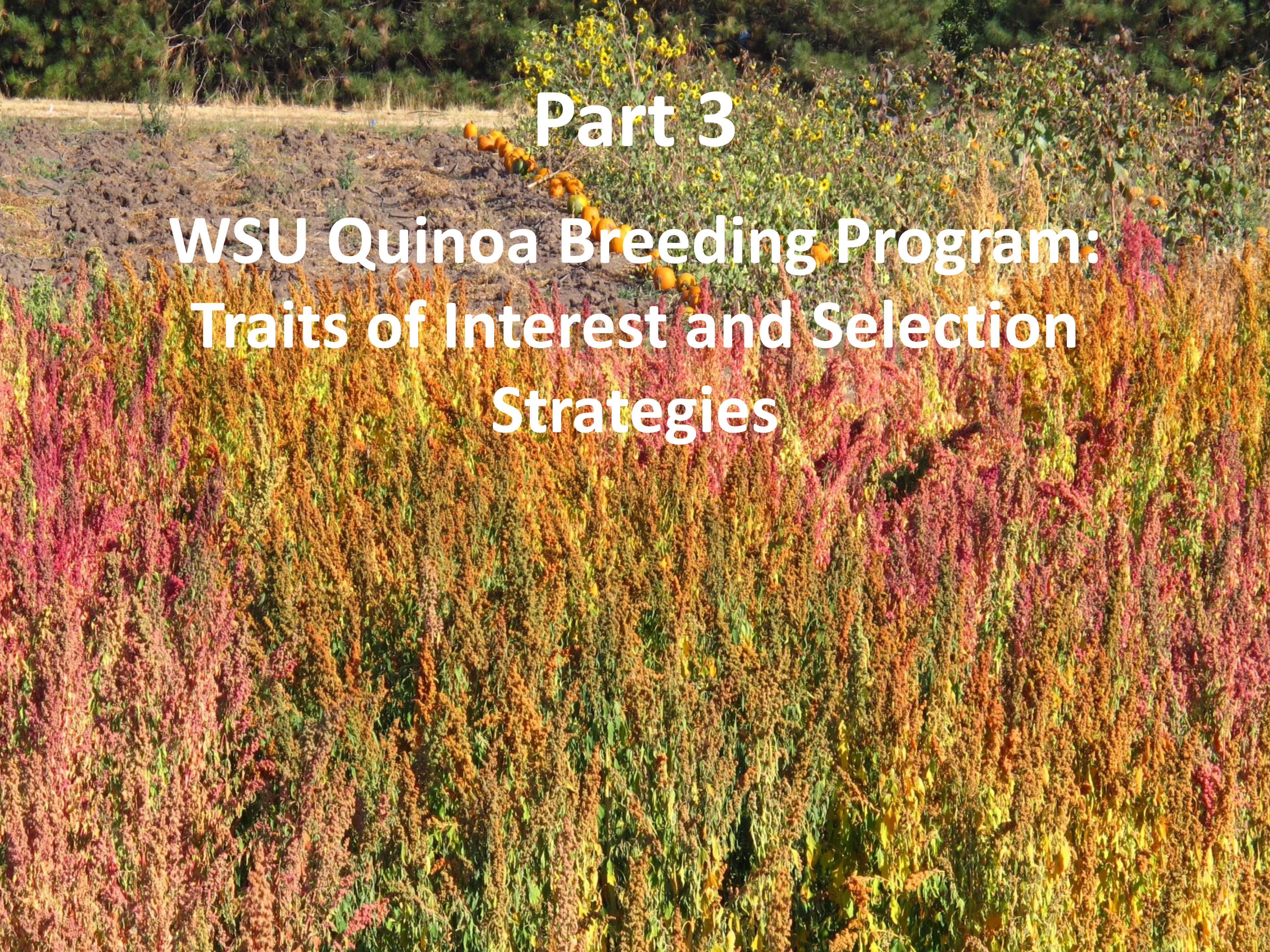
- *Chenopodium berlandieri* (huauzontle, Nuttall's goosefoot)
  - Allotetraploid (2n = 4x = 36) with one diploid ancestor in common with *C. quinoa*
  - Widespread from Mexico to Alaska and native to every US state except Hawaii
  - Evidence of domestication in eastern US and extensively foraged as early as 8500 years ago (seeds found in rock shelters in Kentucky)
  - Still cultivated in Mexico, primarily as a leafy vegetable

C. berlandieri

For more information: Rick Jellen, webinar 'Quinoa phylogenetic insights based on nuclear and chloroplast DNA sequences'
https://www.youtube.com/watch?v=oNErOKrPxUc&feature=youtu.be

Part 3

WSU Quinoa Breeding Program: Traits of Interest and Selection Strategies



Quinoa Hybridization

Quinoa plant ready for isolation (far left), removal of large leaves near inflorescence (left), removal of main flowering bud and leaves surrounding small flower clusters (right), isolation of flower clusters to prevent cross pollination (far right). (Adam Peterson, photos)

Quinoa Hybridization

Isolated quinoa flower clusters ready for emasculation. Dotted white line shows the approximate location to trim flower clusters to reduce number of flowers for emasculation.

Two quinoa plants paired after emasculation of the female parent.

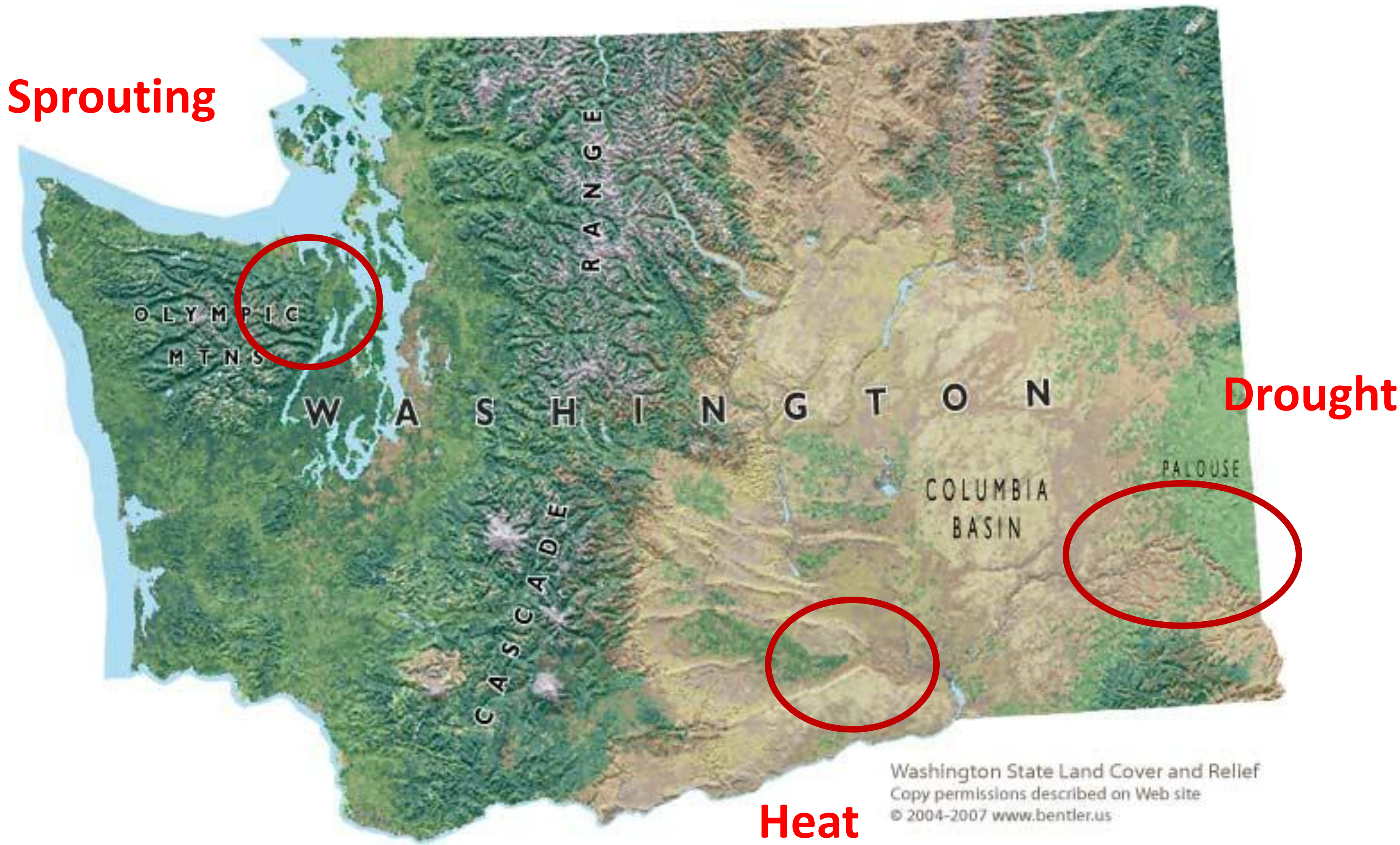
Adam Peterson, photos

F1 Hybrid Verification

Inflorescence color was used as a dominant morphological marker in a cross between Bio-bio (center), and Temuko (left). Two F1s (right) exhibit the dominant pink inflorescence color, as well as leaf morphology intermediate to both parents. (Adam Peterson, photos)

F3-F5 Populations Grown in 2 Diverse Field Environments

Washington State Advanced Yield Trial Locations

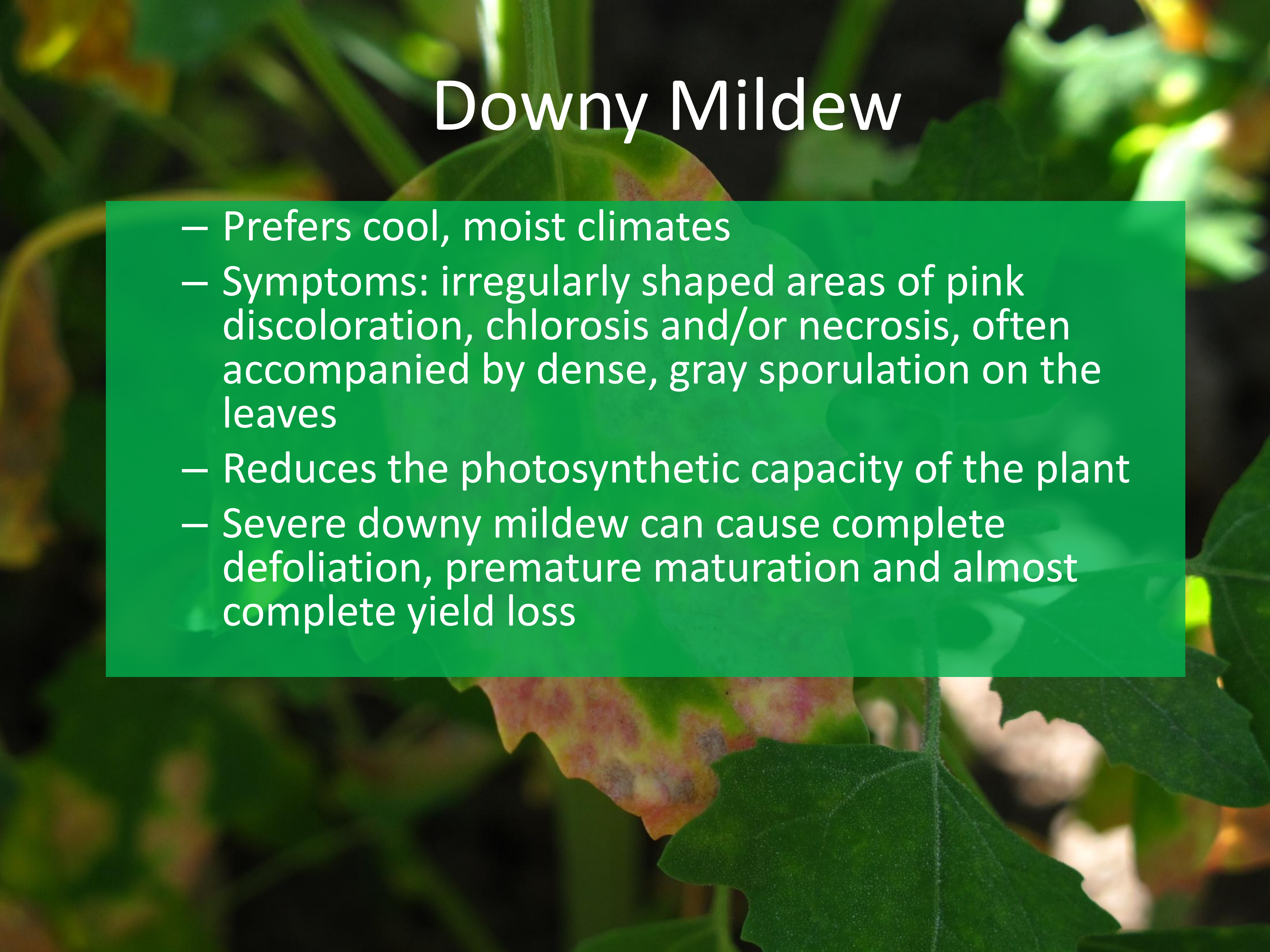


Breeding Objectives

Traits of Interest:

Nutritional Value
Grain yield
Maturity
Heat tolerance
Seed size / color
Lodging resistance
Salinity tolerance
Drought tolerance
Lygus resistance
Aphid resistance
Nitrogen-use efficiency
Saponin content
Sprouting resistance

Downy Mildew



Downy Mildew

- Prefers cool, moist climates
- Symptoms: irregularly shaped areas of pink discoloration, chlorosis and/or necrosis, often accompanied by dense, gray sporulation on the leaves
- Reduces the photosynthetic capacity of the plant
- Severe downy mildew can cause complete defoliation, premature maturation and almost complete yield loss

Resistant Varieties

Pre-harvest Sprouting

Panicle Architecture

Saponins

- Found on outer seed coat / pericarp
- Benefits: Bird deterrent
- Drawbacks: Human deterrent
  - Bitter, soapy and unpalatable

http://articles.herballegacy.com/quinoa-%E2%80%93-the-mother-of-all-grains/

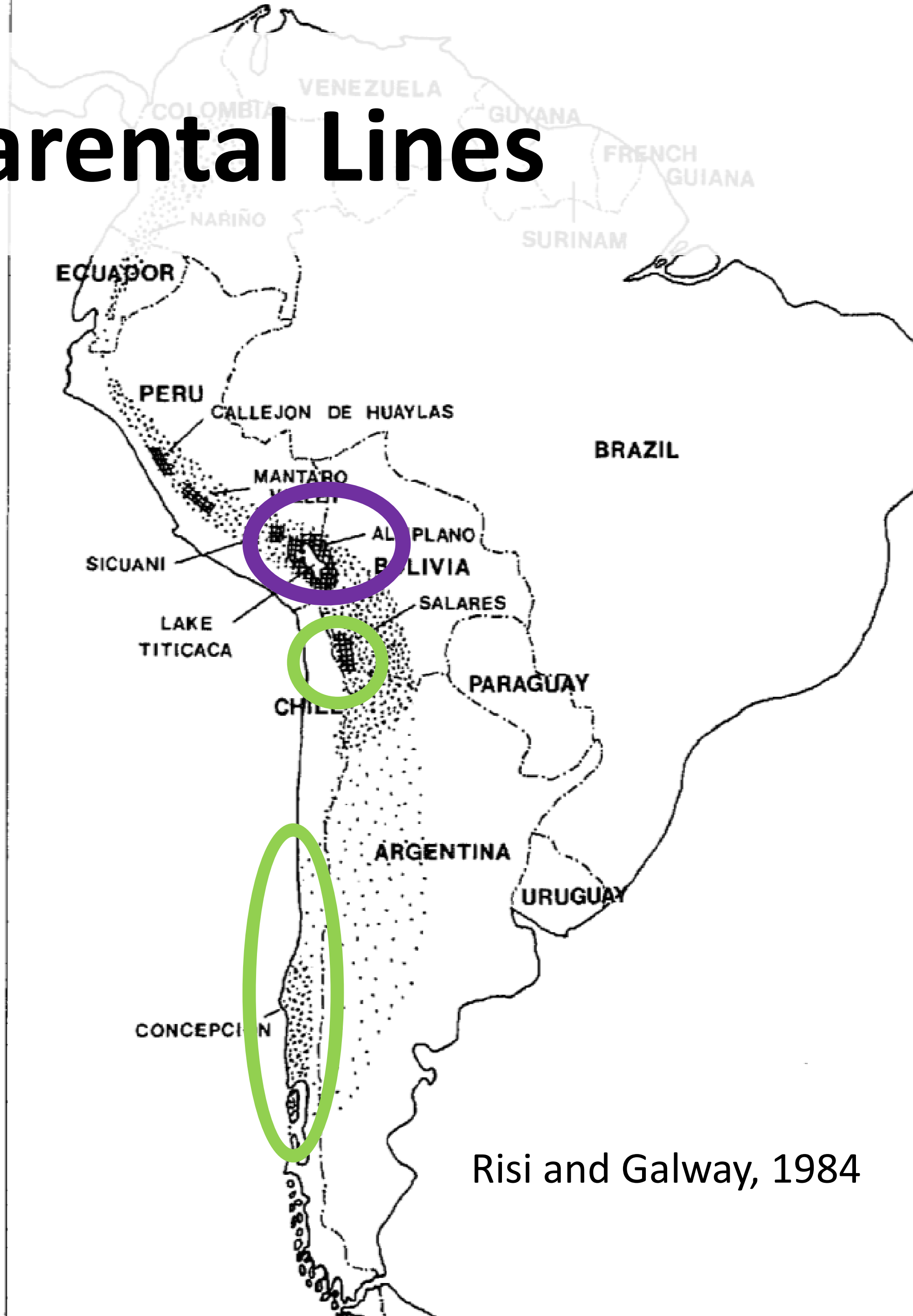
Nutritional Value of Quinoa: Bioactive Compounds & Micronutrients

Quinoa Mapping Populations

- OREI project: develop quinoa for a diverse environment in this region
- Collaborative project with Brigham Young University
  - Genotyped five quinoa populations
- Goals of the Project
  - Identify QTL's for traits
  - Develop varieties for the region
- Results to date
  - Two years of phenotyping
  - Insect and disease pressure

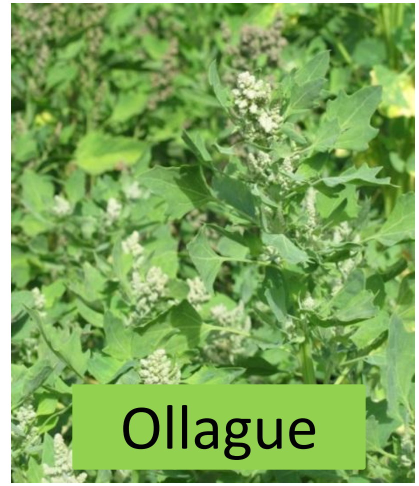
Origin of Parental Lines

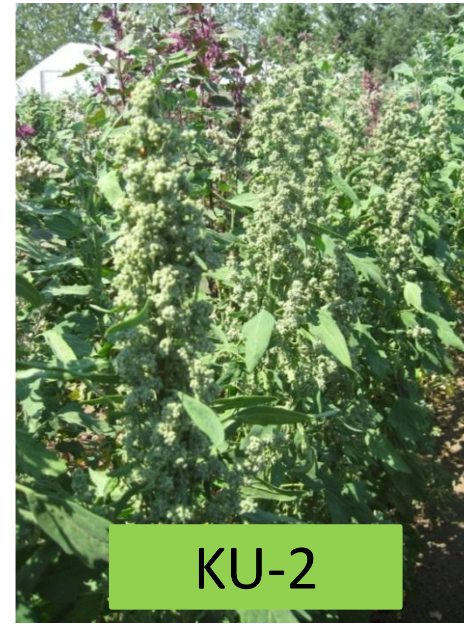
- **L-P Kurmi** N. Altiplano
- **Chucapaca** Bolivia Andean
- **0654** Peru Andean
- **NL-6** Chile coast
- **KU-2** Chile coast
- **G205-95** Chile coast
- **Ollague** Chile salares



Risi and Galway, 1984

Parental Lines





Hannah Walters, photos

Mapping Populations

Population	Parents	# of lines 2012:2013	Generation Planted
1	(KU-2 X 0654)	81:88	F8
39	(NL-6 X 0654)	76:72	F8
40	(NL-6 X Chucapaca)	93:85	F8
M3	(L-P Kurmi X 0654)	84:72	F5
GO	(G205-95 X Ollague)	0:358	F8

Progeny Phenotyping

- Plant height and architecture
- Flowering
- Seed maturity
- Downy mildew
- Leaf and inflorescence color
- Seed color
- Saponin content
- Protein content

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- Organic Farming Research Foundation (OFRF)
- Clif Bar Family Foundation / Seed Matters
- WSU Center for Sustaining Agriculture and Natural Resources (CSANR)
- USDA Organic Research and Extension Initiative



Thanks for joining us today.

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http://www.extension.org/plant_breeding_genomics

http://www.extension.org/pages/60426/webinar-registration-and-archive

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