Domestication, Breeding, and Genetic Modification* of Crop Plants

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**No transgenics. 'We make progress the old fashioned way…. we earn it…'*

Plant Domestication

Domestication is process by which early crops are developed from seed gathered from wild stands.

Key to domestication:

Selective advantage of rare mutants alleles**, which are necessary for* ***survival in cultivation; or those unnecessary for survival in wild.

Selection pressure during cultivation – resulting in allele frequency changes, gradations within and between species, fixation of major genes, and improvement of quantitative traits.

Farmers develop ***'varieties' as 'carrier of traits'*** between growers / locations / cropping seasons

Primary Agricultural Centers and Crop Domestication

Near east (i.e., the **Fertile Crescent**) beginning about **9,500 BC**

Wheat, barley, rye; Flax, pea, lentils, figs, dates, grapes, olives, lettuce, onions, cucumbers, and melons; Fruit and nuts

Meso-america beginning about 7,200 BC

Maize (by 5,000 BC), squash, common bean, lima bean, peppers, amaranth;

Agricultural development was slower in American societies likely due to ***lack of pre-adapted animals*** *that could be domesticated and provide transport and traction.*

Peruvian highlands – beginning about 6,500 BC

Tuber crops, potato, peanut, cotton, maize

China –
beginning about 7,800 BC

Soybean, millet

Far east (Thailand) – beginning about 8,500 BC

Rice, soybean, citrus fruits, coconut, taro, yams, banana, breadfruit, coconut, wet- and dry-land rice, sugarcane.

Earliest record of rice in Thailand is about 9,000 yrs BC.

Plant traits modified during domestication

Elimination or reduction in seed dispersal mechanisms

Non-shattering
Varieties with seeds that are retained and only break off during the threshing process

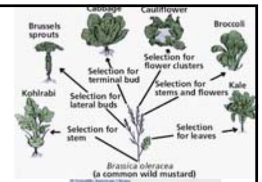
Free threshing
Varieties where the seed easily separates from husk or glumes during threshing

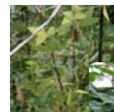
Non-brittle rachis (ex: see photos)
The rachis, as central axis of a raceme or spike, should remain intact to facilitate threshing and minimize seed loss

Non-dehiscence
The spontaneous opening at maturity of a pod or other plant fruit structure

Growth habit, plant morphology

Reduction in branching, height
Synchronous tillering, flowering, ripening
Climbing – to bush habit (i.e., Beans)
Reduction in internode length
Suppression of twining reponse
Determinacy (simultaneous flowering)





Reproductive system

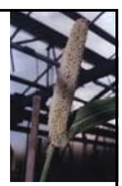
Reduced or absence of sexual reproduction
Vegetative propagation
'instant domestication'
From outcrossing to predominantly self pollinated

Increases in seed (fruit) yield

Increase seed number
Larger, increased # of inflorescence
Reduced sterility

Larger seed
Improved seedling vigor, emergence
More carbohydrates

Non-dormant seeds



Adaptation to taste and food utilization

Processing & cooking quality:
'Functional' starch, protein and oil compositions

Color, flavor, texture, storage quality, cooking quality, uniformity, etc.

Reduced toxic compounds
Cyanogenic glucoside; phenolic compounds bitterness

Genetic control of domestication is relatively simple

Relatively ***few genes and genomic regions*** involved
ex: 1-2 genes control brittle rachis trait in wheat

Genes for domestication represent a only a small subset of unique genes/traits for that species

Several genes have major effect on plant phenotype. Once identified, domestication could occur quite rapidly

Consequences of plant domestication and breeding

1. Crops are a combined product of artificial selection (man-directed) and natural selection

*Modern crop plants have been highly **'genetically modified'** from their progenitor species due to man's intervention and selection over thousands of years*

2. Modern crop plants were selected and bred for growing under cultivated conditions

*Without cultivation, **most crops** are not able compete with weeds and pests and **will not survive 'in the wild'.** Traits and plant architecture important for competitiveness and survival have been lost or eliminated through breeding and selection.*

*In the last 100 years, selection has emphasized plant traits that facilitate mechanized planting, harvesting, and crop management. These **traits are very unlikely to be advantageous to survival** 'in the wild'.*

3. Genetic diversity available in the specie may not be carried through the domestication process

*Numerous **'genetic bottlenecks'** have occurred in development of major crop species, from initial domestication through the release of modern high yielding varieties*

***Conservation of genetic resources**, especially land races and weedy progenitors, is critical to maintain progress in plant improvement and reduce genetic vulnerability to diseases and insects.*

4. Most modern crops are relatively genetically uniform

Highly vulnerable to changing races of diseases and insects.

Plant breeding as a science - application of genetic principles

~1900 - Rediscovery of Mendel's laws
- Hugo de Vries, Carl Correns, Erik Tschermak in Europe
- W.J. Spillman, 1901, Washington Agricultural College (WSU)
  - *Hybridization of wheat for adaptation to the Palouse country*

1906 - Inheritance, inbreeding and hybridization of maize
- G. Shull – observations on reduction / restoration of vigor through crossing

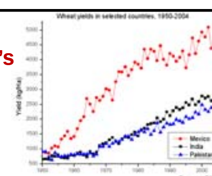
1918 - Double cross hybrid maize to facilitate seed production
- D. Jones – 1st commercial release in 1921; widely available by 1930

1940's - Majority of US maize production is from hybrids
- *by 1950's most hybrids are sold by companies*
- *by 1960's most are single cross hybrids*

US Maize Yields
1990-2005

1940's and '50's - Gene for gene hypothesis for host-parasite interaction
- H. Flor - inheritance of virulence / avirulence of flax and flax rust

The Wheat 'Green Revolution' of 1960's



CIMMYT, Ford and Rockefeller Foundations, USAID

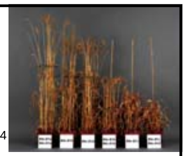
Reversal of food shortages in India and Pakistan

- Averted mass starvations due to exponential population growth in Indian subcontinent
- Average wheat grain yields in the Indian subcontinent were approximately **doubled** between 1955 and 1970.
- Pakistan became self-sufficient by 1968; India by 1974.

Better nutrition via increased income, reduced food prices

- National security through reduced hunger
- Higher farmer income stimulated rural non-farm economies

Components of the 'Green Revolution'



Semidwarf genes (Rht1 and Rht2)

Genes for short, stiff straw types that could withstand higher production inputs and increase grain yields

Identified by Salmon (USDA Ag attaché) in post-war Japan (1945-46), provided to WSU (Orville Vogel, 1948), from Vogel to Borlaug in 1954

N fertilization, management of soil fertility

Irrigation (intensive management)

Result: Exploit interaction of G x N x M
For intensive high-yield cropping systems

'More than just changing plant height'

Maximize light capture, more erect foliage; Increased harvest index;
Higher and more synchronous tillering; Resistance to lodging;
More responsive to nitrogen; Increased head size and fertility

***'Broad adaptation'* from CIMMYT shuttle breeding approach**

Improved tolerance to abiotic stresses; daylength insensitivity;
yield stability; disease resistance, esp. to stem, leaf, and stripe rust

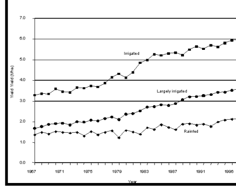
The Asian Rice 'Green Revolution' of the 1970's

IRRI, the International Rice Research Institute
Variety development led by Dr. Gurdev Kush

Development and release of high yield, input responsive, semidwarf rice varieties for Asia

Early maturing varieties facilitated 'double cropping', further increasing total production.

IR8 - The first of the modern, high-yielding, semi-dwarf releases out-produced all existing rice varieties by a ***factor of two***.



Rice yield trends
1967-1996. FAO

Social Implications of the 'Green Revolution':

Increased farmer income through increased grain yields
- Per capita incomes ~doubled in Asia from 1970 to 1995
- General increase in rural demand for goods, services
- Increased need for farm inputs, marketing, transportation milling and baking industries

Better nutrition at local levels, both quantity and quality
- Reduced prices, higher income, more diversified diet

Criticisms of the Green Revolution:

Environmental concerns related to intensive production practices
- Increased fertilizer and pesticide use; irrigation requirements; high water use; soil erosion; salinity from irrigation;

Decreased biodiversity, increased genetic vulnerability
- As related to extensive monoculture of high yield varieties

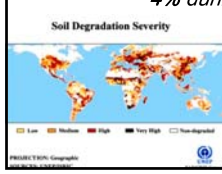
'Some outcomes were inevitable as millions of illiterate farmers used new technologies for the first time; extension programs were inadequate'

But –

'What would have been the environmental impact when the only alternative was to expand farming into huge areas of marginal lands and forested areas??'

World grain production increased from
692 M tons in 1950
to 1.9 billion tons in 1992

Total increase in cultivated land for cereal grains was only
***4%** during the Green Revolution !!*



Modern plant breeding

Identify important traits
Search out 'new genes'
Combine desirable genes
Assess the performance
Release superior lines as varieties

New technologies and information

Genetics – *knowledge and strategies*
Quantitative approaches; genetic interactions; diversity analyses; heterosis and heritability; environmental interactions; population management, etc.

Selection methods – *speed, precision, efficiency*
Tissue culture; doubled haploids; growth chambers; computers; field research equipment; end-use quality assessment; protein, biochemical analyses; DNA based markers; disease and insect screening; statistical tools;

Genetic resources – *widening the gene pool*
Collection, evaluation, exchange of diverse germplasm; introgressions from weedy and related species; mutagenesis; somoclonal variation;

Expanding the crop germplasm base

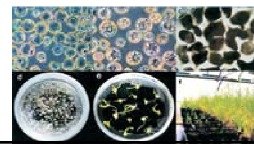
Sustaining progress in yield, quality, and resistances to evolving pathogens and environmental stress

Generating diversity

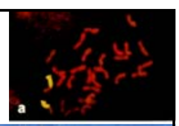
Mutagenesis (radiation, chemical, stress, somoclonal variation)

Exploiting diversity

Intra-specific crossing (primary gene pool)
Inter-specific crossing (weedy relatives)
Chromosome engineering, genetic bridges
Doubled haploids
Tissue culture
Molecular markers



Most modern wheat varieties are products of ***'chromosome engineering'*** incorporating genes, chromosome segments and translocations from different, but ***related species*****.**



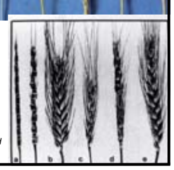
1B/1R and 1A/1R Wheat – Rye translocations
Disease resistance and stress tolerance
Grown on 10's of millions of acres in past 30 years

VPM-1 translocation from Ae. Ventricosa
Resistance to strawbreaker footrot, stripe rust
In major PNW varieties for past 20 years

'Hope' gene from *Triticum turgidum* L. ssp. *dicoccum*
Durable resistance to stem rust (Sr2) on Chromosome 3B

D genome segments from T. Tauschii
Resistance to leaf rust (Lr41, 42, 43), Hessian fly

GPC-B1 from Tr. Dicoccoides
High grain protein, Yr36 resistance to stripe rust



Aegilops tauschii (2 spikes), Triticum turgidum, F_1 self-sterile hybrid (2n=3x=21, ABD) T. turgidum x Ae. tauschii, colchicine-induced fertile C_0 synthetic (2n=6x=42, AABBDD), C_0 fertile selfed progeny with high fertility

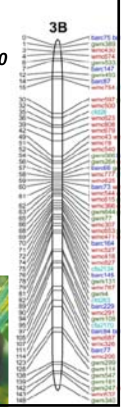
Molecular and Analytical Tools for Crop Breeding

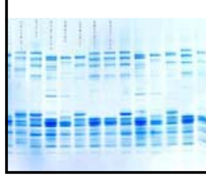
Compositional analyses
Protein (Eletrophoresis, HPLC)
Starch (size, binding, gelation)
Fiber (digestive methods)

Physiologic measures
Photosynthesis; respiration; Water use efficiency
Biochemistry of drought, cold, heat tolerance;

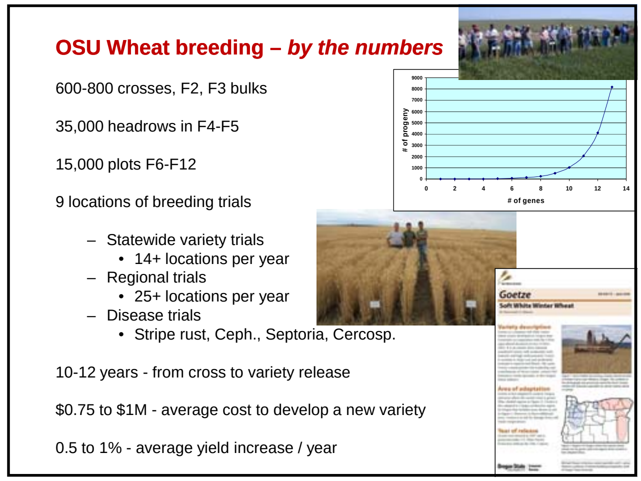
DNA molecular markers
PCR based; SSR; SNP; DArT, etc.
Associations with major genes, quantitative traits

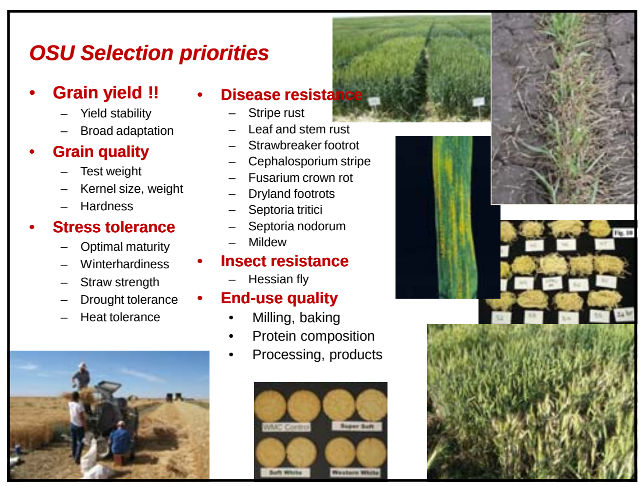
Yr30






OSU
Wheat
Breeding
Using all
available tools…


OSU Wheat breeding – by the numbers
600-800 crosses, F2, F3 bulks
35,000 headrows in F4-F5
15,000 plots F6-F12
9 locations of breeding trials
– Statewide variety trials
• 14+ locations per year
– Regional trials
• 25+ locations per year
– Disease trials
• Stripe rust, Ceph., Septoria, Cercosp.
10-12 years - from cross to variety release
$0.75 to $1M - average cost to develop a new variety
0.5 to 1% - average yield increase / year
# of progeny
# of genes
Goetze
Soft White Winter Wheat


OSU Selection priorities
• Grain yield !!
– Yield stability
– Broad adaptation
• Grain quality
– Test weight
– Kernel size, weight
– Hardness
• Stress tolerance
– Optimal maturity
– Winterhardiness
– Straw strength
– Drought tolerance
– Heat tolerance
• Disease resistance
– Stripe rust
– Leaf and stem rust
– Strawbreaker footrot
– Cephalosporium stripe
– Fusarium crown rot
– Dryland footrots
– Septoria tritici
– Septoria nodorum
– Mildew
• Insect resistance
– Hessian fly
• End-use quality
• Milling, baking
• Protein composition
• Processing, products

Why the concern??

Increases in cereal productivity are slowing

60's and 70's -– 2.3% per year
80's and 90's -- 1.5% per year
90's and 00's -- 1.0% per year

World's crop land is being lost to urban growth

Nearly 40% of the world's agricultural land is seriously degraded

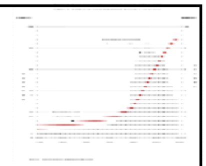
Water quality and availability for agricultural uses are declining

Growing competition between food and fuel

Impact of 'global climate change' on world food production??

Funds for international aid, economic development, agricultural research and in developing countries ***are declining***

World farmers will need to double their output by 2050!!



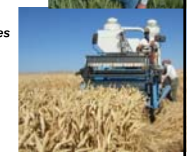
How can we achieve the 'next' Green Revolution??

Technology components??

- ***Precision Ag***
- ***Sustainable Ag***
- ***No-till management***
- ***Integrated Pest Management***
- ***Organic farming***
- ***Conventional plant breeding***
- ***Molecular genetics***
- ***Genetic engineering and GM crops***
- ***Mechanical engineering***
- ***Changes in land and water-use***
- ***Public and/or private research***

Barriers to adoption??

- ***Intellectual property rights***
- ***Public investments in R&D***
- ***Technology access***
- ***Technology acceptance***
- ***Financial, educational issues***
- ***Donor $ commitment***
- ***Acceptance of GM crops***



Questions

How does 'genetic modification' of crops through applications of modern breeding and genetics methodology differ from non-scientific 'genetic modification' that occurred during domestication?

What are positive and negative consequences of domestication and breeding?

How can we achieve the next 'Green Revolution'??

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