The Latest Innovation in Plant Breeding: Genome Editing

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Plant (and Animal) Breeding: A Numbers Game

- Finding useful variations
- Combining useful variations
- Selectively propagating useful combinations
- Takes lots of generations = lots of time

INNOVATIONS = More variations in more combinations in less time
Innovations in Plant Breeding

- Domestication – B.C.
- Mutation and Selection – A.D.
- Induced Mutations - 20^{th} Century
- Genetic Transformation – 1980’s
- Marker-Assisted Selection – 1990’s
- Gene & Genome Editing – 2011
Domestication: Selection Breeding by Native Americans

Without knowing about genes, our ancestors selected and propagated useful plants.
Genomes are instruction manuals

The letters are AGCT

Genes are instructions to cells written in the language of DNA.
Traditional Breeding Depends on Useful Variation and Selection

- Flowering plant genomes have 25,000-50,000 genes
  - between 70 million and 100 billion base pairs
- In nature, mutations only happen at frequencies of about 1/100,000 base pairs.
- Most mutations are neutral or cause losses of gene functions.
- Very few mutations are advantageous, either for the plant itself or for human uses of the plants.

Potatoes

Apples

Wheat
Examples of useful gene mutations: dwarfing genes of rice and wheat

Green revolution (1960-1970)

Green revolution leads to greatly increased crop yields based on the incorporation of dwarfing genes discovered by Norman Borlaug and the widespread use of agrochemicals.
Needed: More Variability

- Crossing
  - Bring in whole genomes
- Induce mutations
  - Radiation (X-ray and fast neutron) break chromosomes (deletions, new combinations)
  - Chemicals and ultraviolet light trigger error-prone DNA repair (substitutions)
Crossing to make new combinations

For any set assembled without regard to parent:
½ red deck, ½ blue deck
Crosses scramble the genomes, so you can lose favorable combinations

Wild emmer wheat

Domesticated durum wheat

The Solution: Back-crossing
Back-Crossing to Clean up the Genome
Mutations change the text, but in random ways
Even if you get a useful mutation, there are usually many other mutations in that plant. The genome has to be "cleaned up".

The Solution: Back-crossing
Back-Crossing to Clean up the Genome
Searching for useful genetic variability

Near infrared image of vegetation showing chlorophyll content
What happens when the variability is subtle and/or time-consuming to detect and/or involve many genes?

- Yield
- Food quality
- Pest resistance
- Drought resistance

Enter DNA Sequences
DNA tags for genes - Marker Assisted Selection

- Marked cards.
- The more markers, the more efficiently your favorite variety can be “reconstructed” with a new gene.
The value of genome DNA sequences

- Bookmarks for the locations of genes in the genome.
- Knowing the page number for each gene helps a lot.
- Having search engines helps a lot. We can find matching DNA sequences.
- Having the complete instruction manual helps a lot.
More Variability: Genetic Transformation

Introduce a new instruction into the book.
Genetic Transformation allows us to verify the identity of genes and make perfect molecular markers.

Breeders introduced a chromosome segment from wild emmer wheat into domesticated durum wheat.
Gene Confers Partial Resistance to Stripe Rust

Effective at high temperatures against all races tested!
Summary

- A gene from wild emmer wheat makes domesticated wheat plants partially resistant to all tested races of stripe rust at higher growth temperatures.
- The DNA sequence of the wild emmer gene has been used to design molecular markers for use by breeders.
- Jorge Dubcovsky & other breeders are releasing durum and bread wheat cultivars with this gene in their varieties.
The Latest: Gene or Genome Editing Technologies

- Use DNA sequence to **SPECIFY** genome changes.
- Combines strengths of genetic transformation (directed and specific) and mutation breeding (new variation in existing genes in their native contexts)
- Known by their acronyms: CRISPR/Cas9, TALEN, ZFN
Genome Editing: Genetic Transformation + Targeted Mutation
Genome Editing

- Uses genetic transformation, but the final plant can’t be distinguished from one produced by traditional mutagenesis.
- No crossing to “clean up”.
- No foreign DNA.
- Can be used to mark genes.
The Latest Innovation: Genome Editing
Questions?