New Breeding Technologies: Applications in Crop Improvement

- Drivers of Breeding Innovation
- The Seed is Planted
- Breeding Innovations
  - Accelerated Breeding
  - Photosynthesis
  - Asexual Seed Production
  - Crop Gene Therapy
- Breeding Democratization

Jack Okamuro, National Program Leader, Crop Production & Protection
USDA Agricultural Research Service (ARS)
USDA Agriculture Outlook, February 21, 2019, Washington, D.C.

Drivers of Innovation: Global Challenges

Agriculture Today

2014

75% increase in Agricultural Output

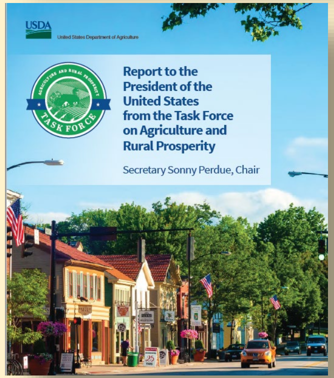
2050

Climate Change

Agricultural Resources

Nature Editorial, *How to feed a hungry world*. 2010

Consumers & Producers
New Products & Markets
Global competition
Leadership



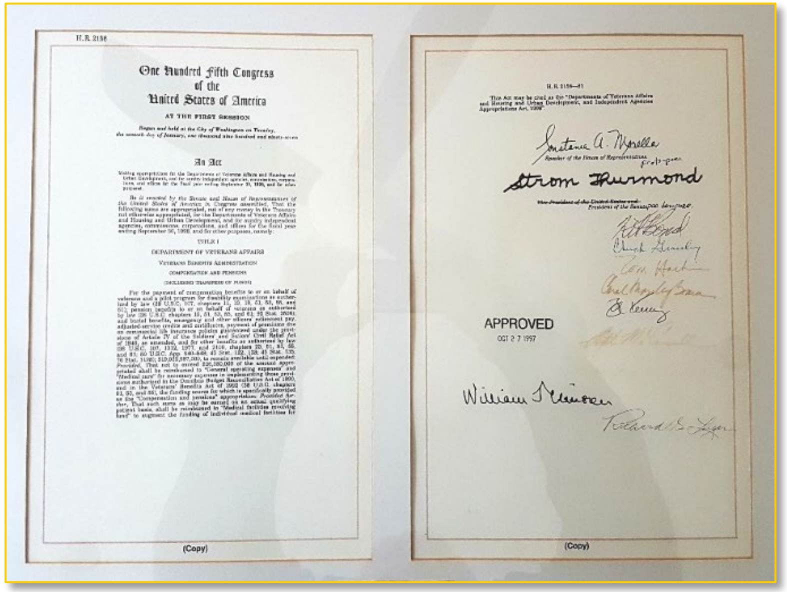
USDA

The Seed is Planted

USDA Agricultural Research Service

USDA United States Department of Agriculture
National Institute of Food and Agriculture

NSF



National Corn Growers Association, commodity groups, professional societies & industry
Pam Johnson, Kellye Eversole, Ron Phillips,
Judy St John, Kay Simmons (USDA ARS)
Ed Kaleikau, Sally Rockey (USDA NIFA/CSREES)
Mary Clutter, Machi Dilworth, Jane Silverthorne, (NSF)
Greg Dilwort (DOE)

The National Plant Genome Initiative (NPGI)

- Established by Congress in 1998 as a coordinated Federal program on the genomics of economically important crop plants;
- To develop a basic knowledge of the structures and functions of plant genomes;
- *To accelerate discovery and innovation for economically important plants.*

Breeding Impacts

- Disease resistance
- Stress tolerance
- Nutritional improvement

Breeding Revolution

Breeding Evolution

Phenotypic Selection

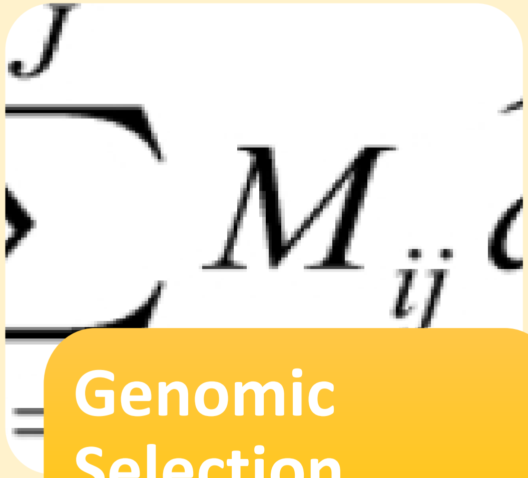
- First 10k years
- Testing species diversity

1.0

Controlled Trials

- Quantitative Genetics
- Exp. design
- Statistics
- Harvesters

2.0



Genomic Selection

- Marker assisted breeding
- Whole genome prediction

3.0

Designed Genomes

- Causative nucleotides
- Editing
- Physiology

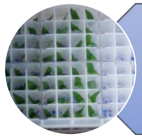
4.0

Breeding Innovations: USDA-ARS Wheat Breeding

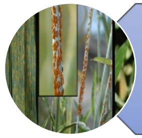
USDA-ARS Wheat Research Collaboration

World-Class System for Variety Development

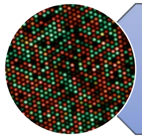
ARS Germplasm Gene Bank



ARS Genotyping Centers

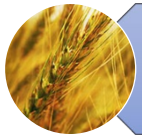


ARS Disease and Insect Resistance



ARS Quality Laboratories

ARS Uniform Nurseries



Wheat Growers

Breeding Innovations: USDA-ARS Impacts

162 New Hard Red Winter Wheat Varieties since 2000

JUST TO NAME A FEW…

Smith's Gold	2017	Oklahoma State University
Langin	2016	Colorado State University
LCS Chrome	2016	Limagrain Seed Co.
Hot Rod	2015	Kansas State University
Ruth	2015	University of Nebraska
WB4303	2015	WestBred - A Unit of Monsanto
Northern	2015	Montana State University
TAM 204	2014	Texas A&M University

Pacific Northwest Wheat Varieties

Breeding Innovations: Accelerated Breeding

Tree Fruit Production

- Public breeders drive genetic improvement
- Production is vulnerable to rapidly emerging threats—disease, pests, drought, heat, freezing
- Juvenility is a major barrier to rapid improvement, e.g. 3-7 years for peach, plum, apricot, and cherry to reach maturity.

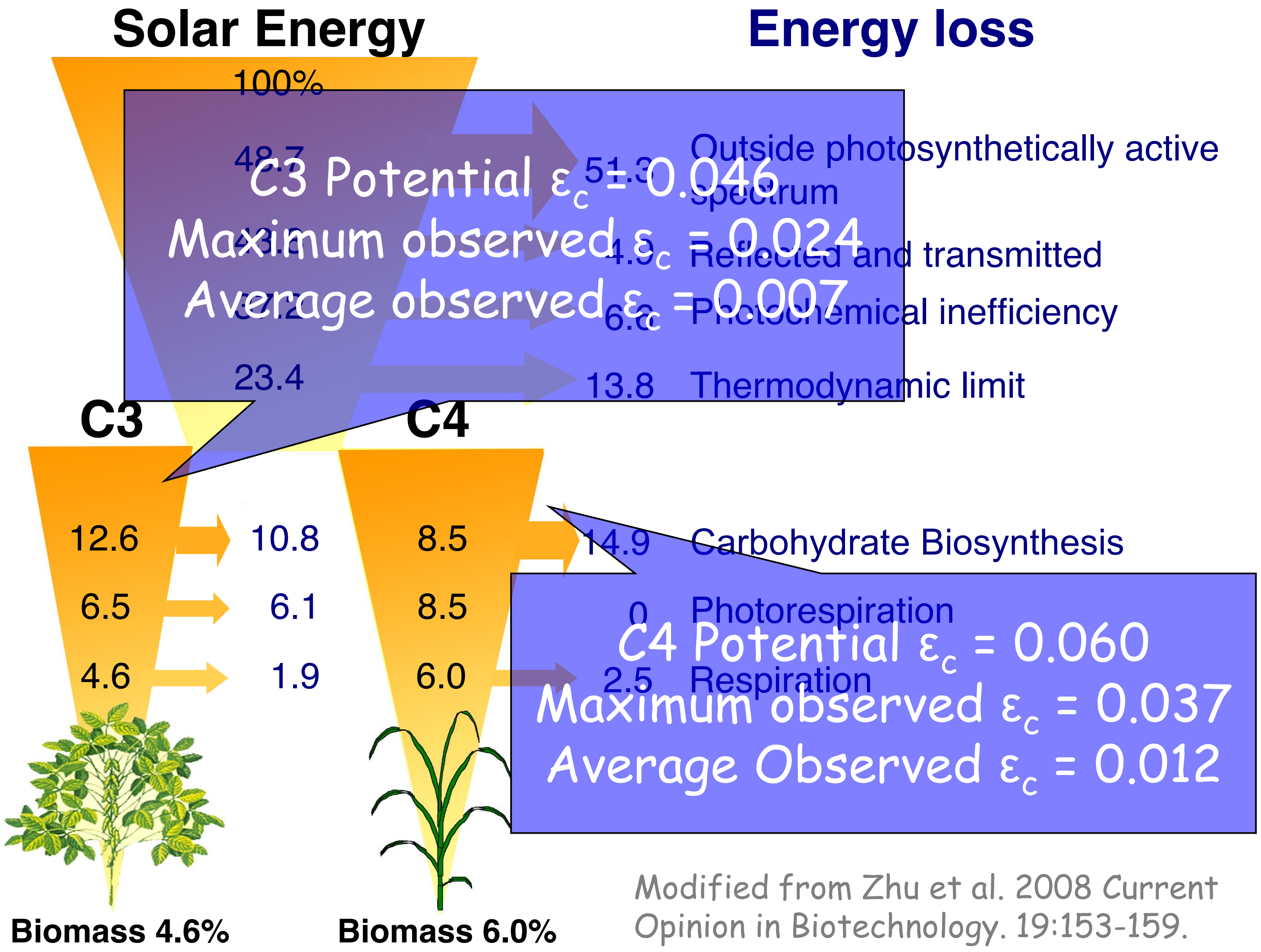
Böhlenius, H., Huang, T., Charbonnel-Campaa, L., Brunner, A.M., Jansson, S., Strauss, S.H., Nilsson, O. 2006. The conserved CO/FT regulatory module controls timing of flowering and seasonal growth cessation in trees. Science 312:1040-1043

Breeding Revolution: FasTrack 1.0

TODAY: FASTRACK TREE FRUIT BREEDING
USDA ARS Kearneysville, WV

Breeding Innovations: Photosynthesis 2.0

Steve Long, Don Ort, UIUC, USDA ARS collaborators. USDA ARS Administrator's postdoctoral fellow Paul South



C3 Potential ε_c = 0.046
Maximum observed ε_c = 0.024
Average observed ε_c = 0.007

C4 Potential ε_c = 0.060
Maximum observed ε_c = 0.037
Average Observed ε_c = 0.012

Modified from Zhu et al. 2008 Current Opinion in Biotechnology. 19:153-159.

Breeding Innovations: Photosynthesis 2.0

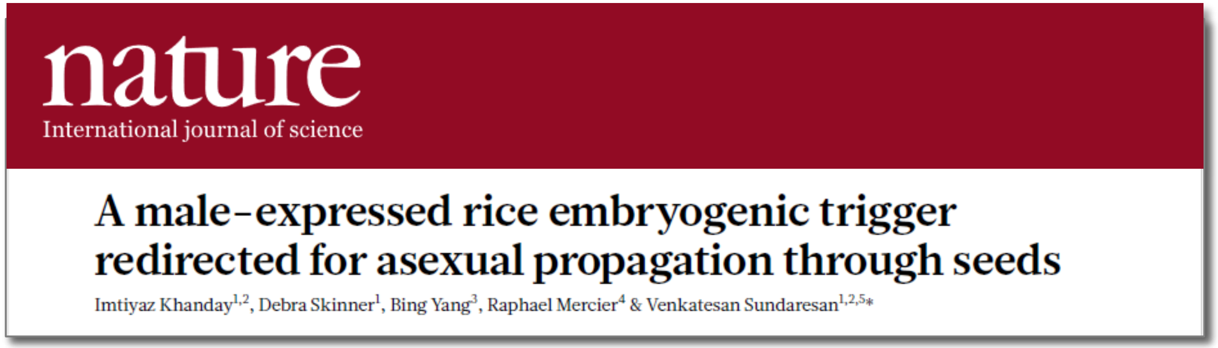
Targets for Improving Photosynthetic Efficiency

- **Optimizing Canopies**, e.g. chlorophyll content, canopy structure
- **Improving Rubiscos**, e.g. natural variation in fixation kinetics, enhance Rubisco biogenesis—RAF1
- **Photorespiratory Bypass***, e.g. H-protein OX in leaf increased biomass, ~40% increased productivity
- **Relaxing Photoprotection*,** e.g. increase rate of photosynthetic recovery under varying light intensity—OE of AtZEP, AtVDE, AtPsbS, ~20% increased productivity
- **Mesophyll conductance**
- **Water use efficiency**, e.g. OX Psb2 decrease stomatal opening, reducing water loss

See RIPE (https://ripe.illinois.edu/)

Zhu, Long, Ort (2010) Ann Rev Plant Biol 61, 235-261.
Kromdijk et al. (2016). *Science 354*, 857-861.

Breeding Innovations: Asexual Seed Production 0.4

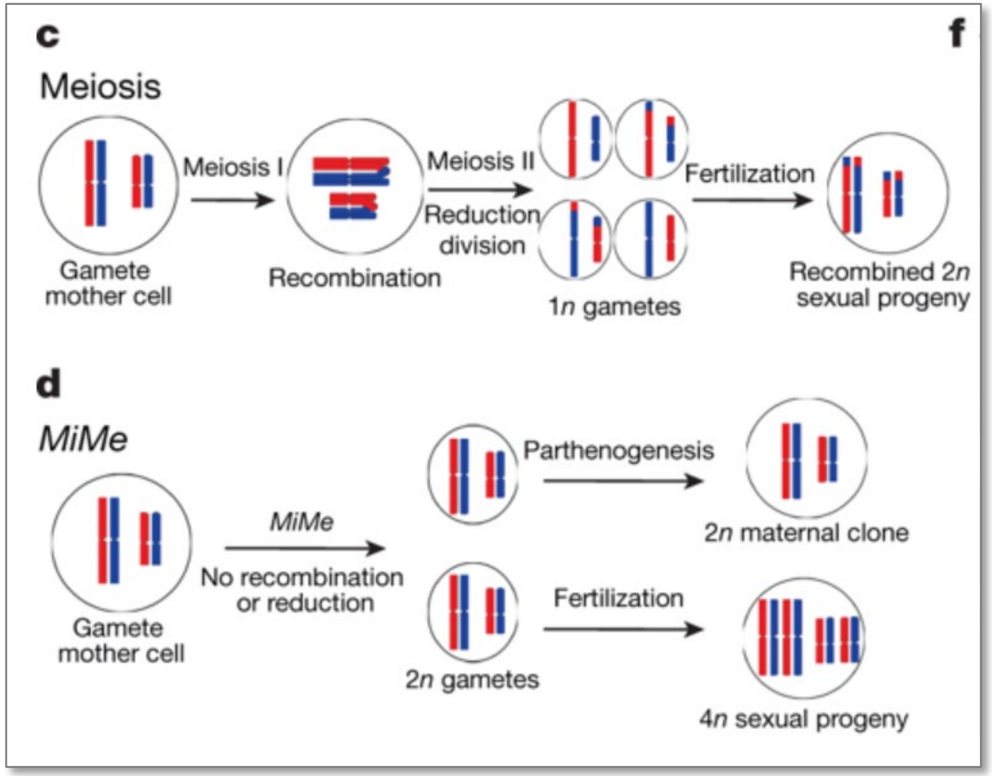

nature

International journal of science

A male-expressed rice embryogenic trigger redirected for asexual propagation through seeds

Imtiyaz Khanday[1,2], Debra Skinner[1], Bing Yang[3], Raphael Mercier[4] & Venkatesan Sundaresan[1,2,5]*

- More than 400 species of plant can produce seed asexually, essential clone themselves, e.g. dandelion.
- Target *BBM1* expression to the egg cell.
- Eliminate recombination and substitute mitosis for meiosis using *MiMe* (*REC8, PAIR1, OSD1*).
- Knockdown endogenous zygotic embryo development; *BBM1, 2, 3.*



11-29% of progeny are diploids

Remainder are tetraploid

UCDAVIS UNIVERSITY OF CALIFORNIA

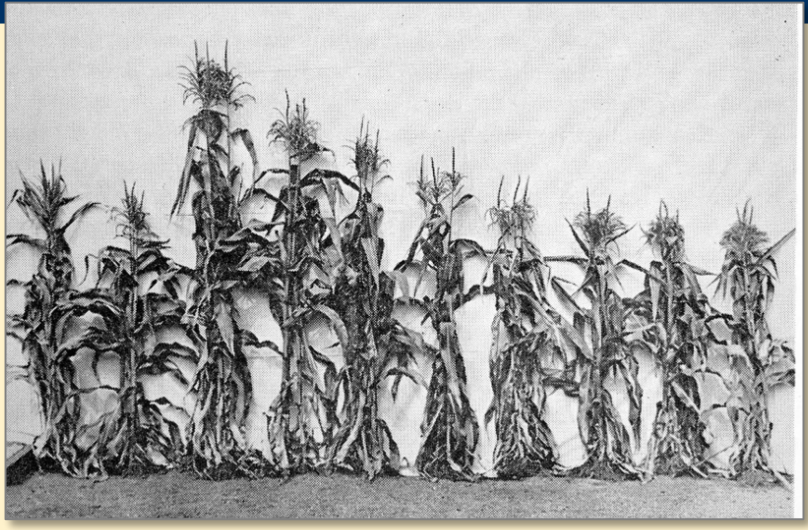
NSF, USDA, UC Innovative Genomics Institute, NIH

USDA

Breeding Innovations: Crop Gene Therapy

Deleterious mutations are at the heart of inbreeding depression, hybrid vigor, and potential targets for gene therapy

- Evolutionary profiling across 150 myr reveals conserved regions of the corn genome
- Deleterious mutations are enriched in low recombination regions.



PNAS

Recombination in diverse maize is stable, predictable, and associated with genetic load

Eli Rodgers-Melnick[a,1], Peter J. Bradbury[a,b,1], Robert J. Elshire[a], Jeffrey C. Glaubitz[a], Charlotte B. Acharya[a], Sharon E. Mitchell[a], Chunhui Li[c], Yongxiang Li[c], and Edward S. Buckler[a,b]

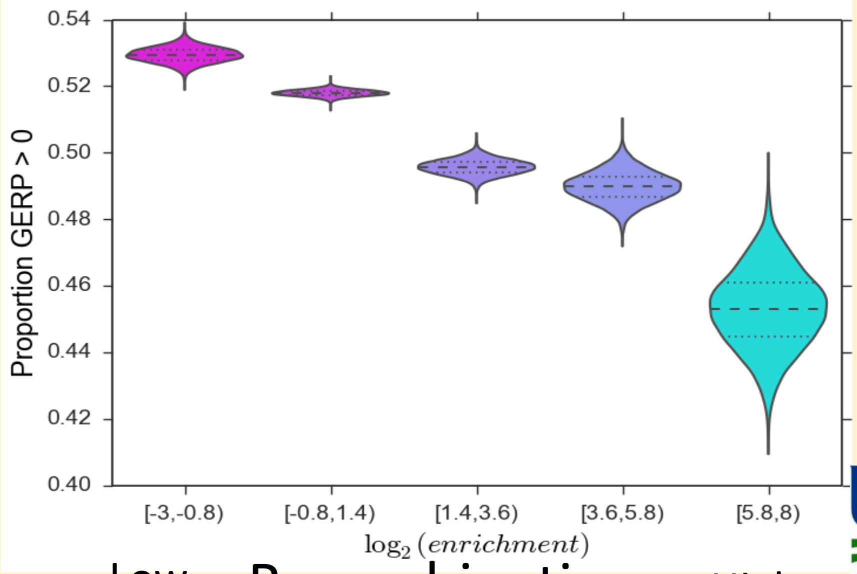
[a]Institute for Genomic Diversity, Cornell University, Ithaca, NY 14853; [b]US Department of Agriculture-Agricultural Research Service, Ithaca, NY 14853; and [c]Institute of Crop Science, Chinese Academy of Agricultural Sciences, Beijing 100081, China

Edited by Qifa Zhang, Huazhong Agricultural University, Wuhan, China, and approved February 6, 2015 (received for review July 21, 2014)

Among the fundamental evolutionary forces, recombination arguably has the largest impact on the practical work of plant breeders. Varying over 1,000-fold across the maize genome, the local meiotic recombination rate limits the resolving power of quantitative trait mapping and the precision of favorable allele

On a molecular level, chromatin structure heavily influences the cross-over rate in plants. Not only are heterochromatic regions generally depleted of cross-overs (11), but KO of *cytosine-DNA-methyl-transferase* (*MET1*) in *Arabidopsis thaliana* leads to both genome-wide CpG hypomethylation and a relative in-

Deleterious →



Low Recombination High

Rodgers-M
PNAS

USDA

Breeding Democratization: Regulatory Modernization

Plant Breeding Innovations
USDA APHIS (March 28, 2018)

Under its biotechnology regulations, USDA does not currently regulate, or have any plans to regulate plants that could otherwise have been developed through traditional breeding techniques as long as they are developed without the use of a plant pest as the donor or vector and they are not themselves plant pests.

Categories of gene edits that USDA will not regulate
This can include plant varieties with the following changes:
Deletions—the change to the plant is solely a genetic deletion of any size.
Single base pair substitutions—the change to the plant is a single base pair substitution.
Insertions from compatible plant relatives—the change to the plant solely introduces nucleic acid sequences from a compatible relative that could otherwise cross with the recipient organism and produce viable progeny through traditional breeding.
Complete Null Segregants—offspring of a genetically engineered plant that does not retain the change of its parent.

https://www.usda.gov/media/press-releases/2018/03/28/secretary-perdue-issues-usda-statement-plant-breeding-innovation

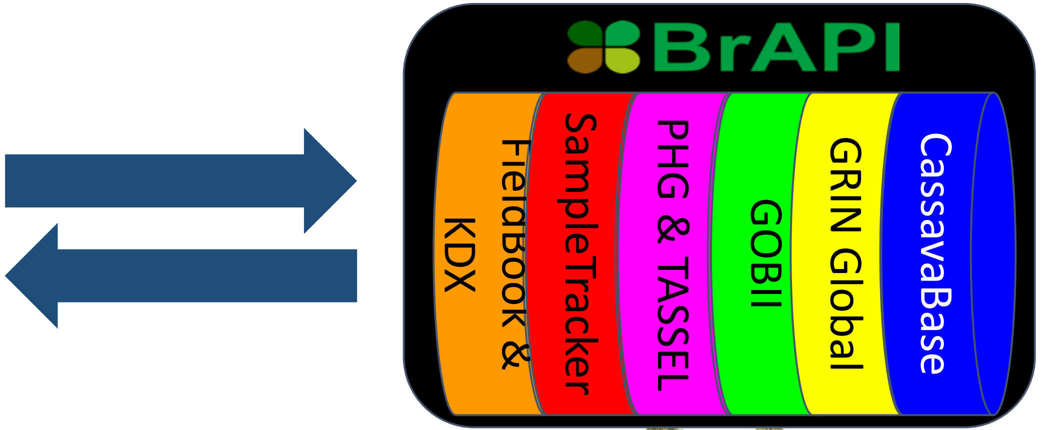
BREEDING INSIGHT

Breeding Democratization

https://www.breedinginsight.org/

Customized, shared informatics support for genome-assisted breeding.

Breeders



Cornell University

Director + Staff (programmers, application specialists, and coordinators)

Plant Genetic Resources, Genomics and Genetic Improvement

Specialty Crops

Human Nutrition

Food Animal Production

Aquaculture

Product Quality and New Uses

USDA

Key Needs for Breeding 4.0

- Skilled multidisciplinary workforce teams
- Open public FAIR data systems (Findable, Accessible, Interoperable, and Reusable)
- Low cost automated field data capture systems (phenotyping) across multiple environments and management practices
- Grower/researcher collaboration, interagency collaboration

Thank You!

Jack Okamuro@ars.usda.gov

Vision: Plant Breeding Innovations

USDA Press Release and Statement on Plant Breeding Innovations (March 28, 2018)

Statement

USDA Statement Regarding Plant Breeding Innovations

USDA is committed to helping farmers produce healthy, affordable food in a sustainable manner that protects this country's natural resources and offers more choices for consumers. Through innovative methods, plant scientists can now create new plant varieties that are indistinguishable from those developed through traditional breeding methods. These new approaches to plant breeding include methods like genome editing and present tremendous opportunities for farmers and consumers alike by making available plants with traits that may protect crops against threats like drought and diseases, increase nutritional value, and eliminate allergens.

In keeping with our responsibility to protect plant health, USDA has carefully reviewed products of these new technologies to determine whether they require regulatory oversight.

As USDA works to modernize its biotechnology regulations, the vision and direction of this Department will be to continue to focus regulatory initiatives on the basis of risk to plant health.

Under its biotechnology regulations, USDA does not currently regulate, or have any plans to regulate plants that could otherwise have been developed through traditional breeding techniques as long as they are developed without the use of a plant pest as the donor or vector and they are not themselves plant pests. This can include plant varieties with the following changes:

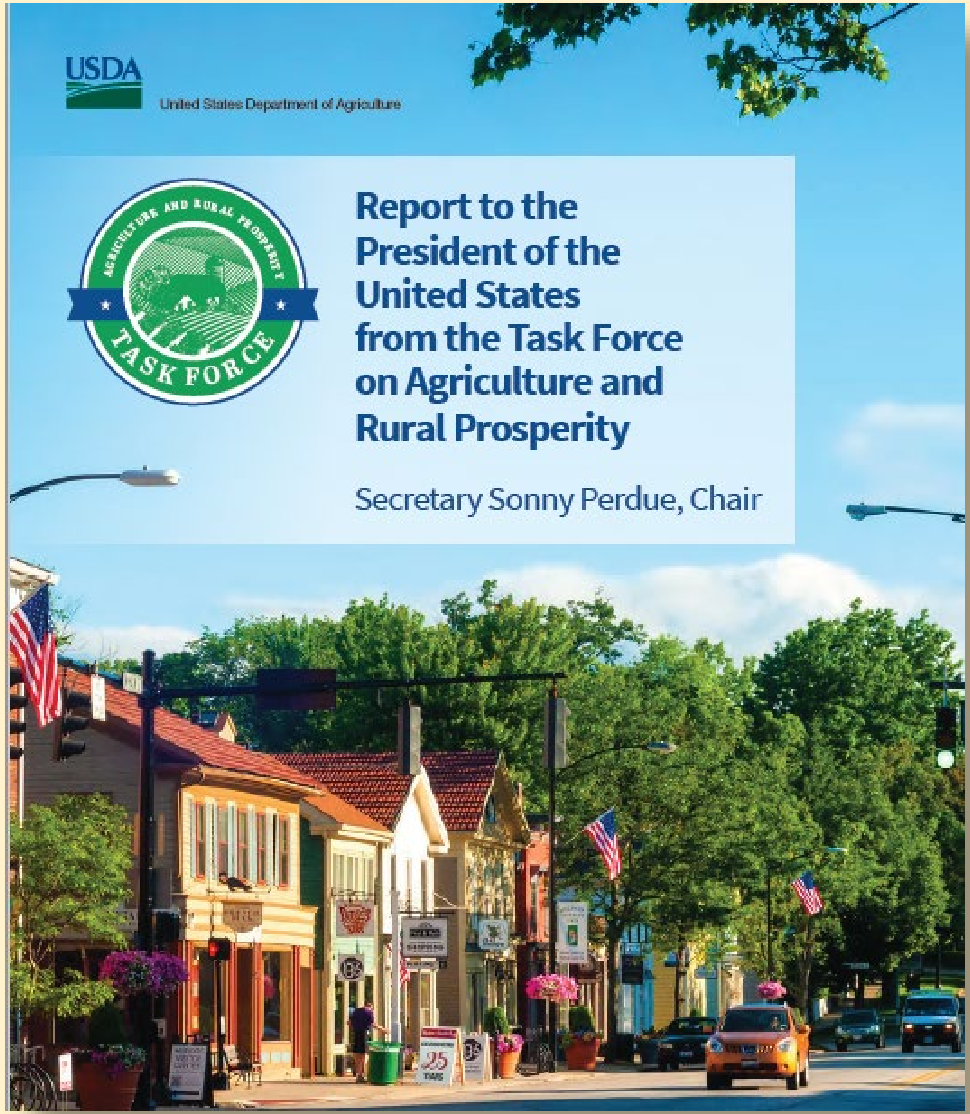
Deletions—the change to the plant is solely a genetic deletion of any size.
Single base pair substitutions—the change to the plant is a single base pair substitution.
Insertions from compatible plant relatives—the change to the plant solely introduces nucleic acid sequences from a compatible relative that could otherwise cross with the recipient organism and produce viable progeny through traditional breeding.
Complete Null Segregants—off-spring of a genetically engineered plant that does not retain the change of its parent.

USDA will continue working with other Executive Branch Departments, our domestic stakeholders, trading partners and international organizations to advance this science-based and practical approach that protects plant health while allowing for technological advancements in accordance with the Report of the Interagency Task Force on Agriculture and Rural Prosperity

https://www.usda.gov/media/press-releases/2018/03/28/secretary-perdue-issues-usda-statement-plant-breeding-innovation

USDA

Drivers of Innovation: Interagency Task Force on Agriculture & Rural Prosperity



Task Force on Agriculture and Rural Prosperity

- 21 federal agencies, offices, and executive departments
- Promote agriculture, technological innovation, energy security, economic development, job growth, infrastructure improvements, quality of life.

Harness Technological Innovation

- Expand STEM education, research, regulatory modernization, and infrastructure.
- Increase crop yields
- Improve crop quality, nutritional value, food safety.
- Develop data management capabilities.
- NEEDS
- Listening sessions, workshops, annual briefings

https://www.usda.gov/ruralprosperity

Breeding Innovations: Biology Assisted Breeding