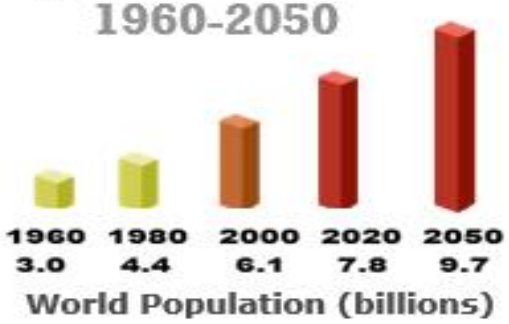
Plant Breeding in the 21st Century

- Khusi R Tiwari, Ph.D.
  - Bayer Crop Science
  - Principal Plant Breeder
  - Mississippi, USA.

Why Plant Breeding

Population Growth 1960-2050



Rise in the Middle Class

Changing Economies & Diets

43% increase in calories from animal protein

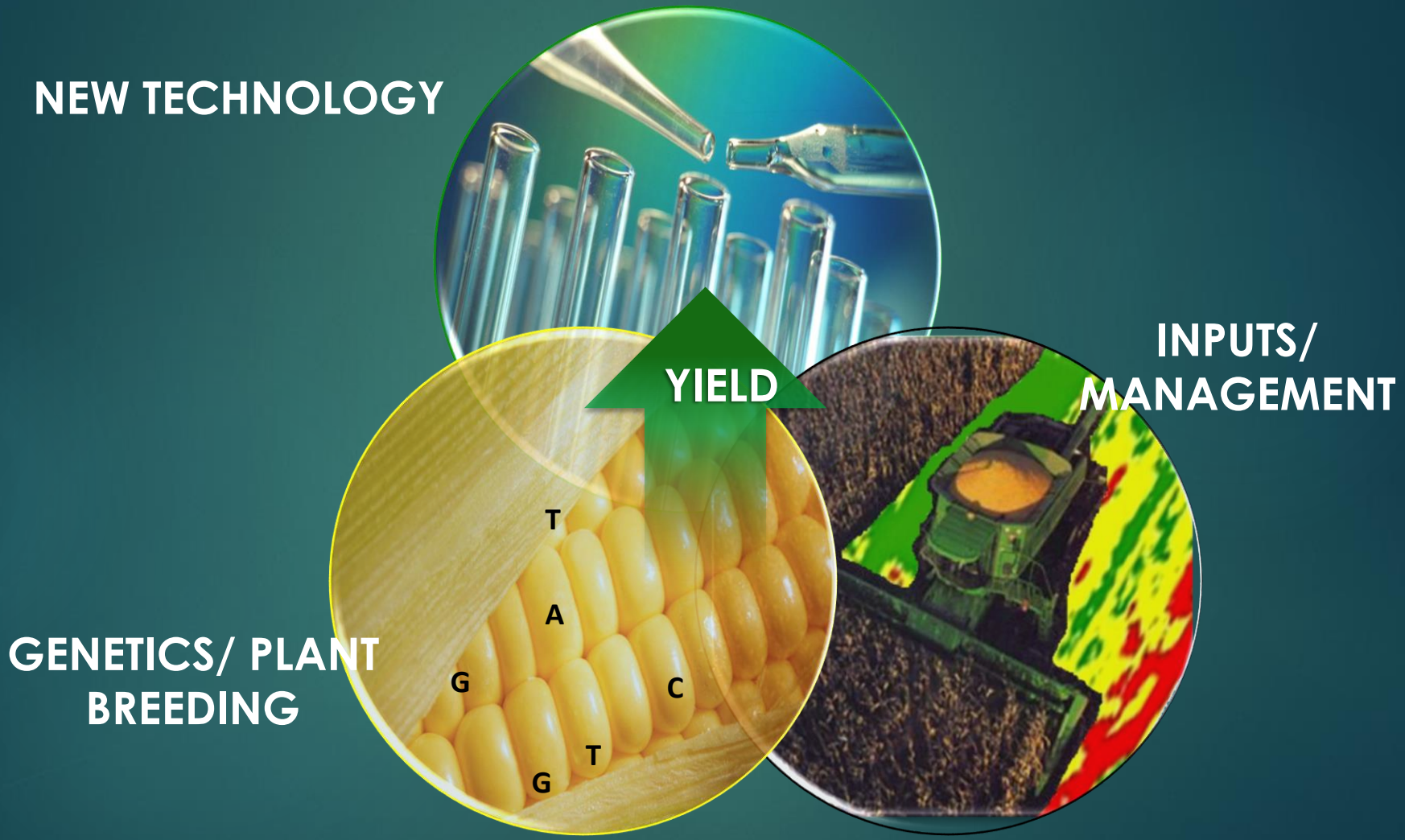
= 2X FOOD DEMAND BY 2050 TO FEED OVER 9.7 BILLION PEOPLE

Changing Climate & Declining Arable Land

Decreasing Water Availability

Global Food Waste

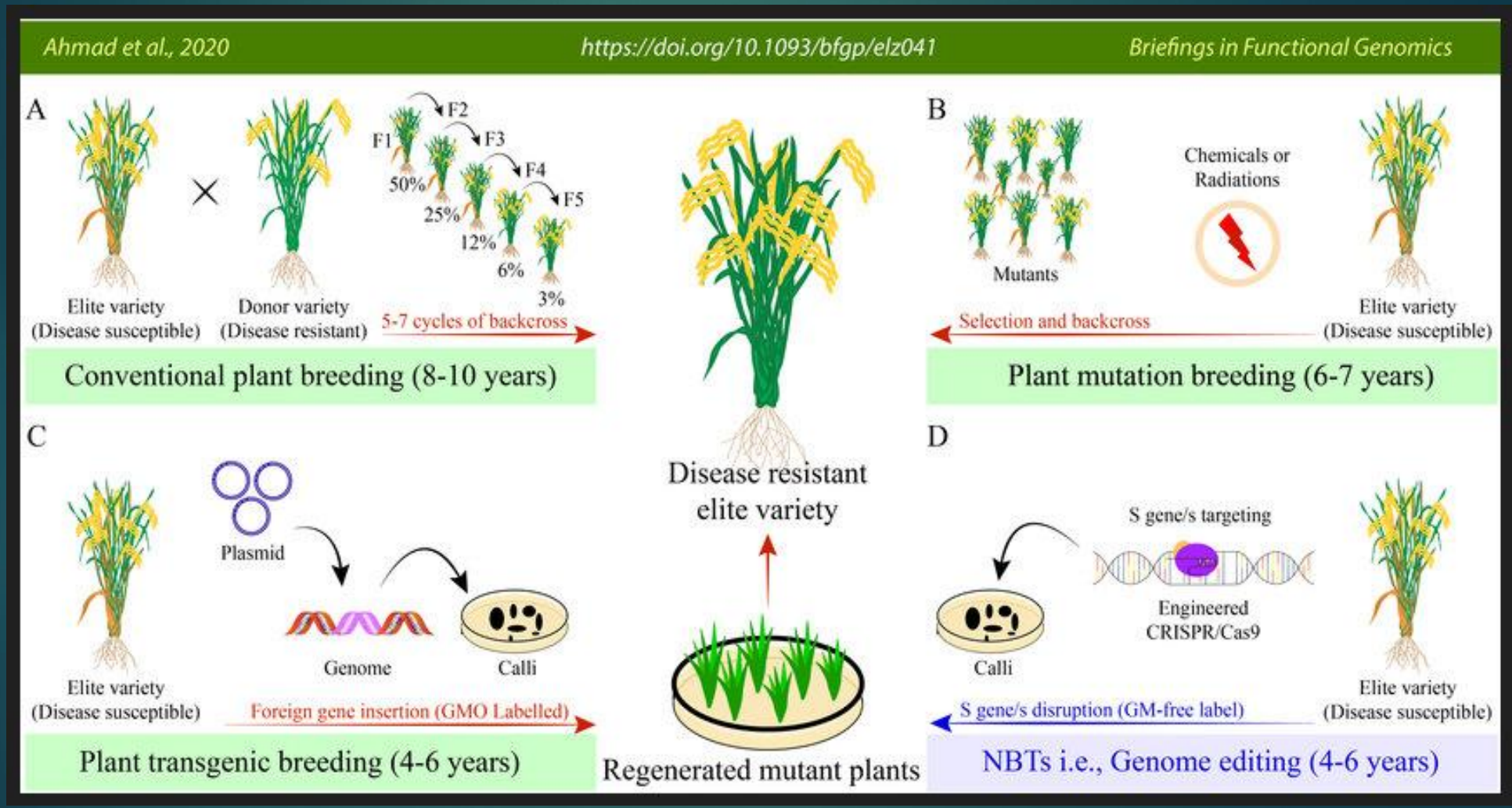
Higher Crop Yields Lie At The Intersection Of Multiple Technologies



Plant Breeding: "The *science, art, and business* of improving plants for human benefit"

All due to mutations and genomic alterations
All required <u>human intervention</u> for breeding and/or selection

Methods in Plant Breeding



Gene/Genome Editing

- CRISPR-Cas9 (Clustered Regularly Interspaced Short Palindromic Repeats).
- Cas9, an RNA-guided DNA endonuclease
- CRISPR/Cas9 is a relatively cheap and easy to implement.
- Game-changing technology (Belhaj et al 2015).
- Regulation….

Maximizing Yield Potential On Each Acre Takes A System Of Solutions

CHALLENGE:

OPPORTUNITY:

Multiple R&D platforms = Multiple Solutions

	Breeding	Biotech	Agronomic Solutions
WEED CONTROL		✓	✓
INSECT CONTROL	✓	✓	✓
STRESS TOLERANCE	✓	✓	✓
DISEASE CONTROL	✓		✓

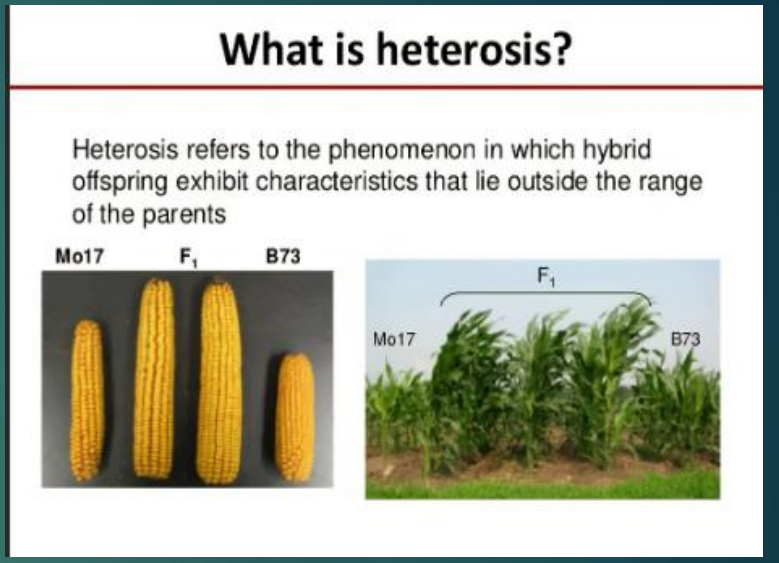
In between the planting and harvesting of a crop, a lot of factors can limit yield.

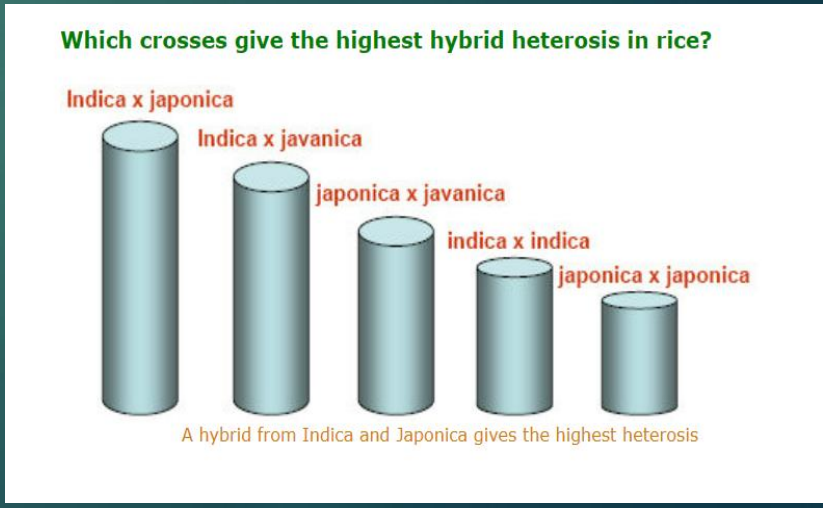
Maximizing Total Yield Potential

We need to Focus on Hybrids-

Why Hybrids?

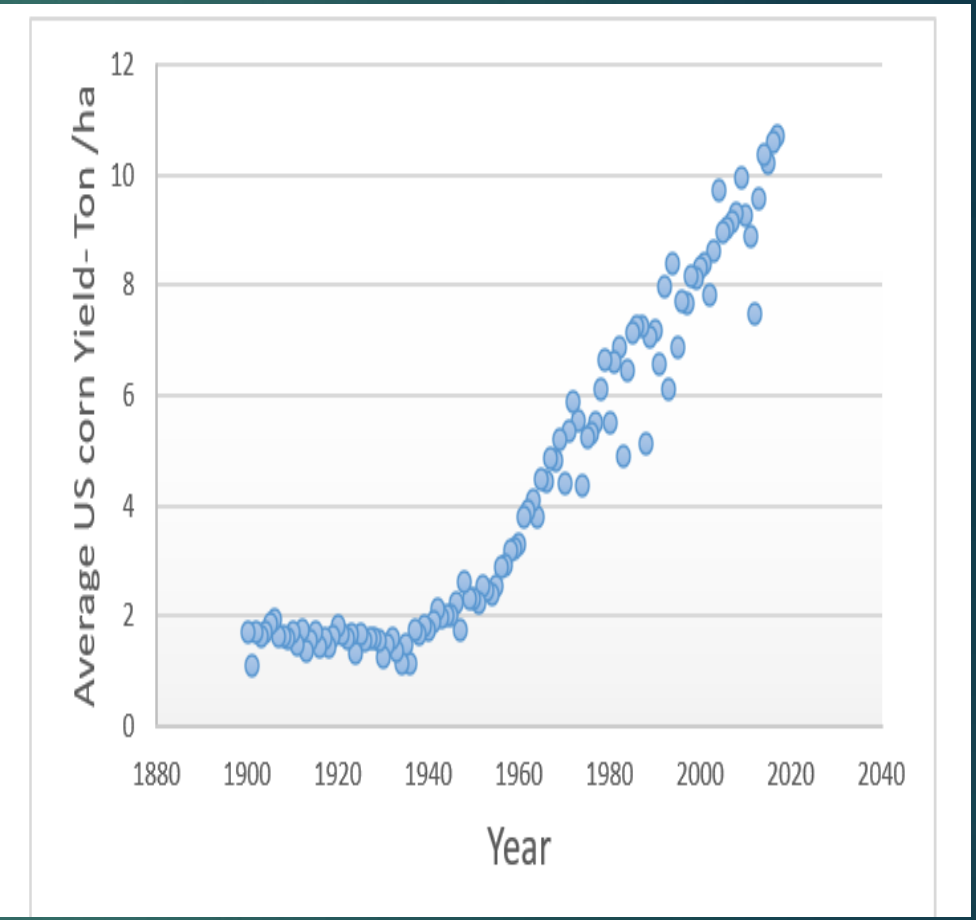
- Higher Yield, vigorous plants, flowers, and larger fruits.
- Better disease resistance.
- Stronger seasonal hardiness.
  - Climate resilience
- Intense flower and foliage colors.
- Cannot reuse the seed for the next year!
  - Reduction in vigor and yield potential





Hybrid Vigor and Heterosis

-Very Important to develop Heterotic Groups.
-National programs should work closely with Int. programs (IRRI, CIMMYT) to maintain and improve heterotic pattern.
-Corn Example-
    -SSS: Stiff Stalk Synthetic, female
    -NSS: Non Stiff Stalk, Male pool
-Rice- Indica x Japonica.
-Breeding crosses are made within the heterotic group and hybrid crosses are made between the heterotic group.
-Private sector should be encouraged to start breeding programs in vegetables and cereal crops.



Average U.S. corn yields from 1900 to 2021.

Hybrids- Rice and Maize

Yuan Longping : Yuan Longping

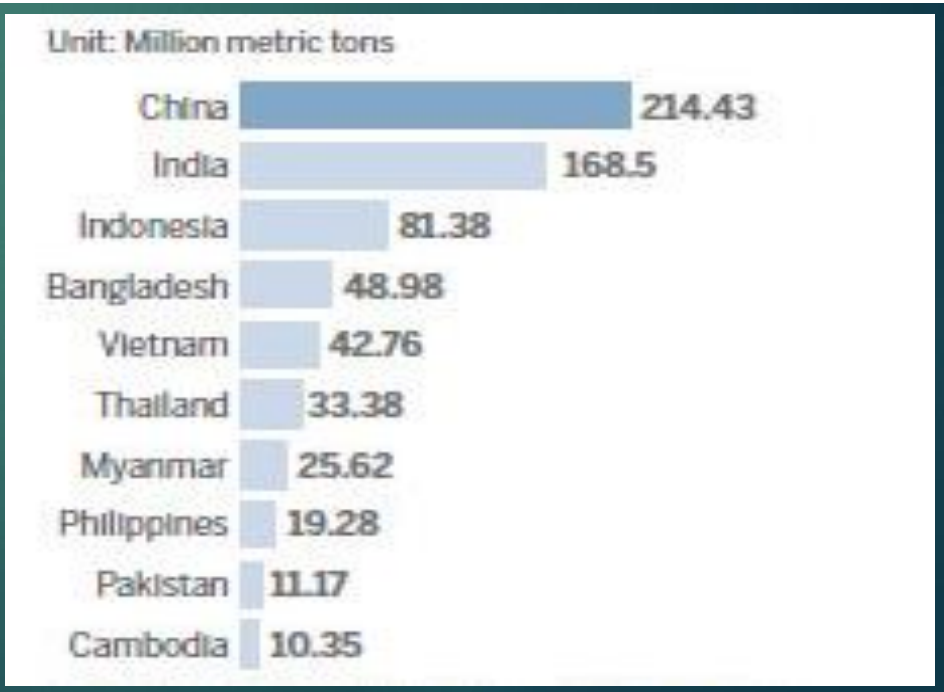
Hybrid Seed Production- Maize

Hybrid Rice

- China- Started in 1974. Very Strong hybrid rice program (53% of rice acreage)
- Nepal/NARC need to increase collaboration
- NRRP-
- Nepal- 8-10% of area, Majority Chinese and Indian hybrids

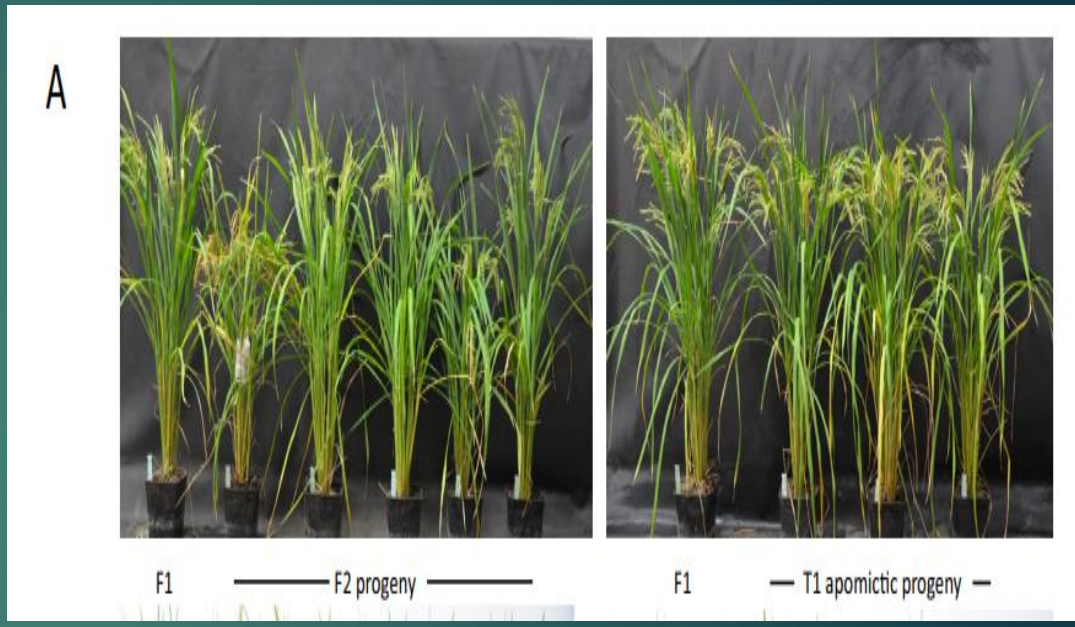
- Public-Private Partnership (PPP)

Yuan Longping



Hybrid Rice- Synthetic apomixis is a new Potential

- Hybrids-complex male sterility systems, resulting in a high seed cost.
- A revolutionary alternative is asexual, clonal mode of reproduction called apomixis.
- By inducing MiMe (Mitosis instead of Meiosis) mutations and egg cell expression of BBM1 (BABYBOOM1) in a single step (Vernet et al., 2022).
- Generate hybrid plants that produce more than 95% of clonal seeds across multiple generations.



A. Phenotypes of plants grown under controlled greenhouse conditions. Left: Five F2 progeny plants derived from the self-fertilization of BRS-CIRAD 302 compared to a BRS-CIRAD 302 F1 plant. Right: Three T1 progenies from T314 15.1 event compared to a BRS-CIRAD 302 F1 plant.

Direct Seeded Rice (DSR)

- Increasing water deficiency under a changing climate and escalating labor shortages.
- Flooded transplanting to direct-seeded rice (DSR).
- DSR saves water, reduces maturity time, labor, and negative env. footprints (Methane).
- In Asia, 22% of the acreage is under DSR (Shekhawat et al., 2020).
- Weed control- Needs attention.

Direct Seeded Rice Fields.

Perennial Rice- A sustainable Production System

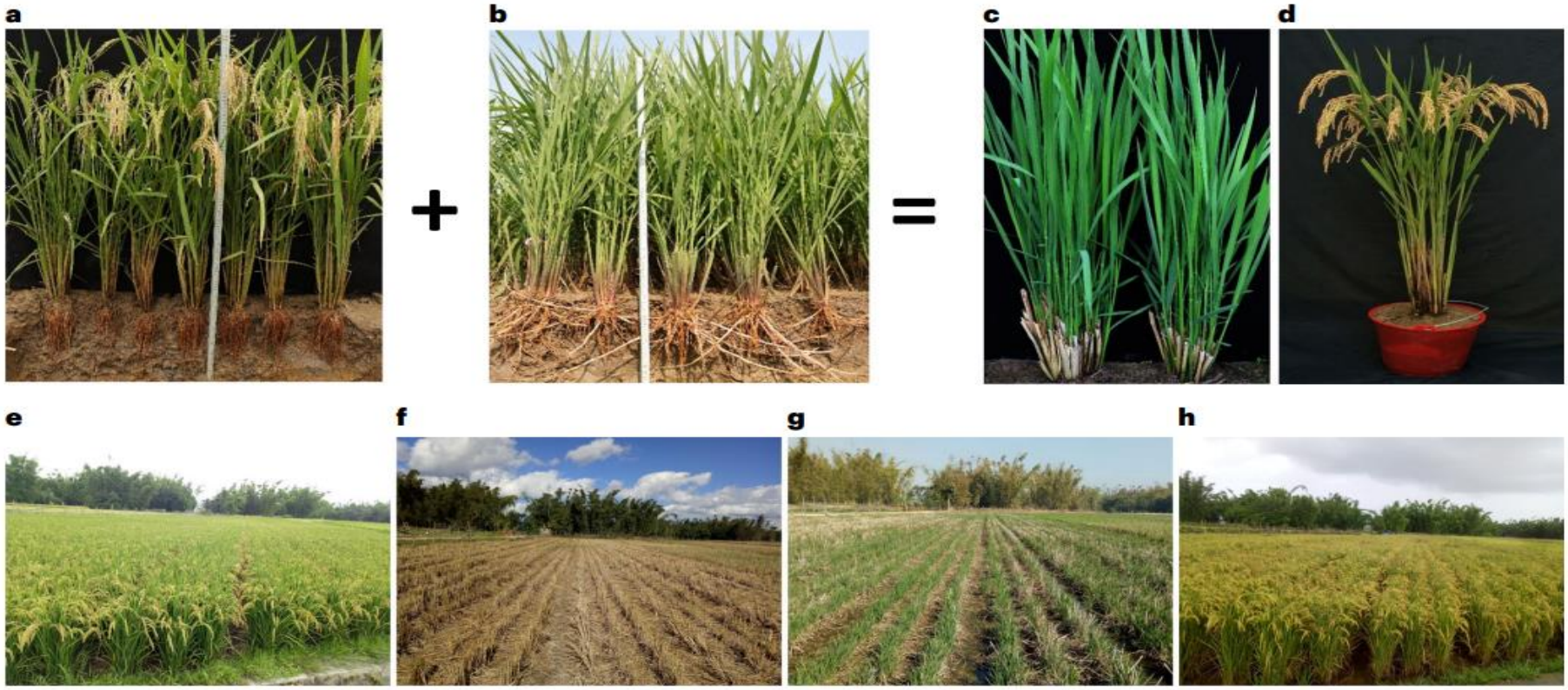


Fig. 1 | Innovation of PR for sustainable production. a, RD23, *Oryza sativa*, annual rice as female parent. **b**, *O. longistaminata*, perennial rice with strong rhizomes as male parent. **c**, PR23, perennial rice selection showing excellent regrowth above ground. Note both the numerous new green shoots and the cut brown shoots from the previous season. **d**, PR23 at maturity after regrowth. **e–h**, Performance of PR23 in Mengzhe, Yunnan, China (21° 57′ N, 100° 14′ E, 1,255 m). **e**, PR23 at maturity in the first year. **f**, PR23 overwinter in the first year. **g**, PR23 regrowth in the second year. **h**, PR23 at maturity in the second year. Note strong plant stand and high yield.

Zhang et. al., 2022

Germplasm Development

- Hybrid Breeding and variety development
  - Germplasm collection and Evaluations
  - Introductions
- Development of Heterotic pattern
  - Hybrids
  - Tester selection
- Initiate breeding crosses
- Germplasm Introgression
- F2s, BC1s and BC2 Strategy
- Appropriate Checks
- Testing locations and environments

Inbred Development

- Selfing/backcrossing local adopted varieties
  - Selfing to F5/F6- 2-3 generations/ year.
  - Doubled Haploids (DH)
- Introductions
  - CIMMYT, IITA, India, Thailand, IRRI (Rice)
- Heterotic groups Alignment
  - Yield testing
  - Fingerprinting
- Genetic diversity

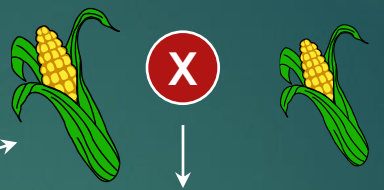
Plant Breeding- Varieties

- Easy Description
  - Cross good x good
  - Inbreeds, Varieties
  - Pick the right Checks
  - Test/Evaluate
    - Locations
    - Years
  - Data Collection & Analysis
  - Select the best lines (10-20%)
  - Release

Breeding – primary steps

- Set objectives
  - Combine the desirable traits of two or more genotypes in a new improved variety or line.
- Identify or create genetic variability for traits.
  - Conventional, exotic material, transgenic
- Test
  - Evaluate single plants, progeny rows, families based on yield trials.
- Select.
  - Advance generation for further inbreeding and testing
- Retest and select for eventual commercialization

Traditional Breeding Process



Year 1

Choose parents based on data, judgment

Recombine genes

Years 2-6

Select best based on phenotype → Make hybrids, Yield test

Advance Inbreeding

Select, Make Hybrids

Advance Inbreeding

Yield test

Advance Inbreeding

Select, Make Hybrids

Advance Inbreeding

Yield test

Advance Inbreeding

Select, Make Hybrids

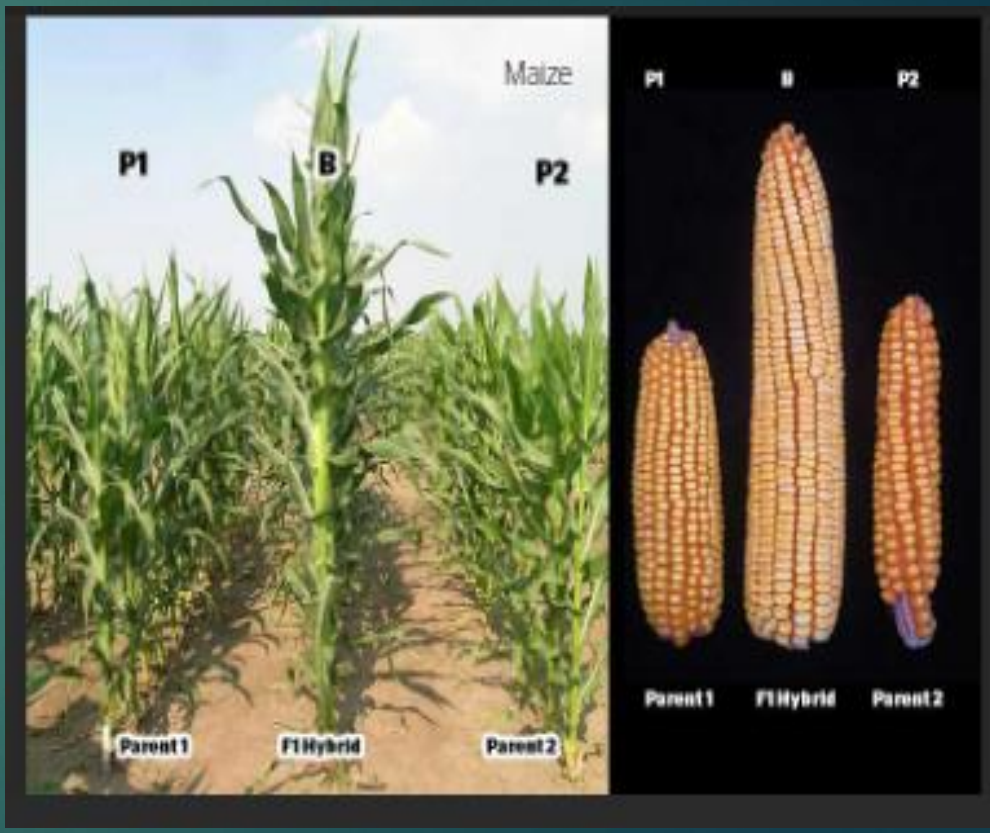
Year 7

Success rate <.01%

Advanced Trials, Commercialize

6- to 8-year process

Developing Inbreds and Hybrids



Key traits under selection in a Corn Breeding program

- Yield, Yield, Yield
- Agronomic traits based on breeding target market.
  - Tolerance to root and stalk lodging, early vigor, etc.
- Disease Traits
  - GLS, NLB, SLB, Rusts, Ear rots, etc.
- Consistency over diverse growing conditions.
- Production characteristics (COGs).

Cotton- Very Imp. Crop in the Southern US

Important Crop in the Southern US with Biotechnology traits-

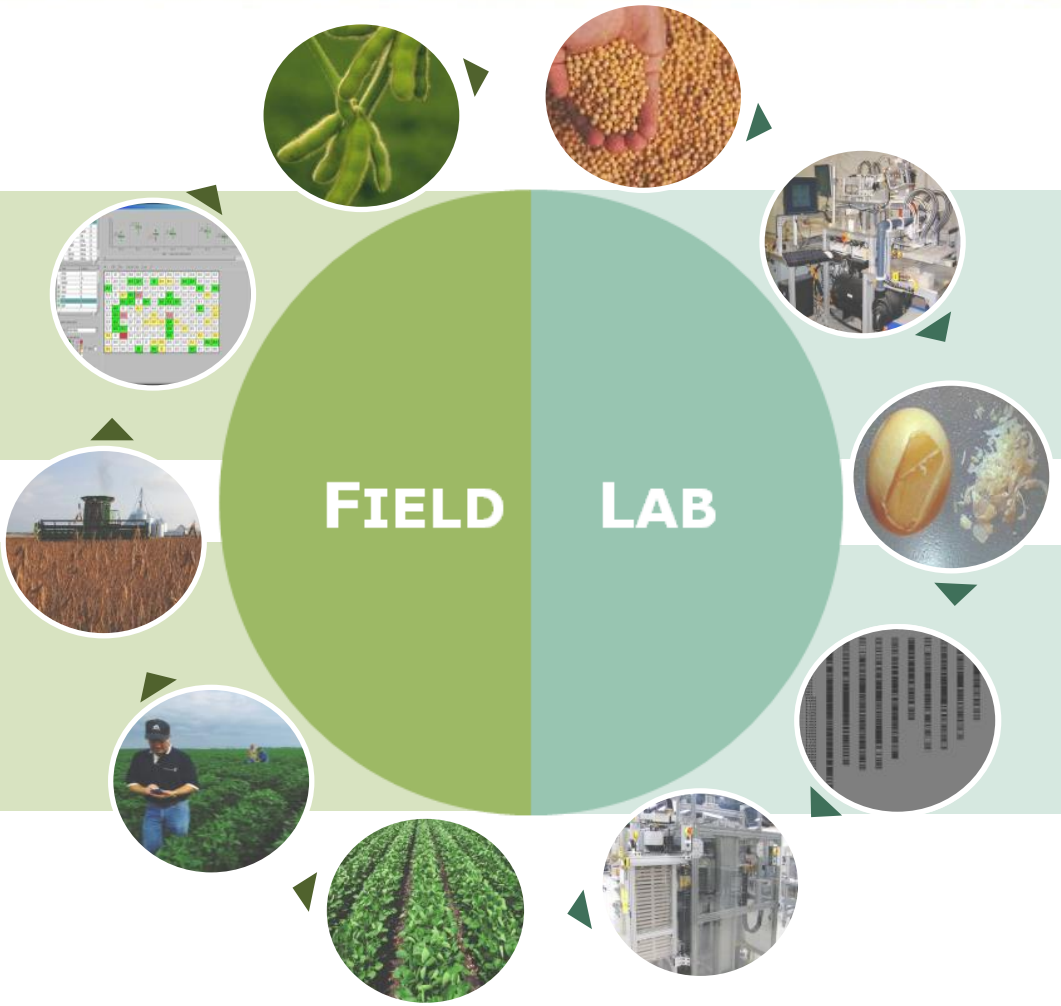
- -Insect protection
- -Round up Ready

Advanced Plant Breeding

The odds of finding a desired trait are one in a trillion.

- The seed chipper helps to look inside the seed without planting it.
- DNA sequencing helps identify the desired traits.

TODAY'S PLANT BREEDING IS POWERED BY OUR KNOWLEDGE OF GENETICS



Improved Seeds Selected

Automated Seed Chipping

Performance Evaluation

DNA Analysis and Selection of Improved Seeds

Our breeding teams working across 120+ locations in 25+ countries crossbreed plants from distant locations to create valuable new seed products.

These seeds are developed to provide crop qualities that include:

- Increased Yields
- Disease Resistance
- Stress Tolerance
- Grain Quality/Added Value

Developing Inbreds- DH?

- Speeds up inbreeding
- Corn-
  - Inducer Lines
  - Haploid Identification and doubling of Chromomsomes
  - Colchine
- Rice, Wheat and many vegs- Anther and ovule cultures
  - Doubling of Chromosomes

Mechanization is key to achieve needed plot capacity

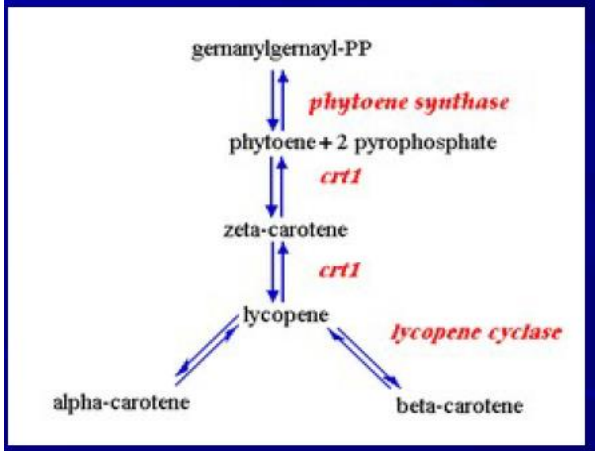
Biotechnology Traits

- ABO- ECB Protection- *Bt* Genes
- ABB- above and below ground protection- Corn root worm and Ear worm protection
- Trecepta- Ear worm protection
- Herbicide Resistance- RR, Round-up ready- Corn,
- Short (Smart) Corn system
  - Conventional
  - Biotech
- Soyabeans- RR,
- Cotton- RR, Insect Resistant.

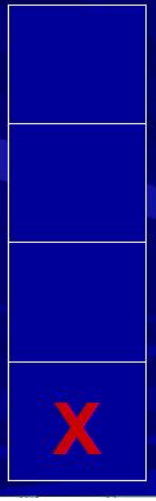
Golden Rice

Golden Rice

Opposition to golden rice cost $2 billion to farmers in developing countries and 1.4 million human years – Wesseler et al., 2014



- 250,000-500,000 children go blind each year
- Half of them die within 12 months of losing their sight
- 1.9-2.7 million deaths per year may be due to VAD
- Impoverished families cannot afford vitamin A-rich food sources
- Supplementation is expensive and limited in effectiveness



Farmers

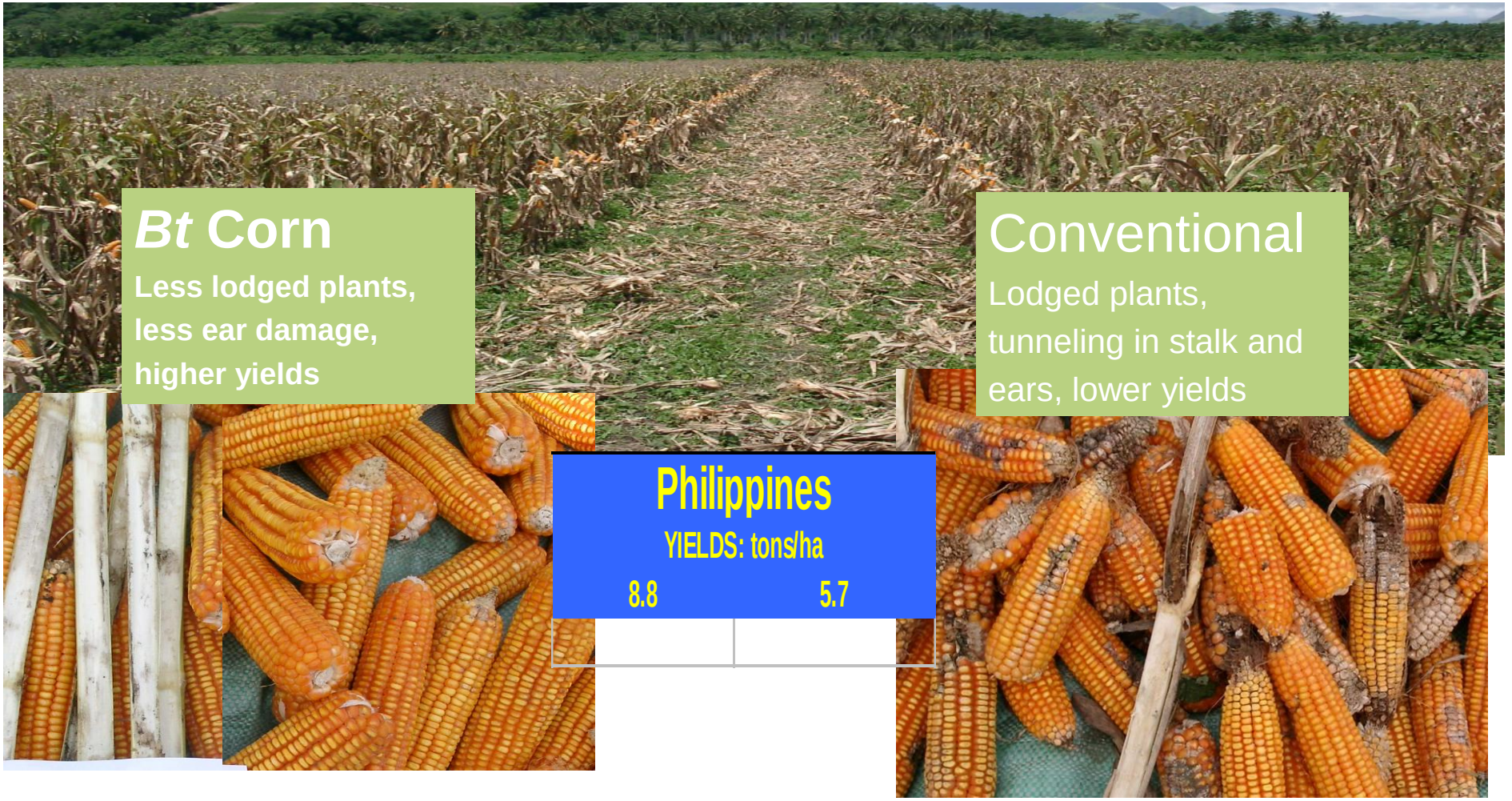
Consumers

Environment

Needy

Source: Dr. Kevin Folta, UF.

Value of Biotechnology is Enormous



Product: Corn Rootworm (Bt) vs. control

Short Corn- Europe and US

Bt Brinjal in Bangladesh

BT Cowpea in Nigeria

- *Bt* Gene- Donated by Bayer
  -Cry1AB
  -Cry2AB
- -Project led by AATF (African Agricultural Technology Foundation) and also supported by USAID
- Pod Borer control
- Field trials started 2009 and commercialized in 2019
- 20% Yield Increase

Paul McDivitt | Genetic Literacy Project | January 23, 2018

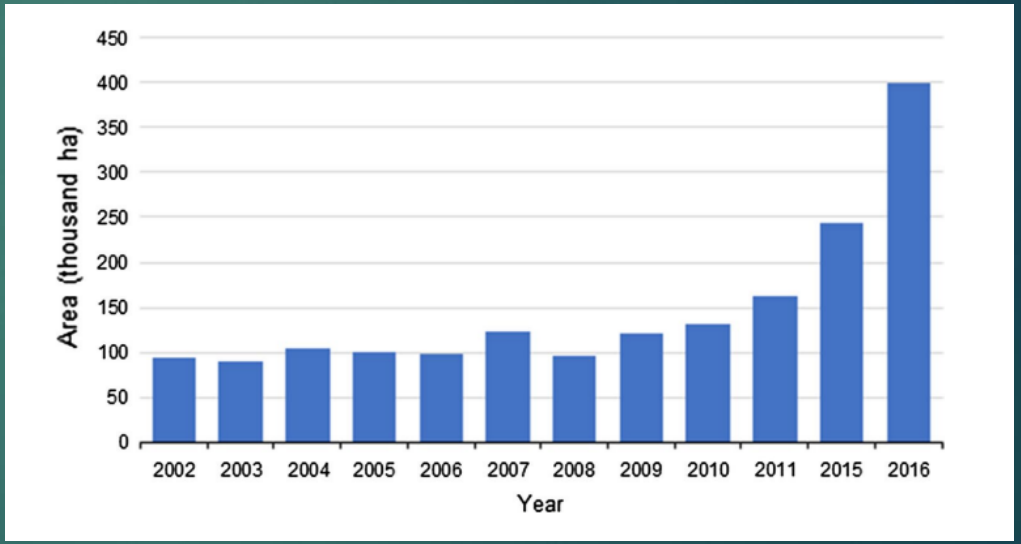
HB4 Wheat-Drought Tolerance

- HAHB4 (*Helianthus Annuus* Homeobox-4)- HB4
- Introducing sunflower genes for drought tolerance.
- **Bioceres**- Argentinian company is commercializing this technology
- Argentina in 2020 (First country to commercialize transgenic wheat)
- Brazil 2021
- USA, Australia, New Zealand, Nigeria and Columbia in 2022.

Hybrid Wheat- Real potential in the future

- Hybrid wheat- despite the earlier failures, renewed efforts in recent years have been produced and marketed in European countries (Gupta et al., 2019)

Test Plot of Hybrid Wheat in USA- Syngenta



Area occupied by hybrid wheat in France during 2002–2016

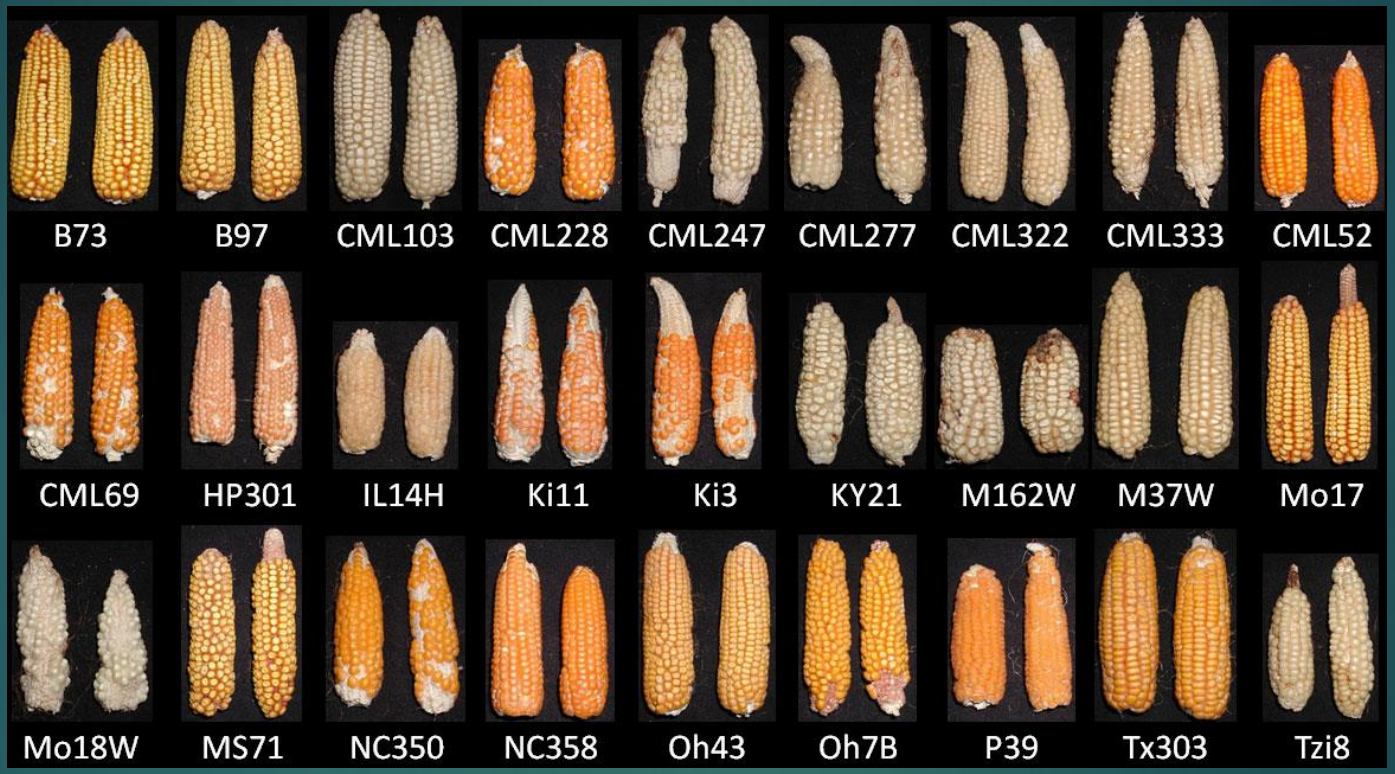
Wheat Improvement

- **Integration of exotic material significantly increases yield under heat stress compared to elite lines (Molero et al., 2023).**
- No significant yield penalty under favourable conditions.
- Physiological evaluation of HiBAP I (High Biomass Association Panel I)-149 diverse lines under heat stress
- Three exotic-derived genetic loci underlying this heat tolerance-yield inc. over 50%.
- *Aegilopes tauschii* introgression was the most significant of these associations.
- Three ch- 1B, 2B and 6D that when stacked increase yield by 56.5% and reduce temp. by 2 °C
- Three markers can be deployed into marker-assisted breeding
- The germplasm is available through IWYP.org request.

Hybrid Vegetables

- Approximately 73% of the vegetable production area in Nepal is estimated to be covered by hybrid varieties.
- Most of the hybrid seeds in vegetable crops are imported.
- Nepal has the potential to export quality hybrid vegetable seeds.
- Tomato- Srijana (2010), Khumal-2 and Khumal-3 (2020)
- Cucumber, Eggplants, Hot Pepper, Bitter-gourd in progress.
- Billions of Rupees are lost every year to import hybrid seeds of important vegetables…
  - Cauliflower, Broccoli, Cabbage, Okra, Radishes etc…

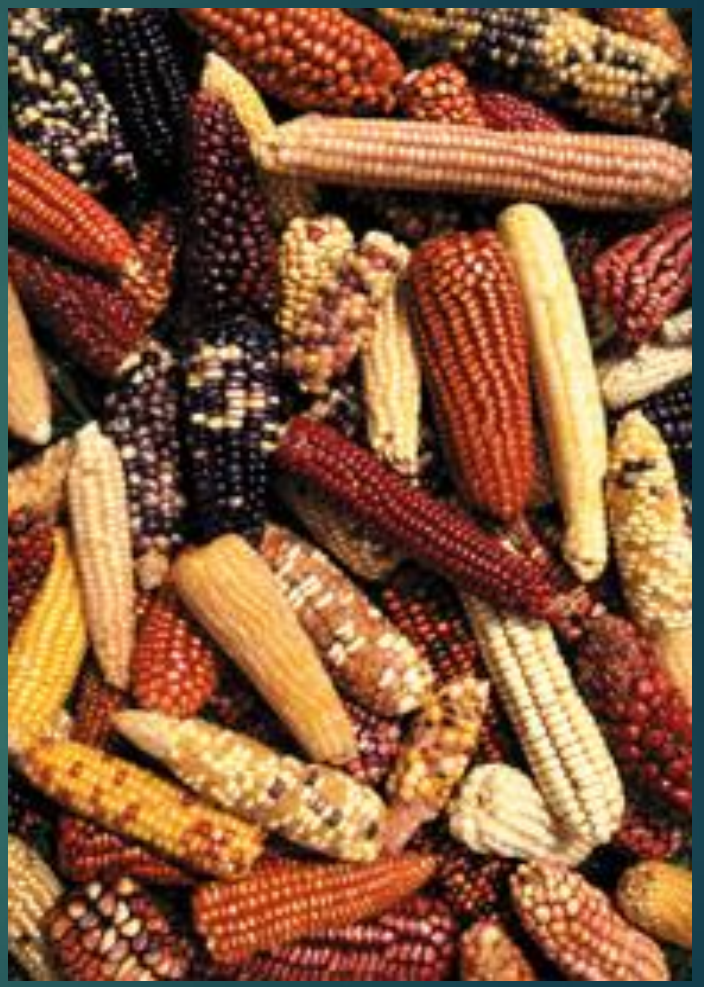
Dilemma in corn breeding: Finding new sources of useful genetic variation



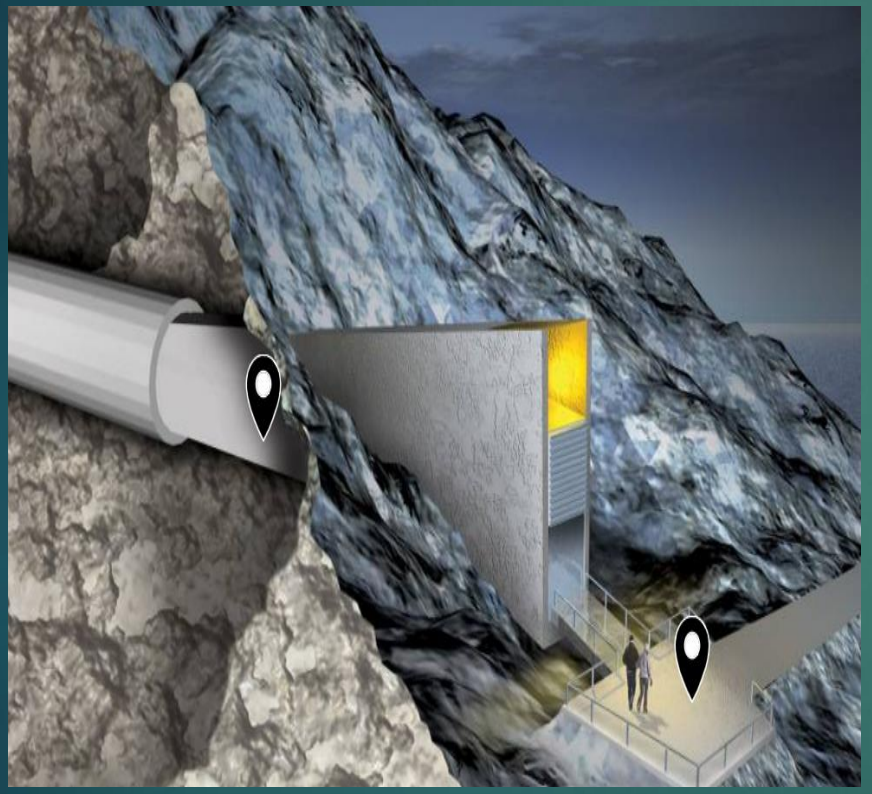
Germplasm

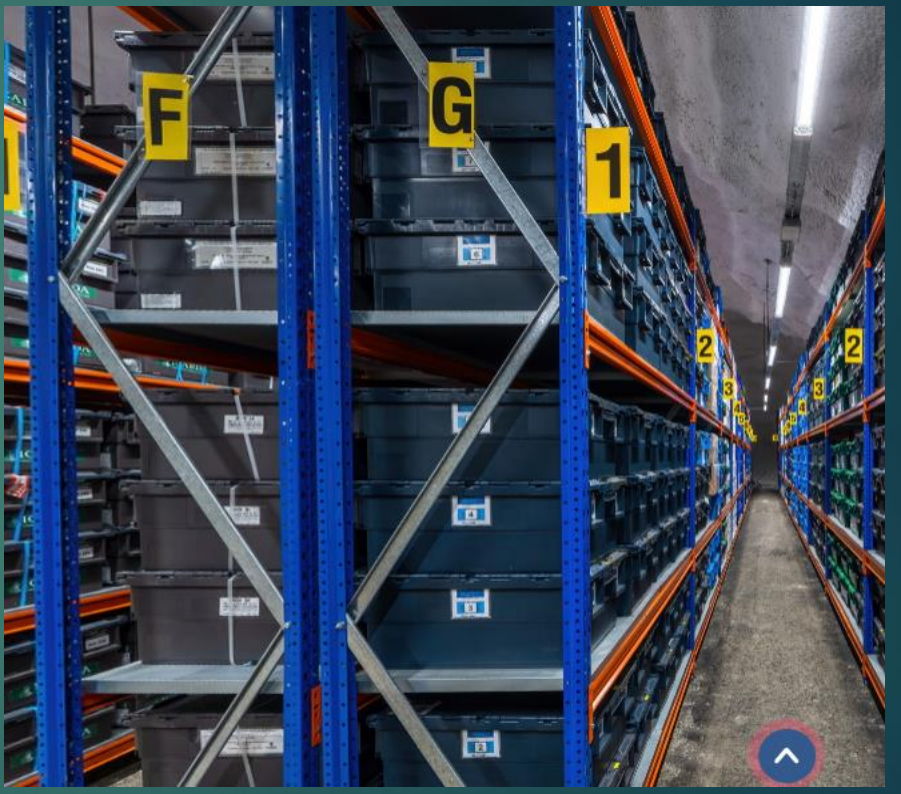
Genetic Diversity

- Very Important for long term crop sustainability
- Pests and Stress tolerance
- Heterosis and Yield Potential
- Nutritional and quality traits
- Others……



Svalbard Global Seed Vault Norway- 15 Years





-18 degree C., 30 plus countries. Back up storage.

Trait Integration (TI) Links the Products of Breeding and Biotechnology

Winter Nursery dramatically accelerates the product development process

- Breeding
  - Corn
  - Soybean
  - Canola
  - Cotton
  - Wheat

- Breeding
  - Corn
  - Soybean
  - Canola
  - Cotton
  - Wheat

Historically breeding programs used winter nursery Sites to grow a second generation during the "winter" season decreasing development time by 50%

Leaf and Seed sampling for marker analysis

DNA Markers are very powerful to screen for hard to evaluate traits
Affordability getting better
GWS, QTLs, SNPs.

What we have learned about yield history

- Corn breeding has delivered approx.
  - 60% of yield gain is improved genetics vs. improvement in agronomic practices.
- Yield gains associated with
  - Improving the ability of the plants to retain yield potential while increasing plant populations.
  - Withstand environmental stresses.
- Environment has a profound impact in determining which hybrids perform best.

SUMMARY

- Exploit the potential of hybrid vigor/heterosis
  - Maize, Rice, wheat and other crops
- Perennial and direct seeded rice has the potential.
- Public-private partnership (PPP)
  - Public Institutions- Develop Inbred lines for Royalty
  - Private- Seed production and marketing in short term
    - Start Breeding programs
- **Plant Variety Protection-** Plant variety protection
  - Research Investment
- Biotechnology-
  - Golden Rice/Drought tolerant wheat/BT Brinjal
  - Molecular Labs, Genome editing.

Thank You ALL

RAMPURES

RAMPURES