

# Fundamentals of Genomic Prediction and Data-Driven Crop Breeding (November 24-28, 2025)

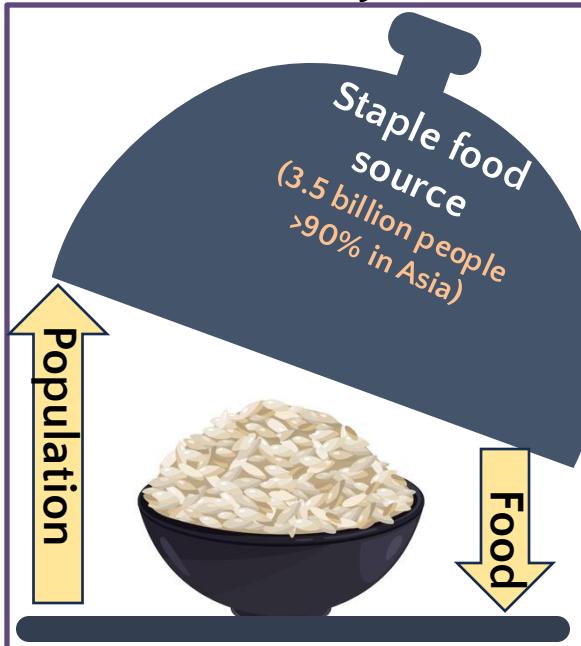
## Modern Breeding Approach and Population Improvement

**Module 2**  
**November 25, 2025**

**Waseem Hussain, Mahender Anumalla and  
Margaret Catolos**  
Rice Breeding Innovations Platform  
IRRI

# Big Challenge of Food Security

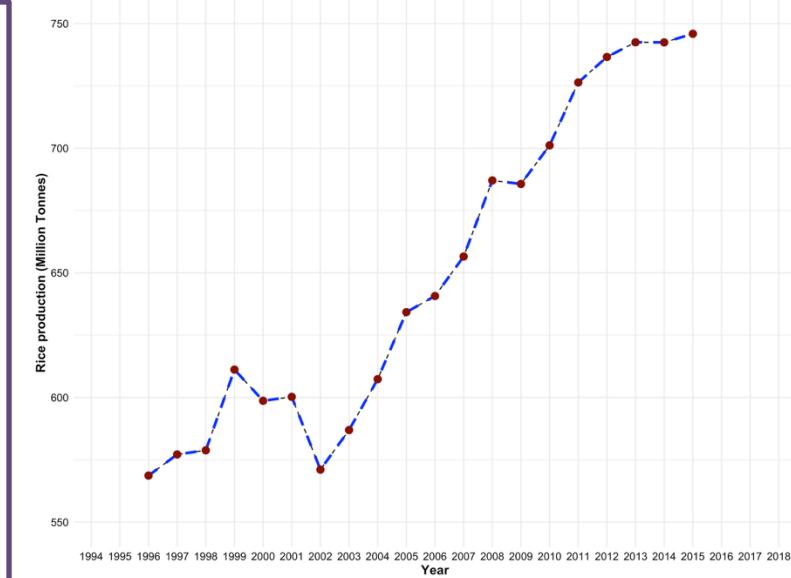
## Food Security



## Climatic variations



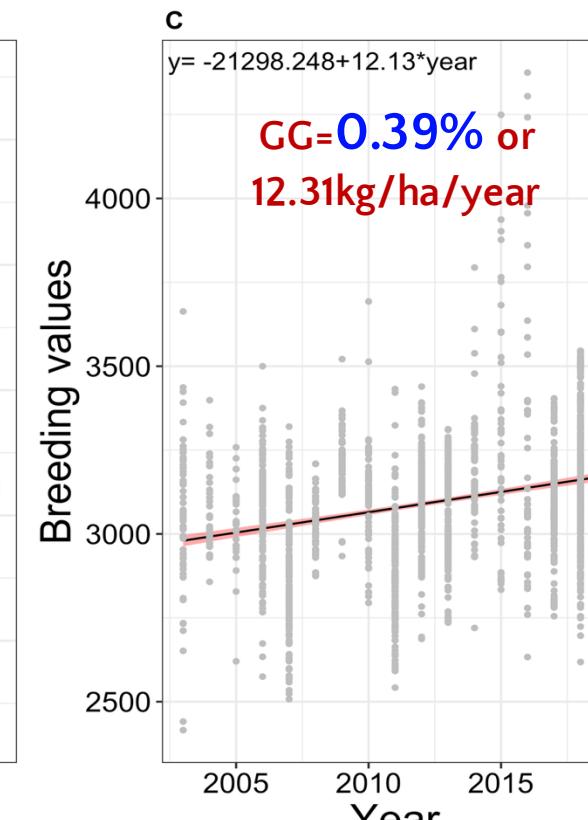
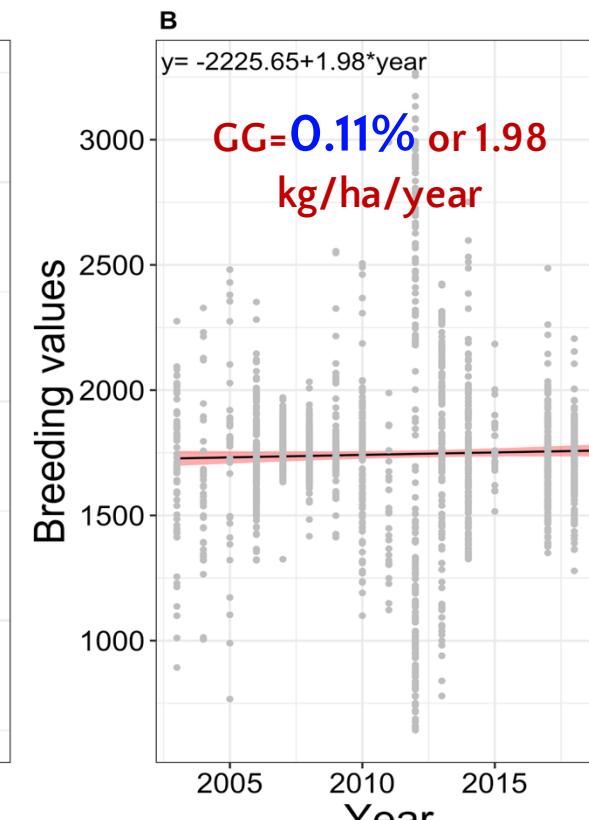
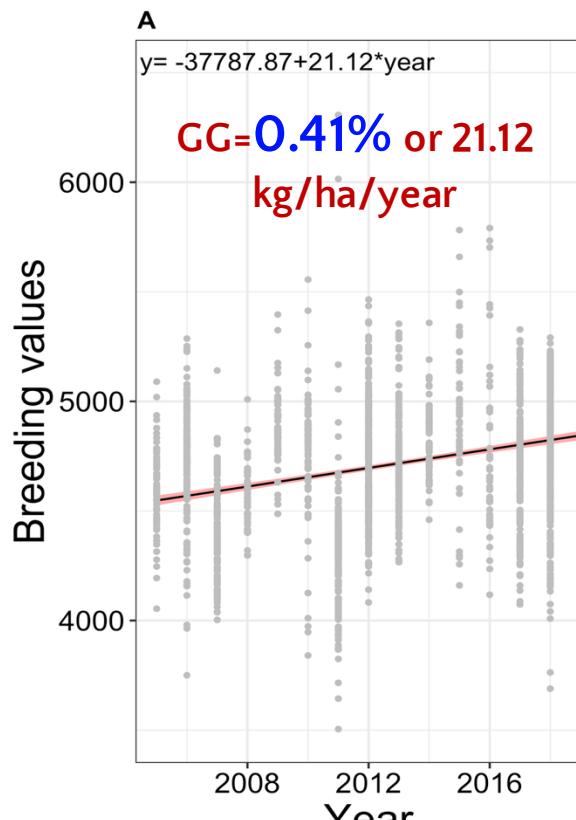
Global Rice Production Trends



- Extreme environment: Stress factors—Abiotic and biotic
- Food demand: **35% to 56% by 2050**
- Attention to yield improvement
- Lack of HGY with tolerant/resistance breeding lines

**Production is increasing but not at the rate population is increasing**

# Genetic Gain: IRRI's Drought Breeding Program



Khanna et al. *Rice* (2022) 15:14  
<https://doi.org/10.1186/s12284-022-00559-3>

Rice

ORIGINAL ARTICLE

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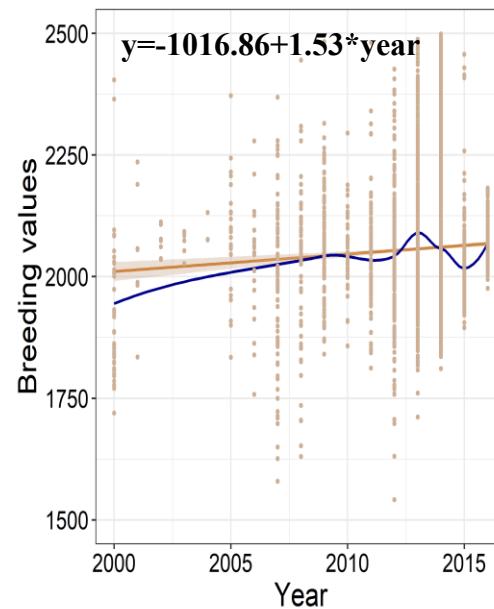
Genetic Trends Estimation in IRRI's Rice Drought Breeding Program and Identification of High Yielding Drought-Tolerant Lines

Apurva Khanna<sup>1</sup>, Mahender Anumalla<sup>1</sup>, Margaret Catolos<sup>1</sup>, Jérôme Bartholomé<sup>2</sup>, Roberto Fritzsche-Neto<sup>1</sup>, John Damien Platten<sup>1</sup>, Daniel Joseph Pisano<sup>1</sup>, Alaine Gulles<sup>1</sup>, Ma Teresa Sta. Cruz<sup>1</sup>, Joie Ramos<sup>1</sup>, Gem Faustino<sup>1</sup>, Sankalp Bhosale<sup>1</sup> and Waseem Hussain<sup>1\*</sup>



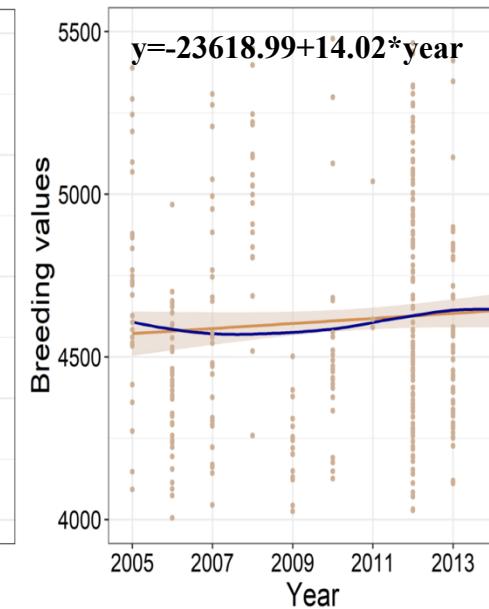
# Genetic Gain: IRRI's Salinity Breeding Program

**Yield 1.52kg/ha**  
**0.15% gain per annum**



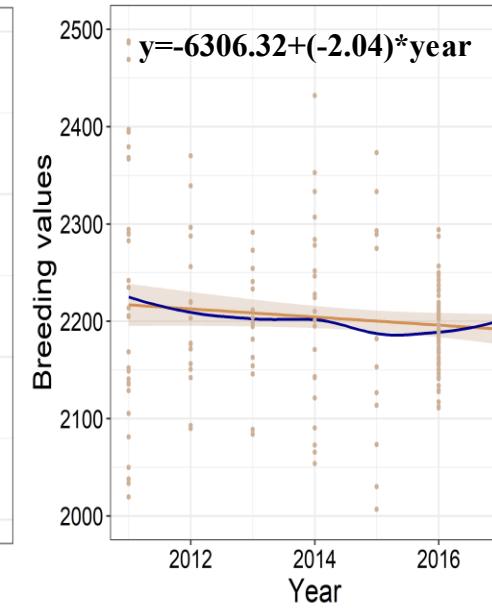
Philippines

**Yield 14.2kg/ha**  
**0.31% gain per annum**



Bangladesh

**Yield 2.55 kg/ha**  
**0.12% gain per annum**



India

Theoretical and Applied Genetics (2024) 137:37  
<https://doi.org/10.1007/s00122-024-04545-9>

ORIGINAL ARTICLE



**Genetic gains in IRRI's rice salinity breeding and elite panel development as a future breeding resource**

Apurva Khanna<sup>1</sup> · Mahender Anumalla<sup>1</sup> · Joie Ramos<sup>1</sup> · Ma Teresa Sta. Cruz<sup>1</sup> · Margaret Catolos<sup>1</sup> ·  
Andres Godwin Sajise<sup>1</sup> · Glenn Gregorio<sup>2</sup> · Shalabh Dixit<sup>1</sup> · Jauhar Ali<sup>1</sup> · Md. Rafiqul Islam<sup>4</sup> · Vikas Kumar Singh<sup>4</sup> ·  
Md. Akhlasur Rahman<sup>3</sup> · Hasina Khatun<sup>3</sup> · Daniel Joseph Pisano<sup>1</sup> · Sankalp Bhosale<sup>1</sup> · Waseem Hussain<sup>1</sup> ⓘ

# Factors Hindering the Genetic Gain

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01

## Diversification of Elite Pool

Crossing a non-elite line with elite line (QTL introgressions)

02

## Breeding Cycle

Long breeding cycles (Fast recycling is key)

03

## Candidate Selection

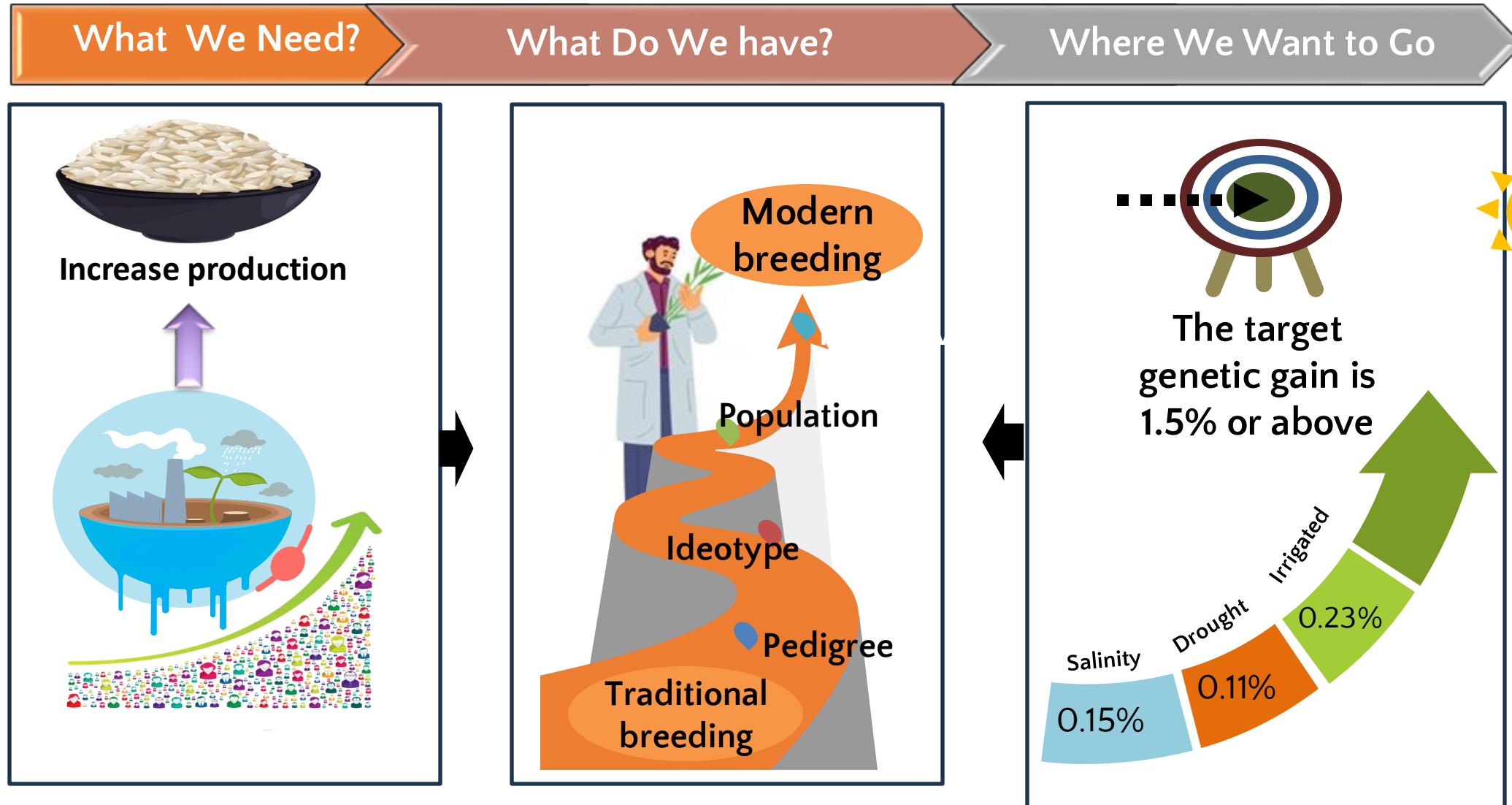
Selection based on Phenotypic values rather than Breeding values.

04

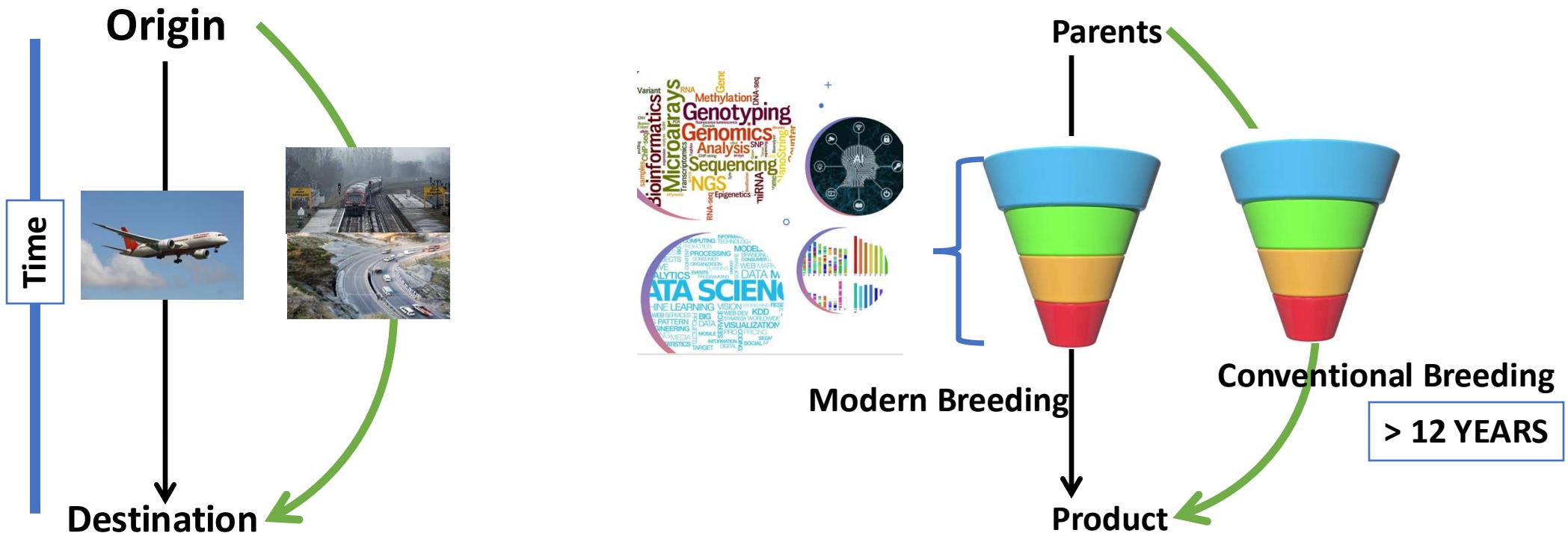
## Population Improvement

Limited focus on recurrent selections

# What We Have and Where to Go

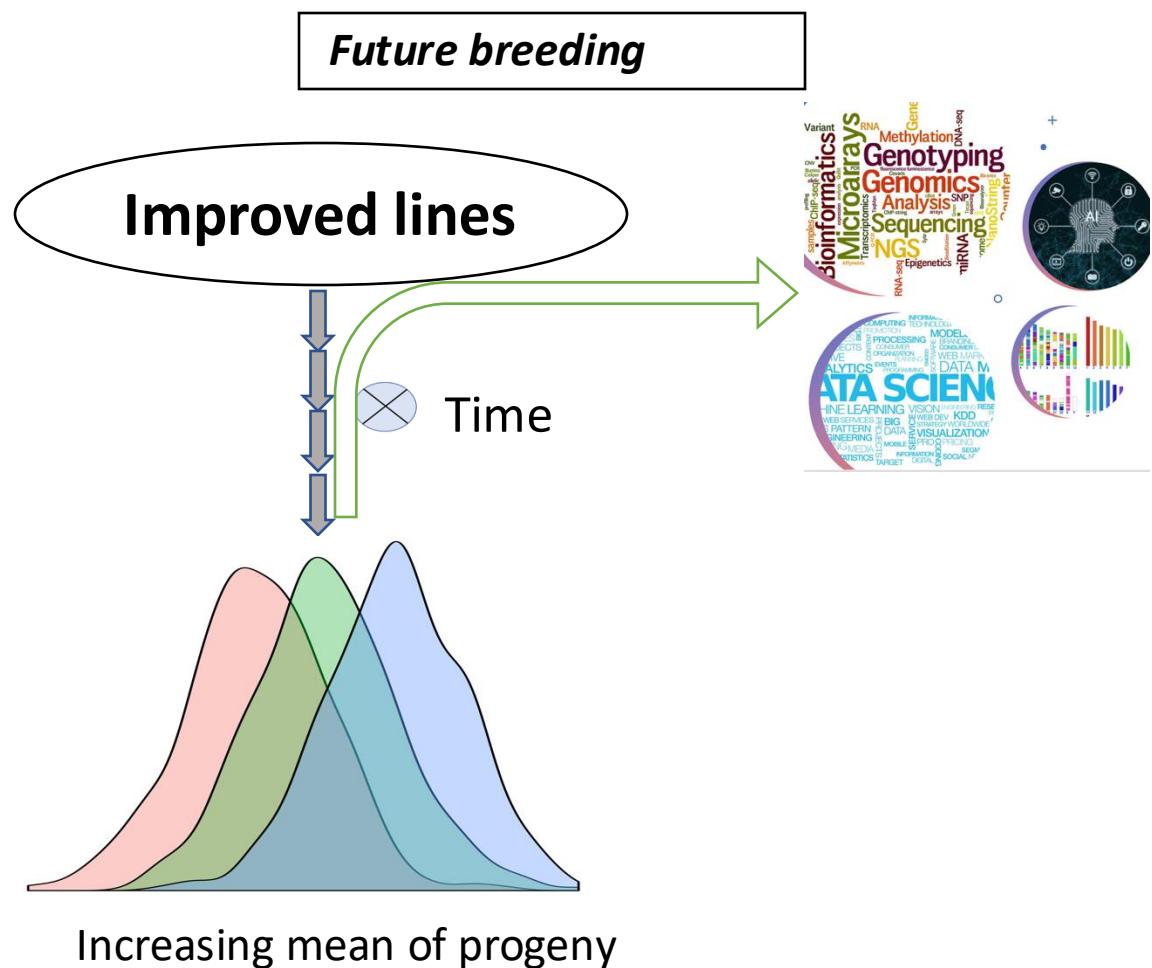


# Why to Redesign the Breeding Program to Modern Breeding?

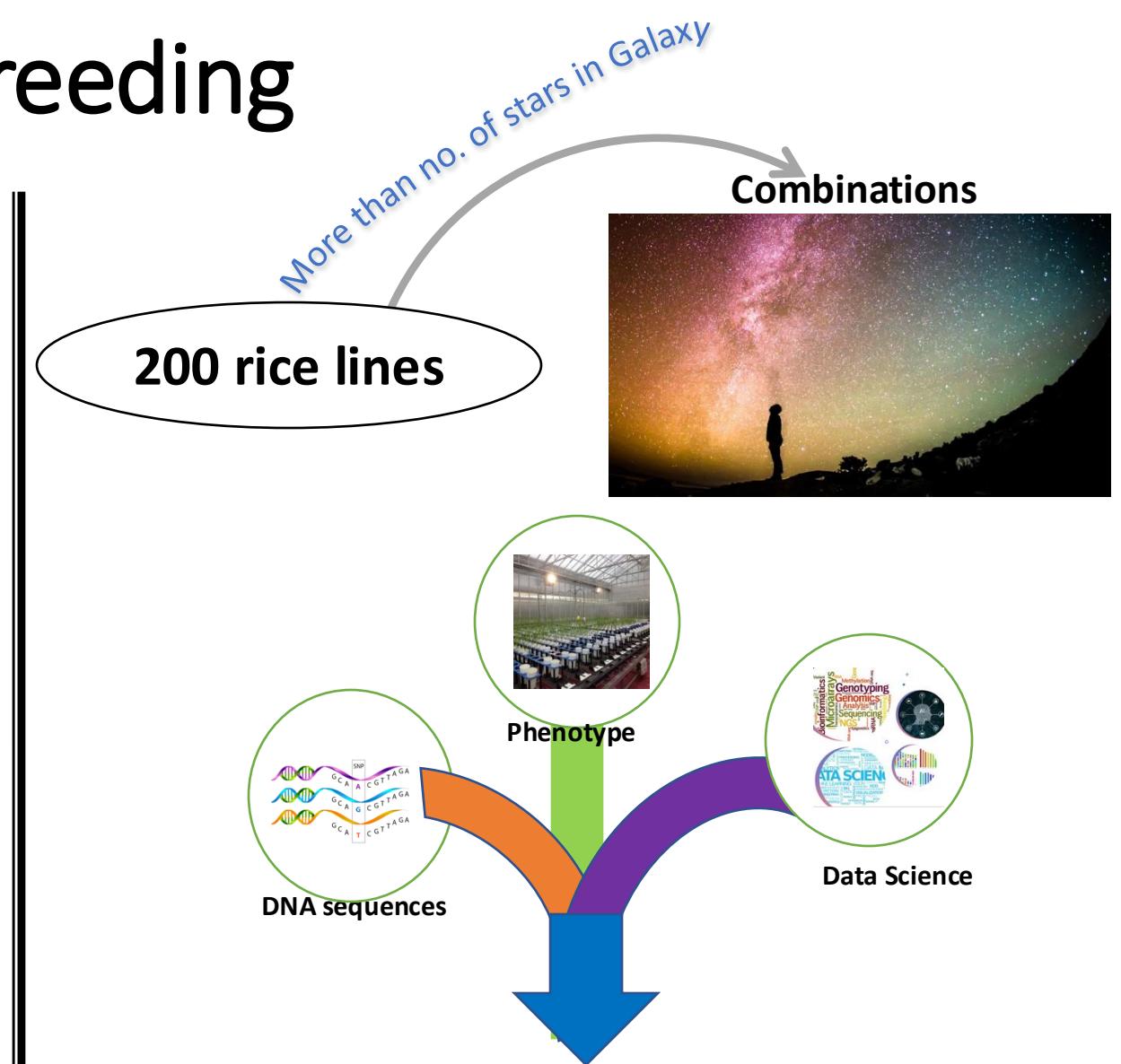


*Making Breeding Precise, Targeted, Efficient, Effective and Quick!*

# Modern Breeding

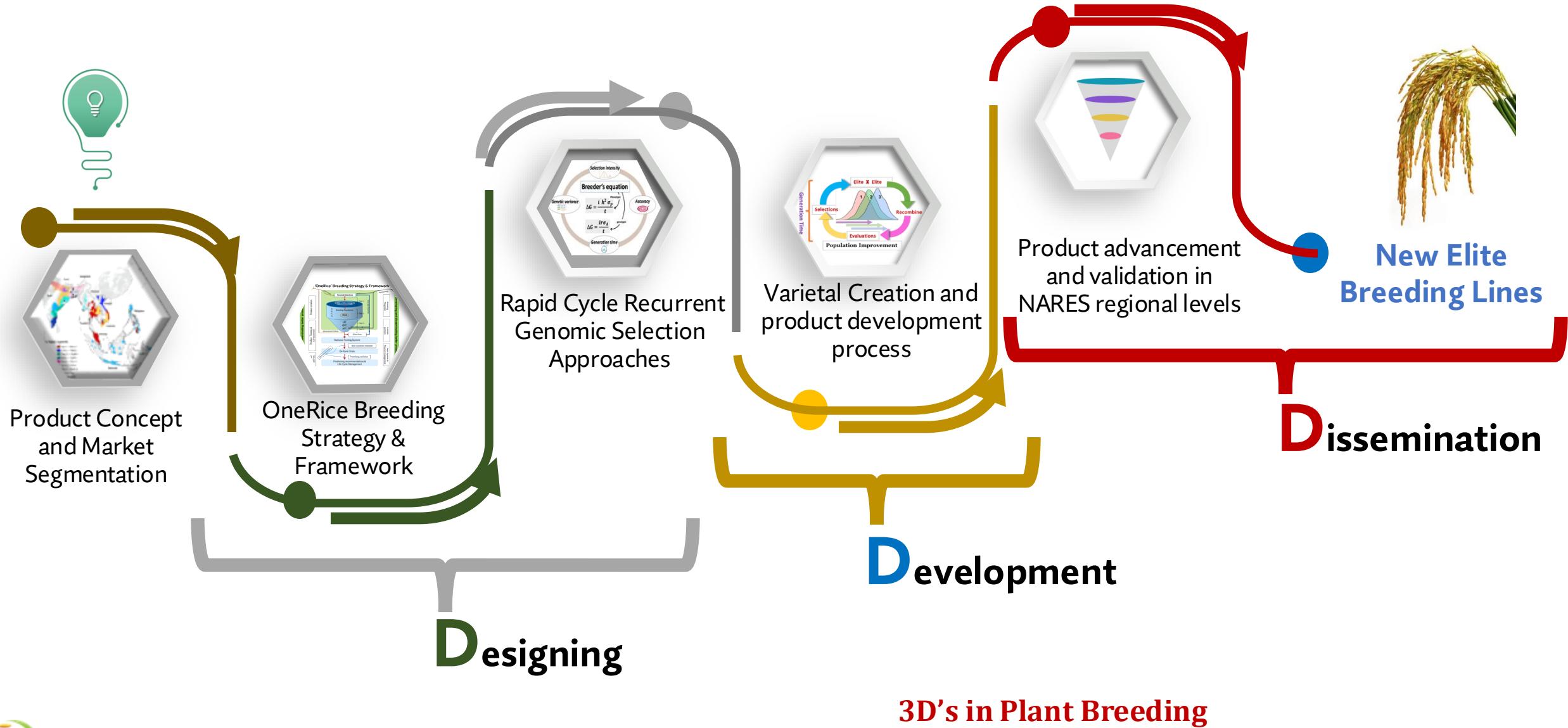


Maximize the genetic gain for yield using population improvement supplemented with modern tools



- Which genes are associated with what traits
- Which combinations are desired
- Which parent to cross
- What is contribution of each parent
- When to select quickest

# Modern Unified Framework to Breed and Deliver

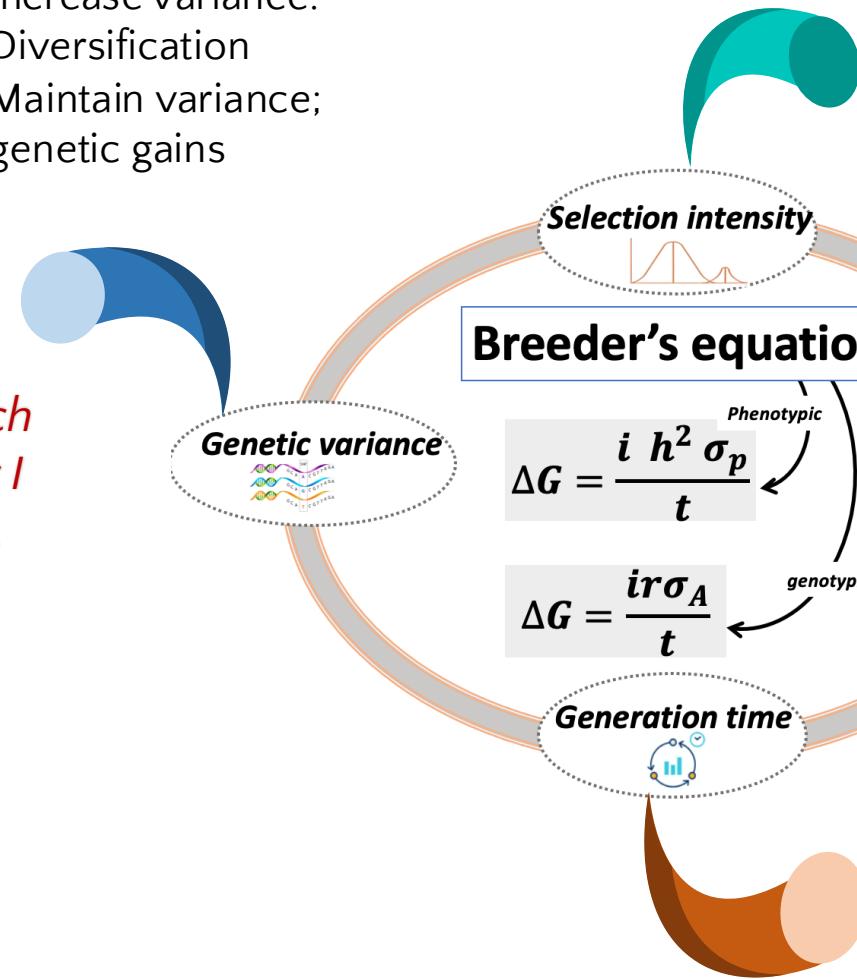


# Heart of Breeding Program: Breeders Equation



*Know which parameter I need to fix, when and How?*

- Increase variance:  
Diversification
- Maintain variance;  
genetic gains



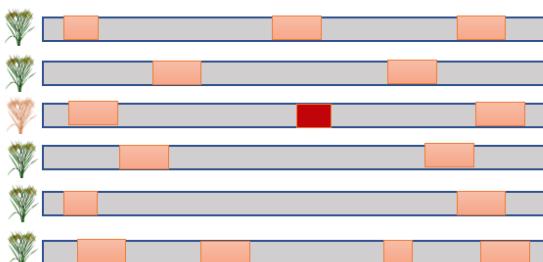
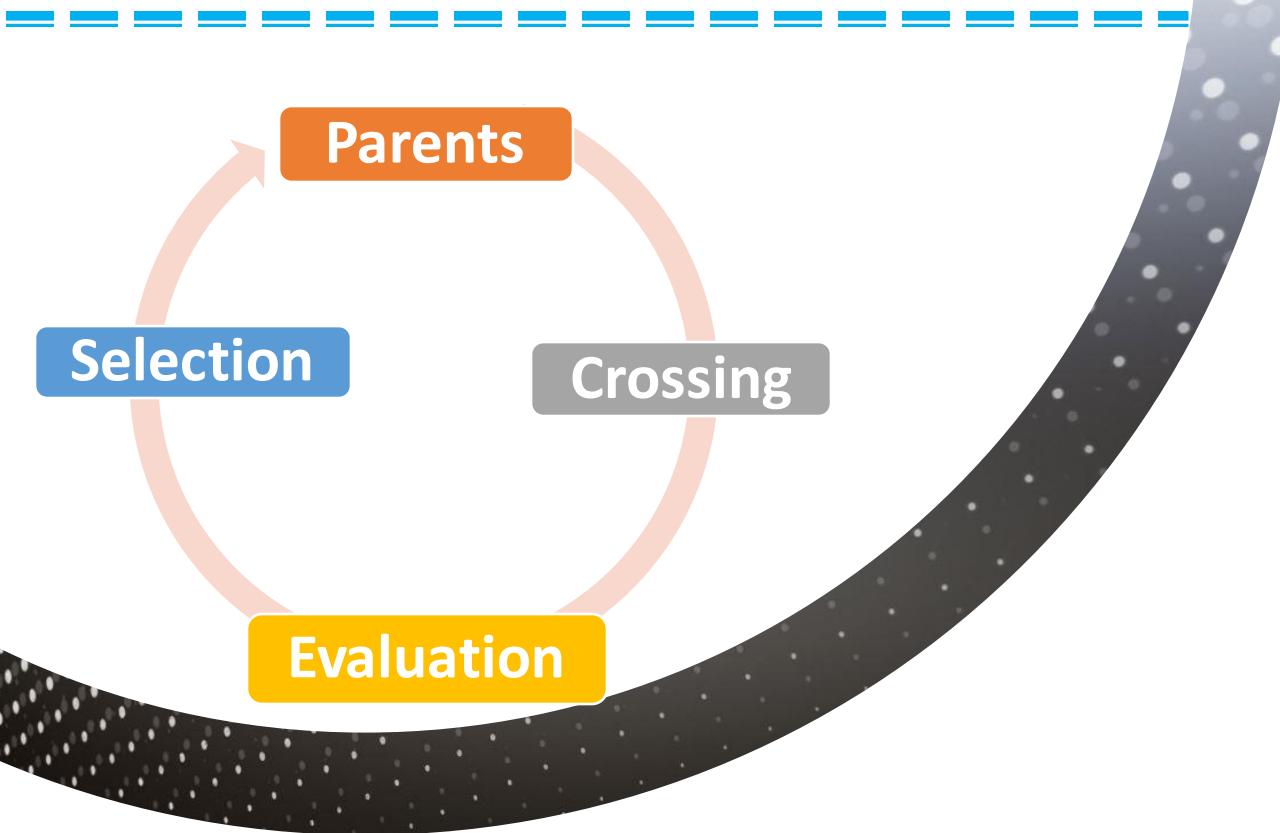
- High BV of proportion lines selection next cycle
- Coverage families
- Explore more crosses with few progenies

- Best experimental design
- Best coverage TPE
- Spatial models
- Using GBLUPs higher accuracy
- Best capture family diversity

- Recycle fast, reduce cycle time

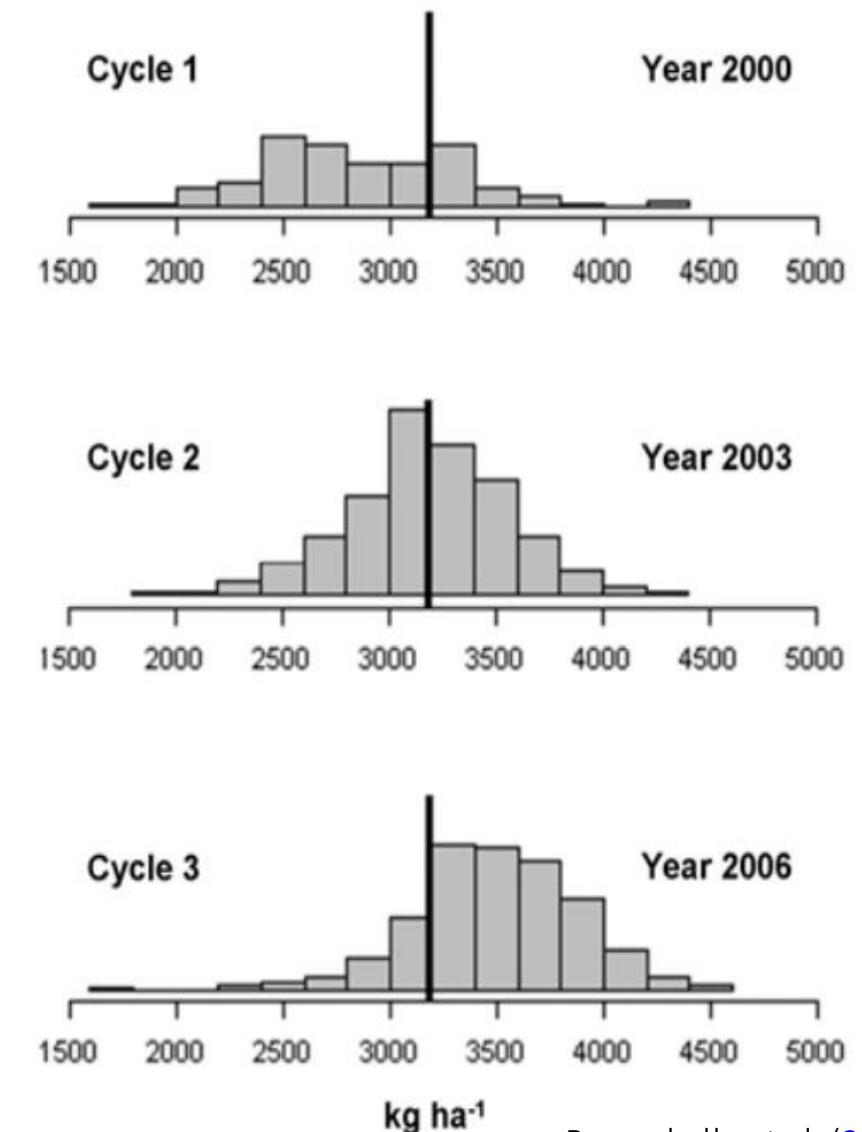
# Recurrent selection is Key

*Breaks linkages and creates variation*



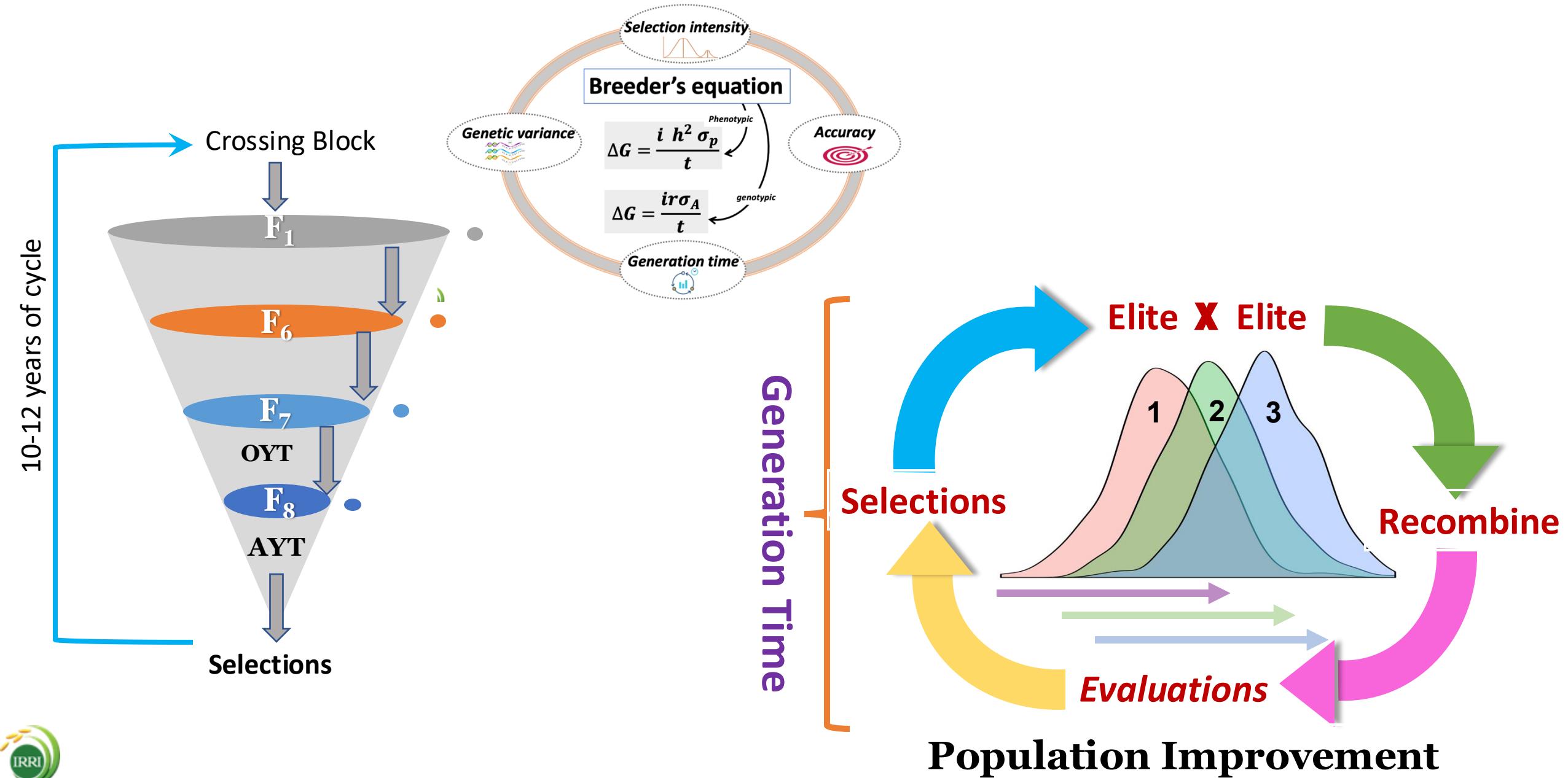
Selection and recombination Increase the frequency of favorable allele

3.6% per year over three cycles of RS



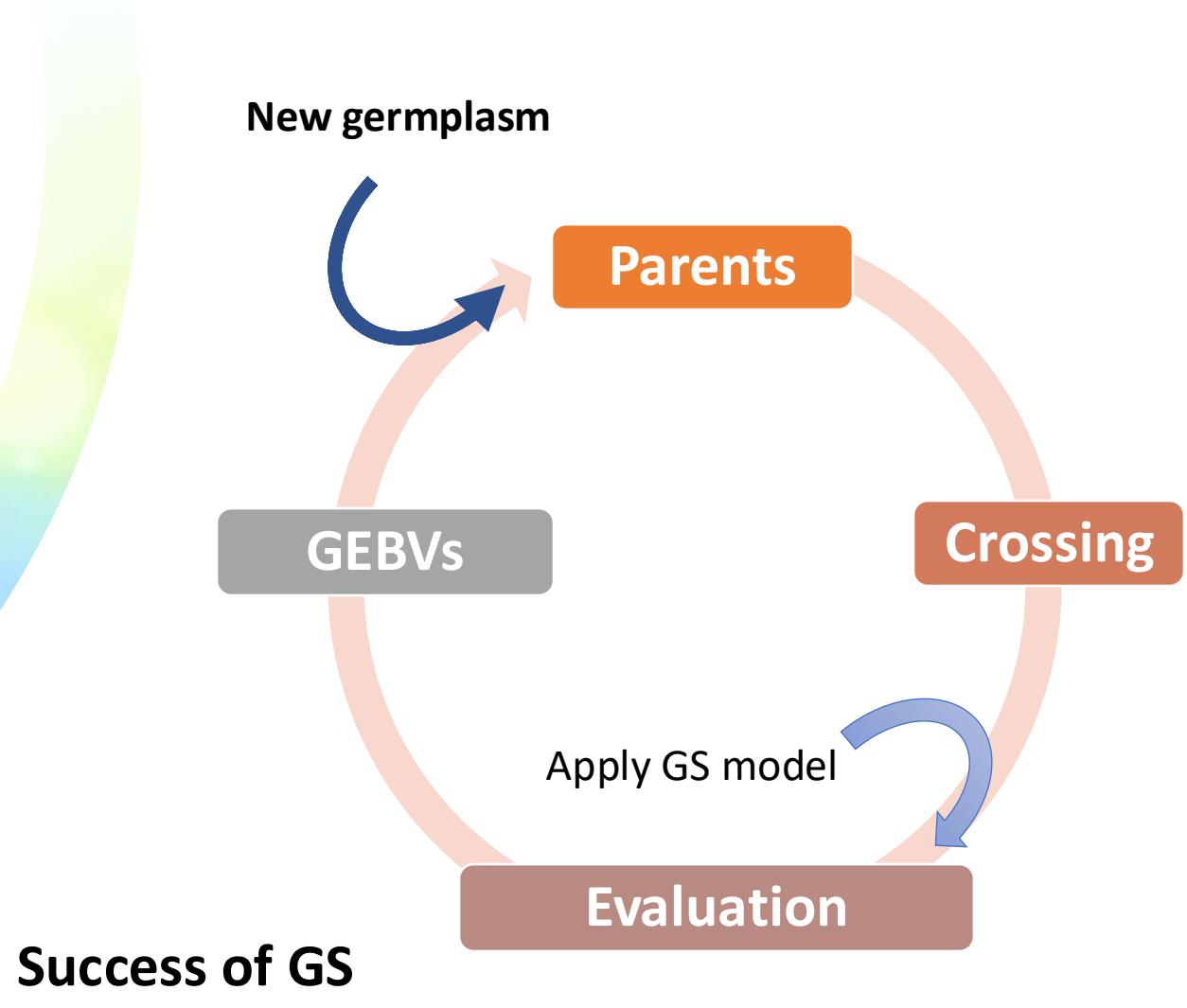
Breseghello et al. (2009)

# Long Cycles and Population Improvement



# Genome-wide Recurrent Selection

- Select genotypes in earlier stages of the breeding program
- Reducing breeding cycle and
- Increasing the rate of early genetic gain



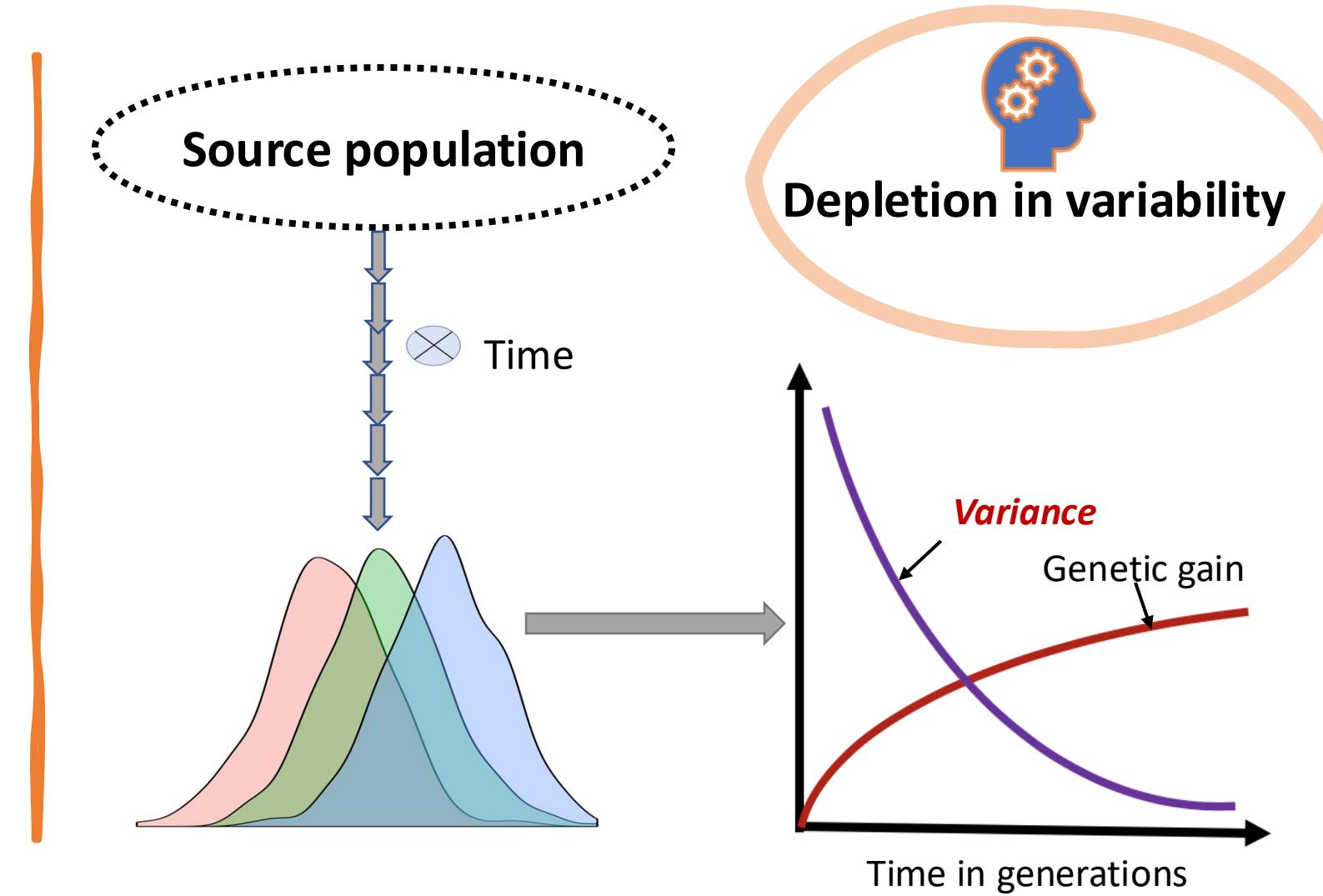
## Success of GS

- Relationship and size of training population.
- Regular update of training model.
- LD between markers and QTL
- Accuracy
- Cost of genotyping

# We Need to Diversify: Everyone Says That

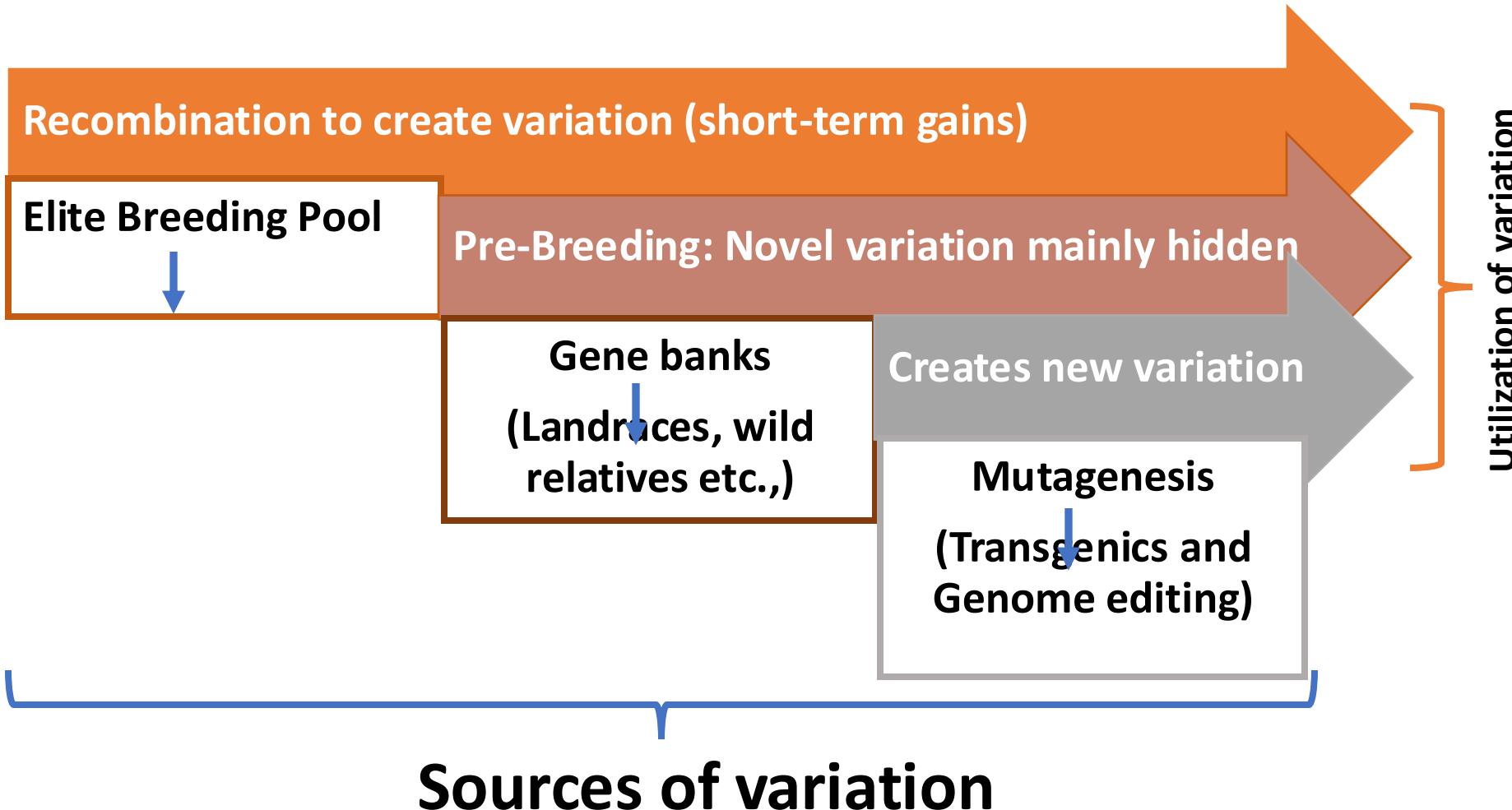
Is Recurrent Selection feasible for Long term Genetic Gains?

Effective population size 32  
65 years to deplete the variability!!!!

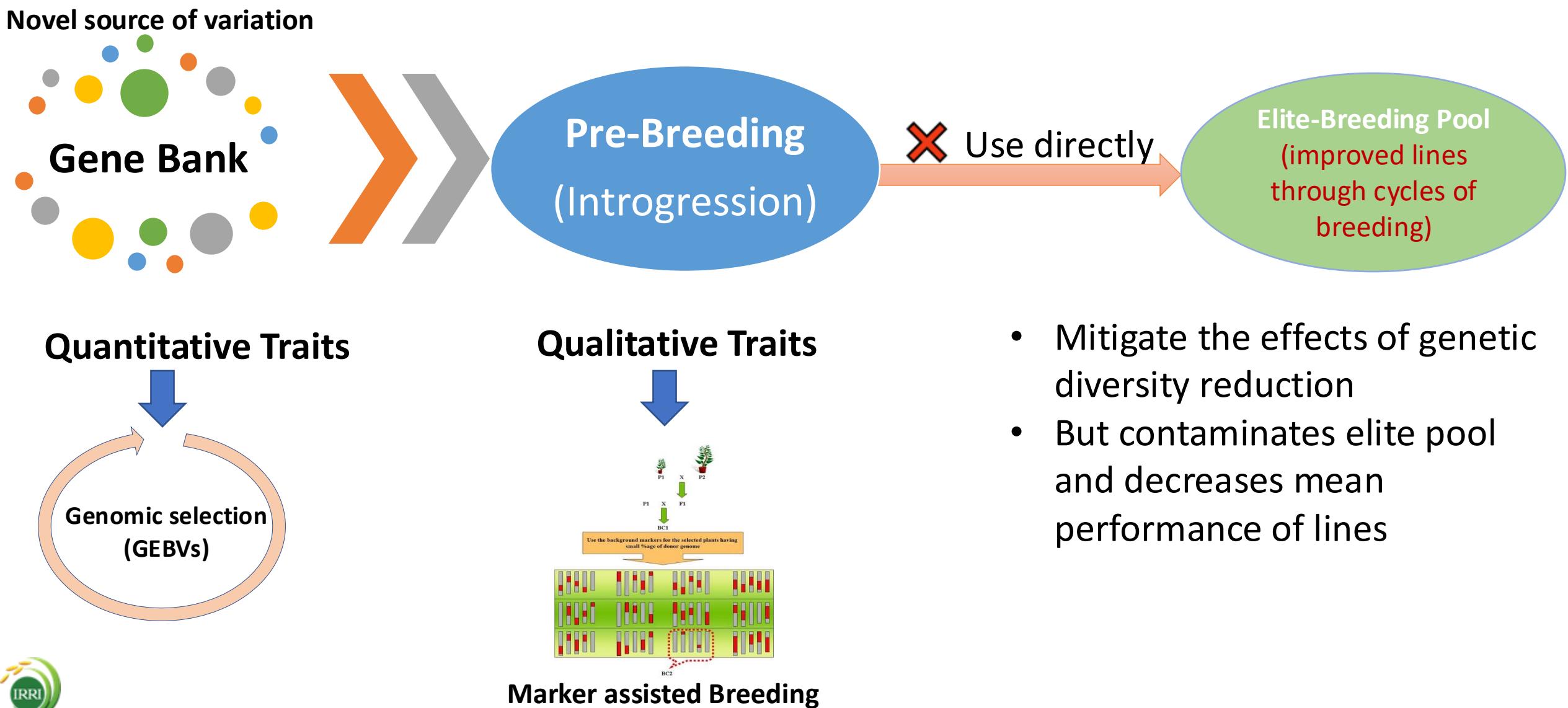


***GS fixed alleles much faster by selecting desirable combinations***

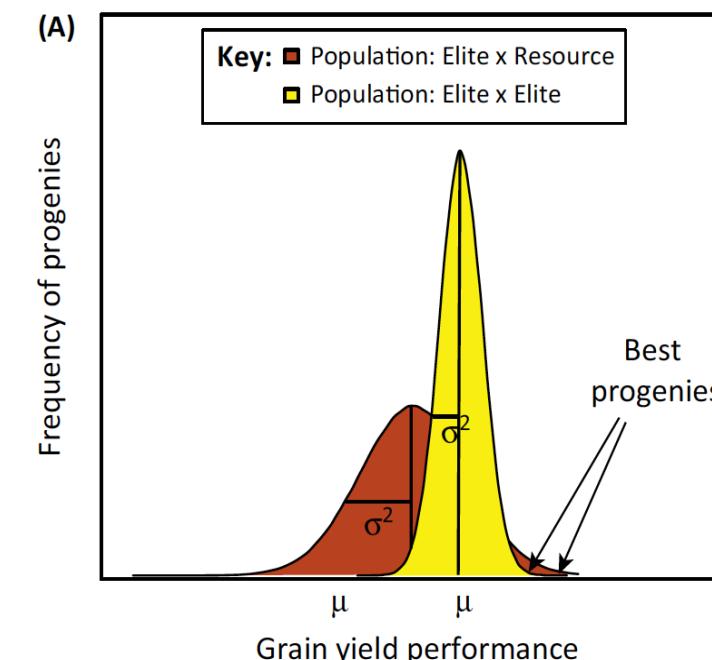
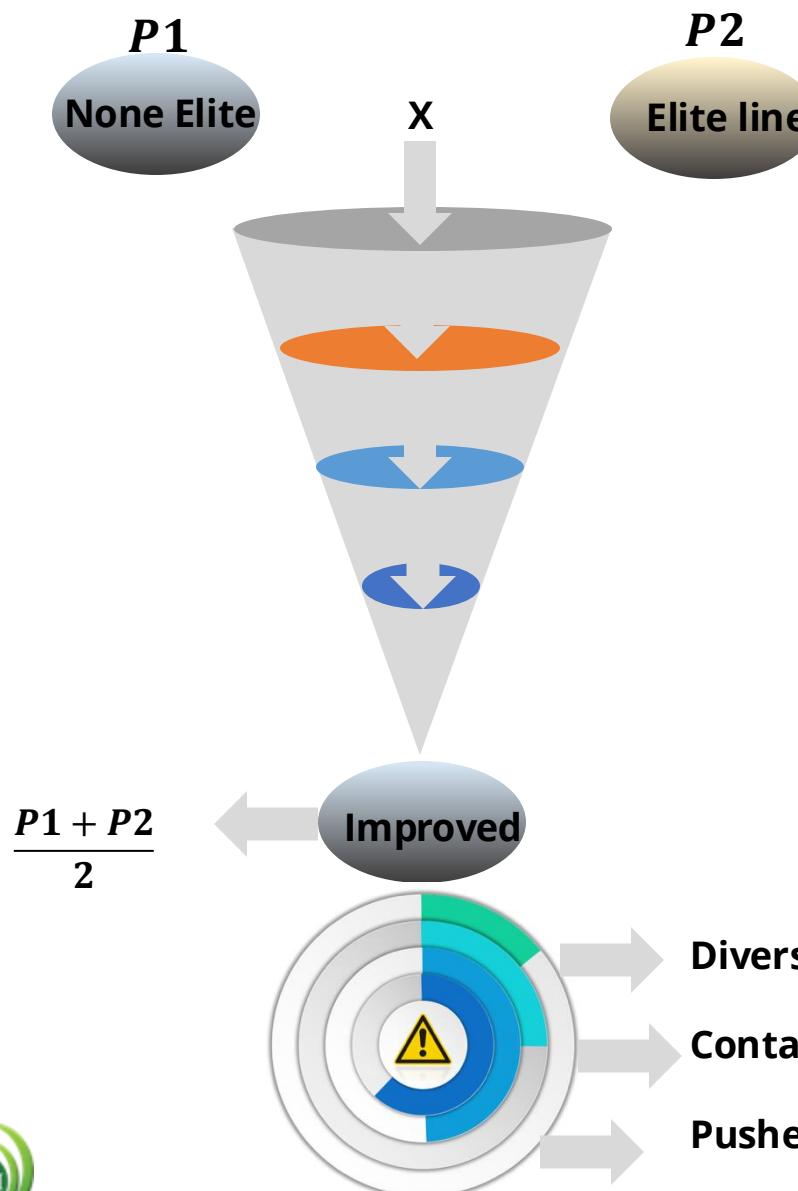
# How to maintain the Genetic variation



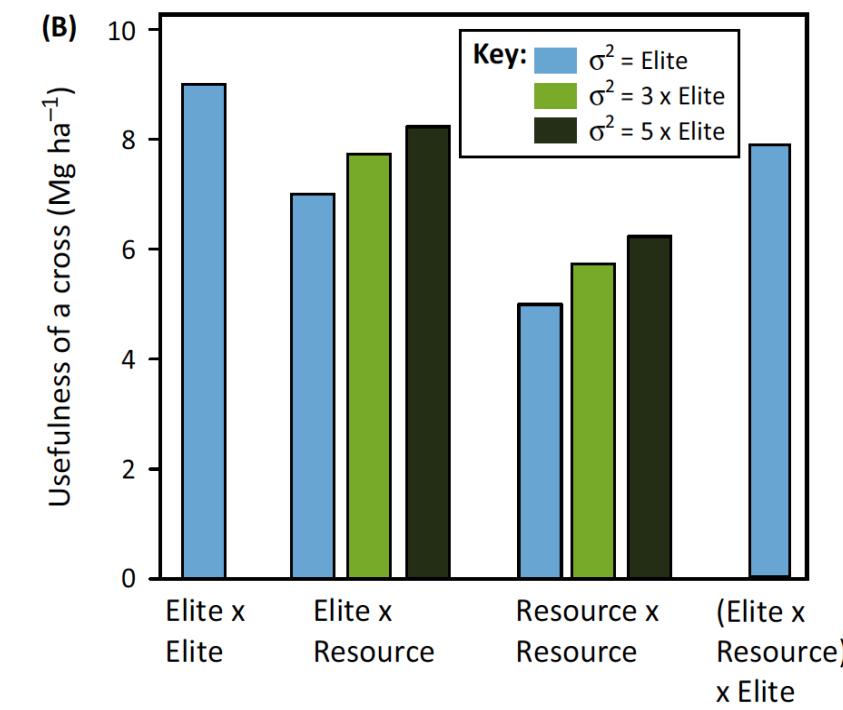
# How to maintain the Genetic variation



# Is Direct Introgession a Valid Strategy?



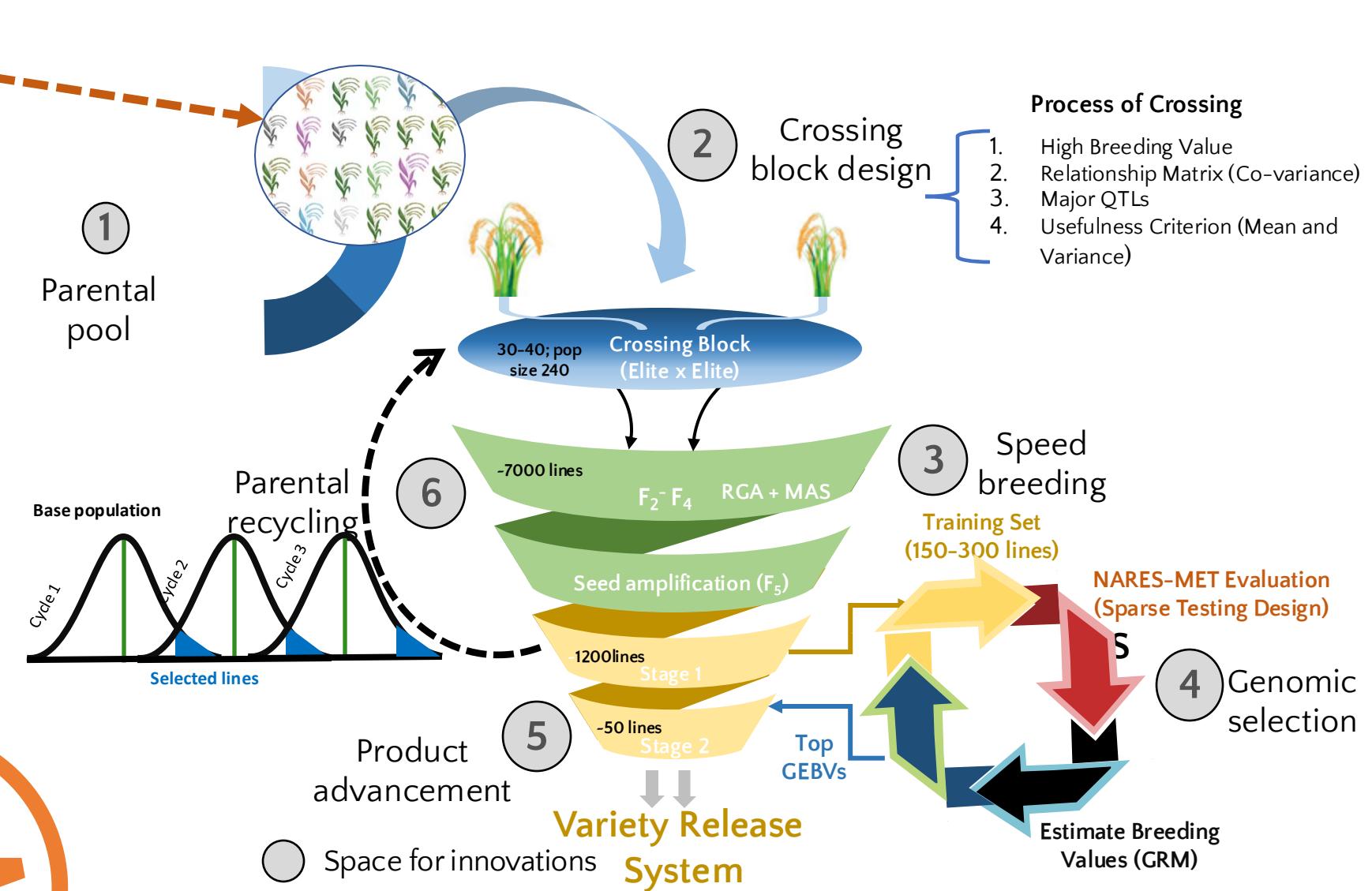
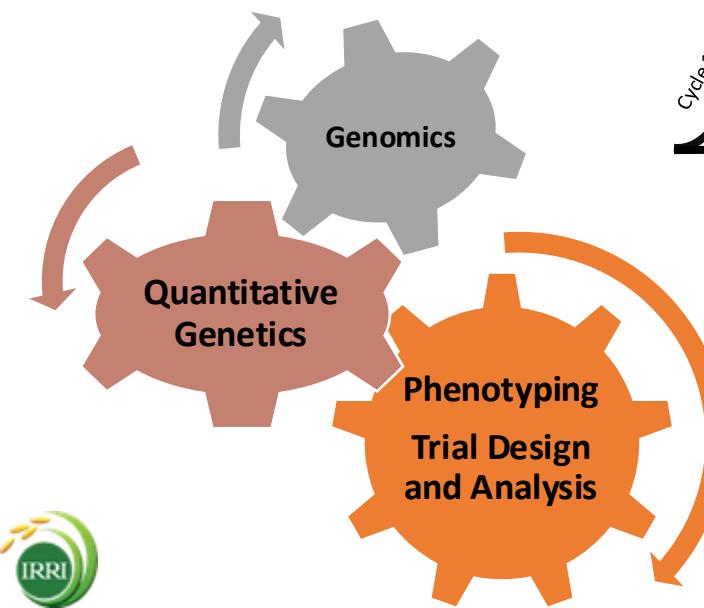
*The increased genetic variance due to using genetic resources can barely counterbalance the lower mean*



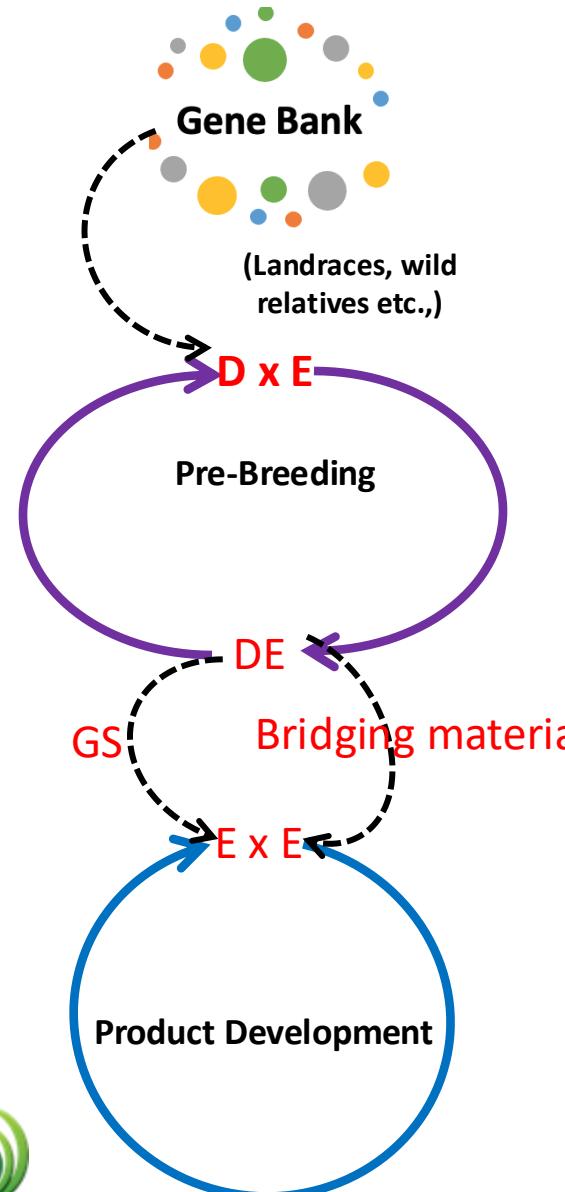
**Need a Systematic Pre-breeding**

# Holistic Framework to Diversify and Enhance Genetic Gains

## Re-thinking and Redesigning Breeding



# Strategies to Diversify Elite Gene Pool



- Cross donor with elite tester (Longin and Reif, 2014)
- **De-couple recurrent Selection with line development (Gorjanc et al. 2016)**
- GS-based strategy to predict the performance of gene bank germplasm (Yu et al. 2016)
- Optimal contribution (Cowling et al. 2017)

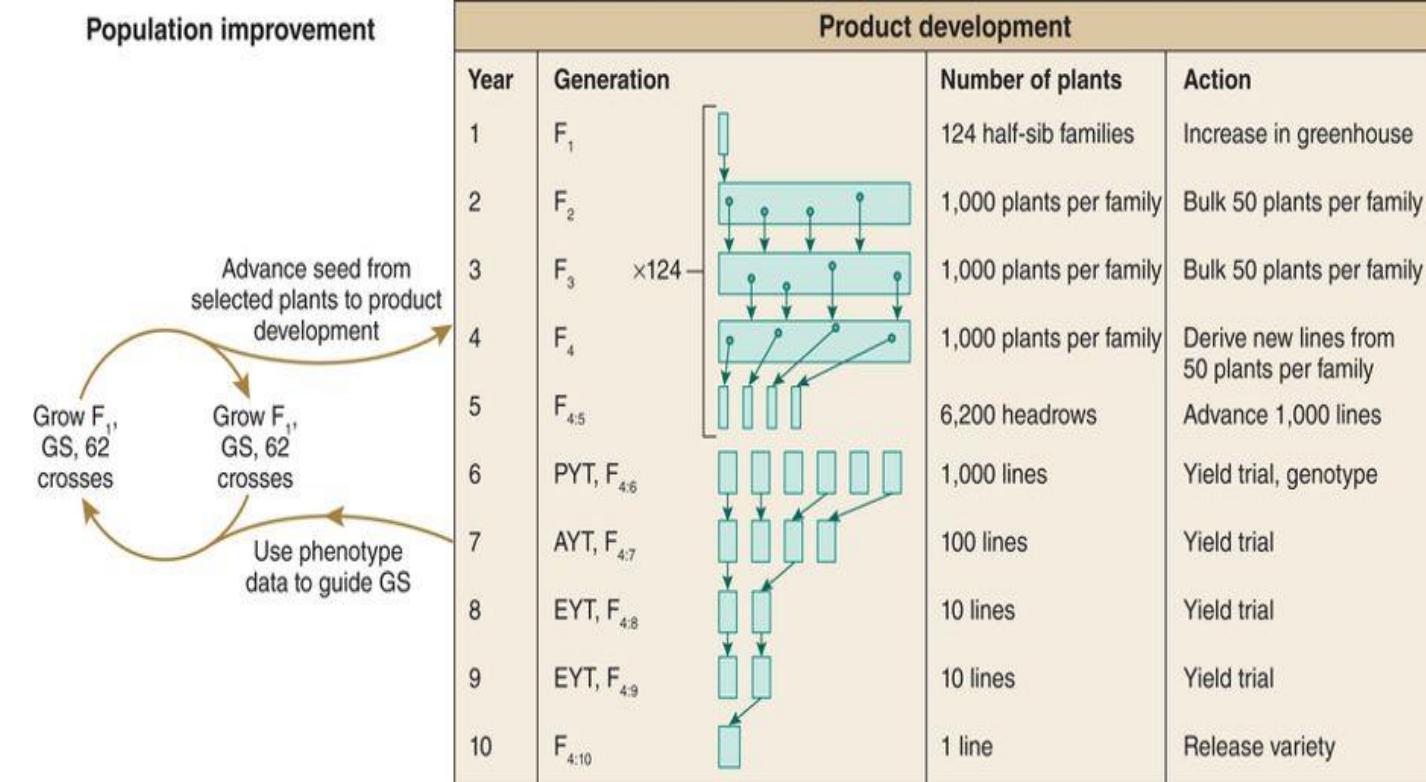
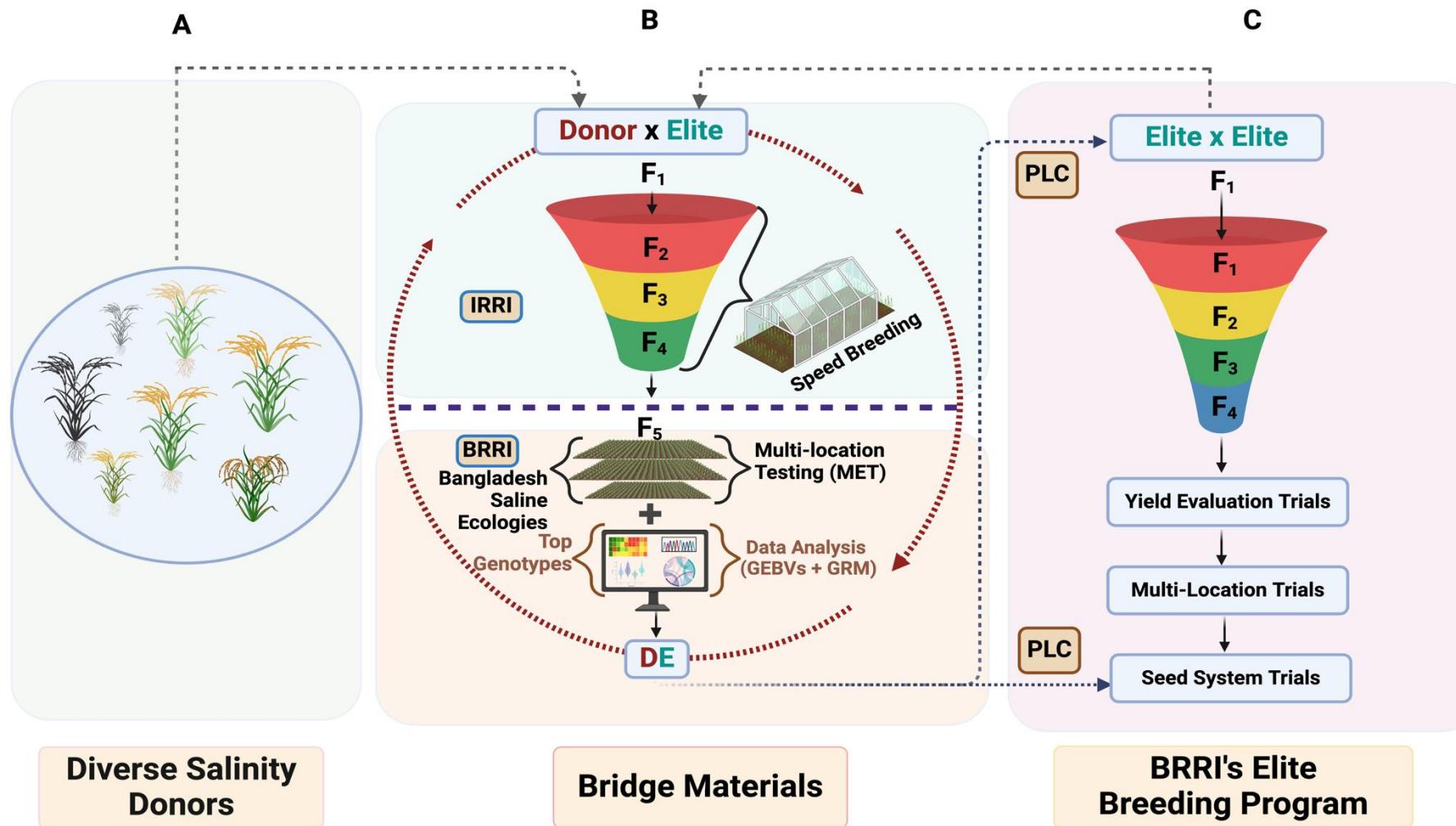


Figure adopted from Hickey et al, 2018; <https://www.nature.com/articles/ng.3920>

# Connected Breeding Approach

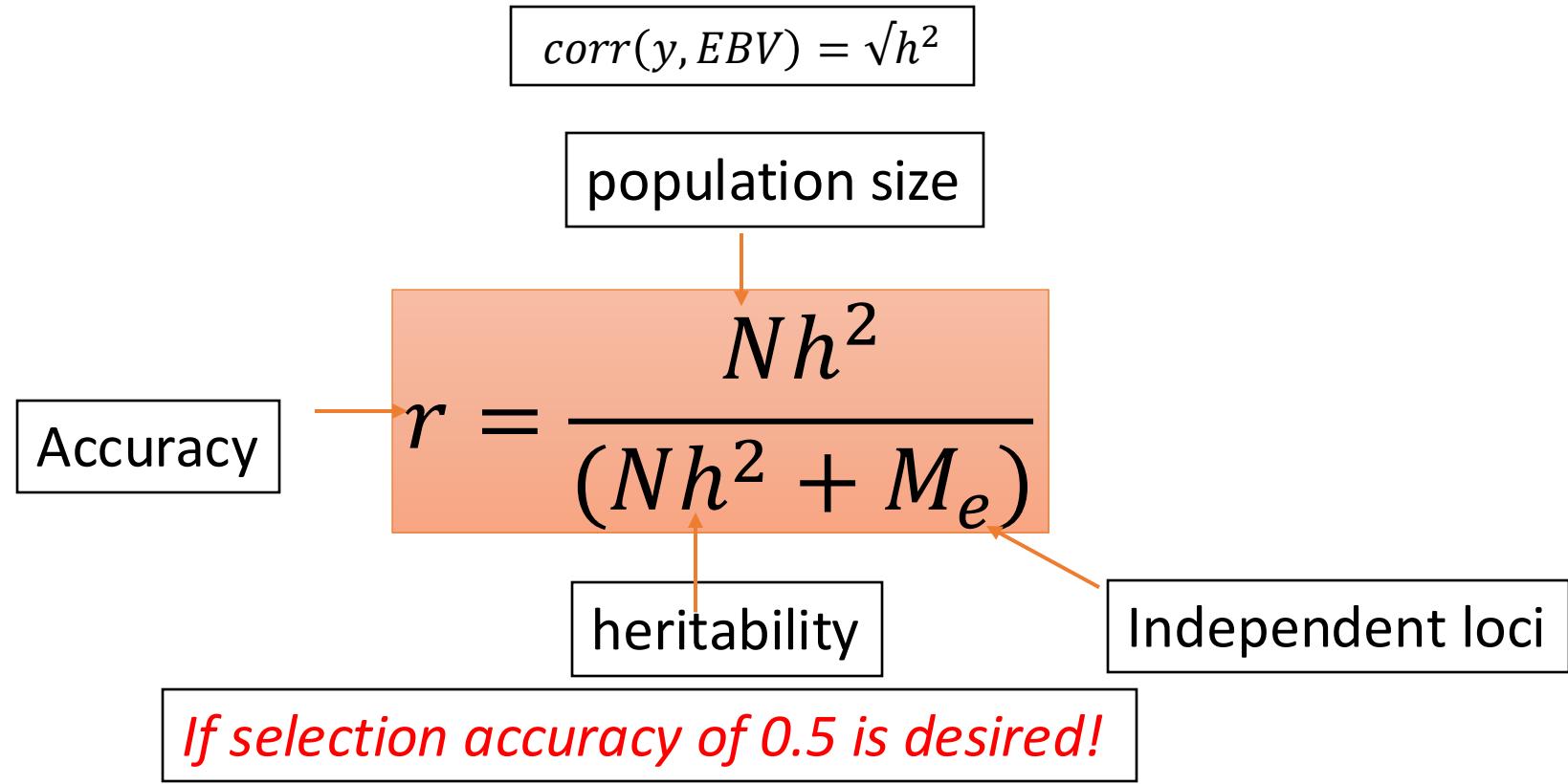


- Overcomes Limitations of MAS
- Effective for complex traits
- Genomic prediction can be leveraged
- Fast, reliable and effective

Hussain et al. 2024; <https://doi.org/10.1093/jxb/erae299>

Mahender et al. 2025; <https://doi.org/10.1016/j.cpb.2025.100518>

# Selection Accuracy



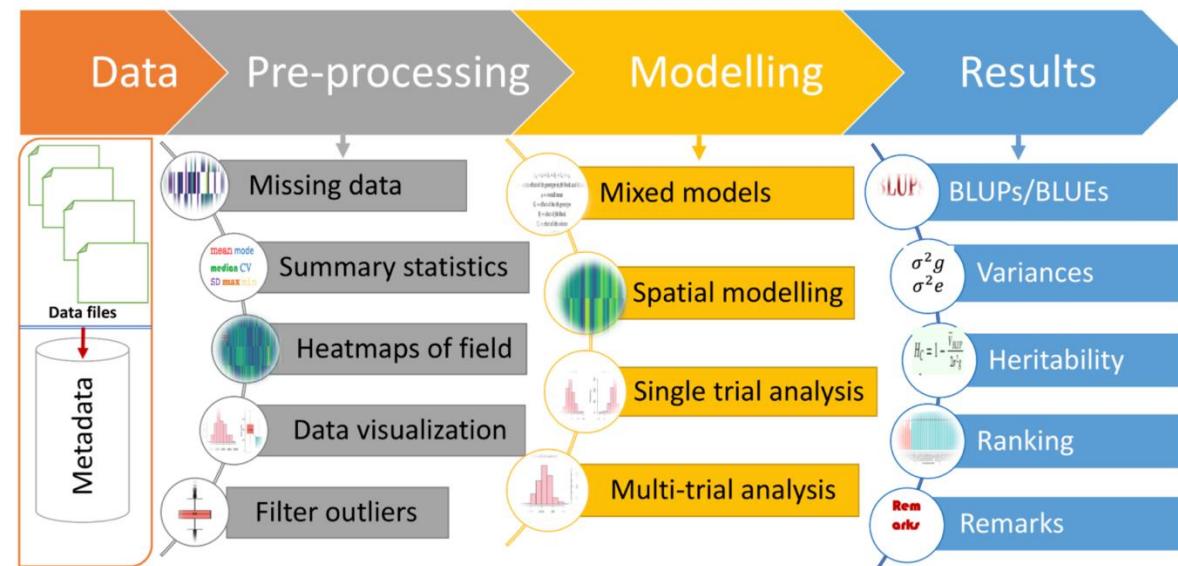
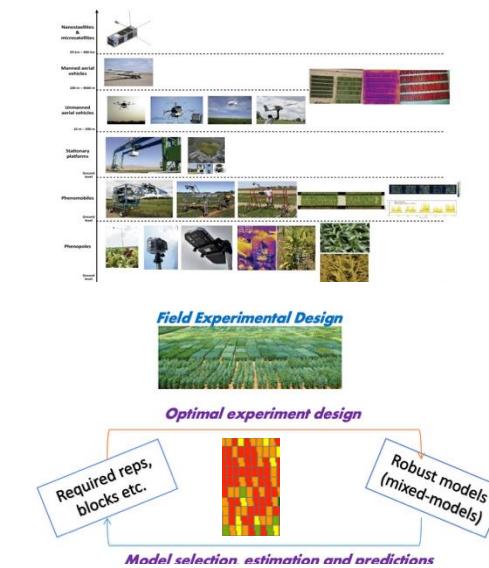
Heritability ( $h^2$ )	Population size	Phenotyping
0.01	10,000	Poor
0.2	5,000	Accurate
0.4	2,500	Improved

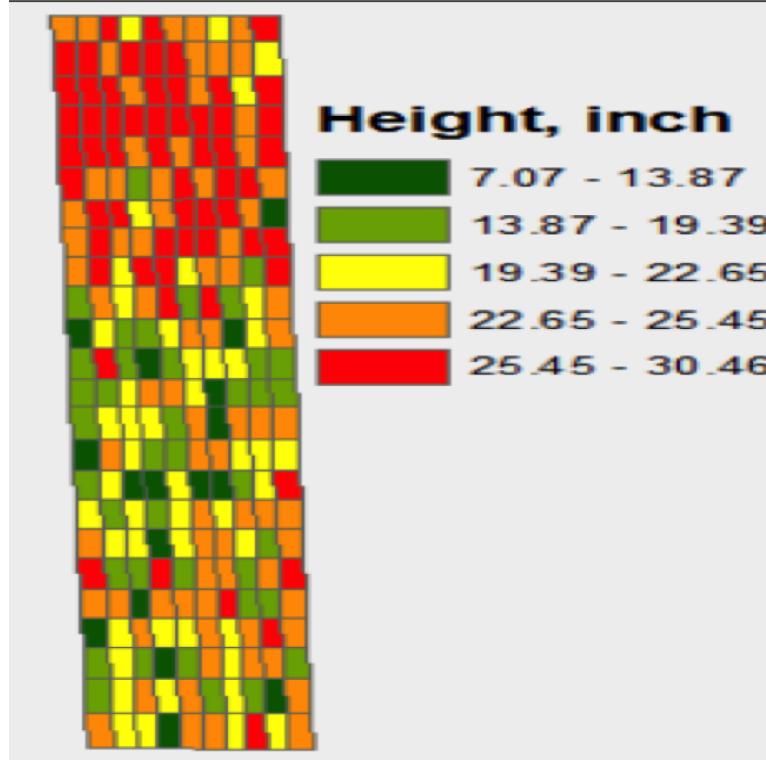
# Selection Accuracy



## Separate the Noise

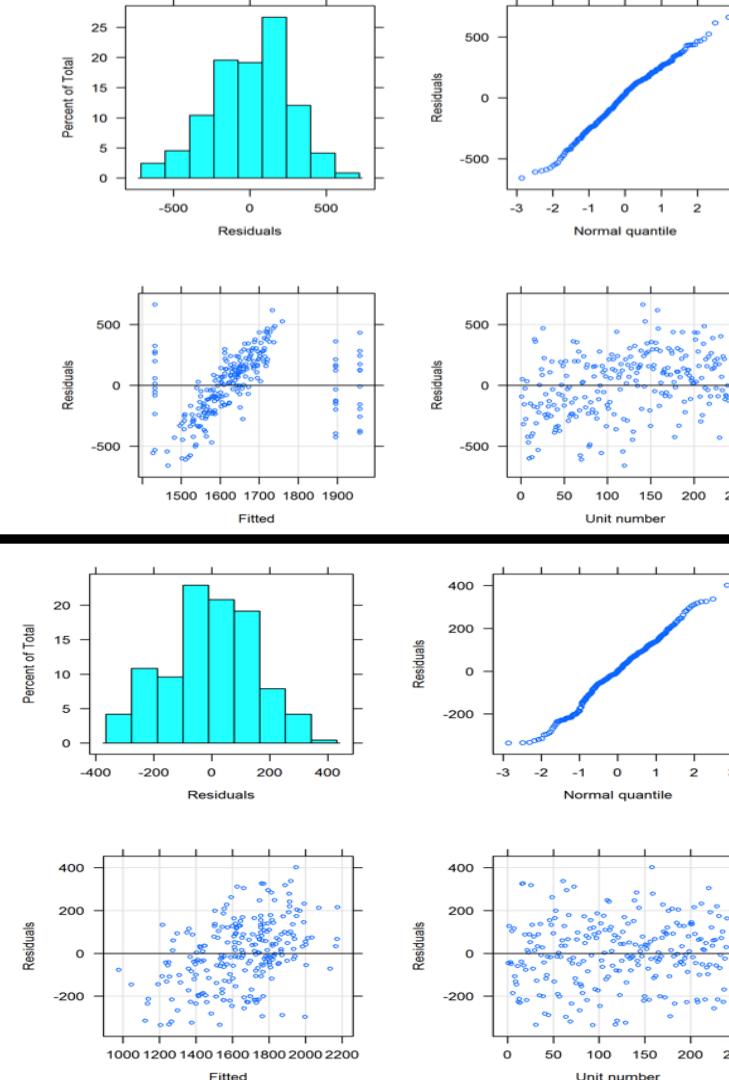
- Accurate phenotyping
- Robust experimental design
- Good replications/testing
- Accounting for design, spatial variations etc.
- Accounting G x E





# Spatial variations

Mixed models to account for spatial variations



Accounting for  
only block  
variation

Accounting for  
block, row,  
column and co-  
variance

# Selection Accuracy and Genetic Gains

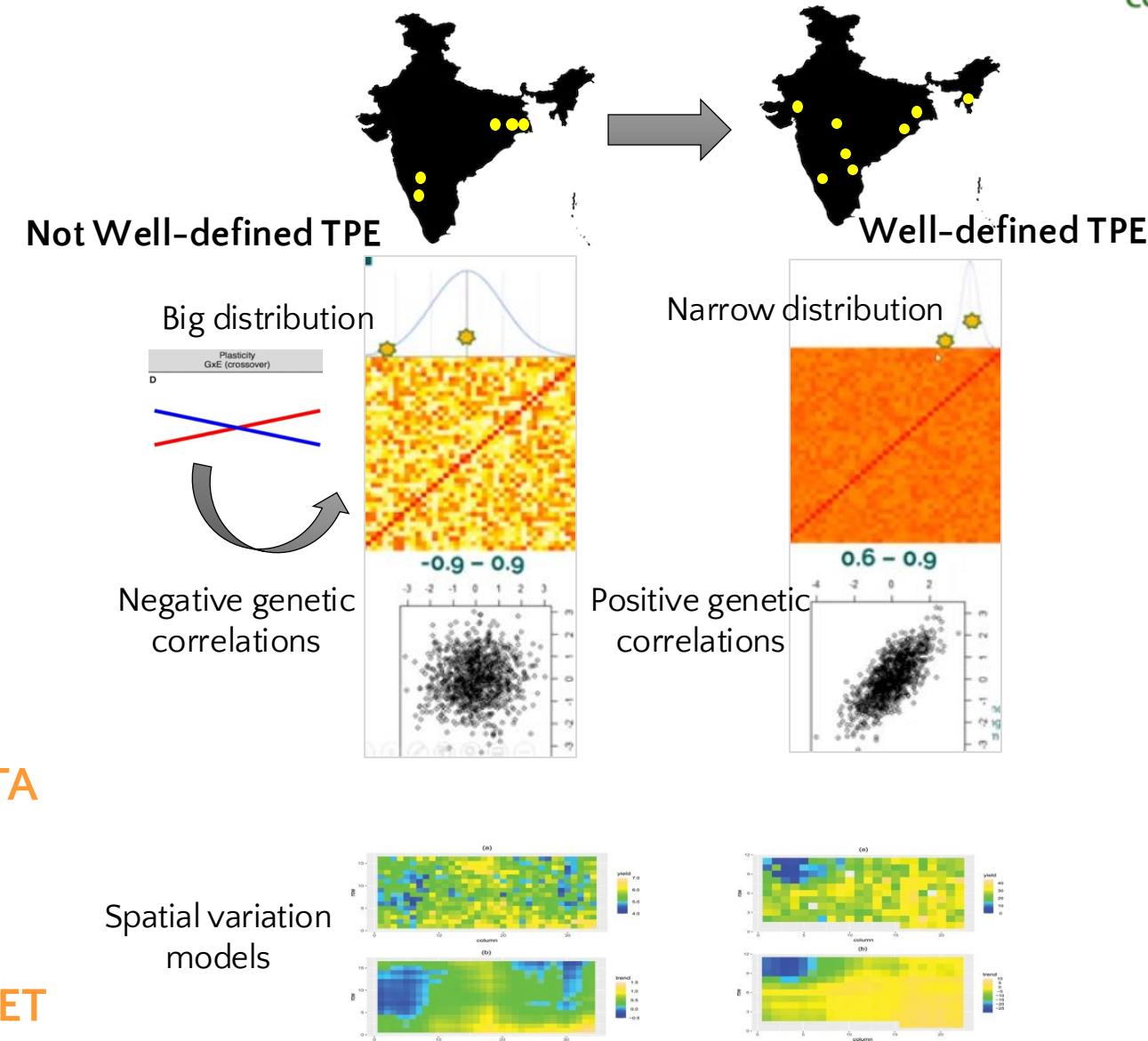
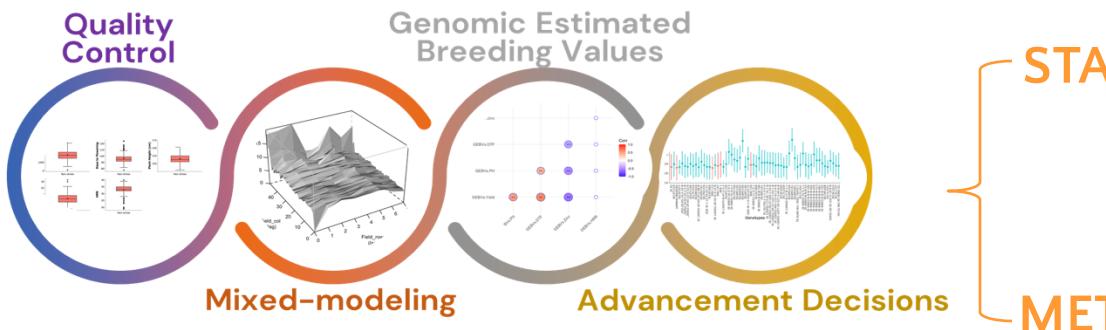
Ensure reliable genetic value is critical for  $\Delta G$  and turnover of improved varieties.

Best experimental design

Mixed model approaches

Capture accurate breeding value.

- Data trial quality and assessment is foremost in STA, consider taking MET decision
- Well, capturing TPE as best as possible
- Maintain diversity and minimize relatedness
- Predict breeding values-includes GRM
- Use selection indices and breeding values for parental recycling

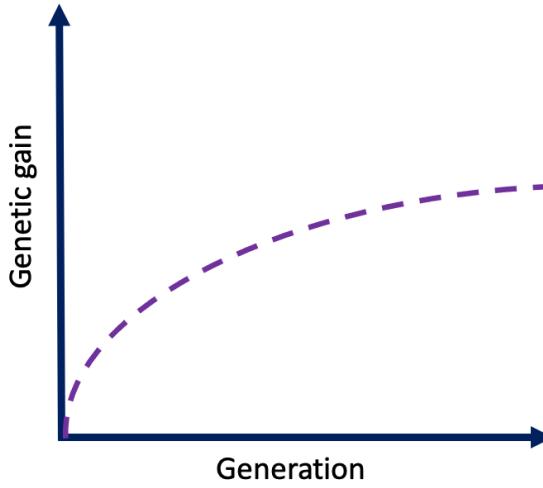


# Selection Intensity

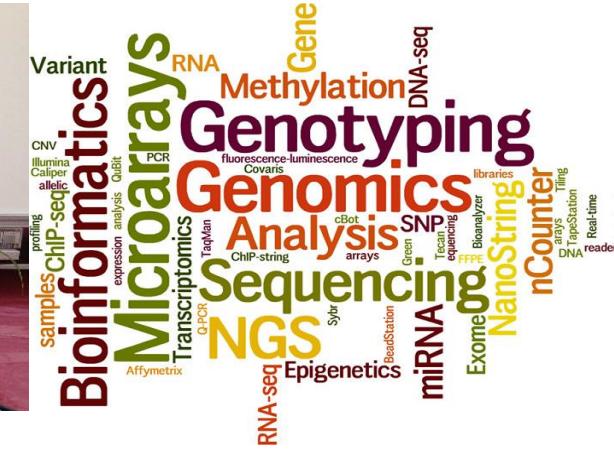


*Selection intensity* ( $i = \frac{s}{\sigma_p}$ )

Proportion of the population selected from the total population.



- Increase but to a limit!
  - Relationship with response is not linear
  - Smaller the population size faster the inbreeding



- Low-cost HTP tools reduce costs will allow resources to be allocated to generation and management of larger populations.
  - Efficient targeting of novel genetic variation.
  - GS will allow to select for more candidates thus increasing  $i$
  - *Optimal contribution solves conflict between  $i$  and loss favorable variation*

# Be Smarter what “*i*” to select

# Take Home Message

Huge challenges to achieve our target



We have a Mission and vision.

Realistic and Precise Phenotypic Screening

Best parent selection and smart breeding

More science with Smart-skills

Systematic and integrated modern breeding team approaches

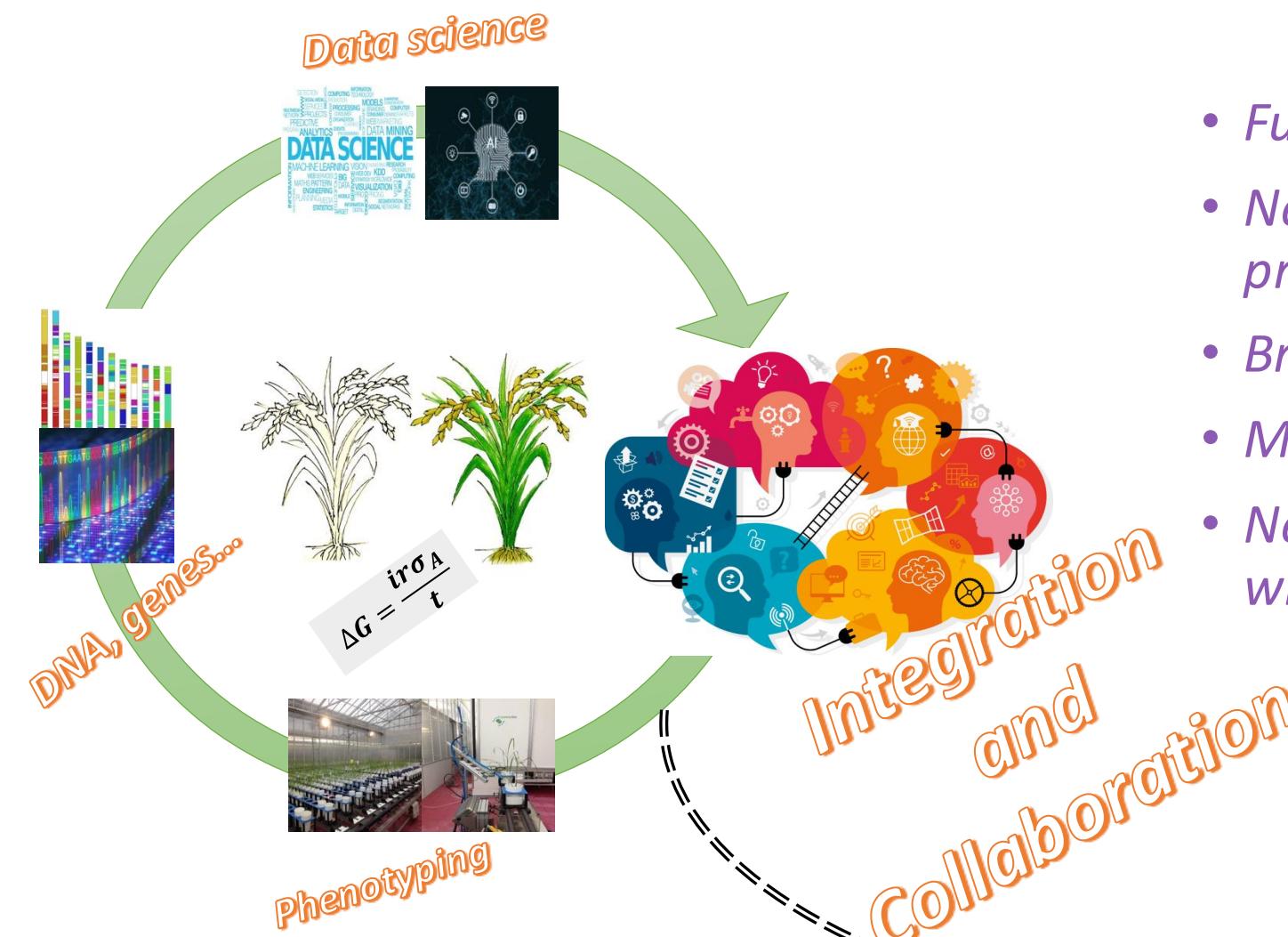
Deliver better and faster products.

Long-term impact



Making Breeding Efficient, Effective, and Quick in Engagement with the Regional Partners

# Conclusion



- Future breeding is collaboration.
- Need Army of Skilled people to drive the program?
- Breeding is more Science than Art.
- Making “Breeding Equation” better!
- Need to be smarter! Know when, how and where to through technologies!



*Innovations do not come from  
brain, innovations come through  
sharing of ideas*

+  
o

Thanks

