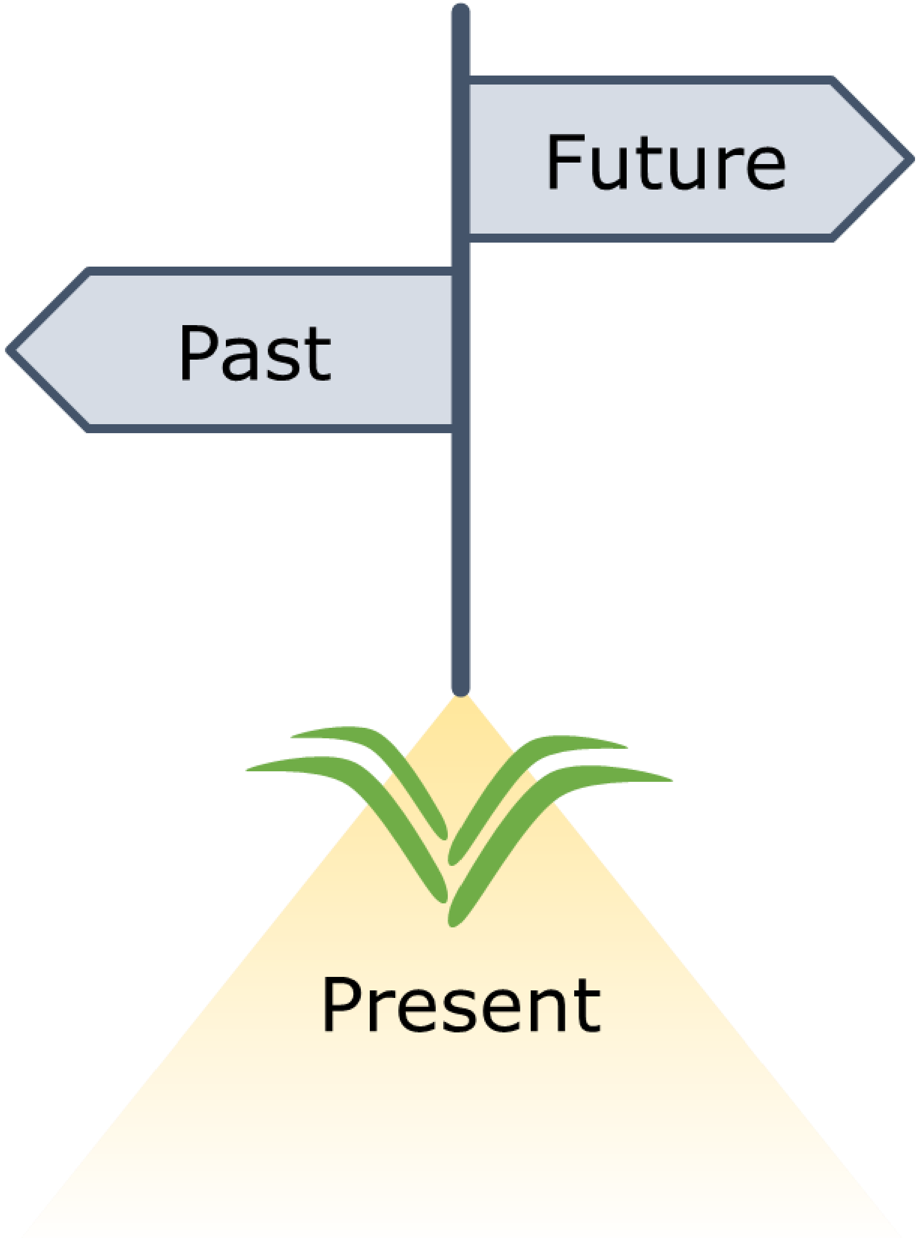
Note:

Slide 2-39 are for 1-hr research talk

Slide 40-50 are for a short talk to growers' association



The past, present and future of quantitative genetics in plant breeding

CJ Yang

Aug 2, 2023

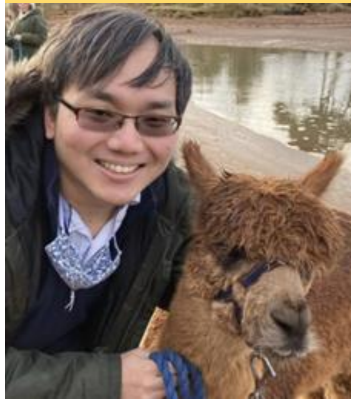
Self introduction

Wisconsin
2012-2018
PhD Genetics

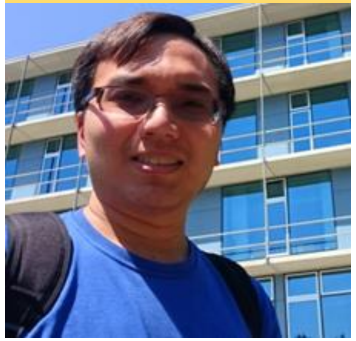
Indiana
2009-2012
BSc Biotech, Math

Map from R/maps

Edinburgh
2019-now
Postdoc

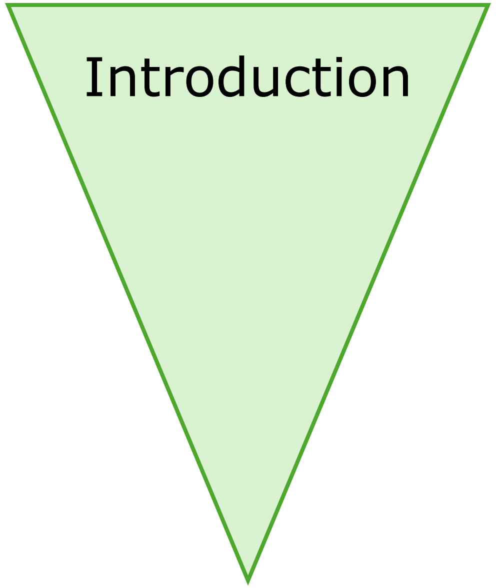


Freising
2018-2019
Postdoc

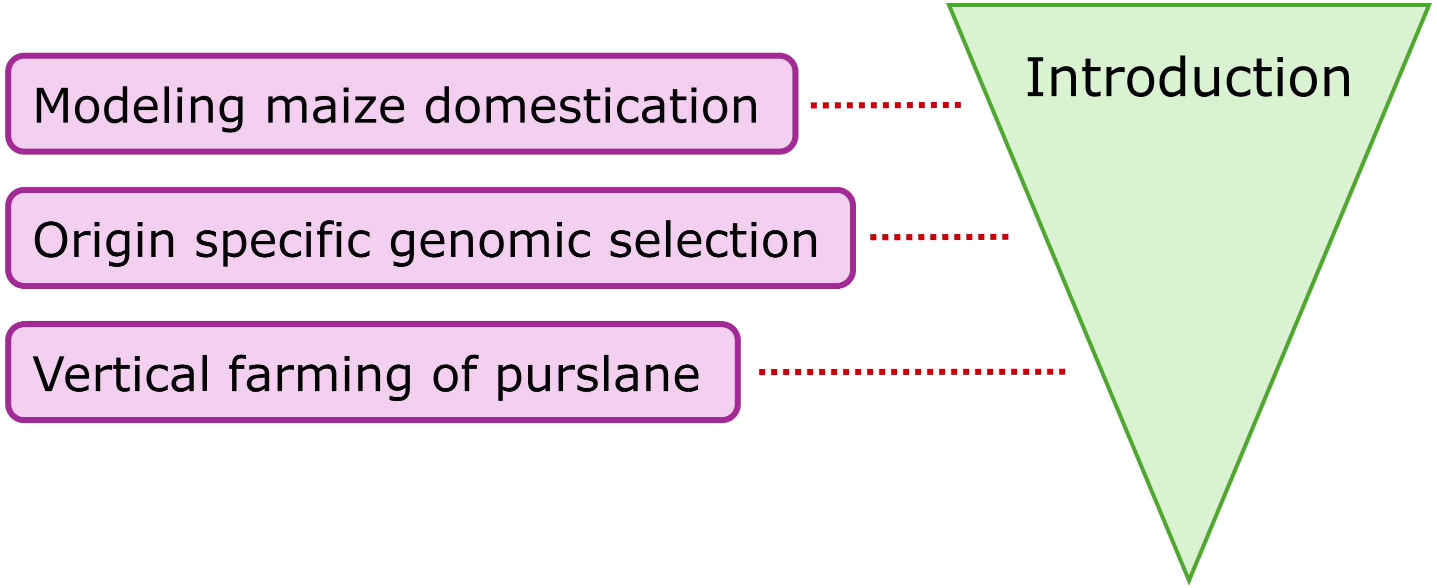


Malaysia
1990-2009

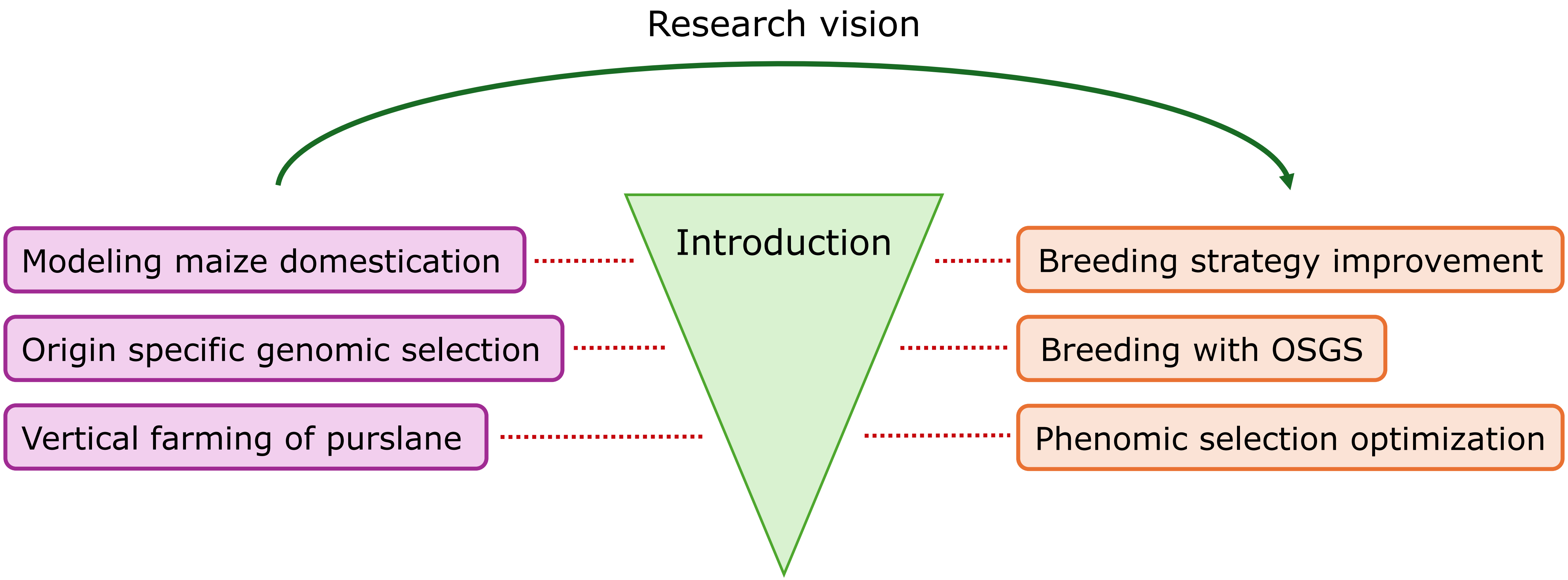
Talk outline



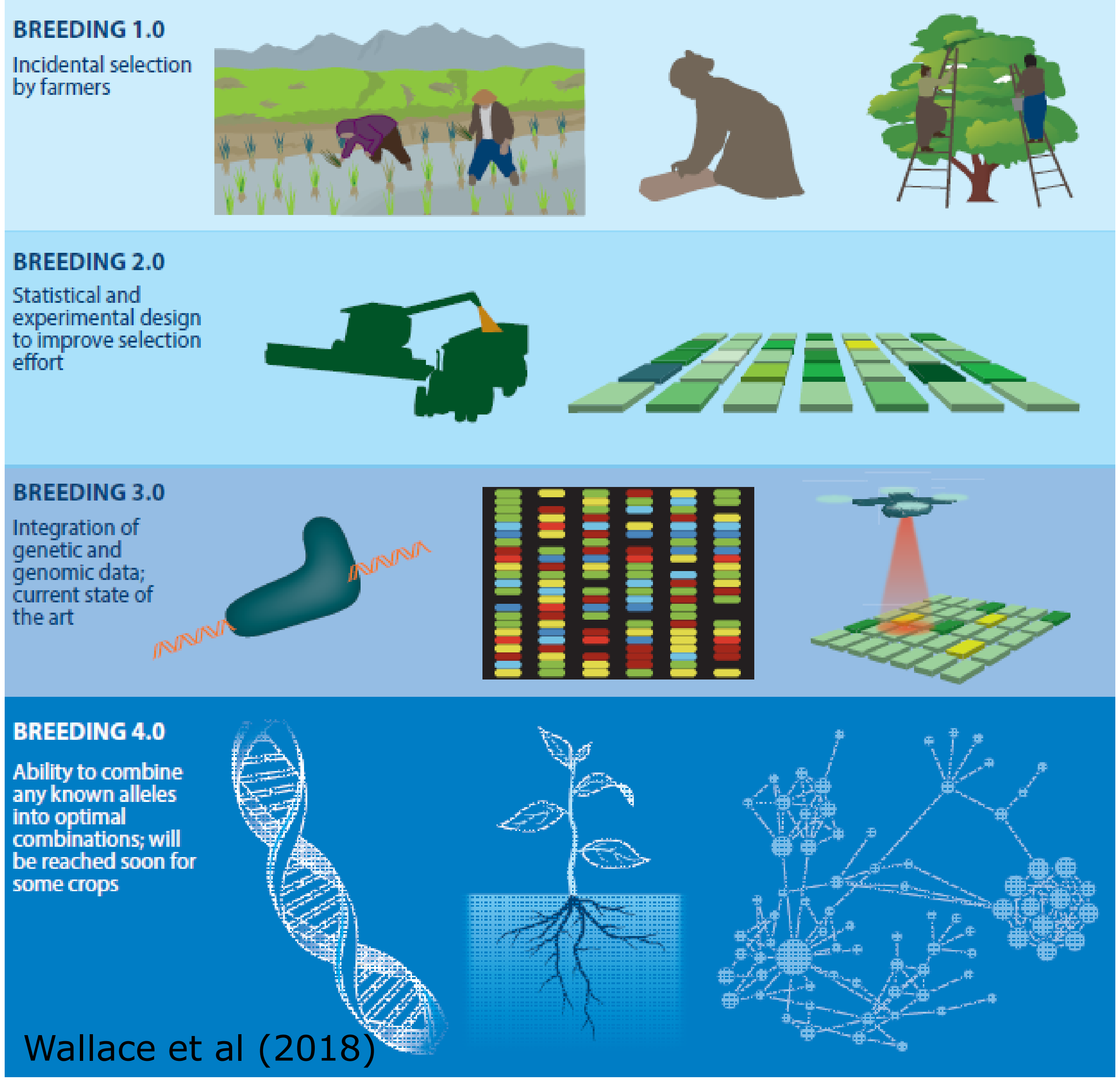
Talk outline



Talk outline



Introduction – Plant Breeding



Wallace et al (2018)

- Domestication
- Improvement

- Experimental design

- Marker assisted selection (MAS)
- Genomic selection (GS)
- Phenomic selection (PS)

- Biology-Breeding
- Functional variants
- Gene editing (GE)
- Machine learning (ML/AI)

Introduction – Genetic Gain

Breeder's equation (Lush 1937)

$$R = h^2 S$$

$$R = \frac{\sigma_g^2}{\sigma_p^2} \sigma_p i$$

$$R = \frac{\sigma_g}{\sigma_p} \sigma_g i$$

$$R = h \sigma_g i$$

Rate of genetic gain

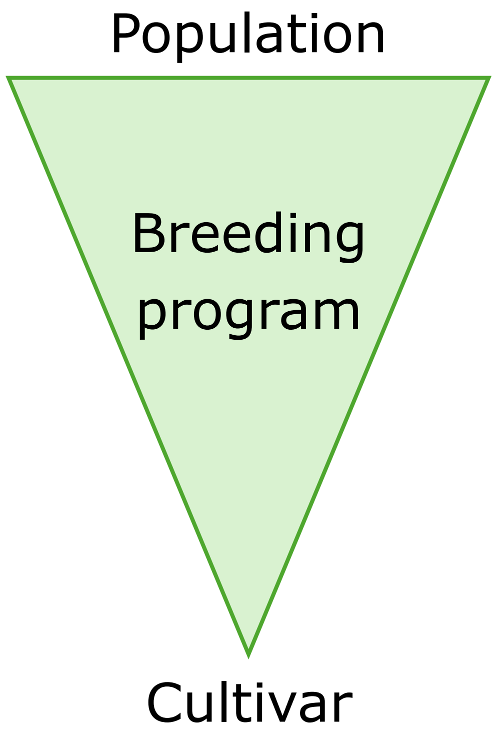
$$\Delta R = \frac{h \sigma_g i}{t}$$

$$\Delta R = \frac{sel.accuracy \times genetic\ variation \times sel.intensity}{time}$$

Framework for quantitative genetics

Introduction – Improving ΔR

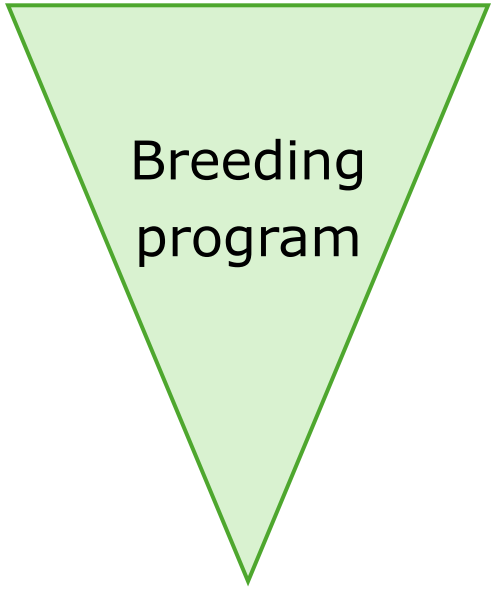
$$\Delta R = \frac{sel.accuracy \times genetic\ variation \times sel.intensity}{time}$$



Introduction – Improving ΔR

$$\Delta R = \frac{sel.accuracy \times genetic\ variation \times sel.intensity}{time}$$

Population



Cultivar

Multiparental population, mutation, pre-breeding.

MAS, GS, GE, phenomics, trials.

Larger trials, cheaper evaluation.

Rapid cycling, speed breeding (SB/RGA).

Introduction – Improving ΔR

$$\Delta R = \frac{sel.accuracy \times genetic\ variation \times sel.intensity}{time}$$

Population

Cultivar

Multiparental population, mutation, pre-breeding.

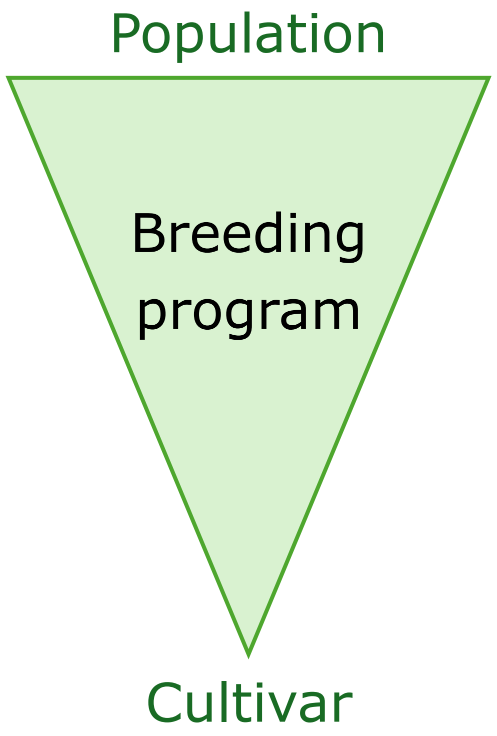
MAS, GS, GE, phenomics, trials.

Larger trials, cheaper evaluation.

Rapid cycling, speed breeding (SB/RGA).

Introduction – Improving ΔR

$$\Delta R = \frac{sel.accuracy \times genetic\ variation \times sel.intensity}{time}$$



Multiparental population, mutation, pre-breeding.

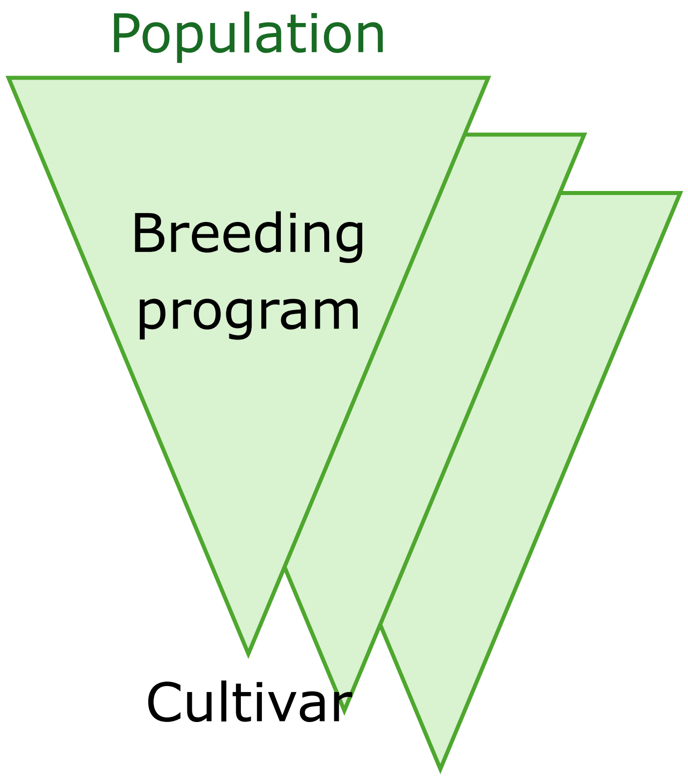
MAS, GS, GE, phenomics, trials.

Larger trials, cheaper evaluation.

Rapid cycling, speed breeding (SB/RGA).

Introduction – Improving ΔR

$$\Delta R = \frac{sel.accuracy \times genetic\ variation \times sel.intensity}{time}$$



Multiparental population, mutation, pre-breeding.

MAS, GS, GE, phenomics, trials.

Larger trials, cheaper evaluation.

Rapid cycling, speed breeding (SB/RGA).

Primitive Technology 101: Domestication

This earliest form of plant breeding is known as domestication, where plants were selected to be more productive, easier to harvest, or more aesthetically or gastronomically pleasing (Flint-Garcia 2013).

Primitive Technology 101: Domestication

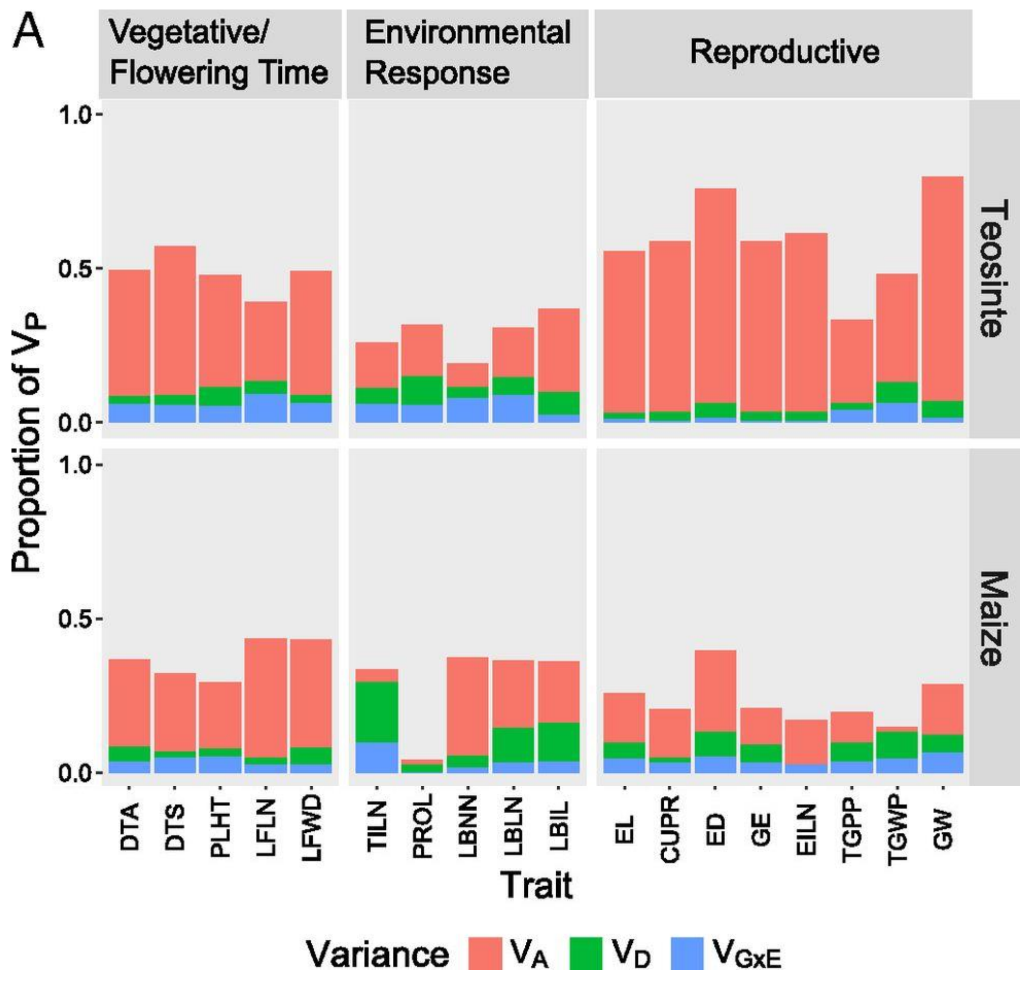
This earliest form of plant breeding is known as domestication, where plants were selected to be more productive, easier to harvest, or more aesthetically or gastronomically pleasing (Flint-Garcia 2013).

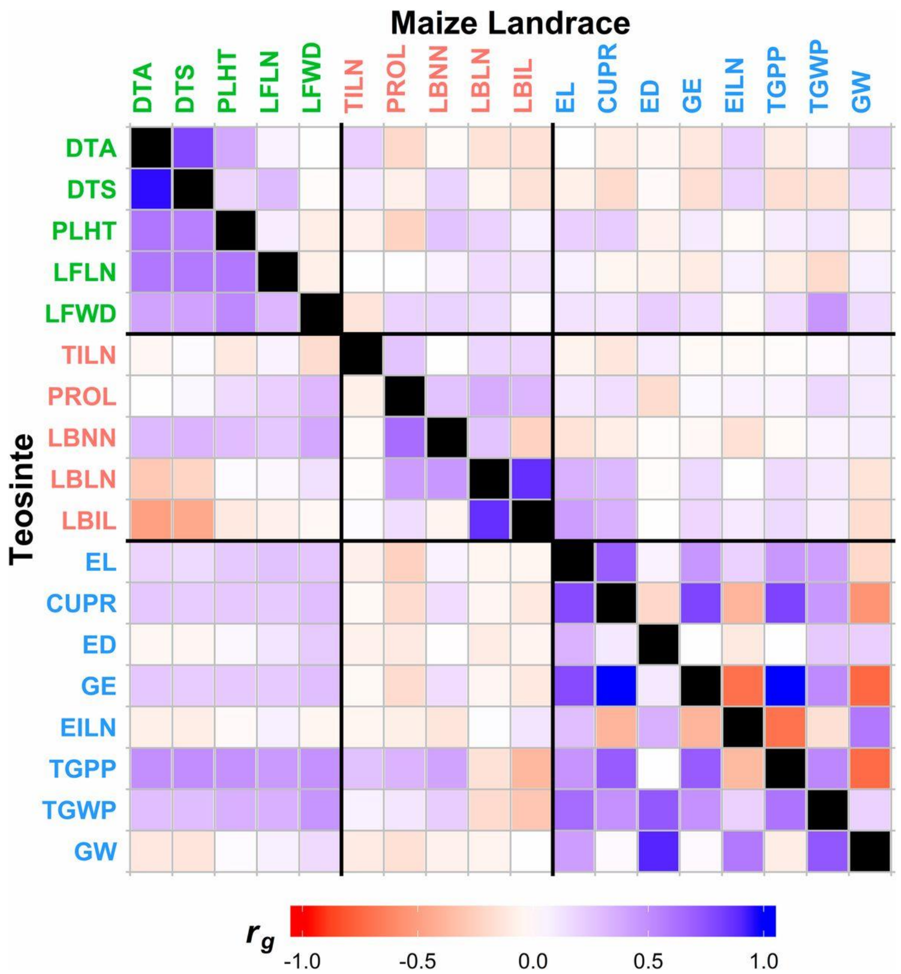
Teosinte (left) and maize (right) in Homestead, FL, 2013-2017.

Drawings from Doebley et al (1990)

Primitive Technology 101: Domestication

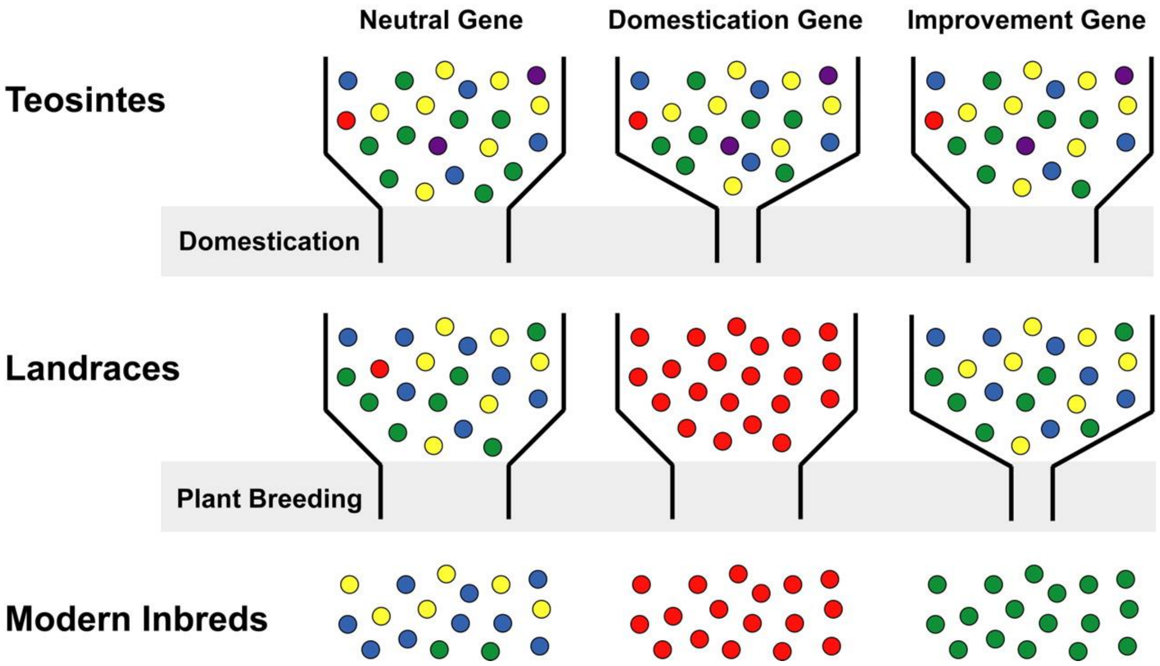
Domestication reduced the genetic variances and changed the genetic correlations.





Yang et al (2019), see also Chen et al (2020, 2021) and Samayoa et al (2021)

Shuffling genetic diversity



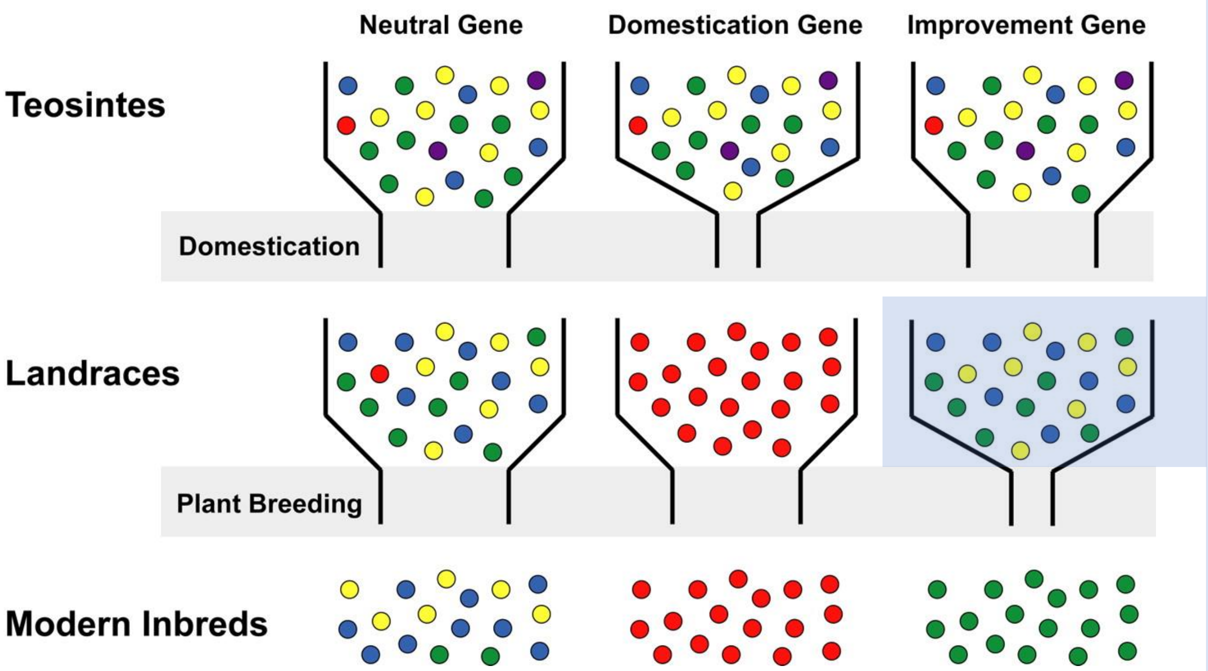
Yamasaki et al (2005)

Selection reduces genetic diversity.

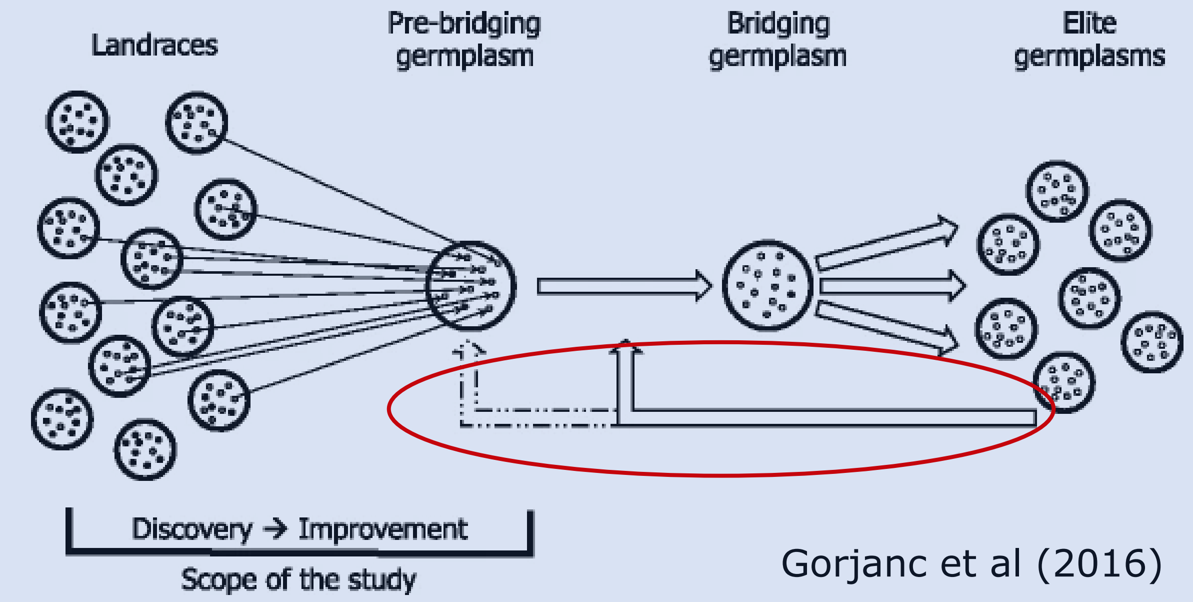
Rely on exotic sources (wild/landrace) for novel alleles, e.g. stress tolerance/resistance.

Linkage drag is a challenge.

Shuffling genetic diversity



Yamasaki et al (2005)



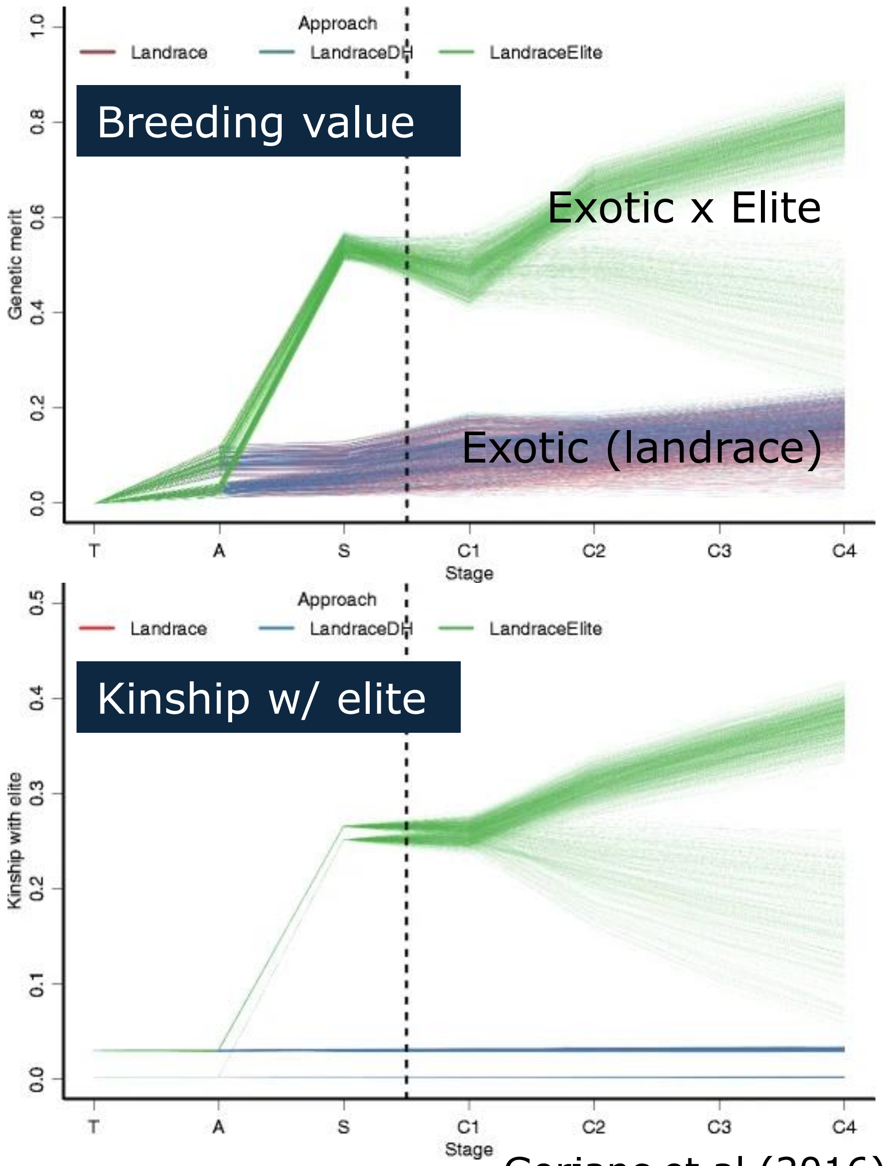
Gorjanc et al (2016)

Selection reduces genetic diversity.

Rely on exotic sources (wild/landrace) for novel alleles, e.g. stress tolerance/resistance.

Linkage drag is a challenge.

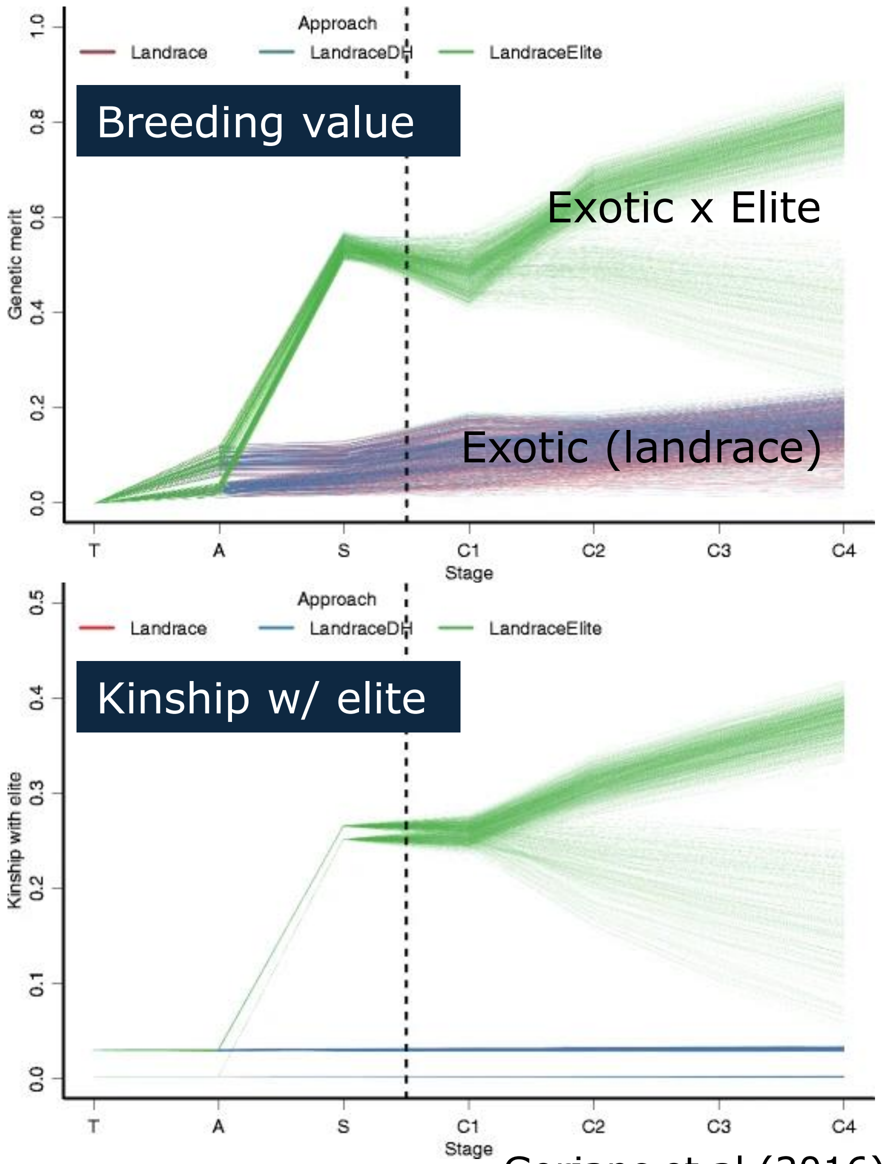
Selection bias



Gorjanc et al (2016)

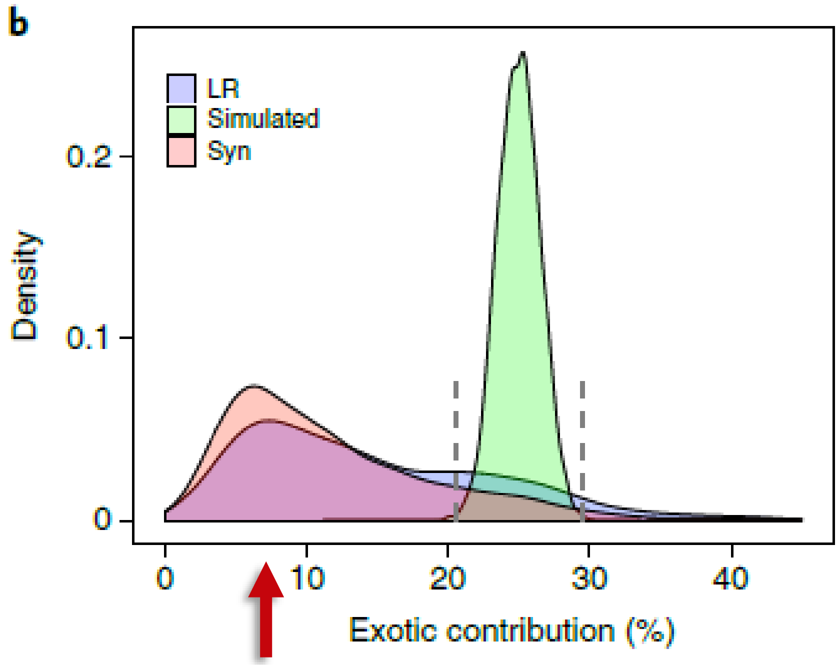
- Simulation study by Gorjanc et al (2016)
- Selection within exotic is slow.
- Selection within exotic x elite reconstitutes the elite genome.

Selection bias



Gorjanc et al (2016)

- Simulation study by Gorjanc et al (2016)
- Selection within exotic is slow.
- Selection within exotic x elite reconstitutes the elite genome.



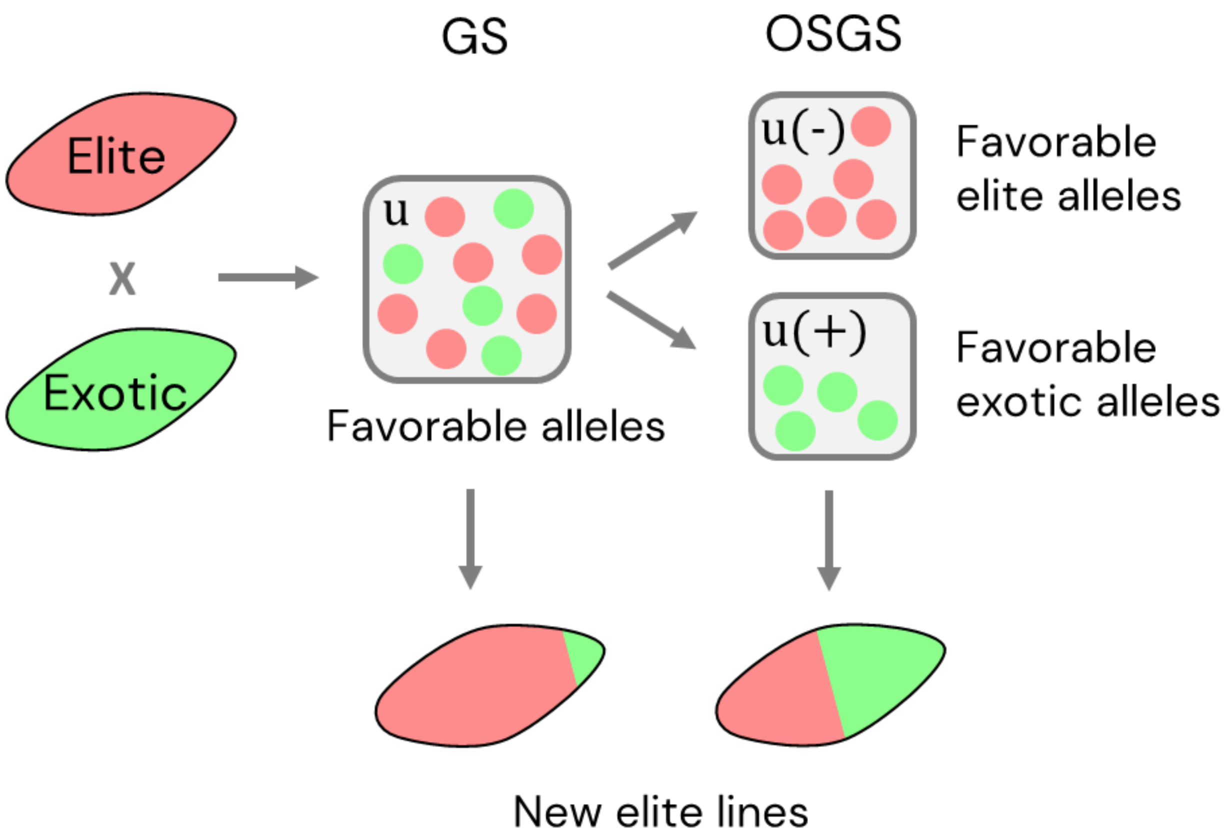
Validation of simulation outcomes in experimental data.

Singh et al (2021)

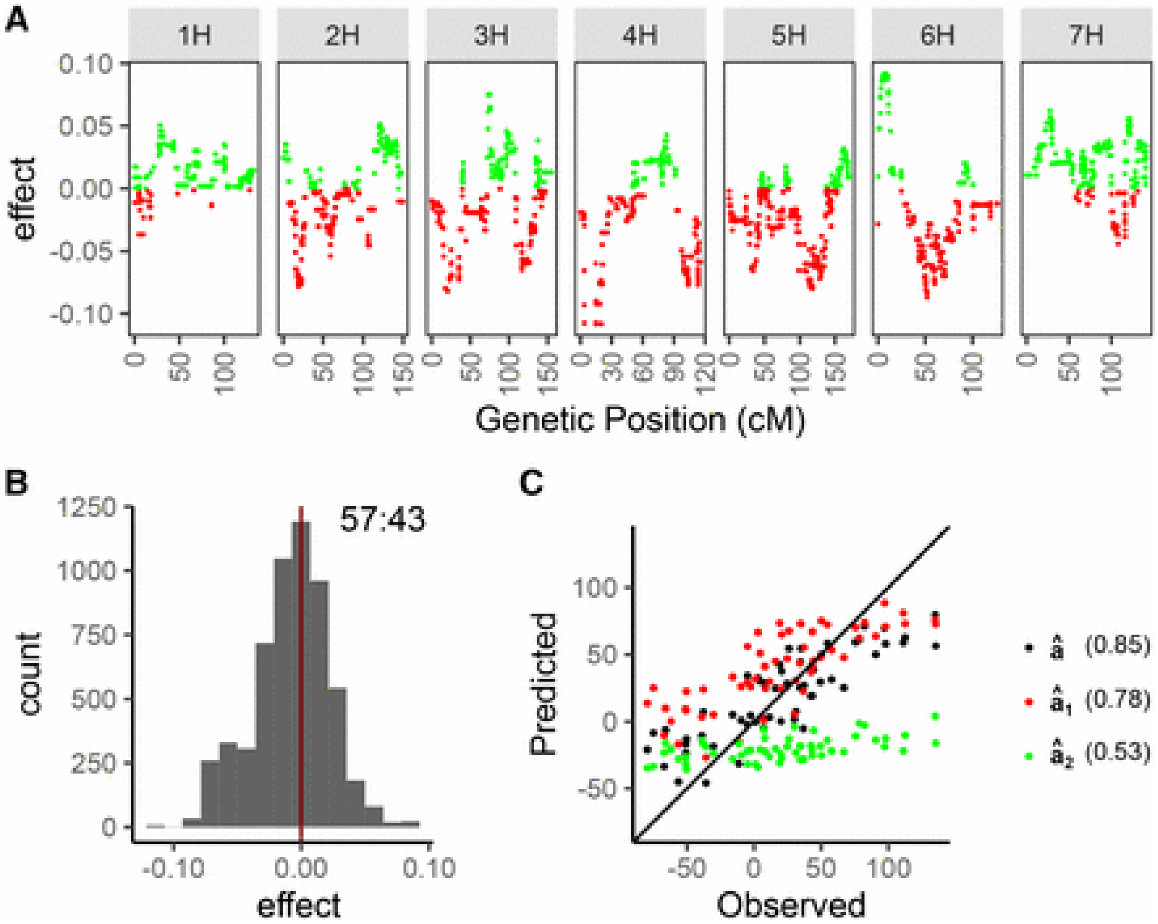
Origin Specific Genomic Selection (OSGS)

How do we improve selection in exotic x elite?

Can we target favorable exotic alleles?

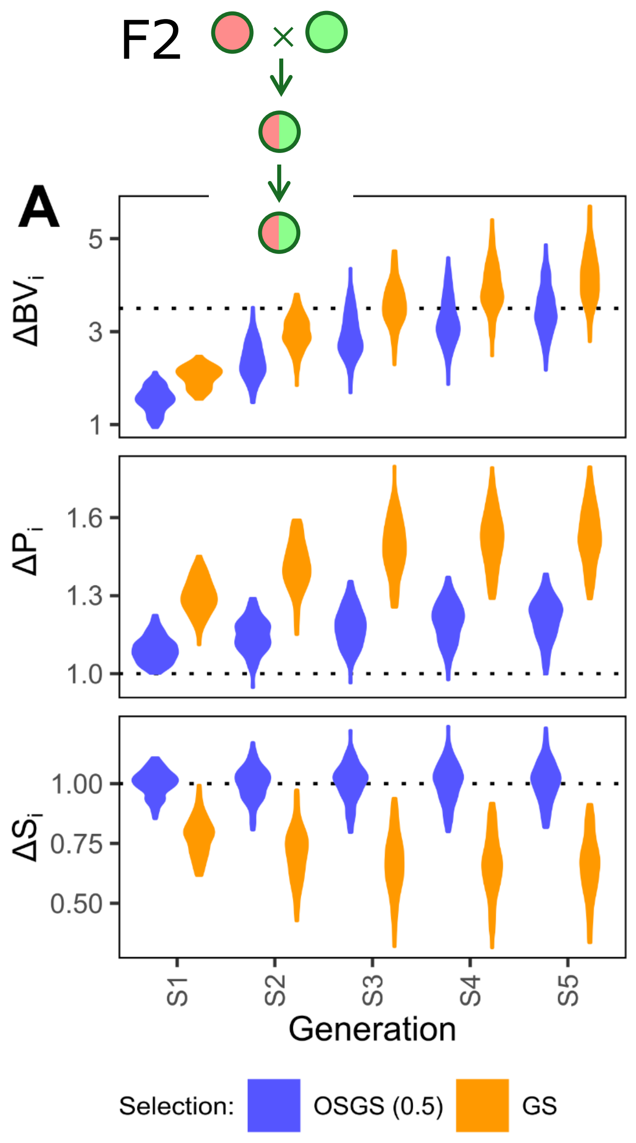


Yield in a barley NAM family (BC1)



Yang et al (2020)

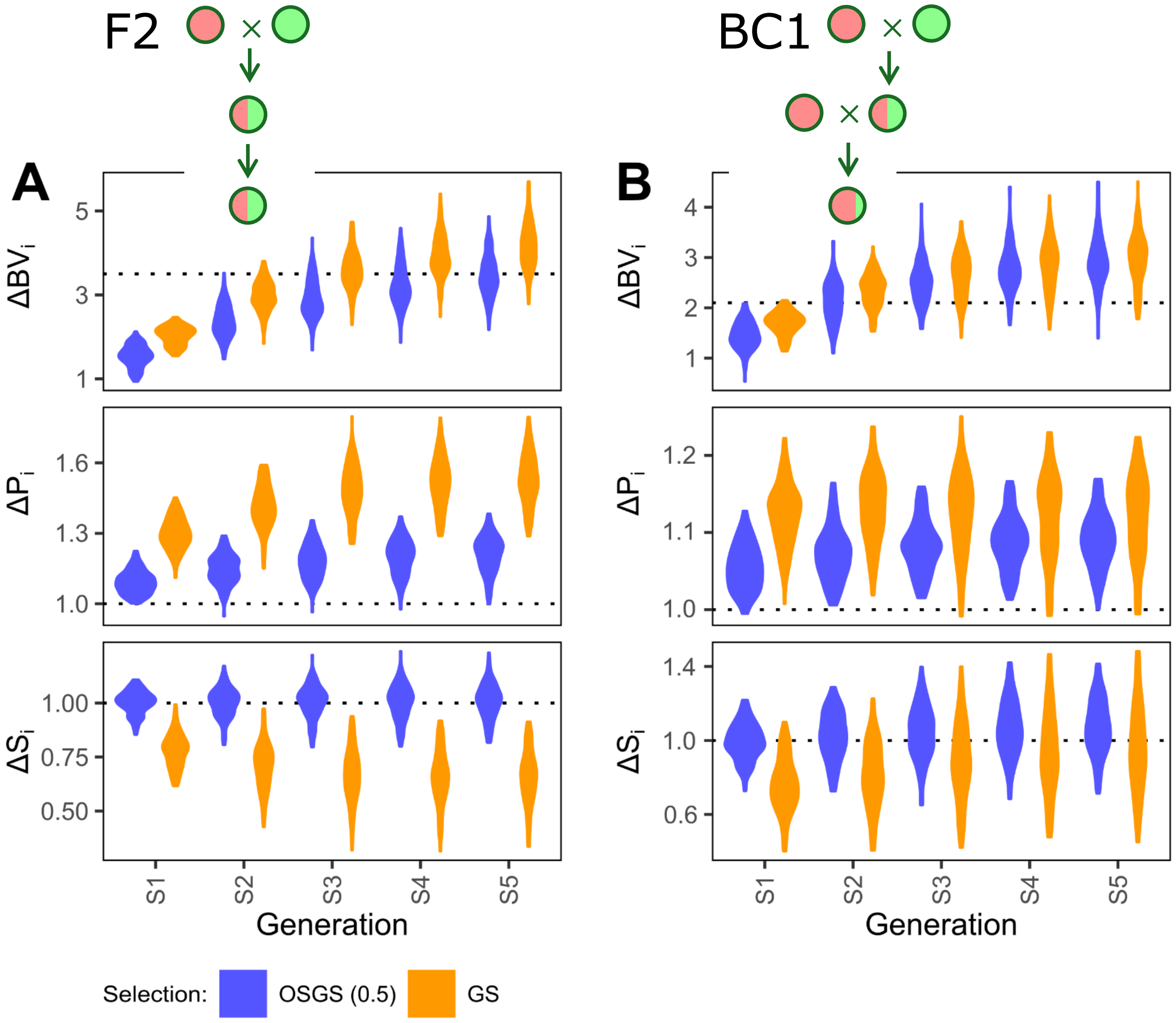
Origin Specific Genomic Selection (OSGS)



- Simulation with 60:40 split in favorable alleles between the elite and exotic parents.
- OSGS prevents selection on the favorable alleles from the elite parent.

Yang et al (2020)

Origin Specific Genomic Selection (OSGS)



- Simulation with 60:40 split in favorable alleles between the elite and exotic parents.
- OSGS prevents selection on the favorable alleles from the elite parent.
- The advantage of OSGS diminishes in BC population.

Yang et al (2020)

Vertical farming of purslane

Green purslane

Golden purslane

- Rich in Omega-3.
- Novel crop in the UK.
- Not adapted to the UK climate.

Purslane cultivation

Growing media

Short vs long day

Fluorescent light

LED

- Evaluate and optimize growing conditions (recipes).
- Green = 4 weeks, golden = 3 weeks.

Extension activities with purslane

PROMOTING
PURSLANE
AS A NEW FOOD CROP

INTRODUCE AN EXCITING, NEW AND NUTRITIOUS CROP TO YOUR KITCHEN... PURSLANE *(PORTULACA OLERACEA)*.

First cultivated more than 4,000 years ago and used in Ancient Egypt as a medicinal plant, purslane has sadly been largely forgotten as a food crop, at least in the UK. This is despite John Gerard writing in the 16th Century '**Rawe purslane is much used in salads with oile, salt and vinegar**' and John Eveleyn in 1699, in the first salad cookbook, giving recipes for '**purslane pickle**'.

Today this leafy vegetable is a high-value ingredient, and a traditional component of the renowned Mediterranean diet with all its associated health benefits. Richer than other salad and green vegetable crops in a wide range of nutrients, including **vitamins**, **carotenoids**, **polyphenols** and **omega-3 fatty acids**, it has been described as a **"power food"**, a **"functional food"** and as a **"superfood without a marketing team"**.

Often wild foraged in Mediterranean countries, purslane can't be grown outside in the UK but can be under glass or in other protected environments. Purslane's succulence, taste and nutritional characteristics make it perfectly suited as a ready-to-eat product in either full leaf or microgreen form. It has a juicy, crunchy texture and a slightly salty and acidic taste, similar to watercress or spinach. Its most frequent use is raw, in salads.

However, other uses and recipes include sautéed; stir-fried; soups *(purslane can function as a thickening agent)*; grilled; added to pesto; or in a yogurt dip.

Scotland's Rural College (SRUC) | www.sruc.ac.uk
Supports the generation of safe, sustainable and new food chains that deliver healthy diets.

If you would like further information or samples of purslane to try, please contact us. We would welcome your feedback on this exciting new crop.

To discuss further, please contact **Ian Dawson** at **Ian.Dawson@sruc.ac.uk**

ORCHARD INNOVATION

SRUC

- Royal Highland Show (state fair).
- Taste test, survey, flyer, talk, demonstration.
- Other work: PhD student, nutritional profiling, variety registration, market development.

Research vision

Basic science

- Breeding program design
- Innovative strategy
- Technology evaluation
- Method development

Applied science

- Small grains breeding
- Cultivar delivery
- SunGrains
- Population development

Research vision

Basic science

- Breeding program design
- Innovative strategy
- Technology evaluation
- Method development

Applied science

- Small grains breeding
- Cultivar delivery
- SunGrains
- Population development

Research: lab, field, greenhouse, statistics, simulation, programming

Funding: federal, state, industry, commodity board

Collaboration: projects, grants, interdisciplinary

Dissemination: publications, talks, posters, websites, social media, outreach

Engagement: stakeholders, seed industries, growers, consumers

Research vision

Basic science

- Breeding program design
- Innovative strategy
- Technology evaluation
- Method development

Applied science

- Small grains breeding
- Cultivar delivery
- SunGrains
- Population development

Research: lab, field, greenhouse, statistics, simulation, programming

Funding: federal, state, industry, commodity board

Collaboration: projects, grants, interdisciplinary

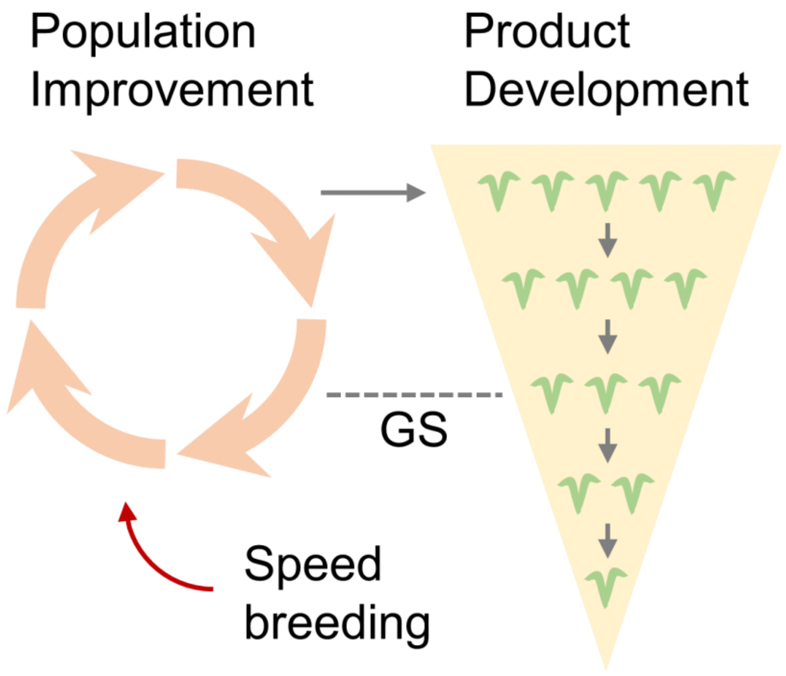
Training: capacity building, independence

Dissemination: publications, talks, posters, websites, social media, outreach

Engagement: stakeholders, seed industries, growers, consumers

Breeding strategy

How can we improve breeding strategy to deliver higher rate of genetic gain?



An example with 2-part strategy (Gaynor et al 2017)

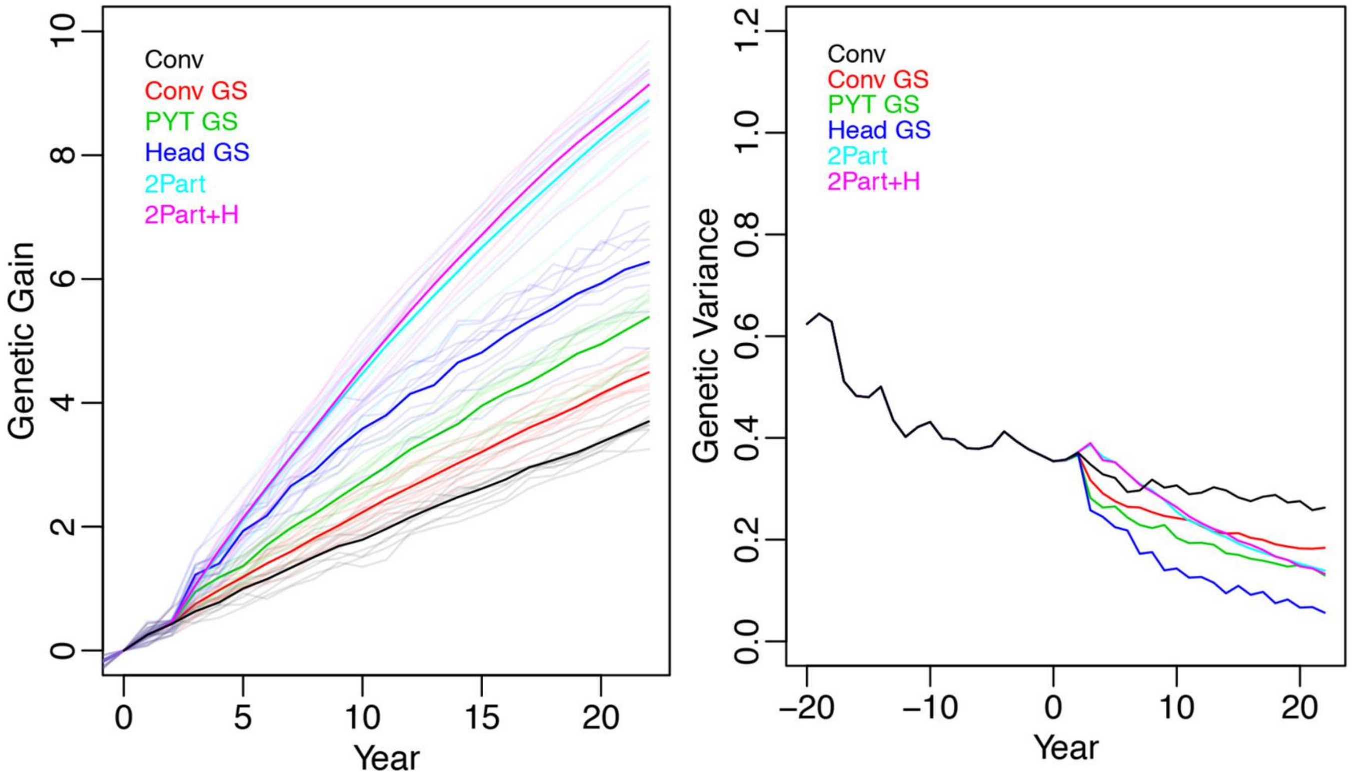
- Isolate breeding program into PI and PD.
- Allows us take advantage of GS and SB.

Questions to follow:

- Trade-off between speed and genetic diversity?
- Trade-off between speed and prediction accuracy?
- Compatibility with crop types?
- How does it work for different traits?
- Is there indirect selection (SSD/SB, epigenetics)?
- Any uptake in real-world breeding?

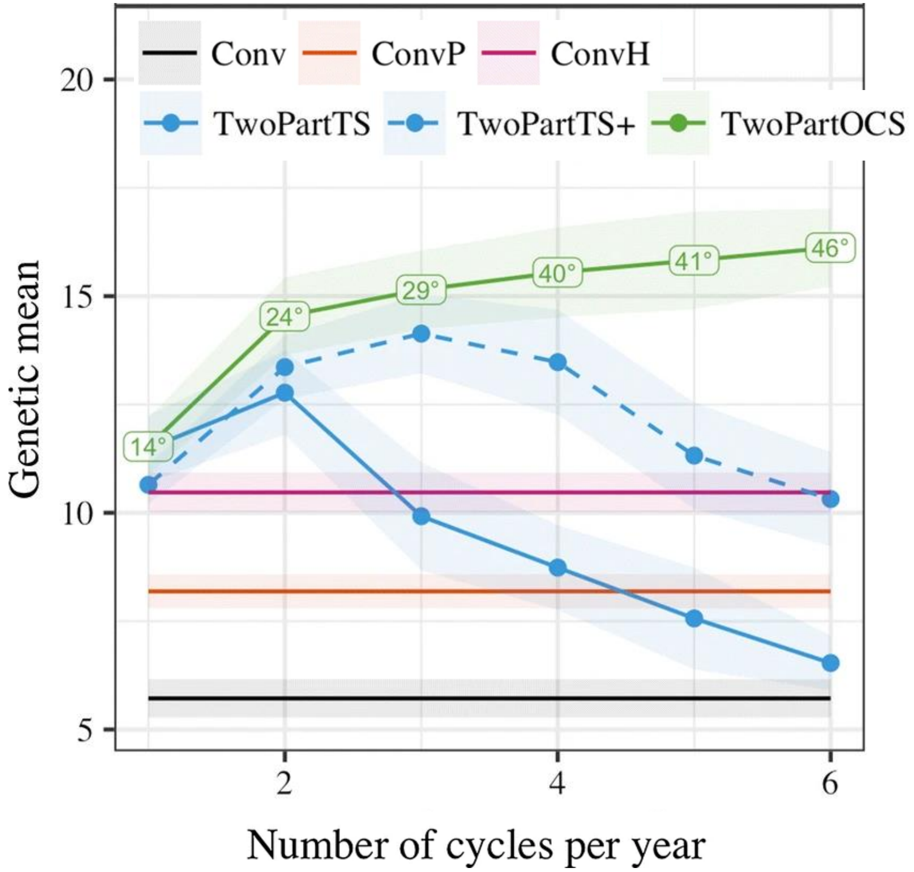
2P: speed vs genetic diversity

Higher genetic gain in 2P at a cost of depleting genetic variance.



Gaynor et al (2017)

Optimal Contribution Selection (OCS) to sustain the genetic gain.



Gorjanc et al (2018)

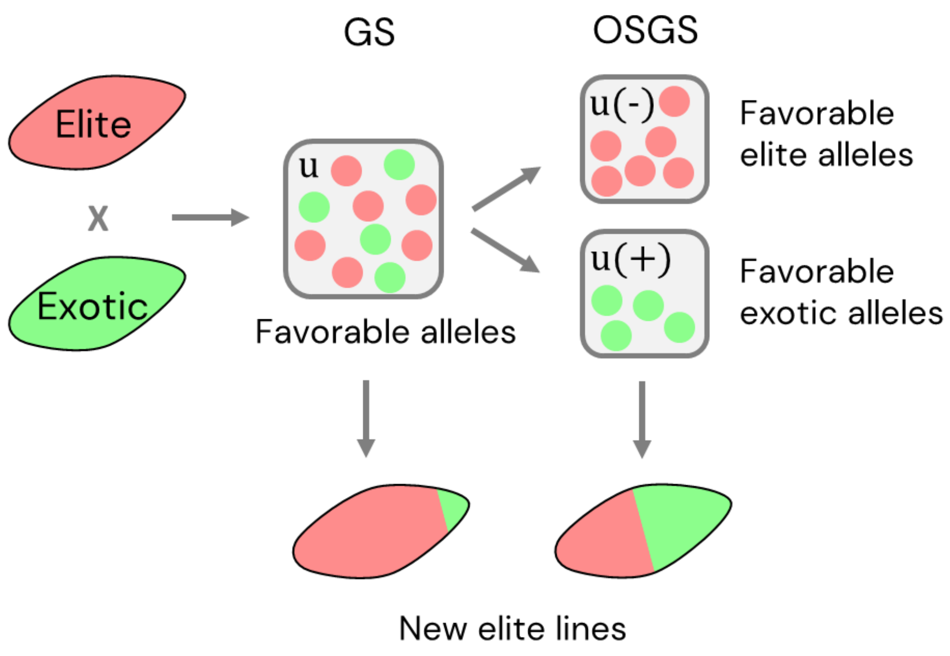
OSGS in cultivar development

In general,

Polygenic traits = Genomic Selection (GS)

Oligogenic traits = Marker Assisted Selection (MAS)

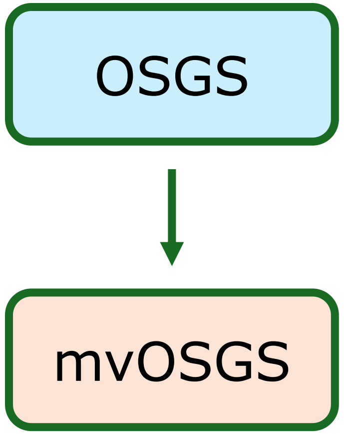
Recall from earlier slides…



- Introgression of polygenic traits.
- E.g. tolerance to abiotic stresses (drought, heat, salinity).
- Important traits for climate change.

Improvement to OSGS

Currently, OSGS has only been shown in single trait in bi-parental populations.

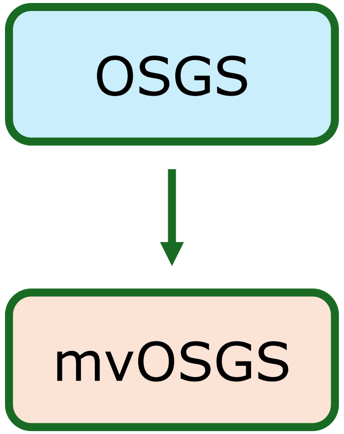


Traits: multi-trait mixed model

Parents: parental probability or haplotype approach

Improvement to OSGS

Currently, OSGS has only been shown in single trait in bi-parental populations.

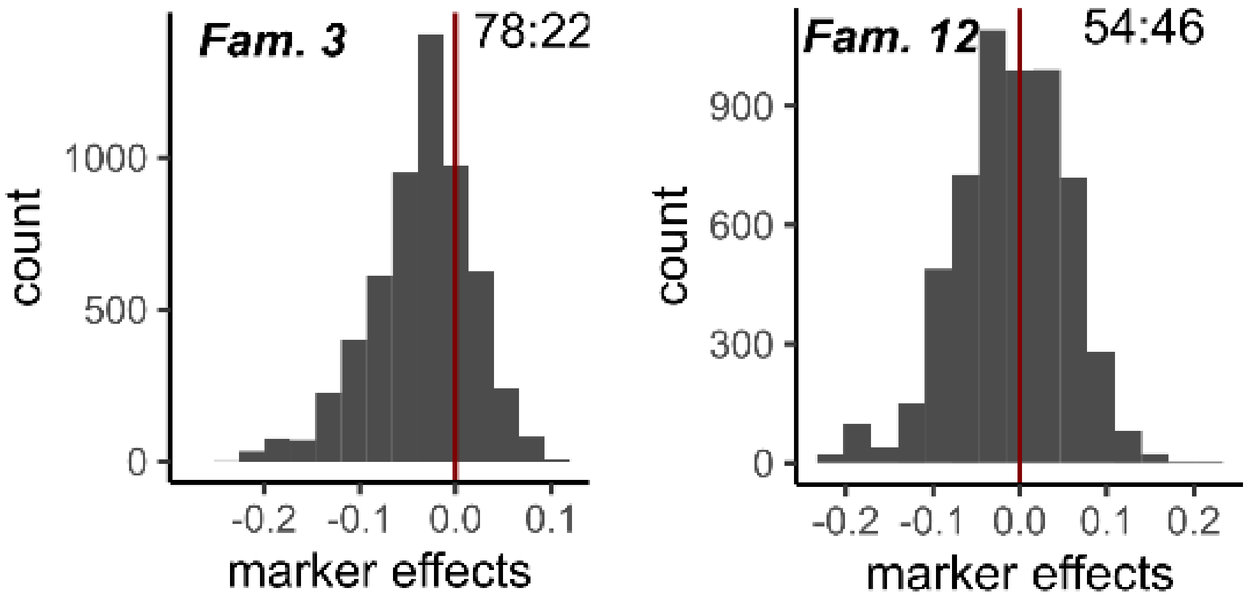


Traits: multi-trait mixed model

Parents: parental probability or haplotype approach

The SNP-BLUP model is $y = X\beta + Wu + \varepsilon$.

And we assume $u \sim N(0, I\sigma_u^2)$.



Yang et al (2020)

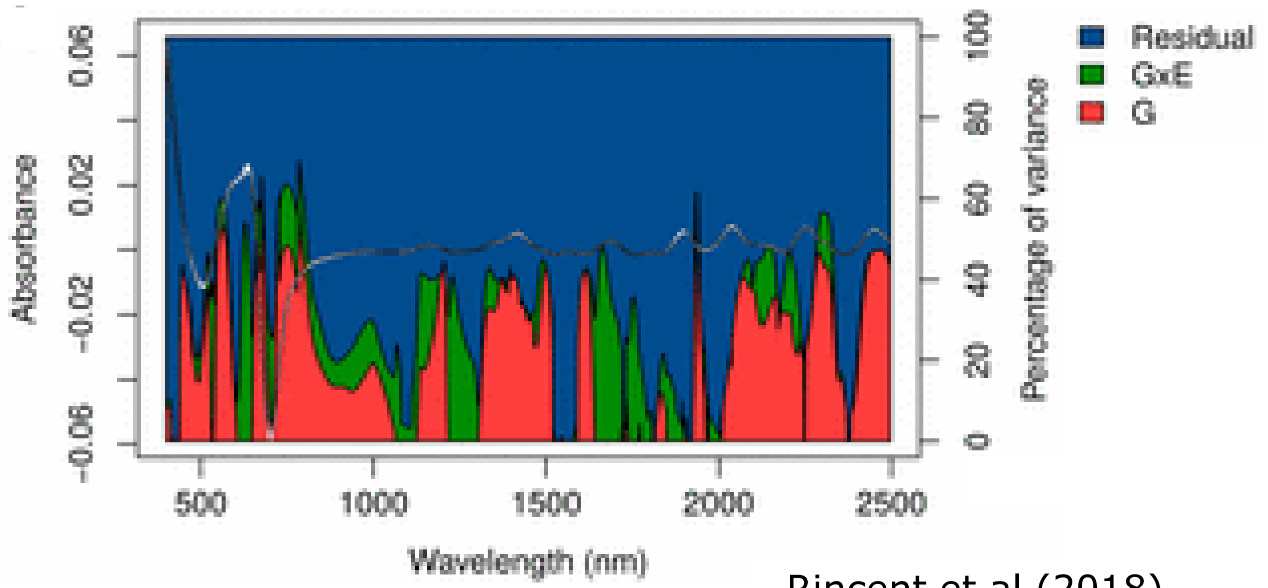
- Does the normality assumption still hold when the two parents are vastly different?
- Is there any bias introduced by the model?

Phenomic selection

The following is a conventional mixed model for genomic BLUP (gBLUP).

$$y = X\beta + Zg + \varepsilon \qquad g \sim N(0, K\sigma_g^2) \qquad K = MM'$$

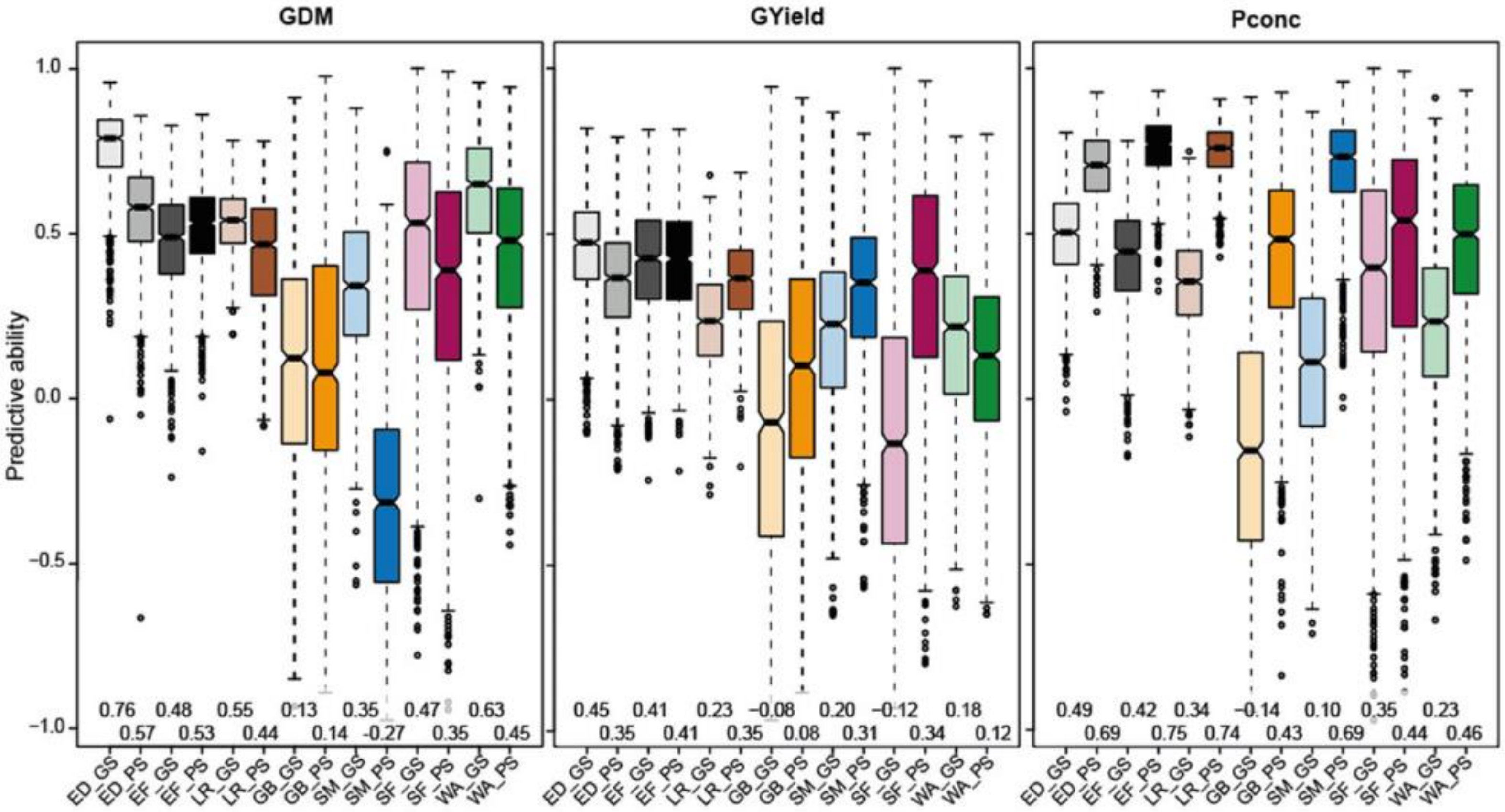
In phenomic selection, the genomic markers (M) are replaced by phenome.



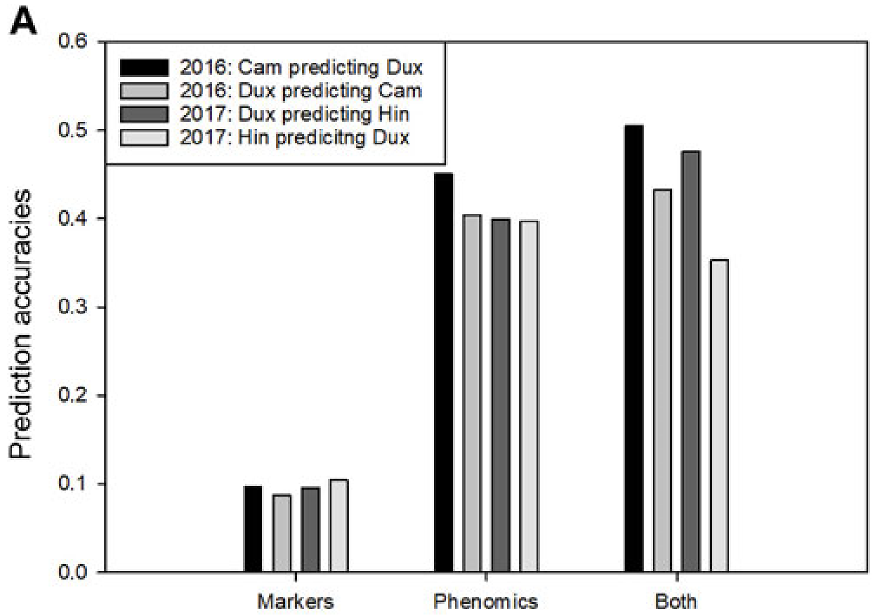
Rincent et al (2018)

- Phenome can be near-infrared spectra (NIRS), image data, etc.
- Part of the phenome is heritable.
- Phenome is cheap(?).
- Phenome captures G x E x M.

Current states of phenomic selection



Weiss et al (2022)



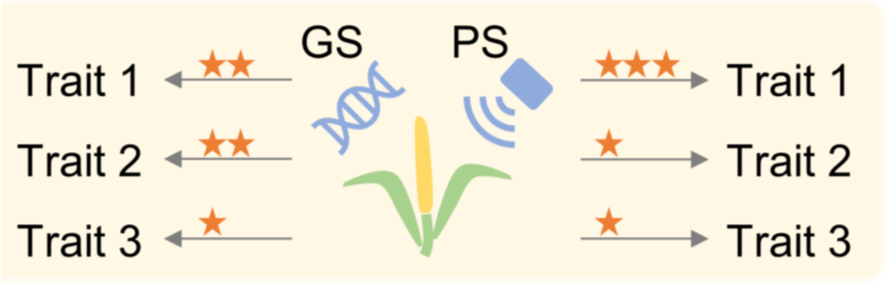
Jackson et al (2023)

- ~40 biparental families in wheat.
- GS ignores family effect.

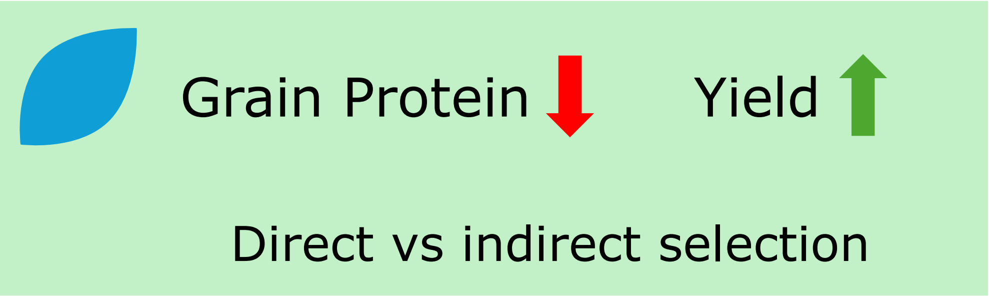
- Maize lines (elite, landrace populations).
- PS vs GS depends on populations and traits.

Opportunities in phenomic selection

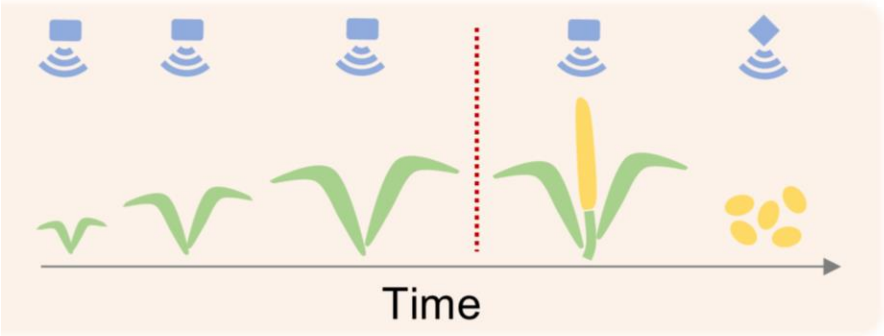
Compare GS and PS for different traits.



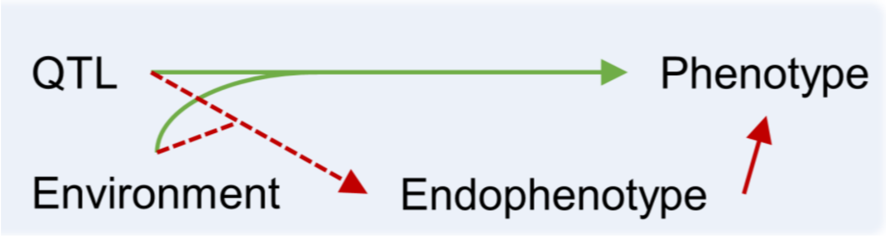
Predictions from PS are biased toward information within the predictors, Dallinger et al (2023).



Evaluate PS across developmental time points.



Simulation is an important part of GS, how can we do that for PS?



Summary

Quantitative genetics, plant breeding

Past

- Domestication
- OSGS
- DUS
- QTL fine-mapping
- MAGIC
- RALLY

Present

- Purslane
- Heterosis
- RL system
- GEM in CE
- Mutation GS

Future

- Breeding strategy
- OSGS in breeding
- Phenomic selection
- ???

Acknowledgement

Many thanks to the Search Committee, Department of Crop and Soil Sciences, NCSU
for the opportunity to present the talk!

Wisc + Others
John Doebley
Ali York
Qiuyue Chen
Wei Xue
Natalia de Leon
Claudia Calderón
Jim Holland
L Fernando Samayoa
Ed Buckler
M Cinta Romay
Peter Bradbury
Many more…

SRUC
Ian Mackay
Wayne Powell
Rajiv Sharma
Nicola Rossi
Emma Irving
David Marshall

OSGS
Gregor Gorjanc
Sarah Hearne

MAGIC
Rodney Edmondson
Hans-Peter Piepho

DUS
Joanne Russell
Luke Ramsay
Bill Thomas

RALLY
Funmi Ladejobi
Richard Mott

RL
Scottish Society for Crop Research

Computing
UK Crop Diversity

https://cjyang-work.github.io/
XXX
@hataraku_cj
cjyang90

Quantitative Genetics

and

Small Grains Breeding

CJ Yang

Aug 3, 2023

Self introduction

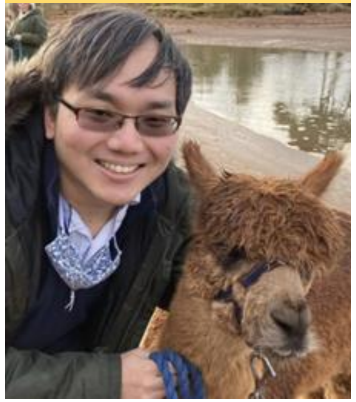
Wisconsin
2012-2018
PhD Genetics

Indiana
2009-2012
BSc Biotech, Math

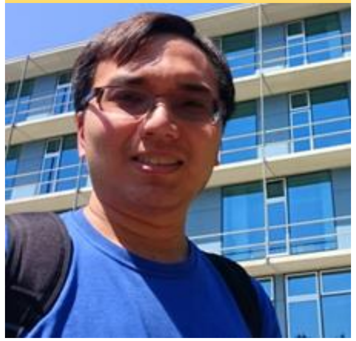
Map from R/maps

Malaysia
1990-2009

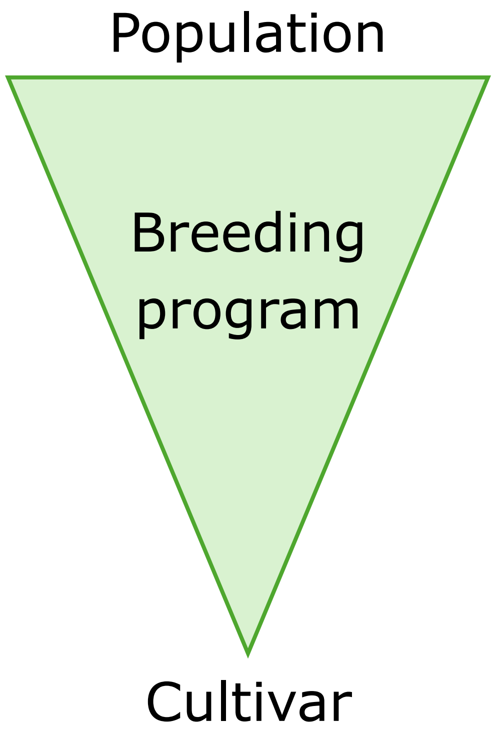
Edinburgh
2019-now
Postdoc



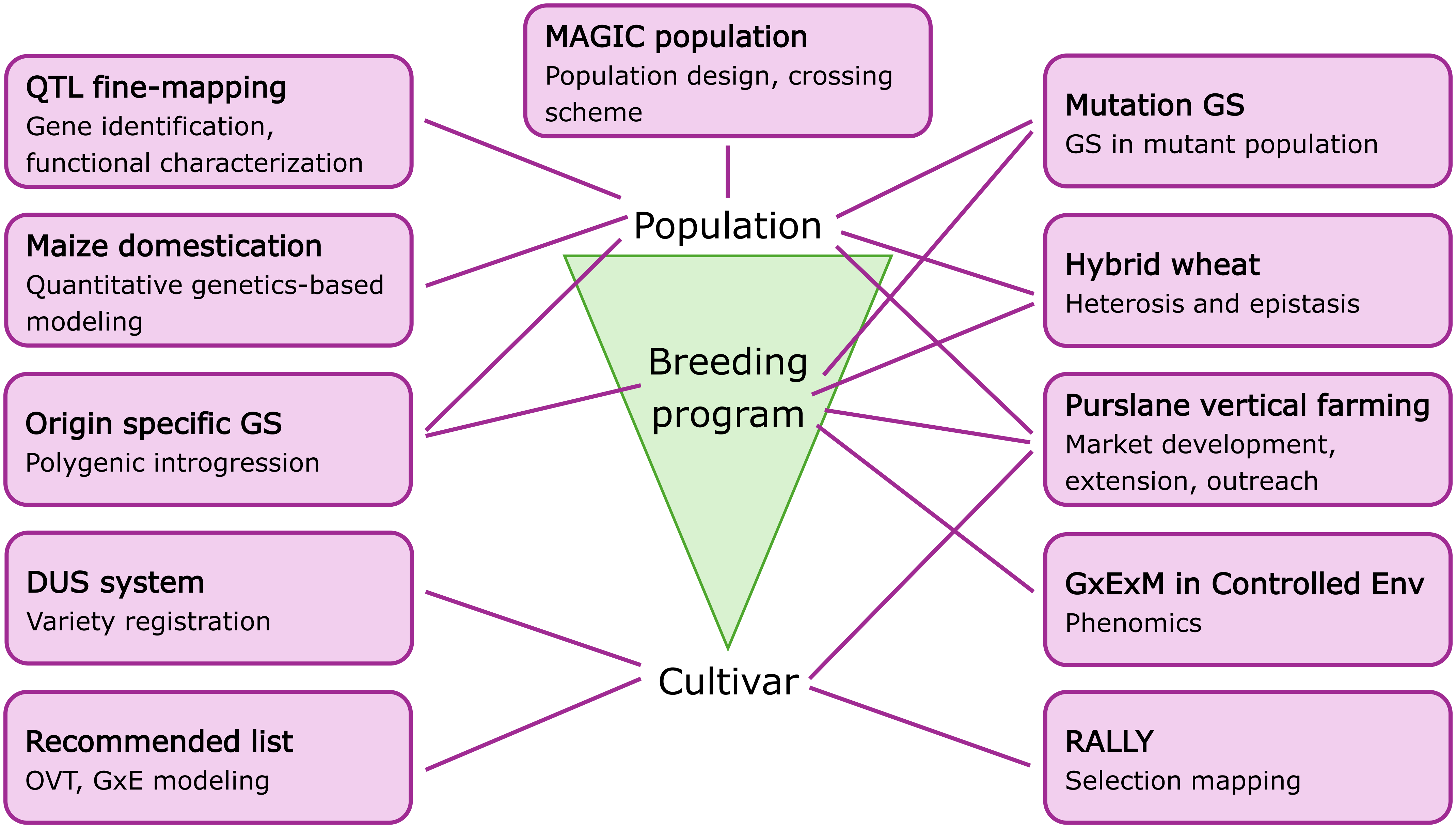
Freising
2018-2019
Postdoc



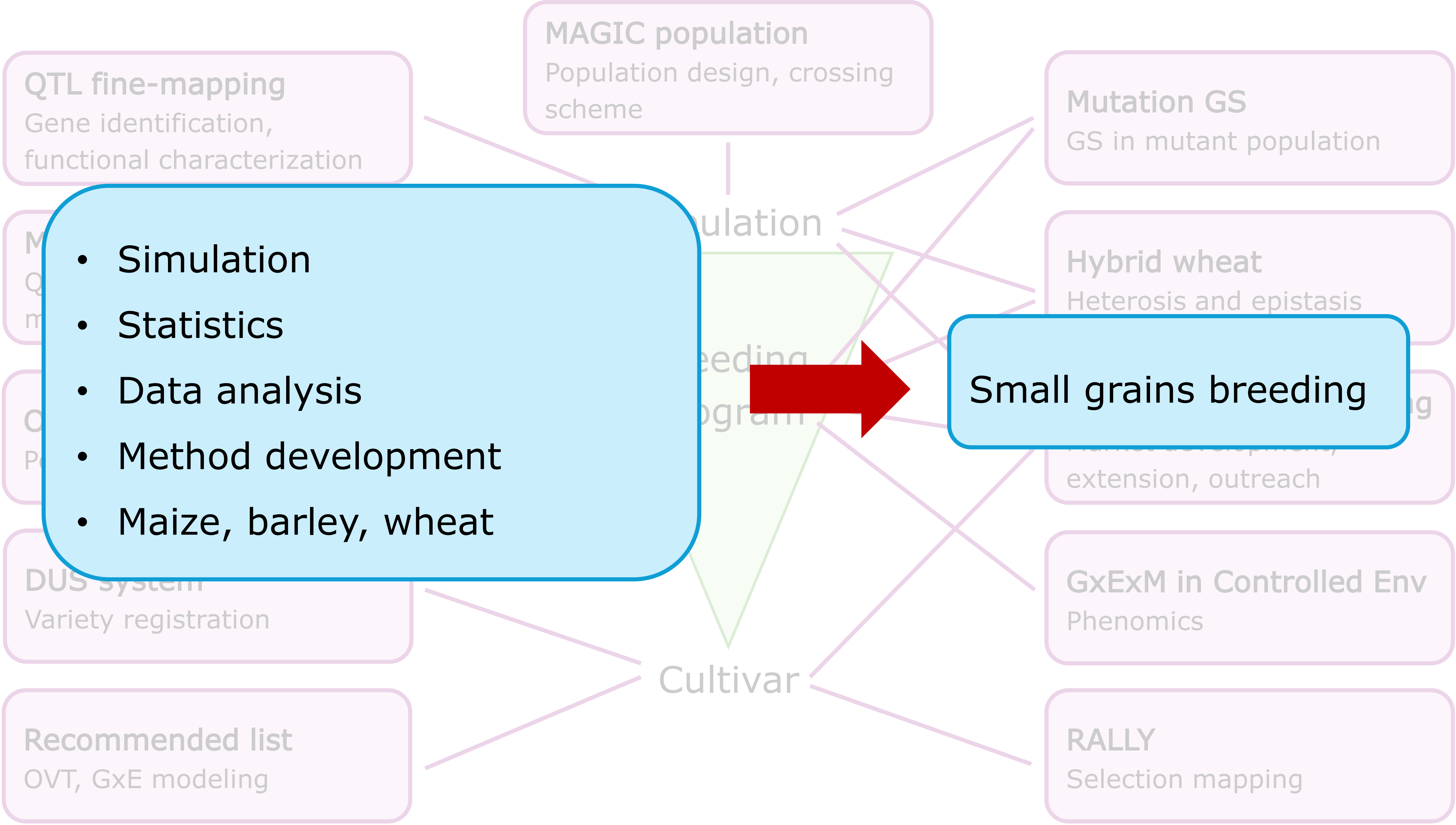
Research background



Research background



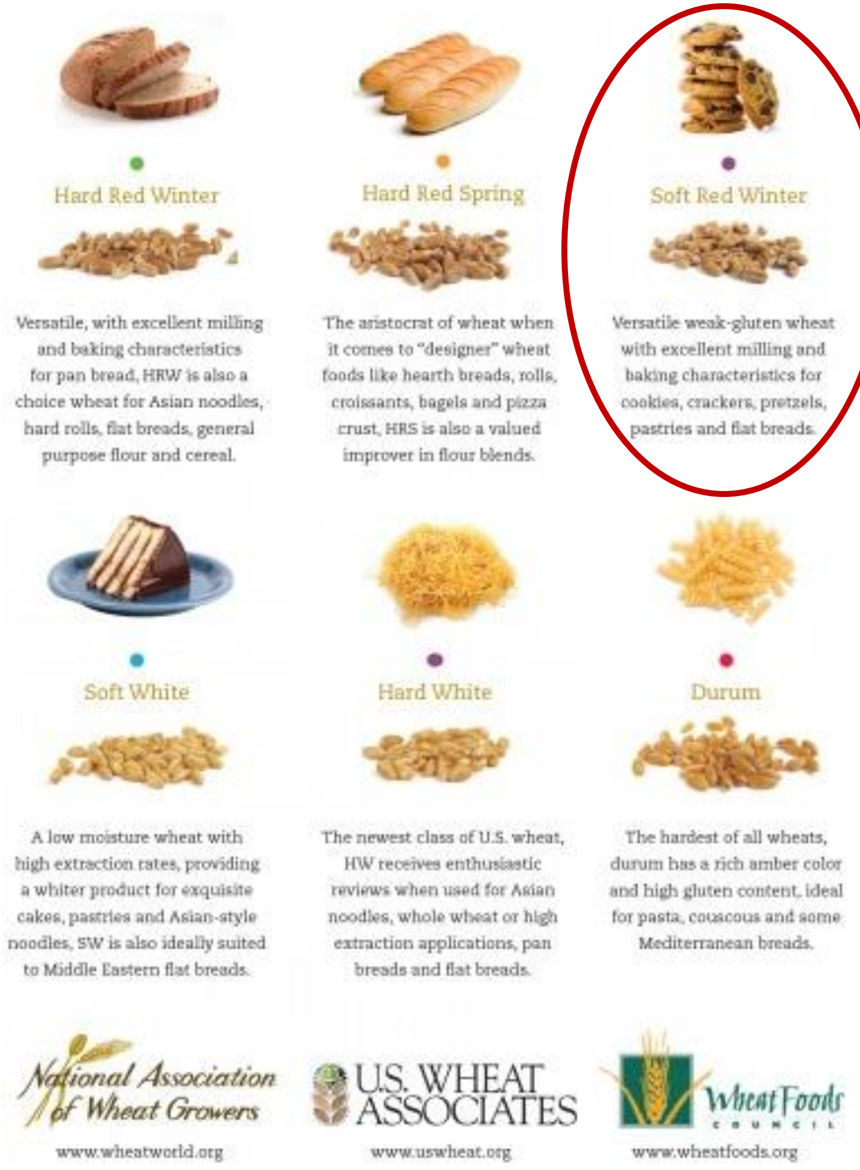
Research background



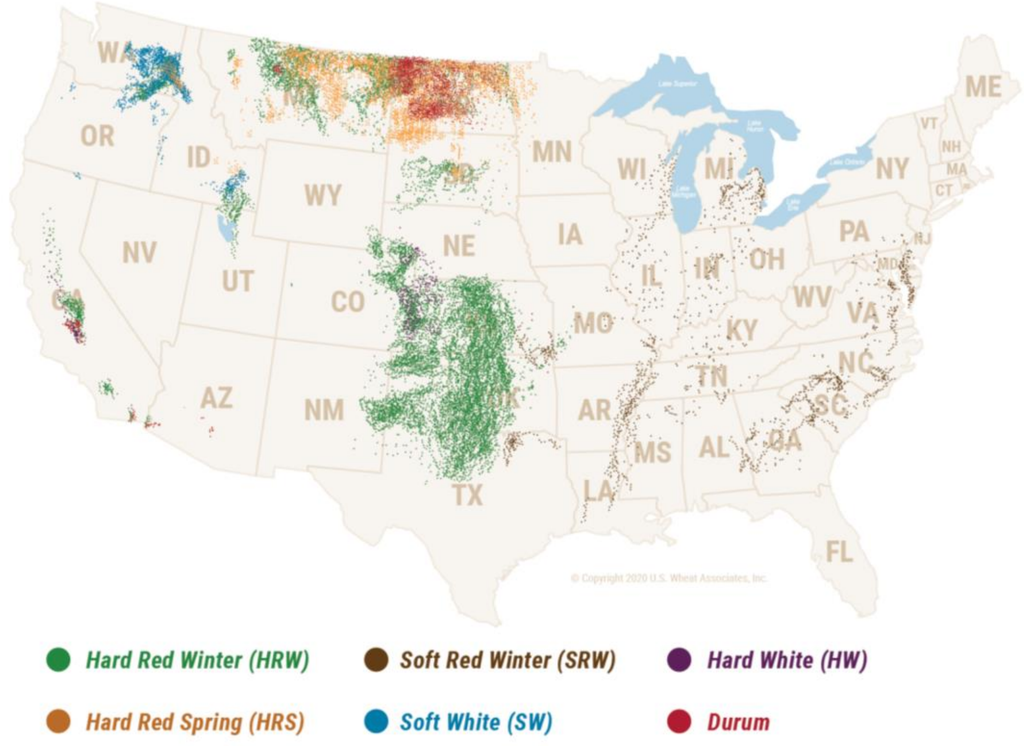
Background – Small Grains Breeding

- Small grains: wheat, barley, oats, rye, triticale, etc.
- 6% of NC total crop production value in 2022 (USDA NASS).
- Winter wheat ranked fifth with a production value of $202 millions.
- Primary use: flour.
- Other uses: feed, malt, cover crop.
- Availability of crop insurance?
- Line breeding, GS, hybrid?
- SunGrains (NC, AR, FL, GA, LA, SC, TX): cooperative breeding, royalty.

Soft red winter wheat



https://kswheat.com/news/which-wheat-for-what



https://www.uswheat.org/working-with-buyers/wheat-classes/

- Low protein content (8.5-10.5%)
- Flour for cake, pastry, dessert, etc.

Research and breeding vision

Basic science

- Breeding program design
- Innovative strategy
- Technology evaluation
- Method development

Applied science

- Small grains breeding
- Cultivar delivery
- SunGrains
- Population development

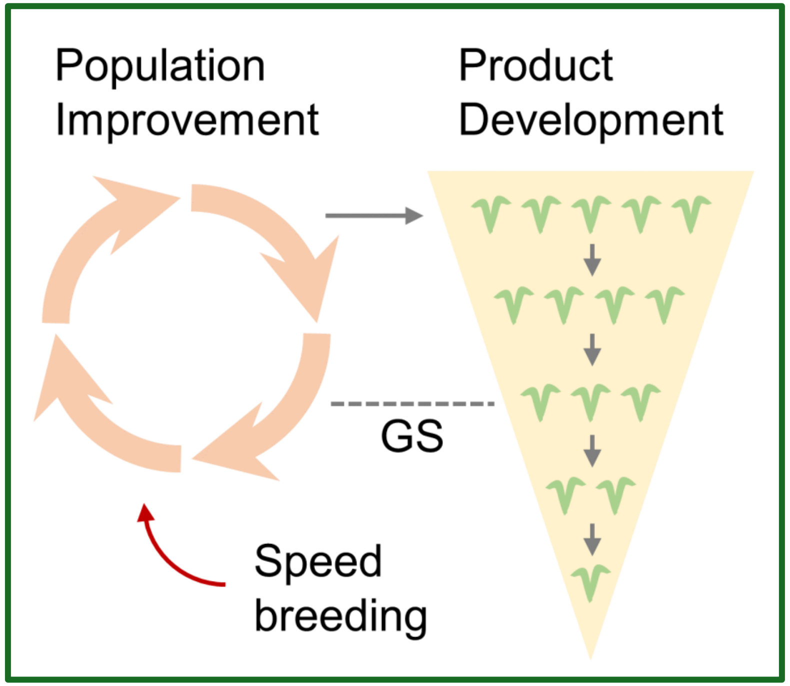
Research and breeding vision

Basic science
- Breeding program design
- Innovative strategy
- Technology evaluation
- Method development

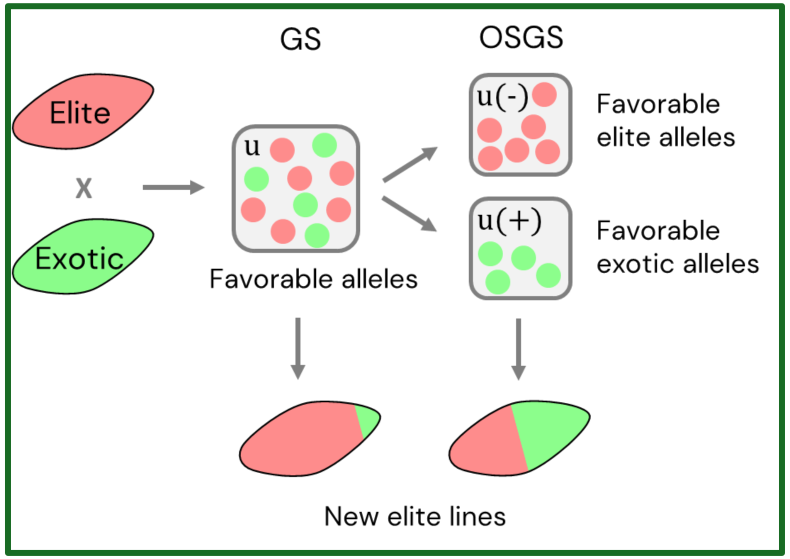
Applied science
- Small grains breeding
- Cultivar delivery
- SunGrains
- Population development

- Link between basic and applied science – test and apply innovations.
- Incorporate end users' interest into breeding.
- Create new markets.
- Maintain/develop healthy relationship with industry/public breeders, growers.
- Train future breeders.
- Learn the process and ensure continuity.

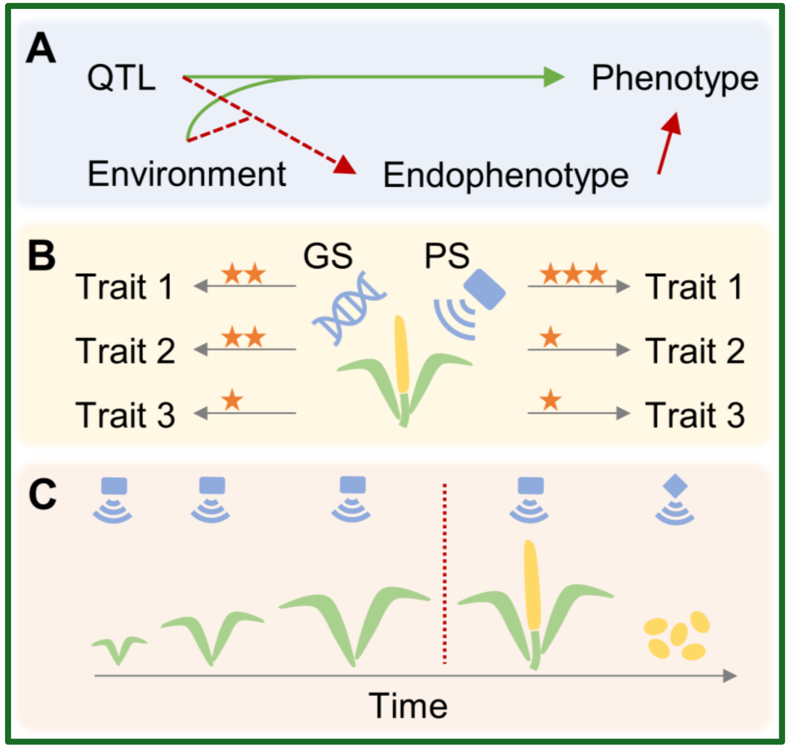
Relevant research areas



Breeding strategy improvement.



Origin specific genomic selection (OSGS) for polygenic introgression.



Phenomic selection optimization.

Closing

Broad research experience in quantitative genetics and plant breeding.

Vision for small grains breeding at NCSU.

Basic research

Small grains breeding