THE UNIVERSITY OF WESTERN AUSTRALIA

Sustainable plant breeding with BRIO

Wallace Cowling

The University of Western Australia

Demand Led Breeding - Africa

28 / July / 2023

My background

Graduate in Agricultural Science from The University of Melbourne, Australia

Trained as a plant pathologist at University of California, Davis

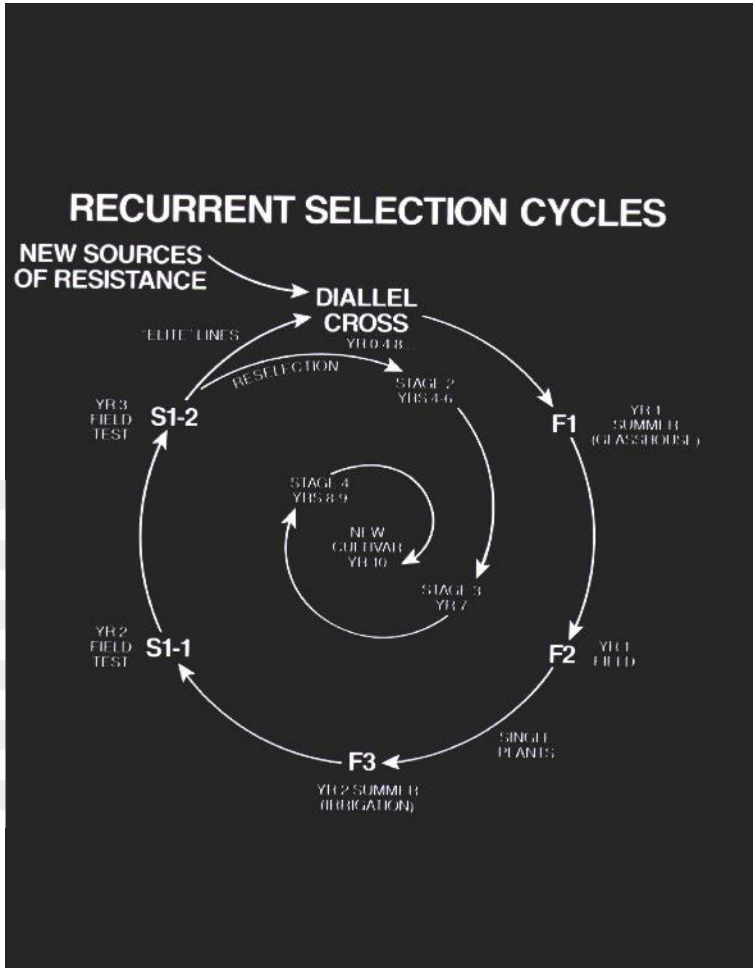
Lupin breeder at the Western Australian Department of Agriculture 1982 to 1999

Canola breeder and researcher at The University of Western Australia 1999 to present

My experience

My experience from 40 years of crop breeding:

- clarify your goals
- eyes and ears open
- learn
- accept when you are wrong
- change
- re-assess
- focus on the science



What are our goals as plant breeders?

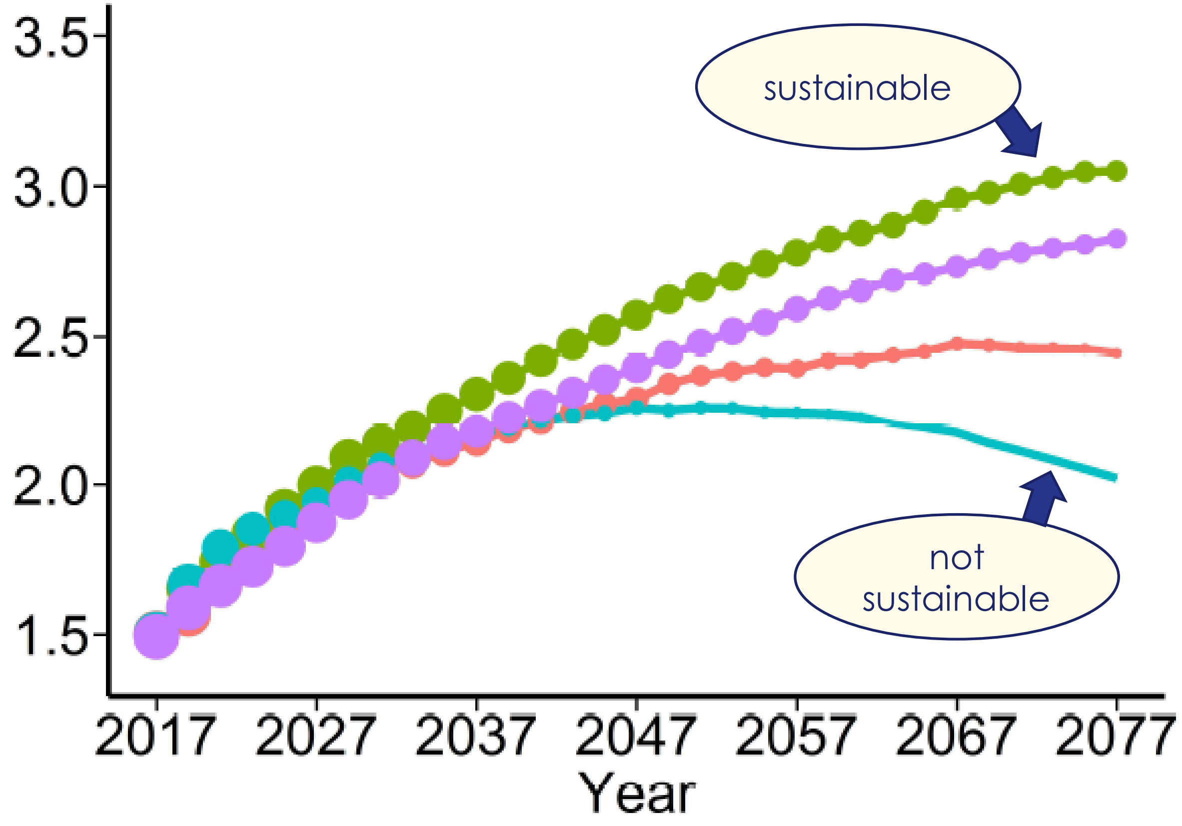
THE UNIVERSITY OF WESTERN AUSTRALIA

High rate of genetic gain in all economic traits

Sustainable genetic gain

Avoid the "yield plateau"

Introgress new traits as required



Cowling et al. 2019. Modeling crop breeding for global food security during climate change. Food and Energy Security 8:e00157

Focus on the science of plant breeding

THE UNIVERSITY OF WESTERN AUSTRALIA

Is plant breeding an "art" or a "science"?

Sustainable plant breeding is based on the science of quantitative and evolutionary genetics (Cowling, 2013, Plant Breeding 132, 1–9)

Four essential questions we all need to answer:

- how should I increase accuracy of selection??
- how should I accelerate genetic gain sustainably??
- how should I optimise selection for all traits??
- how should I design my crosses??

Questions?

Focus on the science of plant breeding

THE UNIVERSITY OF WESTERN AUSTRALIA

Four essential questions we all need to answer:

- how should I increase accuracy of selection??
- how should I accelerate genetic gain sustainably??
- how should I optimise selection for all traits??
- how should I design my crosses??

Sustainable plant breeding with BRÍO

THE UNIVERSITY OF WESTERN AUSTRALIA

Breeding values with high accuracy
Rapid cycles
Index of multiple traits
Optimal contributions selection

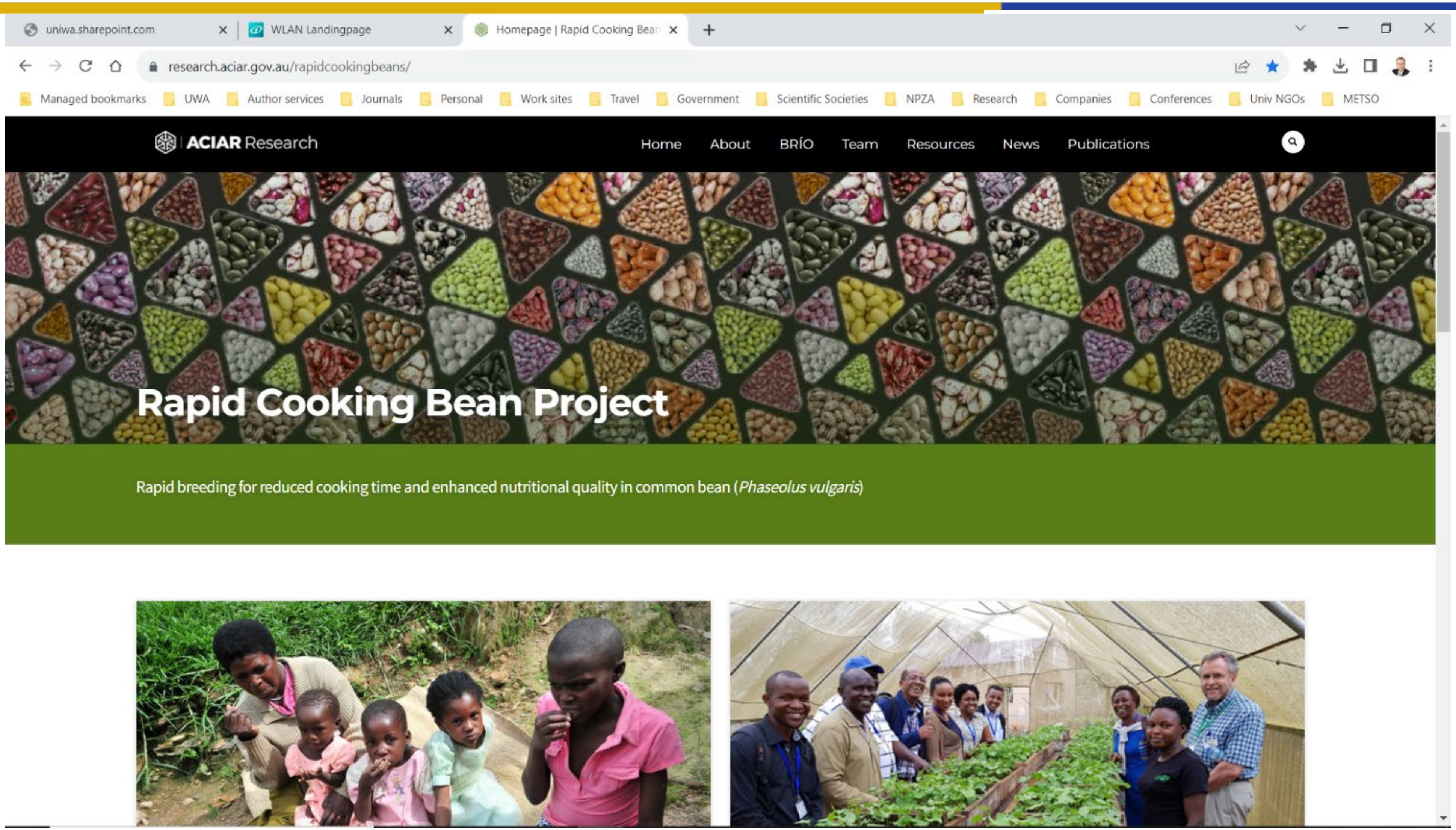
https://research.aciar.gov.au/rapidcookingbeans/brio

Sustainable plant breeding with BRÍO
- the rapid cooking bean project in East Africa

THE UNIVERSITY OF WESTERN AUSTRALIA

Alliance of Bioversity International and CIAT

Australian Centre for International Agricultural Research

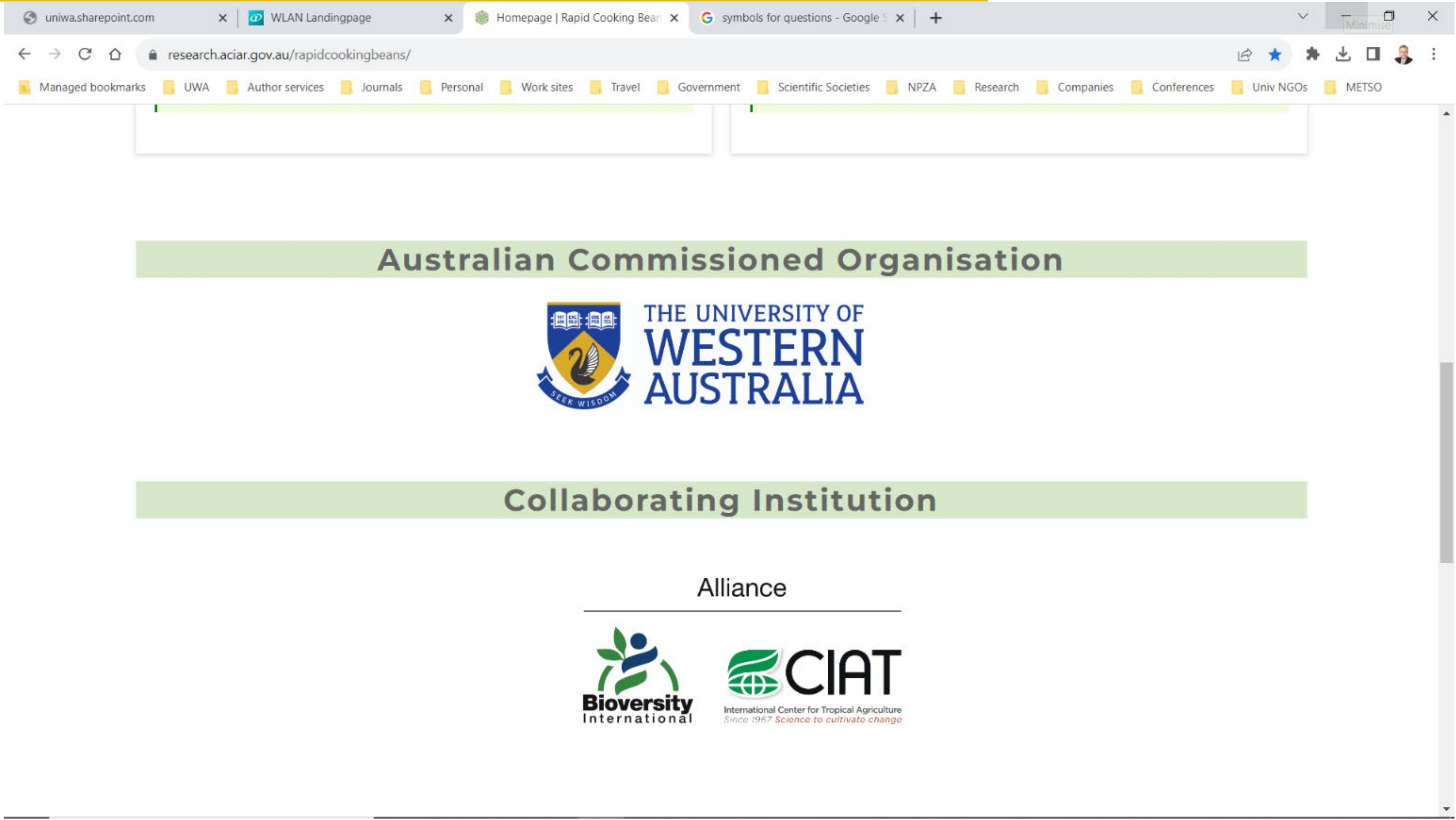


Sustainable plant breeding with BRÍO
- the rapid cooking bean project in East Africa

Alliance of Bioversity International and CIAT

The University of Western Australia

ACIAR



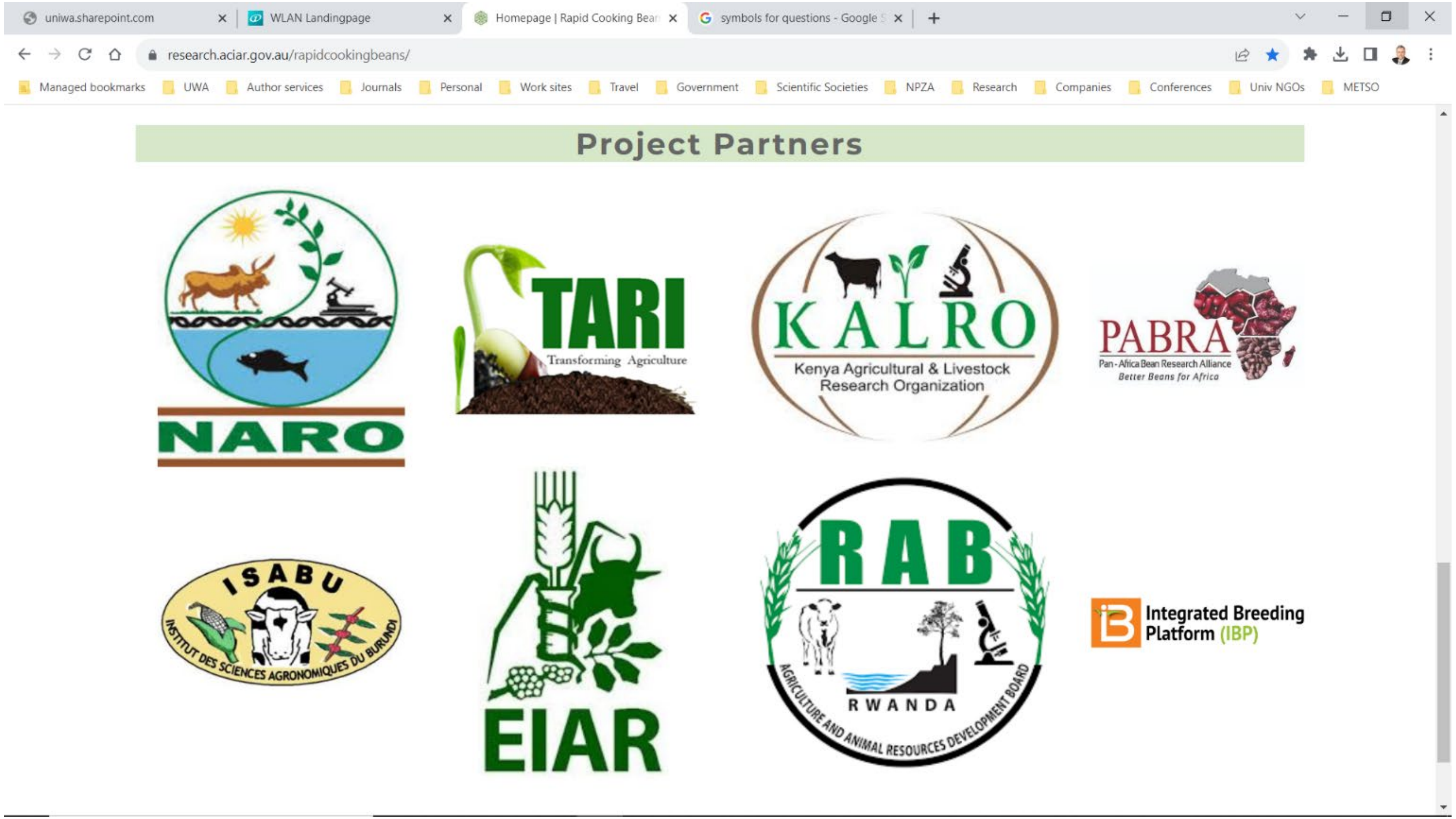
Sustainable plant breeding with BRÍO
- the rapid cooking bean project in East Africa

THE UNIVERSITY OF WESTERN AUSTRALIA

Alliance of Bioversity International and CIAT

PABRA

Six collaborating countries



Back to basics...

Plant breeders aim to develop improved varieties from their elite breeding pools by managing the evolutionary processes of:

- selection
- migration
- mutation
- random genetic drift
- mating systems

The question is, how should we manage these processes to achieve the best result during the coming period of climate change?

Cowling (2013) “Sustainable plant breeding.” Plant Breeding 132:1-9

The breeder’s equation

The “breeder’s equation” is a useful concept to help understand responses to selection:

$$R = \frac{i\sigma_A r}{L}$$

where the response to selection in the next cycle (R) is related to:

- i selection intensity
- σ_A standard deviation of breeding values = genetic diversity
- r accuracy of the breeding values
- L cycle time in years (generation interval)

Cowling (2013) “Sustainable plant breeding.” Plant Breeding 132:1-9

Increasing response to selection...

THE UNIVERSITY OF WESTERN AUSTRALIA

$$R = \frac{i\sigma_A r}{L}$$

...it is possible to increase R by:

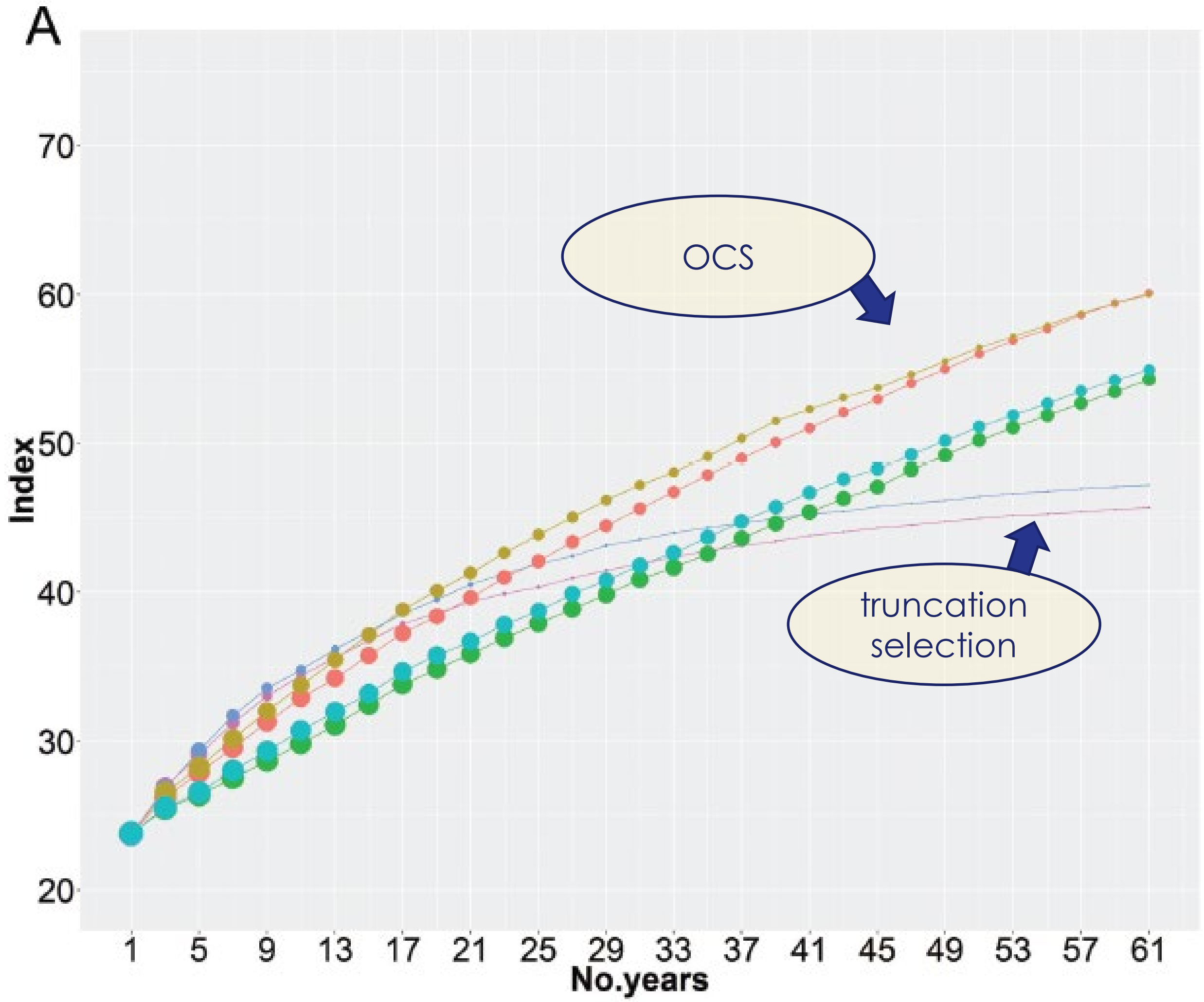
- i increasing selection intensity
- σ_A increasing genetic diversity
- r increasing accuracy of the breeding values
- L reducing cycle time

But, difficult to predict the outcome in future cycles – modelling required!

Cowling (2013) "Sustainable plant breeding." Plant Breeding 132:1-9

Optimal contributions selection promotes long-term genetic gain

Optimal contributions selection (OCS) conserves genetic diversity while optimising long-term genetic gain.



Cowling et al. 2017 Evolving gene banks: improving diverse populations of crop and exotic germplasm with optimal contribution selection. Journal of Experimental Botany 68:1927–1939.

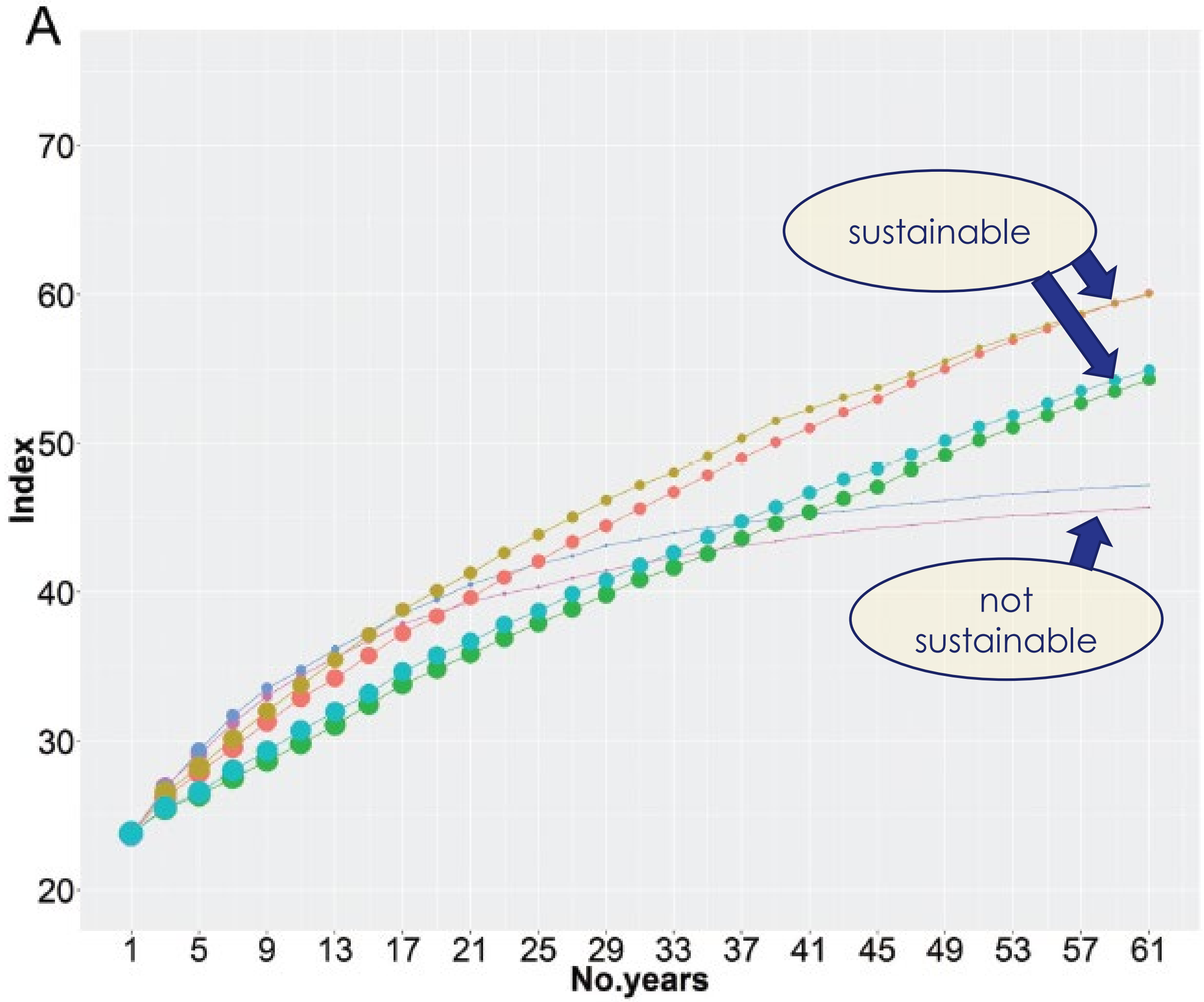
OCS helps to achieve "sustainable plant breeding"

Sustainable plant breeding:

= long-term genetic gain

= conservation of genetic diversity for future genetic gain

Cowling et al. 2017 Evolving gene banks: improving diverse populations of crop and exotic germplasm with optimal contribution selection. Journal of Experimental Botany 68:1927–1939.



Questions?

BRÍO – four essential elements of sustainable plant breeding

(Cowling et al. 2023 Plants 12:383)

THE UNIVERSITY OF WESTERN AUSTRALIA

Breeding values with high accuracy

- diverse breeding pools from AU and EU/CA => high genetic diversity
- multiple sites per cycle
- highly interconnected deep pedigree => accurate predicted breeding values (PBV)

Rapid cycles

- 2-year cycles 2014 to 2020 with field trials on $S_{0,1}$ families

Index

- economic index of multiple traits => grain yield, disease resistance, seed oil/protein…

Optimal contributions selection

- optimised mating designs for maximizing genetic gain; the evolutionary algorithm

Spring canola breeding in Australia, Europe (EU) and Canada (CA) – before 2012

THE UNIVERSITY OF WESTERN AUSTRALIA

125 NPZ Jahre

spring canola

summer-growing season

CA

EU

<u>Canada</u>:
DL Seeds, Manitoba

<u>Europe</u>:
NPZ Germany

125 NPZ Jahre

spring canola

winter-spring growing season

AU

<u>Australia</u>:
NPZ Australia Pty Ltd

(project at UWA)

Cowling et al. 2023 Plants 12:383

Spring canola breeding in Australia, Europe (EU) and Canada (CA) – after 2012

THE UNIVERSITY OF WESTERN AUSTRALIA

125 NPZ Jahre

spring canola

summer-growing season

CA

EU

<u>Canada</u>:
DL Seeds, Manitoba

<u>Europe</u>:
NPZ Germany

CA × AU

EU × AU

125 NPZ Jahre

spring canola

winter-spring growing season

AU

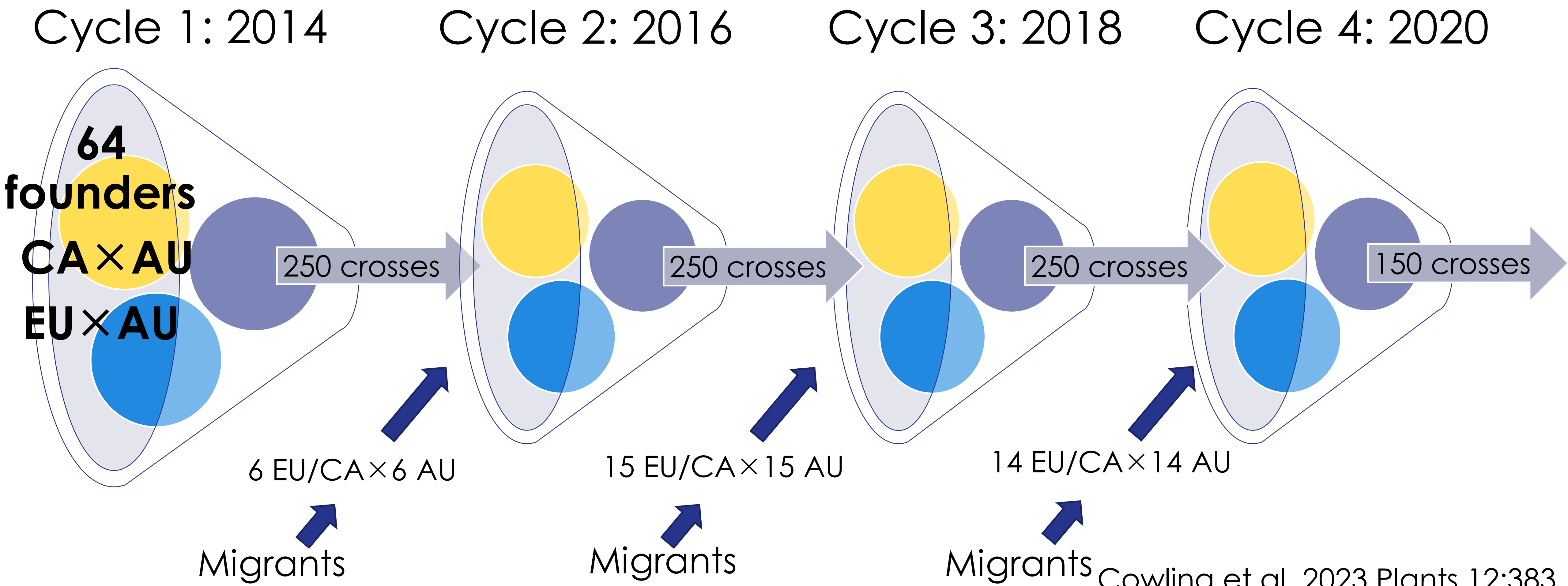
<u>Australia</u>:
NPZ Australia Pty Ltd

(project at UWA)

Cowling et al. 2023 Plants 12:383

Rapid 2-year cycles of selection

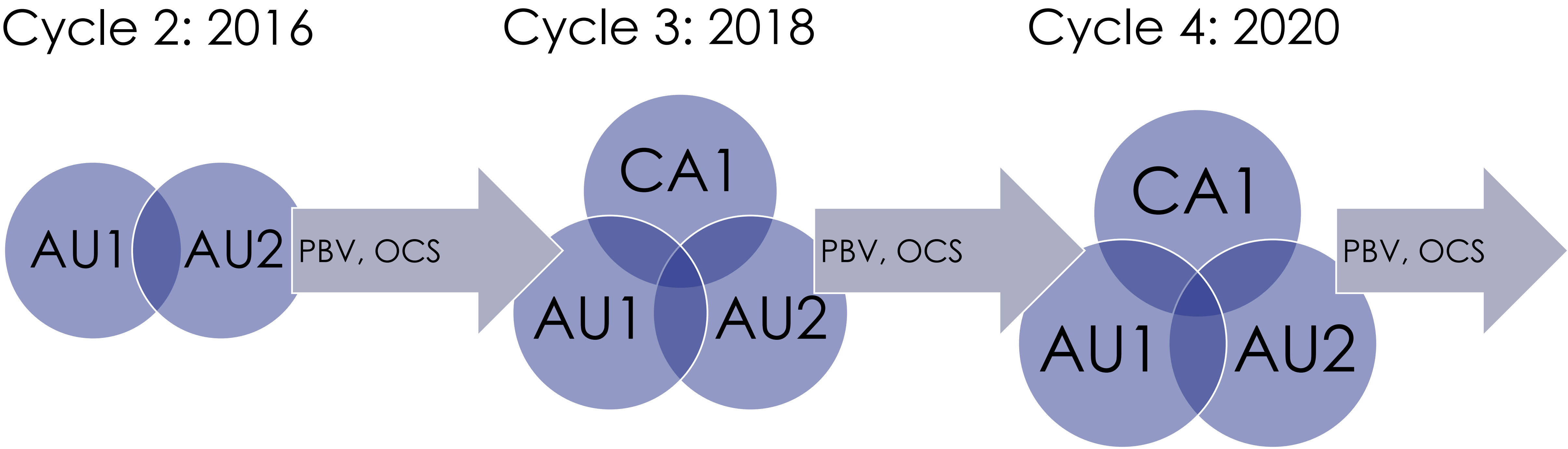
THE UNIVERSITY OF WESTERN AUSTRALIA



Cowling et al. 2023 Plants 12:383

Accurate predicted breeding values (PBV)

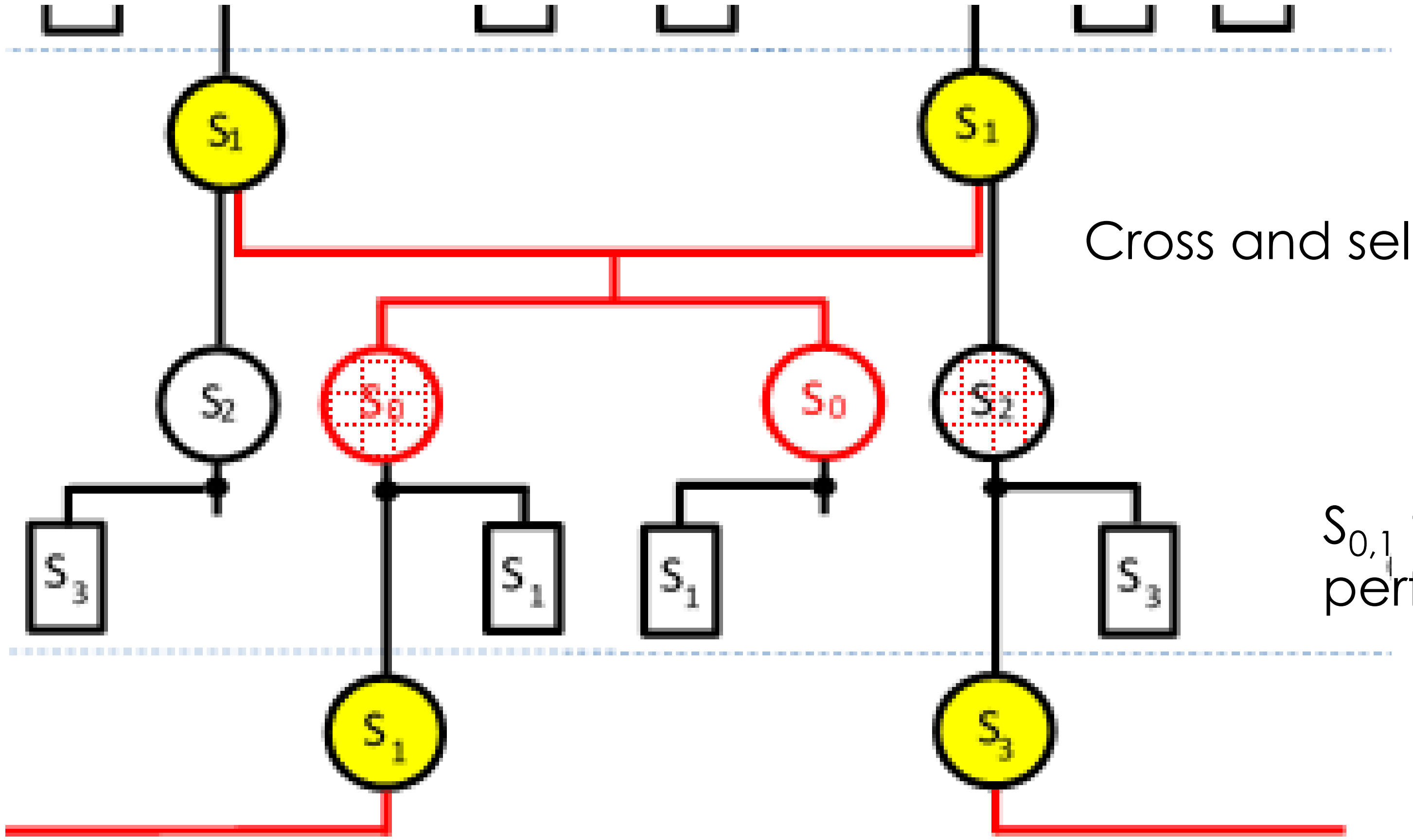
Factor Analytic (FA) analysis of field trials across cycles and sites



PBV: accurate predicted breeding values ($r > 0.80$)
OCS: optimal contributions selection for optimised mating designs

Cowling et al. 2023 Plants 12:383

$S_{0,1}$ family selection



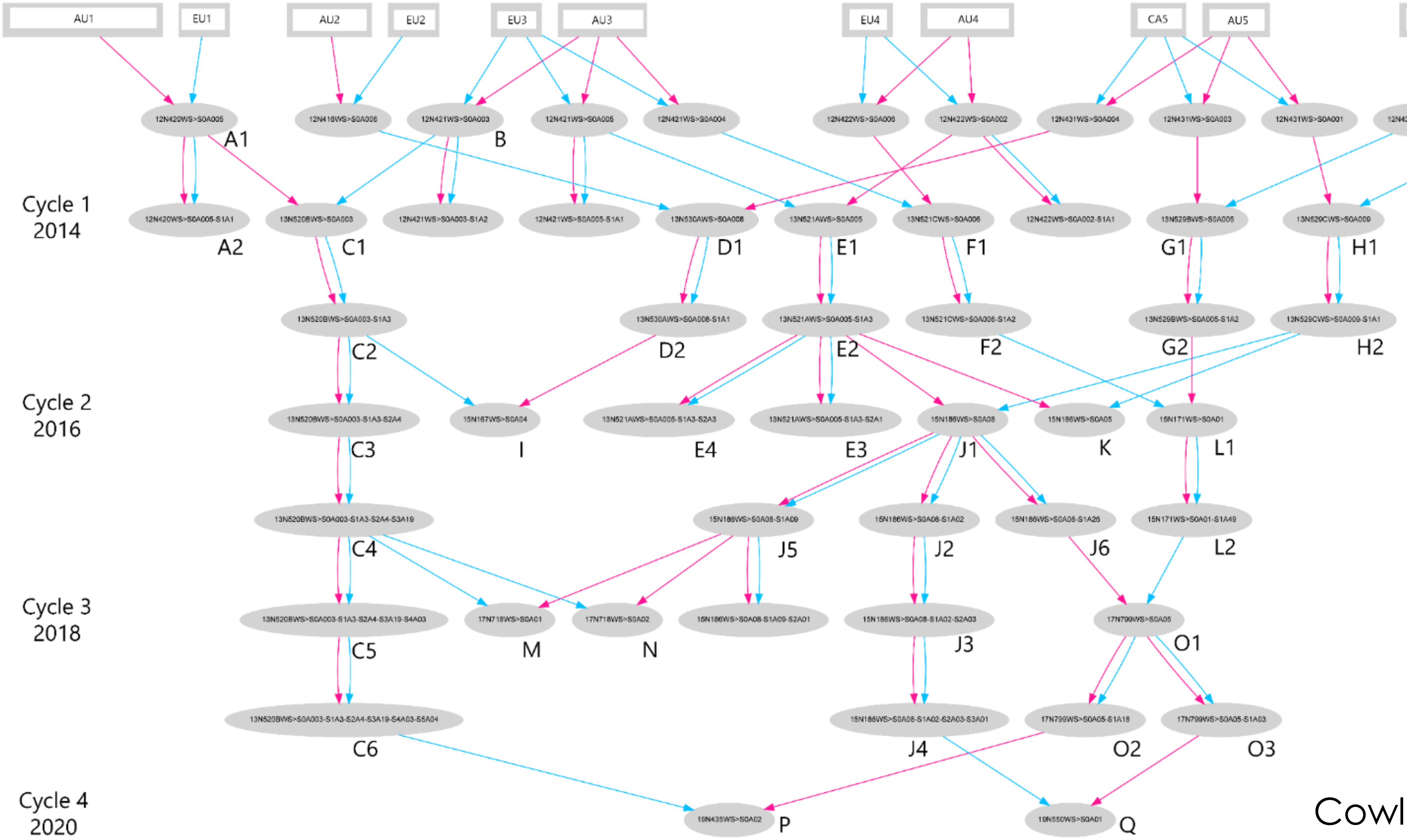
Cross and self

$S_{0,1}$ family performance

Cowling et al. 2023 Plants 12:383

$S_{0,1}$ family selection pedigree across 4 cycles

THE UNIVERSITY OF WESTERN AUSTRALIA



Founders

$S_{0,1}$ family performance

Cross and self

A small portion of the pedigree from 2012 to 2020....

Cowling et al. 2023 Plants 12:383

Moderate to high narrow-sense heritability of traits in AU and CA

THE UNIVERSITY OF WESTERN AUSTRALIA

Trait	Narrow-sense heritability across sites in AU, CA
Grain yield (t ha^{-1})	0.40 (range 0.02 – 0.62)
Days to 50% flower	0.73 (range 0.60 – 0.87)
Plant height (cm)	0.52 (range 0.36 – 0.74)
Seed oil (%)	0.53 (range 0.33 – 0.65)
Protein in meal (%)	0.56 (range 0.35 – 0.74)
Glucosinolates (μmol g^{-1})	0.61 (range 0.18 – 0.76)
Oleic acid (%)	0.83 (range 0.65 – 0.94)
Blackleg (Phoma) resistance	0.44 (range 0.14 – 0.60)
Seed size (100 seed weight, g)	0.66 (range 0.43 – 0.77)

Cowling et al. 2023 Plants 12:383

Moderate to high narrow-sense heritability of traits in AU and CA

THE UNIVERSITY OF WESTERN AUSTRALIA

Trait	Narrow-sense heritability across sites in AU, CA
Grain yield (t ha^{-1})	0.40 (range 0.02 – 0.62)
Days to 50% flower	0.73 (range 0.60 – 0.87)
Plant height (cm)	0.52 (range 0.36 – 0.74)
Seed oil (%)	0.53 (range 0.33 – 0.65)
Protein in meal (%)	0.56 (range 0.35 – 0.74)
Glucosinolates (μmol g^{-1})	0.61 (range 0.18 – 0.76)
Oleic acid (%)	0.83 (range 0.65 – 0.94)
Blackleg (Phoma) resistance	0.44 (range 0.14 – 0.60)
Seed size (100 seed weight, g)	0.66 (range 0.43 – 0.77)

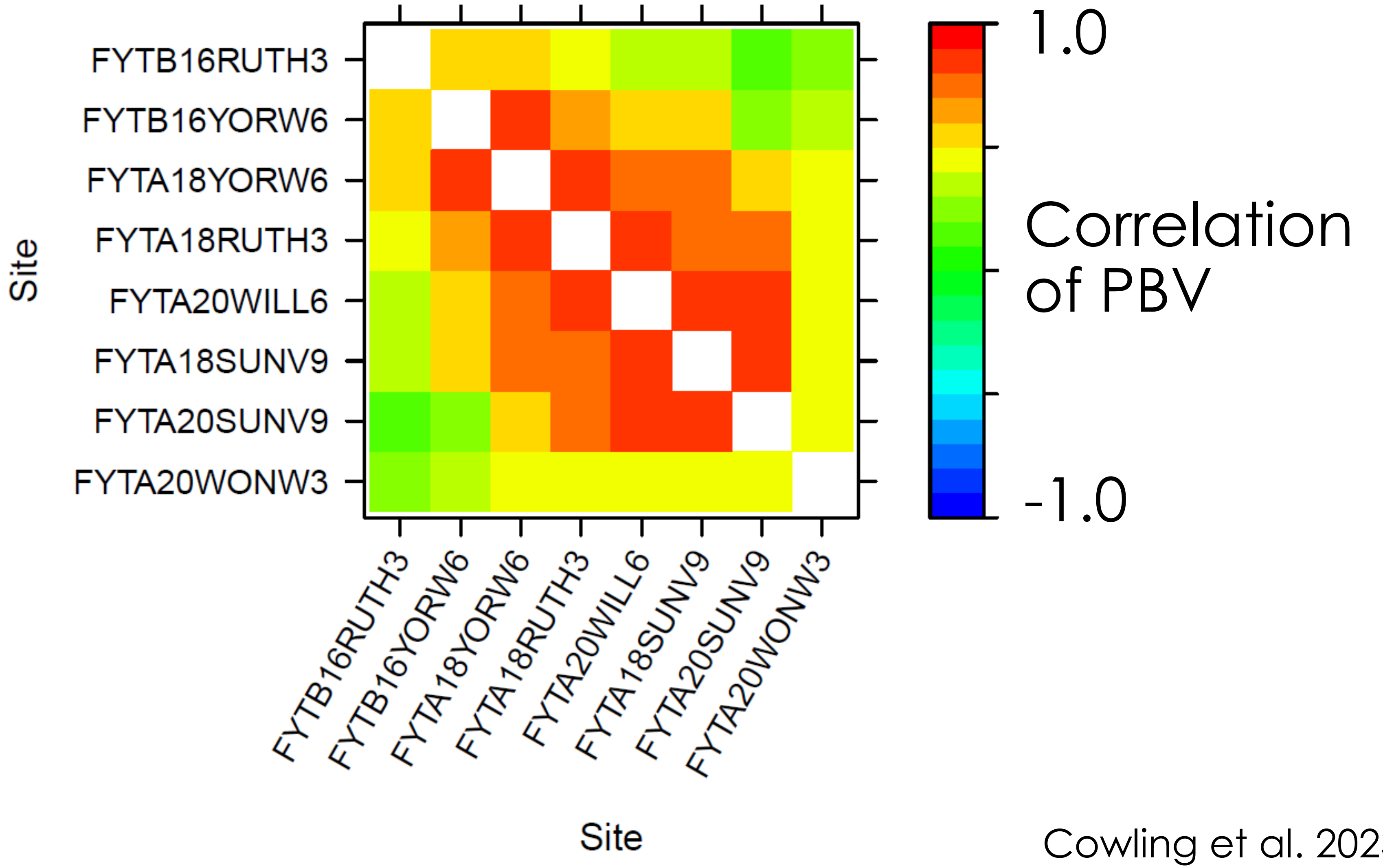
Heritability for grain yield similar to blackleg (Phoma) resistance....

Cowling et al. 2023 Plants 12:383

FA analysis: grain yield

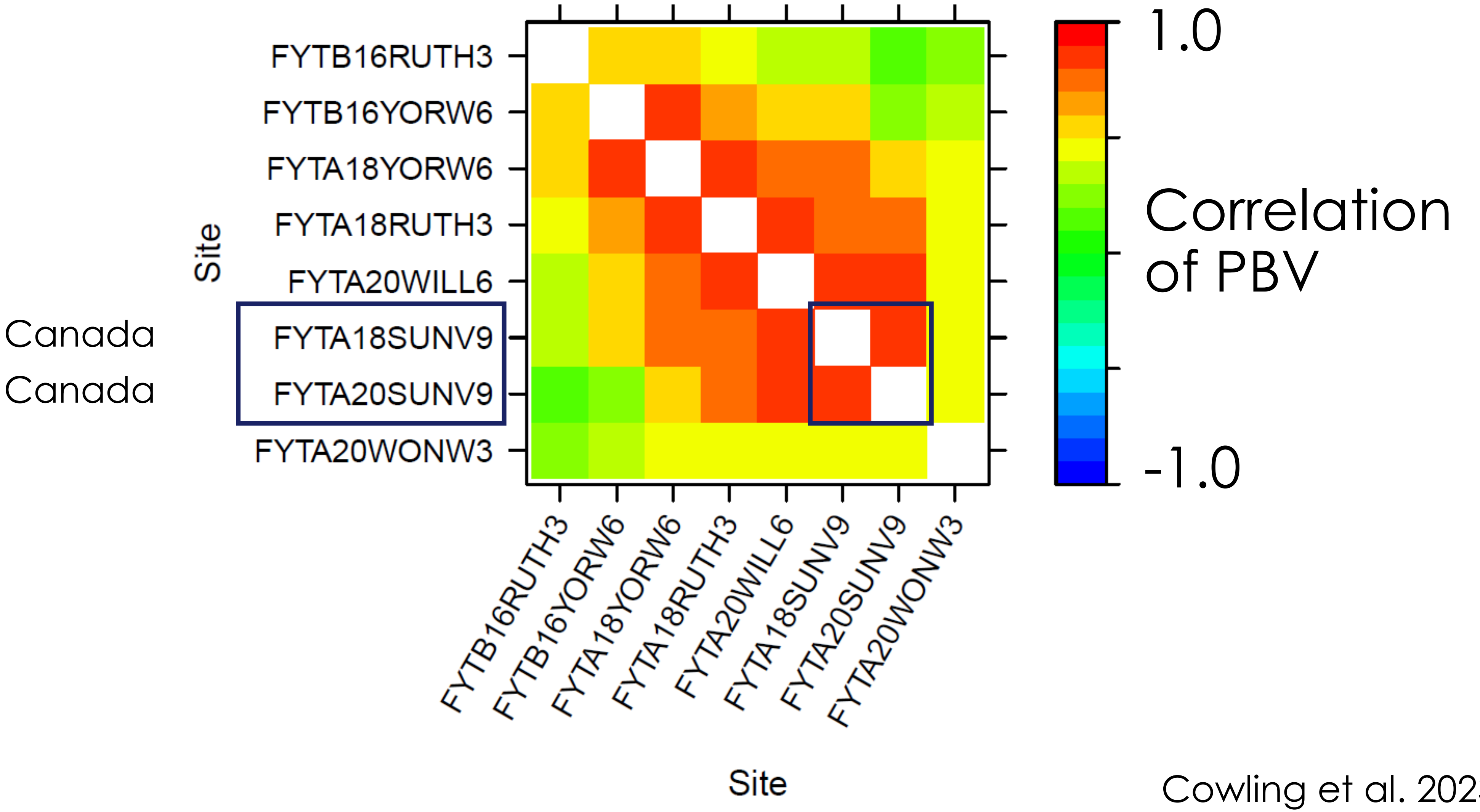
– genetic correlations of PBV across 8 sites in Canada and Australia 2016-2018-2020

THE UNIVERSITY OF WESTERN AUSTRALIA



Cowling et al. 2023 Plants 12:383

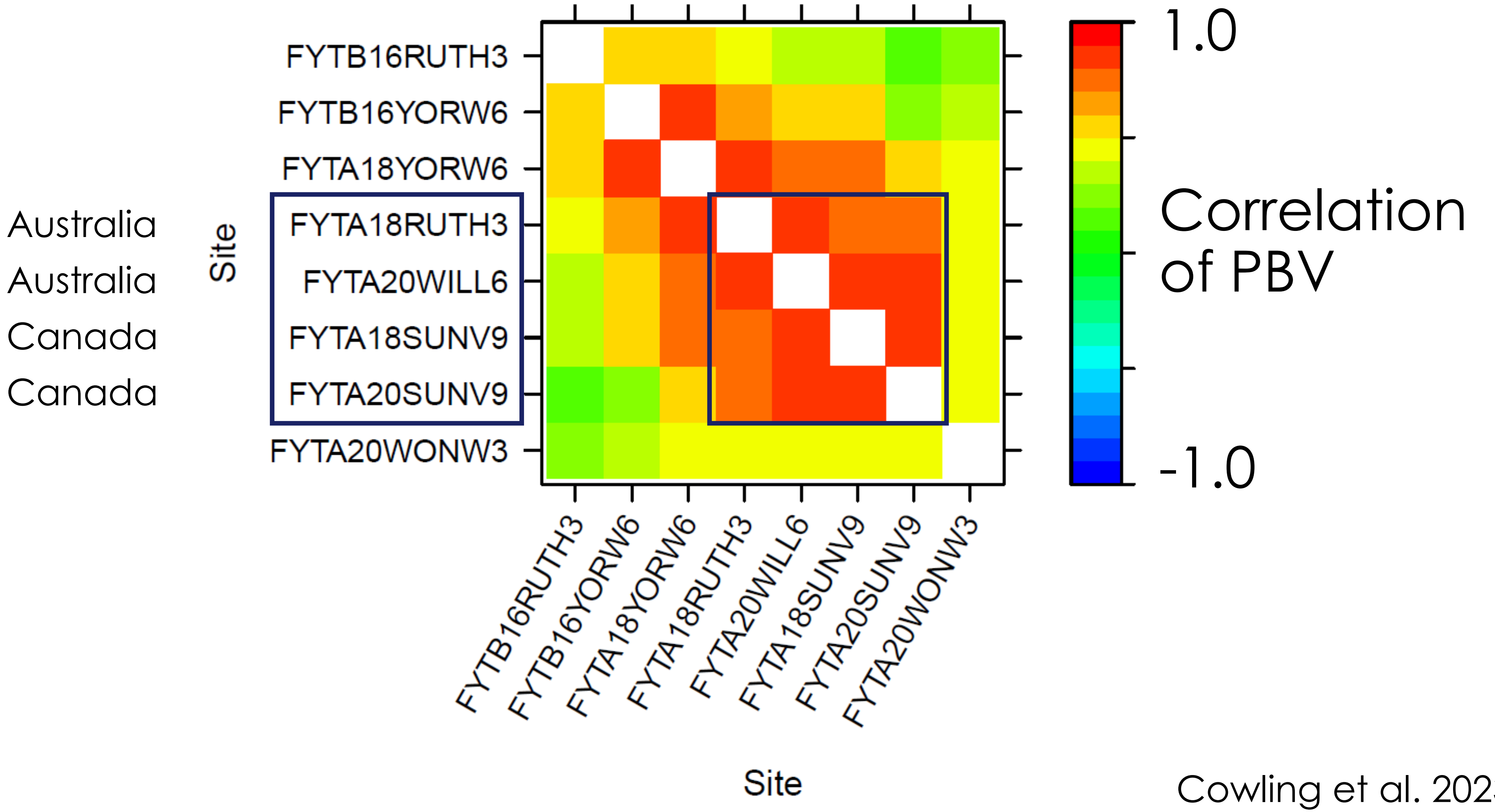
FA analysis: grain yield
– genetic correlation PBV >0.80 across cycles 2018-2020 in Canada



Cowling et al. 2023 Plants 12:383

FA analysis: grain yield

– genetic correlations PBV > 0.80 across cycles 2018 – 2020 and across CA and AU

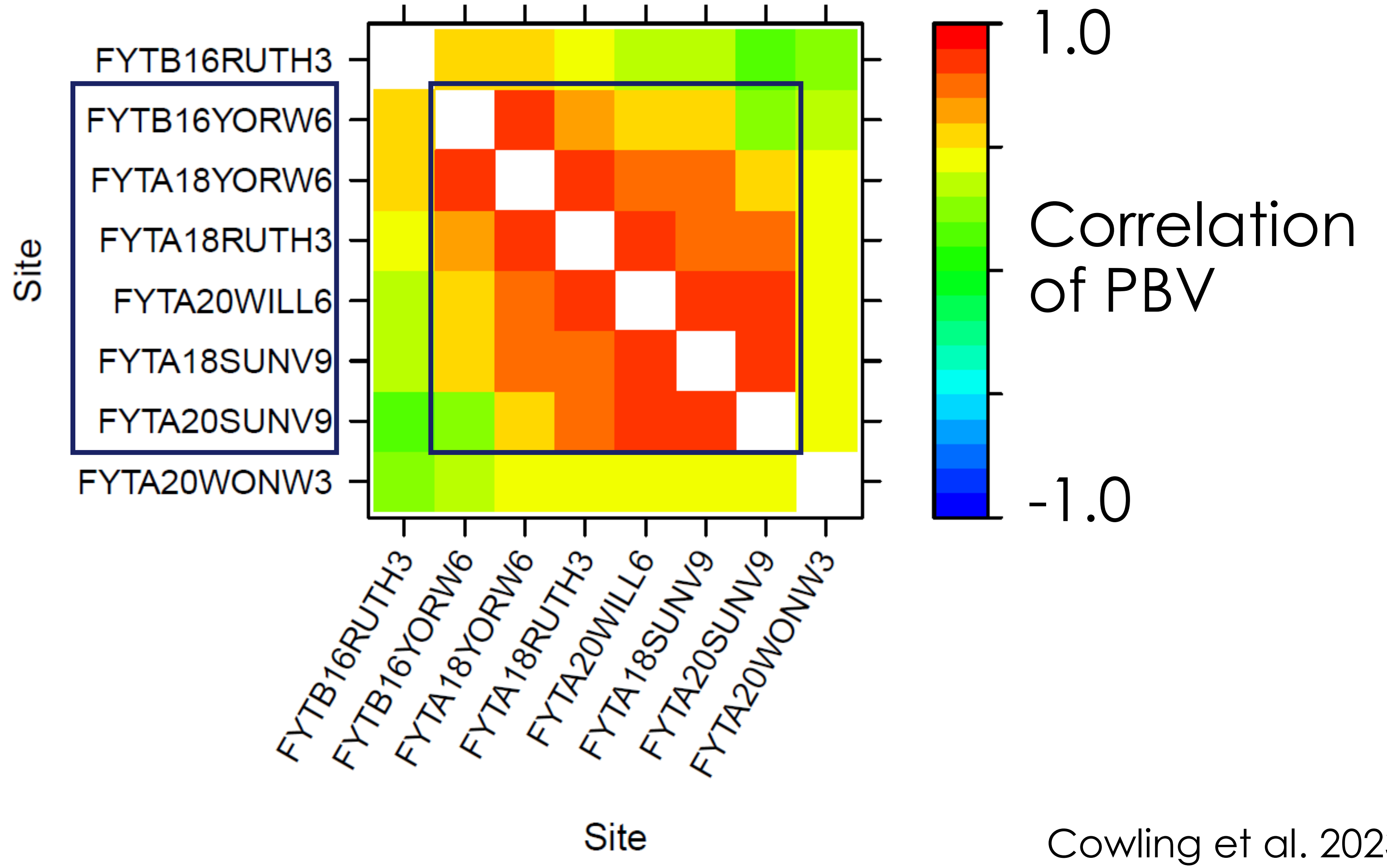


Cowling et al. 2023 Plants 12:383

FA analysis: grain yield

– positive genetic correlations PBV across cycles and countries 2016-18-20

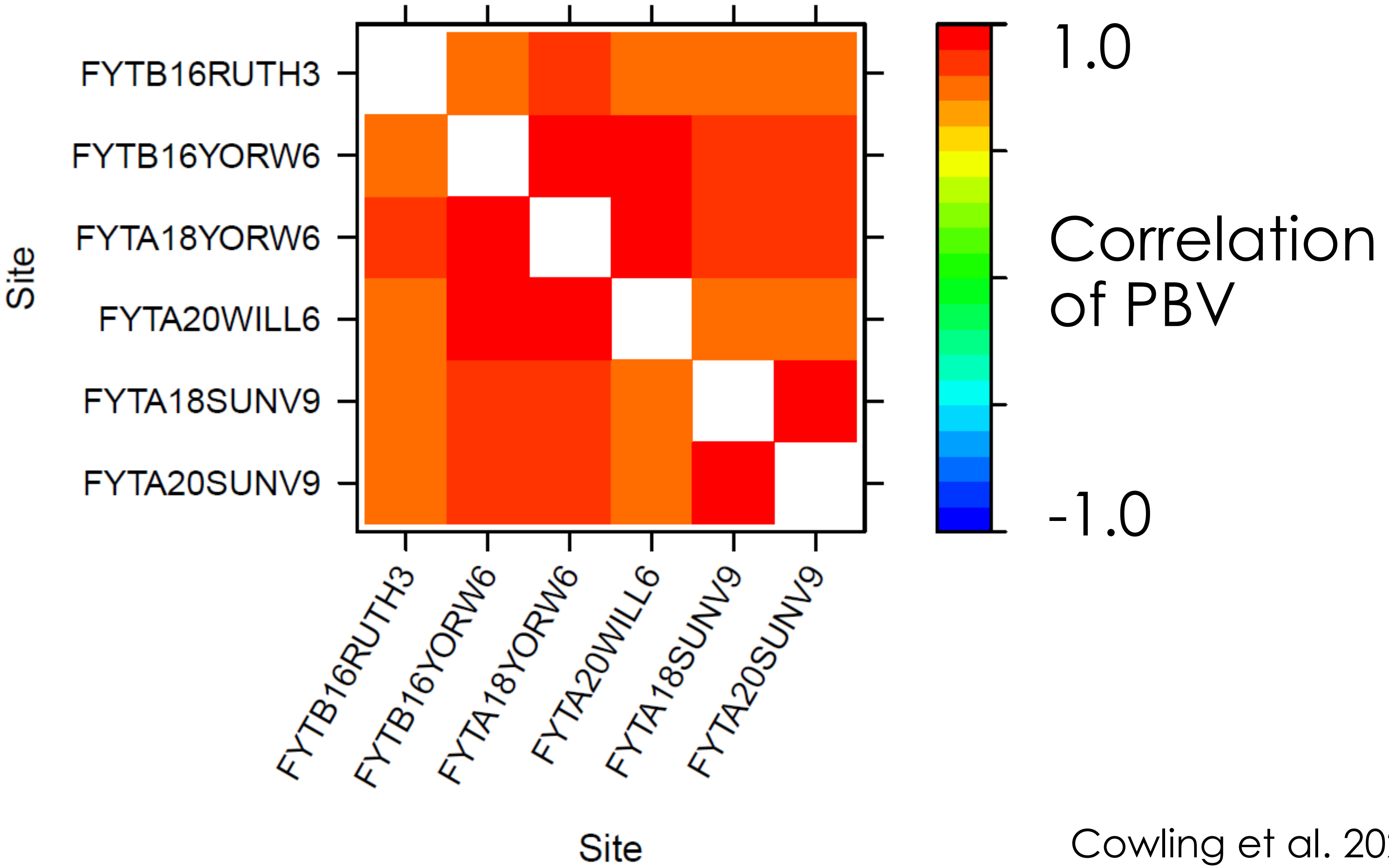
2016
2018
2018
2020
2018
2020



Cowling et al. 2023 Plants 12:383

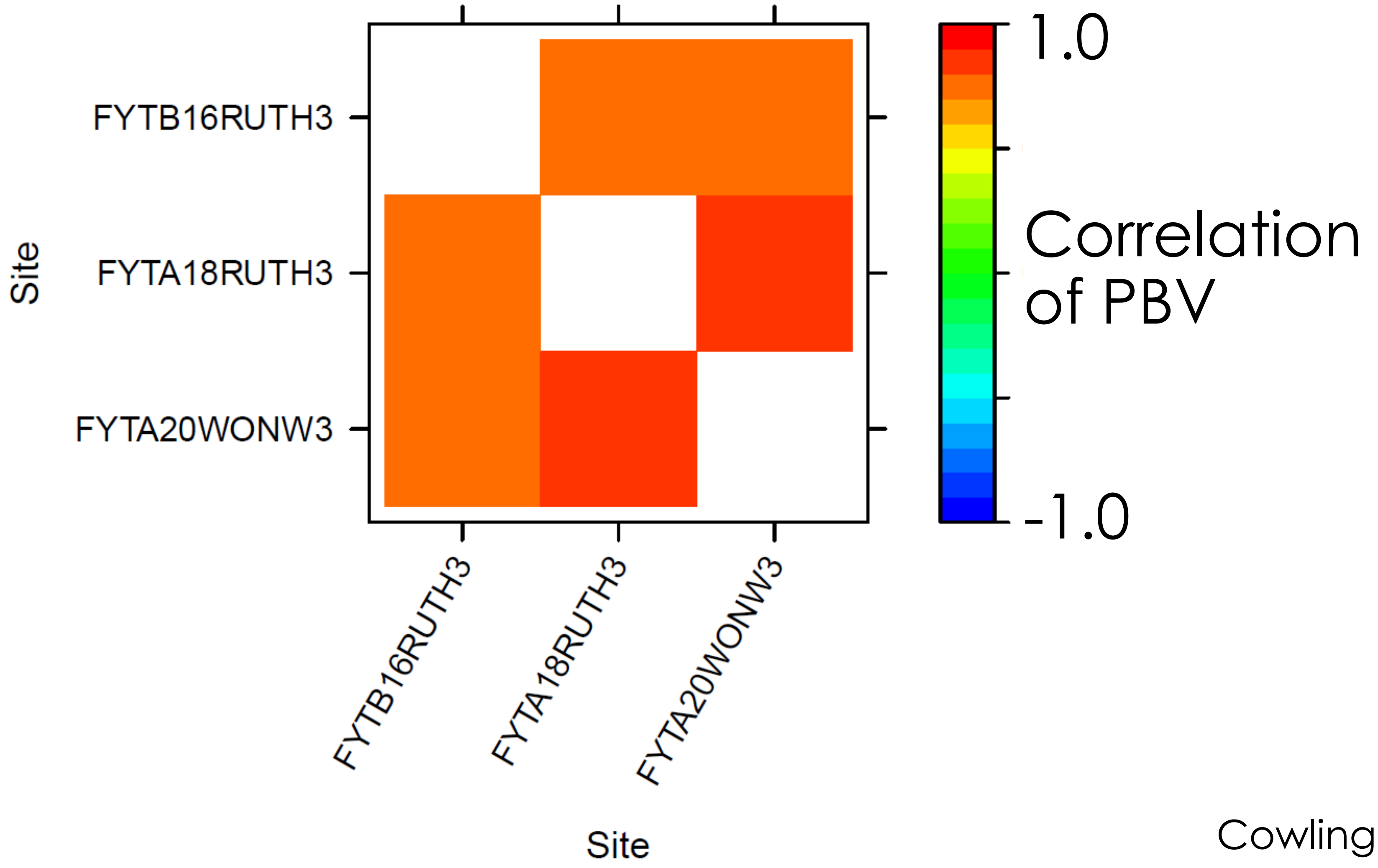
FA analysis: seed oil%
– close genetic correlations across countries/cycles

THE UNIVERSITY OF WESTERN AUSTRALIA



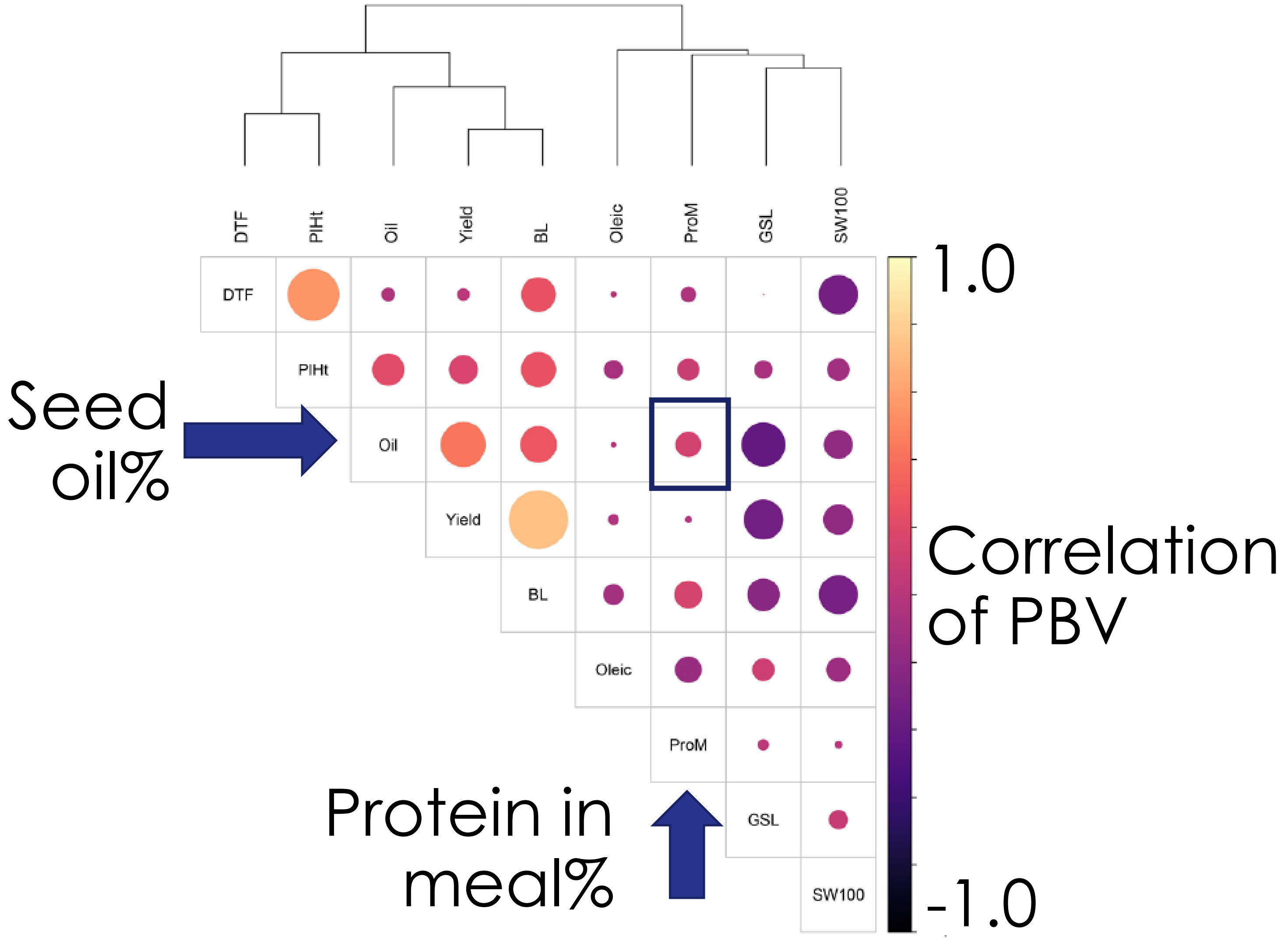
Cowling et al. 2023 Plants 12:383

FA analysis: blackleg resistance
– close genetic correlations across cycles 2016-18-20



Cowling et al. 2023 Plants 12:383

Genetic correlations PBV across traits

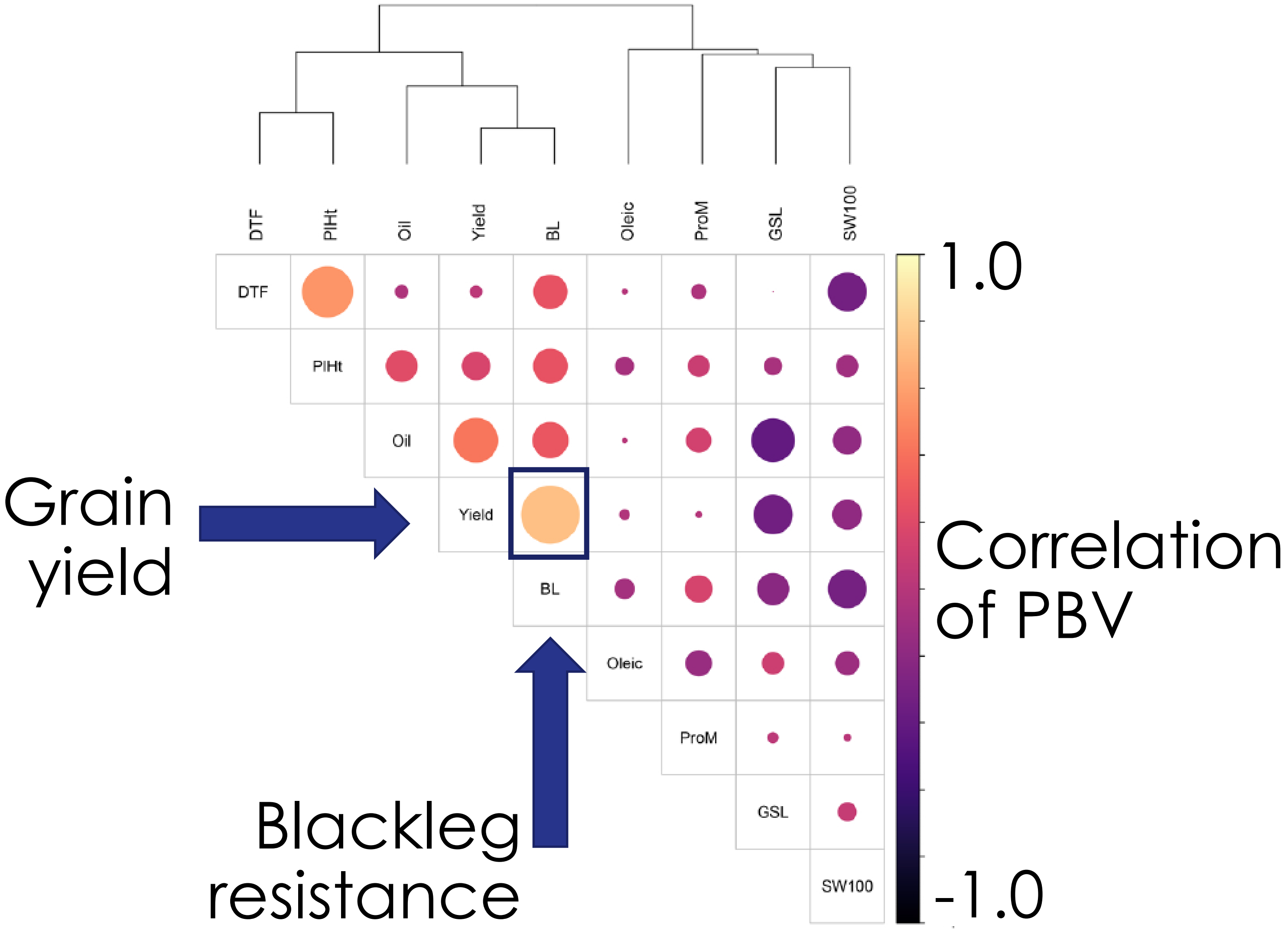


Seed oil % negatively correlated with protein in meal %

=> difficult, but not impossible, to select for *both* high oil *and* high protein

Cowling et al. 2023 Plants 12:383

Genetic correlations PBV across traits

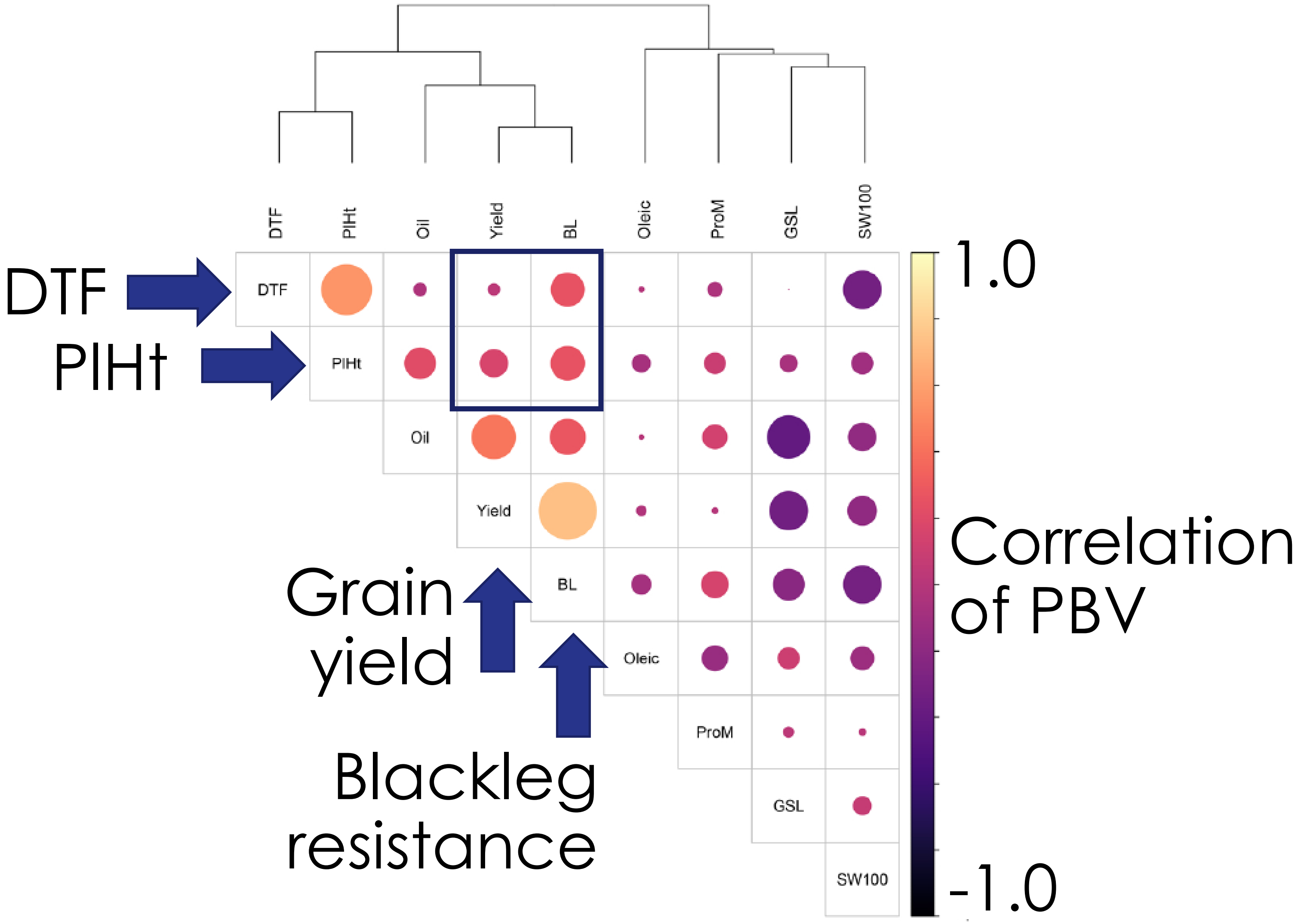


Blackleg resistance positively correlated with grain yield

☺ grain yield is higher in blackleg-resistant genotypes

Cowling et al. 2023 Plants 12:383

Genetic correlations PBV across traits



Late flowering (DTF) and tall height (PlHt) correlated with high grain yield and high blackleg resistance

⇒ resistant types tend to be taller and later flowering ☹

⇒ need negative weights on DTF/PlHt

Cowling et al. 2023 Plants 12:383

Selection index composed of multiple traits
- with economic weights to achieve desired gains

THE UNIVERSITY OF WESTERN AUSTRALIA

Index ($/ha) = PBV grain yield (t/ha) × 750 $/ha

+ PBV seed oil (%) ×economic weight

+ PBV protein in meal (%) ×economic weight

+ PBV blackleg resistance ×economic weight

- PBV plant height (cm) ×economic weight

Economic weights informed by market prices and desired gains

e.g. negative weight on PlHt and DTF (to reduce height and flowering time)

Cowling et al. 2023 Plants 12:383

Mating designs from optimal contributions selection (OCS) using the tool "MateSel"

THE UNIVERSITY OF WESTERN AUSTRALIA

FA analysis

PBV traits

Economic index

+

Pedigree and/or genomic relationship information

OCS

MateSel

OUTPUT:

- optimised mating design (250 crosses per cycle)
- predict genetic gain in next cycle for each trait
- minimise achieved parental coancestry

"MateSel" software

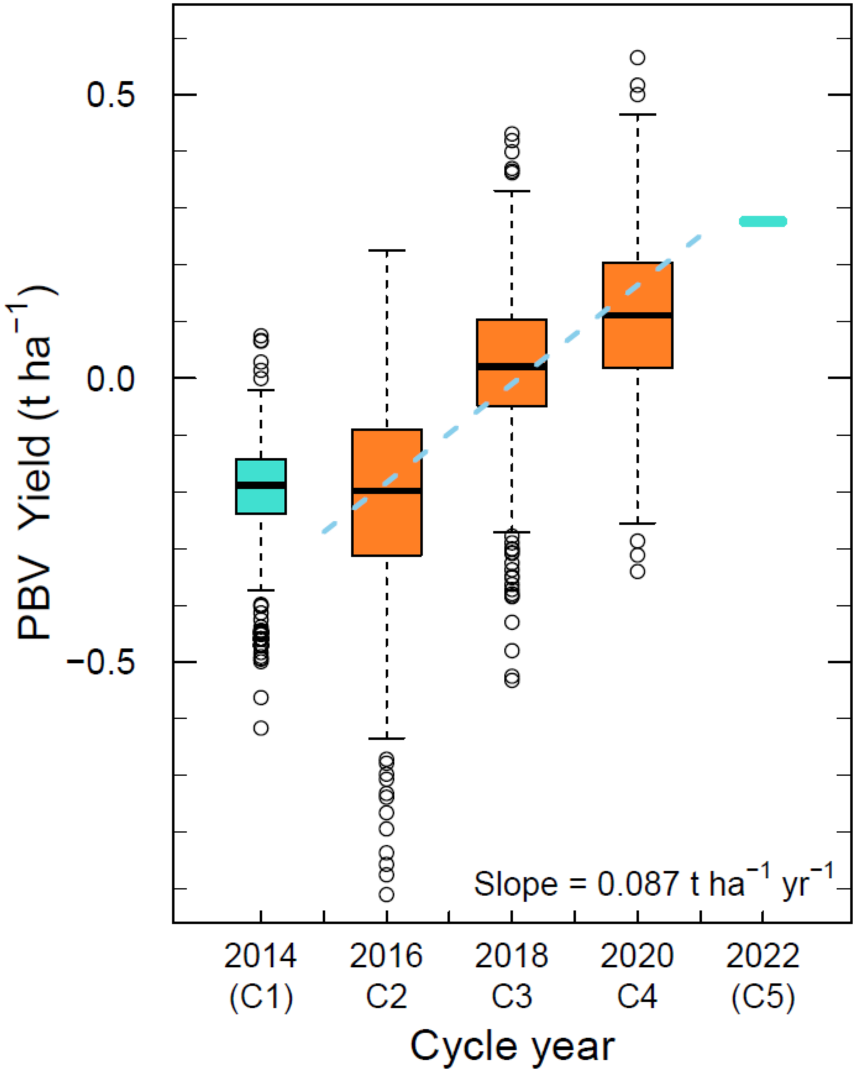
https://bkinghor.une.edu.au/matesel.htm

Cowling et al. 2023 Plants 12:383

Questions?

THE UNIVERSITY OF WESTERN AUSTRALIA

Genetic gain in grain yield
- upward slope in PBV over cycles



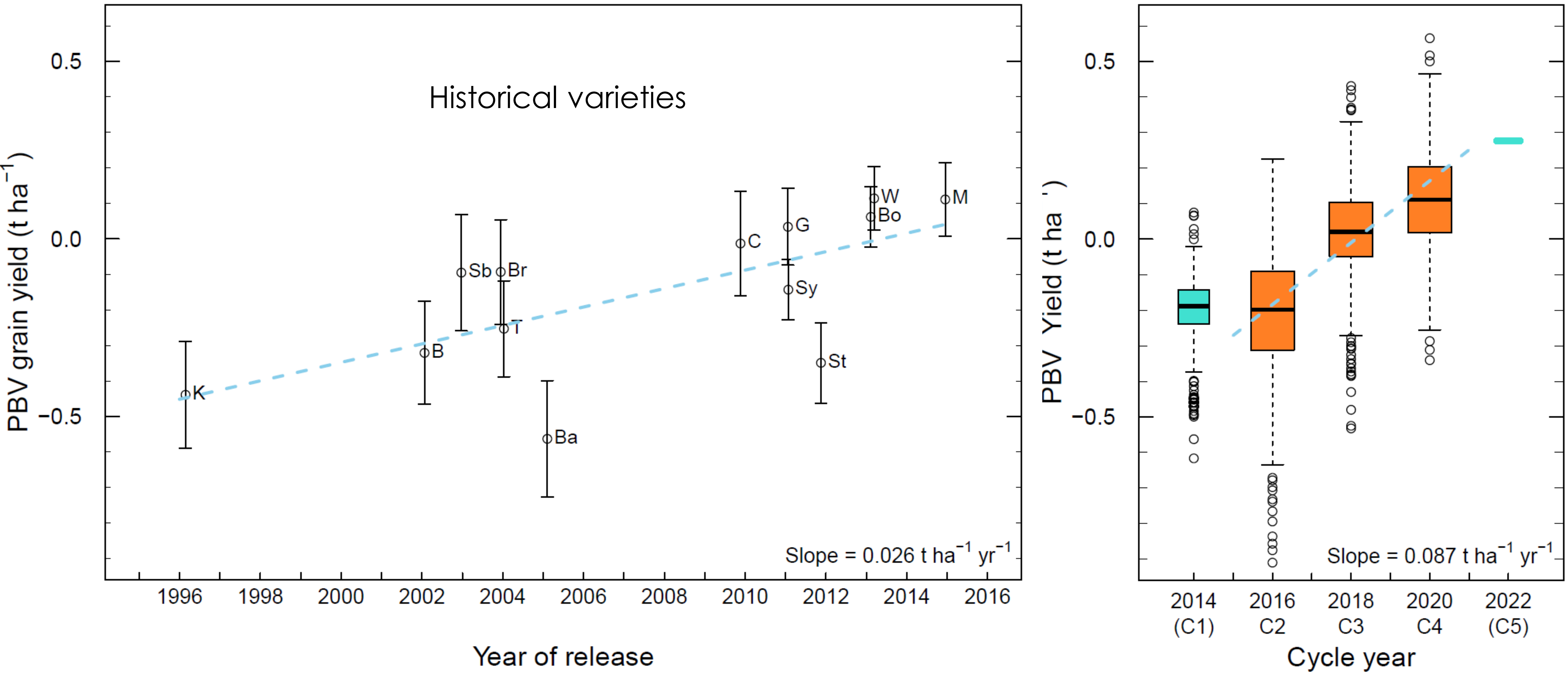
- slope 87 kg ha^{-1} yr^{-1} = 4.3% yr^{-1}
  = 4 times world average for crops!!
- slope predicted to continue to cycle 5 (2022)
- low achieved parental co-ancestry in cycle 4 parents = 0.088

Cowling et al. 2023 Plants 12:383

Genetic gain in grain yield with rapid cycles
- 3x faster than in historical varieties in the same trials

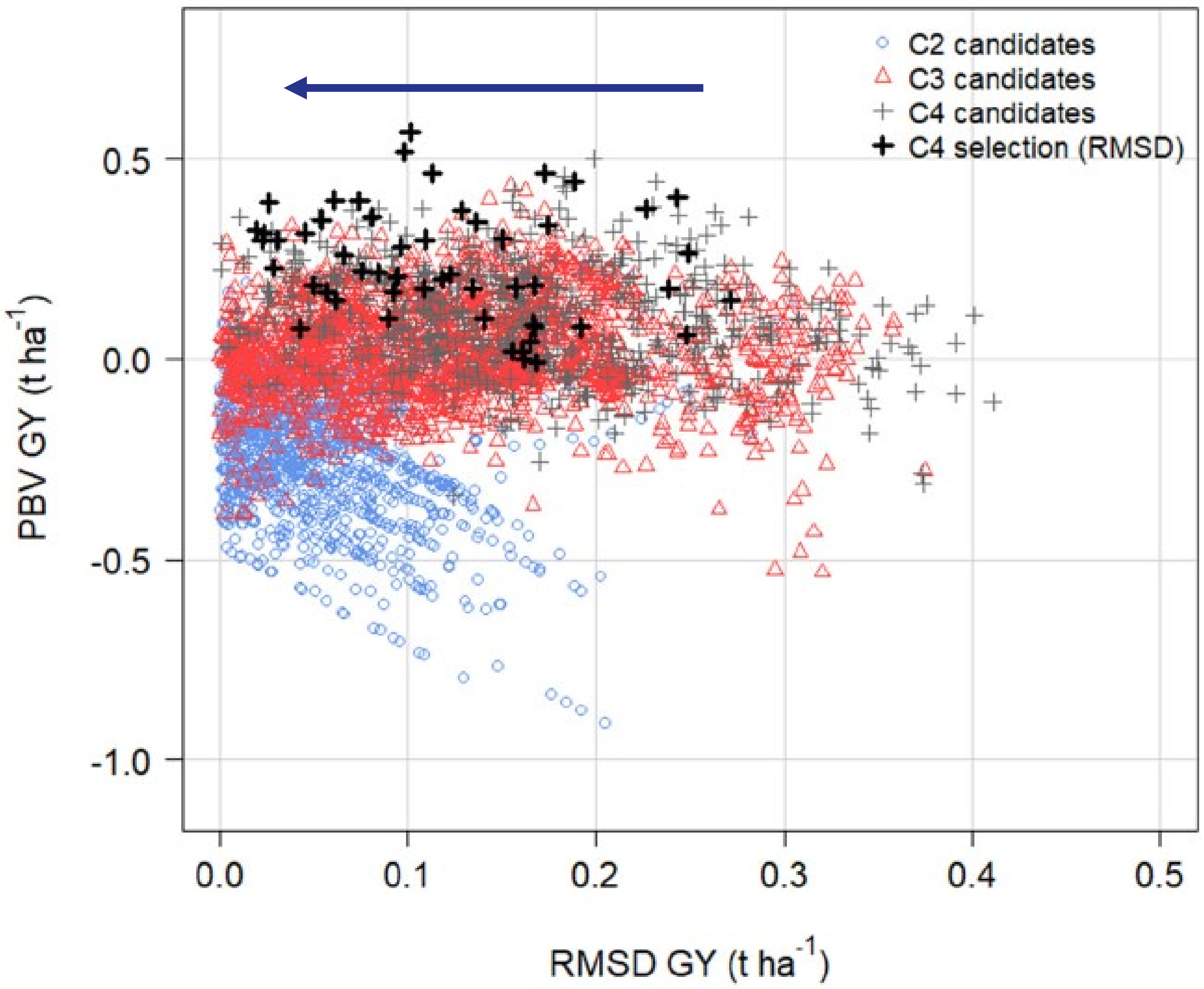
THE UNIVERSITY OF WESTERN AUSTRALIA

Cowling et al. 2023 Plants 12:383



Genetic gain in grain yield stability
- first use of RMSD selection across cycles

Cowling et al. 2023 Plants 12:383



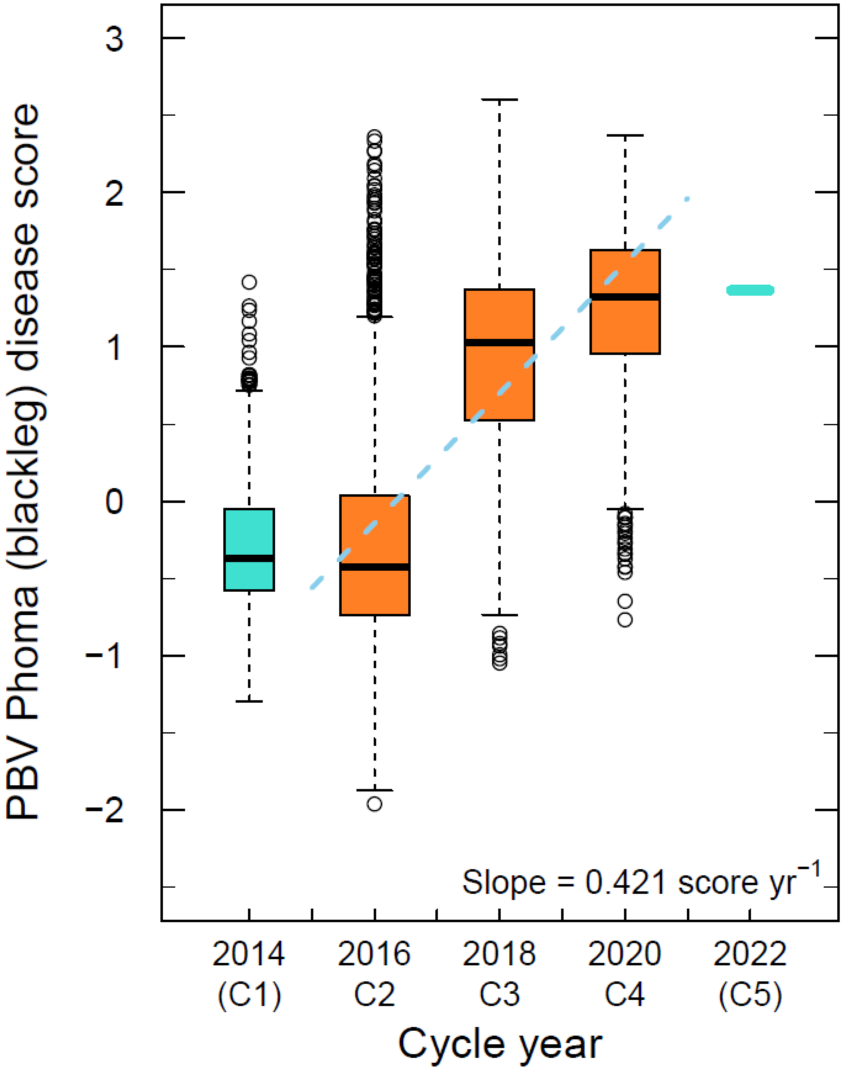
- Select for lower RMSD over cycles = greater yield stability over cycles

Cowling et al. 2023 Plants 12:383

Genetic gain in blackleg resistance
- significant upward slope in PBV over cycles

Resistant

Susceptible



High genetic gain in PBV Phoma (blackleg) score per year:

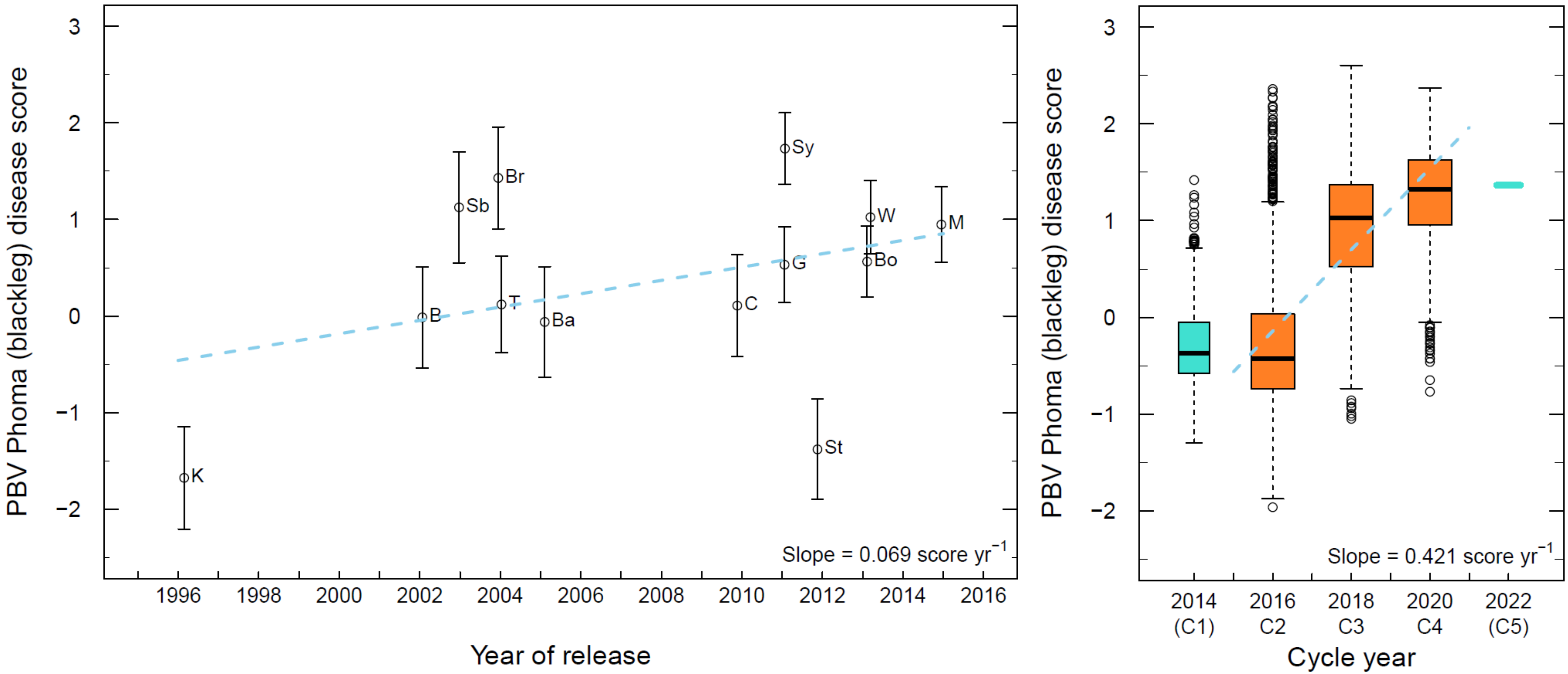
slope 0.42 disease score units yr^{-1} (=8.3% yr^{-1})

Scale = 1 (VS) to 9 (VR), and population mean = 5.1

Cowling et al. 2023 Plants 12:383

Genetic gain in blackleg resistance
- 6x faster than in historical varieties in the same trials

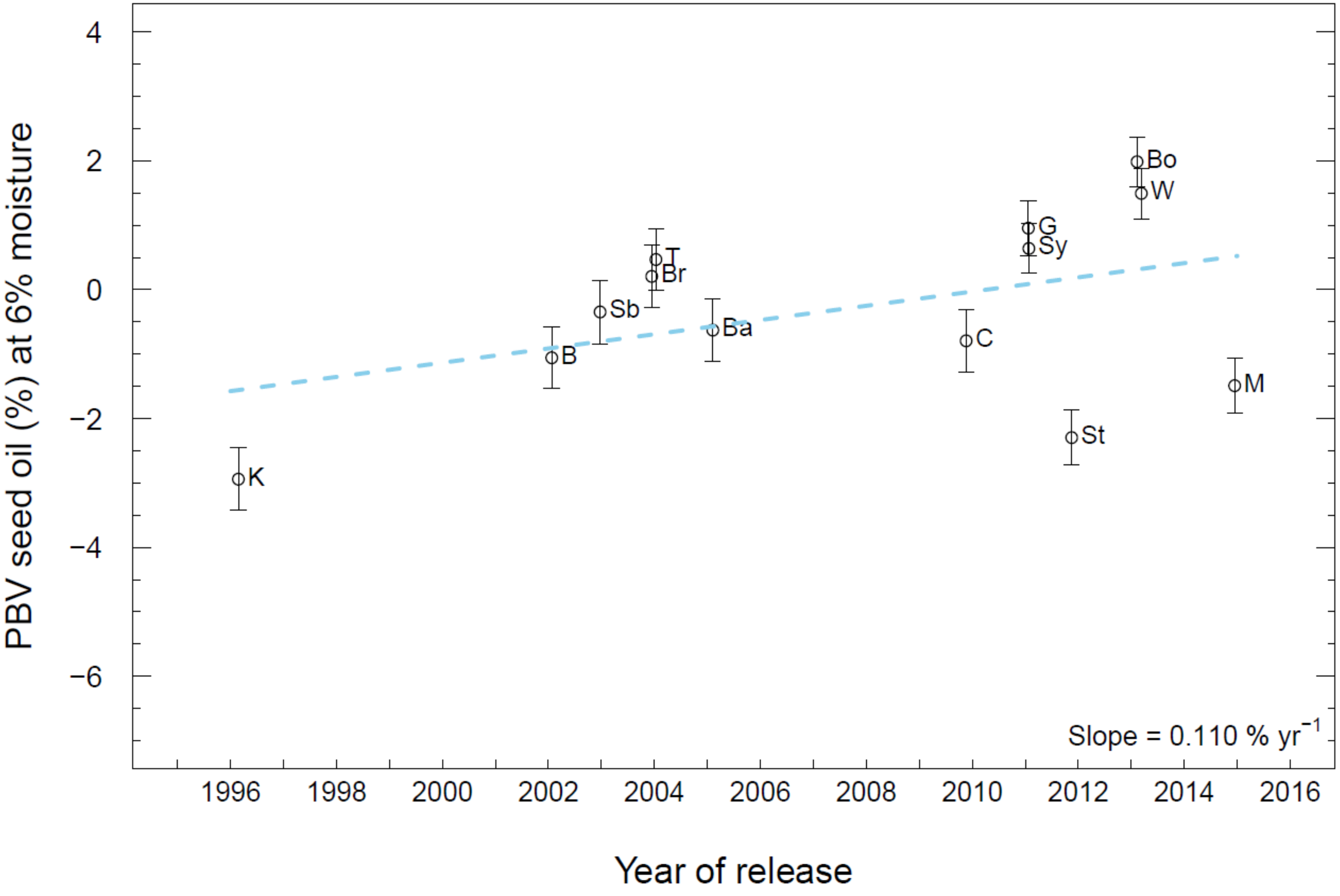
Cowling et al. 2023 Plants 12:383

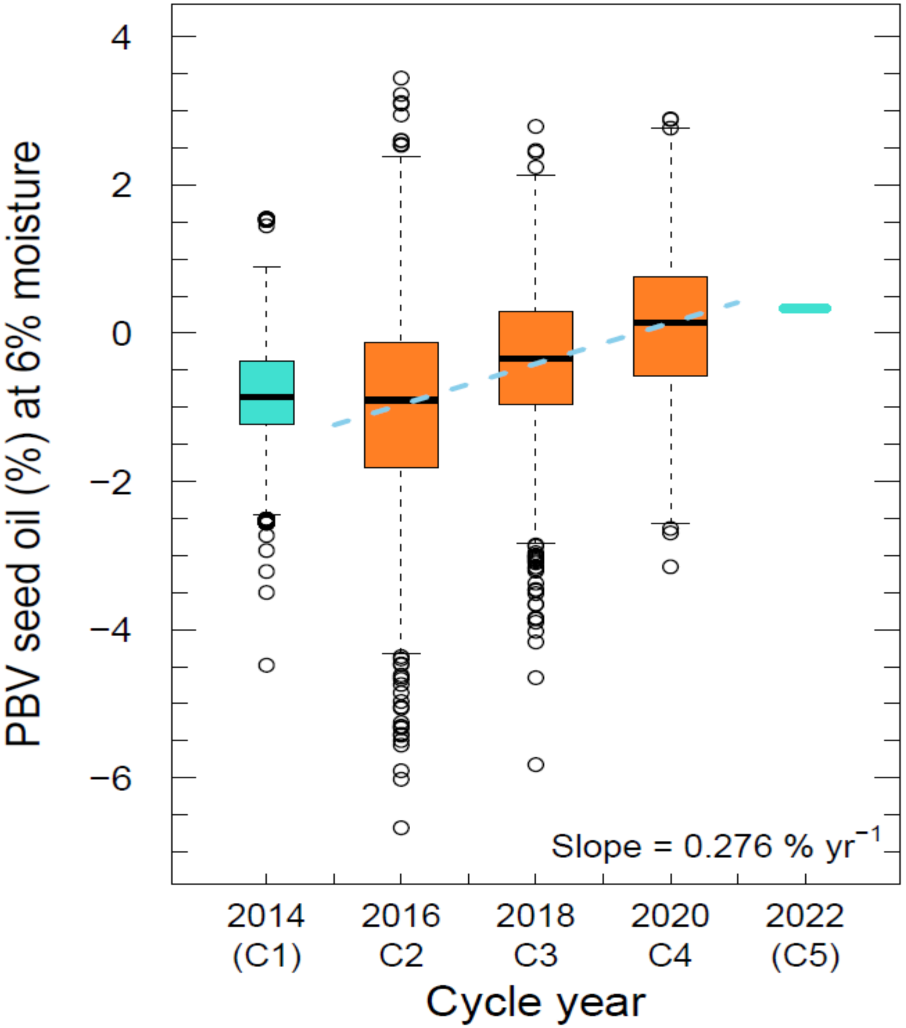


Genetic gain in seed oil%

- more than 2 x faster than traditional varieties in same trials

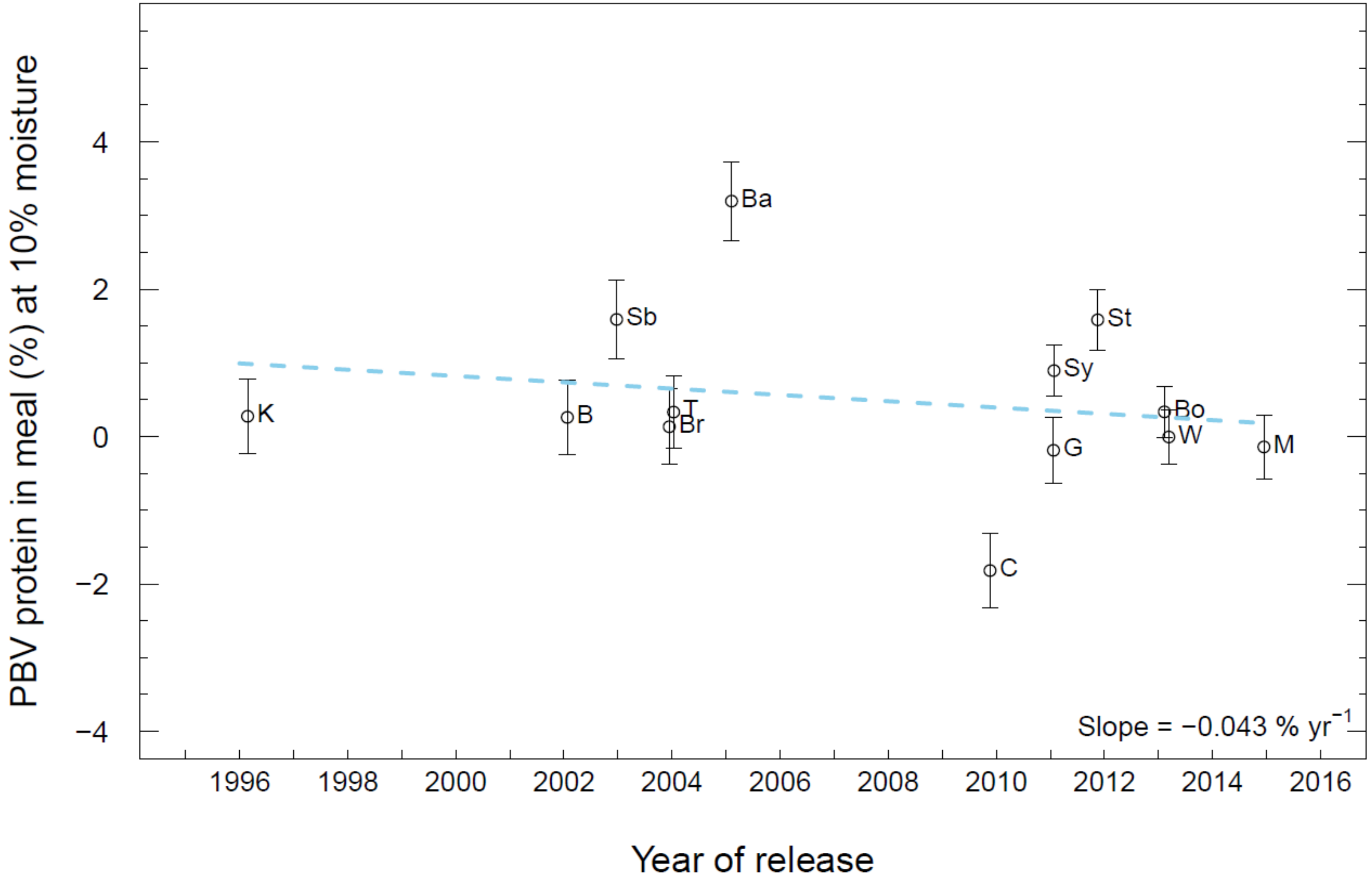
Cowling et al. 2023 Plants 12:383

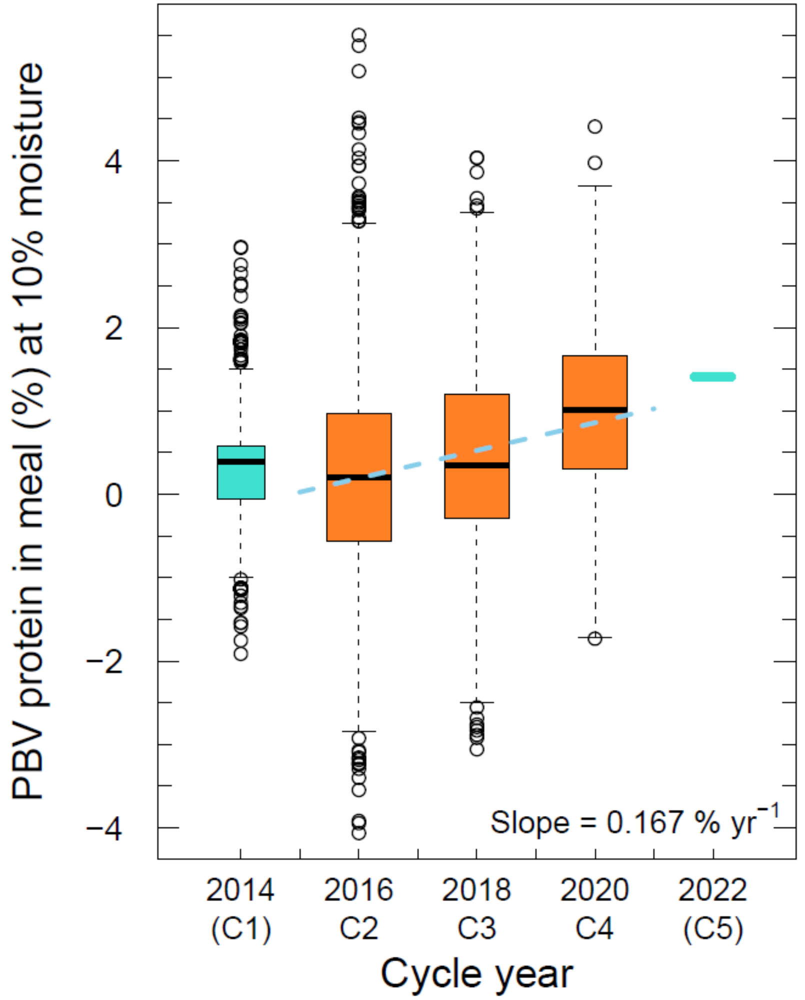




Genetic gain in protein in meal %
- no gain in traditional varieties in same trials

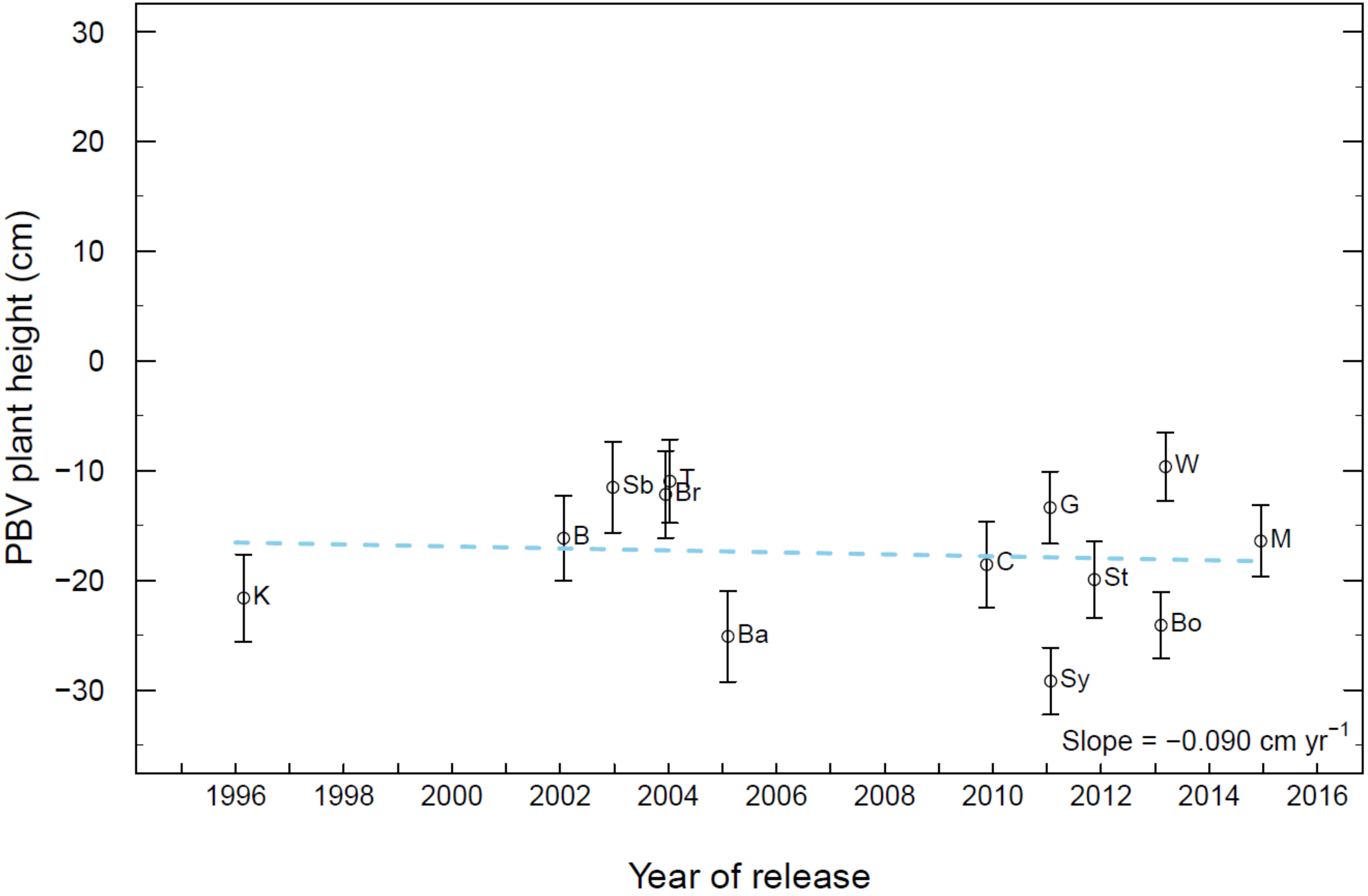
Cowling et al. 2023 Plants 12:383

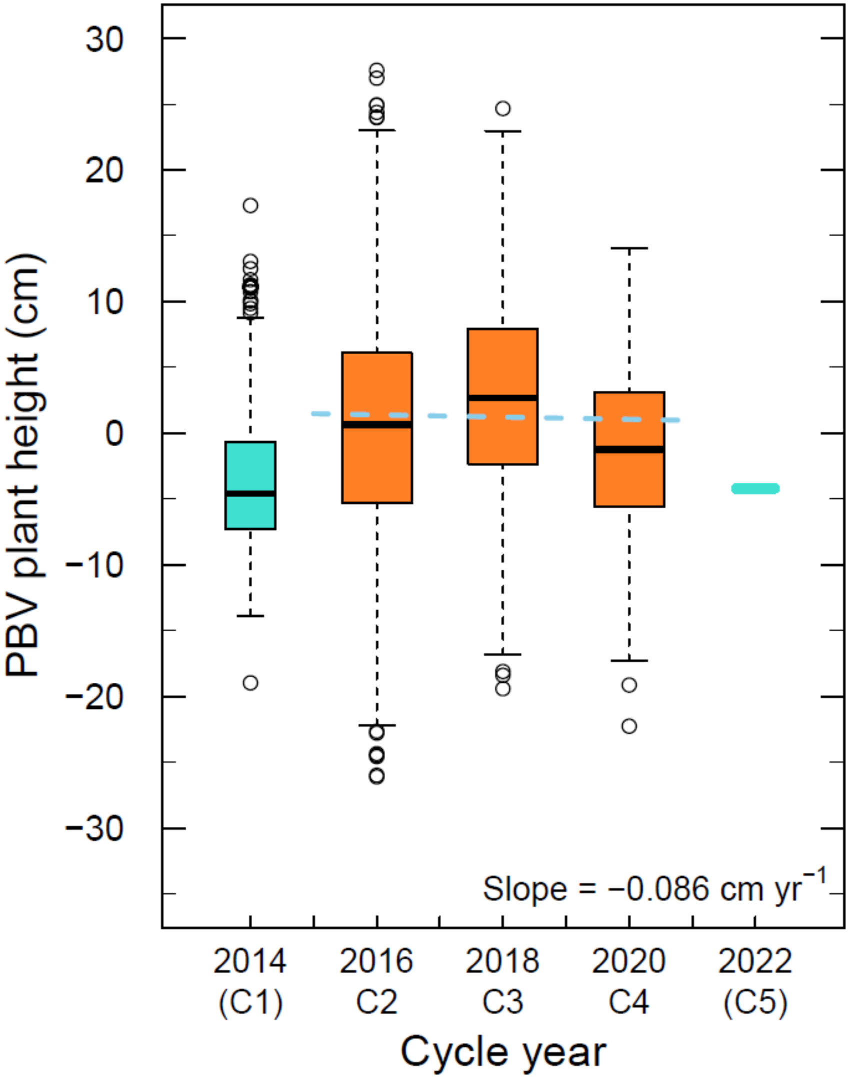




Select against tall plant height (cm) in cycles 3 and 4

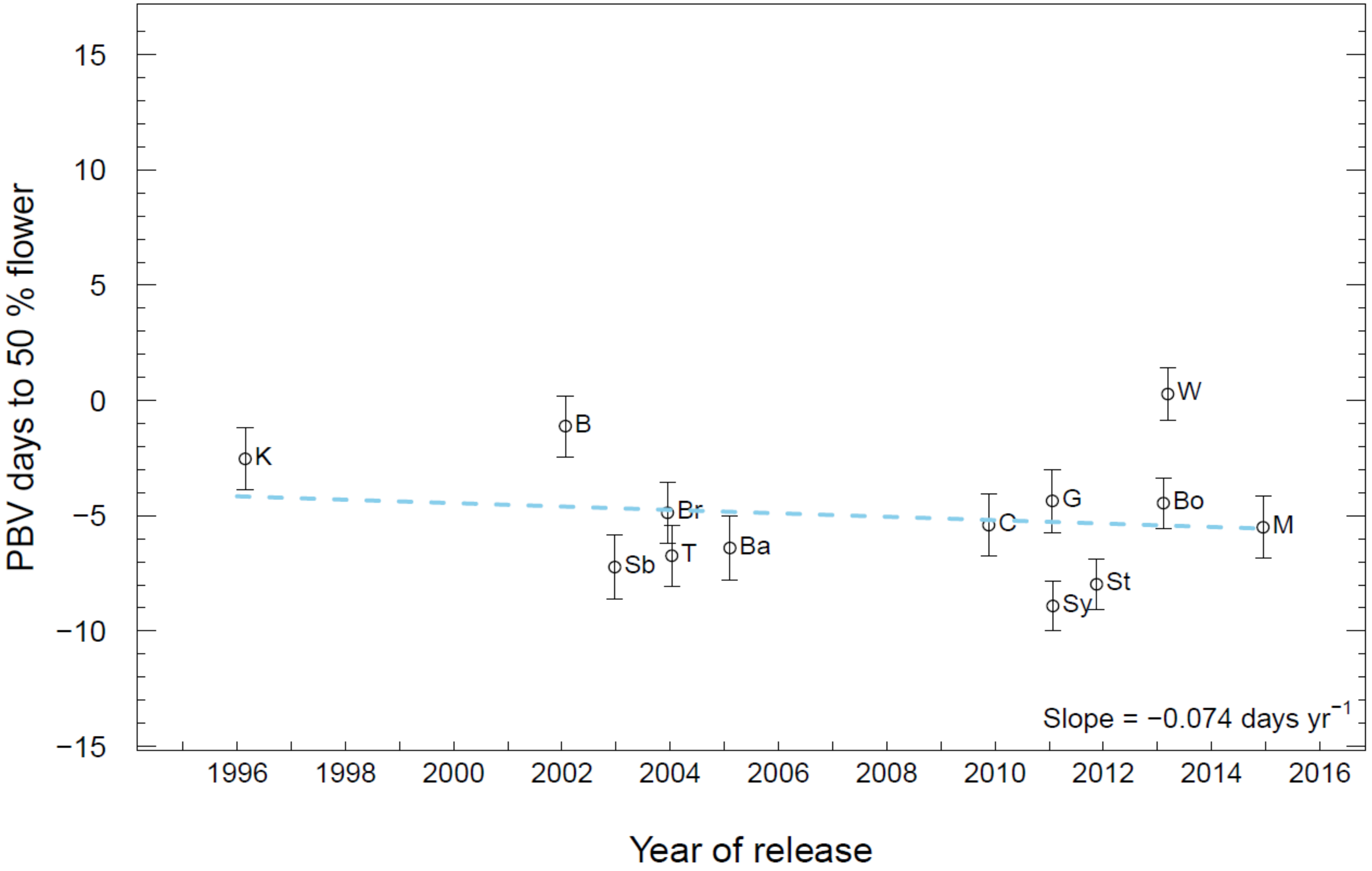
Cowling et al. 2023 Plants 12:383

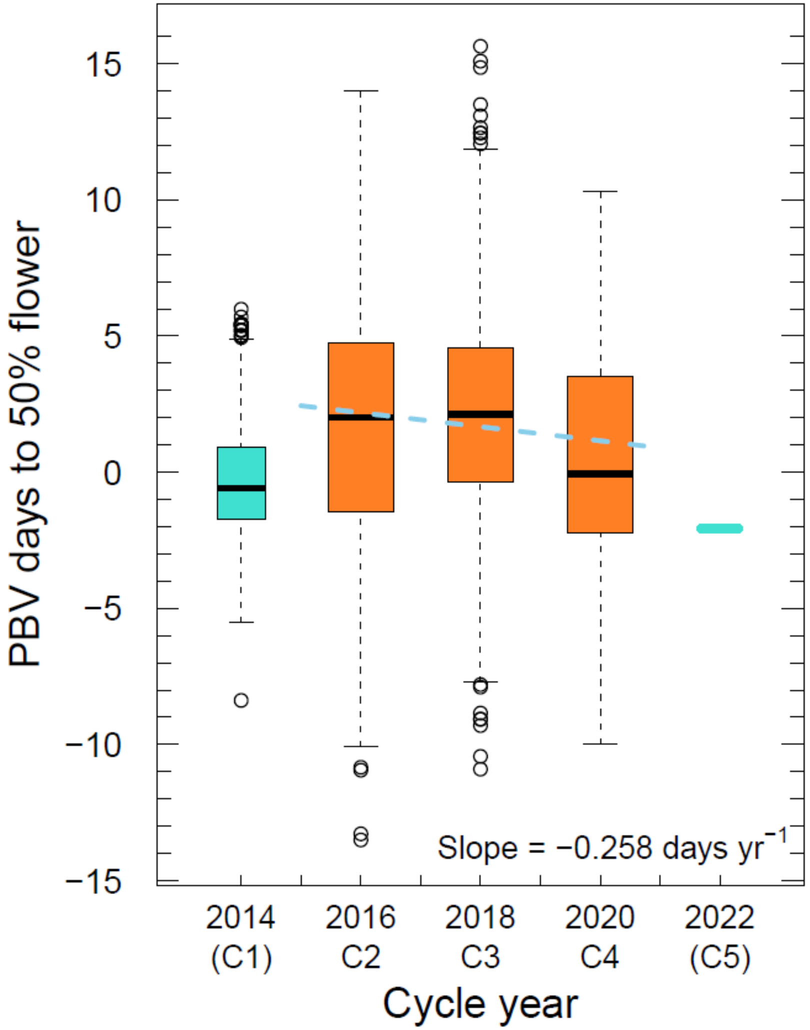




Select against late flowering in cycles 3 and 4

Cowling et al. 2023 Plants 12:383





Sustainable plant breeding for climate change

THE UNIVERSITY OF WESTERN AUSTRALIA

Breeding values with high accuracy
Rapid cycles
Index of multiple traits
Optimal contributions selection

BRIO

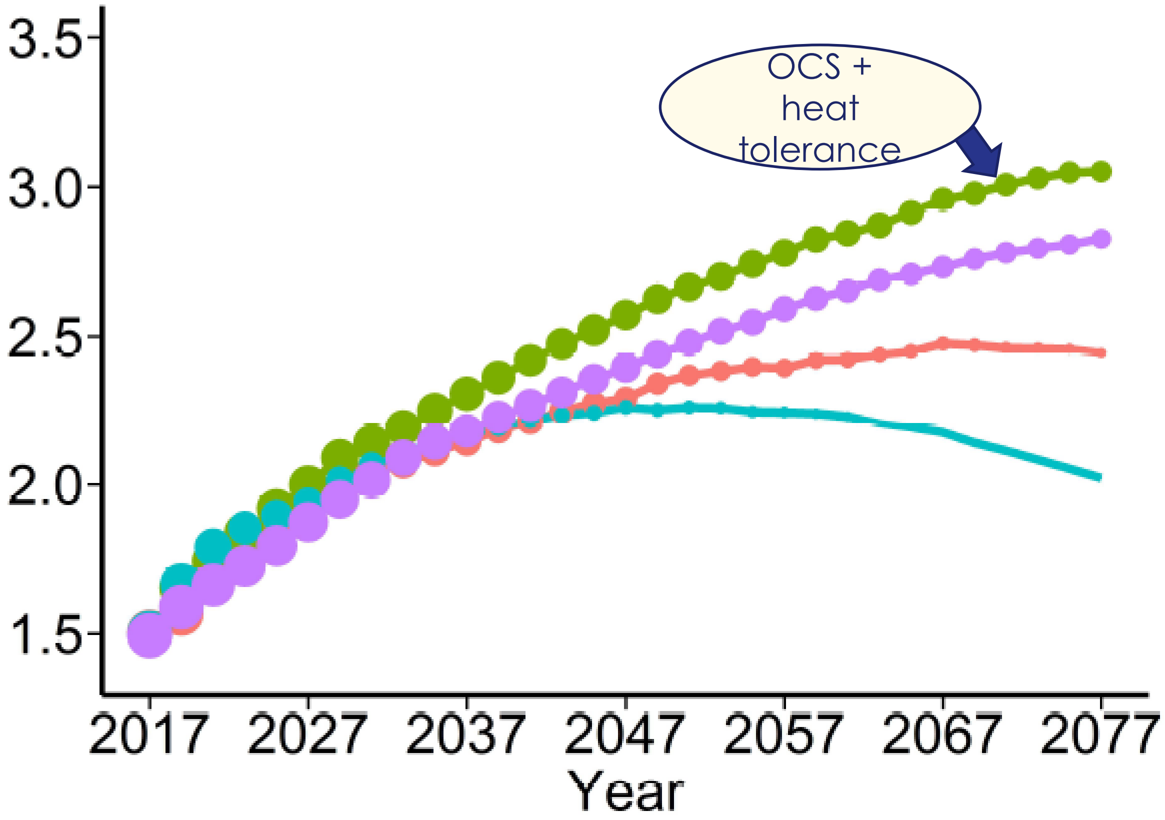
https://research.aciar.gov.au/rapidcookingbeans/brio

*** 4.3% genetic gain per year in grain yield in Canada and Australia 2016, 2018, 2020

+ increase in blackleg resistance
+ increase in seed oil%
+ increase in protein in meal%

Cowling et al. 2023 Plants 12:383

Sustainable breeding starts now ....



...in order to reach the 2009 Declaration of the World Summit on Food Security goal for a sustainable increase in global food production of 70% by 2050.

Questions?

Thank you

Thank you to Dr Nasser Yao, Demand Led Breeding project, for the opportunity to speak at the DLB seminar series

Acknowledgements

THE UNIVERSITY OF WESTERN AUSTRALIA

Prof Wallace A. Cowling
UWA

Felipe Castro
UWA

Dr Katia Stefanova
UWA

Prof Kadambot Siddique
UWA

Dr Renu Saradadevi
UWA

Dr Robert Banks
AGBU, UNE

Dr Li Li
AGBU, UNE

Emer Prof Brian Kinghorn
UNE

Dr Olaf Sass
NPZ Germany

une University of New England

THE UNIVERSITY OF WESTERN AUSTRALIA

125 NPZ Jahre