Soybeans resilience to heat stress during flowering and pod filling

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Soybean Breeders Workshop
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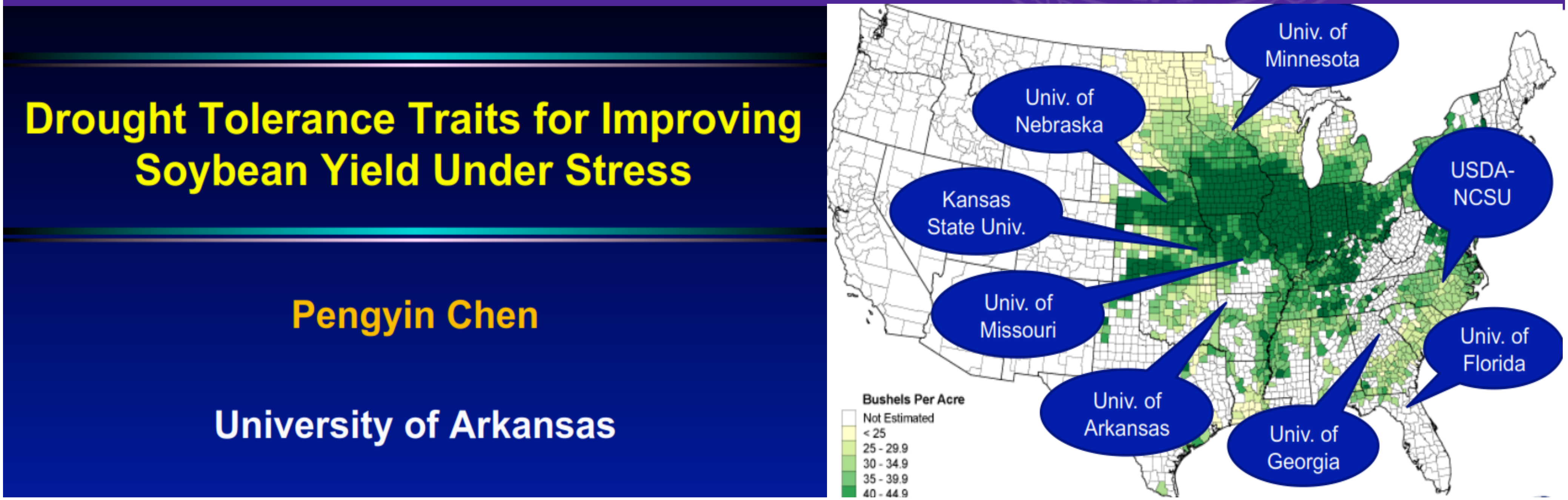
Kansas State University

Kansas Soybean Commission

Kansas Soybean Association


International Rice Research
Institute
Philippines



- **Slow wilting (Extensive use of canopy Temperature)**
- **Rooting traits/structure**
- **N2 fixation and**
- **Yield**

https://soybase.org/meeting_presentations/soybean_breeders_workshop/SBW_2014/presentations/Chen_SBW2014.pdf

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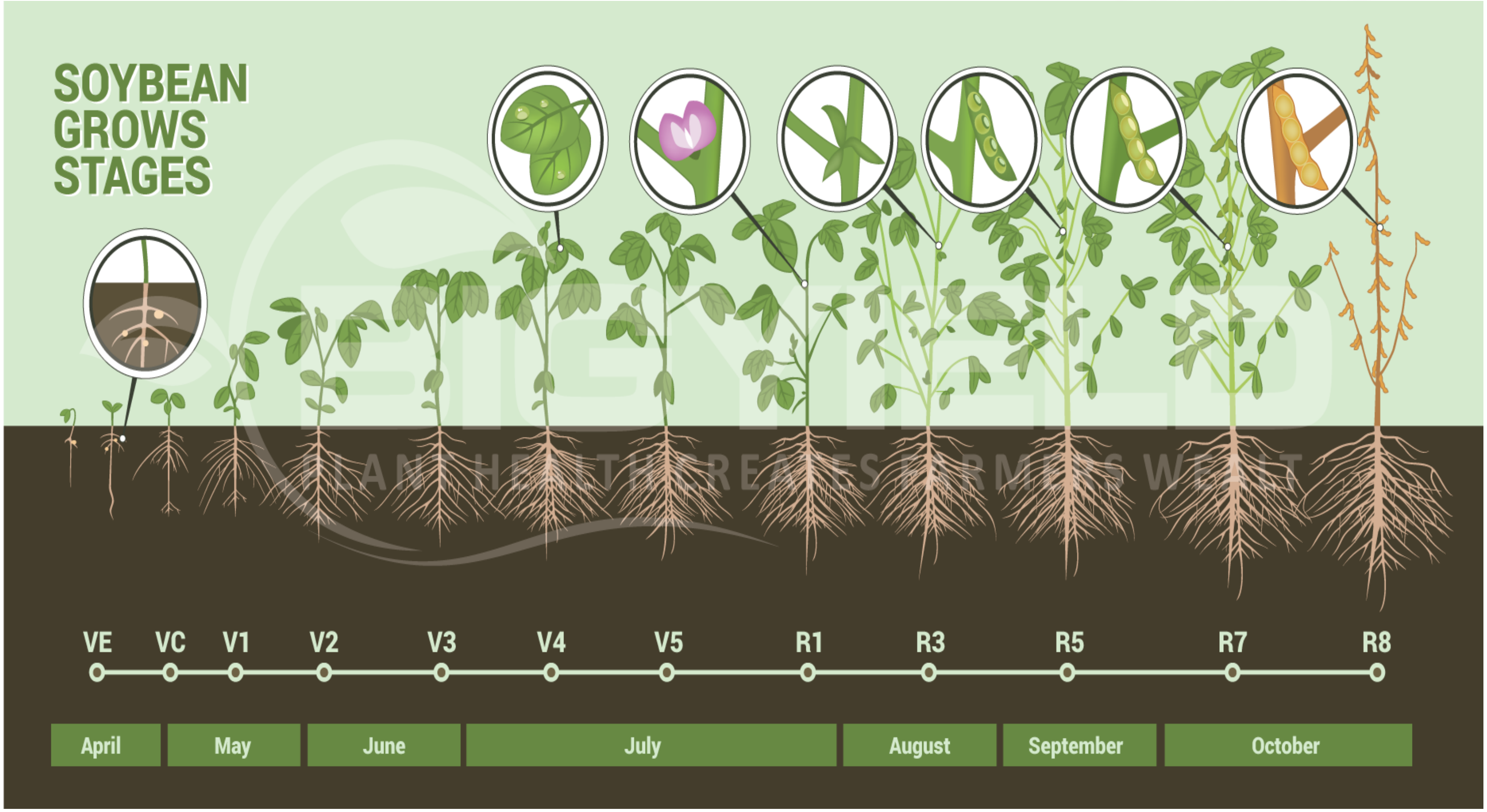
Thoughts for discussion

- **Resilience – escape, avoidance or true tolerance**
- **Differential high night and high day temperature?**
- **Yield and quality tradeoffs (Raju et al., Poster)**

<u>Non-stress conditions</u>

- **Plasticity in soybean cultivars CO2 for responsiveness?**

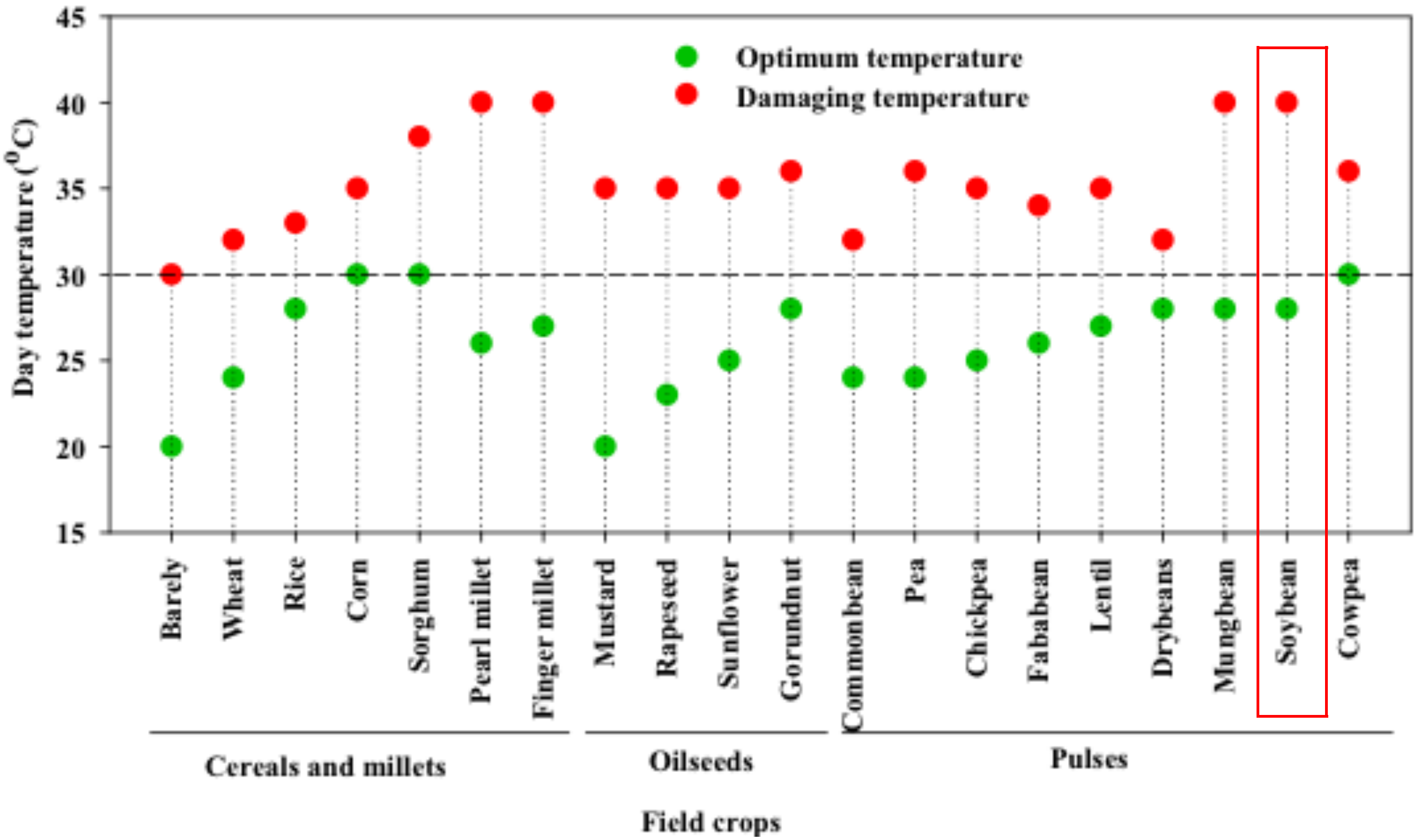
Soybean growth stages



Reproductive stage is extremely sensitive to moisture, **high temperature**, nutrient, deficiencies, lodging, or hail

Reproductive development typically has a lower temperature optimum (26 °C) than vegetative growth (30 °C; Hatfield et al., 2011)

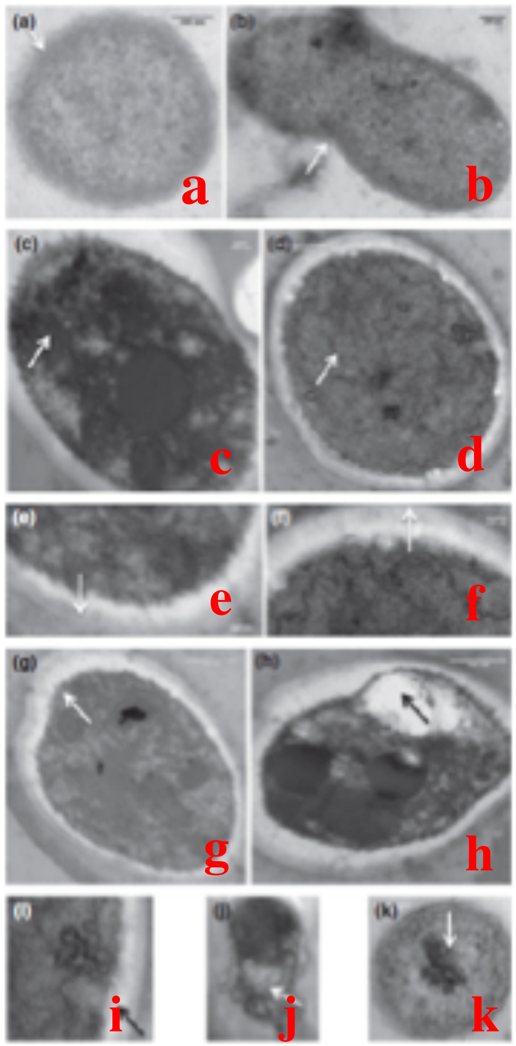
Day optimum and damaging temperature thresholds at reproductive stage in field crops



Soybean is generally considered to be relatively heat tolerant in comparison to other crop plants

Prasad PVV, Bheemanahalli R, Jagadish SVK. 2017. Field Crops Res 200, 114-121

Effect of high temperature on soybean pollen anatomy



Optimum – (a) circular shaped pollen
Heat stress – (b) Pollen grains irregular shaped

Optimum – (c) Dense cytoplasm
Heat stress – (d) Less dense cytoplasm

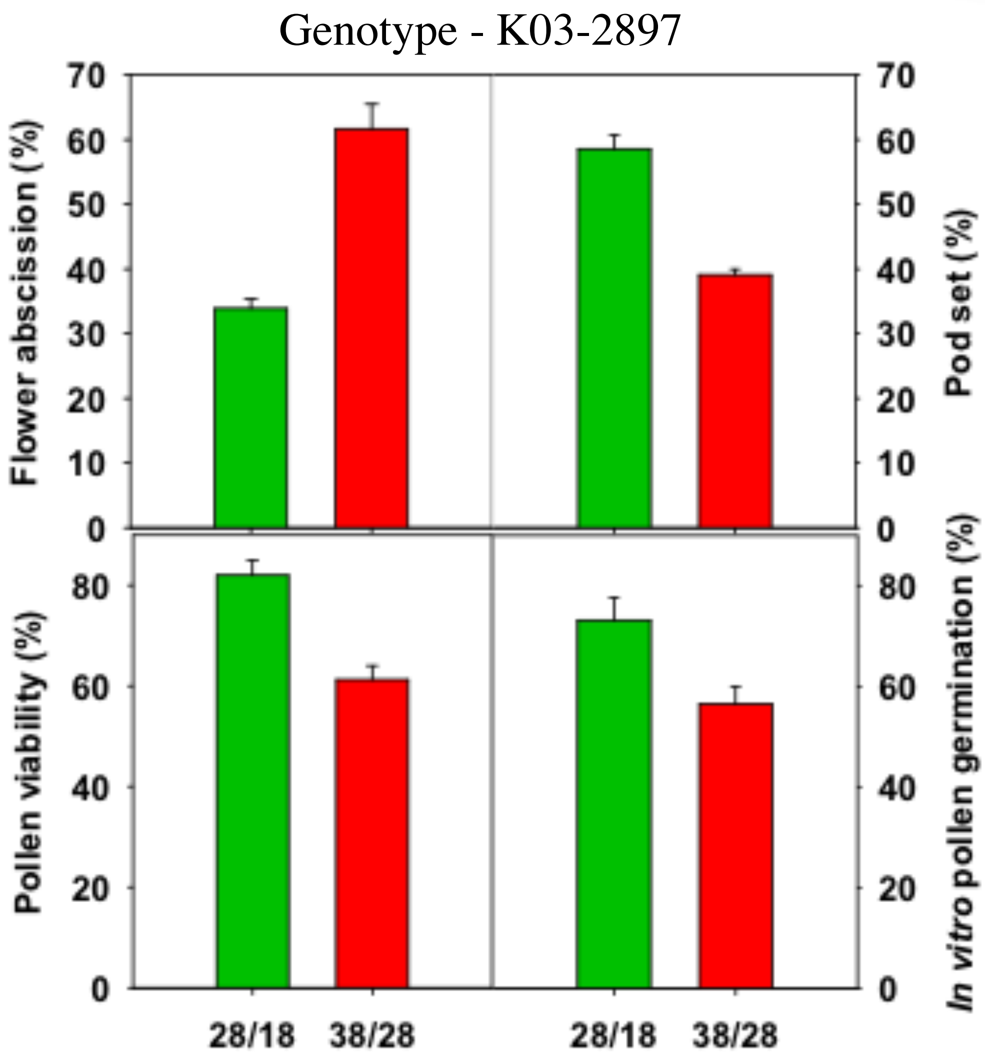
Optimum – (e) Thin exine wall
Heat stress – (f) Thick exine wall

Optimum - (g) Intact tapetal cells
Heat stress - (h) Degradation of tapetal cells

Heat stress - I and J – Pattern of tapetal cell degradation; K – Chromatin condensation

Djanaguiraman et al. 2013. J Agron Crop Sci, 199: 171–177

High temperature and pollen viability and pod set in soybean



Temperature (oC)

Djanaguiraman et al. 2013. J Agron Crop Sci, 199: 171–177

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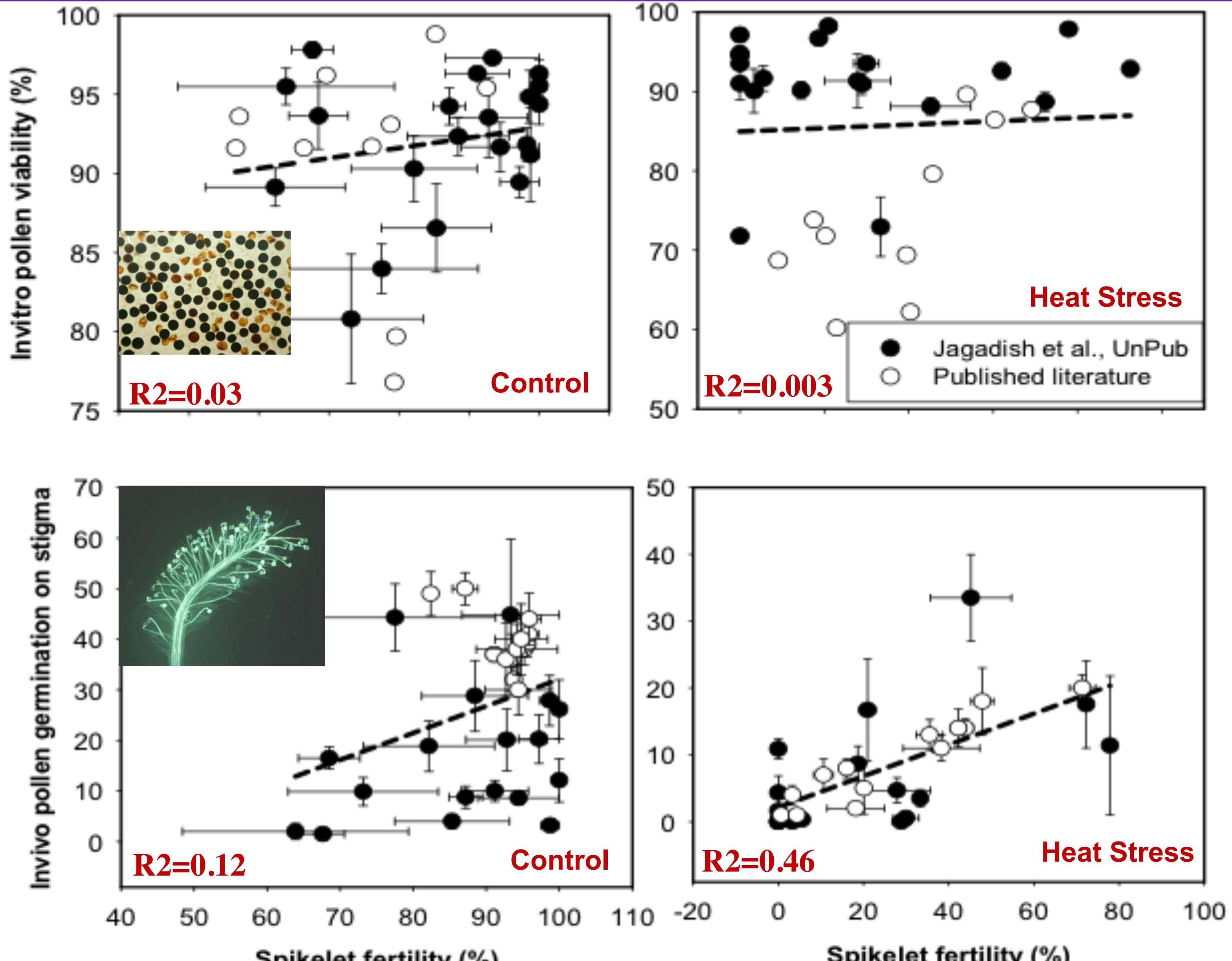
Rice - Pollen viability the sole determining factor?

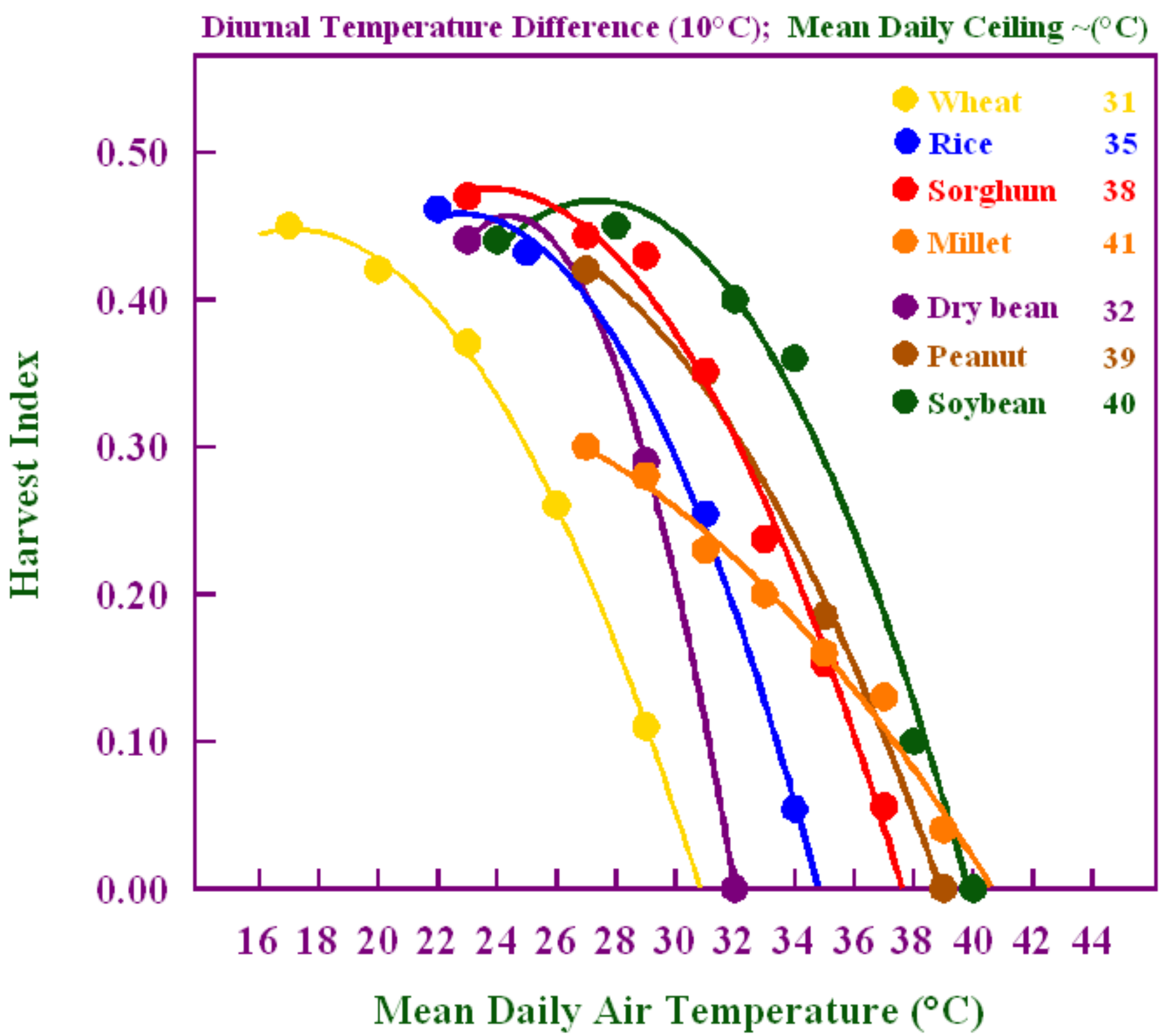


Jagadish et al., Plant Cell Environ., 2014, DOI: 10.1111/pce.12430

Flower opening time, pollen viability, Heat stress escape

5:59 am **Sorghum** 6:27 am

Season long heat stress on harvest index among field crops



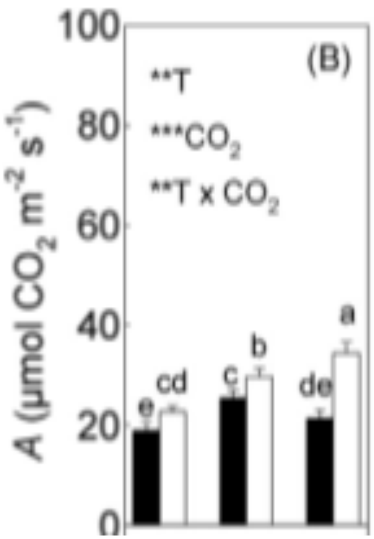
Avoidance through transpiration cooling?

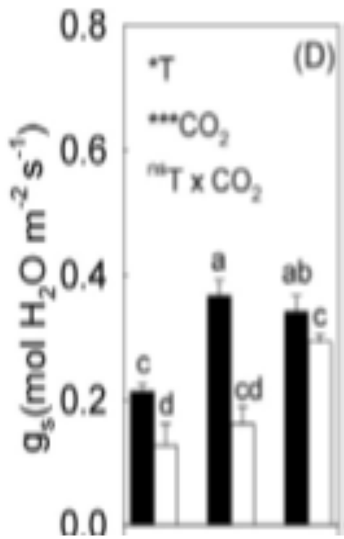
Prasad PVV, Bheemanahalli R, Jagadish SVK. 2017. Field Crops Res 200, 114-121

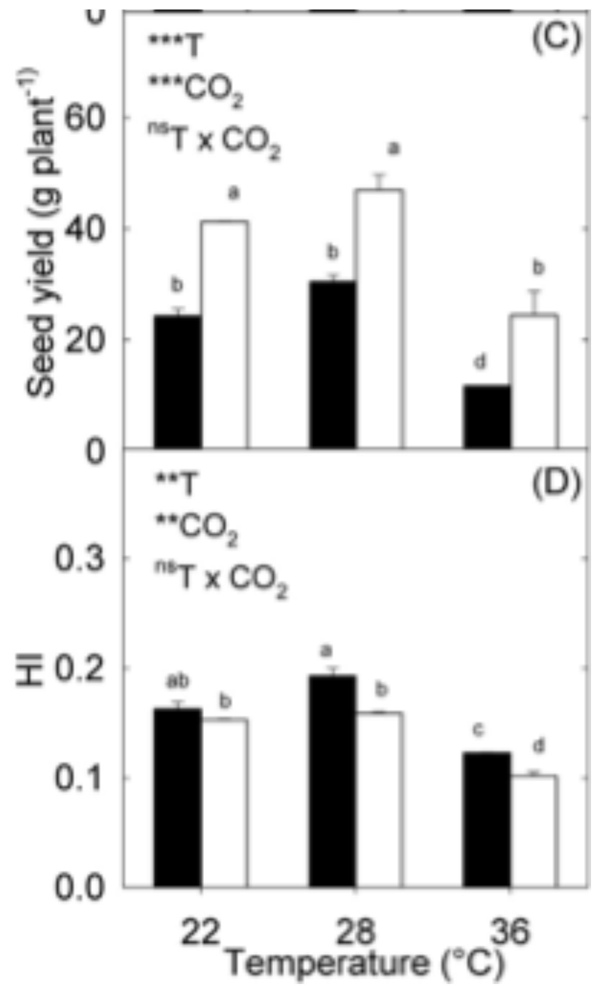
Elevated CO2 and high temperature interactions

aCO2 = 400 ppm
eCO2 = 800 ppm

aCO2 = black bars





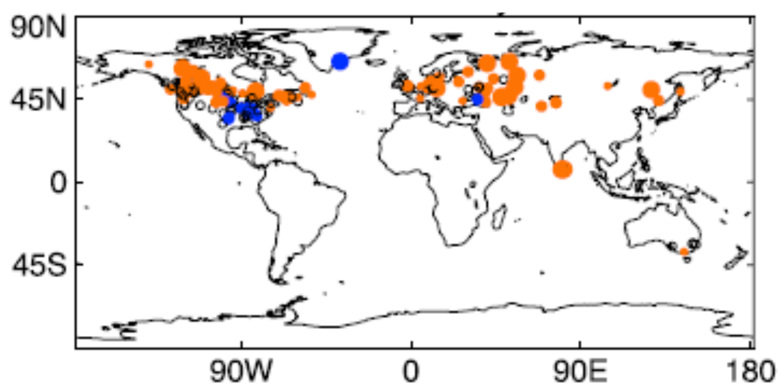


Soybean grown under elevated CO2 benefits more under low temperature than high temperature stress

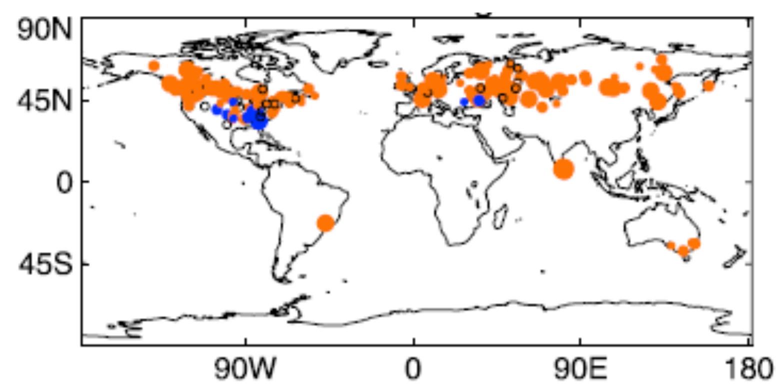
Xu et al., (2016) J Plant Physiol. 205, 205, 20–32

Global warming

- ➢ 0.1°C per decade since 1901 and 0.2°C per decade since 1970s
- ➢ 2001–2010 was the warmest decade
- ➢ **>3 times** increase in Tmin than Tmax.
- ➢ Estimated 10% yield loss for each 1°C increase in Tmin (Peng *et al.,* 2004).



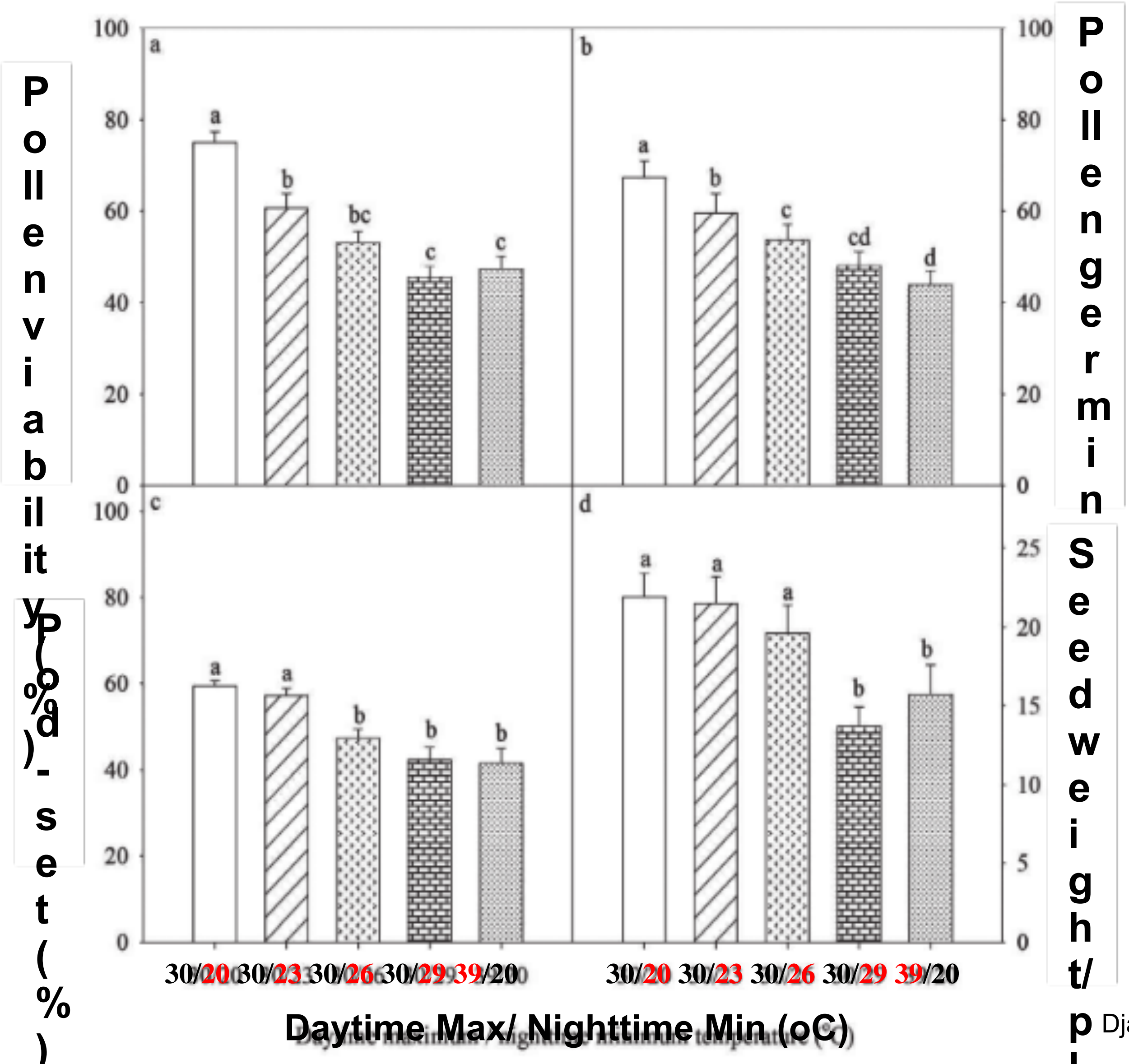
Warm days



Warm nights

Alexander et al., 2006; J. Geophy. Res.

High day and night temperature and reproductive success



Stress induced from R2 for 10 days

Djanaguiraman et al. 2013. Crop Sci 53, 1594-1604

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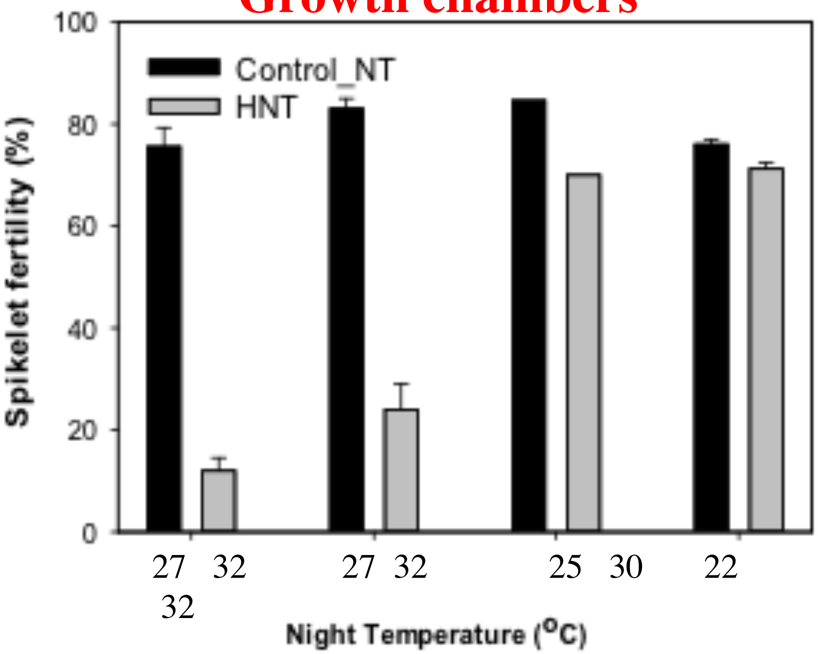
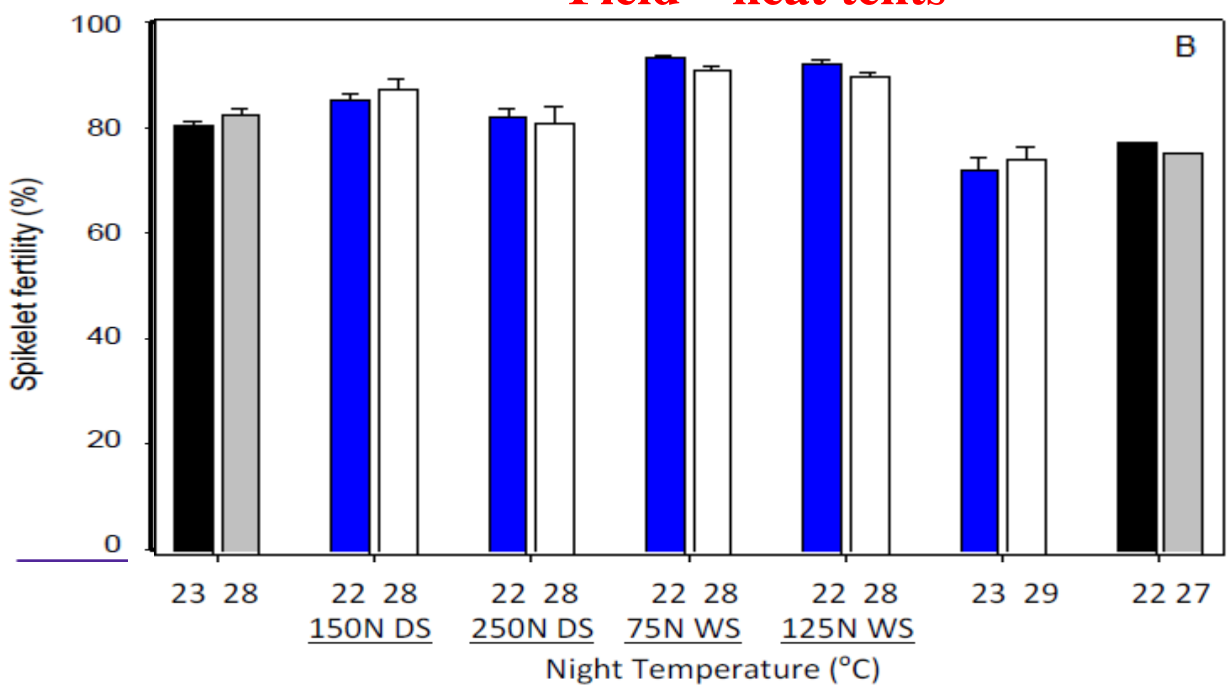
High night temperature tents, IRRI, Philippines

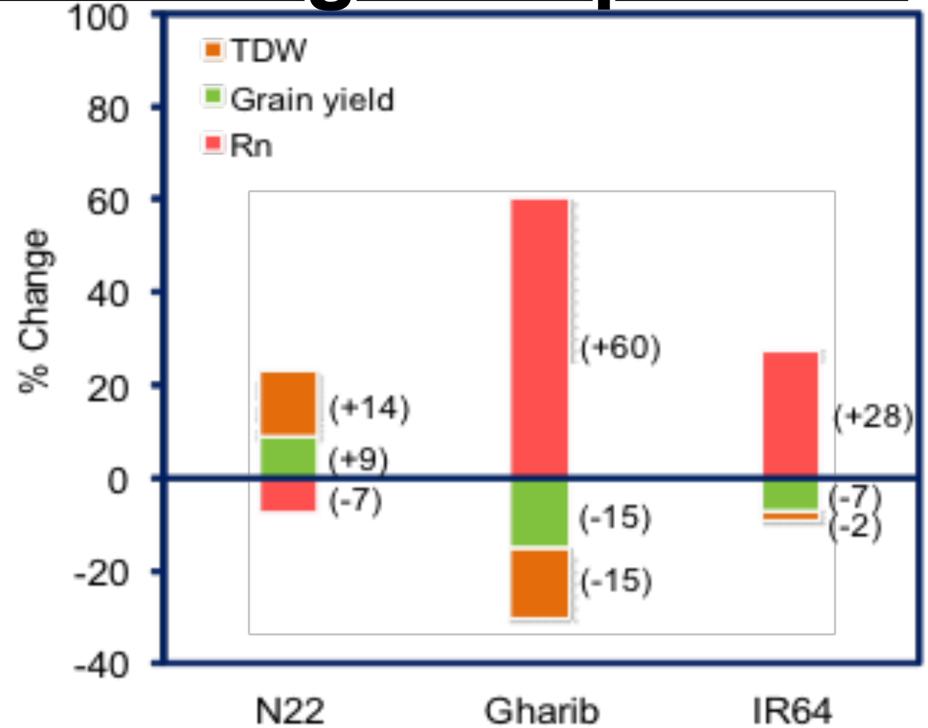
Growth chambers



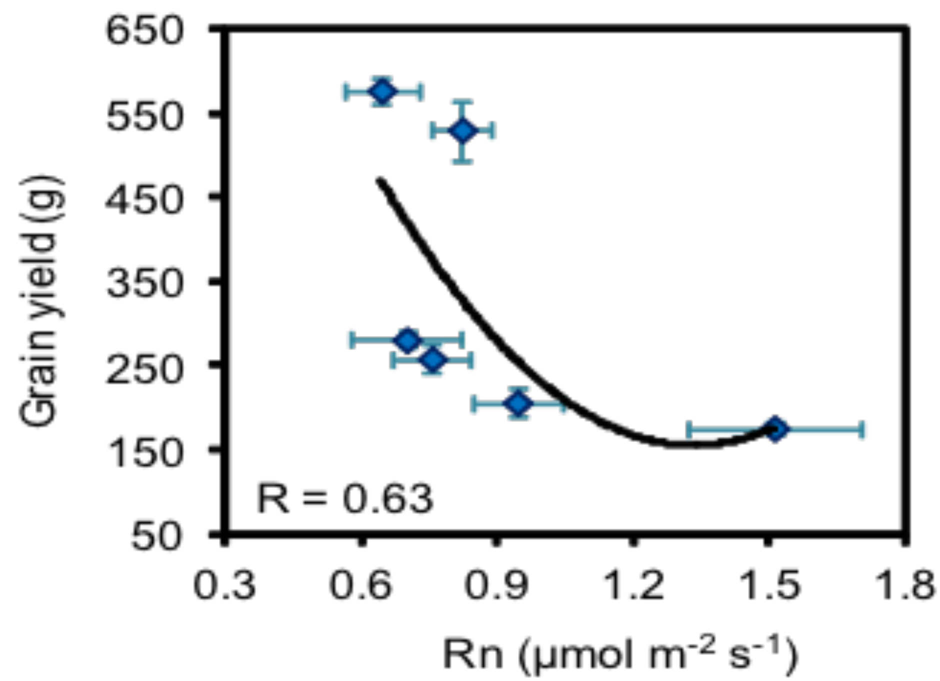
Field – heat tents



High Night Temperature and Night respiration



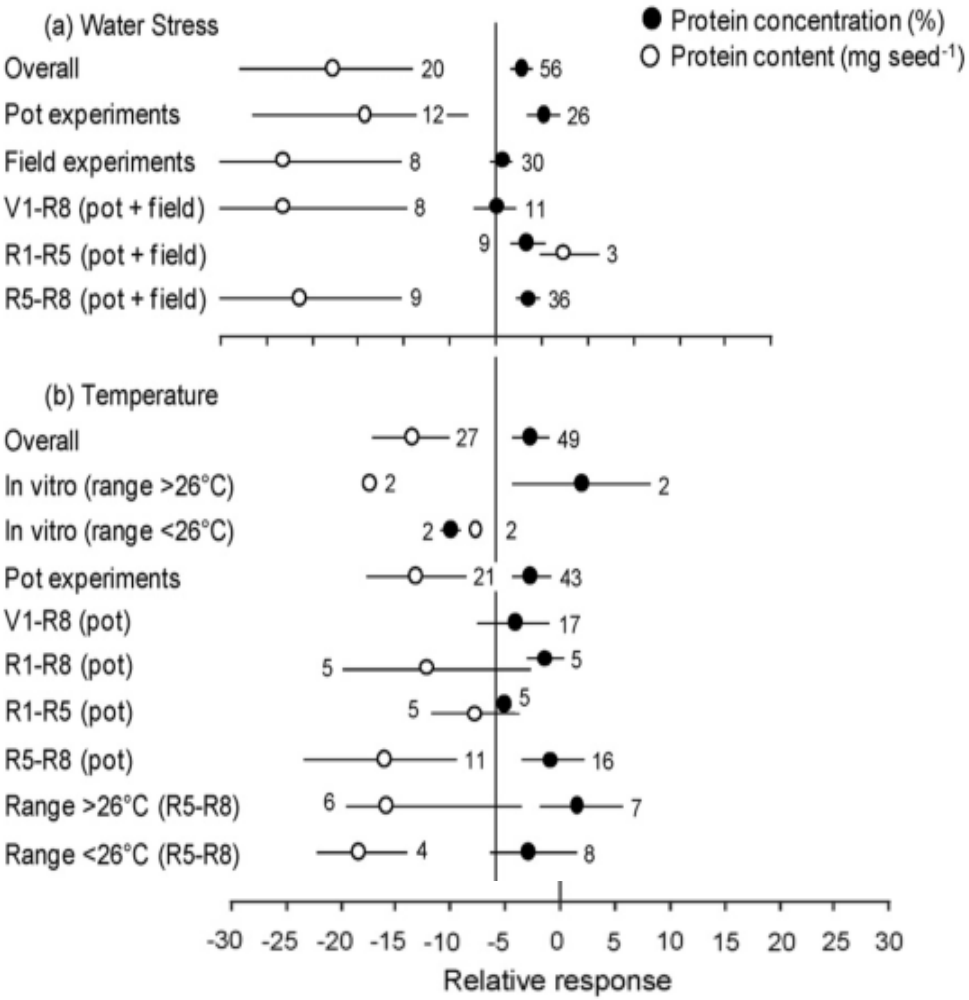
- -43 entries screened
- -Contrasting entries identified
- -In susceptible entry
  - -Spikelet fertility not reduced
  - -Biomass, N, NSC reduced
  - -Rate of grain filling reduced
  - -Grain width reduced
  - -Quality deteriorated

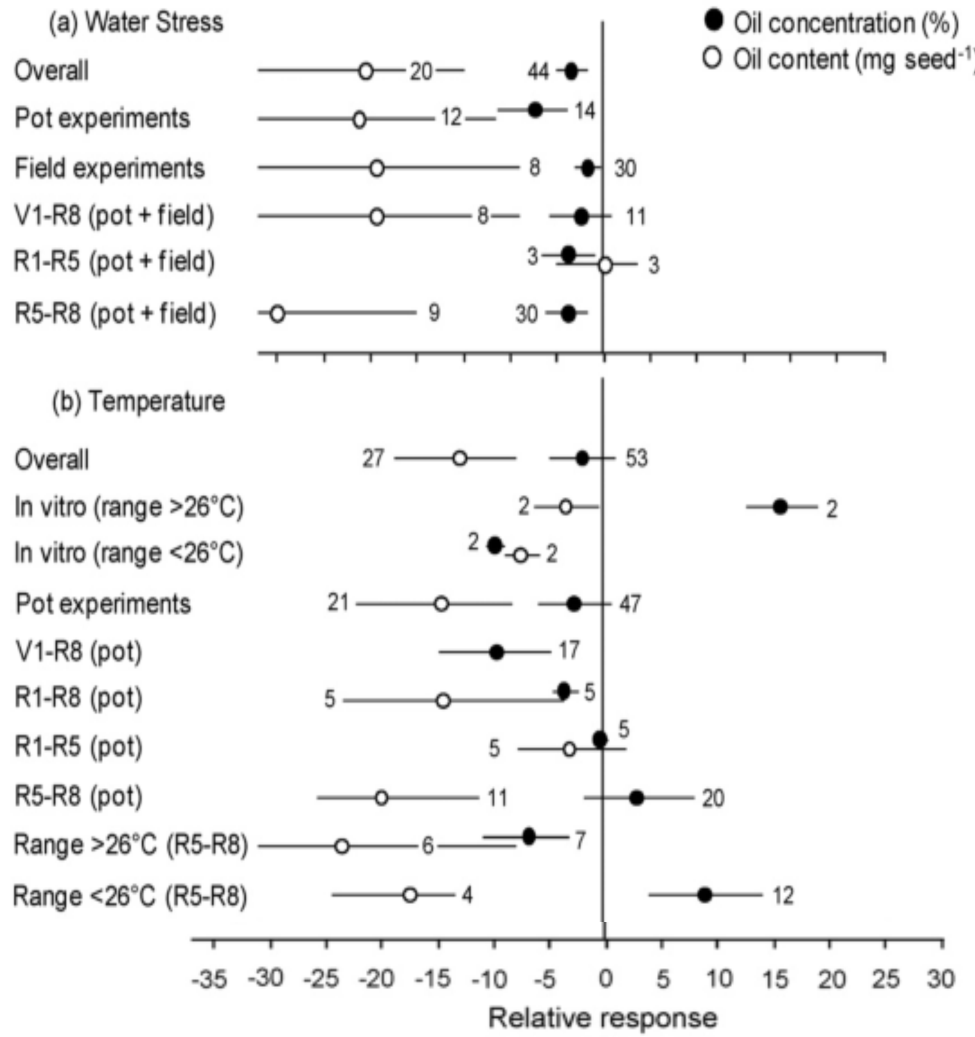


W. Shi et al., 2013 New Phytologist , 197, 825–837

Bahuguna et al., 2016 Physiol Plant doi:10.1111/ppl.12485

Environmental effect on seed component content





Rotundo and Westgate 2009,Field Crops Res, 110:147–156

Developing high yielding quality beans

Genetic materials

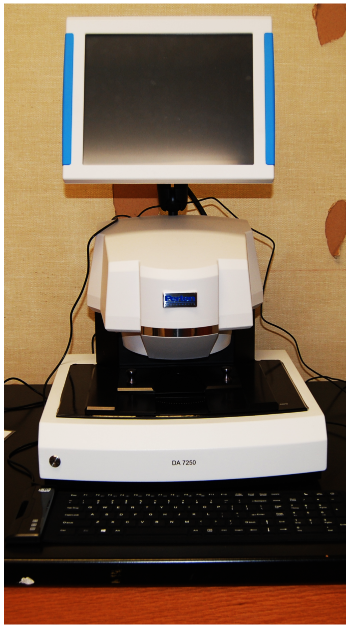
Elite/ breeding lines
Samples from 2 to 3 environments

Plant introductions

Mapping populations

Production plots

Reflectance based
(Screening)



DA 7250 (Perten)

950 to 1650 nm

Validation

- Wet lab
- GC-MS (2)*
- Outsourcing

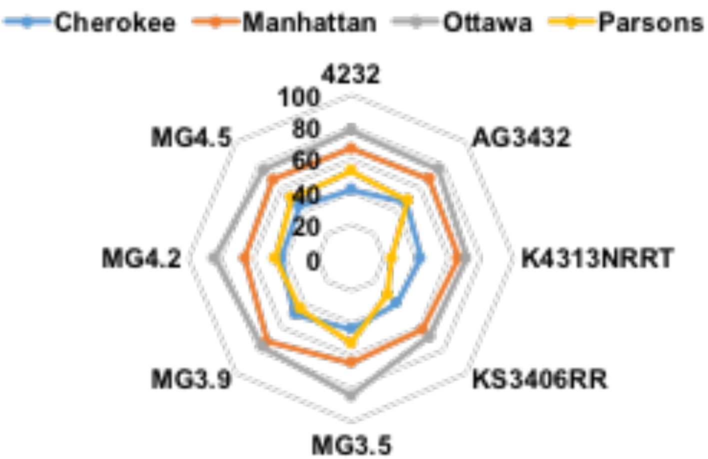
To establish spectral curve using samples covering the diversity

* Post doc (chemist)

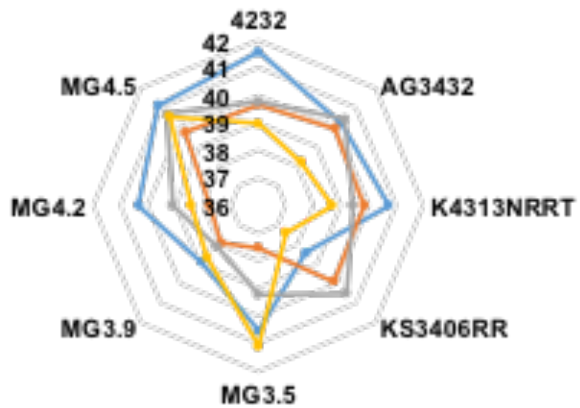
Soybean yield and quality tradeoffs

Raju BR et al., (Poster)

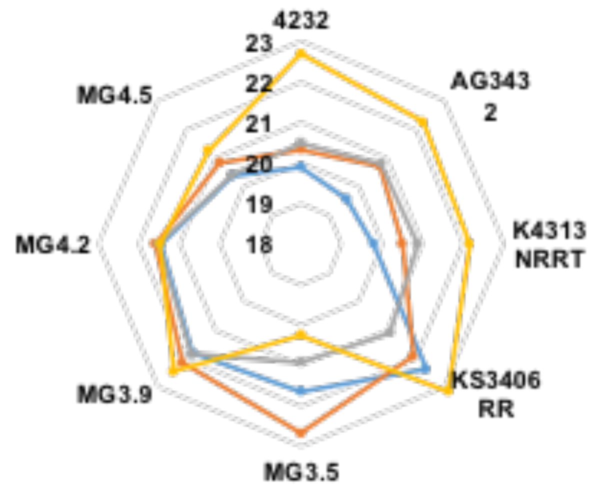
Yield



Protein (%)



Oil (%)

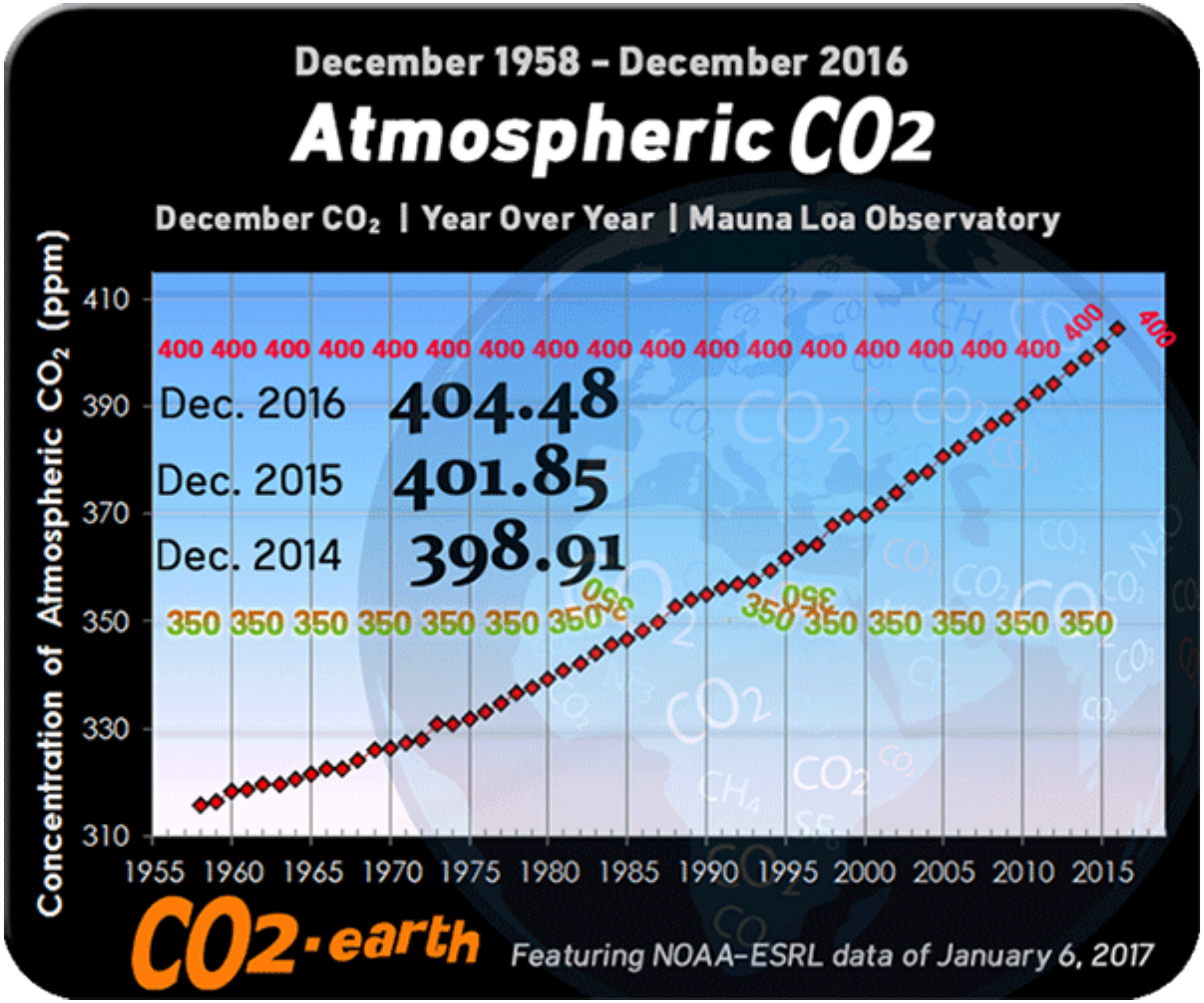


ADDITIONALLY All Amino acids and Fatty acids

G x E x M (mapping) yield and quality tradeoffs
G = genotype
E = Environment
M = Management

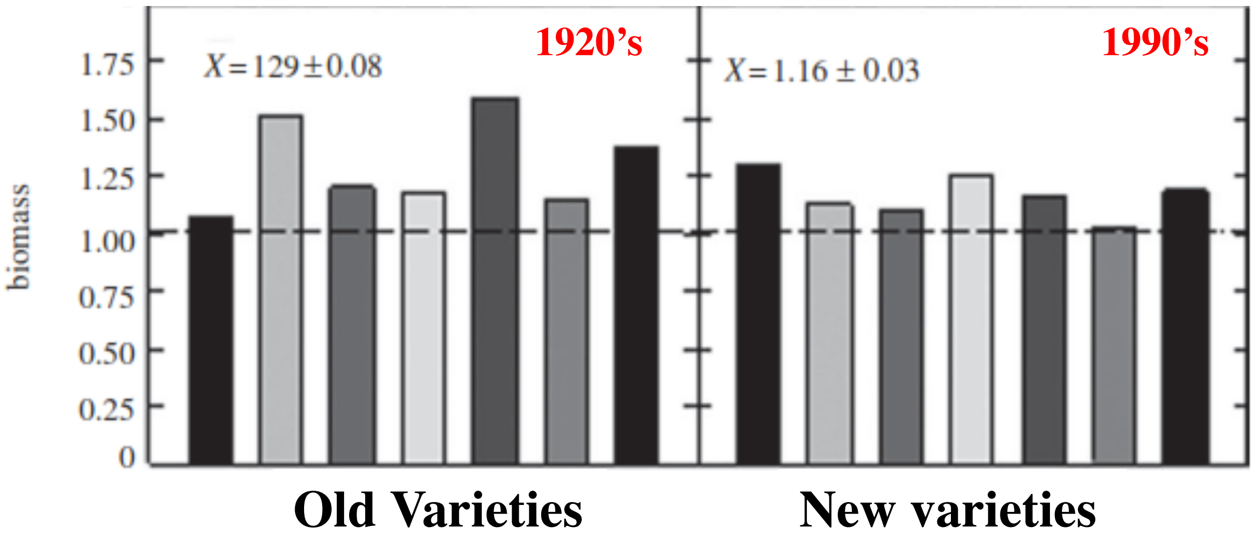
Have we been breeding beans for CO_2 responsiveness under <u>NON-STRESS</u> conditions

Are we benefitting from increasing CO2?



Are we not automatically selecting for CO2 responsiveness through breeding efforts?

Do newer lines perform better than old releases?



Released varieties of Oats (*Avena sativa*) for 7 geographical locations exposed to 100 μmol mol-1 CO2

Ziska et al., 2012, Proc. R. Soc. B, 279, 4097–4105

CO2 enrichment (control – **379** and elevated **689** ppm) and yield components in old and newer released **spring wheat** cultivars (# Varieties = 6). **Values are ratio of high/low**

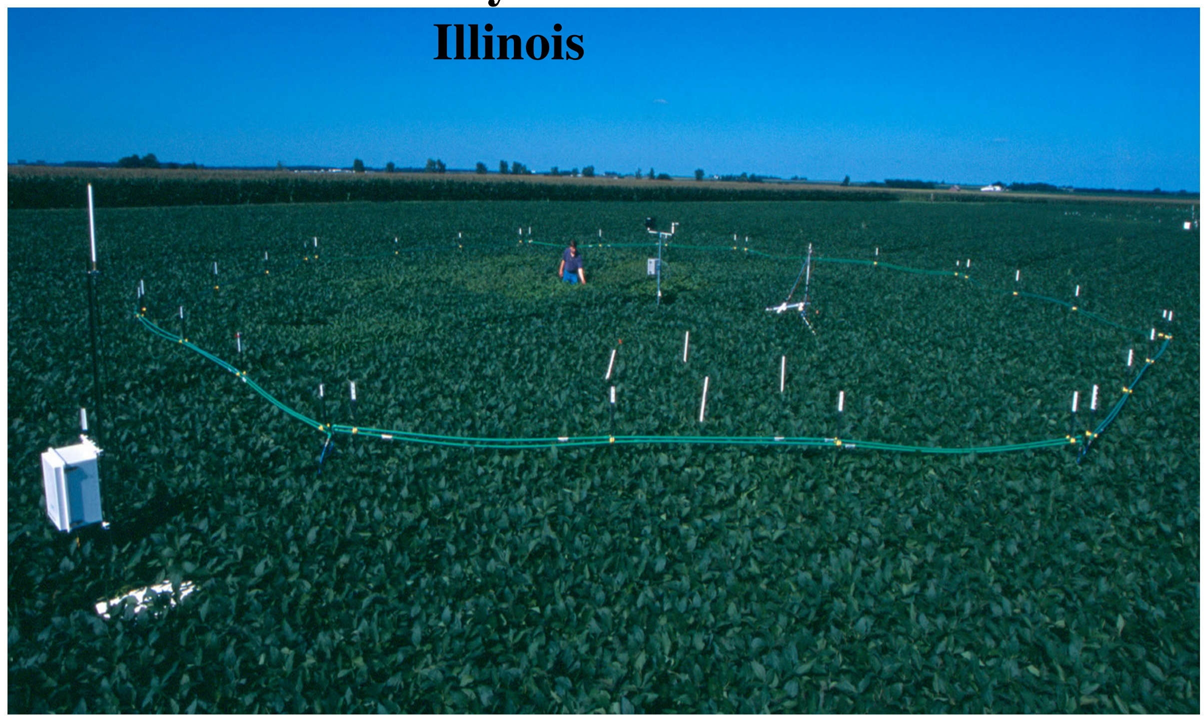
Variable	1890	1914	1943	1965	1979	1988
Kernal weight (mg)	1.03	1.04	1.08	1.06	1.06	1.12
Grain number/plant	**1.35**	**1.42**	**1.36**	1.13	1.11	1.16
Grain number/ear	**1.12**	**1.11**	1.04	0.94	0.98	1.01
Grain yield/plant	**1.39**	**1.47**	**1.51**	1.21	1.20	1.38

Manderscheid and Weigel, 1997, Agric. Eco. Environ. 64, 65-73

Expensive and hard to excite breeders

Open top field chambers

SoyFACE - Illinois

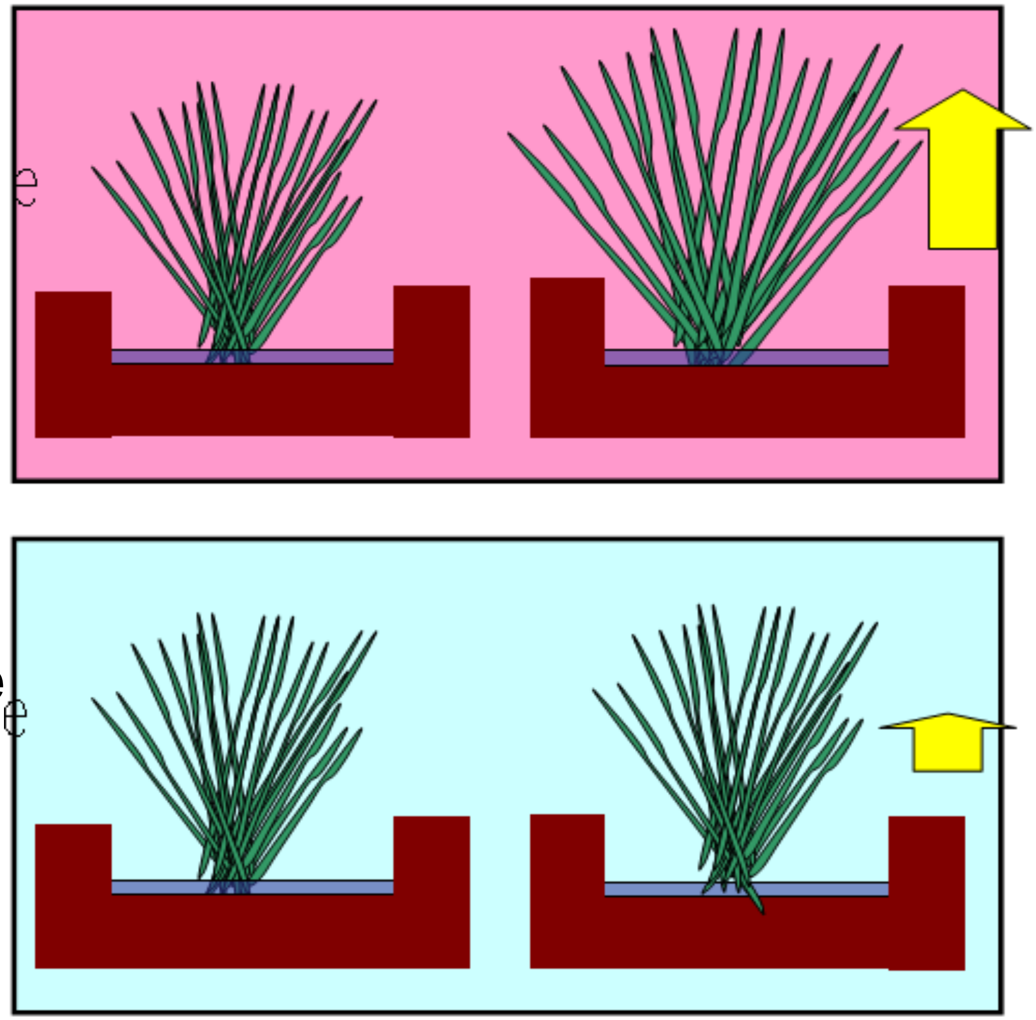


Alternative (pre) screening for CO_2 responsiveness

Normal | Elevated CO_2

High Responsive Cultivars

Low Responsive Cultivars



<u>Mechanism</u> **Elevated CO_2 increases carbohydrate supply due to increased photosynthesis**

<u>Screening</u> **FACE, OTC reliable but too expensive and unsustainable**

Cheaper option?

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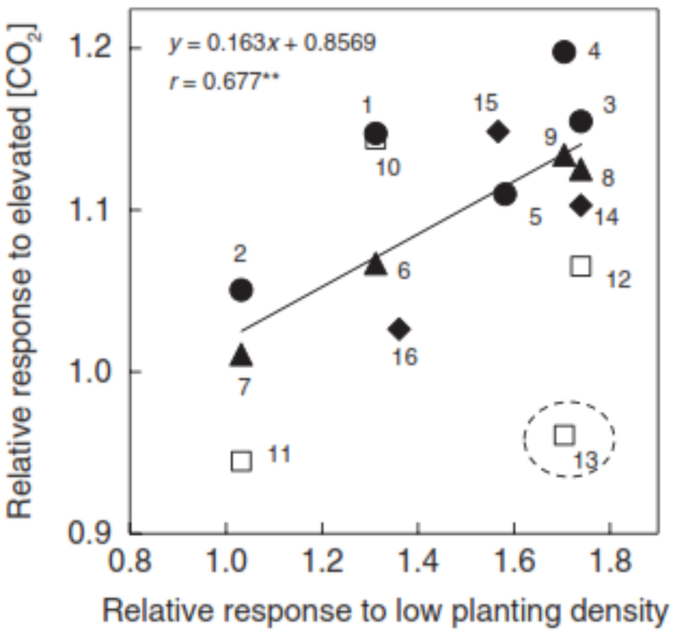
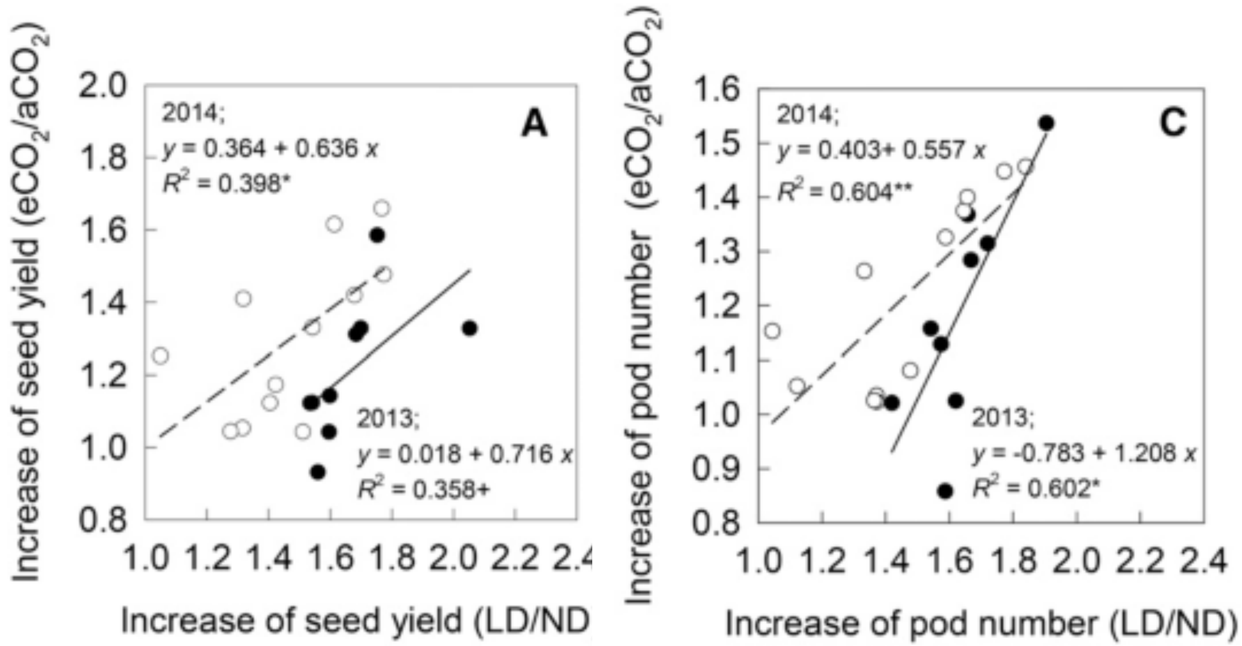
Low planting density for CO2 responsiveness tested and



Rice - Free Air CO2 Enrichment (1-5), Temperature Gradient Chamber (6-9), TGC low temperature (10-13) IRRI, Philippines (14, 15 and 16 from Moya et al., 1998.

Shimono et al., 2014 Physiol Plant. 152: 520-528



Soybean – Relationship between ratio of values at eCO2 and aCO2; and the ratio of Low density to normal density in 2013 (black circles) and 2014 (while circles). **12 cultivars with maturity groups I to IV and VII**

Kumagai et al., 2015, Plant Phys. 169, 2021–2029

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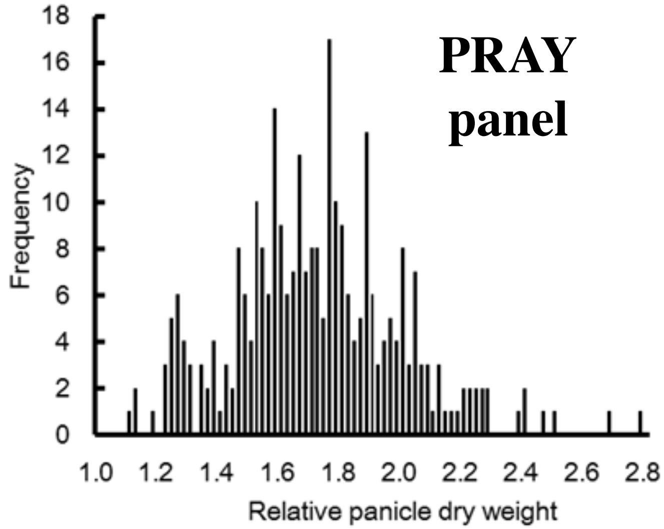
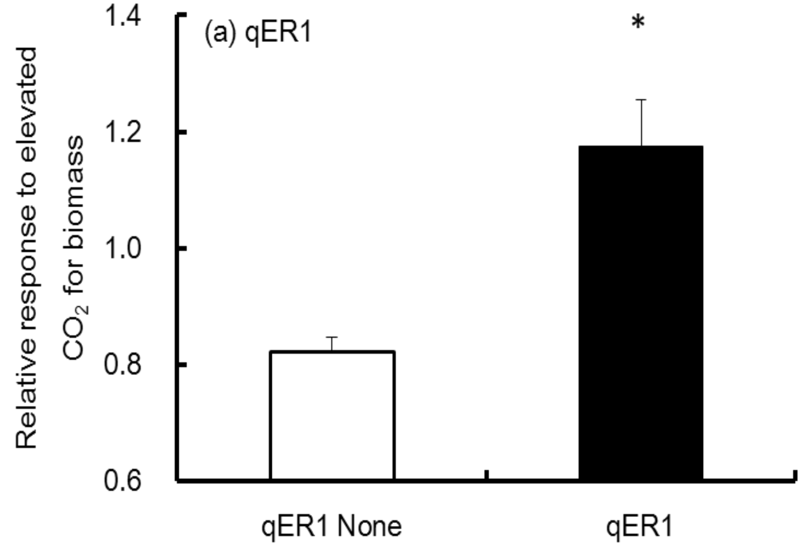
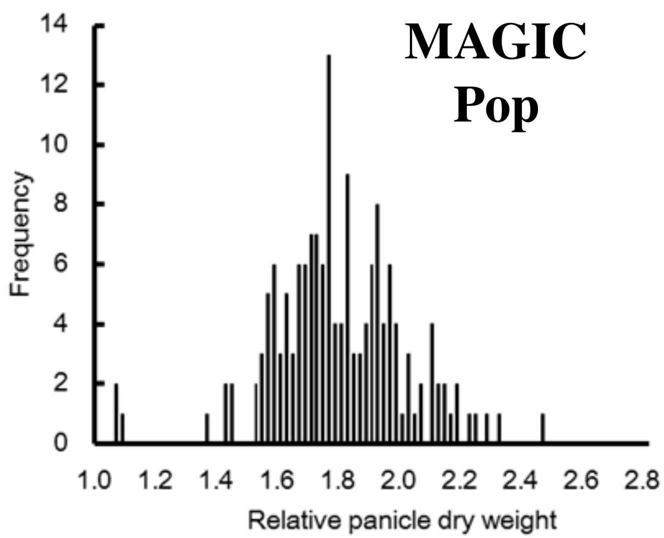
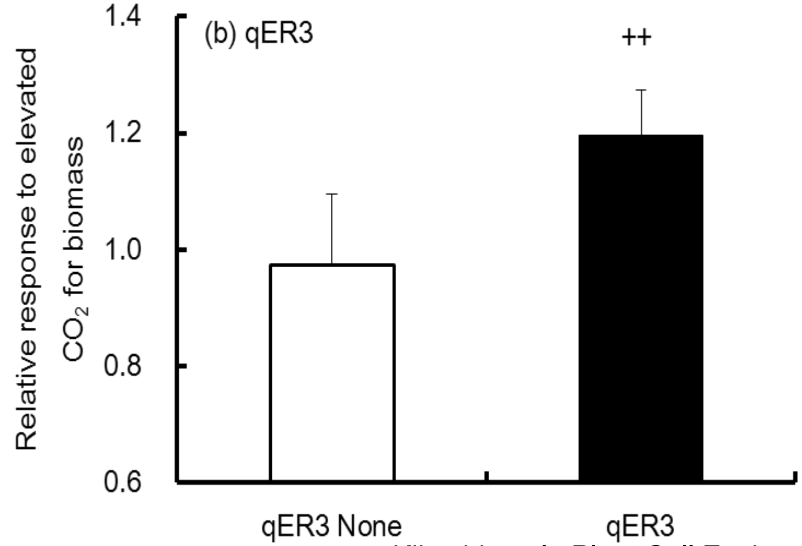
Genetic mapping for CO2 responsiveness in rice



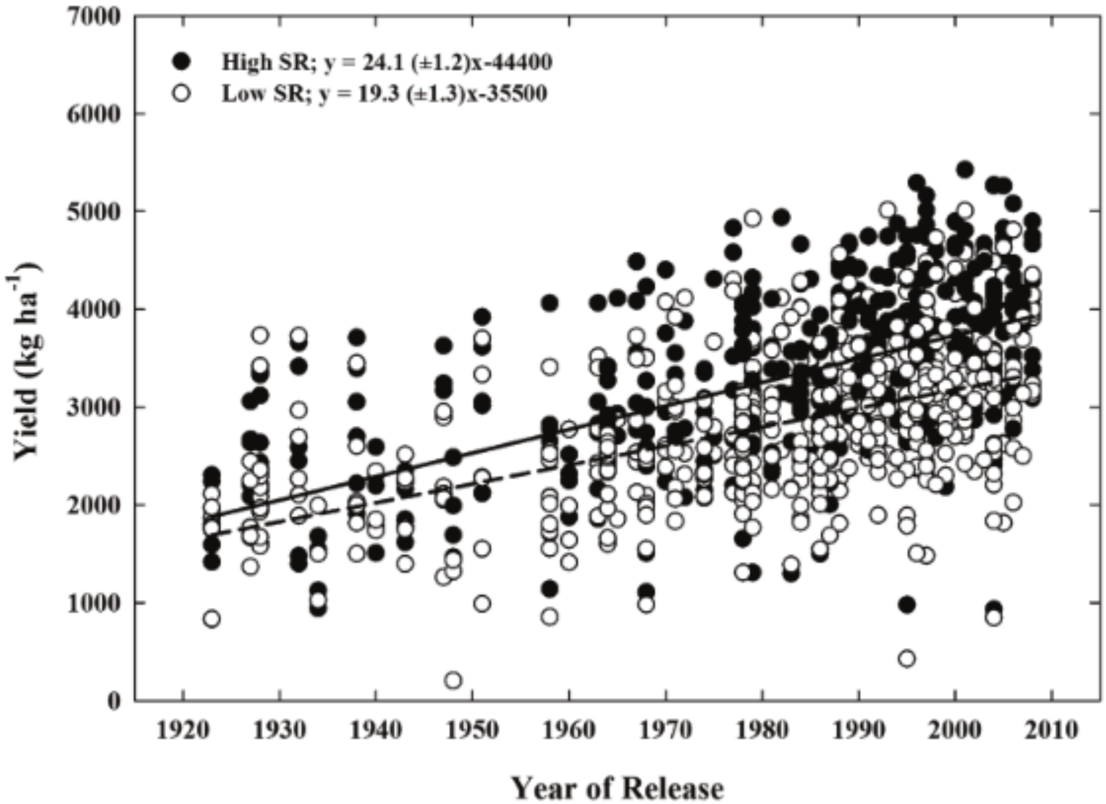






Kikuchi et al., Plant Cell Environ (Minor Revisions)

Soybean breeding and management efforts

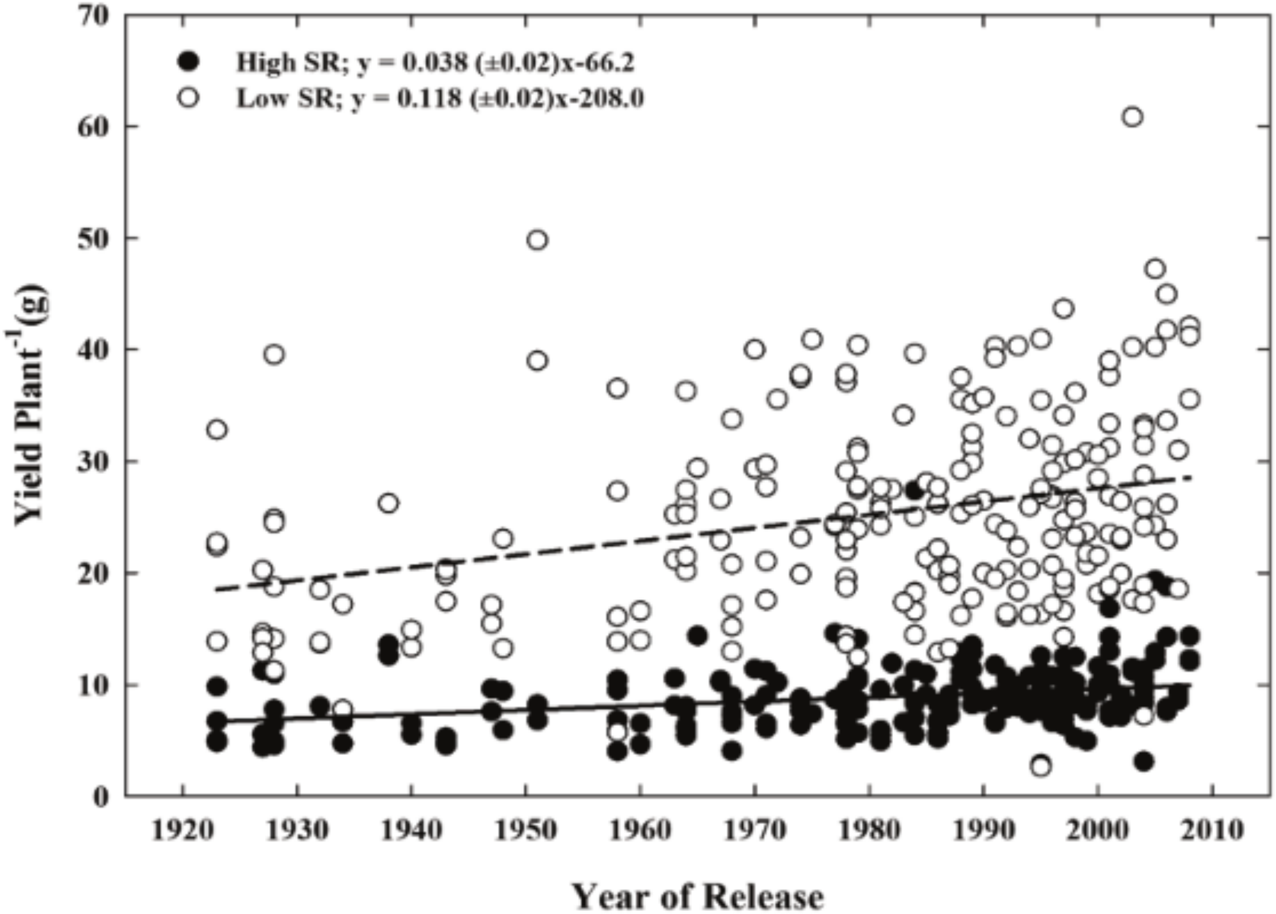


High seed rate – 445, 000/ha
Low seed rate – 148, 000/ha

- **Achieved considerable seed yield gains over the last century**
  (23.4 kg ha–1 yr–1 between 1924 and 2011 (USDA-ERS, 2011; Suhre et al. 2014)
- **Limited amount of genetic diversity explored**

Suhre et al., 2014 Crop Ecol Physiol 106, 1631-1642; Chebrolu et al., 2016 Metabolomics, 12, 28

Plasticity exists



Suhre et al., 2014 Crop Ecol Physiol 106, 1631-1642

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Summary and future direction

- Soybean resilience to heat stress could be either due to escape, avoidance or true tolerance
- Pollen germination alone may not capture the entire impact of heat stress at flowering
- Impact of high day and night temperatures cannot be assumed to be same – would need alternative breeding strategies?
- Environment, yield and quality interact strongly
- Under non-stress conditions – Can we breed soybean varieties that can be more CO_2 responsive?