Pre-breeding in wheat and legumes
CSIRO Plant Industry, Floreat

Steve Milroy
Research Group Leader: Improving crop production and quality
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Real workers

• Christiane Ludwig
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Funding

- ACIAR
- CLIMA
- CSIRO Appropriation
- DEEWR (=DEST)
- GRDC
Collaborators

- **Links to other research groups in CSIRO:**
  - Brisbane and Canberra

- **International:**
  - ICARDA, ICRISAT, Punjab Agricultural University

- **Local:**
  - CLIMA, DAFWA, UWA
Aim

- Crop adaptation and management for Mediterranean production systems in WA.

- Three crop species:
  - Wheat
  - Lupin
  - Chickpea
Climatic traits

• Mediterranean environment:
  • Excess water early
  • Abrupt terminal drought

• Both issues interact with soil type

• Aspects of both have been considered as well as climate change.
Adaptation

• Key: avoidance (phenology)
  • Wheat - under control
  • Chickpea - limited by cold tolerance
  • Lupin - ill defined

• Secondary: drought tolerance and efficiency
  • Wheat - substantial experimentation
  • Chickpea - little
  • Lupin - some; genetic variation?

• Different research emphasis
Wheat – Vigorous roots for water and N capture
Root systems and N capture

• Collaboration:
  - David Bonnett
  - Fernanda Drecca
  - Greg Rebetzke
  - Michelle Watt

• Wheat crops in the Western Australia are poor users of N.
  • Poor synchronization between the availability and demand for NO$_3^-$

• Can we improve the capture of N by larger root systems?

• Compared root systems of genotypes with high and low early vigour
Root systems and N capture

Key outcomes:

• Early vigour gives earlier and faster root growth and proliferation and larger root biomass. (Palta et al. 2006; Palta et al. 2007a).

• Increased the capture of N:
  • By 60-68% in the upper 0-0.2 m of soil
  • Doubled in 0.2-0.7m depth (Liao et al. 2006; Palta et al. 2006).

• Doubled-haploid lines for reduced tillering and vigour with rooting patterns similar to cv. Janz capture less N than those with rooting patterns similar to Vigour 18 (Palta et al. 2006; Palta et al. 2007b).
Key outcomes:

• With adequate access to nitrate: Roots of vigorous wheats had lower respiration per unit of $\text{NO}_3^-$ uptake than the non-vigorous wheats (Palta 2007; Palta and Watt *in press*).
Root systems and N capture

Plans for the future:

• Evaluate rooting patterns and N uptake of
  • Superior vigour lines developed by Greg Rebetzke (Cycle 4).
  • Australian synthetic derivative wheats
• How much of this gets to the grain?
• Evaluate costs for capture of N and water by contrasting root systems.
Vigorous roots for water capture

- Collaboration
  - Michelle Watt
  - David Bonnett
- Field validation of benefits of vigorous root growth
- Potential benefits:
  - Rapid root exploration – increased water and N capture early
  - Deeper root exploration – more water accessed later
- Contrasting environments
  - Heavy soil in NSW
  - Sandplain soil in WA
Wheat – Traits for water limited environments
Physiological traits for water limited environments

- Collaboration
  - Allan Ratty
  - Greg Rebetzke

- Many traits - but limited field testing

- Expect variation with rainfall pattern and soil type:
  - Stored v in-season rainfall
  - Light soils v heavy soils

- Directions for future research
  - Biggest benefits
  - Where suited

- Expand material
Summary - Wheat

• **Achievements:**
  - Value of root form for N uptake
  - Differences in root respiration for N uptake

• **Future:**
  - Confirm generality and value of differences in N uptake
  - Explore value of rooting differences for terminal drought
  - Evaluate relative value of traits for water limited environments

  • Root physiology and metabolism
  • Links to molecular biology
Chickpea

Jens Berger
The state of play in *C. arietinum*

- **GxE studies:** 79 genotypes@26 site/years across India & Australia (ACIAR).

- **Key outcome:** phenology drives specific adaptation in both countries (Berger *et al.* 2004; 2006).
  - Australia-widely adapted material: early with high harvest index, **BUT** low reproductive chilling tolerance limits drought escape potential.
  - podset delayed until mean temperature >14-16°C (Berger *et al.* 2004).

- **Hypothesis:** increasing chilling tolerance will advance the reproductive phase, reduce terminal drought stress and increase both yield and yield stability.
The search for reproductive chilling tolerance

1. Investigate the annual wild relatives of chickpea which have maintained the winter annual lifecycle.

2. Characterize global habitats of chickpea to define areas likely to select for chilling tolerance at flowering. Identify germplasm from contrasting areas.
Chilling tolerance in wild relatives

• Annual wild *Cicer* species are more tolerant than chickpea, BUT…
  - best tolerance is in *C. judaicum* (not in 1° gene pool) (Berger et al. 2005)
  - too few accessions of spp in 1° gene pool to adequately assess potential
    (*C. echinospermum, n=10; C. reticulatum, n=18*) (Berger et al. 2003)
  - more collection is required.
Chickpea global habitat characterization

• Global chickpea germplasm collection and production areas characterized in space and time (Berger and Turner 2007)
  • Where and when is chickpea grown?
  • Chickpea-specific bioclimatic variables calculated for each site
  • Habitats with contrasting reproductive chilling stress defined (Berger 2007)

• Large field trials evaluating germplasm from warm and cool sites during flowering:
  • Northern India (Punjab Agricultural University, Ludhiana; Panjab University, Chandigarh)
  • Northern Syria (ICARDA)
Questions for the future

• What are the adaptive mechanisms that enable fertilization and seed development under chilling stress?

  • Sensitive & tolerant germplasm identified in field screening of wild and domesticated *Cicer* spp. grown under contrasting chilling stress.
    • Australian focus: pollen and ovule development and function, embryogenesis (CSIRO/CLIMA)
    • Indian focus: cellular integrity, metabolism, cryoprotectants…(Panjab University)
Questions for the future

• Are there ecotypic differences in chickpea in the mechanisms driving phenology?
  • Model photoperiod & temperature responses of Indian, Australian & Mediterranean germplasm
  • Promising genotypes become parental material in DAFWA breeding programs (Tanveer Khan & Heather Clarke are DEST project members).
Lupin

Jairo Palta
Jens Berger

CSIRO. Pre-breeding in wheat and legumes
The state of play in *L. angustifolius*

- L Hist trials: 61 site/years of all NLL cultivars released since 1967 (DAFWA)

- Almost no specific adaptation among Australian cultivars = little diversity?
  - Best varieties are good everywhere & *vice versa*.
  - Unproductive, unresponsive genotypes: late flowering & slow growing
    - require vernalization
  - Productive, responsive genotypes: early flowering & fast growing
    - thermoneutral

- Phenology & vernalization responsiveness are confounded.

- Hypothesis: later flowering, non-vernialization responsive genotypes will be specifically adapted for longer season environments (ie southern WA).
Breeders have selected for drought escape, lupin growing areas are now largely short season, northern environments.

How does wild germplasm respond to stress gradients?

Lupin habitats characterized - germplasm from contrasting environments selected as experimental candidates.
Phenology & specific adaptation in *Lupinus* spp.

- **Results** (wild germplasm across natural distribution):
  - *L. albus*, *L. angustifolius* & *L. luteus* flower earlier as habitats become more stressful (higher temperatures, lower rainfall) and uncertain (variable rainfall).
  - Vernalization response only varies between ecotypes in *L. luteus*. Highest response from cool, rainy, long season, higher elevation sites.
  - +ve & -ve responses to vernalization identified in all 3 species (& *L. mutabilis*) in a wide range of flowering time backgrounds.
  - This material (esp. later flowering/non-vernalization responsive genotypes) may introduce specific adaptation to Australian lupin breeding.
Plans for the future: Phenology

- Confirm +ve & -ve vernalization results observed in 2007
  - Bevan Buirchell (Senior Lupin Breeder, DAFWA) keen to use non-vernalization responsive genotypes as parents.

- What mechanisms have nature or man selected?
  - Is vernalization & photoperiod responsiveness always linked in lupins (Christiansen & Jørnsgård 2002)?

- Experiment: vernalization confirmation performed as a factorial under short & long days.
  - Vernalization & photoperiod response across species/habitats.
  - Does unfulfilled germplasm really grow more slowly?
  - What happens to root development?
Apart from drought escape, are there any other adaptive traits?

- In *L. luteus*, domesticated European material is early, but not drought tolerant

Experiment: Wild *L. angustifolius* & *L. luteus* from contrasting environments grown under well-watered & drought stressed conditions.

- Measure plant water relations & metabolism:
  - Leaf water potential
  - Stomatal conductance
  - Osmotic potential
  - Photosynthesis

Promising genotypes become parental material in DAFWA breeding programs.
Summary: Legumes

• Achievements:
  • We know what we need: key adaptive traits identified in target environments in chickpea & lupin using GxE ground truthing.
  • We know where to look for it: habitat characterization allows us to select germplasm from contrasting environments in both species.
  • Can we find it?

• Future:
  • Eco-physiology of phenological mechanisms in chickpea & lupins
    − Chilling tolerance in chickpea
    − Photoperiod/temperature responsiveness in chickpea & lupins
  • Eco-physiology of drought tolerance in lupin
  • Link to CSIRO gene discovery work
Project directions

- Increased focus on terminal drought
- Lupin eco-physiology:
  - Phenological drivers across species/habitats (vernalization/photoperiod)
  - Physiology of adaptation to terminal drought across species/habitats
- Chickpea eco-physiology:
  - Physiology of chickpea tolerance to reproductive chilling
  - Phenological drivers across habitats (temperature/photoperiod)
- Wheat adaptation:
  - Water and N uptake by contrasting root systems and implications
  - Evaluate traits for production in water limited environments