DAF Pigeonpea Initiative:

Developing pigeonpea as a profitable and sustainable summer pulse crop for Queensland (Phase 1)

FINAL RESEARCH REPORT: November 2022

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This publication was compiled by Bruce Winter on behalf of the Pigeonpea Initiative team of Crop and Food Science, Department of Agriculture and Fisheries (DAF).

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EXECUTIVE SUMMARY

Grain farming systems in Queensland lack a reliable and profitable summer legume. To fill this gap, the Department of Agriculture and Fisheries (DAF) is assessing the potential of pigeonpea by identifying the potential genetic options and management strategies to maximise crop yields, reduce production risks and ensure high quality grain for key markets. This project is assessing different types of pigeonpea for local conditions, developing agronomic practices to overcome constraints, and identifying the key research needed to develop pigeonpea into a profitable and sustainable summer pulse crop for Queensland. The project is led by Rex Williams (Director, Crop Improvement), and the interdisciplinary project team includes Bruce Winter, Yash Chauhan, Gabriela Borgognone, Steve Krosch, Doug Sands, Peter Agius, Troy Frederiks, Trevor Volp, Annie Ruttledge, Lisa Kelly, Nikki Seymour, Merrill Ryan, William Martin, Luke Neale, and Andrew Zull.

This final report outlines the key achievements of the first stage of the Pigeonpea Initiative, addressing the outputs of the original project proposal and includes chapters presenting the research results for crop improvement, crop agronomy, insect management, weed management, crop physiology, and soil microbiology.

Highlights include:

- Dr Yash Chauhan and Dr Rex Williams visited the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Hyderabad India in October 2019 and inspected elite pigeonpea lines alongside ICRISAT's lead pigeonpea breeder.
- A total of 60 elite extra-short maturity lines were successful imported from ICRISAT and an additional 100 pigeonpea lines sourced from the Australian Grains Genebank (AGG). These lines were grown out in the glasshouse, and subsequently planted in three field characterisation nurseries. Following selection, a subset of lines was chosen for multiplication for future yield testing.
- Physiology data including canopy dynamics, crop development (phenology) and biomass were collected from the time of sowing trials. Data from these agronomy trials were used to update, parameterise, and validate the current APSIM pigeonpea model for pigeonpea.
- The combination of quick maturing varieties and early sowing produced the best yields in trials at Kingaroy and Emerald. Early time of sowing, under the long days of summer, produced the biggest differences in varieties particularly in the time to flower and length of flowering period. Pigeonpea varieties were shown to have an enormous ability to vary their dry matter production, days to flowering and flowering period in response to sowing time and seasonal conditions.
- The commercially strain of rhizobia (CB1024) was found to be compatible with the seven pigeonpea genotypes tested, enabling the plants to fix the nitrogen required.
- The root and shoot growth for pigeonpea was studied alongside mungbean, soybean and sorghum. Pulse crops have a reputation for shallow root systems. Compared to sorghum, mean root depth for juvenile plants of soybean, mungbean, black gram and pigeonpea was 96%, 80%, 79% and 76% respectively. Despite initially shallower root systems than other crops due to slower initial development, pigeonpea had a higher root to shoot ratio than other tested pulse species. This could be a potential drought adaptation strategy.
- The flowering period is the most significant in determining the susceptibility of pigeonpea to its major pest *Helicoverpa armigera*. Moths are highly attracted to flowering plants and

lay most of their eggs on floral reproductive structures, and it is inside these floral structures where early instar larval populations establish and feed. However, pigeonpea plants cannot compensate for pest damage that occurs during late podding. The compensatory ability present at flowering disappears at podding as *H. armigera* larvae cause direct yield loss by feeding on the developing grain.

- Herbicides have been identified with a registered use pattern in pigeonpea in Australia’s northern states. Other herbicides, particularly imazapic, have been identified as potential candidates for registration. Agronomic techniques have been identified with potential to increase competitiveness of pigeonpea against weeds. Selecting cultivars with high early vigour, varying planting dates and row spacings are techniques worthy of further investigation. Sequential application of pre- and post-emergence herbicides is also likely to be important for controlling weeds in pigeonpea, especially in the early crop growth stages when weeds will likely have greatest impact.
- Several important plant pathogens were identified in pigeonpea crops, including Phytoplasma, charcoal rot, Fusarium wilt, stem blight, white mould and Alternaria leaf blight, but most infections caused minimal damage.
- A range of abstracts were submitted by project participants to two upcoming conferences, the Australian Summer Grains Conference and the Australian Pulse Conference, to report on research findings from the project and promote the DAF Pigeonpea Initiative.

A new project proposal for the second stage of the Pigeonpea Initiative was submitted to DAF in August 2022 with the goal of moving beyond basic proof-of-concept research to focus on the applied research necessary to support a commercial pigeonpea industry in Queensland. The new project has the following expected outcomes:

- Deliver the applied research needed to support a new commercial pigeonpea industry in Queensland in the short to medium term (3-5 years).
- Identify well-adapted breeding lines and insect and weed management strategies that can maximise crop yields, reduce production risks and ensure high quality pigeonpea grain for key markets.
- Drive the development of a future collaborative R&D program that attracts significant co-investment and supports pigeonpea as a new pulse crop for Qld.

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1. OUTPUT HIGHLIGHTS

Output 1. Coordination and leadership in pigeonpea R&D enhanced

- New researchers have joined the pigeonpea team bringing vital expertise in plant breeding, entomology, weed science, plant physiology, soil microbiology, biometry, and food science. Regular team meetings for review, discussion and planning have continued over the last four years, either in person or online via MS Teams.
- Pigeonpea team members were included in the Crop & Food Science's broader 'Plant Protein Team' to promote interaction and integration across groups and disciplines, particularly to progress common opportunities around food chemistry and ingredients.
- Dr Yash Chauhan and Dr Rex Williams visited the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in Hyderabad India in October 2019 and inspected elite pigeonpea lines alongside ICRISAT's lead pigeonpea breeder. They also met with ICRISAT's Director General and other international experts to expedite the sharing of new knowledge and seed of their best pigeonpea lines with DAF. This international visit also identified mutual benefits and a strong willingness to develop a future collaborative project on pigeonpea.
- A total of 60 elite extra-short maturity breeding lines from ICRISAT in India were successful imported into Australian quarantine facilities in October 2020 (after some COVID-related delays). These lines were released from quarantine and an elite subset was selected for further multiplication and field testing in summer 2021-22 and summer 2022-23.
- An additional 100 pigeonpea lines were requested for evaluation following interrogation of the Australian Grains Genebank (AGG) database. These lines were grown out as single plant selections in the glasshouse at Hermitage, and subsequently planted in field characterisation nurseries in Toowoomba, Kingaroy and Emerald. A subset was chosen for multiplication in summer 2022-23, and future yield testing.
- At the request of GRDC, consultants from Colere facilitated a stakeholder workshop, "Pigeonpea in the Australian Farming System" in June 2021 in Toowoomba. Twenty invited participants from DAF, UQ, QUT, processing sectors, crop consultants and exporters attended to discuss opportunities and concerns for around establishing a new pigeonpea industry. A list of key issues was developed from this workshop, but GRDC is yet to act on these recommendations. Four key DAF pigeonpea project staff contributed to these deliberations, developing recommendations and a timeline of activity to guide future coordinated R&D.
- The DAF pigeonpea research team organised a field walk to increase awareness of pigeonpea as a potential new summer legume for Queensland at Kingaroy on 26 Feb 2021. The field day, attended by 50 growers and industry representatives, showcased promising material, was the first public launch of our DAF R&D initiative and introduced DAF's team of expert scientists.

Output 2: Ideal pigeonpea crop type/s described

- A Toowoomba pigeonpea phenology trial quantified pigeonpea development at three sowing dates and with daylength extended to 16 hours using lights. All lines had a facilitative short-day flowering response, but with varying photoperiod sensitivity and base thermal time requirements for flowering. These observations, coupled with results from Kingaroy and Emerald, were used to improve the APSIM pigeonpea crop model for types targeting the QLD cropping system.

- The root and shoot growth for pigeonpea was studied alongside mungbean, soybean and sorghum. Pulse crops have a reputation for shallow root systems. Compared to sorghum, mean root depth for growing soybean, mungbean, black gram and pigeonpea plants was 96%, 80%, 79% and 76% respectively. Despite initially shallower root systems than other crops, due to slower initial development, pigeonpea had a higher root to shoot ratio than other tested pulse species. This could be a potential drought adaptation strategy. Potential useful differences were also observed in the root systems of the determinate and indeterminate lines of pigeonpea.
- Lysimeter studies provided a useful to quantify transpiration. Pigeonpea did not have improved Transpiration Efficiency (TE, ratio of biomass per unit water transpired) compared to other tested crops. Difference in rankings for shoot and root weights highlight the importance of including roots when calculating TE. Quest had a larger leaf area, shoot dry weight, root to shoot ratio, total transpiration and significantly larger root system compared to other pigeonpea types. Importantly, this higher transpiration was not at the expense of transpiration efficiency, with Quest achieving the highest (not statistically significant at $p < 0.05$) TE_{plant} of the tested pigeonpea. Pigeonpea lines from the previous UQ breeding program should be considered in future studies and for any ongoing genetic improvement work.

Output 3: Potential adaptation zones and environmental constraints identified

- Physiology data including canopy dynamics, crop phenology and biomass harvests (at first flower and maturity) were collected from time of sowing trials at Kingaroy and Emerald. Data from these agronomy trials were used to update, parameterise and validate the current APSIM pigeonpea model for pigeonpea to be used in turn to define relevant soil type-climate combinations and the likely production zones and constraints for pigeonpea production.
- Further APSIM refinement work has continued using data collected from all trials in this initiative. Four major drought and heat stress patterns have been identified. Of the seven agro-ecological regions, Western NSW, and Western Downs locations appeared marginal for pigeonpea production. For regions with greater drought frequency (e.g. Western Downs), we may need to reduce sowing density or use wider row spacing. Modifying sowing time may help to overcome heat stress and reduce terminal heat stress. Short duration genotypes, that take about two to three weeks longer to mature than the quickest maturing types, may be a more stable performer for these marginal environments.

Output 4: Agronomic performance of existing lines evaluated

- In summer 2019-20, two matched trials were conducted at Kingaroy and Emerald with seven genotypes and three times of sowing. Samples for ^{15}N analysis were taken from CQ and are being processed to assess nitrogen fixation. CQ grain yields varied from 2.4 t/ha to 0.8 t/ha with dry matter yields varying from 14 t/ha to 2.5 t/ha. The December planting experienced peak summer temperatures and high evaporative conditions but still yielded an average 1.8t/ha. This encouraging yield shows pigeonpea's potential as an early summer dryland sowing option, where other legumes don't perform well.
    - The combination of quick maturing varieties and an early time of sowing produced the best yields. The early time of sowing had the biggest differences in between varieties particularly in the time to flower and length of flowering period.
    - Pigeonpea varieties were shown to have an enormous ability to vary their dry matter production, days to flowering and flowering period in response to sowing time. Changes in response to sowing time did not appear to be driven purely by

    day degree accumulation, with day length having a considerable influence. High harvest index also did not guarantee high grain yields.
- A Kingaroy repeat trial in summer 2020-21, included five short duration genotypes sown on three-row configurations (25, 50 and 75 cm) and three sowing times (27 November and 18 December 2020 and 11 January 2021). The season received 316 mm of rain while the mean minimum temperature was 17.9 °C, mean maximum 29.3 °C.
    - The time to 50% flowering was between 48-70 days. Cultivars took 5-9 days longer to flower in the November sowing than the January sowing. This delay in flowering may be due to the combined effect of photoperiod and temperature. In January sowings, flowering was earlier and occurred for a more extended period.
    - The maximum yields of 3.3 t/ha achieved compare well with the 2019-20 yields under these well-watered conditions. Yield was higher in the wider rows in early sowings and with narrower rows in the later sowings. Higher yields in the earlier sowings appeared to be set on lateral branches which may have been suppressed in the narrower row spacings.
- In a similar Emerald repeat trial in summer 2020-21, the February time of sowing had the best yields regardless of row spacing or variety. Row spacing did not have a clear effect on yield, suggesting that pigeonpea may be able to compensate for low plant populations and wide row spacing in low yielding situations.
    - Central Queensland trials indicate that pigeonpea has some daylength (photoperiod) sensitivity which means it changes its vegetative and flowering periods in relation to daylength. This is particularly noticeable in the longer season varieties where their maturity length is almost the same as the shorter season varieties when planted in February on shortening day lengths, despite much lower temperatures.
    - Yield data from Central Queensland suggests that shorter season varieties have an advantage in the early summer planting window, but the longer season varieties may have an advantage in late summer plantings.
- A daylength extension experiment to understand the dynamics of harvest index changes was imposed, ranging from 11.55hrs-16.30hrs. Pigeonpea is a short-day plant, but its shorter cultivars (<120 days) are relatively insensitive to photoperiod. The yield, harvest index and total dry matter production of the new extra-short duration cultivars show considerable variation in response to planting time.
    - Surprisingly, the time to 50% flowering was not affected by day length extension – the delay due to the extended period was only 2.5 days, confirming their relative insensitivity to day length.
    - Two tested varieties responded differently to the photoperiod treatment. Photoperiod did not significantly affect yield, including seed and pod number in ICPL 88007, whereas in ICPL 86012 yield per plant, dry matter and harvest index decreased significantly under extended photoperiod.
- Outcrossing studies were conducted at Kingaroy with rates varying from 0.2% to 7.7%. This data will inform isolation distances required for future seed purity increases.
- The commercially strain of rhizobia (CB1024) was found to be compatible with the seven pigeonpea genotypes tested and therefore use of this inoculum should facilitate nitrogen (N) fixation.
    - Glasshouse trials clearly showed a significant impact of N level in soil on nodulation and hence N fixation. Uninoculated pigeonpea plants responded well to N fertiliser and required the equivalent of 80-100 kg N/ha to maximise growth. Inoculated plants required no N fertiliser to obtain maximum growth, fixing all they needed.

Output 5: Potential Integrated Pest Management (IPM) strategies proposed.

- The key insight from our pest behaviour research is the significance of the flowering period in determining the susceptibility of pigeonpea to its major pest *H. armigera*. Moths are highly attracted to flowering plants and lay most of their eggs on floral reproductive structures, and it is inside these floral structures where early instar larval populations establish feeding sites. This aspect of pest behaviour and crop susceptibility has implications for three key areas of managing *H. armigera*: developing less susceptible pigeonpea cultivars, field sampling protocols, and insecticide use.
- Importantly, future research aiming to identify host-plant resistance in cultivated and/or wild pigeonpea genotypes should focus on identifying resistance expressed in flowers (Volp et al., 2022). Most recent work conducted by other Australian research groups, has instead looked for resistance in pigeonpea leaves.
- This flower-feeding behaviour has implications for sampling *H. armigera* populations. Heavy egg-lay events can occur in flowering pigeonpea resulting in large populations of *H. armigera* larvae. Early instar *H. armigera* consume relatively little plant biomass, but larger instars do major damage (and are more difficult to control with insecticides). Therefore, to predict large, damaging pest populations in crops, identifying the presence of early instars is critical.
- Insecticides applied to pigeonpea crops must be able to reach *H. armigera* larvae feeding inside reproductive structures. The two insecticides that will form the basis of the *H. armigera* spray regime in pigeonpea (chlorantraniliprole and emamectin) both require ingestion by larvae, but they do have some systemic activity. How well each product penetrates flowers and pods, and their residual activities will need to be investigated in detail.
- Due to the ability of pigeonpea to tolerate pest feeding at flowering, developing an empirical economic threshold for flowering pigeonpea represents a significant challenge. Although crops may be able to compensate for substantial damage at flowering, they may lengthen their flowering period, potentially increasing the risk period for further pest egg lay. Additionally, if the crop maturity is delayed that may present an issue if soil moisture is depleting during pod fill (drought stress risk) or if cold weather is approaching (frost risk).
- Pigeonpea plants cannot compensate for pest damage that occurs during late podding. The compensatory ability present at flowering disappears at podding because *H. armigera* larvae cause direct yield loss from feeding on the developing grain. Therefore, there are no substantial compensatory mechanisms left for the plant to use (other than potentially increasing the seed size of undamaged grains, a trait with limited plasticity). With appropriate investment for replicated trials (multiple sites and/or years), developing a threshold for the podding crop stage will be relatively straightforward. Whereas, developing a threshold for flowering will require more detailed investigation.

Output 6: Potential Integrated Weed Management (IPM) strategies proposed

- Herbicides have been identified with a registered use pattern in pigeonpea in Australia's northern states. Other herbicides, particularly imazapic, have been identified as potential candidates for registration.
- From preliminary work using sand bioassays, pigeonpea is indicated to be a suitable summer crop option following the use of imazapic for fallow weed control. This is an important result, because imazapic is being increasingly used by growers in Australia's northern states.

- A comprehensive review of the literature around potential weed control in pigeonpea has been completed. The characteristics of pigeonpea indicate that it is weakly competitive with weeds, and this point is re-enforced by overseas experience in India, the world leader in pigeonpea production, where weed infestation has been reported to cause from 31 to 80% reductions in pigeonpea grain yield.
- Integrated weed management (IWM) using herbicide and non-herbicide options will be vital to the sustainable mitigation of weed-related production losses. Agronomic techniques have been identified with potential to increase competitiveness of pigeonpea against weeds. Selecting cultivars with high early vigour, varying planting dates and row spacings are techniques worthy of further investigation. Sequential application of pre- and post-emergence herbicides is also likely to be important for controlling weeds in pigeonpea, especially in the early crop growth stages when weeds will likely have greatest impact.
- Herbicide screening in pot trials were conducted for four pre- and six post-emergence herbicides. There are few available herbicides with registrations for current use in pigeonpea crops grown for grain harvest and seeking new herbicide registrations will be critical for commercial production in Queensland. Nufarm BroadSword is currently registered for GM cotton insect refuges, and both Mentor (Adama) and Valor (Sumitomo Chemical Australia) are registered for pre-emergent application in pigeonpea.
- Non-chemical agronomic strategies (genotype, time of sowing and row spacing) were assessed in field trials to ascertain weed suppression relationships using light interception data. Trials at both Kingaroy and Emerald demonstrated that reducing row spacing from 750mm to 500mm resulted in higher crop light interception. One genotype ICPL 88007 provided the highest level of light interception at 30 Days After Sowing (DAS) at both sites suggesting a more rapid rate of canopy development with additional leaf biomass resulting in increased shading. Exploring these tactics in field trials in the presence of weeds would be useful to fully assess direct impact on weed control.
- A crop competition trial was planted in January 2022 at the Leslie Research Facility, Toowoomba, testing an extra-short-duration determinate pigeonpea ICPL 88007, with two grass species (Rhodes and millet) as mimics weeds, two row spacings (500 and 250mm) and two test plant densities (30 and 45 plants/m^2).
    - The highest pigeonpea yields were achieved with the high density and narrow rows (250 mm row 45 plants/m^2), irrespective of the presence of mimic weeds. Conversely, the lowest pigeonpea yields (nil weed) were observed in the wide row spacing with high plant density, possibly due to the high inter row competition of pigeonpea plants.
    - The mimic weeds significantly reduced the yields of pigeonpea, with Rhodes grass having a significantly greater effect than millet. Importantly, the pigeonpea crop also significantly reduced dry weight and grain yield of the millet, and dry weight and reproductive units (seed heads) of the Rhodes grass. The effect of narrow row spacing was larger (approaching statistical significance) than the effect of increasing crop density.
    - Light interception was significantly higher with narrow row spacing, suggesting narrow rows may be useful for increasing crop competition and weed control. For definitive recommendations this result would need to be repeated over more sites and/or years and possibly include trials with actual weeds.

Output 7: Disease incidence and impact assessed

- A total of 17 pigeonpea crops used as cotton pest refuges were surveyed for disease incidence in 2019/20. More than 70 samples were submitted for disease diagnosis with several important plant pathogens identified, including Phytoplasma, charcoal rot, Fusarium wilt, stem blight, and white mould. Alternaria possibly caused leaf blight in the DAF trial at Emerald, with future research needed to confirm this.

- Five pigeonpea crops were surveyed in Queensland in 2020-21 to determine the incidence of diseases present.
- Phytoplasma was observed in approximately 5% of plants growing in the Emerald field trial in April. A total of 15 pigeonpea plants were submitted for disease diagnostics during the 2021 cropping season.
- Charcoal rot (caused by *M. phaseolina*) was confirmed in one plant collected and a species of *Periconia* was isolated from the leaves of seven plants collected from a crop growing in North Queensland that were exhibiting leaf spot symptoms.

Output 8: New funding opportunities identified and progressed

- Dr Rex Williams presented a paper on the potential of pigeonpea and DAF’s R&D effort at the Australian Pulse Conference in Horsham in late 2019. He has also met with key stakeholders from QUT (Prof Sagadevan Mundree) and QAAFI (Prof Ian Godwin) to discuss future collaborative opportunities for funding and R&D activities.
- GRDC funded a review by Ag consultants Colere to assess business opportunities and potential returns from R&D investment for pigeonpea in Australia. The outcomes from the review were highly favourable and further interaction with GRDC is expected.
- The pigeonpea team made important contributions to a project team led by the University of Sydney to support a bid for a potential CRC for Pulse Protein. While this initial bid was unsuccessful, it generated significant interest among potential commercial partners. Hopes are that further opportunities to progress this R&D program may arise.
- Pigeonpea included in pilot plant protein work in C&FS Food Science group in comparison alongside alternative pulse protein options grown in Qld. Protein yield was lower than the other pulses however the protein purity was excellent, second only to mungbean.
- Pigeonpea research linked into discussions around the Modern Manufacturing Initiative, the CSIRO Roadmap and project ideas in the CRC for Food Waste.
- CRC Plant Protein applications progressed – contributions around three sub-tropical pulses including pigeonpea, mungbean and chickpea were submitted.
- A BACI-funded project by Dr. Kirsty Owen at the University of Southern Queensland has commenced, assessing the genetic variance in pigeonpea for resistance to root lesion nematode.
- A new project proposal was prepared to continue the progress made in the Phase 1 project with the following expected outcomes:
    - Deliver the applied research needed to support a new commercial pigeonpea industry in Queensland in the short to medium term (3-5 years).
    - Identify well-adapted breeding lines and insect and weed management strategies that can maximise crop yields, reduce production risks and ensure high quality pigeonpea grain for key markets.
    - Drive the development of a future collaborative R&D program that attracts significant co-investment and supports pigeonpea as a new pulse crop for Qld.
- Several other high priority components of this project are not currently funded:
    - Soil water deficit trial to follow water use in-season with neutron probes – define the mechanism of drought tolerance of pigeonpea
    - Grain quality research – protein content, dehulling and splitting efficiency
    - Isolation requirements for pure seed production
    - Quantify the net level of nitrogen that pigeonpea supplies to the farming system

- Post-harvest grain storage – Assessment of current grain legume storage recommendations and their applicability to pigeonpea
- Genomics – Genomics support possibly provided through UQ bid for an ARC Industry Transformation Research Hub in legume genomics.

2. Crop Improvement

Bruce Winter and Merrill Ryan

Sourcing pigeonpea germplasm

Over the last three years, a range of pigeonpea germplasm from multiple sources has been multiplied and purified under glasshouse, shade house and field conditions. This material will be useful in both crop improvement and crop agronomy and bring more diversity for important traits identified from this initiative. Field screening and characterisation of this material began over the summer season 2021-22 and will continue for several years.

The first set of germplasm to be increased is 49 super-early maturing lines requested from India. These lines were identified from a 2019 study tour to India by Dr Yash Chauhan and Dr Rex Williams and arrived in Australia mid-2020. On 9 November 2020, the material was sown in the Eurofins quarantine glasshouse in Toowoomba. Indian data indicated the flowering range of material to be 47-75 days with maturity at 90-125 days. Initial Australian glasshouse data indicated a much longer duration to flowering around 93-115 days. After clearing quarantine, material was distributed to Kingaroy and Hermitage staff in late July 2021, leaving it too late to conduct a generation of glasshouse seed increase and take to replicated field evaluation this summer.

Glasshouse seed increase began on 5 August 2021 in both DAF locations and subsequent data from Warwick (Figure 1) has the material flowering in 42-68 days, more reflective of the Indian dataset. 40% of the material is determinate and a range of seed colour exists across the 26 pedigrees represented. A subset of these lines was selected based on maturity and plant type in the glasshouse. This subset of Indian lines selections was again increased in grow tunnels at Kingaroy over summer to provide seed for proposed small plot replicated trials in 2021-22.

Figure 1: Quarantine lines from ICRISAT India in summer increase in HRF glasshouse.

The second set to be increased included 78 lines from Australian Grains Genebank (AGG) in Victoria. These were selected by Dr Merrill Ryan who scrutinised the passport data with insights gained from reviewing the historical UQ breeding program outcomes. On growing out the material, variation was present within lines for stem colour, flower colour, pod colouration, seed colour, plant type and maturity. With single plant selections to purify lines, this set has now grown to approximately 200 unique lines ready for comparative evaluation alongside the Indian set and the small set of lines that were the focus of the initiative in the first few years.

This material will give researchers more diversity to explore and provide a subset of lines for replicated yield trials in the season of 2022/2023.

Characterisation of pigeonpea germplasm

These germplasm lines were evaluated in the field at three locations in southern and central Queensland (Toowoomba, Kingaroy, and Emerald) during the summer season of 2021-22 (Figures 2-4). The genotypes were thoroughly characterised for multiple traits relevant to the Queensland production environment, including phenology, photoperiod sensitivity, determinacy, branching structure, height, stem thickness, grain yield and seed size and colour. Elite lines chosen from this material will form the basis of wider regional adaptation trials.

Figure 2: Characterisation nursery at Leslie Research Facility, Toowoomba, in March 2022.

Figure 3: Characterisation nursery at Kingaroy Research Facility in April 2022.

Figure 4: Characterisation nursery at Emerald Research Facility in April 2022.

The number of days from planting to first flowering varied from 48 – 63 days at Kingaroy (Figure 5) and 45 – 83 days at Emerald (Figure 6). The super-early group of lines (45 – 51 days to first flower) did not produce as much grain yield as the later maturity lines at these sites but are expected to do well under more marginal conditions and have a short uniform plant type suitable for mechanical harvesting. The highest yielding line at the Kingaroy site was ICPL 14425, an indeterminate, tall late maturity type, not suited to mechanical harvesting. The highest yielding line from the super-early group at Kingaroy was QPL103, an experimental line from the former University of Queensland program (Figure 7).

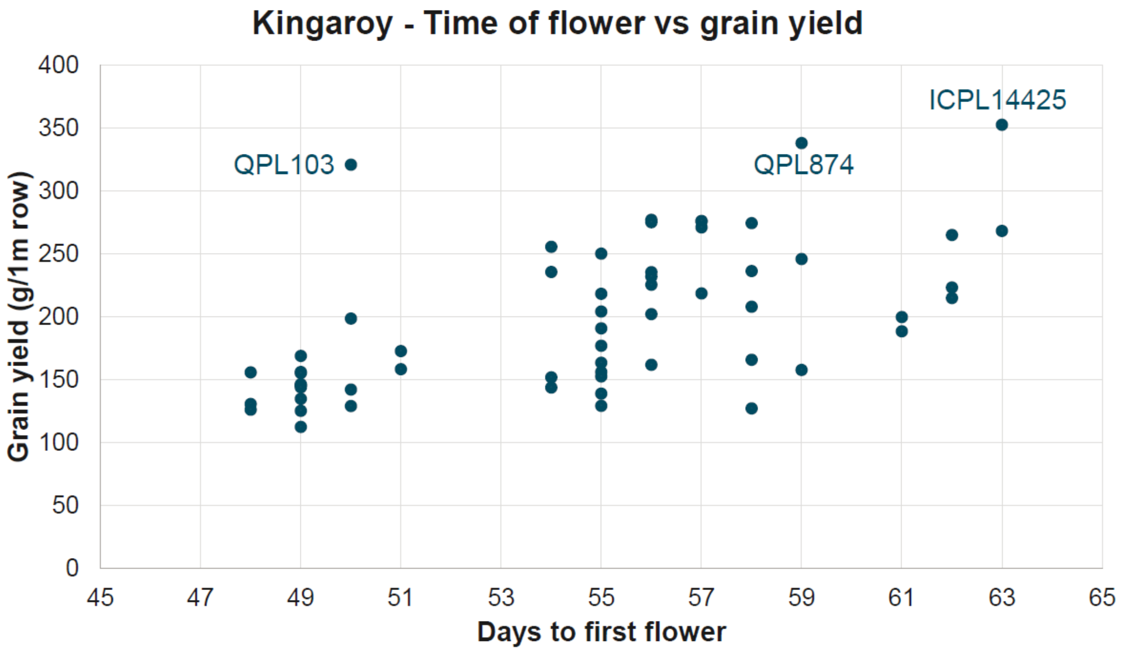

Figure 5: Scatterplot of grain yield and days to first flower for pigeonpea lines at Kingaroy Research Facility in 2021-22.

The scatterplot from Emerald (Figure 6) showed a similar distribution of grain yield and time to first flower. Several slower maturity lines produced very high grain yield, but they tended to be indeterminate in habit, and benefited from the irrigated conditions and long growing season at Emerald. Royes is a long season forage type.

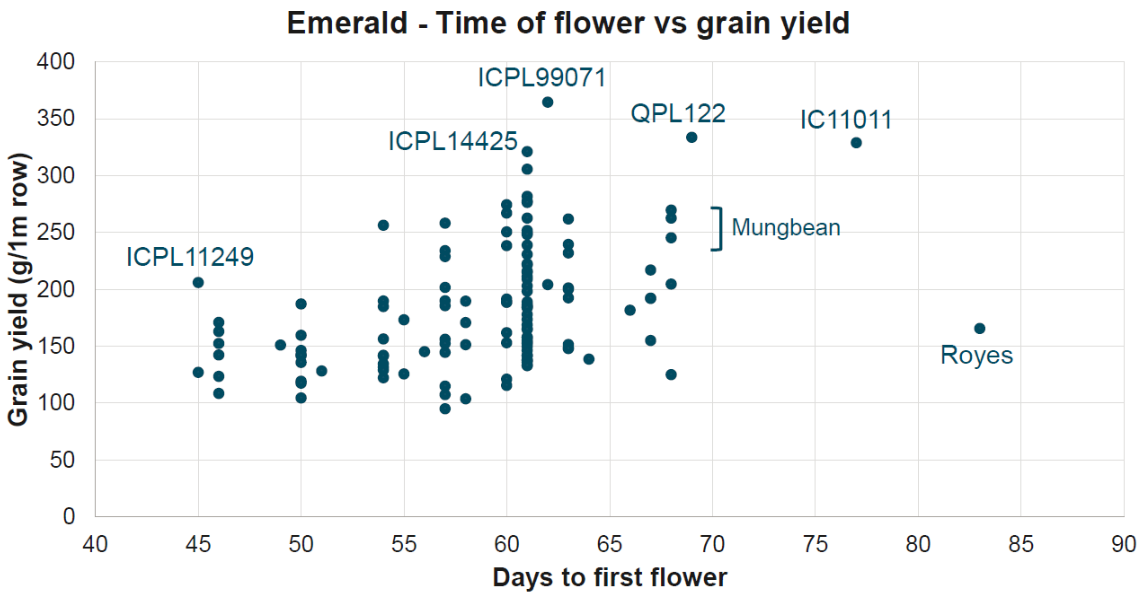

Figure 6: Scatterplot of grain yield and days to first flower for pigeonpea lines at Emerald Research Facility in 2021-22.

Figure 7: The pigeonpea line QPL103 in the Kingaroy characterisation nursery. This line is typical of genotypes with extra-short maturity and short plant height, and high pod number on the upper canopy.

Future evaluation and seed increase

The first small plot replicated trials of the new pigeonpea lines from India will commence in summer 2022-23 and, depending on the availability of funding, expand into multi-location trials in subsequent years. A single small plot trial will be planted at Kingaroy, comprising the entries listed in Table 1. This set comprises the newly introduced super-early lines from ICRISAT (Entries 4-16), a set of 8 photoperiod insensitive selections made by Dr Yash Chauhan from the line ICPL 88007 (Entries 20-27), as well as the commercial check Quest and other previously evaluated experimental lines included as standards.

Table 1: Genotypes selected for a small plot grain yield trial to be planted at Kingaroy in summer 2022-23.

Entry	Genotype	Comment
1	Quest	Commercial check
2	ICPL 94	Standard
3	ICPL 86012	Standard
4	ICPL 11249	Super-early
5	ICPL 11253	Super-early
6	ICPL 11255	Super-early
7	ICPL 11256	Super-early
8	ICPL 11259	Super-early
9	ICPL 11263	Super-early
10	ICPL 11273	Super-early
11	ICP 15597	Super-early
12	ICP 15598	Super-early
13	ICP 15599	Super-early
14	ICPL 20336	Super-early
15	ICPL 20338	Super-early
16	ICPL 20341	Super-early
17	ICPL 85010	Standard
18	ICPL 88007	Standard
19	ICPL 99076	Super-early
20	ICPL 88007–7	New selection
21	ICPL 88007–8	New selection
22	ICPL 88007–11	New selection
23	ICPL 88007–13	New selection
24	ICPL 88007–15	New selection
25	ICPL 88007–18	New selection
26	ICPL 88007–21	New selection
27	ICPL 88007–24	New selection

A second set of 24 lines has been selected for initial seed increase, based on the data collected at Kingaroy in 2021-22 (Table 2). This set comprises lines sourced from the Australian Grains Genebank (AGG) and new single plant selections of existing lines. Genotypes were selected based on super-quick and quick maturity, short to medium plant height, grain yield and physical appearance in the Toowoomba and Kingaroy characterisation nurseries. These lines will be multiplied in Toowoomba, followed by a second season of increase in Kingaroy in 2023-24, and should be available for multi-location trials in subsequent seasons. A third set of lines will be chosen specifically for the central Queensland region, based on observations taken in the Emerald characterisation set in 2021-22. These lines will be multiplied in Toowoomba in 2022-23 and will be further evaluated in central Qld in the following year.

Table 2: Genotypes selected for initial seed increase in 2022-23 and possible yield testing in multi-location trials in future years, based on data collected at Kingaroy in 2021-22.

Genotype	1st Flower (days)	Maturity (days)	Plant ht (cm)	Grain yield (% Mean)	Harvest Index	50SW (g)	Seed Colour
ICPL 94-2	62	96	85	106	0.36	5.23	Tan
ICPL 151-1	55	96	70	74	0.41	4.73	Cream
ICPL 20340-1	48	112	60	62	0.41	5.27	Tan
ICPL 80012-1	56	119	80	130	0.45	6.04	Cream
ICPL 84031-1	56	126	80	107	0.42	4.48	Tan
ICPL 85002-2	55	126	75	84	0.38	5.95	Cream
ICPL 85010-2	54	108	65	72	0.42	4.68	Tan
ICPL 86012-1	56	119	85	131	0.45	6.18	Cream
ICPL 88007-1	50	112	65	94	0.40	5.96	Tan
ICPL 88007-3	51	119	75	82	0.46	5.06	Tan
ICPL 88015-2	55	108	55	66	0.44	4.41	Cream
ICPL 88020-1	51	112	65	75	0.42	4.44	Cream
ICPL 94006-1	59	112	90	117	0.38	6.28	Cream
ICPL 94009-2	57	119	85	131	0.41	5.20	Cream
QPL 1026-1	54	119	75	112	0.40	5.83	Cream
QPL 103-1	50	98	62	152	0.39	5.82	Tan
QPL 202-3	56	112	75	96	0.39	6.21	Tan
QPL 873-2	57	119	80	104	0.35	4.04	Cream
QPL 874-1	59	119	65	160	0.45	4.71	Cream
QPL 884-1	55	112	75	77	0.41	4.92	Cream
Quest-1	59	117	85	75	0.47	5.47	Tan

3. Agronomy and APSIM modelling

Yash Chauhan and Steve Krosch, Kingaroy

Summary

As part of this initiative on pigeonpea, we have conducted agronomic experiments from 2018 – 2022 (Image 1) to make the crop a viable summer cropping option in Queensland. The yield potential (>3t / ha) and yield reliability are promising. We have not had a crop failure related to drought or pests that was feared while commencing this work. Ideotypes that meet agronomic and other challenges have been defined and genetic materials that closely matches this ideotype has been obtained and subsequently evaluated. In addition, by subjecting the crop to selection pressure of extended photoperiod less photoperiod sensitive types have been identified.

Using Computer simulation modelling we have determined frequencies of drought and heat stress, which accounted for much of the yield variation in the seven Queensland production environments simulated. The work on crop modelling is likely to assist tailoring agronomy to specific environments in view of large G x E interactions.

We also evaluated the potential of the crop as a spring crop, initial results are encouraging, but more work needs to be done to capitalise this planting opportunity.

Background

Pigeonpea (*Cajanus cajan* (L)) is a widely-adapted tropical grain legume crop with natural resilience to climate variability and an ability to fix nitrogen (40 – 60 Kg N/Ha). The crop provides a major opportunity for summer production throughout Qld and in northern NSW. Small areas of pigeonpea are already grown in Australia, not to deliver premium grain for export, but to provide 'insect refuges' for GM cotton.

The development of the domestic pigeonpea industry in Australia has been on the radar for over 40 years, but progress has been limited (Ryan 1998). Despite its potential and interest from exporters, pigeonpea has failed to become a grain crop option for growers. Major problems included the inability to control pests, the lack of agronomy support and poorly developed domestic and international markets for the crop. Because of new market opportunities and a push for plant-based protein as a more environmentally friendly source of human nutrition, fresh attempts to reintroduce pigeonpea as a broadacre grain crop are being made under a pilot project of the Department of Agriculture and Fisheries, Queensland. What is needed are appropriate varieties and agronomic packages that effectively and reliably service the high value export markets with high quality pigeonpea. Addressing these limitations requires an integrated platform of R&D focussed on appropriate genetics, crop protection, agronomy, and product development. This report summarises key achievements on agronomy of pigeonpea crop since 2018.

Objectives

- Key traits conditioning success as a potential new grain crop identified for relevant farming systems and markets in Queensland.
- Existing pigeonpea lines sourced, increased, and evaluated for grain yield, quality and crop resilience in target environments.

- Target environments for pigeonpea defined and identified, including potential for underlying constraints and risks to production.

Methodology

A survey of legume researchers and industry was used to identify agronomic traits that may improve the suitable of pigeonpea for broadacre cropping. We further workshopped these findings with experts to define the ideal ideotype and to prioritise the immediate research needs. We studied the responses of promising determinate types to extended photoperiod and selected types that did not continue to grow vegetatively after the commencement of flowering.

To induce true determinateness, the super-short duration cultivar ICPL 88007 and extra-short duration cultivar ICPL 86012 were grown in plastic tubs of 2 x 0.5 x 0.3 m (concave at the bottom) dimension. Half of each tub was planted to ICPL 88007 and a half to ICPL 86012 with about 10 cm between plants. The photoperiod hours were artificially extended to 16.30 h on the day of sowing, which gradually decreased to 11.55 h on 30 April 2021 when the experiment was terminated. This photoperiod routine was designed to follow the natural photoperiod at a latitude of 42°S. The approach has been previously used to identify super early cultivars of pigeonpea (Chauhan et al., 2002). Days to flowering, end of flowering and maturity were recorded by tagging individual plants. Plant height, total dry matter, pod weight, yield, 100 seed weight, and seeds per pod were recorded at harvest.

Agronomic evaluation

Seeds of seven cultivars of varying flowering times, including ICPL 88007, ICPL 85010, ICPL 86012, ICPL 94, ICPL 151, QPL 1019, Sunrise (ICPL 88039, control), and six cultivars were used for agronomic evaluation at Kingaroy in 2019-20 and one super early, 2 near super early (ICPL 88007 and ICPL 85010), two extra early cultivars (ICPL 94 and ICPL 86012) in 2020-21 (Table 2). These were sown on three sowing dates in a split-plot trial with three replicate blocks. Planting was done at 50 cm rows. Pre-sowing irrigation was applied to establish the crop where necessary, but further growth was on the stored water and in-season rainfall. *Helicoverpa* and other pests were effectively controlled by applications of Alticor (@75 g/ha) applied at flowering and another at three weeks after flowering. Days to 50% flowering, plant height, total dry matter, and yield were recorded. Phenology observations were also made in another serial sowing trial at Toowoomba (Leslie Research Facility) in 2019-20. Data collected were analysed using the ANOVA directive of the Genstat 19th Edition (VSN International) statistical program. A 5% significance level was used for all tests.

Modelling pigeonpea phenology

The ability to model flowering and maturity times is key to identify the potential agronomic adaptation and cropping system fit of the crop in different environments. Data on 50% flowering and maturity, growth and yield collected in the field experiments were used to train the APSIM Pigeonpea model (version 7.10). Further, we simulated growth and yield of super early pigeonpea in October to December plantings and used this set up to characterise frequencies of drought, heat stress and define target production regions and major heat and drought constraints.

Spring planting opportunity

We tested the potential of super early and extra early pigeonpea in spring when other summer crops including mungbean and soybean are poorly adapted. Two cultivars ICPL 88007 and ICPL 86012 were grown at 30 plants/m^2 in 350 m^2 plots in isolation at Kingaroy.

Results

Plant type

Potentially adaptive agro-physiological characteristics of pigeonpea for broadacre cropping are given in Table 1. To enable mechanised operations, plants should be preferably determinate and of less than 1 m height with over 10 g/100-seed weight, which may be helpful in processing for "dhal" and be attractive to consumers. Most desired traits are either already available in the germplasm or can be achieved through environmental priming or other techniques. For example, pigeonpea cultivars with coloured seeds can be converted to white seeds by exploiting somoclonal variation (Saxena et al. 2011). The new breed of early pigeonpea lines targeted for broadacre cropping is generally short-statured (<1m height) and are also determinate and have many of the key characteristics listed in Table 1.

Table 1: Ideal pigeonpea plant type – a blueprint for a new broadacre industry

Trait	Target	Priority	Purpose/comment
Seed Size (100 seed wt)	>10 g	High	Attractive dhal quality and recovery
Seed colour	White	High	Market preference (10-20% premium)
Seed consistency	Round	High	Ease of dehulling, high dhal recovery
Grain protein	>22%	High	Selling point/protein food
Plant height (m)	<1 m	High	Machine harvest, pest management
Plant type	Determinate	High	Low height, easy pest protection,
Photosensitivity	Absent	High	Predictable harvest times, high HI
Flowering time (days)	< 55 days	High	Short height, faster turn over
Flowering habit	Synchronous	High	Pest control, uniform maturity
Days to maturity	<100 days	High	Faster turn over, rotational fit, management
Stem diameter	~5 mm	High	Machine harvest, desiccation
Drought	Tolerant	High	More crop per drop, stability?
Grain yield (t/ha)	> 3 t/ha	High	Even consistent 2t respectable
Yield stability	High	High	Consistency of yield
Water use efficiency	>10 kg/mm/ha	High	More crop per drop
Branching	3-4 primary	Med	Compact habit, high plasticity
Waterlogging	Tolerant	Med	Yield stability
Herbicide	Tolerant	Med	Weed management
Weather damage	Resistant	Med	Could be a problem in some years
Early vigour	Yes	Med	Weed competitiveness, biomass
Disease resistance	Yes	Med	Phytophthora root rot problem
Annual	Yes	Med	No desiccation required
Nitrogen fixation (kg/ha)	>100 kg N/ha/y	Med	Low fertiliser use, high residual benefit
Radiation use efficiency	>1 g/MJ	Med	Efficient radiation conversion

Some pigeonpea cultivars though do not respond to photoperiod in terms of flowering they interact strongly for yield and other traits. Photoperiod did not significantly affect ICPL 88007 for traits related to yield, including seed and pod number, whereas ICPL 86012 had very different responses to the photoperiods for these traits (Image 2). Yield per plant decreased significantly, as did the dry matter and harvest index under extended photoperiod. We were able to identify a plant in the mixed ICPL 88007 seed lot which produced little vegetative growth after flowering and had high harvest index. Further generation of this material under 24 hours light extension confirmed its photoperiod insensitivity. This material has produced 26 lines which are being propagated as more determinate and high yielding replacements of ICPL 88007.

We have obtained 54 lines from ICRISAT and additional 200 lines from the Australian Grains Gene Bank. The lines were evaluated at Kingaroy, Toowoomba, and Emerald to identify lines that match with our defined ideotype. At Kingaroy, they varied for key agronomic traits including yield. Some of the lines though very short-statured and grew for less than 100 days to produce over 3 t/ha yield. Such lines need to be evaluated further.

Response to sowing time

Field experiments revealed genotype x sowing date interactions for plant height, days to 50% flowering, and yield at both locations. ICPL 88007 and Sunrise represented two extremes for flowering and plant height at Kingaroy. The total dry matter at maturity varied 2.8-fold due to sowing date x variety interaction at Kingaroy (7.2 t/ha to 20.5 t/ha). At Emerald, the interaction was not significant (dry matter ranged 3.5 to 10 t/ha for planting dates and 5.7 to 7.6 t/ha for cultivars, data not shown). Yields ranged from 1.96 to 3.62 t/ha at Kingaroy and 0.82 to 2.39 at Emerald (Table 2).

Table 2: Days to 50% flowering, plant height at maturity and grain yield of early and extra-early duration pigeonpea cultivars grown under three planting dates at Kingaroy during the 2019/20 season.

	Days to 50% Flowering			**Plant Height (m)**			**Yield (t/ha)**		
Cultivar	Nov	Dec	Jan	Nov	Dec	Jan	Nov	Dec	Jan
ICPL 151	57	57	63	1.2	1.4	1.3	2.66	2.42	2.67
ICPL 85010[a]	54	54	53	0.6	1.0	1.0	2.53	2.45	2.21
ICPL 86012	60	65	73	1.2	1.5	1.4	3.06	2.87	1.96
ICPL 88007[a]	51	54	53	0.7	1.0	1.0	2.16	3.23	2.39
ICPL 94	64	69	73	1.3	1.3	1.2	3.03	2.95	2.66
QPL 1019	59	60	65	0.9	1.2	1.1	3.62	2.62	2.07
Sunrise	63	70	71	1.4	1.7	1.4	2.44	3.44	2.88
LSD between PD[b]		3.6			0.1			0.76	
LSD within PD[c]	3.8			0.1			0.80		

[a] extra-early cultivars; [b] LSD to compare means between planting dates (PD); [c] LSD to compare means within a specific planting date; [d] LSD value to compare ICPL and QPL cultivars with each other; [e] LSD value to compare all cultivars with Sunrise.

Target environments of pigeonpea

We have developed a framework using a biophysical modelling to define such regions as applied to chickpea and mungbean previously. Yield, heat and drought occurrences were simulated and characterised for 45 locations over 119 seasons from 1900 to 2020 using the APSIM 7.10 Pigeonpea Model, which was first improved and parameterised for modern super-short and extra-short duration cultivars (Figure 1). There is wide range of yield that can be realised across different locations (Figure 2). In the studied region, over 78% of the variation in simulated yield across locations could be accounted for by heat stress events, while a similar percentage of variation across seasons was related to rainfall. At each location, temporal variations in grain yield were expressed as yield-percentile seasonal patterns to take away the magnitude effect of the environment on grain yield. Used in a cluster analysis, these local yield percentile patterns enabled the identification of groups of geographically contiguous locations with cohesive temporal variation in yield. These clusters were found to group geographically contiguous locations in way which appeared meaningful to local legume experts, and thus supported the biological relevance of the clustering method (Figure 3). The frequencies of major drought and maximum-temperature patterns revealed more prominent differences between locations across clusters than within clusters. Significant trends in yield percentiles over the years suggested a climate change footprint in some agro-ecological regions. Implications of the findings for the future of the pigeonpea industry in Australia are also discussed. In addition, we anticipate that the proposed method can be applied to other crops and regions to assist in identifying major production environments, characterising them for major abiotic stresses, identifying relevant breeding and agronomic test sites for AER specific agronomy, better characterising the local impact of climate change, and assist germplasm exchanges between regions of the world.

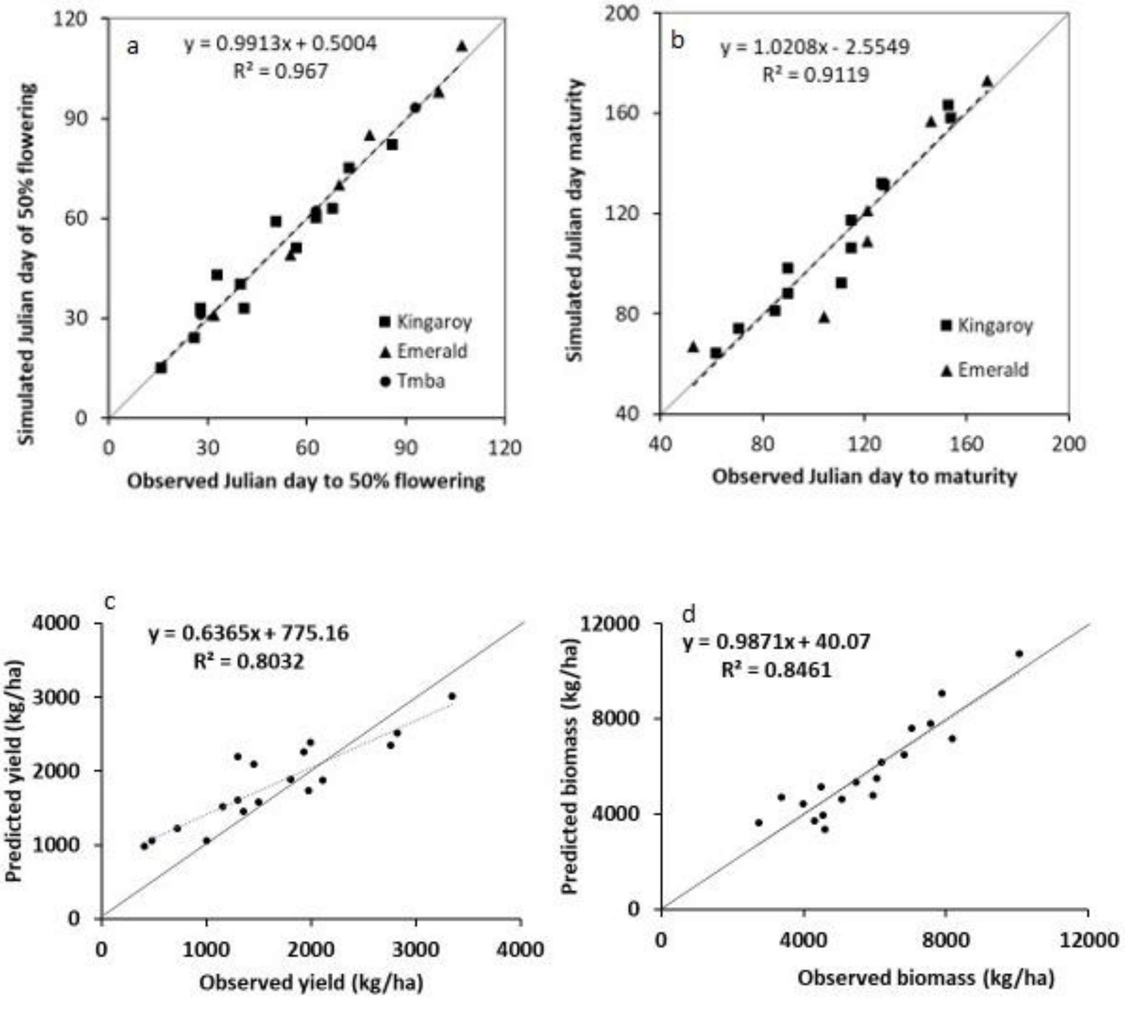

Figure 1: Simulated vs observed for the time from sowing to flowering (a) maturity (b), yield (c) and biomass (d) at Kingaroy, Emerald and Toowoomba in the 2019-20 and 2020-21 seasons.

Spring planting

ICPL 88007 showed up to 1.87 t/ha and ICPL had 86012 2.4 t/ha yield when planted in spring (Image 4 & 5). These yields would have been higher if it was not necessary to remove plants which were later flowering than rest of the population. It is expected that seed from this source will require less culling of off-type plants in the future spring plantings.

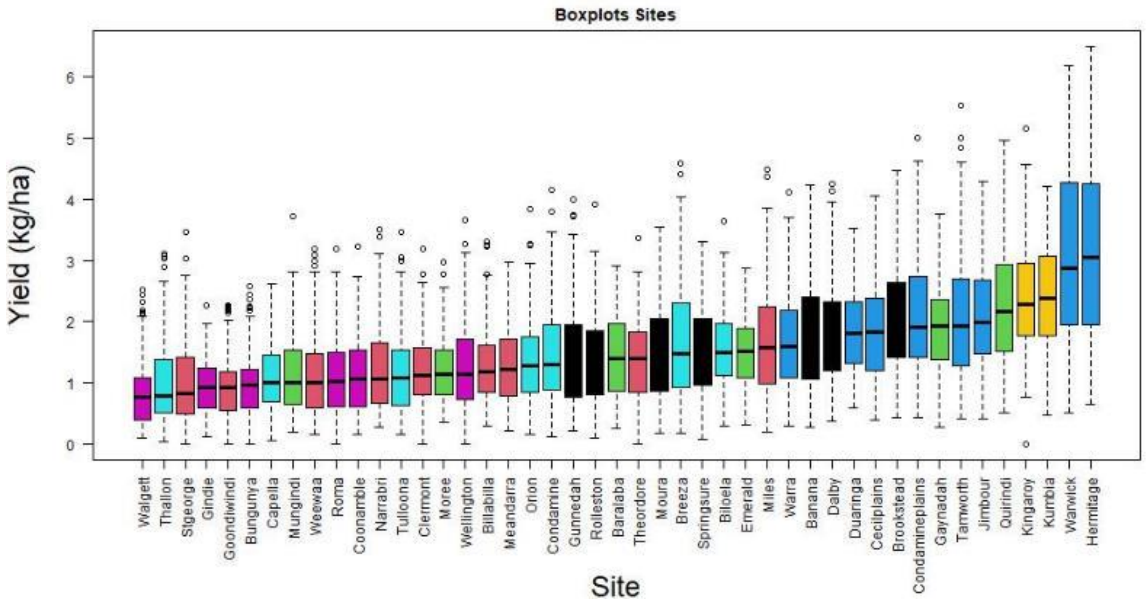

Figure 2: Box plots of simulated yield (t/ha) over 119 seasons in 45 locations across the northern grains region of Australia. (For the boxplots, the middle line of the box represents the median, the upper and lower edges represent the 75th and 25th percentiles; the whiskers the 10th and 90th percentiles; and the dots outside the whiskers represent individual values outside this range.)

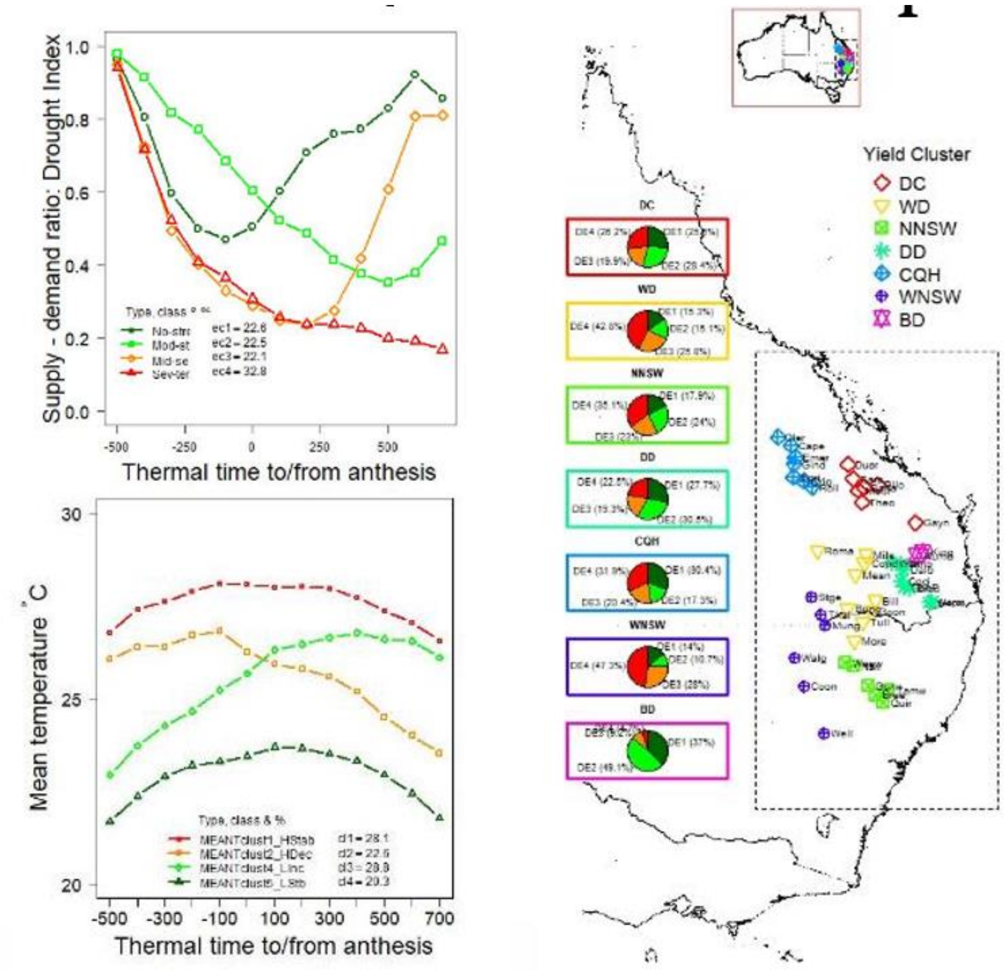

Figure 3: Clustering of locations based on percentile ranks. The agro-ecological regions (i.e. clusters) are generally more contiguous and compact when developed using percentile ranks.

Conclusions

1. The yield potential of pigeonpea is more than 3 t/ha and agronomy to help realise this yield potential has been developed.
2. An ideotype of pigeonpea has been defined. It is determinate, short-statured, high harvest index and yield. Lines that match this have been identified and are being evaluated. Further, selection for photoperiod insensitivity will benefit the development of such types.
3. Strong interaction between genotype x environment x management have been noted. This means agronomy will have to be tailored for each environment. Crop modelling could assist with regional management suggestions.
4. Progress was made in improving the APSIM pigeonpea model. The improved model was used it for defining production environments as well as identify frequencies of drought and heat stress in them. There are eight production environments, differing in the frequencies of these stresses.
5. We found that spring planting of pigeonpea has potential, but cultivars would need to be developed for this season as the crop experiences different climate in this sowing than in the summer season.

Key Messages

Pigeonpea as a summer crop seems a promising option. We did not experience any crop failure even when there was very wet condition during the cropping period.

There is some very promising material in our possession which is close to ideal plant type we have defined.

The production environments closer to easter coast are higher yielding and towards west could have greater risk due to high frequencies of heat and drought stress. However, selection of heat and drought stress tolerant lines combined with appropriate maturity can minimise these constraints.

Pigeonpea as a spring crop seems a promising option as it not only has higher yield potential, but also potential for ratooning. This will help produce more biomass with less N input and contribute to soil fertility for the following winter crops.

Image 1: Five pigeonpea lines on which much of the agronomy research has been undertaken growing in four row strips at Kingaroy in 2022.

Image 2: Response to photoperiod in ICPL 88007. Left picture shows normal day length (left) and extended photoperiod (right). There was very small effect of photoperiod on flowering. Right picture shows photoperiod insensitive selection with an estimated production potential of 2.5 t/ha compared to 1.87 t/ha of its wild parent (ICPL 88007).

Image 3: A high yielding line that produces over 3 t/ha in less than 100 days. It has short stature and very determinate - identified in characterisation of 250 pigeonpea lines at Kingaroy.

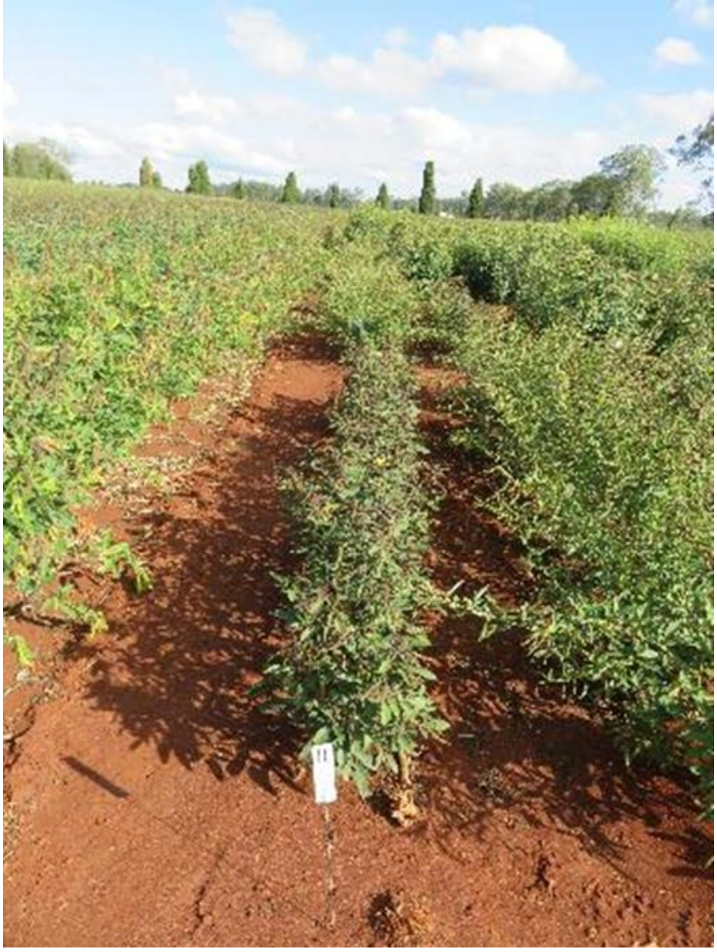

Image 4: ICPL 86012 in the spring season producing 2.4 t/ha.

Image 5: ICPL 88007 in the spring season producing around 1.87 t/ha.

4. Agronomic responses of pigeonpea in central Qld

Doug Sands and Peter Agius

Research Questions

- What is the yield performance of current available pigeon pea lines in relation to time of sowing in Central Queensland?
- Does the time of sowing change the phenology of pigeonpea?
- How diverse are the current available lines of pigeonpea?

Background

Pigeonpea (*Cajanus cajan*) has the potential to be a resilient, dryland summer grain legume suitable for the drier, western cropping areas of Queensland and northern NSW. These are areas where the other common summer legumes (soybeans, mungbean and peanuts) struggle to produce viable commercial yields. This potential needs to be proven through a series of trials to establish its productivity in a range of environments. These trials also offer opportunities to refine our understanding of the basic physiology of the crop and what genetic diversity there is within this species.

2019-2020 Trial Activity

A time of sowing (TOS) trial was established at the Emerald research facility in the summer of 2019/20 with seven pigeonpea varieties sourced from Kingaroy. This trial combined three planting dates by seven varieties across three reps in a randomised split plot design (Image 1). Seed supplies were limited so plots were limited to 2m wide by 10m long. Plots were planted into standing wheat stubble with unplanted buffer areas surrounding each plot to allow for ease of harvest given the expectation for there to be large differences in maturities between varieties.

Image 1: Drone image of the Emerald trial site in 2019-20.

2019-2020 Results

The most noticeable characteristic from the TOS trial was the large difference in total dry matter (TDM) produced by the same varieties. Mean TDM data (Table 1) shows a 3 – 3.5 t/ha difference between each sowing date with December producing the highest and February the lowest. The mean grain yield data for each TOS does not show the same pattern with January and February planting dates being quite similar and December being significantly better. This might demonstrate that the relationship between yield and biomass is not always linked.

Table 1: Mean total dry matter (TDM) and grain yield for each time of sowing (TOS) in 2019-2020.

TOS	**TDM @ maturity (kg/ha)**	**Grain yield (kg/ha)**
December	10080^{c}	1869
January	6401^{b}	1207
February	3572^{a}	1406

Links between dry matter and yield may vary depending on variety (Figure 2). There was no interaction between TOS and variety in relation to dry matter production but there was a small significant difference between varieties (Figure 1) as opposed to the large significant differences between TOS.

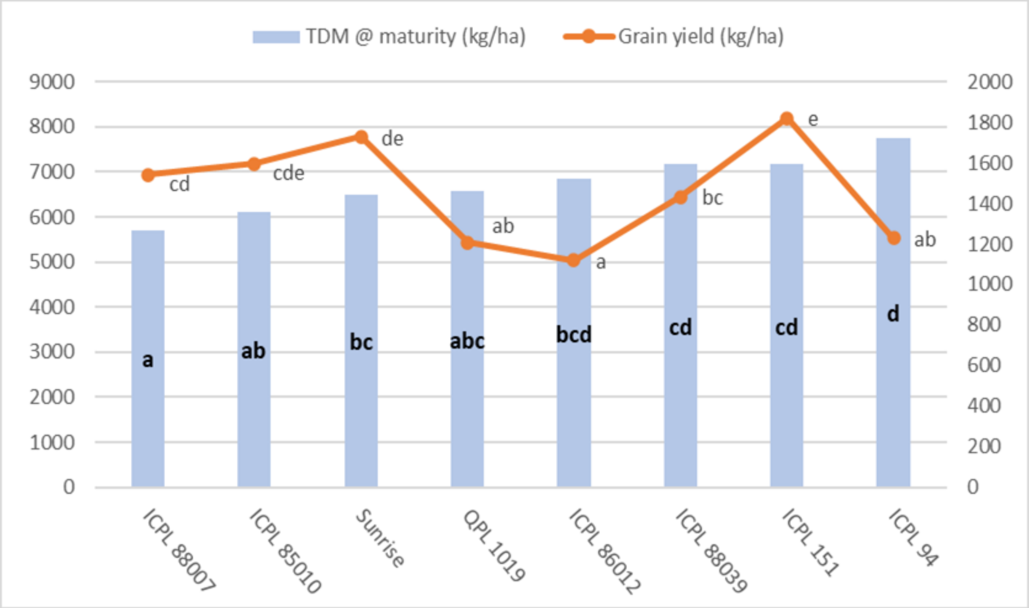

Figure 1: Mean grain yields (right axis) and Total Dry Matter (TDM, left axis) for all varieties across all TOS.

The full results from this season were presented in the 2019-2020 pigeonpea progress report 2.

2019-2020 Insights

This TOS trial has demonstrated a wide range of production levels for pigeonpea with grain yields varying from 2.4 t/ha to 0.8 t/ha and dry matter yields varying from 14 t/ha to 2.5 t/ha. This variability makes it hard to make define conclusions about the productivity of this crop species; however, this data has given some indicators about the crop’s physiology.

- Combination of quicker maturing varieties and an early TOS produced the best yields.
- Early TOS produced the biggest differences in varieties particularly in relation to time to flower and length of flowering period.
- Pigeonpea varieties have enormous ability to flex their dry matter production, days to flowering and flowering period in response to TOS.
- Pigeonpea changes in response to TOS is not purely driven by day degree accumulation. It is possible that day length is also a considerable factor.
- High HI does not guarantee high grain yields.

These characteristics has implications for plant breeding in that the expression of certain traits will change depending on the environment that the plant is in. Genetic performance maybe confined to geographic regions.

It is worth noting that in this experiment, the December TOS had the best performance despite experiencing peak summer temperatures and high evaporative conditions. The adaptation of pigeonpea to hot and dry conditions is an important characteristic in relation to the Queensland dryland cropping systems. Alternative summer grain legumes such as mungbean have a history of not performing well when planted early in the summer in a dryland scenario.

On the downside this experiment also highlighted that the current commercial variety of pigeonpea (Sunrise) was close to the best performing variety across all TOS. This is a variety that was selected for its ability to attract insects as a refuge crop in a genetically modified cotton system, rather than a variety picked for its high grain yields.

A breeding program with a focus on grain production and resistance to insect attack will improve on the yield parameters that were recorded in this experiment.

2020-2021 Activity

A time of sowing (TOS) trial was established at the Emerald research facility in the summer of 2020/21 with four selected pigeonpea varieties. The selection of these varieties was based on selecting two early maturing (more determinant, short season) varieties and two late maturing (more indeterminant, long season) varieties from the time of sowing (TOS) trial; conducted in central Queensland (CQ) from the previous season (2019/20). The 2020/21 trial combined three planting dates by four row spacings across four varieties. These treatments were replicated three times in a randomised split-split plot design. Plots were 4m wide by 12m long.

Image 2: (2a) Improved seed set in January plant (TOS2) and (2b) best seed set in February planting (TOS3).

Image 3: Drone image of trial site. TOS 1 and 2 sprayed out, TOS 3 in grain fill.

2020-2021 Results

Grain yields (Figure 2 and 3) show the February time of sowing as having the best yields regardless of row spacing or variety. In the lower yielding planting dates (December, January) there is a yield advantage to the shorter season varieties (ICPL 88007, ICPL 85010), however this advantage disappears in the February planting date as the yields are more even (Figure 2). The long season variety ICPL 94 shows a small significant yield advantage (~150 kg/ha) over the other varieties in the February planting date. This data may indicate that there may be a place for both long season and short season varieties depending on the TOS that they are planted in.

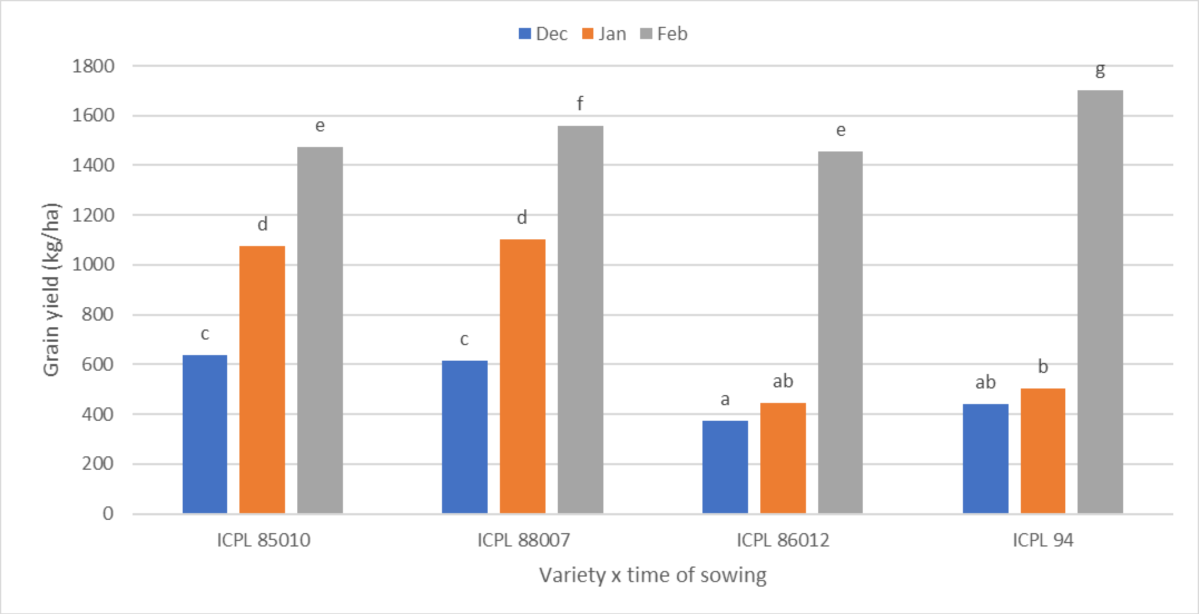

Figure 2: Comparison of mean grain yields across varieties and times of sowing.

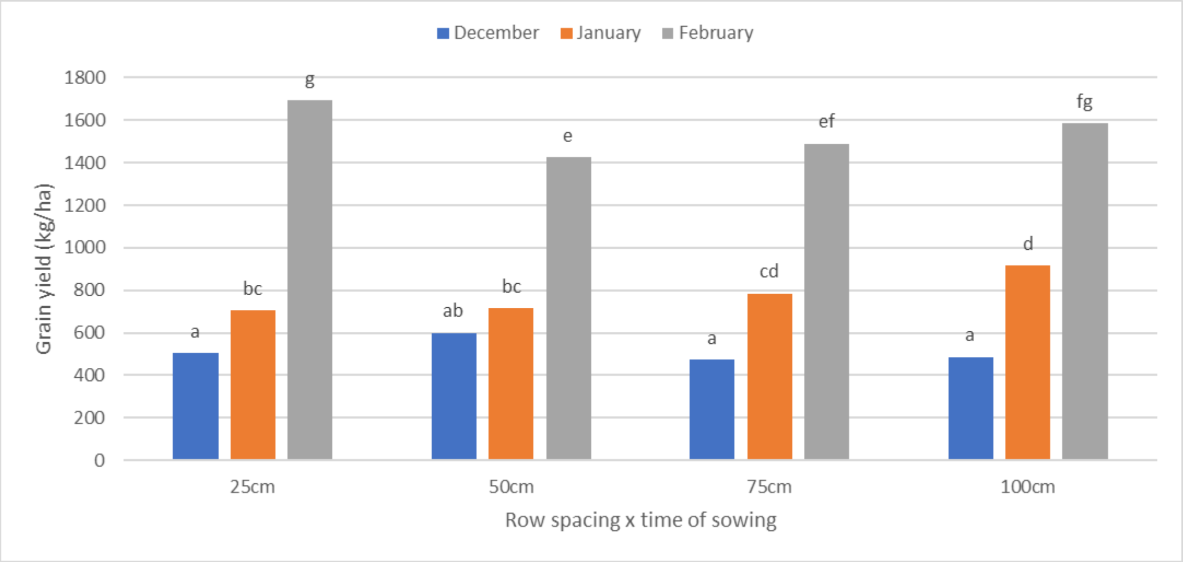

Figure 3: Comparison of mean grain yields across row spacing configurations and times of sowing.

It is unclear whether there is a distinct yield advantage to any row spacing (Figure 4). The December TOS shows no advantage in row spacing at low yields, the January TOS shows a small advantage to the wider rows (75cm, 100cm) and the February TOS shows a small advantage to both 25cm (narrow) and 100cm (wide) in a higher yielding situation. These February yields are still not considered high compared to other regions.

The row spacing data may be an indicator that the pigeonpea plant has a high level of flexibility in its physiology and can compensate regardless of planting configuration in lower yielding situations (<1.5 t/ha).

Comparing yield data for the same varieties across two seasons (Figure 4) shows the contrast in the December TOS where in 2019 it was the highest yielding TOS and in 2020 it is the lowest. One common element from this data (Figure 4) is that the longer season varieties (ICPL 94, ICPL 86012) have generally performed better in the February TOS. This might indicate that some longer season varieties may have a fit in a late summer TOS.

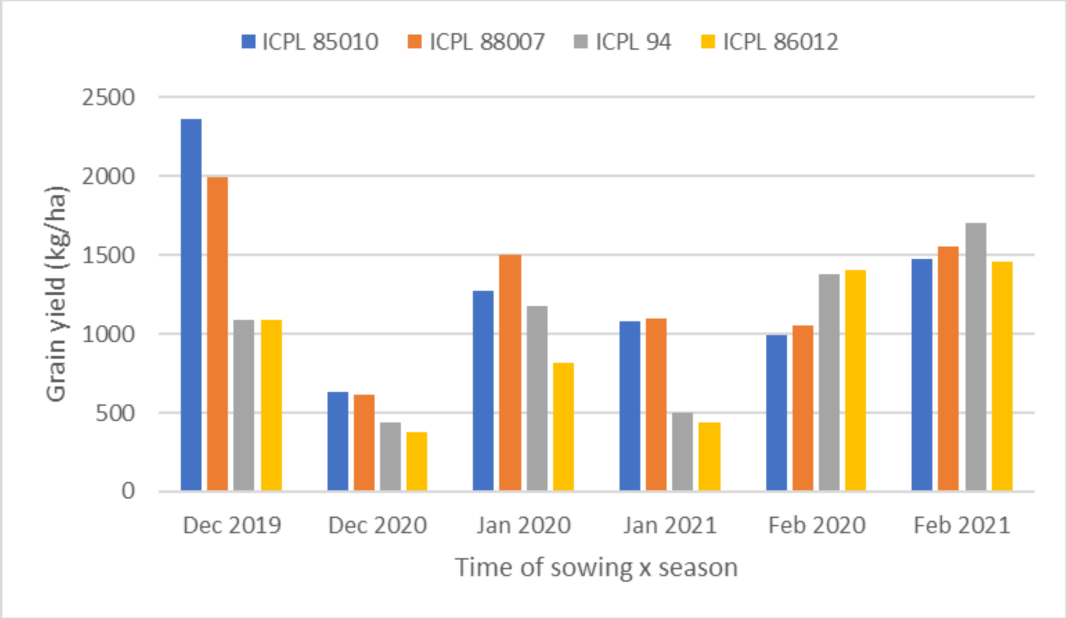

Figure 4: Comparison of mean grain yields across seasons for common varieties (not analysed).

The full results from this season were presented in the 2020-2021 pigeonpea progress report 3.

2020-2021 Insights

The TOS trial for the 2020/21 season has created more question than answers with seemly different set of production results from the previous season TOS trial (2019/20). This has made it difficult to draw any major conclusions around the adaptation of pigeonpea physiology to this environment.

Weather data from the two seasons shows a lot of consistency in relation to temperature and evaporative demand; however, there are some differences in the amount of accumulated rainfall received within each season. The 2020/21 season was far more restricted in relation to in-crop rainfall but did have higher starting plant available water capacity (PAWC) at planting. This may indicate that pigeonpea in general may have difficulty in extracting stored moisture from cracking, clay vertosol soils which then means in-crop rainfall is far more important to pigeonpea productivity. Visual symptoms of plant stress were observed in both December TOS across the two years and these symptoms would disappear after each in-crop rainfall event.

Other observations would indicate that the pigeonpea crop has some daylength sensitivity which means it can change its vegetative and flowering periods in relation to daylength. This is particularly noticeable in the longer season varieties where their maturity length is almost the same as the shorter season varieties when planted in February despite much lower heat accumulation. Yield data would suggest that shorter season varieties have an advantage in the early summer planting window, but the longer season varieties may have an advantage on the late summer planting window. This characteristic may be a symptom of the amount of diversity that is contained in the pigeonpea genetic pool.

The yield data does show some large discrepancy in the productivity of the December sowings, however there is also some consistency in the February sowings. Both TDM accumulation and grain yield were very similar across the two seasons for the same varieties. This may indicate that the conditions in February promote the most consistent yields and therefore a much lower production risk. Day length sensitivity may also mean that the February TOS will never maximise the crops yield potential as it needs the longer days of early summer to maximise its photosynthetic potential, however this is where we see the most plant stress (higher production risk). This physiology characteristic is very similar to soybeans.

With only two years of data collected the conclusions from this work can only be considered preliminary at best. Further experiment work needs to be carried out to understand the physiology of this plant, particularly around the relationships existing between stored moisture, soil type, in-crop rainfall and plant stress. These relationships are critical for pigeonpea to be able to maximise its yield potential in the more arid western cropping zones of Queensland.

5. Integrated Pest Management

Trevor Volp, Toowoomba

Overview

The potential for pigeonpea grain production in Australia is haunted by the ghost of pigeonpea past – the previous collapse of pigeonpea production due to insecticide resistance in the key insect pest *Helicoverpa armigera* (Figure 1), followed by pigeonpea's conversion to a pest refuge for the cotton industry. To develop a sustainable and profitable pigeonpea grain industry, growers and agronomists must be provided with appropriate pest management strategies to give them confidence to adopt pigeonpea as a grain crop. Over the last several years, during the initial investment of the DAF Pigeonpea Initiative, we have conducted research to understand pest feeding behaviour, what factors influence crop susceptibility, and how pigeonpea plants respond to pest damage. Further research can build upon this base to provide industry-ready, practical pest management strategies for the key pests of pigeonpea.

Figure 1: Clockwise from top left: Field trial at Kingaroy Research Station, growth tunnel experiment with ICPL 86012, 6th instar *H. armigera* larva feeding on a pigeonpea pod, 1st instar *H. armigera* larvae on pigeonpea flowers, and *H. armigera* moth on a pigeonpea flower.

Background

Pigeonpea is a hardy grain legume well-suited to Australia's variable climate. Insect pests are the largest biotic constraint to global pigeonpea yields. Although hundreds of species of insects attack pigeonpea across its worldwide distribution, only a few cause significant yield loss (Reed and Lateef, 1990, Shanower et al., 1999). Of these key pests of pigeonpea overseas, several are present in Australia (Table 1), and there are also several Australian insect species that have been recorded attacking pigeonpea, which we expect to be key pests.

Table 1: Potential major insect pests of pigeonpea production in Australia. The eventual pest management paradigm in pigeonpea will be based around these key pests, particularly *H. armigera*.

Species name	Common name(s)	Nature of damage	Notes
Helicoverpa armigera	Heliothis, podborer, bollworm	Flower and pod feeder	Key global pest of pigeonpea production. Resistant to many insecticides.
Helicoverpa punctigera	Heliothis, native budworm	Flower and pod feeder	Australian native. Limited insecticide resistance problems purportedly due to its migratory population mixing.
Maruca vitrata	Bean podborer, spotted podborer	Flower and pod feeder	More problematic in warmer climates (CQ and coastal QLD), but population outbreaks occur in temperate regions during high rainfall years.
Melanagromyza obtusa	Podfly	Pod feeder	There is a single species occurrence record from Australia, but podfly is yet to be detected in QDAF trials. Research overseas indicates podfly is more of a problem in long-duration pigeonpea cultivars (Reed and Lateef, 1990), opposed to the short-duration types in our research.
Nezara viridula	Green vegetable bug	Pod feeder	These ‘pod-sucking bug’ species form a pest complex in summer pulse crops. The composition of the complex varies geographically and seasonally, but they can be managed in unison.
Piezodorus oceanicus	Red-banded shield bug	Pod feeder	
Riptortus serripes	Large brown bean bug	Pod feeder	
Melanacanthus scutellaris	Small brown bean bug	Pod feeder	

During the previous establishment of pigeonpea production in Australia in the 1970s and 80s, management of *Helicoverpa spp.* was dependent on insecticide applications. When referring to the pigeonpea pest problem Wallis et al., 1979 stated “… relatively few well-timed applications should control the insect problem.” Unfortunately, due to the overuse of insecticides to control *H. armigera* in various field crops (particularly cotton), *H. armigera* evolved resistance to all the insecticide groups available at the time (Forrester et al., 1993). As a result, pigeonpea production became uneconomical and unsustainable. Pigeonpea growers either had to spray their crops very frequently (incurring large input costs) or experienced substantial yield loss. Eventually, pigeonpea production for grain was abandoned.

The grains industry’s loss has been the cotton industry’s gain. Since the collapse of pigeonpea grain production, the main purpose for pigeonpea in Australian farming systems has been as a ‘refuge’ crop for the cotton industry. Pigeonpea refuges work by producing susceptible *Helicoverpa spp.* moths to act as ‘genetic diluters’ in the landscape, working to delay the pest species evolving resistance to Bt-cotton (Whitehouse et al., 2017, Wilson et al., 2018).

Currently, *H. armigera* can be controlled in Australian crops with a few modern insecticides: chlorantraniliprole (Altacor/Vantacor); indoxacarb (Steward); emamectin benzoate (Affirm); and spinetoram (Success Neo). There is a moderate level of resistance to indoxacarb, as well as a small but persistent level of resistance to chlorantraniliprole (Bird, 2020). Additionally, the current price of spinetoram makes it too expensive of an option for broadacre growers. As we develop a pigeonpea industry, we must ensure that pest management strategies do not default to dependence upon these few insecticide groups. Ultimately, if we lose a few key products due to insecticide resistance, we will not be able to manage *H. armigera* in pigeonpea.

To prevent insecticide dependence, the pest management research in the first iteration of this pigeonpea initiative has started at the base of the pigeonpea IPM pyramid (Figure 2). From understanding the basis of pest-crop interactions we can develop appropriate management strategies for industry. Most of our research so far has focused on *H. armigera*, although in the first year of the project we focused on brown and green mirids (*Creontiades pacificus* and *C. dilutus*), because they are a major pest of mungbeans with very low thresholds (Brier et al., 2008) and are regularly found in pigeonpea crops (Lawrence et al., 2007). However, from our research, we were unable to detect yield loss in pigeonpea due to mirid infestations (for detail see: Pigeonpea Initiative 2018-19 final report).

Our research approach over the last few years has examined the *H. armigera*-pigeonpea pest-crop interaction at several scales: laboratory, glasshouse, semi-field, and field experiments. We have examined pest feeding behaviour, what factors influence crop susceptibility, and how pigeonpea plants respond to pest damage.

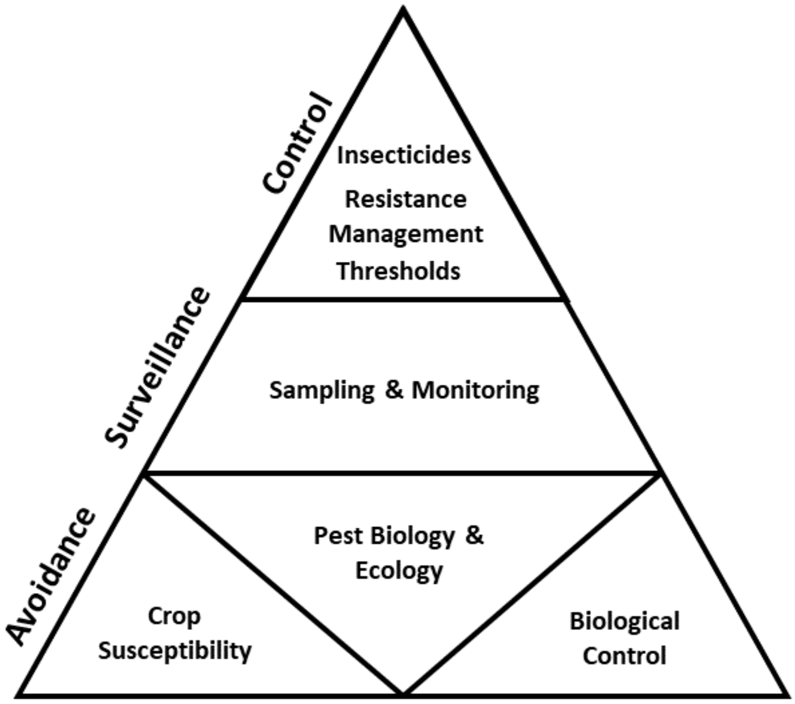

Figure 2: The pigeonpea 'IPM pyramid', a modified version of the generic IPM pyramid and other specific versions created for other pest-crop scenarios. A well-balanced IPM program is based on information from the bottom of the pyramid, enabling pest problems to be minimised.

Activity

Helicoverpa armigera moth behaviour

We have conducted a suite of experiments to examine *H. armigera* moth oviposition behaviour and caterpillar feeding behaviour on pigeonpea plants. Moths and larvae used in all experiments were obtained from a *H. armigera* laboratory colony we have established and maintained for several years. Pigeonpea plants were grown in the glasshouse in 4L pots in a 2:1 mix of potting mix and sand. Glasshouses are maintained at 27 °C ± 4 °C day and 25 °C ± 4°C night and plants are watered as required (typically every second day).

For the no-choice oviposition experiment, moths were group-mated for 3 nights, after which females were placed individually into oviposition cages in the glasshouse containing a potted pigeonpea plant of one of three cultivars (ICPL 87, ICPL 86012, and ICPL 88039) at flowering. Female moths were allowed to lay eggs overnight, if a moth didn't lay eggs, she was allowed another 24 hours, after which she was either recorded as a layer or a non-layer. The number and location of all eggs oviposited within 24 hours was recorded, along with a suite of plant morphometric variables.

For the choice oviposition experiment, female moths were obtained as in the first experiment. In this experiment however, individual females were provided a choice of three flowering plants – one of each cultivar (ICPL 87, ICPL 86012, and ICPL 88039). The number and location of all eggs, and plant morphometric variables were as in the no-choice experiment.

For the oviposition experiment examining different crop stages we only used a single cultivar (ICPL 86012). A group of n=6 *H. armigera* moths (1:1 m:f ratio) were placed in oviposition cages in the glasshouse with three plants of a single crop stage (either vegetative, flowering, or podding). The total number of eggs laid, and their location were recorded after four nights.

Helicoverpa armigera caterpillar behaviour

We conducted a glasshouse experiment examining larval performance (survival, growth, and development) and feeding location on three cultivars (ICPL 87, ICPL 86012, and ICPL 88039) at flowering. Ten neonate larvae were placed per plant, on either flowers or leaves, of one of the three cultivars. At 72 hours after placement, we destructively searched plants for larvae and recorded larval location and performance measures.

Field sampling of Helicoverpa armigera larvae

To determine the efficiency of the beatsheet to sample *H. armigera* larvae in pigeonpea, we compared beatsheet samples to absolute samples in a pigeonpea crop (cv. ICPL 88039) grown at Kingaroy Research Station in 2019. This process involved beatsheeting 1 row metre of plants then counting and sizing all the caterpillars present on the beatsheet. We then cut the sampled plants at ground level, placed them in plastic bags, and returned them to the laboratory where we destructively searched plants for larvae.

Pigeonpea response to pest feeding – growth tunnel experiment

A short-duration determinate pigeonpea cultivar (ICPL 86012) was grown under semi-field conditions in a plant growth tunnel (6m x 12m) located at the QDAF Toowoomba facility in the 2020/21 season. The growth tunnel was covered in a screen mesh that blocks out approximately 30% of incoming photosynthetically active solar radiation. Pigeonpea seeds were inoculated with commercial Group J rhizobium inoculant and hand-planted in 50cm rows at a density of 25 seeds per m^2 on 16/12/20, and the plant population was thinned to 20 per m^2. Irrigation was applied dependent on rainfall, to ensure plants were not drought stressed.

Individual plants were exposed to one of three damage treatments (a single *H. armigera* larvae, simulated damage, and a caged control) at one of two phenological stages (peak flowering and late podding). The number of reproductive structures that were damaged in the simulated damage treatments was determined from the counting the structures damaged in the real *H. armigera* damage treatment. Simulated damage was applied by severing through the calyx of reproductive structures (at flowering) or ‘boring’ into the pods (at podding) with sharp pliers. At flowering and harvest, destructive plant samples were taken for plant mapping, to determine biomass allocation, and seed yield. The trial was replicated in the 2021/22 season, however prolonged heavy rainfall during pod maturation caused destructive levels of weathering to the grain.

Pigeonpea response to pest feeding – field experiments

Two field experiments were conducted over two summer seasons (2020/2021 and 2021/2022) at the Queensland Department of Agriculture and Fisheries Kingaroy Research station. Experiment 1 (Exp 1) (2020/2021) had nine cultivars of pigeonpea, meanwhile Experiment 2 (Exp 2) (2021/2022) had four cultivars (Table 2). These cultivars were selected because they vary in a range of phenotypic traits (determinacy, phenology, and architecture).

Table 2: Pigeonpea cultivars used in the study, displaying a range of phenotypes. Nine cultivars were used in the first experiment (2020/21), but only four in the second experiment (2021/22).

Field experiment		Cultivar	Determinacy (DT-determinate, IDT-indeterminate)	Architecture notes
Exp 1 (2020/21)	Exp 2 (2021/22)			
X		ICPL 88007	DT	Short, clustered racemes
X	X	ICPL 85010	DT	Short, clustered racemes
X		ICPL 87	DT	Medium, clustered racemes.
X	X	ICPL 86012	DT	Medium, clustered racemes
X		ICPL 94	DT	Medium, clustered racemes
X	X	Quest	DT	Medium, clustered racemes
X		ICPL 88034	IDT	Medium, open branches
X	X	ICPL 88039	IDT	Tall, open branches
X		ICP 14425	IDT	Tall, open branches

Exp 1 and Exp 2 were sown on 18th December 2020 and 17th December 2021 respectively. Both experiments were randomised split plot designs. Cultivar was the main plot, whereas damage treatment were subplots. There were four blocked replicates, and the plots were surrounded by a buffer of pigeonpea (cv. Quest). Before planting, pigeonpea seeds were inoculated with commercial Group J rhizobium inoculant and planted at 25 seeds per m^2 with 50cm row spacing using a cone planter. Two weeks after seedling emergence, the plots were thinned to ensure a plant population of 20 per m^2 in each plot. Any pest insects were controlled with insecticides.

Plots were monitored weekly for phenological development. Upon reaching peak flowering (defined as one week post >50% of plants within a plot flowering), we applied simulated damage treatments. Due to the differing phenological development of cultivars in our study, different cultivars had their injury treatments inflicted at different times, but at the same point during their phenological development.

To mimic *H. armigera* feeding (whereby larvae feed on all reproductive structures) we damaged 100 ‘sinks’ per plant (pods, spent flowers, open flowers, and buds). The pattern of damage was standardised by commencing damaging at the first opened raceme near the apical meristem (the terminal raceme for determinate cultivars, the highest raceme to flower on indeterminate cultivars), and then moving down the plant until 100 sinks were damaged.

Sinks were damaged as in the growth tunnel experiment. The level of injury was selected at 100 sinks, to impose an equal level of injury among cultivars. For instance, a proportional amount of injury (i.e. 50%, 100% of structures injured) would result in cultivars with greater numbers of sinks in the undamaged state being inflicted with a higher absolute amount of injury.

In addition to measuring crop phenology, we took destructive samples for plant mapping and biomass at peak flowering (at the same time damage treatments were applied). One sample of 0.5 row m (5 plants per sample) were taken per plot. Plants were cut at the ground with secateurs, placed in a plastic bag, and returned to the laboratory where we recorded a range of phenotypic measurements – plant height, basal stem diameter, mainstem node count, and side-branch count. We also recorded raceme and sink counts for mainstem and branches separately, and determined dry biomass for leaves, stems, and reproductive structures.

Upon reaching physiological maturity, plots were desiccated by spraying glyphosate (Roundup Max 11mL/L) with a knapsack sprayer. Harvest yield and biomass samples were taken in 2 x 0.5 row m per plot. Samples were returned to the lab and morphometric data was again recorded, along with biomass (seeds, stems, and husk weights). Seeds were weighed for yield and counted with a seed counter to calculate mean seed weight.

Results

Helicoverpa armigera moth behaviour

Under glasshouse conditions, *H. armigera* moths laid more eggs on the indeterminate cultivars ICPL 88039 compared with the two determinate cultivars examined (ICPL 87 and ICPL 86012) (Figure 3; P=0.044). However, moth preference among cultivars was not detected under no choice conditions (P=0.10). On average ICPL 88039 plants were taller (P<0.001), had more mainstem nodes (P<0.001), and substantially more bud initials (P<0.001) than the two determinate cultivars.

In the no choice experiment, most *H. armigera* eggs were laid on floral structures (Figure 4). The proportion of eggs on floral structures differed among cultivars (P=0.013), more eggs were allocated to floral structures when moths were provided with plants of the indeterminate cultivar ICPL 88039 (Figure 4). Conversely, the proportion of eggs allocated to leaves also differed among the cultivars (P=0.009), with more eggs laid on leaves on the two determinate cultivars (ICPL 87 and ICPL 86012). Most eggs laid on ICPL 88039 were laid on bud initials (P<0.001), of which there were a greater number in the indeterminate cultivar.

When we examined a single determinate cultivar (ICPL 86012), crop stage significantly influenced moth oviposition behaviour (P=0.009). Moths laid most eggs on flowering plants, and the fewest on vegetative plants (Figure 5).

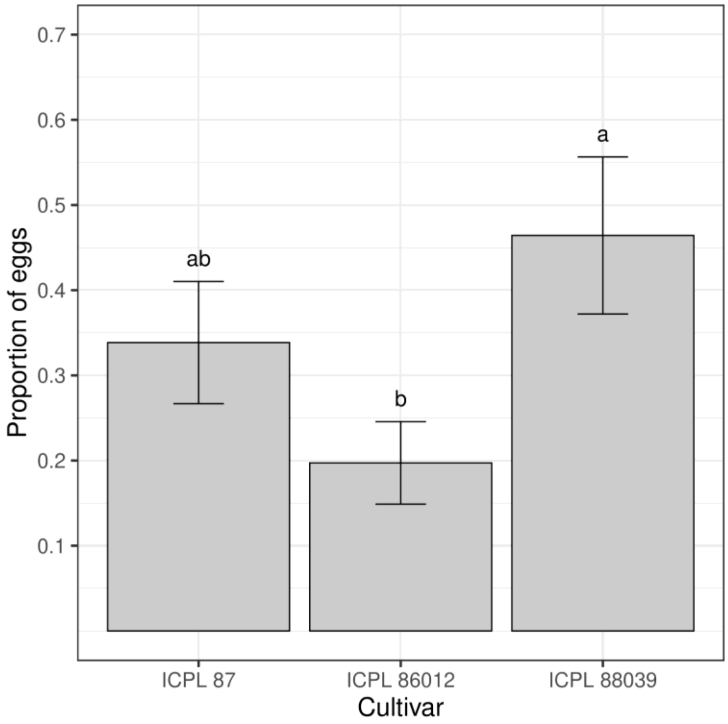

Figure 3: The mean proportion of eggs allocated to the three pigeonpea cultivars in the oviposition choice experiment (n=17 replicates). Error bars are standard error of the means, and different letters above bars indicate a significant difference (*P*<0.05) among cultivars according to Fisher's protected LSD test.

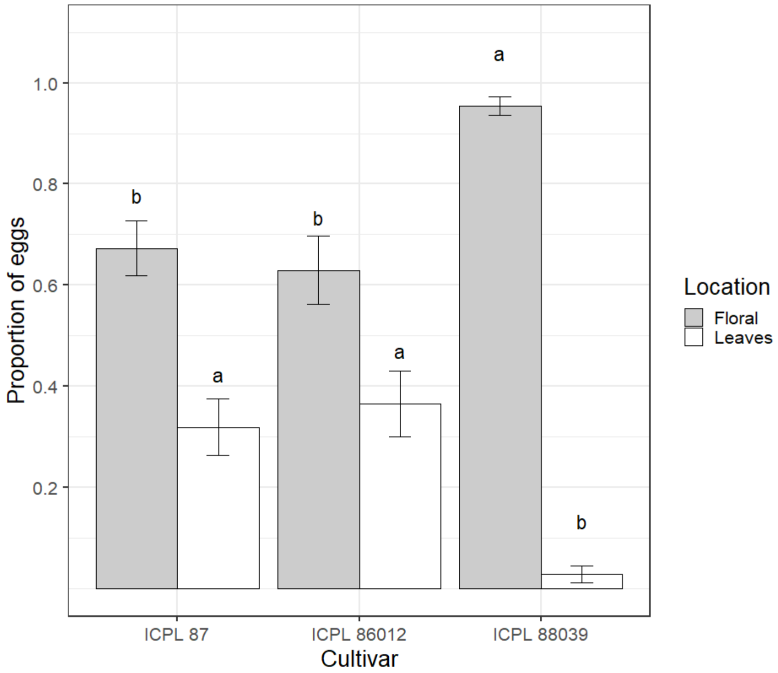

Figure 4: Proportion of eggs allocated to different plant structures in the oviposition no-choice experiment. Grey bars indicate eggs laid on floral structures, whereas white bars indicate eggs laid on leaves. Floral structures include bud initials, buds, flowers, and spent flowers. Bars are the means of proportions and error bars are standard errors. Letters above bars indicates a significant difference (*P*<0.05) among cultivars in the proportion of eggs allocated to a location as determined by Fisher's protected LSD test.

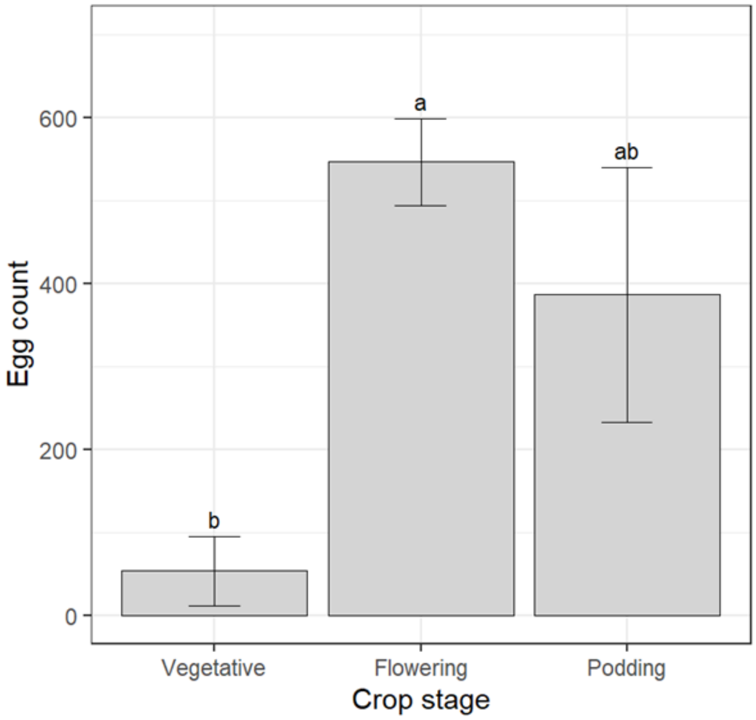

Figure 5: Number of *H. armigera* eggs laid on pigeonpea plants (cv. ICPL 86012) at three different crop stages – vegetative, flowering, and podding. Bars are the mean counts and error bars are standard errors. Letters above bars indicates a significant difference (*P*<0.05), determined by Fisher's protected LSD test.

Helicoverpa armigera caterpillar behaviour

When placing *H. armigera* larvae on pigeonpea plants in the glasshouse, we placed them on either leaves or flowers. Of the 300 neonate larvae that were placed on plants, 247 (82%) were found after 72 hours. Twenty-three of the recovered larvae had died. From the 224 live larvae we recorded at the end of the experiment, 222 (99%) were located on or inside a floral structure. Final larval feeding location did not differ due to cultivar (P=0.60) or initial larval placement location (*P*=0.19).

A range of larval performance measures were influenced by cultivar and placement treatments (Table 3). There was no difference in larval survival among pigeonpea cultivars (*P*=0.16). However, larval placement location did influence survival, with more live larvae found on plants when neonates were placed on flowers (82%) compared to when larvae were placed on leaves (67%) (*P*=0.004). In terms of other larval performance measures, larval weight was affected by both cultivar (*P*=0.004) and placement (*P*<0.001) treatments. Larval development was also affected by cultivar (*P*=0.021) and placement (*P*=0.003) treatments. Larvae weighed more and developed faster when placed on flowers compared to leaves, and larvae developed faster and weighed more on ICPL 86012 compared with the other cultivars, despite ICPL 86012 having been previously reported as 'resistant' (Sison & Shanower, 1994).

Table 3: P-values from ANOVAs for the *H. armigera* larval performance experiment showing the effect of pigeonpea cultivar and larval placement location on the final response variables measured at 72 h – final larval location (proportion in a floral structure), larval survival, larval weight, and larval development (proportion of larvae that reached second instar).

Source of variation	Final location	Survival	Weight	Development
Cultivar	0.60	0.16	**0.004**	**0.021**
Placement treatment	0.19	**0.004**	**<0.001**	**0.003**
Cultivar x placement treatment	0.60	0.35	0.19	0.06
Block (replicate)	0.58	**0.008**	**0.03**	0.21

Field sampling of Helicoverpa armigera larvae

Sampling data from beatsheeting in a crop of ICPL 88039 (indeterminate cultivar) showed that smaller *Helicoverpa* larvae are much less likely to be detected than larger larvae (only 13% of first instar larvae are detected cf. 78% for 4 & 5th instars) (Table 4). Although small larvae (1st & 2nd instars) likely do very little feeding damage and a large proportion of them will die, detecting early instars is crucial for forecasting economically damaging populations.

Table 4: Percent of larvae detected from beatsheeting (n=15 samples) as a proportion of absolute larval populations.

Size class (larval instar/s)	Mean percent larvae detected (±SE)
Very small (1st)	13.88 ± 8.26
Small (2nd)	39.02 ± 10.51
Small-medium (3rd)	59.10 ±9.01
Medium-large (4th)	85.61 ± 6.07
Large (5th and 6th)	71.43 ± 13.77

Pigeonpea response to pest feeding – growth tunnel experiment

There was no significant effect of damage treatment on yield when pigeonpea plants were flowering (P=0.21, Figure 6). However, at podding, both the *H. armigera* and simulated damage treatment caused yield loss to plants (P<0.001, Figure 6). Indicating that pigeonpea plants can compensate better for damage at flowering compared to podding. Additionally, at podding simulated damage appears to be an adequate substitution for actual *H. armigera* damage, as there was no significant difference between treatments.

Pigeonpea response to pest feeding – field experiments

The pigeonpea cultivars we selected for field experiments differed in a range of traits at flowering across both experiments, including flowering biomass (P<0.001), biomass allocated to reproductive structures at flowering (P<0.001), plant height (Exp 1 - P<0.001, Exp 2- P<0.01), branch count (Exp 1 - P<0.001, Exp 2 - P<0.01), and their number of racemes (P<0.001).

Expectedly, at harvest there were strong genotypic differences among yield and its components (Table 5; Figure 7; Figure 8). In Exp 1, experimentally damaging plants resulted in an overcompensation response and damaged plots yielded higher than undamaged (P<0.001; Table 5; Figure 7). In Exp 2 however, damage did not affect yield (P=0.11; Table

5; Figure 8). Across both experiments, there was no significant effect of cultivar x damage, indicating that cultivars did not differ in their ability to compensate for damage.

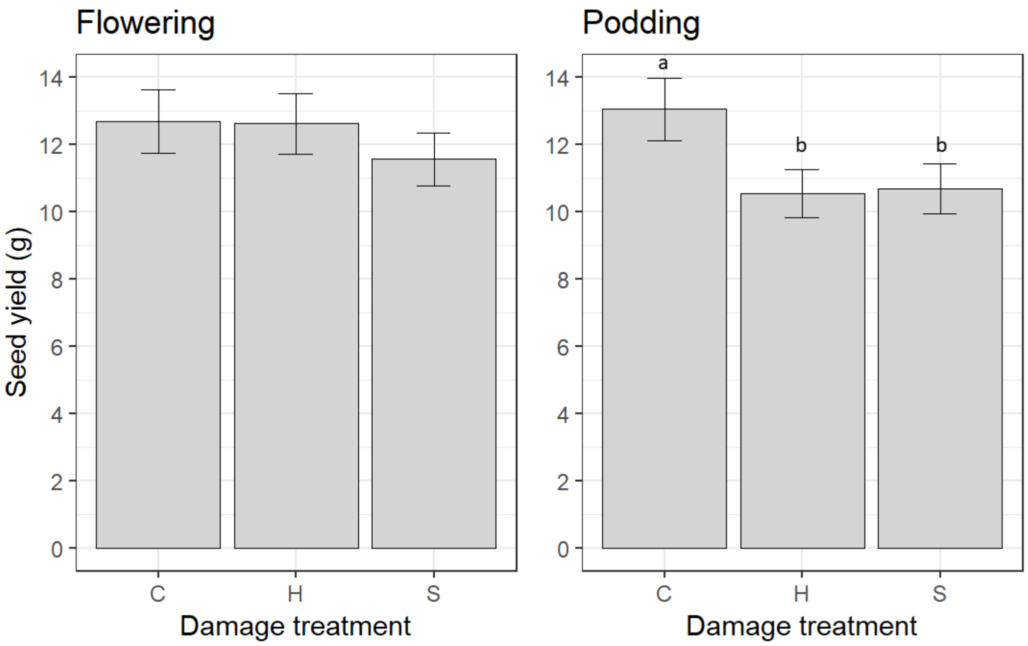

Figure 6: Yield response of pigeonpea plants (cv. ICPL 86012) in the growth tunnel experiment to different damage treatments at flowering and podding. C = control, H = a single *H. armigera* larvae restricted to a plant, and S = simulated pest feeding. Bars are the mean seed yields per plant and error bars are standard errors. Letters above bars indicates a significant difference (*P*<0.05), determined by Fisher's protected LSD test.

Several plant traits changed in response damage, providing an indication of the compensatory mechanisms pigeonpea plants employ. Crops responded to damage by extending their flowering period and delaying their harvest maturity date in both experiments. In Exp 1 damaging crops increased total biomass (P<0.001), increased the number of seeds per pod (P=0.048), increased mean seed weight (P<0.001), increased branch biomass (P<0.01), and decreased the proportion of yield distributed on the main stem (P<0.001). In Exp 2 damage did not change several of the traits seen in Exp 1, but damage did increase pod fractionation (P=0.02) and decrease the proportion of yield located on the mainstem (P<0.001).

Correlations indicate that the main variables associated with yield across the two experiments are total plant biomass, seeds per pod, and mean seed weight (Table 6). Surprisingly, the number of pods per plant did not appear to be a mechanism employed in compensation as the trait was not correlated with yield among cultivar and damage treatments.

Table 5: *P*-values from ANOVAs for key response variables recorded at harvest from the field experiments. HI = harvest index, MSW = mean seed weight, and PF = pod fractionation.

Exp	**Source of variation**	**Yield**	**Biomass**	**Pods (plant^{-1})**	**Seeds (pod^{-1})**	**MSW**	**HI**	**PF**	**Proportion yield on mainstem**
1	Cultivar	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**	**<0.001**
	Damage	**<0.01**	**<0.001**	0.29	**0.048**	**<0.001**	**<0.001**	0.47	**<0.001**
	Interaction	0.18	0.62	**<0.01**	**0.026**	0.11	0.11	0.37	**<0.01**
	Replicate	0.41	0.19	0.29	0.78	0.76	0.76	0.76	**0.04**
2	Cultivar	**<0.001**	**0.02**	**<0.001**	**0.011**	**<0.001**	**<0.001**	**<0.001**	**0.02**
	Damage	0.11	0.56	0.21	0.20	0.18	**<0.001**	**0.02**	**<0.001**
	Interaction	0.32	0.77	0.47	**<0.01**	**<0.01**	**<0.001**	**0.02**	0.08
	Replicate	0.88	0.56	0.95	0.97	0.64	0.47	0.83	0.59

Table 6: Correlation matrix for yield variables from all cultivar x treatment combinations for Exp 1 and Exp 2. Values are correlation coefficients and significance is indicated as **P*<0.05, ***P*<0.01, ****P*<0.001. HI = harvest index and MSW = mean seed weight.

	Biomass	**HI**	**Pods (plant^{-1})**	**Seeds (pod^{-1})**	**MSW**
Yield	0.92***	0.1	0.37	0.66***	0.70***
Biomass		-0.29	0.34	0.65***	0.63***
HI			0.01	0.02	0.11
Pods (plant^{-1})				-0.17	-0.35
Seeds (pod^{-1})					0.62***

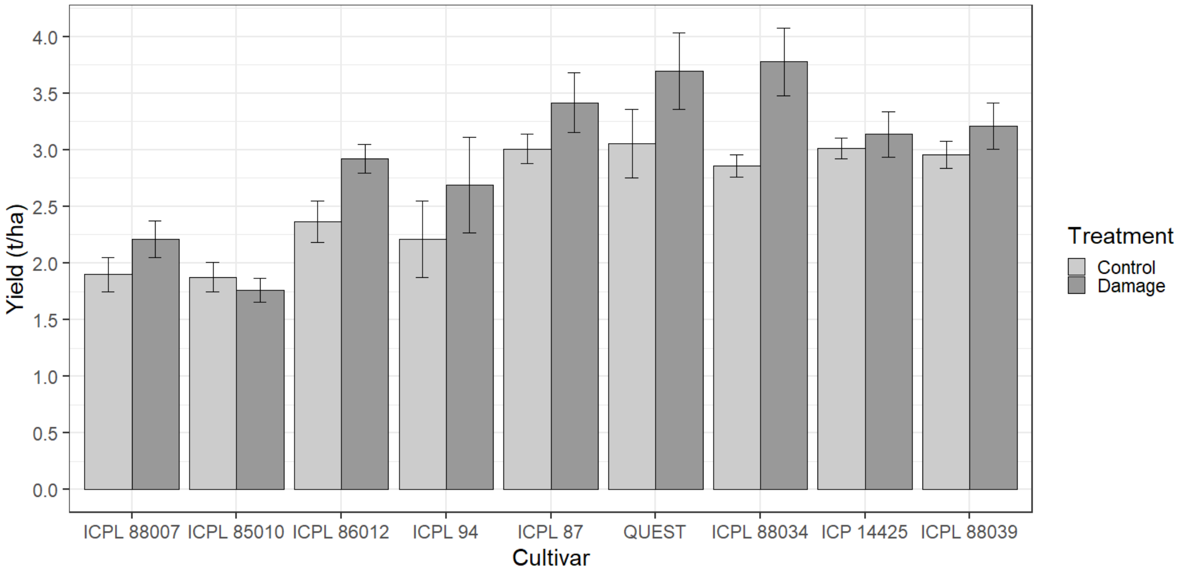

Figure 7: Yield of pigeonpea cultivars in Exp 1 (2020/2021 season) at Kingaroy Research Facility. Bars are the mean yields per plant and error bars are standard errors. *P*-values from ANOVAs are presented in Table 5.

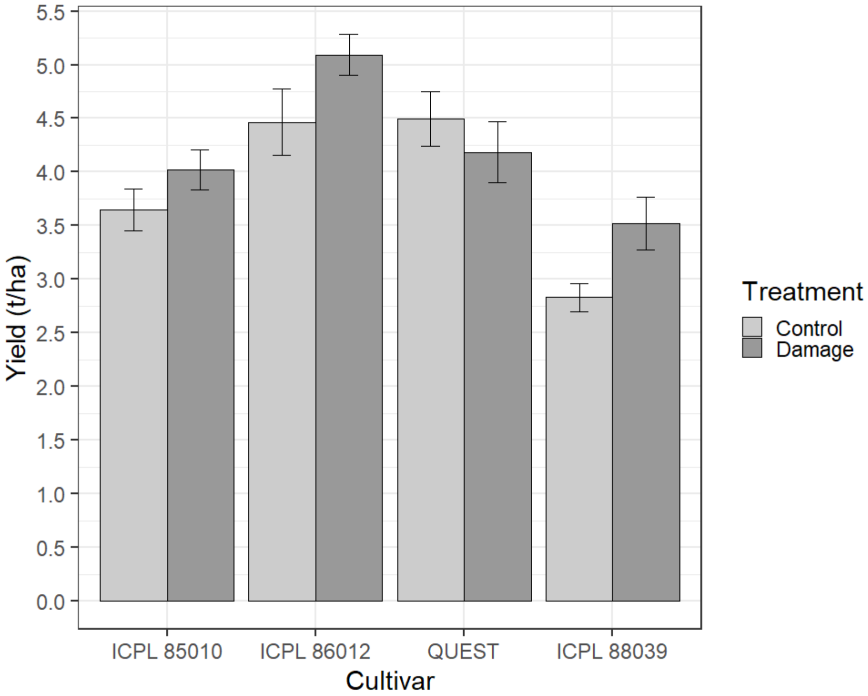

Figure 8: Yield of pigeonpea cultivars in Exp 2 (2021/2022 season) at Kingaroy Research Facility. Bars are the mean seed yields per plant and error bars are standard errors. *P*-values from ANOVAs are presented in Table 5.

Discussion/Insights

Perhaps the key insight from our pest behaviour research is the significance of the flowering period in determining the susceptibility of pigeonpea to its major pest *H. armigera*. Moths are highly attracted to flowering plants and lay most of their eggs on floral reproductive structures, and it is inside these floral structures where early instar larval populations establish feeding sites. This aspect of pest behaviour and crop susceptibility has implications for three key areas of managing *H. armigera*: developing less susceptible pigeonpea cultivars, field sampling protocols, and insecticide use.

Firstly, in terms of developing less susceptible pigeonpea cultivars, future research aiming to identify host-plant resistance in cultivated and/or wild pigeonpea genotypes should focus on identifying resistance expressed in flowers (Volp et al., 2022). Most work that has recently been conducted in Australia, by other research groups, has instead looked for resistance in pigeonpea leaves (Ngugi-Dawit et al., 2020, Vanambathina et al., 2021). Another potentially more successful approach to develop less susceptible pigeonpea cultivars may include developing genotypes with shorter and more synchronous flowering periods which may be at less risk of *H. armigera* infestations.

Secondly, the cryptic flower-feeding behaviour has implications for sampling *H. armigera* populations. Heavy egg-lay events can occur in flowering pigeonpea resulting in large populations of *H. armigera* larvae. Early instar *H. armigera* consume relatively little plant biomass, but larger instars do the bulk of the damage (along with being more difficult to control with insecticides). Therefore, to predict large, damaging pest populations in crops, identifying the presence of early instars is critical. Early instars will likely be located inside buds and flowers, and it is because of this that relatively few early instar larvae are detected with beatsheet sampling (Table 3). Therefore, in addition to beatsheeting, pest sampling regimes should include close inspection of pigeonpea floral structures for eggs and early instar caterpillars. Future research should work to develop appropriate protocols in this area.

Finally, insecticides applied to pigeonpea crops must be able to reach *H. armigera* larvae feeding inside reproductive structures. The two insecticides that will form the basis of the *H. armigera* spray regime in pigeonpea (chlorantraniliprole and emamectin) both require ingestion by larvae, but they do have some systemic activity. How well each product penetrates flowers and pods, and their residual activities will need to be investigated in detail. The efficacy of the biopesticide NPV may be limited for *H. armigera* in pigeonpea due to early instar's sheltered feeding sites, but this area still warrants investigation.

In our experiments examining pigeonpea plant's response to pest damage we have also gained a few key insights. Firstly, due to the ability of pigeonpea to tolerate pest feeding at flowering (as seen in our igloo studies, field trials, and previously published work (Sheldrake et al., 1979, Tayo, 1980)), developing an empirical economic threshold for flowering pigeonpea represents a significant challenge. Although crops may be able to compensate for substantial damage at flowering, they may lengthen their flowering period, potentially increasing the risk period for further pest egg lay. Additionally, if the crop is also delayed in reaching harvest maturity, that may present an issue if soil moisture is depleting during pod fill (drought stress risk) or if cold weather is approaching (frost risk).

We have found that pigeonpea plants cannot compensate for pest damage that occurs during late podding. The compensatory ability present at flowering disappears at podding because *H. armigera* larvae cause direct yield loss from feeding on the developing grain. Therefore, there are no substantial compensatory mechanisms left for the plant to use (other than potentially increasing the seed size of undamaged grains, a trait with limited plasticity). With appropriate investment for replicated site x season trials, developing a threshold for the podding crop stage will be relatively straightforward. Whereas, developing a threshold for flowering will require more detailed investigation. From our research we have already developed an in-depth understanding of how pigeonpea plants respond to pest attack, which will be used to guide future experiments.

There is still a substantial work to be done to develop appropriate management strategies for *H. armigera* in pigeonpea. Including: developing an appropriate sampling protocol for short determinate genotypes, evaluating the potential of biopesticides for *Helicoverpa* spp. control, further threshold development, and evaluating the immediate and residual efficacy of the available conventional insecticides. Our research has developed a fundamental understanding of the major pest problem in pigeonpea – when and why pigeonpea crops are susceptible to the pest, pest feeding behaviour, and how pigeonpea plants respond to pest damage. Future research investment will build upon our understanding in key areas to develop sustainable, economical, and practical pest management strategies for pigeonpea.

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6. Integrated Weed Management

Annie Ruttledge, Toowoomba

Background

To facilitate profitable commercial production of pigeonpea crops in Queensland will require identification of a suite of suitable herbicide and non-herbicide options to sustainably manage weed impacts in pigeonpea crops. Vigorous crops with early canopy closure can outcompete weeds, suppressing weed growth and seed production. In certain crops, various planting tactics can promote rapid crop canopy closure, but in-crop herbicide options are often still necessary, particularly for crops with slow early growth and/or limited leaf area. Additionally, residual herbicides can be crucial for reducing depletion of valuable stored soil moisture by weeds prior to and during pigeonpea establishment. There are currently few herbicides registered for pigeonpea grain crops, as the majority of pigeonpea grown in Australia are as trap crops and refuge for beneficial insects in cotton systems. To facilitate development of a commercial pigeonpea grain industry in Australia will require research to identify and support registration of a suite of safe and effective registered herbicides.

Research activities 2018-2019

To evaluate competitiveness of pigeonpea, pot trials were conducted in a netted enclosure under ambient conditions over summer 2018/2019. Water and fertiliser were applied to maintain optimum conditions for plant growth. One cultivar of pigeonpea (ICPL88039) was compared with various sorghum and mungbean cultivars (representing a range of phenotypes), with 6 replicates (pots containing 1 plant) arranged in a complete randomized block design. At the time, pigeonpea seed increase activities were still underway, and it wasn’t possible to include other genetic lines. Measurements including leaf area and biomass were collected to enable inferences about pigeonpea competitiveness relative to two other key summer crops, mungbean (Figure 1 and Figure 2) and sorghum (Figure 3 and Figure 4).

Pigeonpea had slower growth relative to both sorghum and mungbean, producing little biomass and with very low leaf area. This suggests weeds will have little competition from pigeonpea during the crop establishment phase, and without intervention weeds could reduce pigeonpea crop yields and add substantially to the weed seed bank. Breeding faster maturing cultivars will be important for reducing the critical period for weed competition. Additionally, herbicides are likely to play a key role in preventing weeds during the crop establishment phase.

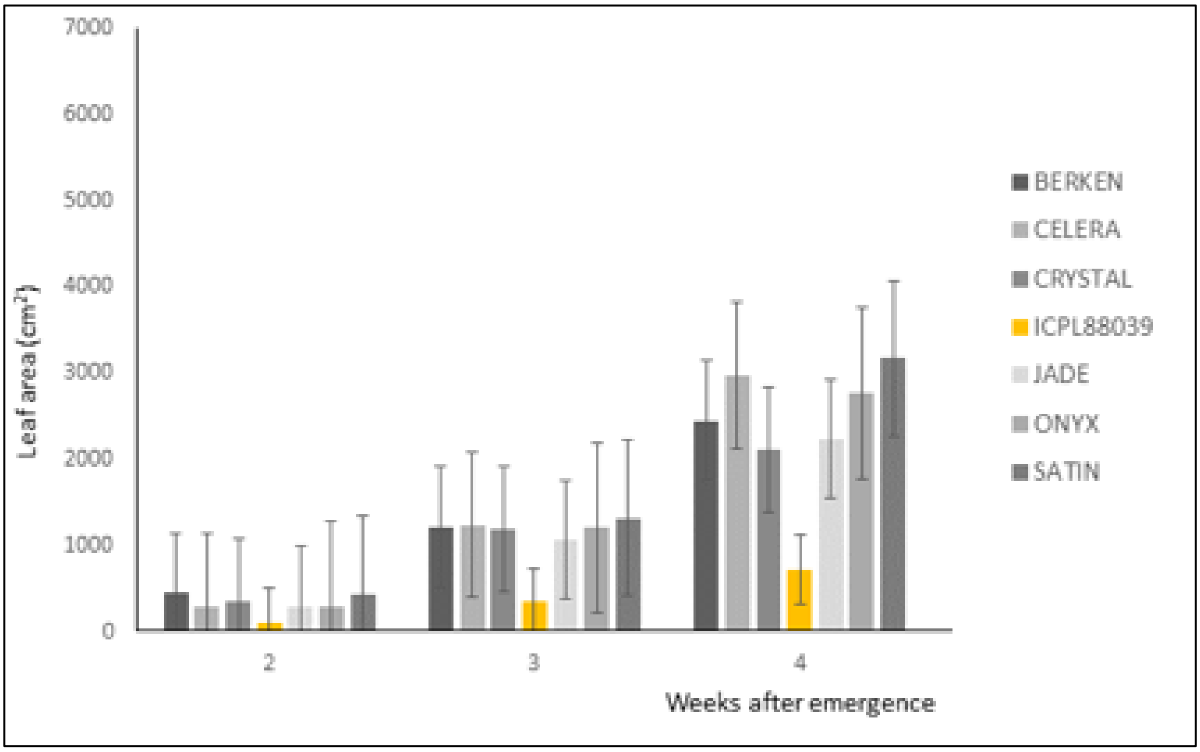


Figure 1: Leaf area (cm^2) of mungbean cultivars compared with pigeonpea (ICPL88039) grown in pot trails. Data was collected at 2, 3 and 4 weeks after first emergence.

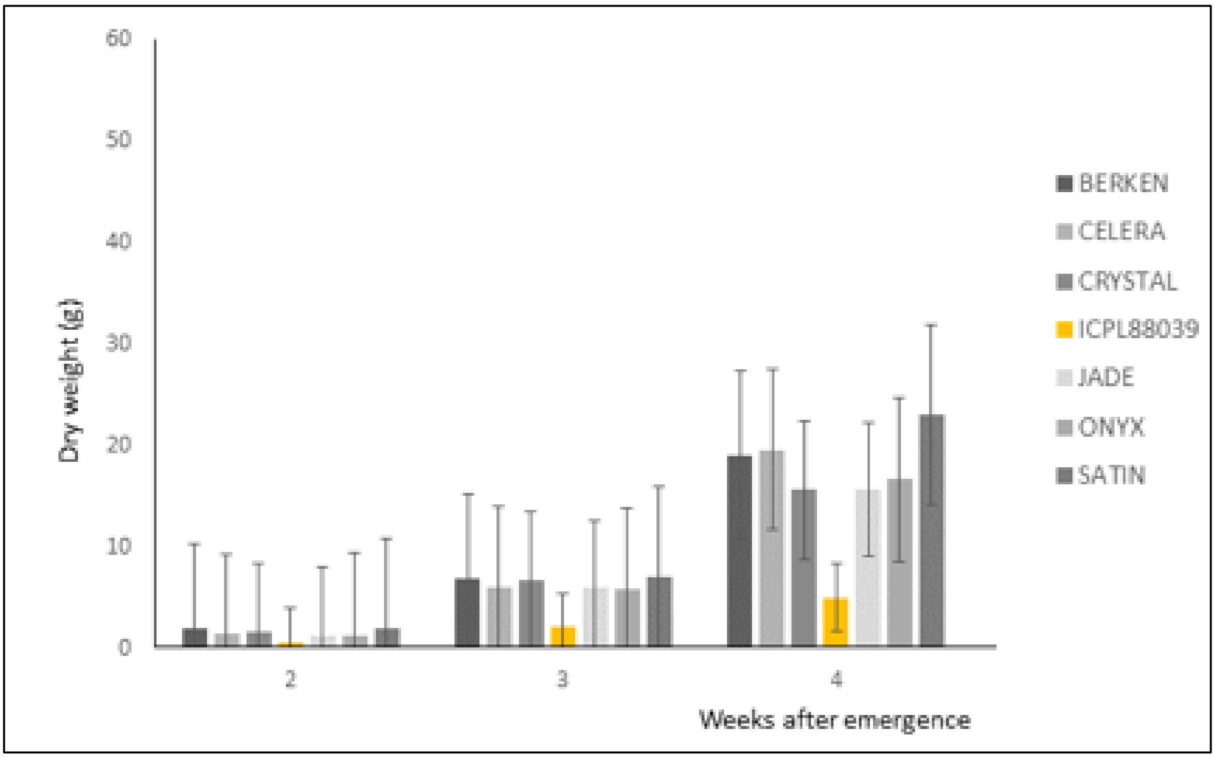


Figure 2: Dry weight (g) of mungbean cultivars compared with pigeonpea (ICPL88039), measured at 2, 3 and 4 weeks after first emergence.

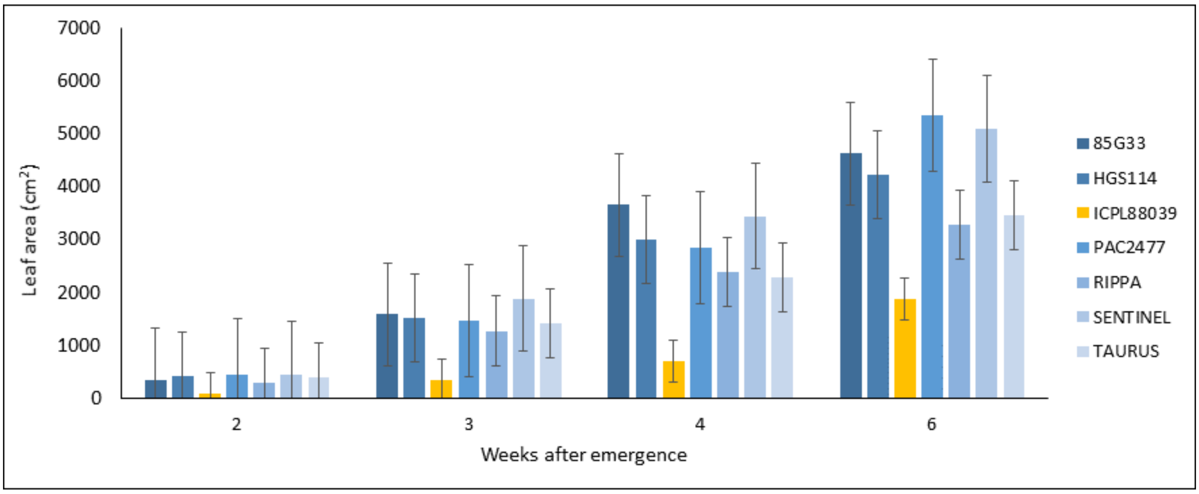


Figure 3: Leaf area (cm^2) of sorghum cultivars compared with pigeonpea (ICPL88039), measured at 2, 3, 4 and 6 weeks after first emergence.

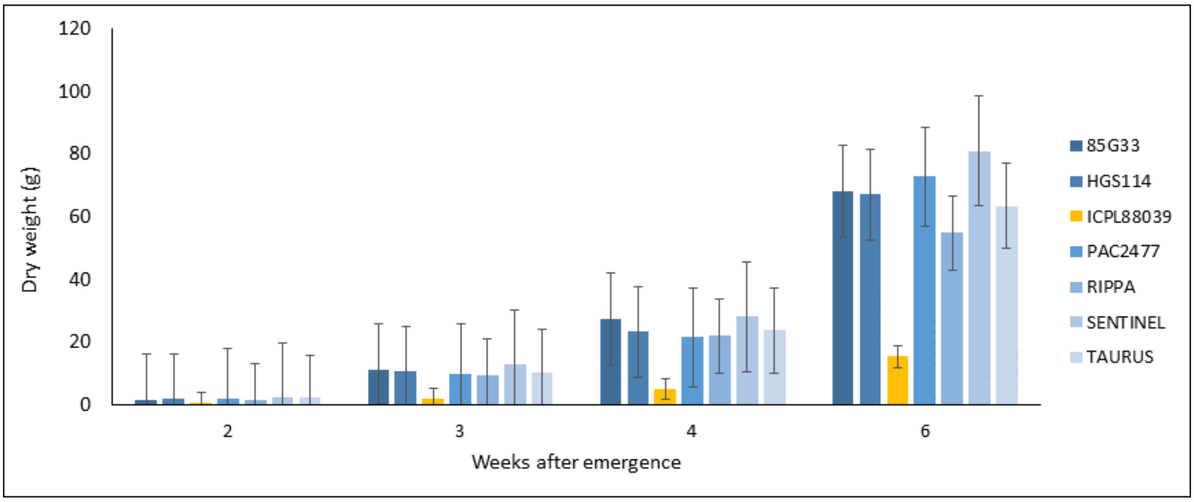


Figure 4: Dry weight (g) of sorghum cultivars compared with pigeonpea (ICPL88039), measured at 2, 3, 4 and 6 weeks after first emergence.

Growth of pigeonpea (line ICPL88039) was also examined in a field trial conducted at Wellcamp in Summer 2018/2019. Pigeonpea and other crops including cereal and legume species were planted, with 3 replicates (6m x 2m plots) for each crop arranged in a complete randomized block design. To gain insights into weed suppression potential from crop shading, crop light interception was measured in each plot between 11 am and 2 pm on clear days with an 80 cm line-quantum sensor (AccuPAR radiometer; Decagon Devices, Inc., USA). Photosynthetically Active Radiation (PAR) was measured at regular intervals, from 2 weeks post emergence through to crop termination (post flowering and prior to grain fill) at 80 days after planting (Figure 5). Crop biomass data at termination was also collected (Figure 6).

Light interception was calculated as:

LI = 1 - (light below canopy/light above canopy)

Where light below canopy/light above canopy is the percent of photosynthetically active radiation.

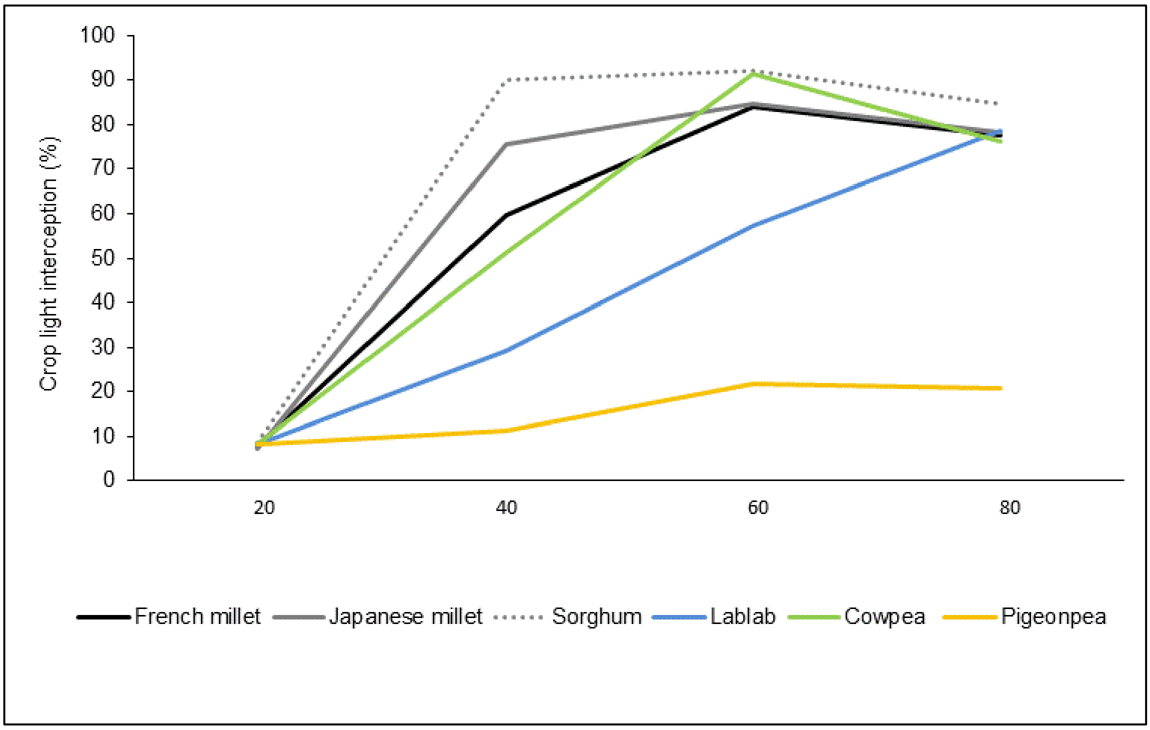


Figure 5: Crop light interception (PAR) of cover crops (legumes and grass species) compared with pigeonpea measured at 20, 40, 60 and 80 days after planting.

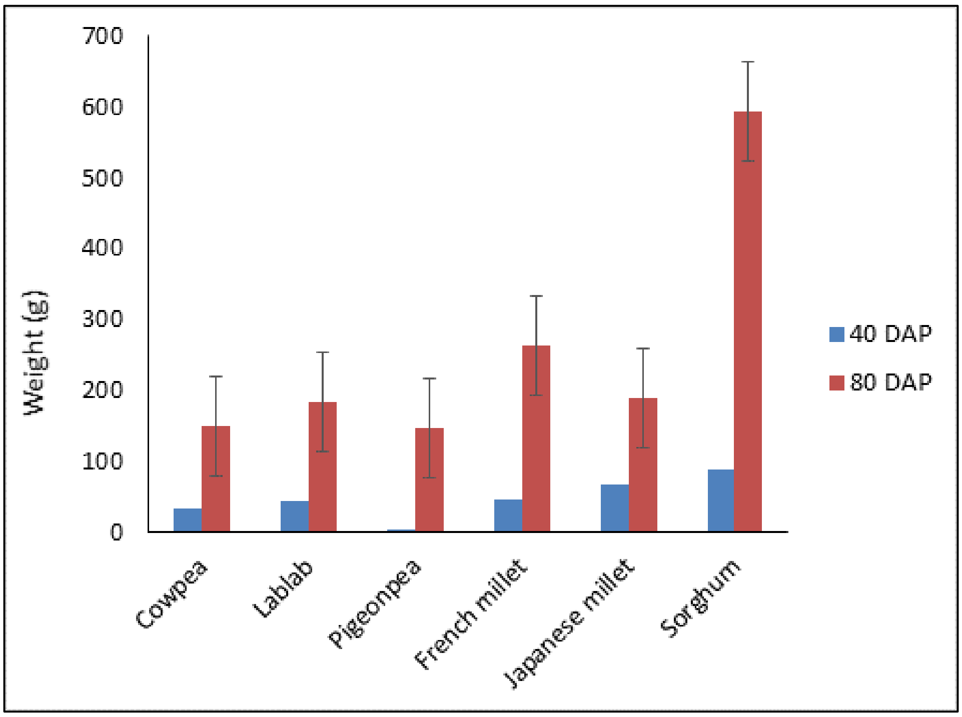


Figure 6: Biomass (dry weight [g]) of cover crops (legumes and grass species) compared with pigeonpea at 40 and 80 days after planting.

As in the pot studies, during the field trial pigeonpea was slow growing, producing lower biomass than any other crop species. Pigeonpea also intercepted very little light relative to the other crop species. Based on the results using this genotype, pigeonpea will compete poorly with weeds. Without the use of mechanical or herbicide tools to manage weeds in-crop, it is very likely that weeds will reduce grain yield. Further, subsequent crops could be impacted due to high weed seed set and depletion of stored water by weeds.

Research activities 2019-2020

Conducting experiments in the 2019/2020 pigeonpea growing season was again constrained due to limited seed for key pigeonpea genotypes. Activities conducted by the weed science team over this period included:

- A comprehensive review of the scientific and industry literature to refine our research questions and develop defined experiments.
- A sand bioassay involving pigeonpea and imazapic. Imazapic is widely used in Australia's northern states for summer weed control in fallow, and the literature review of herbicides highlighted it as strong option for pigeonpea crops.
- Development of a protocol for screening existing (registered) and potential (unregistered) herbicide options for pigeonpea.

Literature review summary

Effective weed control will be key to the successful production of pigeonpea crops in Australia. Sequential application of pre- and post-emergence herbicides is likely to be important for controlling weeds over the first 6-8 weeks of crop growth, which is the critical period for weed control in this traditionally long-duration crop. The literature review has highlighted a suite of available herbicides with a registered use pattern in pigeonpea in Australia's northern states. However, careful consideration needs to be given to the impact of residual herbicides on subsequent crops. Also, the development of herbicide resistance is a major challenge in Australian broad acre cropping systems, and to manage this risk in pigeonpea will require the strategic integration of diverse weed control options, including rotation between herbicide modes of action, appropriate use of strategic tillage, and cultural/agronomic tactics to promote competitive crops.

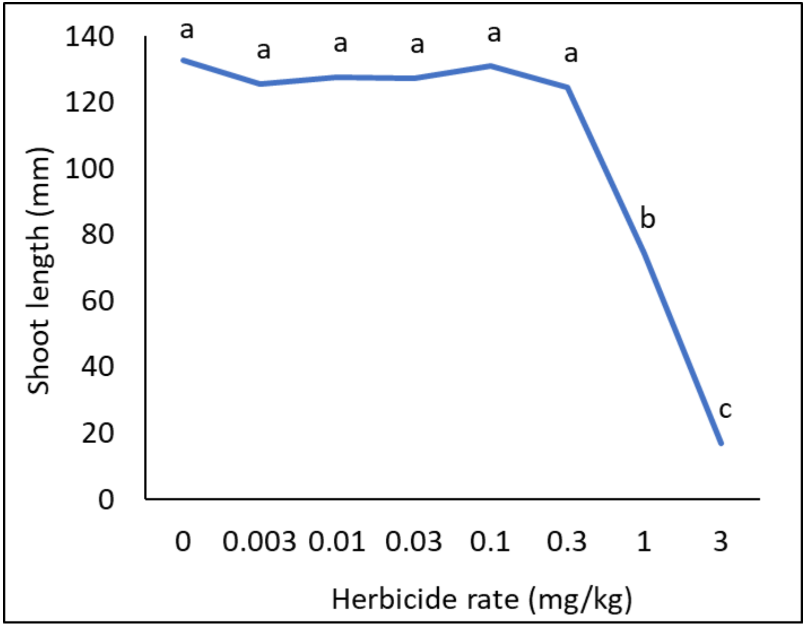
Agronomic techniques have potential to increase pigeonpea early vigour and reduce the vulnerability of pigeonpea to weeds during the critical early crop growth stages. Wide row spacing (50 cm) is typical in pigeonpea, but this practice favours weed growth. Narrower planting arrangements may be useful for weed control, however research into this topic has indicated that reduced row spacing may produce lower yields. There are weed control advantages of wider row spacing, since inter-row cultivation and targeted herbicide application can be more readily deployed at wider row spacing. Research conducted in other countries suggests that intercropping pigeon pea with another summer broadleaf crop, such as mung bean, can assist with weed control in the inter-row spaces. However, of the various agronomic strategies that have been scientifically evaluated in pigeonpea, two strategies appear most suitable for adoption in Australia. These are i) selecting cultivars with high early vigour, and ii) variation in planting dates. These strategies have potential to reduce weed interference in the early stages of crop growth, without incurring yield penalties.

Bioassays

The method used for this experiment is based on relevant international standards for soil toxicity testing in terrestrial plants (ISO 11269-2 and OECD Guideline 208). In separate but concurrent experiments, pre-germinated seeds of pigeonpea and mungbean were placed in contact with river sand that had been washed, dried and sieved before being treated with the test substance (imazapic). These bioassays used sand as a baseline medium to ensure maximum bioavailability of residues (i.e. negligible herbicide sorption). The seedlings were grown in controlled conditions at alternating temperatures (30/20oC), with suitable artificial lighting supplied during the warmer 12-hour temperature cycle.

Seedlings were evaluated for effects at 14 and 21 days. Data was collected on shoot length and biomass (fresh and dry weights of shoots and roots). To aid interpretation of results, visual detrimental effects (chlorosis, mortality, plant development abnormalities, etc.) were also recorded. In both the pigeonpea and mungbean experiments, seedling shoot length of both mungbean and pigeonpea were statistically similar to the control treatment at the label rate for fallow weed control using a commercial imazapic formulation (48 g a.i. ha-1 which is equivalent to 0.03 mg/kg based on bulk density of sand in the top 10cm).

A)



B)

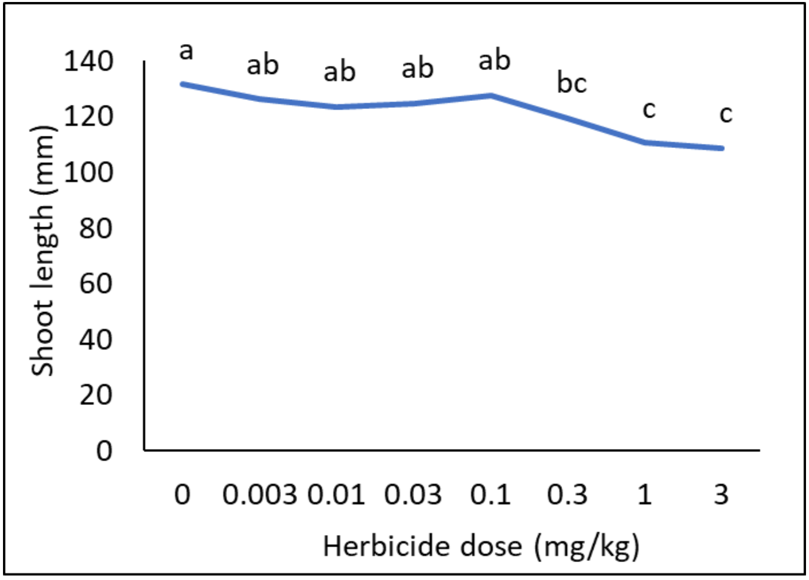


Figure 7: Shoot length data (mm) at 14 days. A) Bioassay of imazapic and pigeonpea. B) Bioassay of imazapic and mungbean. Herbicide rates were 0, 0.003, 0.01, 0.03, 0.1, 0.3, 1, 3 mg/kg. The underlined rate 0.03 mg/kg (48 g a.i. ha-1) is the fallow rate for weed control. Alphabetic characters indicate significant differences using Fisher's unprotected least significant difference test (LSD).

Of the various measurements taken, shoot length was the most reliable for comparing imazapic effects between the two crop types (Figure 7). For both crop types, shoot length was not significantly impacted by imazapic at the field rate for use in summer fallows (0.03 mg/kg (48 g a.i. ha^{-1}). Further, pigeonpea seedlings appeared healthy at x10 the fallow rate for summer fallow weed control, indicating a high degree of natural tolerance to this herbicide (Figure 8).

Mungbean has a relatively short minimum re-cropping interval after use of imazapic, and these results suggest that pigeonpea could be similar. Based on these results, imazapic is a good candidate for further testing using more comprehensive pot and field trials.

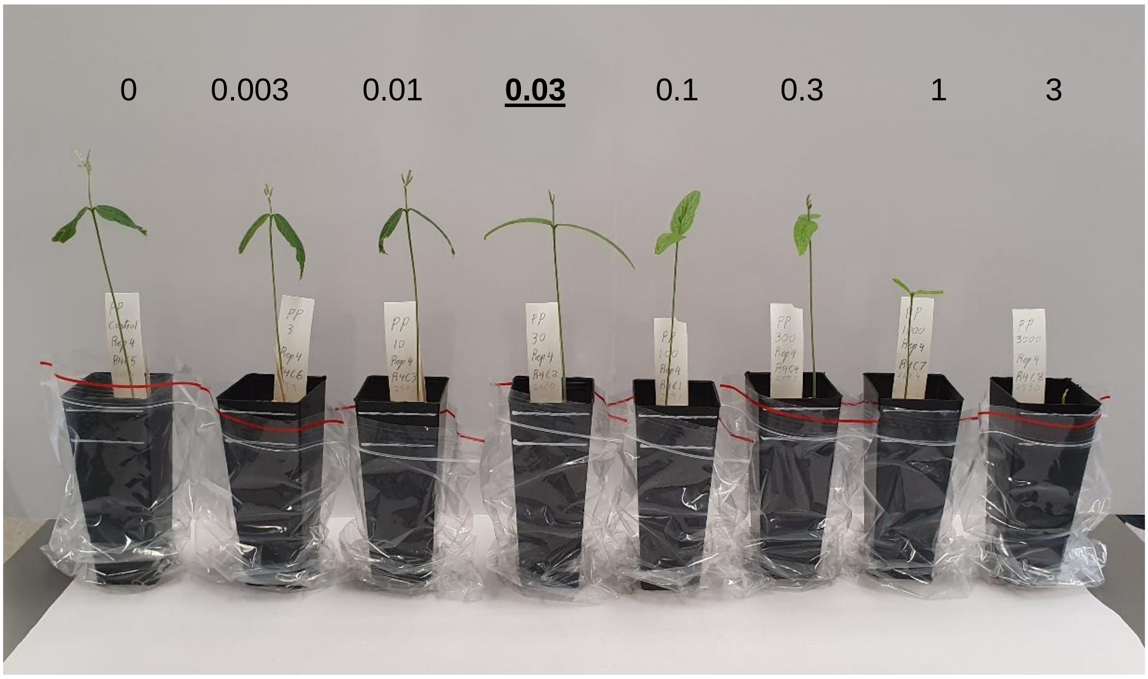


Figure 8: Bioassay for imazapic and pigeonpea at 14 days after planting. Target rate 0.03 mg/kg (48 g a.i. ha^{-1}), as indicated using underline.

Research activities 2020-2021

Agronomic tactics to promote canopy development

Field experiments were conducted by the agronomy team at two locations in Queensland, at DAF research facilities in Kingaroy (southern Queensland) and Emerald (central Queensland). There were three times of sowing (TOS) and three replicates for each time of sowing. The TOS for Kingaroy were November 2020, December 2020, and January 2021. The TOS for Emerald were December 2020, January 2021, and February 2021. The Kingaroy trials had three row spacings (25cm, 50cm, and 75cm) and five genotypes (ICPL 85010, ICPL 86012, ICPL 88007, ICPL 94, and KP1). The Emerald trials had four row spacings (25cm, 50cm, 75cm, and 100cm) and four genotypes (ICPL 85010, ICPL 86012, ICPL 88007, and ICPL 94).

Weeds were controlled in these experiments, so that crop growth and yield could be assessed under optimal conditions. To gain insights into weed suppression potential due to shading, crop light interception was measured in each plot from three PAR measurements above the canopy using a point quantum sensor and three PAR measurements immediately below the green leaves at randomly chosen spots. Measurements were taken between 11 am and 2 pm on clear days with an 80 cm line-quantum sensor (AccuPAR radiometer;

Decagon Devices, Inc., USA). PAR measurements were collected at 30, 50, and 80 days after sowing (DAS) in Kingaroy (Figure 9), and 30, 50, and 70 DAS in Emerald (Figure 10).

For Kingaroy, at DAS 30 there were significant main effects for TOS ($p < 0.001$, LSD = 0.0372), row spacing ($p < 0.001$, LSD = 0.0281) and genotype ($p = 0.012$, LSD = 0.03232). Light interception by the crop canopy was significantly lower for December (LI = 0.155) compared with crops planted in November (LI = 0.2412) and January (LI = 0.2769). All row spacing had significantly different light interception from each other (LI = 0.1799 at 75cm, LI = 0.2135 at 50cm and LI = 0.2795 at 25cm row spacings). Light interception by ICPL 88007 (LI = 0.2631) was significantly higher than the other 4 genotypes, which did not differ from each other significantly (LI = 0.2098, 0.2117, 0.2165 and 0.2205 for genotypes ICPL 85010, ICPL 94, ICPL 86012 and KP1, respectively).

For DAS 50 at Kingaroy there was a significant 2-way interaction of TOS x genotype ($p < 0.001$, Avg LSD = 0.0605), and the main effect of row spacing was also significant ($p = 0.014$, LSD = 0.0281). Light interception was significantly lower for all genotypes sown in November compared with the two later planting dates, for which genotypes did not show significant differences. For the November planting, KP1 and ICPL 88007 intercepted the greatest proportion of light compared to the other 3 genotypes. For row spacing, the same trend was observed at 50 DAS as at 30 DAS. Crops planted at the widest row spacings intercepted significantly less light than at narrower spacings (LI = 0.4425 at 75cm, LI = 0.5362 at 50cm and LI = 0.5833 at 25cm row spacings).

For DAS 80 at Kingaroy, there were significant interactions for TOS x row spacing ($p = 0.012$, Avg LSD = 0.0533) and TOS x genotype ($p < 0.001$, Avg LSD = 0.0611). Light interception at the different row spacings didn’t differ significantly for genotypes in the November and December plantings and were significantly lower than for the January planting. The exception was the 25cm row spacing for November sown crops – which had similar light interception to crops sown in January at the widest row spacing (75cm). For crops sown in January, there was a significant difference in light interception for each decrease in row spacing (LI = 0.7528, 0.8267, and 0.8941 for 75cm, 50cm and 25cm respectively). Light interception by the genotypes did not show significant differences for November and December times of sowing, except for KPI. This genotype intercepted significantly more light than the other genotypes for November, but significantly less light than other genotypes in later plantings (December and January). With the exception of KPI, all other genotypes sown in January intercepted more light than crops sown in November and December, with ICPL 86012 and ICPL 94 intercepting the greatest proportion of light. ICPL 86012 also intercepted the most light in the December time of sowing, but not significantly more than the other genotypes.

At Emerald, light interception data for 30 DAS had significant effects for TOS ($p < 0.001$, LSD = 0.0317), row spacing ($p < 0.001$, LSD = 0.0366) and genotype ($p = 0.001$, LSD = 0.0276). Light interception by the crop canopy differed for all planting dates and was lowest for the January time of sowing (LI = 0.3218) compared with crops planted in December (LI = 0.4008) and February (LI = 0.7006). Narrow row spacing significantly increased light interception, but there was no significant difference between the 50cm and 25cm wide rows. The two wider row spacings (100cm and 75cm) intercepted significantly less light than the two narrower row spacings (50cm and 25cm). Light interception was 0.3905, 0.3996, 0.5417 and 0.5659 for 100cm, 75cm, 50cm and 25cm, respectively. Light interception by ICPL 88007 (LI = 0.5208) was higher than the other 3 genotypes, which did not differ from each other significantly (LI = 0.4483, 0.457, and 0.4715 for genotypes ICPL 86012, ICPL 85010 and ICPL 94, respectively).

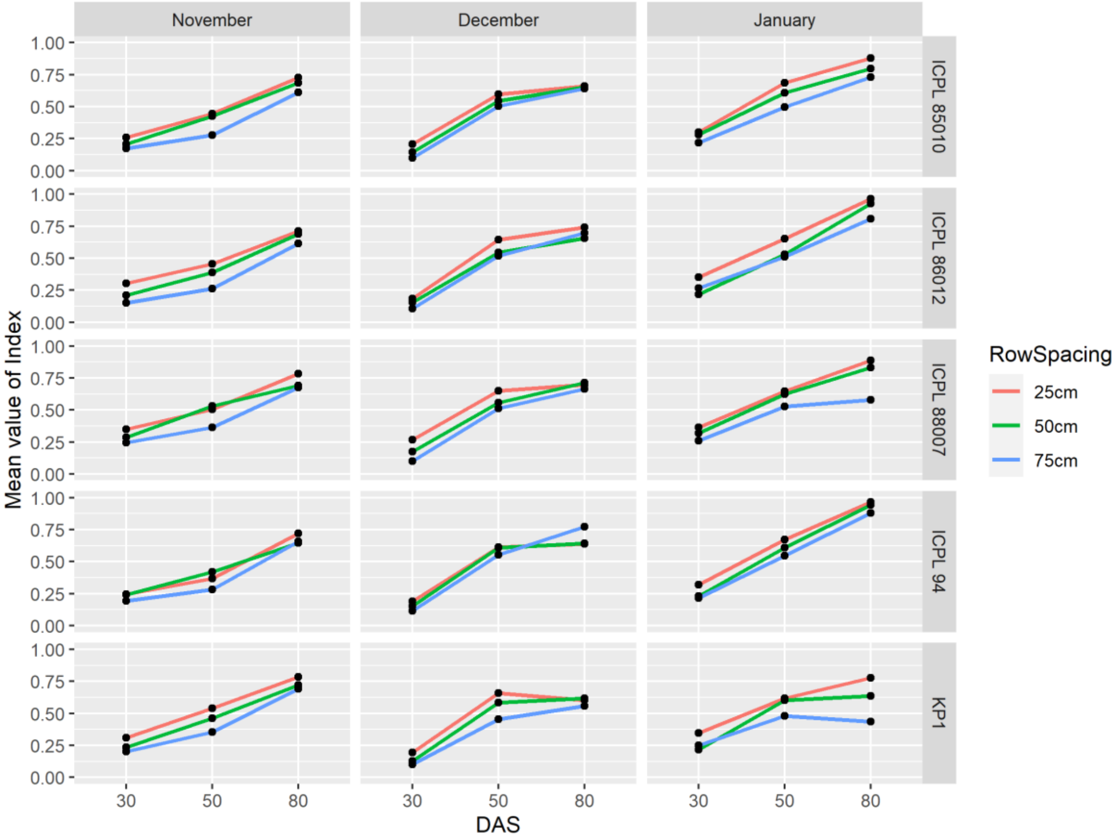


Figure 9: Mean light interception index for the 2020-2021 agronomy trials at Kingaroy (average of 3 replicates). There were three times of sowing (November, December and January), 3 row spacings (25cm, 50cm and 75cm), and 5 genotypes (ICPL 85010, ICPL 86012, ICPL 88007, ICPL 94, and KP1).

For 50 DAS at Emerald, the significant effects were the 2-way interactions of TOS x row spacing (p <0.001, Avg LSD = 0.063) and row spacing x genotype (p <0.048, Avg LSD = 0.059). For December and January, the 75cm row spacing had the lowest light interception (LI = 0.4333 and 0.4189 for December and January, respectively), with light interception being greatest at 50cm (LI = 0.5874) for the December planting and 25cm (LI = 0.5392) for the January planting. In the February planting there were significant increases in light interception for each reduction in row spacing (LI = 0.669, 0.7115, 0.8078, 0.8365 for 100cm, 75cm, 50cm, and 25cm, respectively). Regardless of planting date, light interception at the wider row spacings (75cm and 100cm) tended to be significantly less than at the narrower row spacings (25cm and 50cm) for all genotypes.

For 70 DAS at Emerald, the significant effects were the main effect of genotype (p <0.038, LSD = 0.0276) and the TOS x row spacing interaction (p <0.001, Avg LSD = 0.063). The genotype ICPL 86012 intercepted a similar proportion of light to ICPL 94 (LI = 0.6824 and 0.6587, respectively) but significantly more light than ICPL 88007 and ICPL 85010 (LI = 0.6492 and 0.6457, respectively). There was no clear trend in light interception due to row spacing for any time of planting. Light interception at all row spacings was generally lower for December compared with January and February plantings.

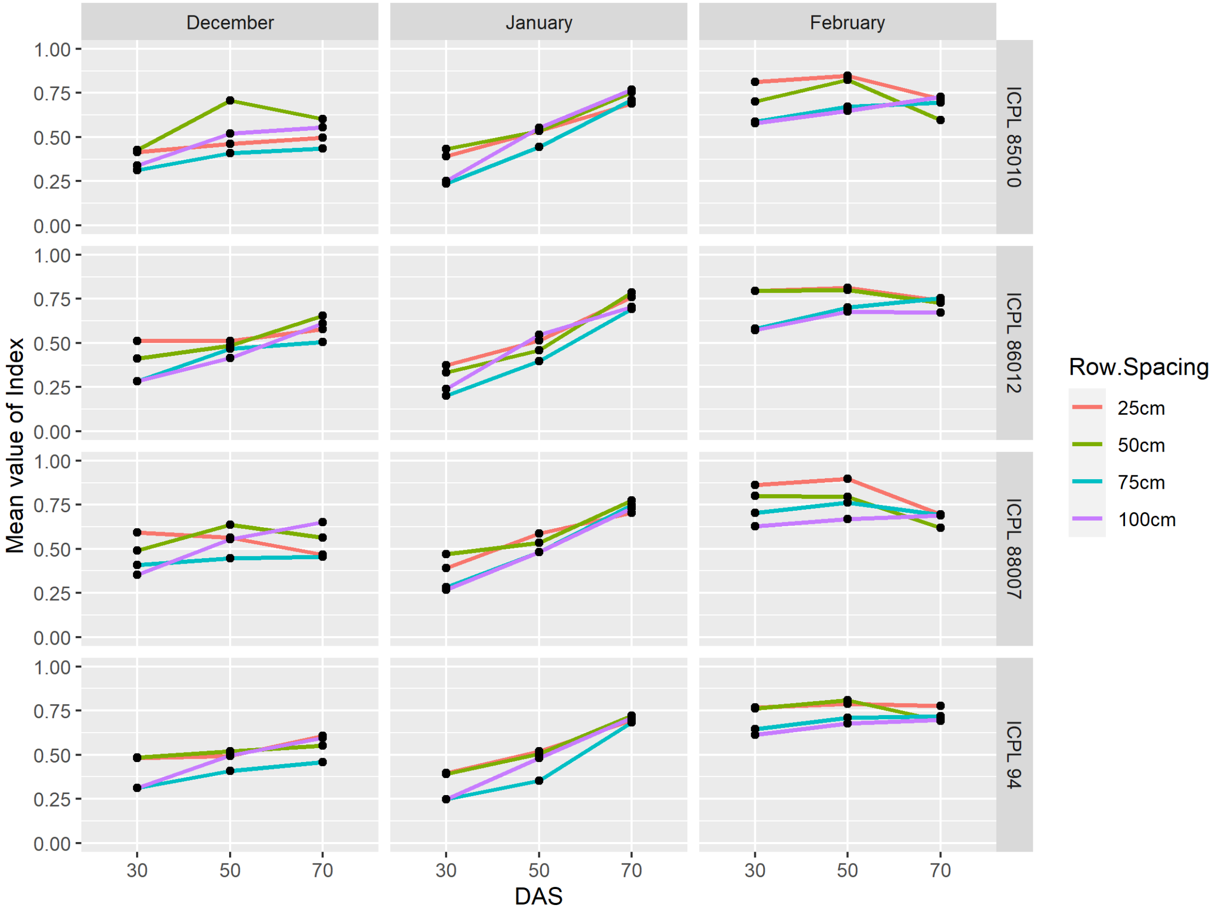


Figure 10: Mean light interception index for the 2020-2021 agronomy trials at Emerald (average of 3 replicates). There were three times of sowing (December, January and February), 4 row spacings (25cm, 50cm, 75cm and 100cm), and 4 genotypes (ICPL 85010, ICPL 86012, ICPL 88007, and ICPL 94).

General comments on agronomy trials

The level of light interception by crops planted in December and January was higher at Emerald than at Kingaroy for 30 DAS, indicating a more rapid rate of canopy development at Emerald. This difference declined over time, with crops at Kingaroy intercepting more light at the later growth stage (80 DAS at Kingaroy and 70 DAS at Emerald).

For both locations, the latest crop planting (January at Kingaroy and February at Emerald) had the highest levels of light interception at 30 DAS. At Emerald the proportion of light intercepted by the canopy decreased at later growth stages – perhaps due to loss of leaf biomass with plant senescence.

Trials at both Kingaroy and Emerald demonstrated that reducing row spacing from 75cm to 50cm resulted in higher light interception by the crop. This advantage was most apparent at early growth stages, lasting up to 50 DAS at Kingaroy. Another similarity between the locations was that the genotype ICPL 88007 provided the highest level of light interception at 30 DAS. This suggests a more rapid rate of canopy development in this genotype, with additional leaf biomass resulting in increased shading.

However, while weed suppression is a useful attribute, it is yield that is typically the most influential factor in planning agronomic strategies and selecting genetic lines for breeding new crop cultivars. The latest crop planting at each site (February at Emerald and January at

Kingaroy) had the highest weed suppressive potential and also produced the highest yields. There was no clear yield penalty associated with narrower row spacing: at Kingaroy there was no significant effect of row spacing (or its interaction with other factors) on yield, while for Emerald there was a significant interaction of TOS by row spacing, meaning that different row spacings produced significantly higher yields depending on TOS. The genotype ICPL 88007, which had the highest weed suppression potential at both sites, did not perform strongly at Kingaroy; however, at Emerald this genotype was significantly the highest yielding for both the December and January plantings, and the second highest yielding for February sown crops. This suggests ICPL 88007 appears to be a good candidate for breeding cultivars suited to Central Queensland, being both high-yielding and potentially yield suppressive in the Emerald trials. For full details on yield and other key crop metrics, see the agronomy trial reports for Kingaroy and Emerald.

Herbicide tolerance screening

Potential herbicide options for pigeonpea were identified using literature review, industry consultation, and searching the APVMA PubCRIS database for products registered for pigeonpea and other pulse crops in Queensland. For both the pre- and post-emergence components (Table 1 and Table 2, respectively), two pot experiments were conducted in controlled climate growth rooms at the Leslie Research Facility, Toowoomba, in 19cm diameter pots with supplementary irrigation. For each herbicide treatment there were three replications. The seed varietal line was ICPL86012. All tests were run in a controlled temperature growth room, with a 12-hour photo period. Average temperatures were 30-33 °C (day) and 18–21 °C (night).

Since pre-emergence herbicide damage is typically more severe in lighter textured soils, a sandy loam soil was used in these experiments to represent worst-case-scenario soil types. This soil was collected from the top 10cm at the DAF Applethorpe Research Facility and was sieved to 4 mm. Herbicides were applied post-planting, pre-emergence and incorporated by watering. Prior to herbicide treatment pre-germinated pigeonpea seeds (radicle length 2-6 mm) were planted into moist soil and covered with approx. 15mm of soil before applying fertiliser to supplement any nutrient deficiencies that could mask herbicide damage. In test 1, seven germinated seeds were placed into each pot. In the repeated round of testing (Test 2), ten seeds were placed into each pot. The herbicides (Table 1) were then applied via a motorised spray cabinet and the pots were immediately irrigated from above to incorporate the herbicide. For the remainder of the experiment pots were watered minimally to reduce movement of herbicide out of the pot while ensuring plants were not water stressed. In the repeat round of testing fertiliser was re-applied after two weeks, because in test 1 the seedlings exhibited signs of nutrient deficiency. The methods were adapted from Rosenhauer and Petersen (2015). At 28 DAT, survival and plant height of each seedling was measured separately and the results averaged per pot. The plant material was clipped at the soil surface, dried at 70 ºC and weighed to record dry weight per pot.

The treatment list for test 2 was slightly different from test 1. The highest rate of Reflex (1500 mL/ha) was not included in the second test due to severe damage in test 1. A higher rate of Titan Pendimethalin (1900 ml/ha) was added in test 2 in line with label recommendations for pigeonpea (i.e. 1.9 to 2.5L/ha), and similarly a higher rate of Valor was added in test 2 within label recommendations for pigeonpea (210 to 280 g/ha).

Table 1: Post-plant pre-emergence herbicide treatments and rates applied in tolerance screening pot trials.

Herbicide product	**Active ingredient**	**Group**	**Active ingredient registered as pre-emergent in pigeonpea in QLD**	**Rate**
Broadsword	Flumetsalam	2	Yes, for GM Cotton Refugia	25 g/ha
Control	NIL	NA	NA	NA
DualGold	S-Metolachlor	15	No	1000 ml/ha
Impose	Imazapic	2	No	400 ml/ha
Kyte 700	Imazethapyr	2	No	Test 1 and 2: 70 g/ha Test 2: 100g/ha
Mentor	Metribuzin	5	Yes	470 g/ha
[1] Reflex	Fomesafen	14	No	Test 1 and 2: 500 ml/ha Test 1 and 2: 1000 ml/ha Test 1: 1500 ml/ha (dropped in test 2 due to high mortality in test 1)
[2]Titan Pendimethalin 440	Pendimethalin 455 g/L	3	Yes	Test 1 & 2: 1500 mL/ha Test 2: 1900 ml/ha
TriflurX	Trifluralin	3	No - Registered NSW and ACT only	1200 ml/ha
[3]Valor	Flumioxazin	14	Yes (see Table D of label)	Test 1 and 2: 210 g/ha Test 2: 280 g/ha

[1] Reflex 1500 caused severe damage in test 1 and was not repeated in test 2.

[2] In test 2 an additional rate of Titan Pendimethalin (1900 ml/ha) was added since the label for pigeonpea stipulates 1.9 to 2.5L/ha.

[3] In test 2 an additional rate of Valor was added since the label for pigeonpea stipulates 210-280 g/ha.

In both tests, emergence was similar across the treatments (90-100%), except for the highest rate of Reflex (1500 mL/ha) in test 1 which reduced emergence by 22% compared to the control. Mortality was close to zero for most treatments in both tests, except for the two higher Reflex treatments (1000 and 1500 mL/ha) in test 1, which reduced seedling survival compared with the control (13.5% and 42.9%, respectively).

For the following treatments dry weights were significantly lower than the control in test 1: Dual Gold, Reflex (1000 mL/ha and 1500 mL/ha), pendimethalin (1500 ml/ha), and TriflurX (Figure 11 a). There was also a significant reduction in height for Reflex (at 1000 mL/ha and 1500 mL/ha), pendimethalin, and TriflurX (39.8, 29.5,19.5, and 16.9% reduction respectively).

In test 2 (Figure 11b), the only treatment producing a significant reduction in dry weight was Reflex at 1000 mL/ha. Similarly, this was the only treatment to reduce plant height (15.5%) compared with the control. As stated earlier, Reflex at 1500 mL/ha was not included in test 2 due to high damage levels in test 1. Relative to test 1, the control grew less vigorously in the second test, and therefore did not provide the same strength of comparison. Further testing is necessary to determine the tolerance levels of pigeonpea to the herbicides noted to cause significant reductions in test 1 (Dual Gold, Reflex, pendimethalin, and TriflurX).

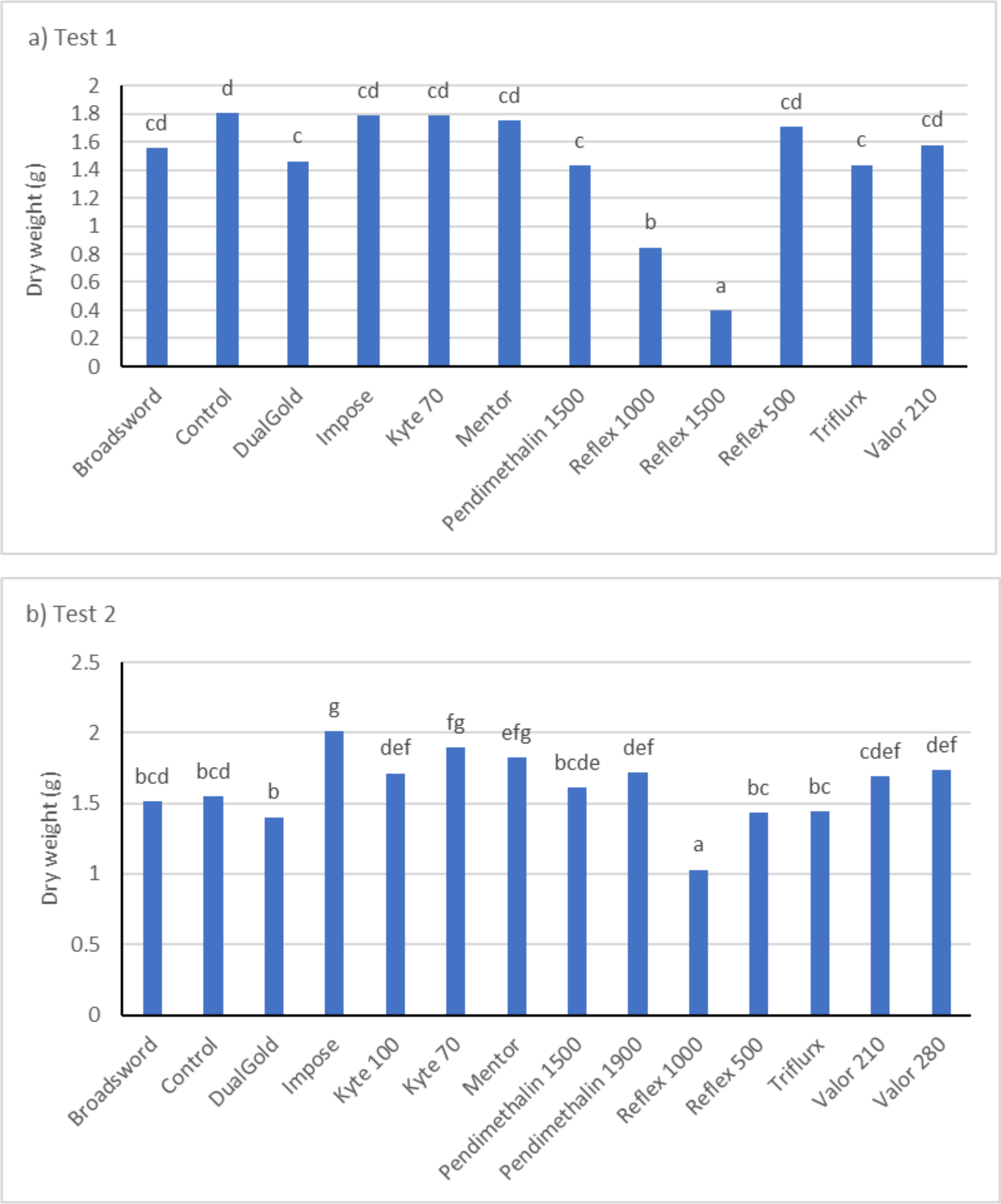


Figure 11: Dry weight (g/pot of 7 plants) of pigeon pea plants treated with a range of herbicides applied post-plant, pre-emergence in pigeonpea tolerance screening pot trials, assessed at 28 DAT.

For post-emergence experiments, commercial potting mix was used to ensure optimum health of the seedlings. Each pot was planted with ten pigeonpea seeds and thinned to seven per pot. Herbicides (Table 2) were applied via a motorised spray cabinet at 4 – 6 sets of leaves. At 21 DAT, plant height of each seedling was measured separately, and the results averaged per pot. The plant material was clipped at the soil surface, dried at 70 ºC and weighed to record dry weight per pot.

Research activities 2021-2022

In 2021-2022 the weeds science team were fully committed on other research projects and played an advisory role only to other pigeonpea researchers conducting field research evaluating row spacing and plant density for suppression of weed mimic species.

Table 2: Post emergence herbicide and rates applied in tolerance screening pot trials.

Herbicide product	Active ingredient	Group	Herbicide active registered for pigeonpea in QLD	Rate	Surfactant
Broadstar	Bentazone	6	No	2000 mL/ha	BS1000 (125mL/100L = 0.125% v/v)
Control	NIL	NA	NA	NA	NA
Gesagard	Prometryn	5	No	1500 mL/ha	NA
Impose	Imazapic	2	No	400 mL/ha	Hasten 1L/100L = 1% v/v
Kyte 700	Imazethapyr	2	No	100 g/ha	BS1000 200mL/ha = 0.2% v/v
Claw	Imazamox	2	No	100 mL/ha	Hasten 1L/100L = 1% v/v
[1]Reflex	Fomesafen	14	No	Test 1: 1000 mL/ha Test 2: 500 mL/ha	Hasten 1L/100L = 1% v/v

[1] Reflex at 1000 mL/ha caused severe damage in test 1 and was reduced to 500 mL/ha in test 2.

Average seedling dry weight was significantly lower for Reflex and Gesagard in both rounds of testing (Figure 12). In the second test the application rate of Reflex was decreased by 50%, but even at the lower rate this herbicide significantly damaged seedlings in post-emergent application. Across all treatments, the plants were smaller in the first round, possibly due to overwatering. Despite this, the treatments behaved in a similar fashion for both tests. Most of the herbicides were not statistically different from the control, except for Gesagard and Reflex. Compared to the control, Gesagard had lower dried biomass (64% in test 1 and 59% in test 2), and so did the Reflex treatment (76% in test 1 at 1000 mL/ha, and 67% in test 2 at 500 mL/ha). Impose did significantly reduce seedling height (14.4% and 14.5% reduction in test 1 and test 2, respectively), but this did not significantly impact dried biomass; perhaps due to additional branching observed in this treatment.

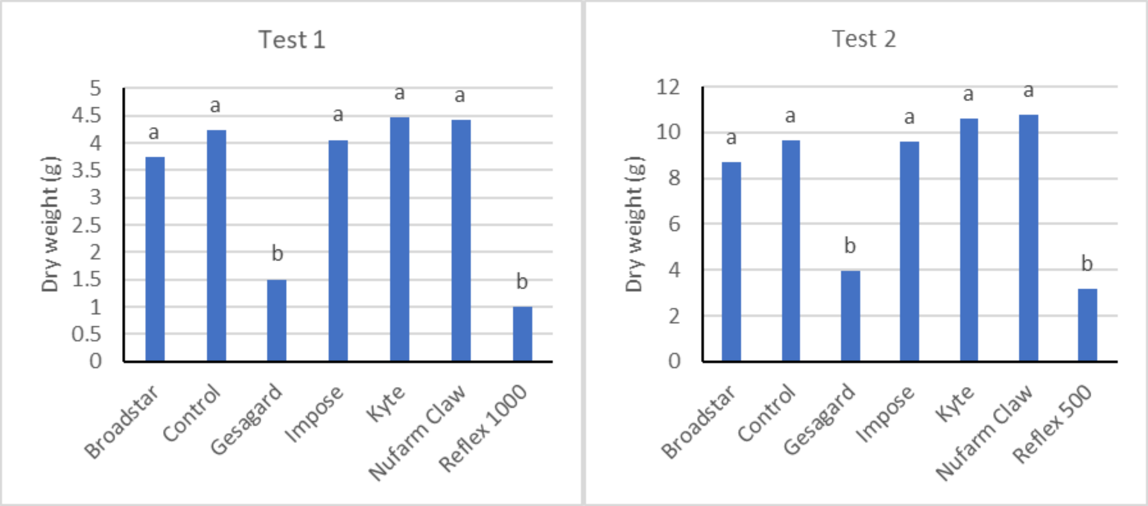


Figure 12: Dry weight (g/pot of 7 plants) of pigeon pea plants treated with a range of herbicides applied post-emergence in pigeonpea tolerance screening pot trials, assessed at 21 DAT.

Key findings and future directions

Effective weed control will be key to the successful production of pigeonpea crops in Australia. Agronomic techniques have potential to increase pigeonpea early vigour and reduce the vulnerability of pigeonpea to weeds during the critical early crop growth stages. In the weed-free agronomic trials at Emerald and Kingaroy, light interception data collected early in crop development (at 30 DAS) indicated that time of sowing, row spacing, and genotype are all techniques with potential to suppress weeds during the critical period for weed control. Delayed time of planting appeared from this study to provide advantages for both yield and weed suppression. Similarly, genotype (ICPL 88007) had both high yield and high weed suppressive potential at the Emerald trial site. There was no clear yield penalty associated with row spacing; for certain times of sowing wide rows produced higher yields, while at other times narrow rows produced higher yields. The research demonstrates there is value in exploring these tactics further in field trials in the presence of weeds to more fully assess direct impact on weed control. This could also be evaluated in pot studies.

Sequential application of pre- and post-emergence herbicides is likely to be important for controlling weeds over the first 6-8 weeks of crop growth, which is the critical period for weed control in pigeonpea. The herbicide tolerance studies established that the following herbicides did not cause significant levels of damage to pigeonpea in post-emergent application: BroadStar (Bentazone), Impose (Imazapic), Kyte 700 (Imazethapyr), and Nufarm Claw (Imazamox). In post-plant, pre-emergence application, the following products were not observed to cause significant harm to pigeonpea in two rounds of testing: Broadsword (Flumetsalam), Impose (Imazapic), Kyte 700 (Imazethapyr), Mentor (Metribuzin), and Valor (flumioxazin). Reflex (fomesafen) was not observed to cause damage at 500ml/ha, but higher rates of this product were very damaging to pigeonpea. Most of these herbicide products are not currently registered for use in pigeonpea crops in Queensland. Broadsword is currently registered for GM Cotton Refugia, and both Mentor and Valor are registered for pre-emergent application in pigeonpea. There are currently few available herbicides with registrations for use in pigeonpea crops grown for grain harvest and seeking new herbicide registrations will be important when developing this crop for commercial production in Queensland. Herbicides identified in this research as being safe for pigeonpea seedlings should be applied in field studies, ideally across a range of environments, and evaluated for impacts on later growth stages of pigeonpea, including grain yield.

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7. Pigeonpea Physiology

Troy Frederiks

Overview

The rationale of physiology studies was to better understand the phenology, drought adaptation, and roots architecture of pigeonpea.

To best deploy pigeonpea in the QLD cropping system it is important to understand how the crop develops, particularly the duration from sowing to key stages (phenology), such as flowering and harvest. The duration to flowering change with sowing date, temperature, and latitude. This phenology study found pigeonpea had a facilitative short-day response with varying key thermal time required at differing daylengths. This information was integrated into an improved APSIM pigeonpea phenology model.

Drought is a major issue for rain-fed broadacre cropping in Queensland. Pigeonpea has the reputation as a drought adapted crop. Crops with drought adaption may access more water, use water more efficiently and/or time water uses to the growth stage where the greatest yield gain is achieved. Transpiration efficiency (TE) is a ratio of biomass produced for water transpired. Improved TE has been identified as a way of improving crop drought adaptation (delivering more crop per drop). Crops with high TE may use available water more efficiently. This study quantified TE of pigeonpea and other locally important summer crops (including other pulse cropping options (mungbean, black gram and soybean), sorghum (C4 cereal) and cotton (C3 dicot). Pigeonpea did not show significantly improved TE over other locally important summer crops.

The spatial positioning and growth of crop roots (root architecture) influences the timing and amount of soil water and nutrient extraction. Pigeonpea root development and architecture was observed in 1.5m PVC tubes and 600 x 400mm clear sided root chambers. Pigeonpea had a high root to shoot ratio compared to other pulse crops, a potential drought adaptation strategy. The determinate pigeonpea ICPL88007 tended to have a wider, more branched, root system than indeterminate Sunrise. Root studies are difficult and time consuming. With the aim of developing a high throughput screen, seedling root development was observed in clear pots.

To complement herbicide work undertaken by the Leslie DAF weeds team, a pilot crop competition trail was completed to test if manipulating pigeonpea row spacing and plant density are useful strategies to suppress weed growth and seed production. This trial also provided information on the optimum row spacing and plant density for pigeonpea, canopy development, and row spacing and density influence on crop light interception. A summary of this experiment is presented separately later in this report (Section 8. Maximising the competitiveness of pigeonpea crops).

Background

Phenology

The key to achieving the potential of pigeonpea (*Cajanus cajan*) is to identify the optimal crop duration (phenology) and the timing of key management decision to maximise productivity in the QLD cropping system. Crop development or phenology determines the timing of key developmental stages (such as optimal planting and corresponding harvest dates) so it is vital to crop adaption and minimising the effects of environmental stresses.

Pigeonpea is generally considered to have a facultative (quantitative) short-day response. However, the current APSIM pigeonpea crop model (Robertson *et al.* 2001) treats pigeonpea as an obligate short-day plant, with flowering delayed until a trigger photoperiod is reached. To improve crop simulation models, local field phenology data is required. Robust crop simulation models, coupled with historic weather data, would allow the performance of pigeonpea to be explored at a range of QLD cropping sites, and the viability of the new industry to be quantified.

Comparing Transpiration Efficiency using lysimeter systems

Pigeonpea has a reputation as a drought tolerant crop. To maximise the potential of pigeonpea, it will be useful to better understand the underlying physiology of any drought adaption mechanisms. Two lysimeter trial was completed to quantifying water use (transpiration) and transpiration efficiency of pigeonpea, and other locally important summer pulse crops. Transpiration Efficiency (TE) is the ratio of biomass produced for water transpired. Improved TE improves drought adaptation to deliver more crop-per-drop.

Comparing root growth in pigeonpea

Fundamental to crop productivity is the capture and conversion of resources to biomass and ultimately yield. Key environmental limits to plant growth include incoming light and water uptake. Intercepting light is dependent on leaf attributes and the canopy structure. Crop water uptake depends on the characteristics of the plant root system and their spatial positioning in the soil. Plant roots are difficult to study but have a disproportionally large effect on overall crop performance. For example, Hammer *et al.* (2009) suggests improved root system architecture and water capture in maize (*Zea mays*) had a greater direct effect on increasing US yields over the last 70 years than changes in canopy architecture and light capture. The physiology of most pulse crops is not well understood, particularly that of the roots. These studies aimed to observe shoot and root growth of pigeonpea and other key pulse crops. Plants were grown in 1.5m PVC tubes and 600 x 400 mm root chambers. Given the difficulty of observing root growth in mature plants, characterising seedling roots in clear pots was evaluated as a potentially more efficient screening method.

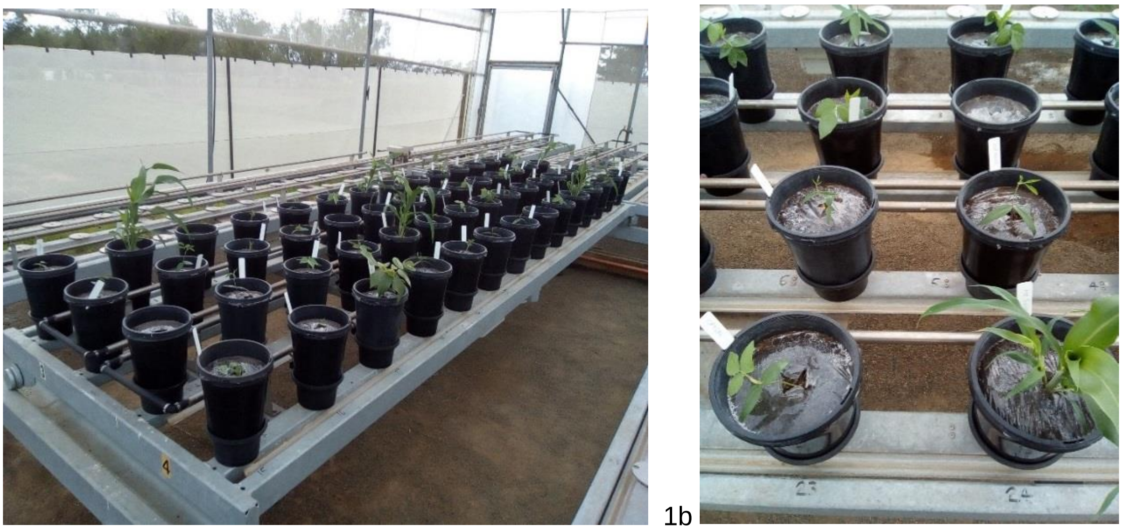
Activity

Phenology

Pigeonpea lines representing a range of potential growth habits were planted with serial sowings at the Leslie Research Facility, Toowoomba. With the final sowing a paired planting was established with an artificially extended 16-hour day-length. A range of alternative summer crops were also included as controls. These included sorghum (MR Buster), mungbean (Jade-AU and Crystal), blackgram (Onyx-AU), soybean (Richmond) and peanut (Middleton).

Comparing Transpiration Efficiency using lysimeter systems.

Two lysimeter trials were completed to quantifying water use (transpiration) and transpiration efficiency (TE) of pigeonpea, and other locally important summer crops. One trial was conducted in the QAAFI UQ Gatton, high-throughput, automated APad lysimeter facility (Chenu et al. 2018), Figure 1. A second trial used a simple “pot-in-bucket” lysimeter as described by Fletcher *et al.* (2018) is shown in Figure 2. Transpiration of individual pots was calculated by subtracting the mean water use of the Nil-plant control pots.



1a 1b

Figure 1a and 1b: High-throughput automated lysimeter APad facility at the University of Queensland Gatton campus. Individual plants were grown in 200mm pots. To minimise pot evaporation a clear plastic film (pallet shrink wrap) was stretched over the potting mix. Plants were grown under well-watered conditions, with water wicking from the pot base reservoir (holding ~600ml). Each pot and base sits on an individual load cell. Watering and weighing are automated. At 6 am pots bases were filled to overflowing. Load cell weights were logged every 10 min and these weights used to calculate accumulated water use. A web interface provides a real-time view of lysimeters weights and accumulated water use.

Figure 2: Pot-in-bucket lysimeter. Plants were grown in 150mm pots positioned in buckets with a constant water table. The water table was regulated with a float valve in the bucket and fed using a syphon from the 5 L water reservoir. To minimise pot evaporation, the soil surface was mulched with 25mm of pine wood chips. Water used from the reservoir was quantified by weight.

UQ Gatton Automated lysimeter – the APad trial included four pigeonpea lines (variety Sunrise (ICPL 88039), ICPL98011, ICP14425 and ICPL86022); three mungbean varieties (Jade-AU, Crystal and Berken); a blackgram (the newly released DAF Black Gram variety – Onyx-AU); a soybean (Richmond); and a C4 cereal reference (sorghum variety MR Buster).

The trial was monitored regularly, with weekly phenology observations, plant heights and counts of leaf number and node number. Plant leaf area was estimated from published formula and non-destructive measurements of leaf length and width. Pots were harvested approx. 50 days after emergence; just prior to anthesis for sorghum and at initial pod formation (R3) for mungbean, blackgram and soybean, pigeonpea plants had not reached anthesis at harvest. At harvest: final leaf area was destructively measured and fresh and dry weights of leaves, stems and pods/heads taken.

Pot-In-Bucket lysimeter – trial included five pigeonpea lines – Sunrise (ICPL 88039), a selection from Quest, ICPL 88007, ICPL 85010 and ICPL 94; a mungbean (var. Jade-AU); a soybean (var. Richmond); and a C3 reference (cotton var. 714B3F). Water use was measured weekly. In addition, weekly measurements were taken of leaf length and width, to allow leaf area to be calculated using published formula. Pots were harvested after 49 days (7 weeks); just prior to anthesis for pigeonpea, cotton and soybean and prior to podding in mungbean. At harvest: plant heights and final leaf area was destructively measured, and fresh and dry weights of leaves and stems taken. Roots were washed and fresh and dry weights measured.

Comparing root growth in pigeonpea

1.5m Tubes – Plants were grown in 1.5m lengths of 90mm PVC pipe in the field at the Leslie Research Facility, Toowoomba. Five replicates of each genotype were harvested 23, 32 and 39 days after sowing to quantify root and shoot development. Leaf number, leaf area, shoot fresh and dry weights were measured. After harvest the tubes were split lengthways, and the soil washed from the roots on a nail-board. The nail-board maintained the two-dimensional position of the roots during washing, allowing root growth and basic architecture to be observed. Maximum root depth was recorded and roots on the nail-board photographed. Roots were subsampled by depth into 150mm sections, scanned, and root lengths estimated by counting root intersections on a grid (Tennant 1975). Root fresh and dry weights were recorded for each 150mm section.

Small root chambers – A determinate pigeonpea (line ICPL 88007), indeterminate pigeonpea (var. Sunrise), mungbean (var. Jade-AU) and soybean control (var. Richmond) were grown in 600 x 400 x 50 mm root chambers (as described in Manschadi et al. 2008) at the Leslie Research Facility, Toowoomba, Figure 3a. Five replicate chambers of each genotype were planted on 21 December 2020 and roots photographed after 18 days (Figure3b).

Plants were harvested on day 23 to quantify root and shoot development. Leaf number, leaf area, shoot (leaf and stem) fresh and dry weights were measured. After harvest the chambers were disassembled, the soil containing roots transferred to a nail-board, and the soil washed from the roots. The nail-board maintained the two-dimensional position of the roots during washing, allowing root development and architecture to be observed. Roots were photographed and images analysed with ImageJ.

Clear pots – clear pots were used to observe seedling roots of pigeonpea, mungbean, soybean, and sorghum, with the aim of identifying useful root attributes (Similar to the technique described for wheat in (Richard et al. 2015)). Root depth, lateral root number, total root length and root weight were measured.

3a 

3b 

Figure 3a: Twenty 600 x 400 x 50 mm root chambers positioned into five randomised replicates (photographed on 13th January 2021 at day 23).

Figure 3b: Day 18 photograph of pigeonpea ICPL 88007 with roots visible through the Perspex side of the root chamber.

Results

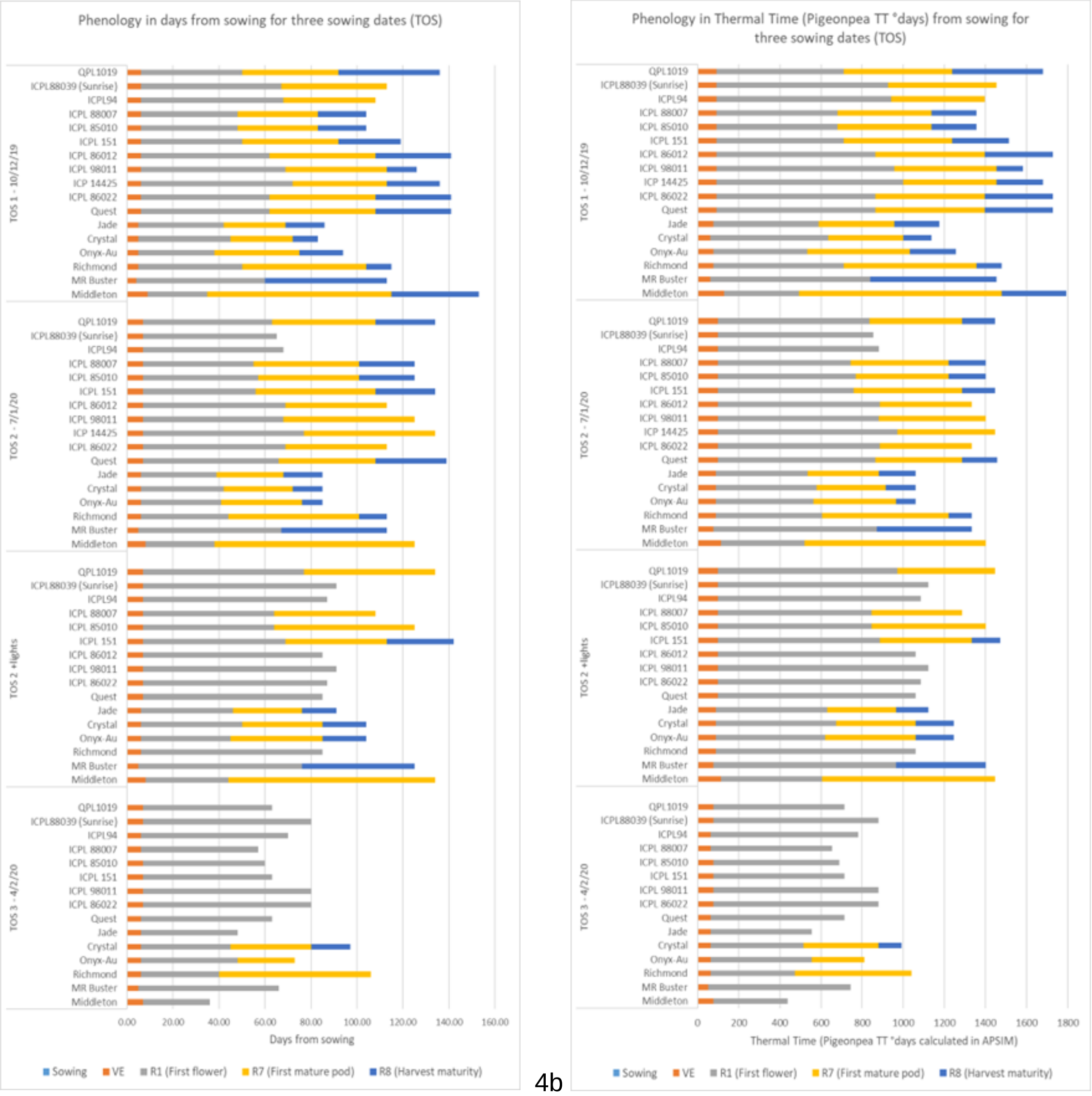
Phenology

Phenology observations are presented in Figure 4a and b. In latter plantings, with shortening days, thermal time to flowering reduced (Figure 4b). The extended day length plot had the longest duration to flowering, however, all lines flowered in the extended 16-hour days. The study finished in June 2020, before all lines had reach full maturity. The extra-short duration pigeonpea lines ICPL 88007 and ICPL 85010 flowered as early as 48 days after sowing and reached maturity in approximately 104 days.

Comparing Transpiration Efficiency using lysimeter systems

UQ Gatton Automated lysimeter – APad:

Significant differences ($p < 0.05$, indicated with superscript lettering) were observed between crop species for total transpiration, shoot dry weight, leaf area, Specific Leaf Area (SLA), stem to shoot ratio, transpiration efficiency (TE_{shoot}) and daily transpiration per unit leaf area (l/m^2/day). Sorghum had significantly higher total transpiration (7685^a g) than soybean (5404^b g) and blackgram (5017^b g), with pigeonpea (2144^c g) and Mungbean (1979^c g) having lower total transpiration. Shoot biomass was greatest in sorghum (58^a g) followed by soybean (23^b g), blackgram (18.5^c g), pigeonpea (7.6^d g) and mungbean (7.5^d g). Sorghum had approximately double the TE_{shoot} of pigeonpea (0.0076^a g/g and 0.0038^b g/g respectively). TE_{shoot} was similar for all tested pulse crops (ranging from 0.0043 g/g in soybean to 0.0037 g/g in blackgram, mungbean had similar TE_{shoot} of 0.0041 g/g). Pigeonpea lines generally had higher transpiration for a given green leaf area than blackgram or soybean and significantly higher ($p < 0.05$) than mungbean varieties and the sorghum reference.



4a 4b

Figure 4: Phenology stage in days (4a) and Thermal Time (4b, calculated using APSIM, TT degree days) from sowing to key developmental stages (emergence/flowering/first mature pods/harvest maturity).

Pot-In-Bucket lysimeter:

Shoot dry weight was highest in cotton (*var.* 714B3F 11.031^{a} g) followed by soybean (*var.* Richmond 9.611^{ab} g), mungbean (*var.* Jade-AU 8.8^{abc} g) and pigeonpeas – Quest (7.169^{bcd} g), ICPL 85010 (6.774^{cd} g), ICPL 94 (6.505^{cd} g), ICPL 88007 (5.789^{d} g) and Sunrise (4.923^{d} g). Quest had significantly higher root dry weight (3.516^{a} g) than all but the soybean (3.472^{a} g) and munbean (2.509^{ab} g). Root dry weight for the other pigeonpeas and cotton was significantly lower (ICPL 88007 (2.256^{c} g), ICPL 85010 (2.197^{c} g), cotton (2.189^{c} g), ICPL 94 (2.105^{c} g) and Sunrise (1.766^{c} g). Root to shoot ratio in Quest (0.49^{a}) was not significantly different from ICPL 88007 (0.4235^{ab}), but significantly higher than soybean (0.3566^{bc}), Sunrise (0.3507^{bc}), ICPL 94 (0.3225^{c}), ICPL 85010 (0.3167^{c}), mungbean (0.2818^{cd}) and cotton (0.2042^{d}). Total transpiration (Figure 5a) was not significantly different, but was highest in Soybean (3603 ml), then Cotton (3550 ml), Quest (3538 ml), mungbean (3386 ml), ICPL 85010 (3117 ml), ICPL 94 (2983 ml), ICPL 88007 (2728 ml) and Sunrise (2248 ml). TE_{plant} (g/l) was not significantly different in cotton (3.729^{a}) and soybean (3.635^{ab}).

Mungbean (3.318^{bc}), Quest (2.994^{cd}) and ICPL 88007 (2.986^{cd}), Sunrise (2.954^{d}), ICPL 94 (2.922^{d}) and ICPL 85010 (2.911^{d}) had significantly lower TE$_{plant}$ than cotton.

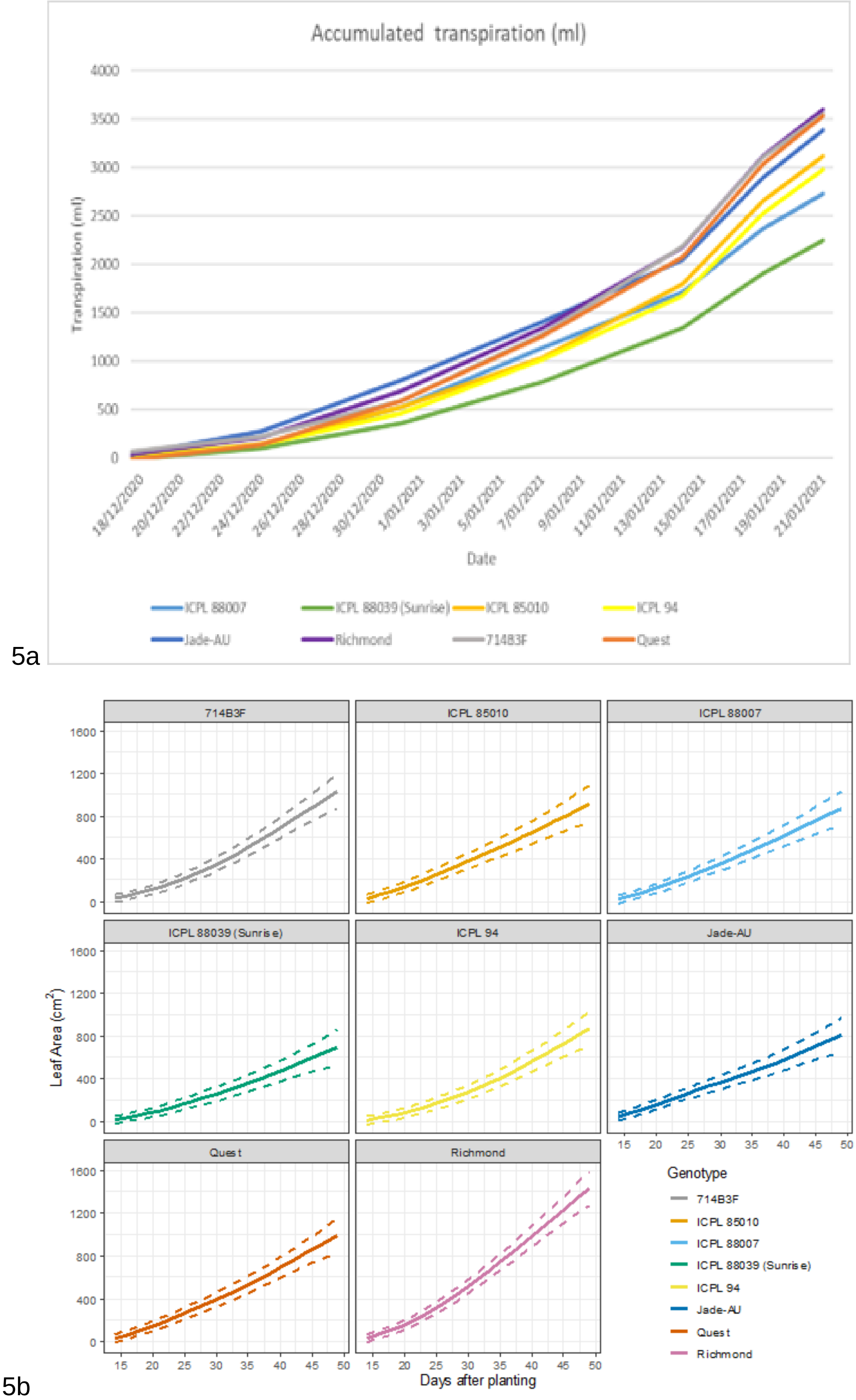


Figure 5: Accumulated mean transpiration (5a) and Leaf area development (5b).

Transpiration tended to follow leaf area (Figure 5a Accumulated transpiration, 5b Leaf area). Final leaf area was significantly higher for soybean than other test lines. However, soybean had the lowest “total transpiration to leaf area ratio” (ml/cm^2) (2.557^{a}). ICPL 94 (3.182^{ab}), ICPL 88007 (3.313^{b}), ICPL 85010 (3.48^{b}), Sunrise (3.56^{b}), Quest (3.614^{b}), mungbean (3.674^{b}) and cotton (3.841^{b}) did not have significant differences in the ratio of transpiration to final leaf area.

Comparing root growth in pigeonpea

1.5m Tubes – Figure 6 shows example photographs of the washed roots on the nail board. The root system of indeterminate pigeonpea “Sunrise” tended to have a single main root at depth. Determinate pigeonpea “ICPL88007” had a shallower, branched structure, with several main roots at depth. Interestingly, by day 32 sorghum roots had started to senesce. Root senescence was observed as a red band to a depth of 600mm 32 days after sowing, extending to depths up to 900mm by day 39.

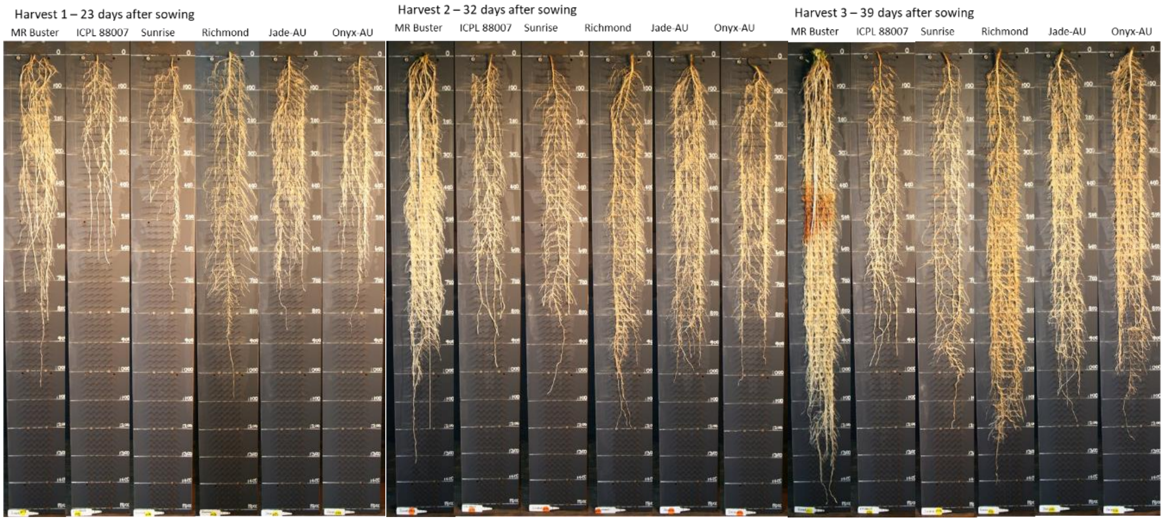


Figure 6: Washed roots on the nail-board for the three harvests, with depths (in mm) on left.

Total root length, shoot dry weight, root dry weight and leaf area increased with each harvest. Sorghum had the highest total root length, shoot dry weight, root dry weight and leaf area, followed by soybean, blackgram and mungbean, followed by pigeonpea. ICPL88007 had higher total root length, shoot dry weight, root dry weight and leaf area compared to Sunrise.

MR Buster sorghum had the highest root to shoot ratio (0.478^{a}) followed by ICPL 88007 (0.348^{b}), Sunrise (0.314^{c}), Jade-AU (0.295^{cd}), Richmond (0.287^{d}) and Onyx-AU (0.259^{e}). MR Buster and Richmond had the greatest mean root depth (1262^{a} and 1212^{a} mm respectively) followed by Jade-AU (1011^{b} mm), Onyx-AU (998^{bc} mm), Sunrise (986^{bc} mm) and ICPL88007 (937^{c} mm).

The mean daily increase in root depth was similar in harvest one and two (35.5mm/day) but reduced in harvest three (32.1mm/day). The rate of increase in root depth (mm/day) was similar in pigeonpea (ICPL 88007, 30.08^{a} and Sunrise, 31.59^{ab}), blackgram (Onyx-AU, 32.09^{ab}) and mungbean (Jade-AU, 32.56^{b}), and higher for soybean (Richmond, 39.03^{c}) and sorghum (MR Buster, 40.65^{c}).

Maximum root depth as a proportion of total plant (shoot+root) dry weight was high in pigeonpea. For example, 32 days after sowing the root depth per gram plant dry weight was 867.6^{a} for Sunrise and 642.5^{b} mm/g for ICPL 88007 compared to 310.3^{c}, 308.8^{c}, 240.1^{c}, 140^{d} mm/g for Onyx-AU, Jade-AU, Richmond and MR Buster, respectively.

Small root chambers – at harvest, Plant Dry Weight (DW), Shoot Dry Weight (DW), Leaf Area and Leaf Dry Weight (DW) of mungbean and soybean were significantly larger than pigeonpea. Pigeonpea Root to Shoot ratio was larger than mungbean, and significantly larger than soybean. Figure 7 shows example photographs of the washed roots on the nail-board. At harvest mungbean had the largest root dry weight (0.2^{a} g) and total root length (3404^{a} cm), followed by soybean (0.166^{ab} g & 1701^{b} cm), ICPL 88007 (0.111^{b} g & 1398^{b} cm) and Sunrise (0.105^{b} g & 1096^{b} cm). Specific Root Length (SRL) of mungbean (173 m/g) was significantly higher than soybean (103 m/g) and pigeonpea. The higher SRL of ICPL 88007 (121 m/g) compared to Sunrise (103 m/g) was consistent with a branched root structure, with more fine roots. There was a strong trend for the determinate ICPL 88007 to have more wide roots than the indeterminate Sunrise.

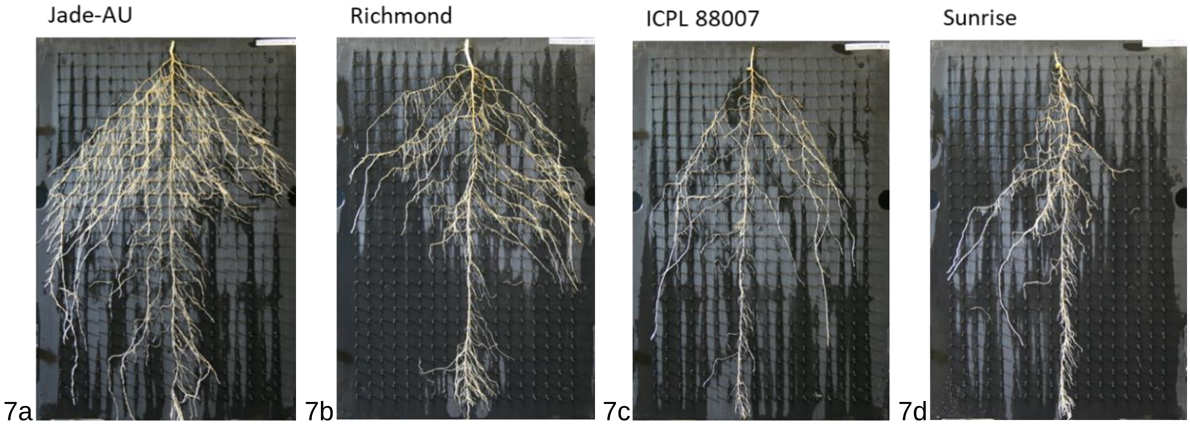


Figure 7: Day 23 washed roots on nail-board for – mungbean (Jade-AU (7a)), soybean (Richmond (7b)), determinate pigeonpea ICPL 88007 (7c) and indeterminate pigeonpea Sunrise (7d).

Clear pots were used to observe seedling roots. Root depth, lateral root number, total root length and root weight were measured (Figure 8 is an example of the root system of plants grown in clear pots). Analysis is ongoing.

Figure 8: Observing seedling root development and architecture of pigeonpea, mungbean soybean and sorghum in clear pots. Day 5 seedling roots, Leslie Research Facility, Toowoomba.

Discussion / Insights

Physiology research over the last three years has improved the understanding of the phenology, water use and root system of pigeonpea, laying the foundation for future research.

Toowoomba phenology trial and developing an improved APSIM phenology model

Field observations suggest all pigeonpea test lines had a facilitative short-day flowering response, but with varying photoperiod sensitivity and base thermal time requirements for flowering. Therefore, modifying the APSIM pigeonpea model to simulate a facultative response will improve the accuracy of simulations. Supplementing the existing (obligate short-day) phenology cultivar classes in the current APSIM pigeonpea model, new facultative short-day varieties have been developed with modified (i) thermal time targets from emergence to floral initiation, and (ii) critical photoperiods and thermal time targets from “end of juvenile to floral initiation” stage. Additional field validation, over a range of latitudes and years, would improve the confidence in the new phenology models.

If the critical photoperiod is known (assumed to be approx. 12.8 to 13 h), a simplified phenology trial could be deployed to rapidly characterise new varieties using a single time of sowing and matched extended photoperiod treatment. Using the difference in the “thermal time to flowering” between a late time of sowing (reducing photoperiod less than the critical photoperiod) and artificially extended daylength plot to modify the thermal time target to “end of juvenile to floral initiation stage”.

Modified code from APSIM pigeonpea model:

```
<x_pp_end_of_juvenile description="photoperiod (h)">12.8 16.0 16.1
</x_pp_end_of_juvenile><y_tt_end_of_juvenile description="TT from end juvenile to floral
initiation">1 “ΔTT lights and ambient” “(ΔTT lights and ambient) + 1”
</y_tt_end_of_juvenile>
```

Comparing Transpiration Efficiency (TE) of Pigeonpea using lysimeter systems

UQ Gatton Automated lysimeter – the APad study generated novel information on water use, growth, development, leaf area development, biomass and biomass partitioning in pigeonpea and mungbean. Preliminary results suggest that, under well-watered conditions, pigeonpea has a similar transpiration efficiency (TE_{shoot}) to other pulse cropping options, such as soybean, blackgram or mungbean.

Pot-In-Bucket lysimeter - was a useful system to quantify transpiration. Pigeonpea did not have improved TE compared to other tested crops. Difference in rankings for shoot and root weights highlight the importance of including roots when calculating TE_{plant}. Quest had a larger leaf area, shoot dry weight, root to shoot ratio, total transpiration and significantly larger root system compared to other pigeonpea types. Importantly, this higher transpiration was not at the expense of transpiration efficiency, with Quest achieving the highest (not statistically significant at $p < 0.05$) TE_{plant} of the tested pigeonpea lines. Released pigeonpea lines from the previous UQ breeding program should be considered in future studies and for any ongoing genetic improvement work.

Comparing root growth in pigeonpea with other locally important crops.

1.5m Tubes – growing plants in 1.5m tubes provided a useful system to phenotype root development of advanced plants. The observed rate of increase in root depth for sorghum (40.65mm/day in sandy test soil) was in line with previous reports (34.3mm/day soil water extraction front in clay field soil, Robertson *et al.* 1993). Potentially useful differences in the root systems of the determinate (ICPL88007) and indeterminate (Sunrise) pigeonpea lines were observed. ICPL88007 tended to have a larger, more branched, but shallower root system than Sunrise. Pigeonpea had a high root to shoot ratio compared to the other tested pulse species, a potential drought adaptation strategy. Similarly, the deep roots relative to total plant weight in pigeonpea may be advantageous – by allowing the development of a deep root system using minimal water. This study challenges the perception that pulse crops have shallow root systems. The mean root depth for soybean, mungbean, blackgram and pigeonpea were 96%, 80%, 79% and 76% respectively of the sorghum control.

Small root chambers – growing plants in root chambers provided a useful system to observe root development and architecture. However, by Day 23 (harvest) the seedlings were reaching the limit of the chambers. Like the previous 1.5m tube study, the determinate ICPL88007 tended to have a wider, more branched, root system than indeterminate Sunrise. Pigeonpea had a high root to shoot ratio, a potential drought adaptation strategy. Pigeonpea had low early vigour compared to mungbean and soybean. For the QLD cropping system, pigeonpea types with high early vigour may be useful.

Clear pots - The study has successfully tested the screen for pulses, identified key traits, and opportunities to further optimise the technique for high throughput screening.

Better understanding of the root system of pigeonpea, and other key pulse crops, may assist with the management of commercial crops, identify strategies to best deploy new crops, and to identify opportunities to develop new varieties.

Future Work

Potential for moisture seeking sowing of pigeonpea – testing the ability of pigeonpea to emerge with deep sowing. Unlike most pulses, where the cotyledons or seed leaves emerge with the seedlings (epigeal germination in crops such as mungbean, soybean and common bean), for pigeonpea the cotyledons remain underground (hypogeal germination) with only the seedling shoot emerging. Typically, crops with hypogeal germination emerge well from a range of depths (for example, up to 200mm for chickpea) increasing sowing options for growers, particularly in dryer seasons. The ability to sow at depth, into soil moisture, can reduce the reliance on rain and allow growers to better optimise planting time for maximum yield. Deep sowing may also improve crop establishment, rooting, nodulation and increase herbicide options.

Observing the roots system of pigeonpea lines – Crop root systems play a vital role accessing water and nutrients and are key to maximising productivity. However, assessing the root of plants is difficult, time-consuming, and expensive. As part of a recent ASQ innovation project, differences in the electrical properties of pigeonpea roots were observed using a novel, high-throughput, root measurement technique. Preliminary results are encouraging, but it is important that potential differences are validated with tradition root washing and quantification techniques.

Water Use Efficiency – due to high temperatures and limited in-season rainfall, current summer grain legume options such as soybean or mungbean are not well suited to much of the QLD cropping area, leading to an over-reliance of sorghum in these cropping systems. Pigeonpea has great potential as a reliable, high-value crop. However, more work is required to understand potential pigeonpea drought adaption strategies. Is pigeonpea able to extract more stored soil water? Alternatively, is pigeonpea able to use the available water more effectively? i.e., is the low early vigour of the crop delayed maximum water use to later in the season, where available water can be deployed for maximum effect? Are drought survival strategies of rapidly shedding leaves and slowing growth counterproductive for achieving harvestable yield under stress?

Acknowledgements

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8. Maximising the competitiveness of pigeonpea crops

Troy Frederiks, Bruce Winter, Annemieke Ruttledge, Michael Widderick and Kerry Bell

Research Questions

- Can modifying agronomic practices improve the competitiveness of pigeonpea to help manage weeds?
- Specifically, are manipulating pigeonpea row spacing and plant density useful strategies to suppress weed growth and seed production?
- What is the optimum row spacing and plant density for pigeonpea?
- How do row spacing and plant density influence crop light interception?

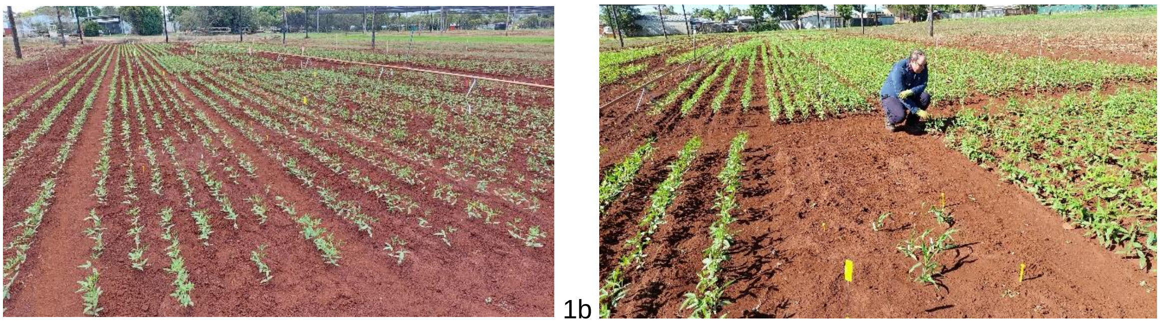
Background

Effective weed control is important to maximise crop yields. To establish pigeonpea as a new high-value legume crop for Queensland, an integrated best-practice weed management system is needed. Effective pre- and post-emergence herbicides will be critical. In addition, maximising the competitiveness of pigeonpea crops could help reduce crop losses and the build-up of weeds. Pigeonpea has a reputation as a poorly competitive crop, often grown in intercropping systems where low early vigour can be balanced by the rapid development of the other crop. However, poor early vigour of pigeonpea can allow weeds to establish, reducing crop yield and increasing the build-up of weed seed for subsequent seasons. This study tests if modifying row spacing and crop density of pigeonpea can suppress the growth and reproductive success of mimic weed species.

Activity

A crop competition trial (based on a method developed by Widderick et al. 2022. ‘Manipulating sorghum agronomy to suppress summer grass weeds’, Agronomy Conference, Toowoomba, 18-22 September 2022) was planted on the 12th of January 2022 at the Leslie Research Facility, Toowoomba, testing an extra-short-duration determinate pigeonpea ICPL 88007 with a range of agronomic strategies. Given the variability of naturally occurring weeds, and to minimise potential of weeds build-up on the research facility, mimics were used rather than actual weeds. Two grass species were chosen as mimics, millet, a moderately competitive type (like Barnyard grass) and Callide Rhodes grass as a highly competitive type (with a similar growth habit to Feathertop Rhodes Grass). Pigeonpea main plots (2 x 13m) were sown with two row spacings (500 and 250mm) and two test plant densities. Higher sowing rates was used to ensure densities of 30 and 45 plants/m^2 could be achieved. Nil-crop main plots were also included to benchmark the performance of the mimic weeds grown without crop competition. The trial used a complete randomised block design with four replicates. Within main plots three randomised subplots (1 x 2m) were established (weed-free, millet and Rhodes grass). Millet and Rhodes grass seed was randomly hand broadcast and raked to incorporate into the soil. Supplementary irrigation was used at planting to ensure the germination of mimic weeds. After emergence the crop and mimic weeds were thinned to the target density in 1 x 1m subplots (Figure 1 LRF crop competition trial showing 2 x 13 main plots and 1 x 1m sub-plot layout). Mimic weeds were thinned to 5 plant/m2.

Light interception measurements were made at approximately two-week intervals until the canopy closed (approximately at anthesis). Light transmitted through the canopy was measured with a 1m ceptometer probe (AccuPAR PAR/LAI Ceptometer Model LP-80) with an integrated Apogee PAR sensor measuring above canopy light intensity. Light measurements were made between 11am and 1pm on clear days. Following light measurements, a destructive harvest was taken (outside the sub-plots) to quantify leaf area and biomass development.



1a 1b

Figure 1a and b: Leslie Research Facility crop competition trial. Main plots (2 x 13 m) were established with two row spacings (250 and 500mm) and target crop density (30 and 45 plants/m^2) with four replicates. Mimic weed subplots (1 x 2m, thinned to 1 x 1 m at 5 mimic weeds/m^2) were randomized within the main plots. Figure 1b shows a millet subplot in the foreground of a nil-crop main plot.

When mature, mimic weeds and crop plants within the 1m^2 subplots were hand harvested. Millet matured, and was harvested, earlier (22nd April 2022) than the pigeonpea and Rhodes grass (harvested 3rd June 2022). The number of live/dead plants and number of pods/seed heads (Reproductive Units, RU for Rhodes grass) were counted. Biomass was measured after oven drying. For millet and pigeonpea heads/pods were hand threshed and grain yield recorded.

Results

The summer of 2022 was unseasonably wet, with 829.4mm of in-crop rain. Mild and wet conditions delayed maturity and harvest of pigeonpea. Significant rain (208.8mm) the week of the 9th of May resulted in water logging and substantial leaf drop in pigeonpea. At harvest the main cohort of pigeonpea pods had reached full seed development, however, there was a range of maturity from over mature pods to new flowers.

The mimic weeds significantly reduced (F prob. <0.001) pigeonpea biomass (480.8^a g/m^2 Nil weed, 462.5^b g/m^2 with millet and 391.4^c g/m^2 with Rhodes grass) and yield (73.85^a g/m^2 Nil weed, 59.64^b g/m^2 with millet and 49.06^c g/m^2 with Rhodes grass) with Rhodes grass having a significantly greater effect than millet. The high crop density (45 plant/m^2) produced significantly more biomass (470.4 g/m^2 vs. 419.4 g/m^2) but yield was not significantly higher (470.4 g/m^2 vs. 419.4 g/m^2) than the low density (30 plant/m^2). Biomass on narrow row spacing (250mm) was higher (approaching significance, F prob. 0.06) than wide row spacing (463.8 g vs. 426.1g). The highest yield was achieved with narrow row spacing (250mm) and high density (45 plants/m^2) but differences in yield between treatments was not statistically significant. Table 1 summarises the biomass and yield for the combinations of row spacings, plant density and the mimic weed species.

Table 1: Pigeonpea biomass and yield with wide (500 mm) and narrow (250 mm) row spacing and high (45 plants/m^2) and low (30 plants/m^2) density.

		Pigeonpea biomass g/m^2			Pigeonpea grain yield g/m^2		
	Mimic Weed	No Weed	Millet	Rhodes	No Weed	Millet	Rhodes
Row Spacing	Crop Density						
Narrow	High	506.1	506	441	83.57	63.95	59.9
	Low	458.2	445.4	425.8	71.28	61.25	46
Wide	High	490.3	490.4	388.8	63.75	60.58	39.73
	Low	468.8	408.2	310.1	76.8	52.77	50.6

The harvest index of pigeonpea was low (0.149^a Nil weed) and reduced significantly (F Prob. 0.024) with mimic weeds (0.149^a Nil weed, 0.13^b with millet and 0.126^b with Rhodes grass).

Millet mimic weed – the pigeonpea crop significantly reduced the biomass and yield of millet (F Prob. <0.001, Figure 2). Millet biomass and grain yield reduced (approaching significance F Prob. 0.053 and 0.059 respectively) with narrow rows (narrow rows 30.2g biomass/7.5g yield and wide rows 53.61g biomass/16.25g yield). The effect of crop density was not significant (high crop density 37.8g biomass/10.1g yield and low density 46g biomass/13.7g yield).

Rhodes grass mimic weed – the pigeonpea crop significantly reduced the biomass and reproductive potential of Rhodes grass (F Prob. <0.001, Figure 3.). Pigeonpea row spacing had a greater effect on Rhodes grass biomass and Reproductive Units (RU) than crop density. However, row spacing, and crop density treatments were not significant.

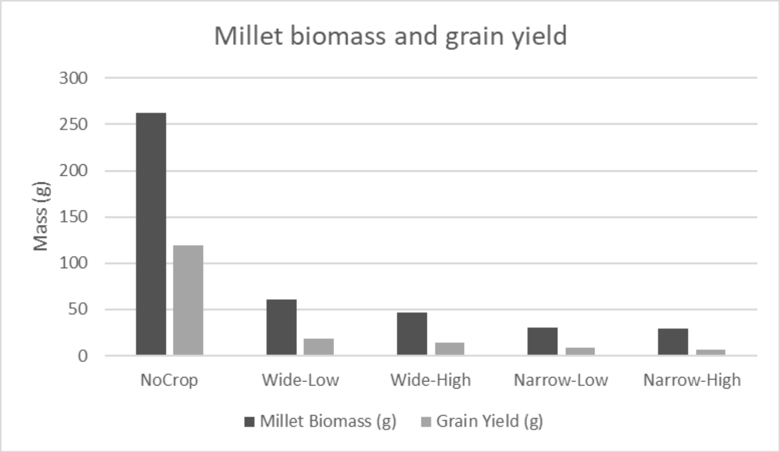


Figure 2: Millet biomass and grain yield reduced significantly with all crop treatments. Narrow row spacing (250mm) resulted in a larger reduction in both yield (F Prob. 0.059) and millet biomass (F Prob. 0.053) than high crop density.

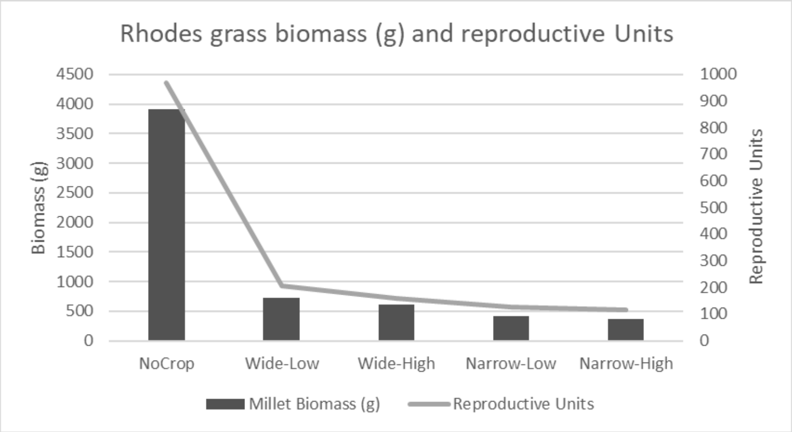
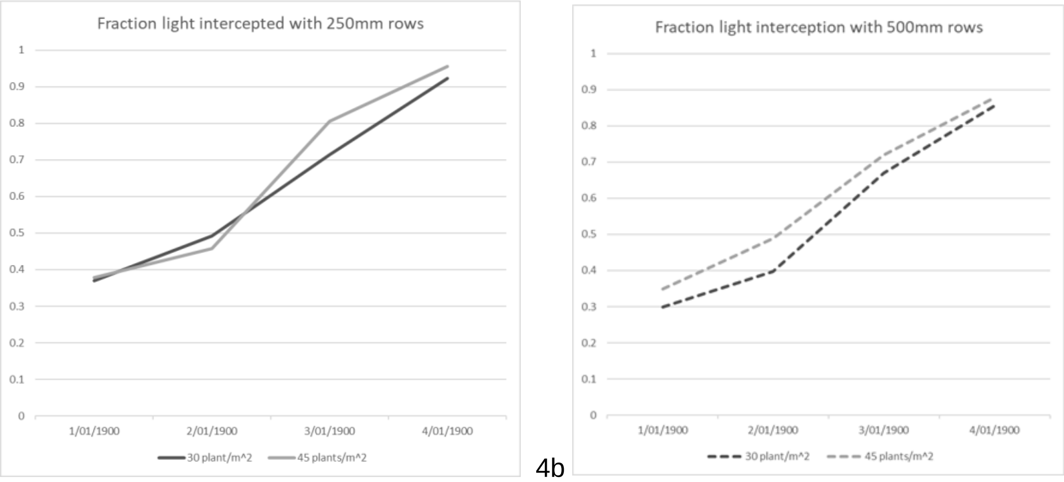


Figure 3: Rhodes grass biomass and reproductive units (seed heads) were reduced significantly with all crop treatments over the Nil Crop control.

Light interception – the fraction of light intercepted by the pigeonpea crop increased significantly (F Prob. <0.001) with time. Row spacing had a greater effect than crop density on light interception. The average fraction of light intercepted was higher (F Prob. 0.002) for narrow rows (0.637[a]) than wide rows (0.5821[b]). Higher crop density tended (F Prob. 0.053) to have higher light interception (See Figure 4a and b).

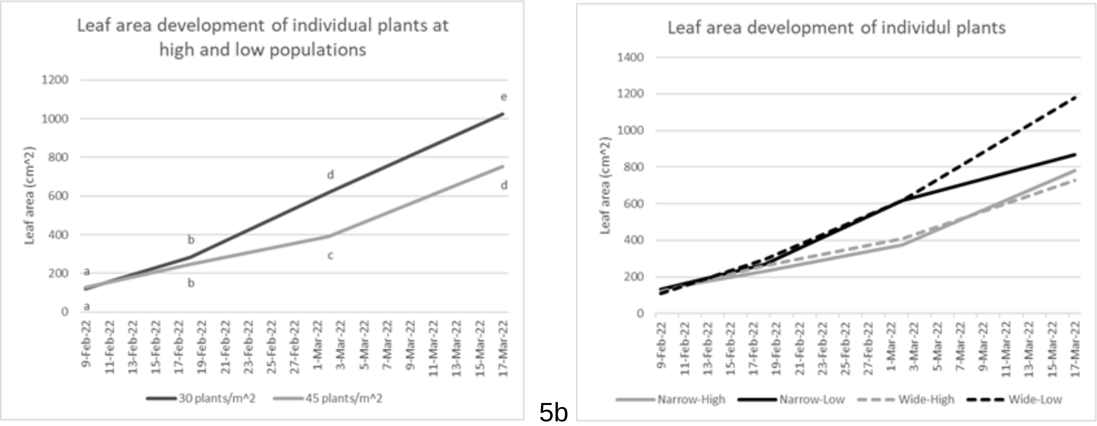
The leaf area of individual pigeonpea plants increased significantly over time (F Prob. <0.001). At later dates (2nd and 17th of March) the leaf area of individual plants was significantly higher at low density (Figure 5). The Leaf Area Index (LAI) increased significantly (F Prob. <0.001) with time and was significantly (F Prob. <0.001) higher with high plant density (Figure 6).



4a

4b

Figure 4: Fraction of light intercepted was significantly higher with narrow (250mm Figure 4a) vs. wide (500mm Figure 4b) row spacing. High crop density (45 plant/m^2) tended (F prob. 0.053) to have higher light interception than low (30 plants/m^2) density.



5a

5b

Figure 5: Leaf area development of individual plants increased significantly over time (4a and 4b) and was significantly higher at low plant density (30 plant/m^2).

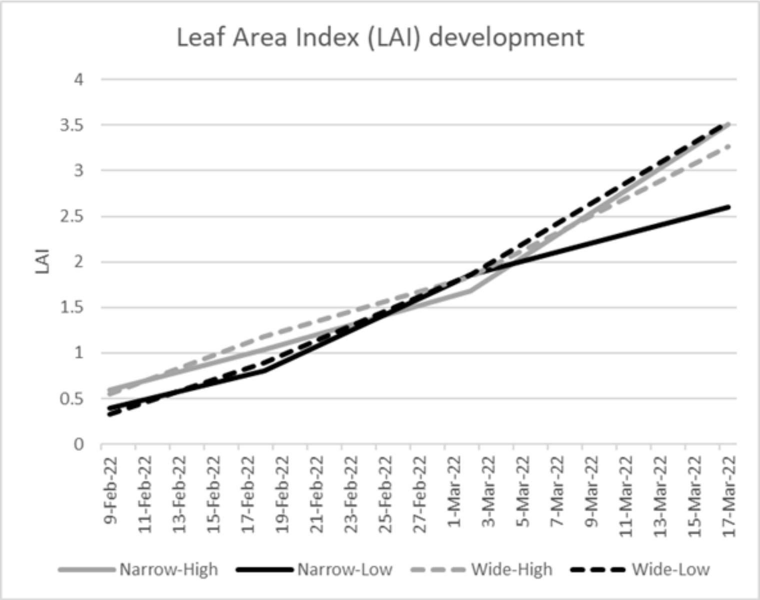


Figure 6: Leaf Area Index (LAI) increased significantly over time and was significantly higher at high plant density.

Insights

With limited options for in-crop weed control, and increasing concerns about herbicide resistance, agronomic practices with the potential to supress weed growth and seed production have potential to complement herbicide use. However, effective and crop safe herbicides will be crucial to establish a Queensland pigeonpea industry.

The highest pigeonpea yields were achieved with the high plant density and narrow rows (250 mm row 45 plants/m^2), irrespective of the presence of mimic weeds. Conversely, the lowest pigeonpea yields (nil weed) were observed in the wide row spacing with high density, possibly due to the high inter row competition of pigeonpea plants. The unusually high in-crop rain and mild temperatures reduced the crop yields and delayed harvest.

The mimic weeds significantly reduced the yields of pigeonpea, with Rhodes grass having a significantly greater effect than millet. Importantly, the pigeonpea crop also significantly reduced dry weight and grain yield of the millet, and dry weight and reproductive units (seed heads) of the Rhodes grass. The effect of narrow row spacing was larger (approaching significance for millet dry weight and yield) than the effect of increasing crop density.

Light interception was significantly higher with narrow row spacing, suggesting narrow rows may be useful for increasing crop competition and weed control. For definitive recommendations this result would need to be repeated over more sites and/or years and possibly include trials with actual weeds. Leaf area development for individual plants was lower at high plant density. Despite the lower leaf area of individual plants, higher density resulted in significantly higher Leaf Area Index (LAI). Interestingly, impressively high light interception (fraction < 0.9) was achieved with a moderate Leaf Area Index (>3 LAI) for the narrow-low (250 mm row 30 plants/m^2) treatment, suggesting an unusually high light extension coefficient for pigeonpea at narrow row spacing.

9. Effect of Rhizobia on pigeonpea lines

Nikki Seymour

Summary

The commercially available strain of pigeonpea rhizobia (CB1024) was found to be compatible with the seven genotypes tested and therefore use of this inoculum should not be a constraint to nitrogen (N) fixation if any of those lines were to be selected as being agronomically suitable. New genotypes progressed in the future should be screened for their compatibility particularly if from differing parentage.

Our glasshouse trials clearly showed a significant impact of N level in soil on nodulation and hence N fixation. Uninoculated pigeonpea plants responded well to N fertiliser and required the equivalent of 80-100 kg N/ha to maximise growth. Inoculated plants required no N fertiliser to obtain maximum growth, fixing all they needed.

To date, the amount of N fixed and the available after pigeonpea are grown in the field has not been determined. The Kingaroy site did not fix nitrogen in the pigeonpea plants given the large amounts of N in the soil profile already. Recently processed samples from the Emerald field trials will be sent for ^{15}N analyses to determine levels of N fixation at the trial.

Background

As pigeonpea is a legume, it is known to form associations with rhizobia and fix N from the atmosphere to satisfy N requirements for growth and seed production. Studies by Herridge and Holland (1993) in northern NSW showed that the then current strain CB756 was not compatible with new genotypes (particularly when in field trials) at the time and so the commercial strain for pigeonpea was changed to CB1024.

It is well established that nitrogen status of the soil will affect level of nodulation and hence amount of N fixation in a legume. The higher the level of N, the less nodulation and N fixation but the tolerance point varies for different plant species and also different genotypes, hence it will be important to establish this value for pigeonpea lines we are interested.

Research questions

1. Is the current commercially available strain of rhizobium (CB1024, Group J) compatible and effective with potential genotypes of pigeonpea for QLD?
2. At what N level in soil does nodulation and N-fixation in pigeonpea reduce or stop?
3. How much N is fixed by agronomically- suitable pigeonpea lines and how much could be added to the farming system?

Glasshouse Trial 1:

Objective

Assessment of compatibility of current commercial strain (CB1024) with new pigeonpea genotypes completed in glasshouse by March 2021

Methods

A glasshouse experiment was conducted at Leslie Research Facility Glasshouse 1a with seven genotypes (ICPL151, ICPL85010, ICPL86012, ICPL88007, ICPL88039 (Sunrise), ICPL94, QPL1019) to test the compatibility of the new genotypes with the current commercially available pigeonpea strain (CB1024). For this trial the following treatments were tested: seven genotypes x three inoculation/N treatments (inoculum - CB1024, nil inoculum, nil +N) x four replicates = 84 pots.

Pots (2L volume) were filled with a medium consisting of 2 parts sand to1 vermiculite, autoclaved and then leached of any trace amounts of N by flushing twice with boiling water. Pots were allowed to drain. Four pre-germinated, surface sterilised pigeonpea seeds/pot for each genotype were planted at 1-2 cm deep and inoculated using liquid dropped directly onto the seed surface (1mL of Yeast Mannitol Agar cultured rhizobia strain CB1024, approx. 10^9/mL in 1% sucrose solution). Uninoculated pots were given an equivalent dose of sterilised 1% sucrose solution.

Plants were thinned to two per pot approx. ten days later. A basal application of all essential nutrients in solution excluding N were added on a weekly basis to supplement the pigeonpea. Plants were grown for 41 days. Plant tops were removed at harvest, dried, and weighed for a total above-ground biomass dry weight.

Results

A statistically significant interaction between genotype and N source did occur (Figure 1) – some contamination in some of the nil inoculum means some were fixing N giving a different response to inoculation. In general, all genotypes tested showed good compatibility with CB1024 in that all lines grew as well without N when inoculated, as their corresponding N fertilised treatments. This means that the rhizobia were fixing N at an adequate level for all plants.

Confirmation of compatibility should also be assessed in a field trial (soil with low N). Also, any new genotypes introduced to our trials should be checked for compatibility with CB1024 as a duty of care (particularly if the genotype is of largely different heritage to those tested here and if it shows promise for QLD industry).

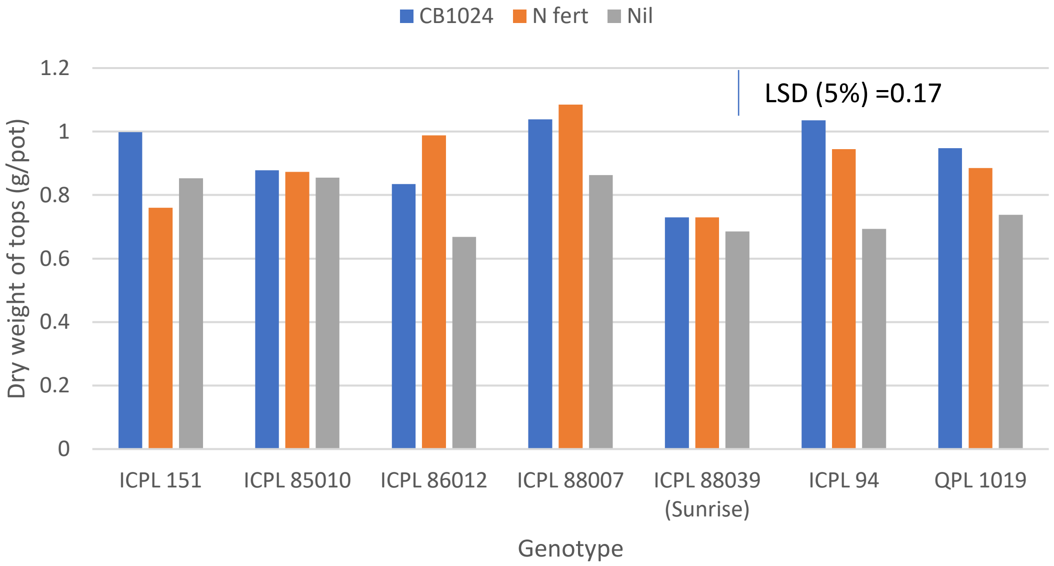


Figure 1: Dry weight response of various pigeonpea genotypes to inoculation with commercially available rhizobia strain (CB1024) and to unlimited N.

Glasshouse Trial 2:

Objective

Assessment of compatibility of current commercial strain (CB1024) with new pigeonpea genotypes completed in glasshouse by March 2021.

Method

Determination of soil N level at which nodulation and N fixation in pigeonpea is reduced or eliminated - completed in glasshouse by March 2021. A glasshouse trial was conducted under controlled conditions to determine the soil nitrogen level were nodulation and N fixation are reduced. Inoculated and uninoculated pigeonpea plants were grown at the following equivalent soil nitrogen levels in pots: 0, 5, 10, 20, 30, 40, 50, 60, 80, 100, 120, 150 kg N/ha. Four replicate pots of each treatment were grown, giving 96 pots in total.

Pots (2L volume) were filled with a medium consisting of 2 parts sand:1 vermiculite, autoclaved and then leached of any trace amounts of N by flushing twice with boiling water. Pots were allowed to drain, then the next day (27 January 2021), N treatments (delivered as urea in solution) were applied and four pre-germinated, surface sterilised pigeonpea seeds (cultivar ICPL 88007/pot were planted. Each seed was planted in a dibbled hole of 1-2 cm deep and inoculated using liquid dropped directly onto the seed surface (1mL of Yeast Mannitol Agar cultured rhizobia strain CB1024, approx. 10^9/mL in 1% sucrose solution). Uninoculated pots were given an equivalent dose of sterilised 1% sucrose solution.

Plants were thinned to two per pot approx. twelve days later. A basal application of all essential nutrients in solution excluding N were added on a weekly basis to supplement the pigeonpea. Plants were grown for 37 days. Plant tops were removed at harvest, dried, and weighed for a total above-ground biomass dry weight. ^{15}N in tops was measured at UC Davis Stable Isotope Facility, from which levels of N fixation at the various N rates was determined. Roots were washed from the sand: vermiculite medium and assessed for nodulation using a 0 to 8 rating where 0 = no nodulation and 10 is >30 nodules per plant.

Results

When plants were inoculated with rhizobia, there was no significant growth response (as measured by dry weight of shoots at 37 days, Figure 2a and Figure 3) to applied N indicating that inoculated, well nodulated pigeonpea plants can fix enough N for their requirements and do not require added N. However, when not inoculated a quadratic response to applied N was observed, with the optimum level of N between 80-100 kg/ha (Figures 2 b, 3, and 4).

Figure 2: Growth responses of pigeonpea (ICPL88007) with rhizobia (left side photo) and without (right side photo) at increased rates of N of 0, 5, 10, 20, 50, 100, 150 kg N/ha.

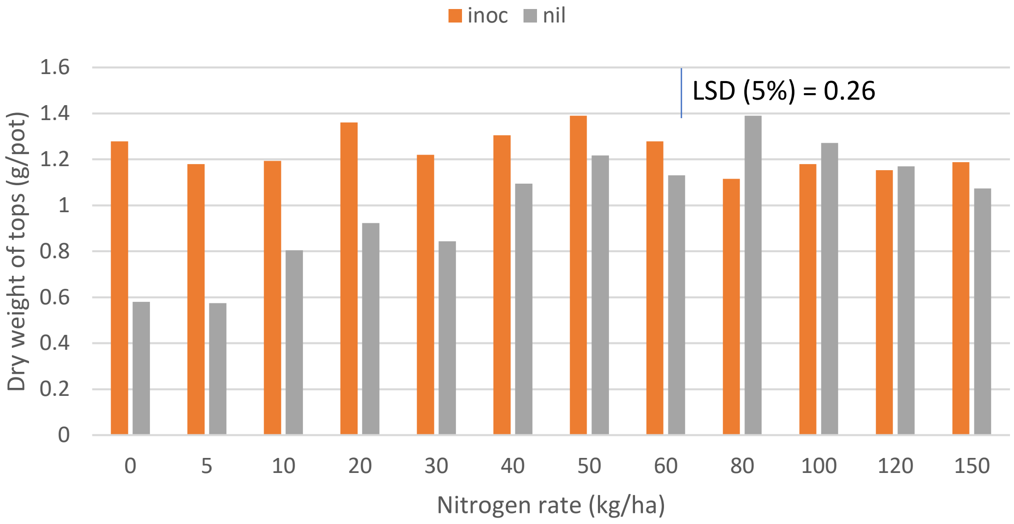


Figure 3: Dry weight response of pigeonpea (ICPL88007) to applied N fertiliser with and without inoculation with rhizobia (strain CB1024).

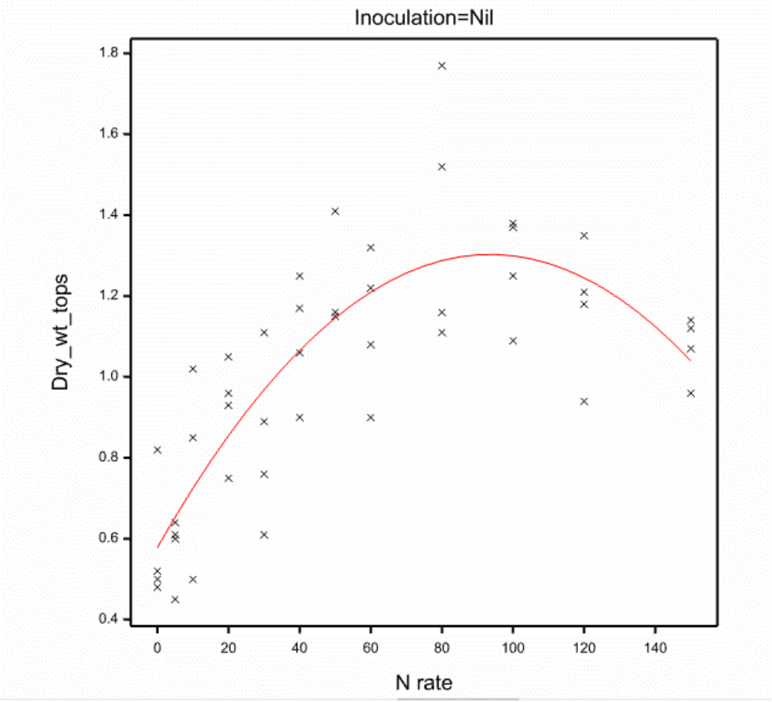


Figure 4: Dry weight of pigeonpea tops in response to increasing rates of applied N fertiliser when not inoculated with rhizobia.

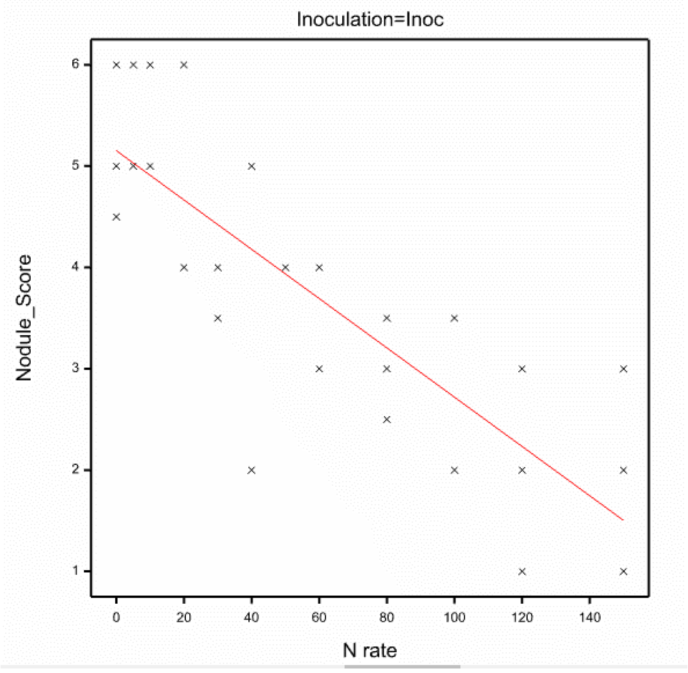


Figure 5: Decline in nodulation of inoculated pigeonpea as applied N rate increases.

Nodulation scores showed a significant steady decline in nodulation as N rate increased (Figure 5). Nodulation was inhibited completely at the highest N rate we tested (150kg N/ha) but N fixation was certainly have been severely reduced at this level as shown in Figure 6.

Analyses of the proportion of N derived from the atmosphere vs that from fertiliser should be possible once ^{15}N analyses are completed. This will help determine a critical level of soil N above which N fixation is less effective than added fertiliser N, for future inoculation and fertiliser recommendations.

Field trial

Objective

Potential nitrogen fixation benefits from agronomically-suitable pigeonpea lines in the field described by July 2021.

Method

As a value-ad to the agronomy field trials and given limited seed amounts for specific trials on N fixation, it was thought that the field trials in Emerald and Kingaroy may be useful to assess the amount of N fixation in the various agronomic treatments for various lines of pigeonpea. Refer to Agronomy trials by Yash Chuahan (Kingaroy) and Doug Sands (Emerald) for full details of methodology and results. These replicated trials incorporated five pigeonpea lines, three times of sowings and three row spacings. Non-nodulated peanuts (Kingaroy) or sorghum (Emerald) were also grown alongside the pigeonpea trials as reference plants for determining N fixation by the pigeonpea in the field.

At the Kingaroy trial, plants were sampled at maximum biomass (2 x 1m row) and roots were dug up from the sampled plants (approx. 10-15 plants per plot) and examined for nodulation for trials at two of the three planting times. Nodulation was extremely poor (rating only a 0 - 2 out of 10 for number of nodules on roots, where 0 is no nodules and 10 is >30 nodules/plant). It was therefore considered of no use to analyse the tops for N fixation. Soil tests showed high amounts of N in the soil before planting as this site had been pasture for several years before cultivating and planting the pigeonpea trial.

The CQ trial will be considered as an option for N fixation analyses on the tops however nodulation (as a guide of good fixation) has not been assessed. Samples of pigeonpea shoots from this Emerald trial at maximum biomass and sorghum reference samples were dried, ground and pelleted and recently received in Toowoomba for sending to UC Davis for ^{15}N analyses. Discussions with project leaders and staff will be carried out to determine if these analyses will be beneficial.

Future trials for this work will be best located on sites with low levels of soil N.

Figure 6: Pigeonpea roots from Kingaroy field trial (Planting time 2) showing poor nodulation of the roots by rhizobia.

References

Herridge, DF and Holland, JF (1993). Low nodulation and N_2 fixation limits yield of pigeonpea on alkaline vertisols of northern NSW. Effect of iron, rhizobia and plant genotype. Aust J Agric Res 44:137-49.