Agronomic characteristics of pigeonpea as a summer crop for Queensland

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Abstract
Pigeonpea is an important tropical pulse that can assist in sustainably meeting the protein needs of the growing world population. Australian growers are well placed to produce high-quality pigeonpea grain to help meet global production shortfalls and supply plant protein. However, adapting this wild crop to mechanised production systems remains a challenge. We are addressing this challenge by focussing on early maturing types. These types yield in less than 100 days, form compact canopies, and can be mechanically managed to sow, spray, and harvest. In experiments conducted at Kingaroy and Emerald, such cultivars grew < 1m tall and produced up to 3.6 t/ha. However, we observed significant cultivar x sowing time interactions for various traits, suggesting that it will be prudent to recommend agronomically superior cultivars and production practices suited to local production environments. These aspects are being investigated in a DAF initiative on pigeonpea.

Keywords
Cajanus cajan, sowing time, maturity, phenology, modelling

Introduction
More countries may need to grow and consume crops like pigeonpea [*Cajanus cajan* (L.) Millsp.] - a warm-season pulse crop endowed with high (~22%) protein content and nitrogen-fixing ability - to sustainably meet nutrition requirements of a growing population in the face of global warming (Saxena et al. 2018). Being a major pulse exporting nation, Australia is uniquely placed to contribute to this goal by adapting pigeonpea to its broadacre cropping systems in the subtropics and tropics.

The pigeonpea crop evolved around 3500 years ago through spontaneous mutation in a photo-sensitive wild species e.g.,*Cajanus cajanifolius*. Landraces of this crop that emerged were of considerably long duration due to being highly photoperiod sensitive. These were mainly grown in mixed or inter-cropping systems in tropical and subtropical areas. In the middle of the last century in India, scientists identified a few early flowering spontaneous mutants among the longer duration landraces leading to increasing interest in developing early maturing pigeonpea cultivars (Saxena et al. 2019). Some cultivars maturing in less than 100 days have also been designed to expand the adaptation of the crop to a broader range of latitudes and new cropping systems (Chauhan et al. 2002; Vales et al. 2012). Some of these cultivars can be used for developing mechanised production systems for broadacre cropping in tropical Australia.

Development of the domestic pigeonpea industry in Australia has been on the radar for over 40 years, but progress has been limited (Ryan 1998). Major problems included the inability to control pests, agronomy support and poorly developed domestic and international markets for the crop. Because of new market opportunities (Mula and Saxena 2010) 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. This paper highlights key achievements on agronomy of pigeonpea towards its use as a broadacre crop.

Materials and methods
Defining agronomic characteristics of plant type for broadacre cropping
Through emails, a survey was done largely among legume researchers and industry to identify agronomic traits of pigeonpea that may be suitable for broadacre cropping. We further discussed these findings with experts in a workshop to define them more appropriately while prioritising the immediate research needs.

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), were used for agronomic evaluation at Kingaroy and Emerald Research Facilities in 2019-20 (Table 2). These were sown on three sowing dates in a split-plot trial with three replicate blocks at each location. Planting was done at 50 cm rows. Pre-sowing irrigation was given 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 a couple of applications of Alticor (@75 g/ha) applied at flowering and another one 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. Fates of 50% flowering and maturity, growth and yield data collected in the field experiments were used to train the APSIM Pigeonpea model (version 7.10).

Results and discussion
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 somo-clonal 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. Their potential adoption in Australian environments is, however, not fully explored.

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

Trait	Target	Priority	Purpose/comment
Seed Size (100 seed mass)	>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 d	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	>10kg/mm/ha	High	More crop per drop
Branching	3-4 primary branches	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 production
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

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 and Emerald during the 2019/20 season.

Kingaroy	Days to 50% Flowering			Plant Height			Yield		
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	
Emerald	Days to 50% Flowering			Plant Height			Yield		
Cultivar	Dec	Jan	Feb	Dec	Jan	Feb	Dec	Jan	Feb
ICPL 151	61	61	53	1.5	1.3	0.9	1.75	1.00	1.49
ICPL 85010[a]	57	58	53	1.0	1.2	0.8	2.39	1.40	1.02
ICPL 86012	73	68	55	1.6	1.4	0.8	1.10	0.82	1.44
ICPL 88007[a]	50	55	50	1.0	1.1	0.7	2.03	1.51	1.08
ICPL 94	68	68	56	1.5	1.4	0.8	1.11	1.18	1.41
QPL 1019	66	62	54	1.4	1.3	0.8	1.44	0.93	1.25
Sunrise	73	64	57	1.6	1.4	0.9	2.09	1.28	1.62
LSD between PD[b]		2.5[d] /2.1[e]			0.87/0.77			0.67/0.62	
LSD within PD[c]		2.4/1.9			0.73/0.60			0.50/0.41	

[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 (Sunrise had a higher level of replication than the other cultivars in Emerald)

Prediction of phenology using APSIM

The flowering process in pigeonpea is very dynamic due to photoperiod and temperature sensitivity and is the source of significant genotype x sowing date interactions, as highlighted above. Accurate prediction of flowering time can allow evaluation of the crop's fit in different cropping systems. The date of flowering could be predicted using the APSIM model with about 98% accuracy (Fig.1 left) with soil water correction as in the case of chickpea (Chauhan *et al.* 2019). Prediction of crop maturity was slightly poorer but still satisfactory (Fig. 1, right).

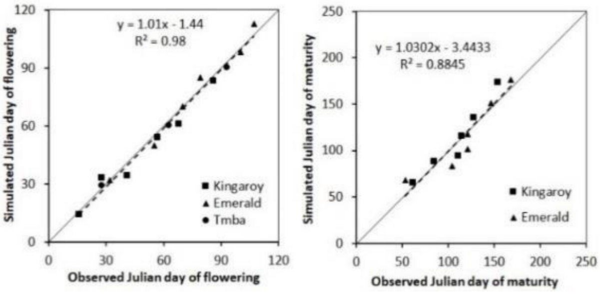

Fig. 1. Prediction of Julian dates of flowering (left) and maturity (right) of extra-early to early duration pigeonpea in three and two environments in Queensland, respectively.

Prediction of yield and dry matter at maturity using APSIM

Prediction of yield and dry matter was poor compared to flowering and maturity times, especially for extra early genotypes (relationships not shown). The association was slightly better at Emerald where overall yields were lower, probably due to lack of enough moisture, although here also simulated yields were less than the observed. The model has been developed initially using data collected at ICRISAT, Patancheru in India, where yields achieved were generally low due to waterlogging and low radiation levels during the growing season (Vales et al. 2012). The model will therefore need to be recalibrated, especially for extra-early and early pigeonpea types grown in Australia.

Conclusions

The initial agronomy experiments have shown considerable promise for pigeonpea as a potential summer crop in Queensland. Some of the cutivars average yields were > 3 t/ha at Kingaroy (November and December sowings) and > 2 t/ha at Emerald (December sowing). We could well predict both flowering and maturity dates in diverse environments with an improved APSIM phenology module. Further improvements in the model to predict growth and yields are required to accurately (a) predict the potential of the crop in different environments, (b) characterise environments, and (c) optimise genotype x environment x management interactions for yield in different environments. In future, we also intend to use newly developed super early cultivars that we have recently received from ICRISAT.

References

Chauhan, Y, Johansen, C, Moon, J-K, Lee, Y-H, Lee, S-H (2002) Photoperiod responses of extra-short-duration pigeonpea lines developed at different latitudes. Crop Science 42, 1139-1146.

Chauhan, YS, Ryan, M, Chandra, S, Sadras, VO (2019) Accounting for soil moisture improves prediction of flowering time in chickpea and wheat. Scientific Reports 9, 7510.

Mula, M, Saxena, K (2010) 'Lifting the level of awareness on pigeonpea-a global perspective.' (International Crops Research Institute for the Semi-Arid Tropics:

Ryan, JG (1998) Pigeonpea improvement. Canberra. Available at (https://ageconsearch.umn.edu/record/47498/files/IAS6.PDF) [Accessed 9/3/2021].

Saxena, K, Chauhan, Y, Sameer Kumar, C, Hingane, A, Kumar, R, Saxena, R, Rao, G (2018) Developing improved varieties of pigeonpea. In 'Acheiving sustainable cultivation of grain legumes: Improving cultivation of particular grain legumes.' (Eds S Sivasankar, D Bergvinson, P Gaur, S Kumar, S Beebe, T M.) Vol. 2 pp. 1-30. (Burleigh Dodds: Cambridge, UK)

Saxena, K, Choudhary, AK, Srivastava, RK, Bohra, A, Saxena, RK, Varshney, RK (2019) Origin of early maturing pigeonpea germplasm and its impact on adaptation and cropping systems. Plant Breeding 138, 243-251.

Saxena, K, Kumar, R, Chintapalli, P, Sharma, K, Mallikarjuna, N (2011) Evaluation of somaclones derived from in-vitro culture induced somatic tissues in pigeonpea. Journal of Food Legumes 24, 175-179.

Vales, M, Srivastava, R, Sultana, R, Singh, S, Singh, I, Singh, G, Patil, S, Saxena, K (2012) Breeding for earliness in pigeonpea: Development of new determinate and nondeterminate lines. Crop Science 52, 2507-2516.