FINAL REPORT

GRDC
GRAINS RESEARCH & DEVELOPMENT CORPORATION

DAN00151

PBA Chickpea - National Breeding Program

PROJECT DETAILS

PROJECT CODE:	DAN00151
PROJECT TITLE:	PBA CHICKPEA - NATIONAL BREEDING PROGRAM
START DATE:	30.06.2011
END DATE:	30.06.2016
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Summary

The aim of this project was to breed and commercialise improved desi and kabuli chickpea varieties for Australian growers. The breeding program has built on the success of previous program releases of Australian bred desi varieties with improved ascochyta blight (AB) resistance, PBA HatTrick⌽ and PBA Slasher⌽, with the release of PBA Boundary⌽ (2011 desi - northern New South Wales (NSW) and southern Queensland (QLD), PBA Pistol⌽ (2011 desi - central QLD), PBA Striker⌽ (2012 desi - south and west), PBA Maiden⌽ (2013 desi - south and west), PBA Monarch⌽ (2013 kabuli), and PBA Seamer⌽ (2016 desi - central NSW to central QLD). New desi and kabuli breeding material with improvements to the key breeding objectives have been developed.

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Conclusions

The main conclusions drawn from the project are:
1. The project represented the second 5-year phase of Pulse Breeding Australia (PBA). The project continued to build on fulfilling two broad objectives that formed the rationale for PBA - increased efficiency within individual breeding programs, and synergies across them. The project was restructured with the consolidation of one breeder for both desi and kabuli chickpeas and screening activities rationalised on the basis of local expertise and comparative advantage. The chickpea program contributed significantly to the overall efficiency of PBA and helped forge its strong national (and international) profile.

2. Host resistance was shown to be a practical and effective means of controlling AB. Although some fungicidal intervention will still be required, it has been demonstrated that varieties released during this project, such as PBA Seamer⦶, can be grown with fewer foliar sprays than for the susceptible (S) and moderately resistant (MR) varieties they will replace. The minimum level of AB resistance varies according to region with a lower level in central QLD and a higher level required in southern and western regions due to winter dominant rainfall. Recently collected highly aggressive AB isolates have reinforced the importance of the trait and the necessity to retain AB resistance as a key breeding objective.

3. Significant yield gains (up to 10%) have been demonstrated for all regions. This has been achieved in particular through earlier phenology (e.g. PBA Pistol⦶ and PBA Monarch⦶). Further significant gains will be achieved by combining other traits (e.g. salt and chilling tolerance) identified in parental and breeding material during the project.

4. Increased resistance to phytophthora root rot (PRR) can be transferred from a wild relative (*Cicer echinospermum*) to a domesticated chickpea background. This resistance, which has not been detected in the chickpea germplasm, is necessary to protect against PRR in high rainfall years or other situations (e.g. waterlogging prone fields) favourable to the disease. In general, hybridisation with wild relatives in the primary gene pool (*C. reticulatum* and *C. echinospermum*) is a practical strategy for improvement in some other previously recalcitrant traits (e.g. chilling tolerance).

5. Improved harvestability (a combination of erect plant type, increased height to lowest pod and improved lodging resistance) will improve the appeal of new varieties, especially in southern NSW where there has been significant expansion in the chickpea growing area. Genetic resources needed to achieve this objective are available within the project's breeding material.

6. Incorporation of novel herbicide tolerance (HT) traits. The program has aligned closely with project DAS00131 to fast-track new HT traits (Group I and Group B) into adapted elite PBA chickpea germplasm. It is anticipated that a HT chickpea variety will have rapid adoption, similar to the impact of Group B HT in lentils.

7. Quality of both desi and kabuli types is critically important to Australia retaining its market share (and reputation). Although marketing difficulties with 6-7mm kabulis have been resolved, the program has shifted focus towards the premium 8-9mm grade. Through the breeding process, elite small kabulis are developed, but emphasis has moved to larger seeded types. Significant improvement has been made in the adaptation and yield of larger seeded types through the development

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of earlier flowering and maturing kabulis.

Recommendations

The following recommendations can be drawn from the project and are directed to subsequent breeding and pulse pre-breeding projects:

1. The rapid growth of Australia's chickpea industry, underpinned by PBA varieties, coupled with quick and extensive adoption of these varieties, opens up the prospect of future chickpea breeding being largely funded by end point royalties (EPR). Opportunities to move substantially towards EPR funding, underpinned by GRDC and state agency support for 'market failure', should be pursued. This needs to be supported by diagnostic variety identification molecular tools to demonstrate the ability to identify varieties and to ensure improvements in variety declarations throughout all chickpea growing areas.

2. There is a need for funding resources to reflect the current and future distribution of chickpea cropping. Following the AB epidemics (from 1998), the industry has contracted significantly in southern and western Australia with a significant expansion in the north-east. Whilst an increase in crop area has occurred in southern NSW, areas in Victoria (VIC), South Australia (SA) and Western Australia (WA) have remained stagnant or declined. Northern NSW and QLD are the dominant regions and funding of future breeding and pre-breeding projects should reflect this reality, with a greater emphasis on relevant traits and developing material adapted to these growing regions.

3. Improved coordination of chickpea pre-breeding projects to facilitate communication with PBA chickpea and streamline interactions. A strong focus on interactions which improve delivery and implementation of outputs from pre-breeding projects would be beneficial to both parties.

4. Use of new technologies such as accelerated single seed descent (aSSD) and cloning of F1 plants to fast track high priority traits. The aSSD technology allows up to six generations per year and cloning F1s will increase population size to provide more effective selection strategies.

5. A 'path to market' for HT traits is urgently required to progress breeding material developed using outputs from DAS00131. This will allow the PBA chickpea program to develop a suitable breeding strategy with full knowledge of any encumbrances that exist with the original and derived material.

6. Collaborative work with the international centres, International Centre for Agricultural Research in the Dry Areas (ICARDA) and International Crops Research Institute for the Semi Arid Tropics (ICRISAT) need to be continued and new opportunities explored. Given that the mandate region for ICRISAT (semi-arid tropics) is most relevant to north-eastern Australia, where the Australian chickpea industry is concentrated, there is a particular need to engage more closely with breeding and other chickpea research programs at ICRISAT. Benefits could also be gained by formalising collaborations with the Crop Development Centre at the University of Saskatchewan, where common research goals for AB resistance, phenology and herbicide tolerance exist.

Outcomes

Economic

The project has delivered clear benefits to the Australian grains industry through improved varieties. The medium seeded kabuli variety PBA Monarch$^{\Phi}$ produces yields similar to the small seeded Genesis™ 090$^{\Phi}$. The increased seed size (greater % of seeds in the 8-9mm and 9-10mm seed size category) can provide a net income of up to $200/ha more than small seeded kabulis and desis. The desi variety PBA Seamer$^{\Phi}$ has significantly improved AB resistance compared to current northern region varieties such as PBA HatTrick$^{\Phi}$. In an average season, growers will save the cost of two fungicide sprays (approx. $30/ha).

Environmental

The environmental benefits of improved chickpea varieties are reduced fungicide and fertiliser use. In northern NSW, southern and central QLD, the adoption of a more resistant variety such as PBA Seamer will result in fewer fungicide sprays (compared to growing a less resistant or susceptible variety). Growing productive chickpea crops with less disease will result in higher biomass and more effective nitrogen (N) fixation.

Social

More profitable chickpea varieties have contributed to the expansion of chickpea production in Australia. This has led to the development of regional handling and processing facilities. The additional labour resources required for cleaning, grading, packing and processing (dhal and flour production) locally produced chickpeas have important implications for regional industry and employment.

Achievements/Benefits

Background

The chickpea industry began in southern QLD and northern NSW in 1979. It was initially concentrated there, but in the 1980s spread to central QLD, VIC, SA and WA. The national area peaked at 310,000ha in the early 1990s, but declined somewhat thereafter due to a mix of factors including price, weeds and herbicide damage, 'hostile' soils, harvestability problems, and, most importantly, disease.

PRR, caused by the endemic pathogen *Phytophthora medicaginis*, has been consistently associated with major crop losses in north-eastern Australia. It has rarely been observed overseas where damage is minimal, so PRR is, and will remain, a peculiarly Australian problem. Widespread adoption of varieties having improved resistance (e.g. Kyabra$^{\phi}$, Yorker$^{\phi}$ and PBA HatTrick$^{\phi}$) has reduced the impact of PRR, however the potential for significant production losses remains in the absence of more resistant varieties.

A more significant impact on the industry was produced by AB which was first observed in SA in 1996. Major losses were first recorded in 1998 with a large number of crops abandoned in an arc from SA to southern QLD - the epidemic spread to WA in 1999. Because all available varieties were highly susceptible to AB, the chickpea industry had almost disappeared in VIC, SA and WA by 2000. In northern NSW and southern QLD, where the environment is slightly less conducive to AB in most seasons, the industry survived due mainly to an effective management strategy based on foliar fungicides. The deployment of AB resistant varieties from 2005 led to a modest increase in crop area. These varieties were essentially 'stop-gap' measures. Those released for southern and western Australia were introductions (Genesis$^{\phi}$ series varieties) which had generally low yields and poor seed quality, while the locally bred varieties released in north-eastern Australia (Yorker, Flipper$^{\phi}$) were only MR to AB.

The 2009 release of PBA HatTrick provided a more robust combination of AB and PRR resistance. It was rapidly adopted by growers in the northern temperate region with more than 100,000ha in its first year of commercial production, 2010. Six years later it is now estimated to occupy 70% of the chickpea production in this region (approx. 550,000ha in 2016). PBA HatTrick has been instrumental in the expansion of chickpea production in Australia which has peaked at more than one million ha in 2016.

Objectives

The major task facing the project at its inception was to provide regionally adapted chickpea varieties (desi and kabuli) having sufficient AB resistance to significantly reduce the reliance on foliar fungicides. Beyond this, improvements in other characteristics would be required for industry expansion.

The specific project objectives were to:

1. Develop and commercialise an AB resistant desi variety each for central QLD, north-eastern Australia and the southern and western regions. Develop and commercialise an AB resistant kabuli variety.
2. Develop germplasm with improved traits (resistance to AB and PRR, tolerance to salt, herbicides and chilling, increased yield, and improved harvestabilty and seed quality) for potential release or progression in the next PBA chickpea project.

Project achievements

1. New varieties released.

For central QLD (Region 1), PBA Pistol$^{\phi}$ (CICA0702) was released in spring 2011. Although not resistant to AB, PBA Pistol was widely adopted because of its significantly increased yield potential (10% higher yielding than Moti$^{\phi}$ and Kyabra), improved harvestability (tall and lodging resistant), and herbicide (isoxaflutole#) tolerance. Although seed size and colour were improved compared to Moti, after its release PBA Pistol was found to express a high incidence of tiger stripe or blotch marking on the seed coat in some environments.This has caused concern to the industry and was the impetus for a new GRDC project (DAN00196) to further understand the issue. PBA Pistol was also found to be more sensitive to vegetative frost

than Kyabra, the other main variety now grown in central QLD.
PBA Boundary$^{\phi}$ (CICA0511) was released in the northern temperate region (Regions 2 and 3) in spring 2011 and combines better AB resistance (18% yield loss compared to 30% for PBA HatTrick) with increased yield (4% higher than PBA HatTrick). PBA Boundary is moderately susceptible (MS) to PRR and all extension communication has been very clear to ensure that all growers are aware of this and avoided paddocks with a history of PRR or prone to waterlogging. Due to the MS response, PBA Boundary had a smaller uptake than PBA HatTrick, but is still an important variety, particularly in southern QLD.

PBA Seamer (CICA0912) was released in the northern temperate and central QLD regions in spring 2016. It has yields similar to PBA HatTrick and PBA Pistol, but significantly improved resistance to AB (rated resistant (R) in these environments), MR to PRR and superior lodging resistance to current varieties. The yield advantage of PBA Seamer in a high disease year (such as 2010) is significant and up to 30% higher than PBA HatTrick. PBA Seamer was also observed to have lower levels of botrytis grey mould (BGM) in 2010 due to its semi-erect plant type, providing superior lodging resistance and providing better air flow through the canopy. Seed size and dhal yield are greater in PBA Seamer than PBA HatTrick. There has been very strong interest from growers and reports of early seed orders indicate the variety will be rapidly adopted.

For the southern and western regions (Regions 4 and 5), PBA Striker$^{\phi}$ (CICA0603) was released in 2012 and is the highest yielding variety for short season environments such as WA. PBA Striker has early flowering and maturity and has a MR rating to AB.

PBA Maiden$^{\phi}$ (CICA0717) was released in 2013 and has much improved seed quality (large seed, attractive colour) for the premium whole seed market. PBA Maiden yields similarly to PBA Slasher$^{\phi}$ and has a MR rating to AB.

The kabuli variety PBA Monarch$^{\phi}$ (CICA0857) was released in 2013 and has medium seed size and high yields, particularly in short season environments such as SA and the Mallee region of VIC. PBA Monarch is early flowering and early maturing with a MS rating for AB. The increased seed size (greater % of seeds in the 8-9mm and 9-10mm seed size category) can provide a net income of up to $200/ha more than small seeded kabulis and desis.

2. Improved germplasm
A. AB resistance. The program has released a number of varieties with good levels of AB resistance to common isolates of the *Phoma rabiei* pathogen (e.g. PBA Slasher and PBA Seamer). In the 10 to 15 years following the AB outbreak, chickpea varieties and breeding lines have ranked similarly in field AB nurseries in NSW, VIC, SA and WA. This data gave the program confidence that the resistance in advanced breeding lines was robust across the range of Australian chickpea growing environments. The GRDC funded, Griffith University led UM00052-UG is collecting information on the variability of the *Phoma rabiei* pathogen and providing new knowledge and isolates to the PBA chickpea program. In recent years, a number of highly aggressive isolates have been identified which cause high disease on Genesis™ 090$^{\phi}$ (resistant kabuli) and moderate disease on ICC03996 (resistant desi). Knowledge from UM00052-UG was implemented in controlled environment screening conducted in the PBA chickpea project using isolates collected in the northern and the southern growing regions. From 2015, an increasing number of lines in this screening have shown significantly different responses in resistance to these recently collected isolates. This new knowledge has resulted in the breeding program reassessing its AB resistance breeding effort and investigating minor resistance sources that exist in the program and new alternative sources. The program had commenced characterising parental material and advanced breeding lines (2015 crossing block and 2014-2015 S3-2 lines) using AB molecular markers developed in the Pulse Molecular Marker program (DAV00136), however with the discovery of new AB isolates, the markers are less useful predicting resistant phenotypes. In 2016, at the Curyo PBA chickpea breeding site in the southern Mallee, a highly aggressive isolate of AB reduced all current chickpea varieties to a MS or S response. This included Genesis™ 090$^{\phi}$, PBA Slasher and PBA Seamer. Three breeding lines in the Stage 2 desi trial have shown an MR response. These lines will be used as parents in 2016 and the original F3 populations they were selected from (crosses from 2010) will be screened in a controlled environment to develop further lines with the best performing pedigrees. This highlights the value of the program's procedure of storing all historical F3 populations for selection for resistance to new isolates.

B. PRR resistance. Extensive evaluation of the chickpea germplasm has revealed only moderate levels of resistance to PRR. Much superior resistance was discovered in a wild relative (*C. echinospermum*) that hybridises readily with chickpeas. A program designed to transfer this resistance into a domesticated, AB resistant background was initiated in an earlier breeding project and continued in this one. Third back and topcross lines were evaluated in S2/1 trials and PRR and AB nurseries in 2015. Highly PRR resistant lines (PRR rating = 1.3-3.0 compared to 5.0 for Yorker, 7.0 PBA HatTrick and 8.0 PBA Boundary, where 1 = no disease and 9 = all plants dead) were identified which also had good levels of AB resistance, plant type and seed quality. The breeding program is working closely with the GRDC funded NSW Department of Primary Industries (DPI) and University of Adelaide (UA) project DAN00172 which is providing new knowledge about the pathogen and molecular markers to assist the resistance breeding effort.

C.Early flowering, early maturity and chilling tolerance. A large number of breeding lines have been developed using the chilling tolerance developed by the University of WA (UWA) and the Department of Agriculture and Food WA (DAFWA) and released as Sonali$^{\phi}$ and Rupali$^{\phi}$. However, it became apparent that a higher level of chilling tolerance was required to be coupled with early flowering to provide reliable pod set, particularly in late winter and early spring. Closer observations of the inter-specific material developed from *C. echinospermum* for PRR resistance indicated it was less sensitive to temperature for pod set, despite most material being late flowering. The program has developed new breeding lines which combine excellent early vigour (for plant height), early flowering and early pod set. A number of these lines are in Stage 1A and row evaluation in 2016.

D. Salt tolerance. Previous studies had demonstrated genetic variation within chickpeas, which is regarded as a salt sensitive species. Breeding lines were routinely screened during the project using Genesis™ 836$^{\phi}$ as a tolerant check. Some lines have consistently been more tolerant, or as tolerant as, Genesis™ 836. Tolerant lines identified in this project have been crossed with other sources of tolerance with the objective of recovering increased salt tolerance in an AB resistant background. Some lines from the Council of Grain Growers Organisation (COGGO) Alliance have shown useful salt tolerance and have been used as parents in the crossing block for this trait.

E. Herbicide tolerance. Routine screening of advanced breeding lines has shown most have acceptable tolerance of registered herbicides at recommended rates. In some years, however, the screening has highlighted susceptibility of some lines to some herbicide(s). Tolerant lines have also been chosen as parents, either to increase the tolerance level within breeding populations or to combine resistance to different herbicides. Landrace lines published as having tolerance to imazapyr[#] were used as parents in 2010 and breeding lines developed. One hundred and four F6 lines derived from these sources are being screened in the field in 2016. Whilst there is variation for tolerance, the best lines will be superseded by novel herbicide tolerance developed by ethyl methanesulfonate (EMS) mutation in the GRDC and SA Research and Development Institute (SARDI) DAS00136 project. Desi lines with Group I and Group B tolerance and kabuli lines with Group B have been used as parents and fixed lines with Group I tolerance were selected in 2015. F4 Group I selections will be top-crossed with elite PBA lines in 2016.

F. BGM resistance. Breeding lines have been routinely screened for resistance to BGM, although all lines were rated MS-S, some genotypic variation was apparent. Significantly, one of the least susceptible lines (PBA Seamer) had the lowest apparent infection (and highest yields) in severely BGM-affected trials in NSW and QLD in 2010. The main contributor to superior yields is thought to be due to plant architecture rather than resistance. Phenotyping for resistance has been difficult and variable.

4. Organisational and structural developments
This project marked a significant change in the organisation of breeding chickpeas in Australia with a centralised core breeding program under a single breeder. The consolidation of all germplasm at Tamworth has enabled greater exploitation of PBA germplasm across the five agro-ecological environments (Regions 1-5). This has allowed for gains in yield potential, plant type and phenology within each target region.

Benefit to Industry
New varieties provide a direct and readily quantifiable benefit to the chickpea industry. The largest component of benefit derives from reduced fungicide costs due to increased AB resistance. In northern NSW and southern QLD, where most (74% in 2016) production occurs, the replacement of older varieties (Kyabra, PBA HatTrick and PBA Boundary) by PBA Seamer will lead to a reduced number of foliar sprays needed to control AB.

A less quantifiable, but nonetheless significant, benefit of the project's outputs will be the increased confidence of chickpea growers. A more stable industry will set a platform for increased chickpea growing area and consequently a higher farm profitability through increased rotational benefits.

Other research

The following research and development (R&D) opportunities were identified during the project:
1. Chilling tolerance to improve early pod set. Chickpeas are highly sensitive to cool temperatures during flowering and podding, with cool temperatures resulting in flower and pod abortion. This issue has been a major concern for chickpea

growers in recent seasons. The varieties Sonali⦶ and Rupali⦶ were released in 2004 due to their early flowering and improved chilling tolerance compared to other varieties, but both are susceptible to AB and PRR. The breeding program developed early flowering material using these varieties, but found a much higher level of chilling tolerance was required to achieve early and reliable pod set in most seasons. The PBA chickpea program has been developing inter-specific material for PRR resistance and has combined early flowering with *C. echinospermum* backgrounds. This material appears to have improved chilling tolerance compared to Rupali and Sonali. An inter-specific recombinant inbred line (RIL) population of Rupali x *C. echinospermum* was developed to study PRR resistance. During multiplication of the RILs, large variation for early pod set within this population was observed, suggesting it would be suitable to further investigate chilling tolerance. Molecular tools to improve selection for chilling tolerance would greatly enhance and speed up the breeding effort.

2. Improved understanding of the reproductive physiology of chickpeas. Whilst it is expected that chilling tolerance would greatly enhance chickpea productivity, there is a poor understanding of chickpea physiology in Australian growing conditions, particularly in seasons highly conducive to high biomass and high soil moisture during the reproductive phase.

3. Alternative sources of resistance to aggressive AB isolates. Recently collected AB isolates in southern Australia have found to be highly aggressive on current varieties and most breeding lines. New sources of resistance need to be identified to ensure good levels of resistance can be maintained in future chickpea varieties. Molecular tools which assist pyramiding minor resistance genes would be of great benefit.

4. Interaction of waterlogging and phytophthora. PRR of chickpeas occurs following prolonged soil saturation, and chickpeas are highly sensitive to waterlogging, particularly during the reproductive phase. From field observations, it is thought that genotypic differences to waterlogging sensitivity exist, and that this confounds genotypic susceptibility to phytophthora. Protocols have been established to screen for waterlogging sensitivity in other pulse crops, and genotypic differences have been recorded. A project to screen PRR resistant and susceptible chickpea germplasm could help clarify the role of waterlogging in response to PRR infection and the potential to improve the response of chickpeas to both constraints.

Intellectual property summary

Varieties produced by the PBA chickpea breeding program released during this project (PBA Boundary⦶, PBA Pistol⦶, PBA Striker⦶, PBA Maiden⦶ and PBA Monarch⦶) have been protected under the Plant Breeder's Rights (PBR) scheme. PBA Seamer ⦶ currently has the Part 1 of the PBR application accepted with full PBR expected to be granted following the completion of the distinctness, uniformity and stability (DUS) trial in the 2016 season.

Any breeding material developed by the program and provided for evaluation by third parties has been done so under the protection of a Material Transfer Agreement (MTA).

Additional information

Anon (2012). PBA Boundary⦶. Plant Varieties Journal. 24(4).
Anon (2013). PBA Maiden⦶. Plant Varieties Journal. 25(4).
Anon (2013). PBA Striker⦶. Plant Varieties Journal. 25(4).
Anon (2014). PBA Monarch⦶. Plant Varieties Journal. 26(4).

Attachments

1. PBA Boundary⦶ Fact sheet.

2. PBA Maiden⦶ Fact sheet.

3. PBA Monarch⦶ Fact sheet.

4. PBA Pistol⦶ Fact sheet.

5. PBA Seamer⦶ Fact sheet.

6. PBA Striker Fact sheet.