Horticulture Innovation Australia

Final Report

National Potato Breeding program: Cultivar improvement

Tony Slater
The Dept of Economic Development Jobs, Transport & Resources

Project Number: PT07017

PT07017

This project has been funded by Horticulture Innovation Australia Limited using funds from the Australian Government and the following organisations:

McCain Foods (Aust) Pty Ltd
Snack Brands Australia
Abel Agrico International & BJC Foods
Mitolo Developments Pty Ltd
East Coast Cultivars Pty Ltd
SA Potato Packers R&D Co Pty Ltd
PG & SL Scott Pty Ltd
Agricultural Produce Commission Potato Producers Committee

ISBN 0 7341 3683 8

Published and distributed by:
Horticulture Innovation Australia Limited
Level 8, 1 Chifley Square
Sydney NSW 2000
Tel: (02) 8295 2300
Fax: (02) 8295 2399

Final Report for Horticulture Australia

Project No: PT07017 (30th June 2012)

Project Title: **National potato breeding program: Cultivar Improvement**

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Funding sources:
This project has been funded by HAL using a voluntary contribution from eighteen potato companies and matched funds from the Federal Government.

Published by the Department of Primary Industries, June 2012.

Authorised by the Department of Primary Industries, 1 Spring Street, Melbourne 3000.

Date: June 2012.

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Media Summary

Potatoes are the fourth-largest food crop internationally, and account for 20% of all vegetable production in Australia. Although potatoes are a valuable food crop, the current main commercial cultivars suffer from a number of production and quality issues, and the Australian potato breeding program will develop new cultivars that address these issues.

Prior to the start of this project the breeding program was reviewed on its scientific activities, and the involvement with industry members to establish a firm route to market. This required commercial investment for the development of improved cultivars, with the opportunity open to all the industry. In total 18 companies have participated.

The program has distributed 217 cultivars for commercial evaluation over the last four years, with this season's cultivars still to be identified. Twenty-five cultivars are progressing towards commercialisation.

Over the last five years, potato breeding in Australia has changed. It used to involve comparing characteristics of potential new cultivars. Numbers mattered in the search to find a superior cultivar. Now the populations are designed and tested to determine the better families, parents and cultivars with greater insight. This change is due to the adoption of advanced computing and molecular techniques, which has reduced the reliance on large seedling populations.

The program is now using molecular markers to identify cultivars with resistance to potato cyst nematode, *Potato virus Y* and *Potato virus X*, and will utilise estimated breeding values to obtain significant genetic gain in a number of important traits, such as yield.

By analysing the genetics, we can now have early field generations run locally by industry partners, but under the guidance and analysis of the central program. This development would enable trials to be run in states such as Tasmania and Western Australia, without the current biosecurity constraints.

As well as the investors benefiting from the development of cultivars, there will also be flow-on benefits to the rest of the industry. Those companies in the supply chain of the investing companies will benefit and the research into the genetics of resistance will enable growers to use resistant cultivars as part of their management strategy.

Technical Summary

Potatoes are the fourth-largest food crop internationally, and account for 20% of all vegetable production in Australia. Although potatoes are a valuable food crop for Australia, the current main commercial cultivars suffer from a number of production and quality issues. An Australian breeding program will develop new cultivars that are continuously improving against Australian conditions and issues.

Prior to the start of this project the Potato Breeding Program was reviewed twice to identify a direction for the future. The scientific activities of the program were reviewed, as well as the interaction with industry members to establish a firm route to market for the cultivars. This required commercial investment for the development of improved cultivars, while levy funds have been directed to a pre-breeding focus to develop techniques and understand the biology and genetics of important traits.

As a result of the last five years work, potato breeding in Australia has changed. It used to involve comparing characteristics of potential new cultivars. Numbers and population size used to matter in the search to find a superior cultivar. Now the populations are designed and tested to determine the better families, parents and cultivars. This change is due to a better understanding of potato genetics, the genetics and biology of the traits, quantitative genetics and molecular genetics. Now computing and technological advances are far more important than numbers, and have been adopted to modernise the conventional breeding program. The program is now in a position to continually improve cultivars and build significantly on previous efforts.

The program has met annually with the investing companies to discuss the direction and progress. These meetings are held ‘in-confidence’ to enable commercially sensitive information to be provided. The companies are invited to the harvest of their respective trials. The program screens the germplasm to describe plant characteristics, tuber characteristics, marketable yield, disease symptoms, cooking response, specific gravity, dormancy, susceptibility to greening and bruising and marker-assisted selection for disease resistance.

The program has distributed 217 cultivars for commercial evaluation over the first four years, with this season’s cultivars still to be identified. The commercial evaluation of these cultivars is the responsibility of the companies, and this is also showing progression as 25 cultivars have been placed into tissue culture for advanced evaluation.

As molecular markers were validated by the pre-breeding program, they were immediately deployed. The breeding populations have been screened for potato cyst nematode, Verticillium wilt, PVY and PVX resistance.

The pre-breeding project has also investigated the quantitative genetic control for complex traits, such as yield. This has included cross generation prediction and the development of estimated breeding values. From this research, the predicted rates of genetic gain have been calculated and have doubled from the start of the current project. This could see the average gain for an important trait such as yield be as much as 9 tonnes per hectare per year, if we selected on yield alone. These analyses for calculating estimated breeding values will be applied to identify superior parents and individuals to progress to the next trials. The program will also alter selection rates within each trial to maximise genetic gain for these traits.

The alteration in the selection rates could change the necessity of having the breeding and early generation selection at a single central site, to a model where companies could undertake the early field generation trials locally in their own districts, but under the guidance and analysis of the central program with good science support. This would see the future development of cultivars suitable to anywhere in Australia, and enable programs to be run in Tasmania and Western Australia, without the current biosecurity constraints.

As well as the investors benefiting from the development of cultivars that are specifically designed for them, there will also be flow-on benefits to non-investing members of the industry in the supply chain of the investing companies. Also by understanding the biology and genetics of important traits has led to the identification of the local PCN pathotype, and an understanding of why there has been a recent outbreak of PVY. This information will enable growers to use resistant cultivars as part of their management strategy.

As some of these results have already been published in international scientific journals, progressive international breeding programs will also adopt our findings. Some of our published techniques have already been adopted in the United Kingdom and North America. Therefore, this work will have benefits to any company that is interested in new cultivars, even if they are developed elsewhere.

Introduction

Potatoes are the fourth-largest food crop internationally, and account for 20% of all vegetable production in Australia. There is approximately 1.2 million tonnes of potatoes produced annually in Australia, valued at $557 million per annum at the farm gate (ABS 2009). The retail value is estimated to be worth $550 million for fresh market sales, $600 million of processed as French fry style product, and $600 million processed as crisps, which represents 3% of supermarket sales. Processing potatoes account for 56%, fresh potatoes 36%, and seed production make up the remaining 8%. This production is spread across all Australian states (but not Territories) with Victoria, Tasmania and South Australia each accounting for almost one quarter of the crop.

Of the 1.2 million tonnes produced annually, 52,000 tonnes were exported in 2005-06 with South-east Asia being the major export destination. There is anecdotal evidence that the Peoples Republic of China will be a significant competitor in these markets in the near future. Two thirds of these exports were fresh or chilled, while the remainder were processed. Seed tuber exports are an increasing component of the Australian potato market. Potatoes are consumed by the Australian public as fries, crisps, dehydrated and other frozen or semi-processed product and through home preparation.

Clearly the Australian potato industry is a large and important industry for Australia and the Australian Potato Breeding Program has considerable and vital responsibilities to support the aspirations of those in the industry and to contribute to the sustainable economic growth of Australia.

Although potatoes are a valuable food crop for Australia, the current main commercial cultivars still suffer from a number of production and quality issues. Disease susceptibility, tuber distortion, internal disorders, and storage problems are to name just a few. Disease susceptibility in particular can be potentially catastrophic for the industry, as major outbreaks do occur worldwide. Abiotic factors such as water availability, temperature, nutrition and photoperiod also effect crops across the various production areas in Australia. It is also likely that the deficiencies of current commercial cultivars could be a factor in the declining consumption of fresh potatoes.

An Australian breeding program will develop new cultivars that are continuously improving against Australian conditions and issues. Potato cultivars can be introduced to Australia from off-shore breeding programs, however these imported cultivars were bred for environments that are cooler, with longer growing seasons, and often have traits that address off-shore priorities rather than Australian issues. The disease resistance screening work done in collaboration with the Australian Potato Research Program phase 1 (APRP1), illustrated the importance of this, as internationally recognised resistant cultivars were susceptible to disease when screened against Australian strains of diseases. Other diseases e.g. Tomato Spotted Wilt Virus (TSWV) are only a problem for the Australian potato industry. An Australian program will develop cultivars screened against Australian disease priorities and threats.

The development of new potato cultivars that are suited to the Australian environment and that meet consumer needs is essential if the Australian potato industry is to expand and remain sustainable in the future.

Prior to the start of this project the Potato Breeding Program was reviewed twice to identify a direction for the future (Brennan et al., 2004, DArT, 2006). They reviewed the scientific activities of the program, as well as the interaction with industry members to establish a firm route to market for the cultivars developed in the program. These reviews have seen the program develop a strong pre-breeding focus as well as the aim to develop improved commercial cultivars. The pre-breeding area is focusing on developing technologies, more effective screening techniques and developing a germplasm collection that will underpin the future Australian potato industry, while the second area will adopt these technologies to support conventional breeding techniques to accelerate the development of improved commercial cultivars. Due to the involvement of the industry members, the advanced selections will be rapidly transferred to the investors for commercial evaluation and subsequent commercialisation.

The Brennan review of the National Potato Breeding Program identified that the program would be enhanced by the use of gene markers (Brennan et al., 2004). At the time the Victorian DPI was using this technology in other plant breeding programs such as wheat, canola, temperate grasses and legumes. It was seen that the potato breeding program would benefit from this enhancement as a number of key breeder's traits may be efficiently selected using molecular markers, including disease resistance and tolerance to abiotic stresses (particularly water limitation). Molecular markers will allow the detection of pre-existing genetic variation for these factors at the glasshouse seedling stage or early field generation trials. The activities have concentrated on the evaluation of genetic variation within the germplasm collection, and the establishment of associations between molecular markers and genes for important agronomic traits, as a prelude to marker-assisted breeding.

The pre-breeding program has also investigated the genetic analysis of complex traits that is undertaken in livestock breeding programs within the Victorian DPI. These analyses have developed Estimated Breeding Values (EBVs) for a number of important traits within dairy cattle, beef cattle, fat lambs, poultry and salmon breeding programs that have resulted in a substantial improvement in important traits for these industries.

Over the last few years, the Australian Potato Breeding Program has established collaborative links with James Hutton Institute (JHI, Scotland), United States Department of Agriculture (USDA), New Zealand Plant & Food Research (NZ P&FR), Agriculture and AgriFood Canada (AAFC), Teagasc (Ireland) and Wageningen University (the Netherlands). We now have interaction with potato breeding companies and research groups around the world, and we have visited a number of these programs in order to adopt the most advanced breeding techniques used anywhere in the world.

This report is a public report on a confidential project. Separate "In-Confidence" reports were made to the investing companies, and are to remain confidential.

Objectives

This project aimed to develop improved commercial cultivars in partnership with the investing companies to ensure good market intelligence and adoption. We also aimed to adopt more effective screening techniques through the adoption of molecular markers, and estimated breeding values for complex traits, in order to reduce the breeding cycle and accelerate the rate of genetic gain.

Materials and Methods

Industry direction and interaction

The Potato Breeding Program has been meeting annually with the investing companies to determine the specific breeding priorities for their company or syndicate and their respective supply chains, and to discuss the results of the various trials. These meetings are held 'in-confidence' to enable commercially sensitive information to be provided and to discuss details of the cultivars in the trials.

The general priorities include:

- Market fit
- Plant characteristics
- Tuber characteristics
- Disease resistance
- Postharvest performance
- Improved quality for industry and consumers
- Reduced inputs to maximise production efficiency.

The companies were then all invited to the harvest of their respective G2 and G3 trials. The harvest of most G3 trials were attended, while attendance at the G2 harvests required a longer time and was less frequent.

Program stages

A conventional potato breeding strategy employs phenotypic recurrent selection over a number of generations. Typically a large breeding population is created by conducting controlled pollinations to combine selected parents, and then subjecting the progeny to a progression of selection pressures to reduce the population size, while concurrently increasing the number of plants of each cultivar being evaluated (Bradshaw and Mackay, 1994, Jansky, 2009). As potatoes are an annual crop, glasshouse and field activities are conducted annually. These activities include the crossing program, glasshouse seedlings and 3 field generations.

Crossing Program - Controlled Pollinations

Once the parents for each season's crosses are identified using their performance against the breeding priorities, tubers are grown in pots under glasshouse conditions. The tubers are planted in a way to suppress tuber production and to promote plant growth and flower production. The controlled pollinations are conducted using parents that in combination may produce offspring with desired characters. The flowers to be pollinated are emasculated and protected from any undesired pollen contamination. The fruit is collected at maturity and the seed stored for use.

Glasshouse Seedlings (G0)

Seed from the desired parental combinations is germinated and seedlings are established in trays and transplanted to individual pots in the glasshouse. Plants are allowed to grow through to senescence. From each pot (single plant), a single seedling tuber is collected for multiplication in the following season's field seedlings crop. Additional seedling tubers are retained in family groups for progeny testing.

Field Seedlings (G1)

Tubers collected from the glasshouse seedlings are field-planted at wide spacing. Each plant in this field seedling or first field generation crop is genetically unique. At maturity plants are individually hand harvested to keep them separate. Tubers from each plant are examined and reasonable individuals are selected to advance to the next season. All of the tubers from these selected plants are collected to maximise the size of the following generation's selection plots. A sample of tubers are also collected from the rejected cultivars and retained in family groups for progeny testing.

Selection Plots (G2)

Using both cut and whole seed from tubers of the previous seasons single plants, selections are planted in short row plots of up to 30 plants. At harvest, plots are machine harvested and the more promising types selected based on plant type, maturity, tuber characteristics, disease incidence and yield. Samples are also taken to assess dormancy and cooking performance. The investors are invited to view the harvest of this material and review the data in order to advance the more commercially promising types to the following season's replicated comparative trials. The larger families are progeny tested.

Replicated Comparative Trials (G3)

Replicated trials are grown of the most promising selections from the preceding season's selection plots to compare their performance against industry standard cultivars. The selections are assessed on emergence, maturity, tuber characteristics, disease incidence, marketable yield, specific gravity, cooking performance (direct from harvest and storage), greening and bruising.

The investors are invited to view the harvest of these trials as they will be offered the better selections for evaluation at the end of this field generation. This short time frame from pollination to commercial evaluation makes this program a world leader, compared to other breeding programs, in the release of material for commercial evaluation.

Reporting

The program provides as much information as possible on each genotype by the end of the 3rd field generation. This information includes data on plant characteristics, harvest tuber characteristics and postharvest screening from the G2 and G3 trials. Digital images are taken of the performance of the G3 genotypes at harvest and after cooking. The data is provided to the respective companies at the end of each trial to identify the superior performing cultivars.

Program support activities

Parent collection maintenance

In order to maintain a diverse collection of approximately 300 parental cultivars and superior advanced selections, they are planted annually as small plots in the field. This allows for the cultivars to be assessed for desirable characters to be selected as parents. It allows for the comparison of similar cultivars. It also allows for the retention of material of superior selections that could be used as parents for genetic gain.

G3 seed multiplication and distribution

A seed multiplication crop is grown each year of all the cultivars in the G3 trials. This material is grown as a seed crop and inspected for all required pest and disease issues for the respective Australian states or countries that will receive the seed. This material is currently grown in the Toolangi Plant Protection District to ensure that all the imposed biosecurity measures are met.

Screening methods

The breeding program is currently screening the germplasm to describe the plant characteristics, tuber characteristics, marketable yield, disease symptoms, cooking response, specific gravity, dormancy, susceptibility to greening and bruising and marker-assisted selection for disease resistance.

Plant characteristics

The selections are assessed visually on emergence, plant structure and maturity.

Tuber characteristics

At harvest the tubers are assessed visually on a range of tuber characteristics that relate to the market use. These characteristics include shape, size, eye depth and brow prominance, heel depth, skin colour and texture, flesh colour, internal defects and the consistency of these characteristics. The cultivars are scored for these characteristics using the Breeder's Visual Preference (BVP) scale described below.

BVP scale

9	Size and shape uniform, shallow eyes and heel. Fresh market - bright skin. Good yield. No deformities, no internal problems, no issues.
8	Size and shape quite uniform, shallow eyes and heel. Fresh market - bright skin. Good yield. Deformities and issues rare, no internal problems.
7	Size and shape reasonably uniform, shallow eyes and heel. Fresh market - bright skin. Good yield. Few deformities or issues, no internal problems.
6	Size and shape regular, shallow to med eyes and heel. Fresh market - good skin. Reasonable to good yield. Occasional deformity or issue, no internal problems.
5	Size and shape slightly irregular, med eyes and heel. Reasonable yield. Some deformities or issues, no internal problems.
4	Size and shape irregular, deep eyes and heel. Moderate to reasonable yield. Some deformities, issues or internal problems.
3	Size and shape irregular, deep eyes and heel. Moderate to low yield. Number of deformities, issues or internal problems.
2	Size and shape irregular. Low yield. Number of deformities, issues or internal problems.
1	Size and shape irregular. Very low yield. Severe deformities, issues or internal problems.

Marketable yield

In the comparative replicated trial the marketable yield of the selections is compared against standard cultivars for the relevant market use. The number of tubers are counted that are in a number of size categories in order to determine total yield, marketable yield and the number of tubers per plant.

Disease resistance screening

While good hygiene practices are maintained at all times, minimal disease control is practiced in the screening trials in order to observe disease symptom expression. Plant foliage is assessed for early and late blight. Early blight regularly occurs at the field site, although late blight was observed in 2012. Tubers are visually assessed for common scab, powdery scab, black scurf, rhizoctonia, silver scurf and black dot.

Cooking

The cooking tests currently used are boiling, crisping and french frying. The colour of the fried product and its consistency from storage, along with the boiled tubers colour, after cooking darkening, sloughing and texture are all assessed.

Specific gravity

Specific Gravity is a measurement of the relative density of a substance compared to a reference substance. In the case of potato tubers, they are compared to the weight of the same volume of water, due to their water content. It is measured by weighing a sample of tubers in air and then under water, and it reflects the percentage of dry matter or total solids.

Dormancy

Dormancy of selections is measured by the number of days from harvest to sprout initiation. To assess dormancy, three tubers from each of the selections were stored at $12^{o}C$ immediately following harvest. Tubers were observed weekly, and dormancy was recorded as having broken when sprouting was detected in at least 2 of the 3 tubers. Dormancy can be very short (<30 days) to very long (>76 days), and was scored using the following scoring scale.

Dormancy scale

Dormancy	Number of Days After Harvest
Very short (VS)	< 30 days
Short (S)	31-45 days
Medium (M)	46-60 days
Long (L)	61-75 days
Very long (VL)	> 76 days

Greening

To determine the greening response of cultivars to light exposure, 10 medium size (200-250gm) tubers, 5 from both replicates were collected of each variety. The tubers were randomly arranged on a bench in a single layer and exposed to fluorescent lighting for a period of 72 hours. The level of lighting was similar to that of retail displays.

After exposure, the skin was lightly peeled away and the degree of greening just under the skin subjectively characterised and recorded as either: nil, weak, medium or strong. For each variety the number of tubers in each category was then multiplied by a weighting given to that category: 1 for nil, 2 for weak, 3 for medium and 4 for strong and then totalled. The following scale was then applied to rate the degree of greening in tubers on exposure to light for each cultivar.

Greening scoring scale

Totalled Score	Greening Reaction to Light
14 or less	Nil
15-18	Negligible to Weak
19-22	Weak
23-26	Weak to Moderate
27-30	Moderate
31-34	Moderate to Strong
35 or more	Strong

As well as a greening response, some cultivars (i.e. Coliban) develop a purpling of the skin from increased anthocyanin content, due to prolonged exposure to light. Purpling can also develop due to cold storage (ie at 4^{o}C) of tubers. When cultivars exhibited the purpling response, it was characterised as nil, weak, moderate or strong.

Bruising

Selections are hit with a known force to determine their susceptibility to bruising. The degree of blackspot bruising in the flesh is measured, as is impact or shatter bruising to the tuber surface.

The bruise test was conducted on 20 medium size (200-250gm) potatoes of each cultivar, selected at harvest from the G3 trials. After storage for one month under cool conditions, two impact sites were marked on each tuber using liquid paper, one at the stolon end, the other on one side. This mark allowed the impact site to be identified for peeling later. A 100gm steel sphere (2cm diam) was dropped vertically from a height of 30cm through a guide tube, the open end of which had been placed over each marked impact site. To determine the force of impact, a Techmark® instrumented sphere 100 (an impact recording device), registered an impact force of 190 x g (one g, or 'gravity', is the normal acceleration due to gravity, that is 9.8 m/s^2). Impacted tubers were then stored at 17^{o}C for 48 hours to allow development of bruising.

Shatter bruise was subjectively assessed using a severity of damage scale of 1 to 4, where 1 = nil, 2 = slight, 3 = moderate, and 4 = severe. The degree of blackspot bruise was scored using a scale of 1 to 4, where 1 = nil (no bruising evident at first peeling), 2 = slight (bruise removed with 2nd peeling), 3 = moderate (bruise removed with 3rd peeling), 4 = severe (bruise still present after 3rd peeling).

The following scale utilises the averaged score of 20 tubers tested to indicate the susceptibility of a cultivar to both types of bruising.

Bruising scale

Averaged Score	Susceptibility
1 - 1.1	Nil
>1.1 - 1.5	Negligible to Slight
>1.5 - 2.0	Slight
>2.0 - 2.5	Slight to Moderate
>2.5 - 3.0	Moderate
>3.0 - 3.5	Moderate to Severe
>3.5	Severe

Marker-assisted selection

Leaf samples were collected from each selection for DNA analysis for the presence of molecular markers indicating genes for resistance to potato cyst nematode (PCN), Verticillium wilt, *Potato virus Y* (PVY) and *Potato virus X* (PVX).

Results

Separate Programs

In 2007/08 there were 7 programs running separately. At the end of that year 2 programs ceased due to their own reasons. One company was sold and changed priorities, while the second program was funded by an industry group and felt that it should be privately funded. From 2008/09 to 2010/11 there were five programs running. In 2011/12 a sixth program commenced.

Trials

The program conducted the following trials.

2007/08

- Crossing program
- Glasshouse seedlings (08 series)
- Field seedlings (07 series)
- Selection plots (06 series)
- Replicated comparative trials (05 series)

2008/09

- Crossing program
- Glasshouse seedlings (09 series)
- Field seedlings (08 series)
- Selection plots (07 series)
- Replicated comparative trials (06 series)

2009/10

- Crossing program
- Glasshouse seedlings (10 series)
- Field seedlings (09 series)
- Selection plots (08 series)
- Replicated comparative trials (07 series)

2010/11

- Crossing program
- Glasshouse seedlings (11 series)
- Field seedlings (10 series)
- Selection plots (09 series)
- Replicated comparative trials (08 series)

2011/12

- Crossing program
- Glasshouse seedlings (12 series)
- Field seedlings (11 series)
- Selection plots (10 series)
- Replicated comparative trials (09 series)

All investing companies were invited to attend the harvest of their G2 and G3 trials.

Annual Reports

The results from the trials have been reported to the investing companies in the annual reports from the program. These following annual reports on the program are appended to this final report. The front part of each report is available to everyone, while the trial data remain in strict confidence.

1. Slater, T., Wilson, G., Lauder, S. and Verstraten, M. (2008). National Potato Breeding Program trials 2007/2008. Department of Primary Industries. Toolangi.
2. Slater, T., Wilson, G., Lauder, S. and Verstraten, M. (2009). National Potato Breeding Program trials 2008/2009. Department of Primary Industries. Toolangi.
3. Slater, T., Wilson, G., Schultz, L., Cogan, N., Forster, J. and Verstraten, M. (2010). National Potato Breeding Program trials 2009/2010. Department of Primary Industries. Knoxfield.
4. Slater, T., Wilson, G., Verstraten, M., Schultz, L., Cogan, N. and Forster, J. (2011). National Potato Breeding Program trials 2010/2011. Department of Primary Industries. Knoxfield.

The annual report for the 2011/2012 season's trial is due to be distributed in July/August 2012.

Distribution of advanced selections

Each year following the G3 trial, the results were analysed by the breeding program and the investing companies, the superior advanced selections were distributed to the companies for evaluation under commercial conditions. The program distributed the following number of advanced selections in the respective years from this project.

- 2008: 70 genotypes were distributed to seven groups
- 2009: 39 genotypes were distributed to five groups
- 2010: 53 genotypes were distributed to five groups
- 2011: 55 genotypes were distributed to five groups

Commercialisation and commercial progression

During this project 25 cultivars have been placed into tissue culture for progression to extensive commercial trials and commercial production. Currently there are 6 cultivars that have excelled and are at the following stages of commercialisation:

- 03-19-03 is a fresh market cultivar that is currently on the increase. 30 tonnes were harvested this year, and this is anticipated to increase to 130 tonnes next year and 400 tonnes the following year.
- A crisping cultivar, 04-128-09, has been performing excellently as an Atlantic replacement when both freshly harvested and from storage and is processing superior to any other cultivar. There are currently 20 tonnes of this cultivar's seed in advanced trials.

- There are two niche market coloured flesh cultivars, that are due to be launched in the supermarkets next Autumn.
- A French fry cultivar, Mirridong, grew and processed well, but failed when it was placed into long term storage due to storage rots. At the time it was abandoned there was approximated 7,000 tonnes in production.
- A processing company is progressing two promising crisping cultivars. There are currently approximately 20 tonnes of each at the G3 seed multiplication stage.
- R2D2 is a fresh market cultivar which has a route to market for the washed and brushed market. It has performed well in commercial trials and there will be 70-80 tonnes of G3 seed available to plant next season

The companies that are commercialising these cultivars are enthusiastic about the opportunities these cultivars present, and consider that a number will have strong commercial uptake. The majority of these companies are also committed to the future development of improved cultivars to address further issues that the potato industry faces.

Discussion

As a result of the last five years work, potato breeding in Australia has changed. It used to involve walking through the paddock making notes, comparing characteristics of potential new cultivars from parents that had been combined by the breeder's intuition or curiosity. Numbers and population size used to matter in the search to find a superior cultivar.

Now the populations are designed and tested to determine the better families, parents and cultivars. This change is due to a better understanding of potato genetics, the genetics and biology of the traits, quantitative genetics and molecular genetics. Now numbers and program size are no longer as important. Computing and technological advances developed in the pre-breeding program are now far more important, and have been adopted to modernise the conventional breeding program. The program is now in a position to continually improve cultivars and build significantly on previous efforts.

Trial progress

The program has completed all the glasshouse and field trials needed to run the potato breeding program. At the start of the program the material advancing through the program was aligned with the companies and syndicates breeding priorities. When new instructions were provided by the companies that the breeding program had not previously been targeting, the crossing program addressed these aims in the first year and the material had progressed to the third field generation in the last season of the five year program. This illustrates that the five year time frame for this project was appropriate.

On average the program has distributed approximately 50 cultivars per year for commercial evaluation by the investing companies. This amounts to 217 over the first four years, with this season's cultivars still to be identified by all the companies.

The commercial evaluation of these cultivars is now the responsibility of the investing companies, and this is also showing progression as 25 cultivars have been placed into tissue culture for advanced evaluation.

Unfortunately not all of the commercial evaluation trials have been run successfully and support should be provided to these companies to ensure they are successful. This support could be in the form of financial support to employ a consultant to run the trials. The support could be in the form of training on trial design and data analysis. Alternatively this support could come from the breeding program, and this would have further advantages as the data could be then analysed as a multi-environment analysis, which could identify widely adapted germplasm.

Adoption of new techniques

This program is strongly linked to the pre-breeding program, so during the last five years as molecular markers were validated for important traits, they were immediately adopted. Over the last two seasons the material progressing through the G2 and G3 trials has been screened with markers for potato cyst nematode (PCN) resistance and Verticillium wilt resistance. During the last season they were also screened with markers for *Potato virus Y* (PVY) and *Potato virus X* (PVX) resistance.

Over the duration of the pre-breeding project, the project was investigating the quantitative genetic control for complex traits, such as BVP, yield and cooking performance. This has included investigating modern selection theories, cross generation prediction and the development of estimated breeding values for traits of interest. From this research, the predicted rates of genetic gain have also been calculated and will double from the start of the current project. This could see the gain for just one important trait such as yield in the vicinity of 9 tonnes per hectare per year, if we selected on yield alone.

The breeding program is about to adopt the developed analyses for annually calculating estimated breeding values to identify superior parents and individuals to progress to the next trials. The program will also alter selection rates within each trial to maximise genetic gain for these traits.

Potato breeding model

The model for breeding potatoes in Australia has undergone a number of changes over the last decade. These changes have been in line with the international transition from public to private cultivars. There is a recognition, by most, that breeding is essential for the continuous improvement that is needed, but it is a long term activity, and needs to be properly funded. Plant Breeder's Rights Legislation has been adopted by a large number of countries for the protection of cultivars, which allows breeding companies and investors to obtain a royalty on cultivars to obtain this necessary funding.

The transition has also been due to various countries analysing the role of government and private investment in Research & Development activities. Specifically in plant breeding there has been a recognition that the development of commercial cultivars should be funded by private investment or by royalty return. Internationally, potato breeding has undergone this transition in almost every developed country.

In Australia, this transition started over 10 years ago and took another step 5 years ago when this project was required to find the funding for commercial breeding from companies that had a vision for the future of the potato industry through cultivar development. This was achieved from eighteen companies, and at this point the next generation of cultivars are progressing well towards being commercially available, through these companies' endeavours. The rest of the potato industry should appreciate their foresight and investment or business acumen. Either way, new cultivars are being developed for Australia.

If the predicted results of the genetic research in the pre-breeding project are realised, another phase could develop. The alteration in the selection rates could change the necessity of having the breeding and early generation selection at a single central site, to a model where companies could undertake the early field generation trials locally in their own districts, but under the guidance and analysis of the central program with good science support. This would see the future development of cultivars suitable to anywhere in Australia, the development of market driven improved cultivars, and the development of cultivars that would still be productive if the predicted changes to the climate occur. It would also enable programs to be run in states such as Tasmania and Western Australia, without the current biosecurity constraints that restrict the entry of potatoes.

Industry interaction

Current investors

The breeding program has had a varied level of interaction with the current investors, depending on the investors level of interaction. It has ranged from attending annual meetings to frequent phone conversations and email correspondence. The investors or their representatives attended most G3 trial harvests, and some of the G2 trial harvests. Over the course of the program, the breeding program has endeavoured to seek direction and feedback in order to closely address the investor's priorities and develop cultivars suitable for each company. The breeding program has also provided regular updates on the progress of the pre-breeding research.

Evaluators

The breeding program has endeavoured to have an annual meeting with companies who are continuing to commercially evaluate cultivars developed under the previous project, even though they are not investing in this project. This has been done to understand the progress on the evaluation of these cultivars, either to commercialisation or rejection. These evaluations have been successful in some circumstances, but not in others.

Non-involved industry members

There has been less interaction with non-investing members of the potato industry than in the past, although the program has endeavoured to write articles for Potatoes Australia, and speak at events when invited, to keep those members informed of the progress.

International benchmarking

As the pre-breeding program has sought to develop molecular marker-assisted selection techniques, the program has attended the most important scientific conferences for the potato research community, in particular the last two European Association for Potato Research Trienniel conferences. During these opportunities, we have visited breeding programs in the United Kingdom, France, New Zealand, the United States of America. We have also discussed breeding methodologies with potato breeders from a number of other countries, including Ireland, Canada, the Netherlands, Denmark, Norway and Poland. As well as investigating the most advanced selection techniques in potato breeding, we have also looked at techniques used in other crops and livestock breeding. Due to this benchmarking and the adoption of the most up to date techniques, the breeding program is now a world class program, and more advanced in our techniques than most other programs.

Benefits to the Australian potato industry

The investors will benefit by the development of cultivars that are specifically designed for their markets, that are superior in performance, or will overcome problems that current cultivars experience. This will enable them to market the new cultivars into the mainstream or niche markets depending on their design. Alternatively, these new cultivars could be more productive or resource efficient, thus reducing the cost of production. The cultivars could also be more tolerant of abiotic stresses, and thus be able to still be productive in marginal production areas or with predicted changes in the climate.

There are potentially some huge gains to be made if successful new cultivars are developed:

- A new French fry cultivar to replace Russet Burbank could reduce farm wastage by 20% and factory wastage by 15%.
- A new Crisp cultivar to replace Atlantic will reduce on-farm storage waste by 15% and factory waste by 5%.
- A new fresh white cultivar that is resistant to cracking in winter will reduce on-farm waste by 25% over the period of May to August
- A fresh white cultivar that is resistant to Black dot will reduce farm waste by 50% over the period January to May and September to November.

There will also be flow-on benefits to non-investing members of the industry. Members in the supply chain of the investing companies will also have availability to the new superior cultivars. This will ensure that their businesses remain viable and retain or grow markets.

There will also be further flow-on benefits to the Australian industry by understanding the biology and genetics of important traits for the Australian industry. This has already led to the identification of the PCN pathotype that is in Australia, and the publication of a list of resistant cultivars to this pathotype. It will also lead shortly to an understanding of why there has been a recent outbreak of PVY, and the publication of a list of resistant cultivars. This information will enable growers to use resistant cultivars as part of their management strategy, even though these growers have not invested to have improved cultivars bred specifically for them.

As some of these results have already been published in international scientific journals, and further publications are planned, progressive international breeding programs will adopt our findings. Results and techniques published in 2011, have already been adopted in the United Kingdom and North America. Therefore this work will have benefits to any company that is interested in new cultivars, even if they are developed elsewhere.

Technology Transfer

The breeding program has actively promoted the work that is occurring in the program in various ways. The program has been visited by a large number of industry participants from various sectors in the potato industry, including processors, wholesale packers and growers. The program has also been visited by representatives from companies and potato breeding programs in New Zealand, France, and Scotland.

The program has also presented talks at meetings and field days, so that the work in the program can be presented to a wide audience within the industry. This has also included presentations at the 2010 Potato Industry Conference in Geelong.

Tony Slater also attended four international conferences and transferred the information learned to the breeding team, through an article in Potatoes Australia, and to the investing companies through the annual meetings. These conferences included attending two European Association for Potato Research Trienniel conferences in 2008 and 2011, which are the most important potato scientific conferences held.

The program has actively published articles in industry magazines, newsletters and conference proceedings. The list of articles published from the Potato Breeding Program during projects PT07017 and PT08033 follows:

1. Slater, T., Wilson, G. and Lauder, S. (2007). National Potato Breeding Program trials 2006/2007. Department of Primary Industries. Toolangi.
2. Slater, T., Wilson, G., Lauder, S. and Verstraten, M. (2008). National Potato Breeding Program trials 2007/2008. Department of Primary Industries. Toolangi.
3. Slater, T. (2008). New Potato Varieties – Three new fresh potato cultivars for potential commercial release. *Potatoes Australia*. August. p 28-29.
4. Slater, T., Milinkovic, M., Brown, P. and Kirkham, J. (2008). The European Potato Conference. *Potatoes Australia*. October. p 30-31.
5. Slater, T. (2009). Program breeds new cultivars for industry. *Potatoes Australia*. February. p 32-33.
6. Slater, T. (2009). Resistance is essential. *Potatoes Australia*. June. p 30-33.
7. Slater, T., Wilson, G., Lauder, S. and Verstraten, M. (2009). National Potato Breeding Program trials 2008/2009. Department of Primary Industries. Toolangi.
8. Slater, T. (2009). Moving to private funding for breeding. Potato industry report 08 – 09. p7.
9. Slater, T. (2009). Better screening for desirable traits. Potato industry report 08 – 09. p15.
10. Milinkovic, M., T. Slater and B. Rodoni. (2009). Screening for Tomato spotted wilt virus resistance in potatoes. Proceedings of the 9th International symposium on Thysanoptera and Tospoviruses.
11. Slater, T. (2010). Breeding Better Potatoes. *Potatoes Australia*. June/July. p 20-21.
12. Slater, A.T., Schultz, L., Cogan, N.O.I., Forster, J.W., Rodoni, B. and Milinkovic, M. (2010). Developing molecular genetic marker technology capability to enhance Australian potato breeding. Proceeding of "Potato breeding after the completion of the DNA sequence of the potato genome". p 43. Wageningen. The Netherlands.
13. Slater, T., Wilson, G., Schultz, L., Verstraten, M., Cogan, N., Rodoni, B., Milinkovic, M. and Forster, J. (2010). Australian Potato Breeding Program – Outcomes for Industry. Proceedings of "2010 Potato Industry Conference". pp 23-25. Geelong.
14. Slater, T. (2010). Molecular tools improve breeding and identify cultivars. *Potatoes Australia*. August/September. p 12-13.

15. Slater, T., Wilson, G., Schultz, L., Cogan, N., Forster, J. and Verstraten, M. (2010). National Potato Breeding Program trials 2009/2010. Department of Primary Industries. Knoxfield.
16. Slater, A.T., Schultz, L., Cogan, N.O.I., Forster, J.W., Rodoni, B. and Milinkovic, M. (2010). Developing molecular genetic marker technology capability to enhance Australian potato breeding. *Potato Research.* **53:** 216.
17. Schultz, L., Milinkovic, M., Rodoni, B., Cogan, N.O.I., Forster, J.W. and Slater, A.T. (2010). Development of a robust screening method for Tomato Spotted Wilt Virus infection in Potato. *Potato Research.* **53:** 246.
18. Schultz, L., Cogan, N.O.I., Forster, J.W. and Slater, A.T. (2010). Development and optimization of a genetic identity kit for Australian potato germplasm. *Potato Research.* **53:** 246-7.
19. Schultz, L., Cogan, N.O.I., Forster, J.W. and Slater, A.T. (2010). Evaluation and optimization of the TG689 marker linked to PCN resistance. *Potato Research.* **53:** 247-8.
20. Slater, T. (2010). Developing molecular tools to enhance breeding. Potato Industry Annual Report 2009/10. p 6.
21. Slater, T. (2010). New Australian-bred fresh potato cultivars for commercial release. *Potatoes Australia*. December. p 27.
22. Slater, T. (2011). Cold sweetening resistance – the holy grail for a storage cultivar. *Potatoes Australia*. February. pp 26-27.
23. Slater, T., Wilson, G., Verstraten, M., Schultz, L., Cogan, N. and Forster, J. (2011). National Potato Breeding Program trials 2010/2011. Department of Primary Industries. Knoxfield.

The program has also published two papers in peer reviewed scientific journals:

1. Faggian R, Powell A, Slater A.T. (2011) Screening for resistance to potato cyst nematode in Australian potato cultivars and alternative solanaceous hosts. Australasian Plant Pathology:1-9.
2. Schultz L, Cogan N.O.I, McLean K, Dale M.F.B, Bryan G.J, Forster J.W, Slater A.T (2012) Evaluation and implementation of a potential diagnostic molecular marker for *H1*-conferred potato cyst nematode resistance in potato (*Solanum tuberosum* L.). Plant Breeding 131:315-321.

Recommendations

Over the last 5 years the breeding program has operated under the model proposed by the two reviews of the program (Brennan et al., 2004, DArT, 2006). This required commercial investment for the development of improved cultivars, while levy funds have been directed to a pre-breeding focus to develop techniques and understand the biology and genetics of important traits.

The program has benefited from the direct involvement of the investing companies providing a commercial focus for the development of improved cultivars. In return the interaction has enabled the rapid transfer of superior genotypes to the companies for commercial evaluation. This interaction needs to continue in order to rapidly develop improved cultivars for the Australian industry. An improvement to this current model would be for greater support for the commercial evaluation of the superior cultivars, as this phase is now the sole responsibility of the commercial entities, who will have varying levels of experience to do this job. HAL or the breeding program should have a role in this phase. This role would then ensure that the evaluations are conducted with good trial design and data capture. The collection of this data will also provide guidance to the program and enable a genotype by environment analysis to be conducted. It is also important to support the commercial entities to ensure that they are trained in IP protection, in order to protect their investment in the new cultivars.

As there have been regular meetings with the commercial investors, as the new techniques have been developed in the pre-breeding project, the companies have welcomed and readily adopted the new technologies. Over the last two years, this has seen the identification of PCN and PVY resistant cultivars that are within the breeding populations.

As Tony Slater and Lee Schultz attended and presented papers at International conferences as part of the pre-breeding program, they visited potato breeding programs in Europe and the USA. We discussed various breeding techniques and have adopted the most advanced techniques. We have also investigated selection strategies used in livestock breeding in order to improve selection strategies for complex traits, such as breeder’s visual preference, yield and cooking performance.

From this work we have developed estimated breeding values for these traits, and we now understand their heritability and can predict the expected rate of genetic gain for these traits. The breeding program will now use these calculations to identify which parents to combine and to alter selection rates between generations to maximise genetic gain for these traits. With these changes it is expected that the rate of genetic gain will double, and that the gain for an important trait such as yield could be as much as 9 tonnes per hectare per year.

These findings could change the necessity of having the breeding and early generation selection at a single central site, to a model where companies could undertake the early field generation trials locally in their own districts, but under the guidance and analysis of the central program with good science support. This would see the future development of cultivars suitable to anywhere in Australia, the development of market driven improved cultivars, and the development of cultivars that would still be productive if the predicted changes to the climate occur. It would also enable programs to be run in states such as Tasmania and Western Australia, without the current biosecurity constraints.

Attending international potato research conferences has provided good benchmarking of the potato breeding program and the opportunity to visit other breeding programs. This has also ensured that the program has been able to adopt the most up to date techniques. It is highly recommended that attendance at these conferences is continued by a member of the breeding team and / or other potato researchers and that the findings from the conferences are communicated to the Australian potato research community and industry.

Finally, it is recommended that these advances and opportunities be communicated to the Australian potato industry, through a series of articles in Potatoes Australia, through the HAL extension program, and by presentations at various potato industry events.

Acknowledgements

We would like thank the following people for their involvement and input into the trials;
Julie Blackmore, Larissa Coridas, Barry Coyle, Lyn Craigie, Wayne Duff, James Fewster, Carol Gallagher, Donna Garlick, Carol Gaudion, Graeme Gooding, Brian Hillary, Jill Hillary, Dan Hobbs, Doug Jeffery, Sherilyn Lauder, Leonie Lorenze, Motiul Quader, and Scott Robins, Gordanna Saric, Brenda Stritch, Jamie Stritch, Leanne Uren and Rory Verstraten,

We thank the pre-breeding team of Lee Schultz, Maria Lombardi, Noel Cogan, John Forster Ben Hayes, Brendan Rodoni, Mirko Milinkovic, Linda Zheng and Rob Faggian for their enthusiasm and application into developing the advanced computing and molecular genetic techniques.

We would like to thank Keith Blackmore from ViCSPA for inspecting and monitoring our seed multiplication and G3 trials. Thanks also go to Brendan Rodoni and Chris Bottcher for help with virus management. We also thank Dolf deBoer and Mirko Milinkovic for inspecting our seed crop this year.

Our disease screening trials were conducted with the assistance of Brendan Rodoni, Mirko Milinkovic and Chris Bottcher.

We would also like to thank Fiona Thomson and Debra Partington for biometric support.

Most importantly we would like to thank the companies who invested in this project for their foresight and their key personnel who came to participate and evaluate their G2 and G3 trials.

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