Summary
The Australian Durum Wheat Improvement Program (ADWIP) was initiated in 2007 to merge the ongoing durum breeding program in the New South Wales Department of Primary Industries (NSW DPI) and The University of Adelaide (UA) program into one publicly funded, collaborative program with a national outlook. The project has strong leadership and communication throughout the breeding chain, including pre-breeding research, breeding, variety commercialisation and uptake by growers and use by consumers. The project has developed and released Jandaroi\textsuperscript{P} and Caparoi\textsuperscript{P} (Northern Zone) and Tjilkuri\textsuperscript{P} (Southern Zone). These varieties have enhanced the quality and productivity of the durum industry in both regions and supported local pasta manufacturers, millers and exporters.

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Conclusions

The main conclusions from this project are:

1. The project was successful in establishing ADWIP as a national durum breeding program. This has developed into an efficient and collaborative program. The nodes have their own well defined agro-ecological zones that need specific traits for adaptation. The varieties released to date are well suited for the Australian durum industry and have raised the profile of the breeding program.
2. Significant gains in yield potential (more than 10%) have been achieved during this project relative to the benchmark varieties in both the regions. Further improvements are possible through the use of diverse germplasm in crosses, better selection strategies and improved adaptation.
3. Yield gains have been achieved without loss of quality standards and, as a consequence, Australian durum grain is still sought by European buyers. New varieties in the immediate future could offer improvement in semolina colour and grain size.
4. Increased tolerance to crown rot (CR) has been achieved in Caparoi and some advanced lines relative to EGA Bellaroi. Continued improvements in this regard are very important for the durum industry.
5. The new varieties have strongly benefited the local durum industry including millers and pasta makers, some of whom are offering area contracts to encourage production.

Recommendations

The following recommendations from the project are intended for current and future pre-breeding projects that aim to provide new traits to the durum program:

1. Crown rot (CR) tolerance is vital for consolidation and further growth of the durum industry especially in the Northern Zone. Crown rot is a complex disease and hence it is hard to characterise tolerance. Pre-breeding for CR should be aligned with the breeding programs with full involvement of breeders so that any new tolerant lines are properly characterised, not only for CR tolerance but also agronomic traits and used efficiently in variety development.
2. With the effects of climate change being increasingly felt in durum growing regions, adaptation to early sowing, heat and drought stress will be more important. Consideration should be given to funding germplasm development for these traits.
3. Although there is good tolerance to all three rusts (leaf, stem and stripe) in the current durum varieties, it is important to obtain good characterisation of the genes conditioning this resistance and work towards anticipatory breeding for races of leaf and stem rust in overseas countries to which Australian varieties are susceptible.
4. Collaborative work with the international centres, the International Centre for Agricultural Research in the Dry Areas (ICARDA) and the International Maize and Wheat Improvement Center (CIMMYT) under the CIMMYT-Australia-ICARDA Germplasm Evaluation (CAIGE) project (which provide the best source of exotic germplasm) should continue and this project should specifically include durum which is currently not the case.
5. Semolina yield is a trait that durum millers would like to see improved. This trait is very difficult to measure and needs a
separate pre-breeding project to investigate screening procedures and examine the genetic variation for the trait.

**Outcomes**

**Economic**

ADWIP has provided significant and measureable benefits by developing and releasing improved varieties for both the Northern and Southern Australian durum zones. The benefits for the Northern Zone include earlier maturity, improved yield and quality, superior adaptation and increased CR tolerance relative to Wollaroi\(^6\). For the Southern Zone, the new varieties have provided improved yield, better adaptation to edaphic stresses and clearly superior quality traits such as high yellow pigment levels relative to Tamaroi\(^6\). National Variety Trial (NVT) results (averages of 2009-2011) have indicated 10.3% improvement in yield from new varieties compared with Wollaroi in the Northern Zone and 12% yield improvement over Tamaroi in the Southern Zone. This represents substantial benefits to the 500,000t durum industry.

The improved quality and productivity of durum varieties has provided support to local millers and food manufacturers such as Bellata Gold, Weston Milling and Manildra in the Northern and San Remo in the Southern GRDC regions.

**Environmental**

One aspect of the new varieties from the Northern Zone is their capacity to accumulate higher levels of protein in the grain without the need for extra fertilisers and nitrogen management. This has resulted in reduced environmental impact.

**Social**

The social benefit of new durum varieties is their role in sustaining local production of high quality durum grain for local pasta manufacturers, millers and exporters which generate a significant number of jobs in mills, pasta factories and grain handling facilities.

**Achievements/Benefits**

**Background**

Durum wheat (*Triticum turgidum*), also known as pasta wheat, is a highly valued type of wheat known for its hardness, higher protein content, yellow colour, nutty flavour and excellent cooking quality. It is different from common bread wheat (*Triticum aestivum*) in that it has 28 chromosomes compared with 42 in bread wheat. Durum wheat has been produced in Australia since the 1930s. It has been traditionally grown on the fertile vertosols of northern New South Wales (NSW) and southern Queensland (QLD) that are capable of producing high quality Prime Hard bread wheats. However, in recent decades, the crop has spread to South Australia (SA) and Victoria (VIC).

By world standards durum grain from Australia is characterised by high levels of hard vitreous kernels (HVK), high protein content, very high levels of yellow pigment combined with strong and stable dough properties required for high quality pasta manufacture. Approximately 127,000ha are planted annually to durum in the Northern Zone producing 256,000t grain (10 year average). Most of the Northern Zone crop is exported to Italy for premium pasta making. Currently, the Southern Zone focuses on the domestic market, with growers producing high quality grain to supply the largest domestic pasta manufacturer (San Remo). The current size of the Southern Zone durum industry is approx. 70,000ha producing 220,000t grain. Currently, Australia exports 222,300t of durum annually (to Italy, North Africa and South America), but there is significant potential for expansion of durum exports to the European, Middle Eastern and Asian markets.

Durum breeding began in NSW DPI in the 1930s at Glen Innes Experiment Farm and was transferred to Tamworth after the Second World War. Under the leadership of Dr. Ray Hare, this program has released a number of significant varieties (Kamilaroi\(^6\), Yallaroi\(^6\), Wollaroi\(^6\), EGA Bellaroi\(^6\)) since the 1980s that increased grain yield, grain quality and pasta making quality and brought international attention to Australian durum grain.

A secondary breeding and evaluation program began at the University of Adelaide Waite Agricultural Research Institute under Dr. Tony Rathjen's leadership in response to local demand for durum production. This program released Tamaroi\(^6\) and Gundaroi jointly with the NSW DPI program and Hyperno\(^6\), Kalka\(^6\) and Saintly\(^6\) in later years.

The University of Adelaide Waite Institute program was merged into Australian Grain Technologies (AGT) but by 2007 AGT discontinued the program and transferred the germplasm to NSW DPI to form the current Australian Durum Wheat Improvement Project (ADWIP).
On the basis of the improved varieties from the breeding programs, the industry reached a total production of 796,283 tonnes in 2001/02 raising hopes that it would reach one million tonnes and stabilise at that level. However, a series of drought years, lower prices, marketing issues and susceptibility to CR has resulted in a decline of production to current levels of 450,000-500,000 tonnes.

Objectives
The main objective of the project was to organise durum wheat breeding on a national basis and provide new varieties to the durum industry that maintain the world class quality of Australian grain and provide growers with improvements in yield and disease resistance.

Specific objectives were:

- Establishment of an integrated publicly funded durum wheat breeding program that is national in outlook, collaborative in nature, commercially focussed, market driven, has effective leadership, has effective linkages between and communicates well along all segments of the breeding chain.
- Development of new export quality durum varieties with adaptation to NSW and southern QLD with better grain yield than Wollaroi and comparable to EGA Bellaroi for quality.
- Development of new varieties superior to Tamaroi and Gundaroi to increase production in southern Australia for domestic requirements and export markets with increased CR resistance, improved semolina colour, improved adaptation to southern Australian soil types, maintenance of other quality attributes and adequate resistance to rusts and other diseases.

Project achievements
1. Establishment of the Australian Durum Wheat Improvement Program (ADWIP)
   ADWIP was successfully established with funding from this project to continue breeding work in Tamworth and Adelaide. There have been staff changes with the retirement of Drs. Hare and Rathjen and resignations of Mr. Quinn and Dr. Collard but now there is stable leadership nationally and for both nodes under Drs. Kadkol and Able. ADWIP has been managed through an Advisory Board and the Operations Committee. The Advisory Board set the overall policy and made major commercial decisions. It included one representative each from NSW DPI, UA and GRDC. The Operations Committee included program leaders of the Northern (Dr. G. Kadkol) and Southern (Dr. J. Able) Nodes, Northern Farming Systems research leader, NSW DPI, (Dr. G. McMullen) and key ADWIP scientists (Dr. M. Sissons, Leader, Durum Quality, for both nodes; and Professor D. Mather, Leader, Molecular Markers, for both nodes).
   Technical operations of ADWIP have been overseen by the Operations Committee which met face to face once a year and by teleconference as and when required. This committee was the main forum for information exchange within ADWIP.
   The project has been collaborative with free exchange of information, breeding material and germplasm, and collaborative research projects including student projects. For example, there are currently two masters students, Mr. Salum Harnad and Mr. Domenico Deserio, whose project has involved both nodes. Industry meetings and important field days arranged by one node have been attended by key members of the other node.
   The project is national in its outlook and the molecular and grain quality laboratory facilities are used for the benefit of both nodes. The project has also been market driven and conducted regular meetings with industry stakeholders, known as Durum Industry Advisory meetings.
2. Development and release of new export quality durum varieties for Northern Zone
   Two export quality durum varieties, Caparoi and Jandaroi, have been released from the northern node during this project. These varieties have continued the quality standards of EGA Bellaroi and combined better adaptation and yield potential and crown rot tolerance.
   Jandaroi was released in 2008 as an early maturing variety for QLD and for planting late in NSW. This variety currently has 35% market share in 2011 Graincorp receivals. Jandaroi is reputed to produce very high grain protein content together with very high dough strength even under irrigation.
   Caparoi was released in 2010 as a medium maturity variety for the Northern Zone. Its grain quality is similar to EGA Bellaroi with 6% higher yield while in the 2011 NVT, it yielded 10% higher than Wollaroi. Field data have shown Caparoi to be
significantly more tolerant to crown rot than EGA Bellaroi. Caparoi yields consistently in both dry and wet seasons.

3. Development and release of varieties for SA

Tjilkuri\(^{(1)}\) was released in 2010. It has moderate early vigour with improved grain yield and semolina quality over other varieties such as Tamaroi. Tjilkuri is widely adapted to South Australian soils and yields well in both dry and wetter seasons. It outyielded Tamaroi by 6% overall in 2011 SA NVT. Tjilkuri has good grain weight, similar to Kalka and low screenings compared with Hyperno and Saintly. Uptake of this variety in SA will continue to grow but is currently estimated to be 5-10% as of 2012.

Two further varieties which have been developed under ADWIP are WID802\(^{(2)}\) and Yawa\(^{(2)}\) (WID803). Yawa is a well adapted, very high yielding durum wheat suitable for production in most areas of southern Australia with significant yield advantage over existing durum varieties. Over three years of NVT data, Yawa has outyielded Hyperno by 5.4-13.3%. WID803 may have higher levels of screenings and a smaller grain size. This is somewhat dependent on the district in which it is sown, whether it is sown late and if there is a tight finish to the season. WID802 is also well adapted to southern Australia and has been targeted as a variety for expansion in the south-east and Wimmera region of VIC. While its yield potential is not as high as Yawa, it is nonetheless comparable to Hyperno. Grain weight is good and screenings are low compared with Hyperno or Yawa.

4. Improved germplasm

A. Improved yield potential. Breeding and selection during the project period in the Northern Node has resulted in germplasm that is significantly higher yielding than Wollaroi/EGA Bellaroi in the Northern Zone and Tamaroi/Kalka in the Southern Zone. Results from 2011 NSW NVT have indicated a 10% yield improvement in Caparoi over Wollaroi and a 6% yield improvement over EGA Bellaroi whilst maintaining the quality standards set by EGA Bellaroi. The new NVT entries represent a further 6% yield improvement over Caparoi based on internal results. Similarly, in the Southern Node program significant improvements have occurred in yield potential with new lines showing up to 6% yield superiority over Hyperno and up to 10% superiority over Tamaroi in the 2011 SA NVT.

B. Improved quality. Improvements in grain quality over the project period in the Northern Zone have included increased grain size and increased expression of yellow pigment levels relative to EGA Bellaroi. \(b^*\) (a measure of yellow pigment) values up to 3.5 units better than EGA Bellaroi have been recorded on the advanced lines. Thousand grain weight data have shown up to 3g improvement in the advanced lines over EGA Bellaroi. Significant improvements have also been achieved in the Southern Node with Yawa giving much higher pigment levels relative to Tamaroi and UAD1051096 giving significant improvement in thousand grain weight and screenings.

C. Improved adaptation. Breeding and selection in the two nodes over the project period have resulted in material that is adapted to drier conditions and to various edaphic stresses in the southern region. Caparoi has shown superior performance in drier conditions relative to Wollaroi and EGA Bellaroi and is also a high yielder under wet conditions. The new varieties from the Southern Node are well adapted to mineral deficiencies and other stresses due to poor soils in that zone.

5. Involvement in decisions made by ADWIP

The project provided technical advice to the ADWIP Board through the Operations Committee and helped the Board make commercial decisions.

6. Durum Industry Advisory (DIA) meetings

The project has set up DIA meetings in both zones which are attended by all durum industry stakeholders and provide feedback to the breeding programs. In the Northern Zone, these meetings have also helped organise durum growers and highlight industry issues.

Benefit to durum industry

New varieties are a key benefit to the durum industry. The release of Jandaroi and Caparoi has provided much needed improvement in yield and adaptation over Wollaroi and EGA Bellaroi which have the reputation of adaptation to good moisture and extreme susceptibility to crown rot. These varieties are providing greater returns for growers through increased yield and improved tolerance to biotic stresses. The observed 10.3% yield increase over Wollaroi (based on three years of NVT data) over 100,000 ha and average yield of 2.5 tonnes using a durum 1 (DRI) price of $385/tonne will be worth $9.9 million to growers annually. Similarly, the 12% yield increase in the southern region over 70,000ha would be worth $8.1 million. Such improvements in productivity without negative effects on quality achieved by ADWIP are very important in maintaining the...
place of durum in Australian agriculture and international markets.

Another significant benefit to the industry from the new varieties is increased interest and confidence amongst growers in durum cropping. This is difficult to quantify but is important.

**Other research**

The R&D opportunities identified in the project include the following:

1. Improvement of CR tolerance: CR is a complex disease and in durum wheat it interacts strongly with drought tolerance of the host varieties. The interaction with moisture stress has not been studied in detail and is poorly understood. There is also a perception that there is no genetic variation for CR tolerance in durum. There is a strong need to generate data to assess this aspect of research.

2. Genetic variation for resistance to rust diseases in durum germplasm: While durums are largely resistant to the three rusts, this could change due to new races arising from mutations and introductions. It is important to understand the genetic basis of the current resistance, variation in germplasm collections and to pyramid new genes into durum varieties.

3. Genetic basis of root lesion nematode (RLN) resistance and tolerance in durum: Durums are generally resistant and tolerant to RLN and this is a natural advantage for the crop in the Northern Zone. It is important to understand this resistance and maintain it in new varieties.

4. Effect of lipoxygenase (LOX) on stability of yellow pigment: Characterisation of the importance of LOX in Australian durum and optimisation of a protocol for marker based screening for the trait are important to enhance the quality of Australian durum grain. There is genetic variation for the trait in Australian durum but the current varieties are heterogeneous for the trait.

5. Alternative dwarfing genes: The current Australian durums are based on the Rht1 gene which is considered to have a negative influence on spikelet fertility and coleoptile length. Genes such as Rht18 might offer an opportunity to improve on these disadvantages from Rht1.

6. Semolina yield: Research on developing a rapid screening assay for milling yield for use in early generation is needed. A better understanding of the fracturing of durum grains in milling to improve semolina milling yield is also desirable since there has been no improvement in this property since the introduction of Kamilaroi. Progress in this trait remains stagnant and new research is needed.

7. Bioactive compounds: Improvement of the amount of bioactive components in the durum grain while maintaining technological quality would help develop durum as a functional food material.

**Intellectual property summary**

Varieties developed by ADWIP or released during this project or to be released soon after, have been protected or will be protected under the Plant Breeder's Rights (PBR) scheme.

Any breeding material developed by the program and provided for evaluation by third parties has been subject to protection under a Material Transfer Agreement (MTA). Both nodes have signed MTAs with ISOPRO SOCIEDAD ANNONIMA for commercialisation of the released varieties in Chile. ISOPRO SA, Chile has an agreement with Chile's largest grain company (Copeval) to provide seed and services. ISOPRO SA has sourced Caparoi, Jandaroi, Tjilkuri, Yawa and WID802 from ADWIP for the 2012 season.

Any breeding material for use in breeding from a third party has been obtained under a suitable licence arrangement with freedom to operate.

**Additional information**


More research is being carried out in project DANO0163 - Durum Breeding Australia.