Barley Improvement for the GRDC Northern Region

Summary

DAQ00038 was designed to transition the Northern Barley Improvement Program (NBIP) away from malting barley and towards developing high yielding, disease-resistant feed varieties. Strategic changes occurred in order to accomplish this leading to major improvements in disease screening, quality assessment, and field trials. Three new barley varieties were released during the project timeframe, and many new breeding lines and populations were developed. Project extension was delivered via presentations, field days, grower guides, scientific papers and other means. The project has provided a solid base for the establishment of Barley Breeding Australia's Northern Node (BBA-North).

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Conclusions

Drought has impacted heavily on northern grains region barley production (e.g. Jan 1999-May 2007 data for Bell show an accumulated rainfall deficit of approximately 1,175mm [almost twice the 650mm long term average rainfall]). However, there has been growth into new areas, in particular the more marginal central Queensland (CQ), western QLD (WQ) and northwest (NW) New South Wales (NSW) cropping regions. Northeast (NE) NSW has suffered least from rainfall deficits and has seen the uptake of higher yielding types such as Gairdner, Mackay, Binalong, and Dash, while reliable varieties such as Skiff and Grimmett have maintained consistent market share. Higher rainfall areas also have a tendency to favour varieties which can make malting, as many growers still want the option of a premium product. As the feed grain market matures and malting premiums are eroded, fewer growers will stay committed to malt-barley production. However, this will quickly reverse if malting prices improve. Disease remains a big issue for the northern grains region.

Another major driver of success for the NBIP will be the ability to collect End Point Royalties (EPR) in a deregulated feed grain market. Unlike the Southern and Western Regions, which, until recently, have had regulated marketing and a large percentage of grain going through bulk handling systems, the north is dominated by feed grain and farm to end user trading. It is estimated that less than 50% of Northern barley goes through a bulk handling facility. This system relies on grower returns and paper trails to recover royalties. Support from the end users who purchase and feed barley will be essential. Otherwise, it is unlikely high EPR capture rates will occur in the Region.

The NBIP underwent substantial changes between 2002 and 2006 to significantly increase program efficiency and effectiveness. The challenge of refocusing towards the development of high-yielding, disease-resistant ‘feed’ barleys was substantially addressed. Strategic changes included restructuring the early generation and yield trial programs, foliar disease screening and quality assessment protocols. New technologies have been adopted. However, the program’s greatest strength in reinventing itself has arguably been the upgrading of traditional breeding systems through integrating new high throughput systems and the latest advances in statistical knowledge.

While change has been implemented, the NBIP has continued to develop a substantial, mature pipeline of breeding material with Regional adaptation. Much of the new early generation material has been bred for multiple disease resistances, with the first significant commercial pay-offs for this work due to appear as varieties between 2011 and 2014. Meanwhile, trial data have shown current commercial varieties sliding further down in the yield rankings each year. This is a sign of good things to come, as new varieties with significant advantages in yield and regional adaptation should be available for northern region growers within the next 3-5 years. The first examples of these varieties are Grout and Fitzroy, which have the potential to regrow confidence in regional barley production and reinvigorate the industry.

In conclusion, DAQ00038 has laid a solid foundation for the development of the BBA-North national program. BBA-North will have the benefits of a mature breeding program and germplasm pool behind its operations, together with a well-established and highly respected team of research and technical staff.

Recommendations
The principal recommendation is that BBA-North must continue to maintain a strong focus on 'feed' or non-malting barley; to be defined as well adapted, high yielding, disease-resistant, agronomically desirable varieties. The key driver for this recommendation is the need to increase both the supply and stability of supply of feed grains in the Northern Region. Within this direction, there is also a specific need to target increased barley production in the northern and western cropping areas of the northern region.

However, it is also strongly recommended that yield improvement is not achieved at the cost of a reduction in the feeding value of the grain. Barley is one of four grains in the Northern Region feed grain system, the others being wheat, sorghum and maize. While quantity is recognised as a critical issue, any reduction in the perceived feeding quality of barley is likely to result in movement of the price differential between the grains in favour of wheat or sorghum. This would not be a desirable outcome for Northern Region barley growers. To both the intensive cattle and pig industries, barley feeding quality essentially means high content of extractable energy. High energy barley has value to the livestock producer, as it leads to high average daily gain. Lower energy grain costs money and time. Grain size and uniformity are important processing characteristics of the grain, and if poor, can add significantly to the cost of feed rations.

It is therefore vitally important to retain quality assessment procedures and ensure that the feed quality of the BBA-North barley varieties (and by association, the Northern barley crop) does not slide backwards over time. The data continue to suggest that assessment of malt extract, whether by near infrared (NIR) or wet chemistry, is currently the best available and the most cost effective measure of extractable energy from the grain. Although the intensive livestock industries do not currently pay for quality, it seems inevitable that some form of quality related feedstuff pricing will develop over the next decade (discounting for poor quality grain may be expanded). Breeding programs need to plan for the future, with a 10-year vision in mind. That means trying to anticipate market directions well in advance.

A final recommendation is to continue the separate management and operations of a Northern Region barley germplasm pool. This is driven by the many socio-environmental differences between the three major Australian regions. The most noteworthy are the sub-tropical weather patterns, as opposed to the temperate and Mediterranean patterns seen in the South and West. These weather patterns lead to significant adaptive differences in agronomic requirements, maturity, disease resistances and grain qualities (such as resistance to pre-harvest sprouting and pre-germination). There are additional differences in soil types, cropping systems and timing of extreme events such as frosts and storms, which also have both significant and subtle effects on varietal adaptation. Maintenance of the Northern gene pool is essential to those regional grain growers continuing to have access to varieties with the best possible adaptation, as opposed to a more generic product which would offer a steady decline in relative crop productivity over time.

**Outcomes**

The overall aim of DAQ00038 was to rebuild confidence in the regional barley industry. Northern Region barley production is typically 700,000-900,000t/pa. Medium term production trends have been greatly influenced by unreliable winter rainfall and fallout from the 1998 blight epidemics. QLD cropping areas have particularly suffered, with planting in traditional barley areas reduced by 50% or more. However, north west NSW, western QLD and central QLD have seen steady increases in barley sowing. This is partly due to feed grain demand, but also the improved adaptation of new varieties such as Mackay\(^5\) and Grout.\(^6\)

New varieties derived from this project will contribute to overall market stability through both productivity increases and risk reduction. Barley supplies underpin the region's more than $2 billion feedlot and more than $2 billion brewing industry value chains. Regional demand for barley has increased. This is dominated by the feedlot industry, which consistently pays prices above export feed and equal to, or better than, domestic malt. The feedlot industry has been growing by 7% per year, a trend predicted to continue. In work done by the Barley Industry Development Officer (BIDO), it was indicated that livestock industries prefer to access grain from within 50km of their enterprise. A doubling of capacity at the Fosters Group Yatala brewery has also contributed to regional demand. While barley can be sourced from other regions, increasing transport costs can add $50-70 per tonne onto the landed cost to the end user. These added costs reduce the economic viability of the industries and are either passed on to the consumer or negatively affect grain prices. The earlier northern harvest and regional demand are key drivers for price setting in the south and west.

Individual grain growers benefit from varieties that deliver increased on-farm productivity, marketable grain and protection against biotic and abiotic loss. The use of barley in rotations also contributes to soil health and topsoil retention, efficient water use, reduced runoff and evaporation, and helps avoid problems associated with monocultures. These attributes have
long term benefits to the environmental sustainability of Northern Region cropping systems. Incorporation of genetic resistances to biotic agents (fungi, insects) reduces the use of agricultural chemicals and benefits human and environmental health.

Farm viability in the Northern Region depends on profitable crop rotation, to which barley contributes as one of three main winter cropping options. Barley is a short season crop and establishes well in less than ideal planting conditions. Furthermore the demand for low protein grain gives it an advantage over other winter cereals for double cropping. Successful and profitable grain farms contribute significantly to regional rural communities. The barley value chain is a major employer in regional QLD and NSW.

Achievements/Benefits

Project DAQ00038 was a transitionary project, taking the NBIP from a malt quality focus to emphasise high yielding, disease-resistant feed varieties. A key driver for this change was the growth in regional demand for feed grains.

The transition required changing the NBIP’s focus, addressing shifts in regional barley production, improving program efficiency, decreasing the breeding cycle, expanding disease testing capabilities, using more NIR testing, and implementing molecular marker based selection tools. In addition, the project would help to rebuild the team after the loss of the previous team leader.

A 70:30 (feed:malt) resource allocation target was set for the end of the project, with changes to both cross design and selection pressures being key strategies. Estimates of the feed:malt resource split, as calculated for the 2004–05 and 2005–06 seasons, were 65:35 and 70:30, respectively.

The program planned for the last full cropping season reported under this project (2005) included: more than 130 new crosses, 166 F1s, 81 F2 populations, 60 F3 to F7 populations grown in hill plots, 4,250 pre-trial increase rows and more than 2,500 genotypes being tested across more than 15,000 yield trial plots and 16 locations. Although drought and pre-harvest storm damage resulted in the loss of some trial plots, the majority of the program proceeded as planned.

Varieties Released

Three barley varieties were commercially released during the project term. Mackay and Grout were bred and selected by the NBIP team and released as feed varieties. Fitzroy, a malting variety, was bred by the Victorian Department of Primary Industries (DPIVic) but released on the basis of NBIP trial data.

Mackay was released in 2002. Pre-release trial data showed 15-20% yield increase above the commercial malting varieties and a 5-15% yield advantage over popular feed varieties. Mackay performed well in commercial crops and achieved a respectable regional market share. It has been particularly successful in developing areas of the northern region such as Walgett, CQ, and western QLD, where it has improved both the yield and reliability of barley.

In the recent dry seasons, Grout demonstrated outstanding yield performance and an ability to retain large grain size under stress. Grout clearly out-performed all other commercial varieties in stressed or late planted trials and was released in 2005. It shows potential for domestic malting and is undergoing commercial scale evaluation, having passed all assessments to date. A final decision is expected on Grout’s classification by 2008. However, it seems to be building a solid reputation with regional growers and is likely to reach a significant market share, regardless of its final classification. The quick maturity, high yield and good grain size of Grout has the capacity to continue to grow the northern barley crop into more marginal cropping areas. It also provides an ideal option for growers in higher rainfall areas for short fallow and double cropping situations.

Fitzroy was released in 2005, but was not available commercially until 2006. It had been shelved by DPIVic until the NBIP team recommended its release for the Northern Region on the basis of trial performances. Preliminary indications are that the combination of Grout and Fitzroy has potential to reinvigorate the Northern Region barley industry, thus contributing to the project outcome.

Breeding and Evaluation

Crossing strategies were refocussed to produce 100-150 new crosses each year. Most new crosses were designed to target high yield and multiple disease resistance, using a combination of well adapted NBIP parents and introduced material. Parents were selected from yield trial and disease screening data. Most populations continued to be developed from two-way
crosses, however, some material was developed from backcross or topcross strategies.

An early decision was made to cease in-house doubled haploid (DH) production and redirect funds into core breeding. Rapid generation advancement services, such as DH or single seed descent (SSD), were to be outsourced and discussions were held with the Department of Agriculture Western Australia (DAWA), the South Australian Research and Development Institute (SARDI) and Crop Breeding Services (CBS). In reviewing the program needs, it became apparent that SSD should be the tool of choice because feed barleys require less stringent genetic uniformity than malting barleys, minor genetic variation within varieties may assist in broader adaptation, SSD creates more genetic recombination than DH, and SSD costs less per line than DH. Five high priority populations were commissioned for SSD through CBS (2005-07), with others being sent to The University of Queensland (UQ) in 2006.

The use of Marker Assisted Selection (MAS) has increased substantially through the Australian Winter Cereal Molecular Marker Program (AWCMMP) validation and implementation projects DAQ00046 and DAQ00078. By 2005/06, MAS was in use for cross enrichment and selection for rust, spot and net form net blotch (SFNB and NFNB), and Russian Wheat Aphid (RWA) resistances. Markers were also used for recurrent parent recovery in backcrossing and planning crossing strategies based on estimated genetic distance.

The use of hill plots was significantly increased for early generation material, moving away from the previous 6m row system, because less land and time were required to grow and visually evaluate material. Hill plots produce enough seed for NIR quality tests and disease testing. However, seed production and nursery strategies had to be changed slightly to ensure sufficient seed for early field trials.

One of the most significant tasks was restructuring the field trial program. Trial sites were redistributed and rationalised across the entire region, leading to a net reduction in test sites from more than 25 to 16. Trials were more evenly distributed across eastern and western cropping areas, as well as across northern NSW and QLD. This placed greater emphasis on regional production trends, as well as improving environmental sampling.

Trial stages were cut down from five to three, reducing the testing cycle by at least one full year and possibly saving a further year through faster promotion of material due to improved confidence in the data. The Stage I Cross Evaluation Trial (CET) was retained, with its unique focus on evaluating populations for yield potential. However, it was augmented by targeting the populations likely to produce the highest yielding material. Remaining Stage I lines were tested at a reduced number of sites in ‘Germplasm Development’ trials, focussing primarily on multiple disease resistance.

Cutting edge statistical design and analysis procedures were adopted by the program (e.g. it was the first in Australia to adopt partially replicated trial designs). These replaced grid designs and increased the precision of variance estimates. The designs were applied across entire trial series, effectively making each series a single, multi-site, replicated experiment, improving statistical power and minimising the risk of data loss from site failures. The NBIP team had also been rapid adopters of spatial techniques and the ASREML computer model across site x year analysis. The net effect of adopting these systems was improved selection power, while keeping plot numbers to manageable levels.

A bar coded electronic data capture system was adopted. Under this system, trial data could be captured, downloaded and analysed almost immediately after harvest. Fast data turnaround, together with capture of pathology data, enabled a large number of seed rows to be discarded prior to harvest. Nursery harvest efficiency was significantly improved. Each trial and nursery plot was linked to a unique bar coded identifier which could be used to trace each grain sample through weighing, cleaning and quality assessment processes.

Pathology

The foliar pathology group conducted routine screening for six diseases (NFNB and SFNB, leaf and stem rust, spot blotch and powdery mildew). Isolated nurseries were established to screen for field resistance in advanced material and specific breeding populations, while glasshouse tests were used to assess seedling resistances in both advanced and early generation lines. Field screening for resistance to scald was implemented during the project and conducted by workers based at Tamworth.

The team also developed a high-throughput single plant screening system which enabled single generation testing for up to three diseases. Surviving plants were transplanted to field nurseries where single plant assessment for additional diseases could take place. Initial concerns about the seedlings showing acquired resistance proved to be unfounded. The system has
proven to be highly effective and quadrupled the number of F2 plants and F3 lines evaluated by the program; over 70,000 individual disease assays were conducted in 2005. The breeding philosophy behind the system is that the surviving derived lines contain all of the desired resistance genes. Once the best performing lines are identified, they can be reselected to find single plants possessing the full suite of resistances. The bioassays also have the advantages of being more cost effective than markers and occurring in real time.

A major development in soil-borne pathology was the identification of *Hordeum spontaneum* backcross derived lines that appeared to possess effective crown rot (CR) resistance. Crosses were made to develop both breeding and mapping populations. The mapping work has had some preliminary success (USQ00007), however, the breeding populations have proven to be relatively unadapted - an expected outcome given the wild nature of the parent stock. Second generation crosses have been made with NBIP parents in 2005/06, and it is intended to use phenotypic and marker selection to get the resistance into more commercial material.

Quality assessment

Quality assessment also underwent substantial restructuring. By 2006, the laboratory was capable of processing well over 15,000 whole grain samples and 3,000 malt samples per year. Detailed grain quality tests, including grain size, test weight, and physical and chemical traits estimated by NIR (protein, starch, hardness, fibre and husk content) were assessed at all stages of the breeding program with data ready for the February selection meeting. This required testing of around 10,000 plots within a 10 week timeframe.

The NBIP barley quality laboratory was the first Australian cereal chemistry laboratory to obtain ISO9001 quality assurance (QA) certification (through the Australian Malting Barley Centre (AMBC) project). Consequently, the breeding program had access to a world class QA system for all of its grain and malt quality assessment.

Staff worked closely with biometricians from the National Statistics Program to include comprehensive two-phase statistical analysis in all laboratory analysis, being the first in Australia to adopt these new statistical design methodologies. This allowed NBIP staff to improve their understanding of genetic and environmental aspects (and heritability) of grain, feed and malt quality. The analysis has also allowed the program to rationalise some of the quality testing by conducting a robust analysis of quality variance components. The result of this was strategic targeting of only a few select sites for grain analysis with confidence that the data relate to performance across the region.

Near infrared (NIR) was rapidly adopted to assess malting potential throughout the breeding pipeline. The application of NIR enabled earlier selection for grain and malt quality, enabling resource intensive micro-malting assays to be conducted on only a select subset of advanced lines.

As a result of refocusing towards feed quality, the group established a collaborative linkage with Dr Jan Bowman (Montana State University). This relationship gave the NBIP access to in sacco cattle feed quality assessment of up to 200 trial grain samples per year. Thus, the NBIP was able to directly assess advanced material for the key feed quality traits of grain hardness, acid detergent fibre (ADF) and husk content; from which a predicted Average Daily Gain (ADG) could also be calculated. The data were also used to develop NIR calibrations for the feed quality traits, which have been used for selection in the NBIP since 2004. Further, project data have been used for a detailed study on the relationship between malt quality and feed quality. The results suggest that selection for malt quality is a useful indicator of cattle feed quality. Several publications have arisen from this work.

Industry Development

Extension of project findings and outputs, as well as barley promotion in the Northern Region was lead by the BIDO. Annual information packages and barley planting guides were a primary extension tool and covered variety selection, targeting nitrogen (N), plant population, storing malt barley, planting time and herbicide sensitivity. The documents were made available in hard copy and web-based formats. The project also contributed to the development of the NSW Department of Primary Industries (NSW DPI)’s “Green Book” and Winter Crop Variety Sowing Guide and the QLD Department of Primary Industries and Fisheries (DPI&F)’s Winter Crop Management Notes.

The BIDO published many press articles, including a monthly column in the QLD Country Life Grains Outlook. She developed the NBIP field day and grower and agronomist program, which included trial site inspections, variety launches and specific functions for targeted audiences. The BIDO also took over the role of coordinating the Northern Region Barley Advisory
Committee (NRBAC), a key industry consultative process.

Later in the project, the BIDO's role expanded to include other feed grains and lead the process to gather data on feed barley usage and quality needs. These have been used to further develop breeding objectives and strategies. In 2006, the BIDO co-facilitated a feed grains value chain workshop, with the intent of capturing critical information for use in strategic planning to improve feed grain supplies.

Other research

1. Feed Quality Attributes. Industry forecasting indicates that an increasing amount of Australian grain will be consumed domestically by the intensive livestock industries. The cost of grain is one major criteria for feed users. However, grain quality, energy availability, animal intake and processing costs are also important. Even the livestock industries recognise that current feed grain trading parameters bear little resemblance to actual animal requirements. It is therefore vital that, while pursuing higher yield, effort should also be put into feed quality research to define critical traits affecting barley feed quality, identify genetic variation and develop routine, cost-effective selection tools. This will ensure price maintenance and profitability for both the grains and livestock industries. There is an opportunity for the NBIP to use a DPI&F feed testing facility, which is located in Rockhampton and uses fistulated cattle from dominant Australian breeds. It has recently become more important to the NBIP following the cessation of MSU feed quality research. Research is also encouraged to review potential for quality based pricing systems in feed grain markets.

2. Physiological adaptation to northern cropping environments. There has been substantial research activity in wheat and sorghum physiology for Northern Region cropping systems. It seems natural to exploit this work and identify links to barley which can be exploited or modified to improve production in the northern grain growing areas. This could include research on tolerance to heat, moisture and frost stresses (connecting growth stages with event timing in the Northern Region) and inclusion of barley into the Agricultural Production Systems simulator (APSIM) crop modelling systems.

3. Potential for expansion in non-traditional areas. Barley is arguably the world's most widely adapted crop, being grown from the tropics through to alpine areas. With the increasing demand for feed grains driving production and the recent government drive to examine cropping potential in areas of northern Australia, it may be timely to scope opportunities for expanding barley production to outside traditional areas. Such a study, if successful, might lead to further research in crop physiology, disease resistance and adaptation. It would also lead to developing collaborative arrangements with existing barley breeding programs in more tropical environments, such as India and Thailand.

4. Forage barleys. There is significant regional interest in barley as a grazing, hay or silage product. Traditional barley varieties are currently grown in moderate quantities for forage uses. Potential exists for work that links to the core BBA-North and DPI&F forage oat breeding projects, through which forage barley varieties could be developed. However, this raises the issue of how royalties could be collected for these production systems.

5. Expanding two-phase quality testing. DPI&F biometricians are major contributors to the National Statistics Project, and in particular, the development of statistical procedures to improve analysis of test scale quality data. The NBIP quality team have worked closely with the biometricians in developing, testing and implementing the new design and analytical systems. This presents further opportunities to refine the statistical techniques, lead the world in this area of science, and facilitate the ability of breeding programs to provide Australian industries with varieties of the very best quality.

Intellectual property summary

Genetic material developed through this project has been made available to other Australian and international barley researchers and breeders under the control of legally binding Material Transfer Agreements (MTAs), which protect the rights of the Intellectual Property (IP) owners.

The two NBIP-bred varieties commercialised during the course of this project, Mackay and Grout, were protected by legally binding commercialisation licences. The licensees were selected through standard departmental tendering processes, including financial returns to the IP owners through collection and distribution of End Point Royalties (EPRs). Fitzroy was commercialised by the Maltling-barley quality improvement program (MBQIP).

Publication of data and research outcomes is managed through departmental publication guidelines and internal review processes. Any such publications are protected by copyright law.

Additional information
Relevant publications include 21 refereed journal papers, one PhD thesis and 18 conference papers.

Although the contribution from project DAQ00038 to this body of published work varies for each document, none would exist in their published form without the direct or background knowledge generated from the project.