



An Economic Analysis of GRDC Investment in the Australian Winter Cereals Molecular Marker Program



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Australian Winter Cereals Molecular Market Program**

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Executive Summary

Conventional cereal breeding is time consuming with breeding a new variety taking between 8 and 12 years from the time of the first cross. Speeding up the time it takes to produce a new variety can have a large impact on the economics of breeding. Use of molecular markers can contribute to this efficiency gain in breeding.

The Australian Winter Cereals Molecular Marker Program (AWCMMP) was an attempt to coordinate and focus effort on improving genetic gain through identification, validation and application of molecular markers in breeding programs. The investment evaluated here consisted of 25 projects funded predominantly over the years ending June 2002 to June 2007.

The principal outputs from the investment were the identification, validation, and application of genetic markers for cereals for a range of traits of commercial importance. Information about the markers, as well as markers developed earlier and outside the program, is currently being used in cereal breeding programs for a range of purposes. Many of the markers being used do not reside within the gene of interest, however, their use increases the likelihood of improvement. However, cereal breeders are making selection decisions earlier and with more confidence.

The use of the markers in the breeding programs will have impacts on the characteristics of varieties that are released in future. These impacts will be in the form of being able to more quickly build improved disease and pest resistance, adaptation to water and soil constraints, and enhanced quality traits in new varieties of wheat and barley that are aligned with consumer requirements.

The AWCMMP has, and potentially will, impact firstly on how breeding programs are conducted resulting in a shorter time period to produce a variety with a given set of properties. In addition, improved varieties with particular traits may be produced with the use of markers that would not have been able to be produced without the application of considerable time and resources. This means that improved varieties can be adopted sooner and benefits to grain producers can be higher and flow earlier than otherwise. Speeding up the time it takes to produce a new variety can have a large impact on the economics of breeding.

There are a number of difficulties in valuing the benefits derived from this investment. These include:

- The indirect rather than direct use of the end products of the investments aligns this investment more with strategic research, that is, it is difficult to directly trace the linkages between the identification of a marker and its validation and use, and the benefits it ultimately provides.
- The various markers addressed in the period of investment are at different stages of development and application in breeding programs.
- Some markers identified in previous investments have been used in the past decade of breeding programs so that assumptions are required about the difference the new information generated by the investment will make.
- There are many different production and quality traits in different cereals that potentially could be improved by the use of the markers identified.

However, an attempt has been made to value the benefits through a set of broad assumptions about the impact of molecular markers using models of breeding investments for barley and wheat. Broad assumptions of the extent of benefits and their timing are made. Due to the generalisations necessary, use is made of sensitivity analyses to test the impact of varying the critical assumptions on the investment criteria.

The total investment in this investment cluster of \$39.3 million (present value of costs in 2009 \$ terms) has been estimated to provide a net present value of \$362 million and a benefit-cost ratio of 10 to 1 (analysis over 30 years and at a 5% discount rate).

An overview of identified benefits in a triple bottom line categorisation is shown in the following table. Not all of the identified benefits are valued in this analysis. Of the identified benefits, the economic benefits are the principal category valued.

Categories of Benefits from the Investment

Levy Paying Industry	Spillovers		
	Other Industries	Public	Foreign
<u>Economic Benefits</u>			
1. Increased rate of genetic gain in wheat and barley 2. Earlier benefits generated from reduced chemical control costs 3. Access to knowledge generated overseas	6. Private breeding company intellectual property (end point royalties)	7. University and state agencies intellectual property (end point royalties)	
<u>Environmental Benefits</u>			
4. Reduced chemicals in the farm environment		8. Reduced chemicals in the community environment	
<u>Social Benefits</u>			
5. Reduced risk of toxic contamination from chemicals		9. Increased molecular biology capacity in the scientific community 10. Consumer needs better met	11. International scientific collaboration and capacity building

1. Introduction

This evaluation refers to the GRDC investment in the Australian Winter Cereals Molecular Marker Program (AWCMMP) over the period June 2002 to June 2007. This investment followed on from the Australian Winter Wheat Molecular Marker Program and the National Barley Molecular Marker Program, the latter having been operating since the 1980s. Australia is currently recognised as a world leader in the application of molecular markers to cereal breeding (DAFF, 2007).

The broad aim of the AWCMMP is to meet an overriding industry need for “grain varieties world competitive in their quality for designated end use and with yield, disease resistance and stress tolerance characteristics to maximise their value to Australian farming systems”. Identification and access to molecular markers is considered fundamental for effectively achieving this objective through its crop improvement program.

Quantitative Trait Loci (QTL) mapping in cereals has been carried out using traditional genetic markers that encoded easily observable characteristics. New molecular techniques (e.g. restriction fragment length polymorphism) developed in the past 25 years has allowed examination of differences in DNA which has allowed study of linkages between DNA and organism characteristics.

A number of techniques used for detecting individual variations in DNA that can be used as genetic markers in crop plants including cereals include:

- Restriction fragment length polymorphisms (RFLPs)
- Microsatellite polymorphism or single sequence repeats (SSRs)
- Single nucleotide polymorphisms (SNPs)
- Amplified fragment length polymorphisms (AFLPs)
- Random amplification of polymorphic DNA (RAPDs)

Conventional cereal breeding is time consuming with breeding a new variety from an initial cross taking between 8 and 12 years. Speeding up the time it takes to produce a new variety can have a large impact on the economics of breeding. Use of molecular markers can contribute to this efficiency gain in breeding as well as the development of improved varieties that could only be developed by traditional breeding methods with considerable resources and time.

2. Project Investment

Projects Funded by GRDC

Twenty five GRDC funded projects have been included in this investment cluster. Most of these projects were funded in the years ending June 2003 to June 2007 and most concluded in the years June 2004 to June 2007. The projects are listed in Table 1. Table 2 provides a summary of the objectives of each project.

Projects in only two themes (the Genetic Analysis Theme and the Validation and Implementation Theme) are included. Projects in a third Theme (Emerging Technologies) were not included.

Table 1: AWCMMMP Projects Funded by GRDC Completed in Years ending June 2003 to June 2007

Project Code and Title	Other Details
Genetic Analysis Theme	
DAS00028: Genetic Analysis and Marker-Trait Linkage	Organisation: CRC for Molecular Plant Breeding and South Australian Research and Development Institute Period: July 2002 to June 2004 Researcher: Hugh Wallwork
CSP346: Molecular Markers for Wheat Product Quality and Disease Resistance in the Northern Region – CSIRO Component	Organisation: CSIRO Plant Industry Period: July 2001 to June 2004 Researcher: Lynne McIntyre
CSP00035: Generic resource for the application of perfect markers in winter cereal disease resistance breeding	Organisation: CSIRO Plant Industry Period: July 2002 to June 2007 Researcher: Evans Lagudah
DAW00089: Exploiting Septoria and Stagonospora resistance in wheat: genotyping	Organisation: WA Department of Agriculture Period: July 2001 to June 2005 Researcher: Michael Francki
DAW704: Exploiting Septoria and Stagonospora resistance in wheat: phenotyping	Organisation: WA Department of Agriculture Period: July 2002 to June 2005 Researcher: Robert Loughman
CWQ00009: Phenotyping complex quality traits for marker identification and validation	Organisation: WA Department of Agriculture and Value Added Wheat CRC Period: January 2003 to December 2004 Researcher: Michael Francki
CIM12: Molecular Markers for Wheat Product Quality and Disease Resistance in the Northern Region – CIMMYT Component	Organisation: CIMMYT International Period: July 2001 to June 2004 Researcher: Julie Nicol
DAQ542: Molecular Markers for Wheat Quality and Disease Resistance for the Northern Region – QDPI Component	Organisation: Queensland Department of Primary Industries/Farming Systems Institute Period: July 2001 to June 2004 Researcher: John Thompson
DAV436: Defect Elimination in Wheat (Development of preharvest sprouting resistant breadwheats)	Organisation: Victorian Department of Primary Industries Period: July 2000 to June 2005 Researcher: Francis Ogbonnaya
DAW000126: Enhancing resistance to <i>Stagonospora nodorum</i> in Australian wheat germplasm	Organisation: Department of Agriculture, Western Australia Period: July 2005 to June 2008 Researcher: Michael Francki
DAW724: Molecular markers for abiotic stress in wheat in the Western Region	Organisation: Department of Agriculture, Western Australia Period: July 2001 to June 2004 Researcher: Tim Setter
USQ00004: Data mining and map curation in the AWCMMMP	Organisation: University of Southern Queensland Period: July 2002 to June 2004

	Researcher: Grant Daggard
USQ00005: Molecular markers for novel sources of crown rot resistance	Organisation: University of Southern Queensland Period: July 2002 to June 2007 Researcher: Mark Sutherland
USQ3:Black Point: Marker Development and Gene Isolation	Organisation: University of Southern Queensland Period: July 2000 to June 2003 Researcher: Grant Daggard
USQ4:Molecular markers for wheat product quality and disease resistance in the Northern region - USQ Component	Organisation: University of Southern Queensland Period: July 2001 to June 2004 Researcher: Mark Sutherland
Implementation /Validation Theme	
AGP00003: Wheat marker implementation/validation for Australian Grain Technology	Organisation: Australian Grain Technology/CRC for Molecular Plant Breeding Period: July 2002 to June 2007 Researcher: Russell Eastwood
UA00049: MBQIP implementation and validation	Organisation: University of Adelaide and CRC for Molecular Plant Breeding Period: July 2002 to June 2004 Researcher: Jason Eglinton
DAW00064: Implementation/Validation of molecular markers in EGA - WADA node	Organisation: WA Department of Agriculture and CRC for Molecular Plant Breeding Period: July 2002 to June 2004 Researcher: Rudi Appels
DAQ00047: Implementation/Validation of Molecular Markers EGA - QDPI Node	Organisation: Queensland Department of Primary Industries Period: July 2002 to June 2004 Researcher: Mandy Christopher
GBA00002: Implementation, Grain Biotech Australia	Organisation: Grain Biotech Australia Period: July 2002 to June 2004 Researcher: Nicolas Gosman
DAN00041: Implementation, Validation and Development of Markers in EGA - NSW node	Organisation: NSW Agriculture Period: July 2002 to June 2007 Researcher: Harsh Raman
DAW00068:Validaton/Implementation - Barley, Western Region	Organisation: Department of Agriculture, Western Australia Period: July 2002 to June 2004 Researcher: Chengdao Li
DAN00040: Implementation, validation and development of markers in barley at NSW Agriculture	Organisation: NSW Agriculture Period: July 2002 to June 2007 Researcher: Harsh Raman
DAQ00046: Molecular biology support for barley improvement - North	Organisation: Queensland DPI Period: July 2002 to June 2004 Researcher: David Poulsen
GG00001&GG00003: Implementation of molecular markers for key agronomic and quality traits in wheat and barley using simple high throughput technologies	Organisation: Graingene Period: July 2002 to June 2004 Researcher: Kevin Gale

Table 2: Project Codes, Titles and Stated Objectives

Project Code and Title	Stated Objectives
Genetic Analysis Theme	
DAS00028: Genetic Analysis and Marker-Trait Linkages	To improve the knowledge of genetic control of economically important traits, the location of controlling genes and the associations of useful genetic markers with traits, all contributing to the more rapid release of improved varieties of wheat and barley.
CSP346: Molecular Markers for Wheat Product Quality and Disease Resistance in the Northern Region – CSIRO Component	<ol style="list-style-type: none"> 1. To assist in the application and utilisation of information, knowledge and the data sets produced in the current NWMMP to breeding issues relevant to the Northern Region. 2. To locate molecular markers linked to genes contributing to desirable quality characteristics and disease resistance. 3. To validate those markers in a range of genetic backgrounds relevant to the Northern Region and convert them to PCR-based markers for implementation.
CSP00035: Generic resource for the application of perfect markers in winter cereal disease resistance breeding	To improve the efficiency of selecting disease resistant winter cereals against known or anticipated pathogens and pests through the application of resistance and defence signaling genes from public cereal genomic databases.
DAW00089: Exploiting Septoria and Staganospora resistance in wheat: genotyping	To identify chromosomal regions controlling resistance to SNB in spring and winter wheat germplasm.
DAW704: Exploiting Septoria and Staganospora resistance in wheat: phenotyping	To improve opportunities, through the application of molecular genetics, to breed wheat varieties with enhanced resistance to septoria diseases of wheat.
CWQ00009: Phenotyping complex quality traits for marker identification and validation	<p>To phenotype the WA germplasm derived DH population for quality traits including grain size, flour colour, milling yield, water absorption and null-4A FSV in WA, validate similar and identify novel QTLs expressed in different geographical regions.</p> <p>Specific objectives were:</p> <ol style="list-style-type: none"> 1. To validate common marker-trait associations for various grain quality attributes in WA adapted germplasm based on phenotypic evaluations under WA conditions. 2. To identify alternative QTLs controlling grain quality attributes in WA derived germplasm, identify markers flanking chromosomal regions for implementation into breeding programs. 3. To evaluate the impact of QTL expression by extending the effect of environmental conditions based on phenotypic evaluations of selected DH individuals under NSW conditions.
CIM12: Molecular Markers for Wheat Product Quality and Disease Resistance in the Northern Region – CIMMYT Component	<ol style="list-style-type: none"> 1. To determine the genetic control (same/different, major/minor, additive) of current and newly identified sources of resistance identified against Root Lesion Nematode (<i>P. thornei</i>) 2. To determine the number of genes involved in the resistance against Root Lesion Nematode (<i>P. thornei</i>) with the AUS4930 population and develop the population for BSA analysis in Australia. 3. To establish strong linkages and complementation with the

	northern node regional pathology program.
DAQ542: Molecular Markers for Wheat Quality and Disease Resistance for the Northern Region – QDPI Component	<ol style="list-style-type: none"> 1. To develop molecular markers to wheat quality attributes of importance to the Northern Region (high dough strength and extensibility and good sponge and dough bread quality). 2. To develop molecular markers to serious diseases of wheat in the Northern Region (root-lesion nematodes, crown rot and yellow spot). 3. To validate markers for quality traits and disease resistances before implementation into Northern Region wheat breeding programs.
DAV436: Defect Elimination in Wheat (Development of preharvest sprouting resistant breadwheats)	<ol style="list-style-type: none"> 1. To reduce the losses caused by preharvest sprouting (PHS) in wheat crops in Australia through the availability of adapted bread wheat lines with resistance to PHS from <i>Aegilops tauschii</i> and other sources. 2. To facilitate the incorporation and accumulation of different genes into commercial bread wheat cultivars through molecular markers for different sources of PHS.
DAW000126: Enhancing resistance to <i>Stagonospora nodorum</i> in Australian wheat germplasm	To enhance the levels of SNB resistance in wheat germplasm with the potential to deliver economic benefits to growers.
DAW724: Molecular markers for abiotic stress in wheat in the Western Region	To increase the efficiency of wheat breeding in the Western Region by building capacity to develop and verify markers, and by becoming an active and efficient participant in the CRC for Molecular Plant Breeding (CRCMPB) and the National Wheat Molecular Marker Program (NWMMP).
USQ00004: Data mining and linkage map curation in the AWCMMMP	<ol style="list-style-type: none"> 1. To identify new QTL and marker-trait associations (i.e. data mining). 2. To develop a set of linkage maps of the highest quality through the ongoing refinement of the maps and addition of new markers.
USQ00005: Molecular markers for novel sources of crown rot resistance	To develop improved wheat varieties with enhanced resistance to crown rot caused by <i>Fusarium pseudograminearum</i> .
USQ3: Black Point: Marker Development and Gene Isolation	<ol style="list-style-type: none"> 1. To isolate markers associated with black point resistance. 2. To identify specific genes associated with black point resistance or susceptibility for long-term control of black point symptoms. 3. To incorporate and evaluate DNA markers into national wheat improvement programs.
USQ4: Molecular markers for wheat product quality and disease resistance in the Northern region - USQ Component	<ol style="list-style-type: none"> 1. To apply the knowledge and data sets gained in the NWMMP to breeding issues relevant to the Northern Region. 2. To locate potential molecular markers linked to genes contributing to desirable wheat quality characteristics and disease resistance, by the techniques of either establishing genetic maps or by bulk segregate analysis. 3. To validate those markers in a range of genetic backgrounds relevant to the Northern Region.
Validation / Implementation Theme	
AGP00003: Wheat marker implementation/validation for	To enhance the development of high quality, disease resistant and agronomically superior wheat varieties which will ultimately

Australian Grain Technology	improve wheat productivity and result in premium price in both export and domestic markets.
UA00049: MBQIP implementation and validation	To lead to high quality disease resistant and agronomically superior feed and malting varieties through marker technology which will ultimately improve barley yields for producers and result in premium prices in both export and domestic markets.
DAW00064: Implementation/Validation of molecular markers in EGA – WADA node	To build capacity of the breeding program in biotechnology to effectively use marker selection in the EGA breeding program to accelerate the development of improved varieties.
DAQ00047: Implementation/Validation of Molecular Markers EGA - QDPI Node	To enhance the capability in validated molecular markers in the northern node EGA, where the trait is of high importance and germplasm is currently in the program carrying the trait of interest.
GBA00002: Implementation, Grain Biotech Australia	To develop and define a strategy for cost effective marker implementation and validate the effectiveness of the specific markers for use in other wheat breeding programs throughout Australia.
DAN00041: Implementation, Validation and Development of Markers in EGA – NSW Node	To enhance the capability in implementation, validation, and development of markers positioning the EGA breeding program to efficiently implement useful markers, leading to more rapid development of improved bread and durum wheat varieties.
DAW00068: Validation/Implementation – Barley, Western Region	To develop an improved breeding strategy for accelerating transfer of target genes into elite barley lines and delivery to the barley industry of high yielding malting barley varieties with improved quality and tolerance to biotic and abiotic stress relative to Stirling and Gairdner.
DAN00040: Implementation, validation and development of markers in barley at NSW Agriculture	To achieve through marker assisted selection an improved rate of genetic gain in barley germplasm for malting quality, resistance to biotic and abiotic stress, including exotic threats such as the Russian wheat aphid.
DAQ00046: Molecular biology support for barley improvement - North	To improve through marker assisted selection the rate of genetic gain and selection efficiency in developing barley varieties for Qld and NSW.
GG00001&GG00003: Implementation of molecular markers for key agronomic and quality traits in wheat and barley using simple high throughput technologies	To develop more efficient implementation of marker assisted breeding in the Australian Grains Industry through the use of simple, high throughput DNA marker technologies and therefore help to maintain the competitiveness of the Australian grain export industry with respect to quality and price.

Investment Inputs

Estimates of the funding by GRDC and others by project by year for the twenty projects are provided in Tables 3 and 4.

Table 3: Investment by GRDC by Project for Years Ending June 2001 to June 2008
(nominal \$)

Project	2001	2002	2003	2004	2005	2006	2007	2008	Total
DAS00028	0	0	350,000	360,000	301,238	313,335	325,765	0	1,650,338
CSP346	0	82,829	86,442	88,569	0	0	0	0	257,840
CSP00035:	0	0	121,505	119,952	0	0	0	0	241,457
DAW00089	0	24,000	53,462	80,571	78,533	0	0	0	236,566
DAW704	0	0	55,036	74,941	83,133	0	0	0	213,110
CWQ00009	0	0	100,000	103,000	0	0	0	0	203,000
CIM12	0	15,000	85,000	45,000	0	0	0	0	145,000
DAQ542	0	247,236	348,242	369,109	0	0	0	0	964,587
DAV436	0	0	0	0	50,000	0	0	0	50,000
DAW000126	0	0	0	0	0	190,265	189,332	190,649	570,246
DAW724	0	183,600	204,000	208,950	0	0	0	0	596,550
USQ00004	0	0	100,000	103,000	0	0	0	0	203,000
USQ00005	0	0	100,000	103,000	240,768	241,127	242,466	0	927,361
USQ3	76,892	84,745	86,937	0	0	0	0	0	248,574
USQ4	0	77,511	83,721	83,511	0	0	0	0	244,743
AGP00003	0	0	250,000	258,000	259,753	267,617	276,778	0	1,312,148
UA00049	0	0	210,000	257,110	259,803	267,802	277,158	0	1,271,873
DAW00064	0	0	150,377	159,845	0	0	0	0	310,222
DAQ00047	0	0	130,000	134,000	0	0	0	0	264,000
GBA00002	0	0	65,000	67,000	0	0	0	0	132,000
DAN00041	0	0	189,999	195,779	169,003	146,936	147,725	0	849,442
DAW00068	0	0	80,000	82,623	0	0	0	0	162,623
DAN00040	0	0	80,000	82,000	121,038	116,581	122,704	0	522,323
DAQ00046	0	0	79,988	81,965	0	0	0	0	161,953
GG00001/3	0	0	115,205	111,652	0	0	0	0	226,857
Total	76,892	714,921	3,124,914	3,169,577	1,563,269	1,543,663	1,581,928	190,649	11,965,813

Source: GRDC proposals and final reports

Table 4: Investment by GRDC Partners by Project for Years ending June 2001 to June 2008 (nominal \$)

Project	2001	2002	2003	2004	2005	2006	2007	2008	Total
DAS00028	0	0	261,073	277,430	0	0	0	0	538,503
CSP346	0	135,142	141,037	144,508	0	0	0	0	420,687
CSP00035:	0	0	153,260	137,580	0	0	0	0	290,840
DAW00089	0	54,730	145,370	172,570	186,020	0	0	0	558,690
DAW704	0	0	89,287	93,741	101,649	0	0	0	284,677
CWQ00009	0	0	93,185	186,370	192,530	100,845	0	0	572,930
CIM12	0	160,500	161,860	176,016	0	0	0	0	498,376
DAQ542	0	419,395	590,736	626,133	0	0	0	0	1,636,264
DAV436	0	0	0	0	55,385	0	0	0	55,385
DAW000126	0	0	0	0	0	450,526	482,183	517,674	1,450,383
DAW724	0	198,900	221,000	226,362	0	0	0	0	646,262
USQ00004	0	0	217,424	226,716	0	0	0	0	444,140
USQ00005	0	0	196,200	239,276	399,622	409,537	420,126	0	1,664,761
USQ3	39,639	39,639	39,639	0	0	0	0	0	118,917
USQ4	0	77,511	83,721	83,511	0	0	0	0	244,743
AGP00003	0	0	227,180	235,680	244,510	253,700	263,262	0	1,224,332
UA00049	0	0	138616	132817	137,314	142,023	146,960	0	697,730
DAW00064	0	269,500	285,200	0	0	0	0	0	554,700
DAQ00047	0	0	196,500	196,900	0	0	0	0	393,400
GBA00002	0	0	71,250	64,000	0	0	0	0	135,250
DAN00041	0	0	269,573	277,170	267,112	253,074	279,648	0	1,346,577
DAW00068	0	0	88,400	93,100	0	0	0	0	181,500
DAN00040	0	0	183,729	184,086	152,438	152,816	153,119	0	826,188
DAQ00046	0	0	126,200	132,700	0	0	0	0	258,900
GG00001/3	0	0	141,620	161,636	0	0	0	0	303,256
Total	39,639	1,355,318	4,122,060	4,068,302	1,736,580	1,762,521	1,745,298	517,674	15,347,391

Source: GRDC proposals and final reports

Table 5 shows the combined GRDC and partner investment for each year.

Table 5: Total Investment by GRDC and Partners in AWCMP Projects for Years Ending June 2003 to June 2006 (nominal \$)

Year ending June	GRDC	Partners	Total
2001	76,892	39,639	116,531
2002	714,921	1,355,318	2,070,239
2003	3,124,914	4,122,060	7,246,974
2004	3,169,577	4,068,302	7,237,879
2005	1,563,269	1,736,580	3,299,849
2006	1,543,663	1,762,521	3,306,184
2007	1,581,928	1,745,298	3,327,226
2008	190,649	517,674	708,323
Total	11,965,813	15,347,391	27,313,204

3. Activities, Outputs and Early Stage Outcomes

The principal activities, outputs and early stage outcomes from each of the projects are reported in Table 6.

Table 6: Principal Activities, Outputs and Early Stage Outcomes by Project

Project	Principal Activities, Outputs and Early Stage Outcomes
Genetic Analysis Theme	
DAS00028: Genetic Analysis and Marker-Trait Linkages	<p>Trait data for wheat and barley were converted into chromosome locations using marker linkage data obtained through mapping populations and bulked segregant analysis techniques.</p> <p>Useful molecular markers were identified that could be used by breeding programs.</p> <p>Data was produced to improve understanding of genetic control of traits that could be used in designing crossing and selection strategies.</p> <p>Trait data included that for barley malt and grain quality, wheat end use flour colour, net blotches, root lesion nematode, scald, yellow leaf spot, and common root rot.</p> <p>Framework map for crown rot in wheat completed; map completed for Septoria Tritici blotch in wheat; mapping completed for yellow leaf spot; market identified for common root rot in barley.</p> <p>Marker registrar developed for the entire AWCMMMP.</p>
CSP346: Molecular Markers for Wheat Product Quality and Disease Resistance in the Northern Region – CSIRO Component	<p>This project was one of four closely linked northern region projects.</p> <p>The project focused on wheat quality and root lesion nematode (RLN) resistance.</p> <p>Identified quantitative trait loci (QTLs) for all traits investigated and confirmed the polygenic nature of the quality traits. A framework map was established in a DH population, containing 192 markers distributed on 21 wheat chromosomes.</p> <p>For RLN, a number of QTLs were identified in two middle eastern landraces, showing that further gains are possible in RLN resistance through combining the different RLN resistance QTLs.</p>
CSP00035: Generic resource for the application of perfect	Wheat and barley genes from public data bases were analysed and information integrated into a framework map of potential analogues of disease resistance genes.

markers in winter cereal disease resistance breeding	The map should allow the development of perfect markers for disease resistance in wheat and after the markers are converted to PCR based markers, they will be of use in wheat screening or breeding programs.
DAW00089: Exploiting Septoria and Staganospora resistance in wheat: genotyping	<p>Molecular marker resistance flanking genes for leaf and glume resistance to the fungal pathogen <i>Stagnospora nodourum</i> were identified.</p> <p>A total of 16 chromosomal regions contributing to resistance were identified from spring and winter wheat sources.</p> <p>The sources of resistance and markers identified can be used to track and combine minor genes for resistance during germplasm development by wheat breeding programs.</p>
DAW704: Exploiting Septoria and Staganospora resistance in wheat: phenotyping	<p>Production of phenotypic data for linkage analysis to framework single sequence repeat maps from the concurrent DAW00089 project.</p> <p>An improved understanding of resistance genes in different germplasm sources and the confounding effect of morphological characteristics on gene expression.</p> <p>Contributed to the identification of molecular marker resistance genes to <i>Stagnospora nodourum</i>, in conjunction with Project DAW00089.</p> <p>QTLs for flag leaf and glume resistance are now fixed in selected Australian germplasm, but further investment in disease evaluation is required prior to effective deployment of germplasm in commercial breeding.</p>
CWQ00009: Phenotyping complex quality traits for marker identification and validation	<p>Identification of molecular markers linked to genes controlling variation for wheat quality traits including milling yield, flour colour and water absorption on gene expression across a range of WA environments.</p> <p>Wheat breeders now have knowledge and resources to implement molecular markers for breeding new WA wheat varieties with improved grain quality.</p>
CIM12: Molecular Markers for Wheat Product Quality and Disease Resistance in the Northern Region – CIMMYT Component	<p>An improved phenotypic screening method for assessing the <i>P. thornei</i> resistance of the root lesion nematode (RLN).</p> <p>Improved understanding that the resistance source is controlled by a number of genes.</p> <p>Combination of this resistance source with other known sources of resistance were additive.</p> <p>The resistance was not associated with resistance to Cereal</p>

	<p>Cyst Nematode (CCN).</p> <p>CIMMMYT has continued to work on incorporating sources of <i>P. thornei</i> resistance into high yielding adapted lines of wheat.</p> <p>Several of these lines will be delivered to Australian wheat breeders in 2006 as part of the CIMMMY/GRDC strategic Alliance.</p>
<p>DAQ542: Molecular Markers for Wheat Quality and Disease Resistance for the Northern Region – QDPI Component</p>	<p>Multiple disease resistant germplasm for root lesion nematodes, yellow spot, and crown rot identified and developed.</p> <p>QTLs to chromosomal regions associated with resistance to RLNs and yellow spot have been identified.</p> <p>Outputs will allow northern region wheat breeders to improve the sponge and dough bread making qualities of varieties, and improve overall varietal disease resistance.</p>
<p>DAV436: Defect Elimination in Wheat (Development of preharvest sprouting resistant breadwheats)</p>	<p>White grained pre-harvest sprouting resistance (PHSR) wheats were developed from red grained accessions with high levels of seed dormancy.</p> <p>The white grained synthetic backcross lines were used to transfer PHSR into diverse elite Australian wheat cultivars which were made available to breeding entities.</p> <p>The pre-harvest sprouting resistant lines of wheat developed (representative of the different wheat agroecological zones) were made available to wheat breeders.</p>
<p>DAW000126: Enhancing resistance to <i>Stagonospora nodorum</i> in Australian wheat germplasm</p>	<p>A selection of 671 wheat genotypes for leaf and glume resistance was made using molecular markers but lines with both glume and leaf resistance were minimal.</p> <p>A new flag leaf QTL has been consistently detected.</p> <p>Further investment in phenotyping the mapping population for disease evaluation is required to confirm robustness of QTL in multiple environments prior to deployment in germplasm development.</p>
<p>DAW724: Molecular markers for abiotic stress in wheat in the Western Region</p>	<p>Project identified and validated molecular markers for abiotic stress in wheat including for boron tolerance, aluminium tolerance, sprouting tolerance and water logging.</p> <p>Wheat breeders now have improved knowledge for the implementation of molecular markers for breeding new WA wheat varieties with improved performance regarding a number of abiotic traits.</p>

<p>USQ00004:Data mining and linkage map curation in the AWCMP</p>	<p>Improved and refined genetic maps developed and made available to all in the program.</p> <p>Markers for milling yield and flour colour developed.</p> <p>Analyses showed that very few QTL regions were conserved between cross populations, emphasising the need for region specific quality markers.</p> <p>Wheat breeders now have improved markers for quality traits in wheat (milling yield and flour colour).</p>
<p>USQ00005: Molecular markers for novel sources of crown rot resistance</p>	<p>Phenotypic data for seedling resistance to crown rot obtained.</p> <p>Molecular markers were identified for major QTLs for seedling resistance and these markers are now ready for validation.</p> <p>Wheat breeders now have improved markers for resistance to crown rot.</p>
<p>USQ3:Black Point: Marker Development and Gene Isolation</p>	<p>Molecular markers associated with black point resistance were identified in two double haploid populations.</p> <p>A genetic map was constructed for one of the crosses and QTL analysis was undertaken.</p> <p>The markers have been evaluated for their utility in breeding programs.</p> <p>Wheat breeders now have increased knowledge to implement molecular markers for breeding more black point resistant varieties, although the identified markers need further validation.</p>
<p>USQ4:Molecular markers for wheat product quality and disease resistance in the Northern region - USQ Component</p>	<p>Molecular markers associated with seedling and field based crown rot resistance have been identified.</p> <p>A framework linkage map has been constructed for quality traits including high flour water absorption.</p> <p>Markers for crown rot resistance, milling yield and pre-harvest sprouting have been examined in independent populations.</p> <p>The markers from one source appear to be a reliable predictor of seedling resistance to crown rot and have been made available to breeders.</p> <p>The potential identification/confirmation of markers for quality traits will allow progress to be made on breeding for quality traits in the future.</p>
<p>Validation /Implementation Theme</p>	

<p>AGP00003: Wheat marker implementation/validation for Australian Grain Technology</p>	<p>Markers for nematodes and rust, sprouting tolerance, boron tolerance, quality traits and markers for dwarfing genes were all validated.</p> <p>All of the markers identified and validated are now included in routine implementation in the AGT breeding program, resulting in a higher and speedier rate of genetic gain.</p>
<p>UA00049: MBQIP implementation and validation</p>	<p>Validation has been carried out for markers associated with husk adherence, resistance to stripe rust, and resistance to Russian wheat aphid.</p> <p>Molecular markers have been successfully applied in the breeding program. However, selection using the markers remains technically demanding, and as markers are not perfect, a detailed understanding of the parent material before the application of markers is required.</p> <p>Application of markers has been successfully applied in the MBQIP breeding programs for wheat and barley.</p>
<p>DAW00064: Implementation/Validation of molecular markers in EGA – WADA node</p>	<p>Groups of traits identified where markers are thought to be implementable and another group where more work is required before implementation.</p> <p>Implementation of some markers on a more routine level within the breeding programs through seamless data exchange.</p>
<p>DAQ00047: Implementation/Validation of Molecular Markers EGA - QDPI Node</p>	<p>The project has validated two QTL for resistance to black point; markers for resistance to sprouting was confirmed but closer markers are required; markers for crown rot resistance have been identified but more phenotyping is required for validation.</p> <p>Markers have been implemented for rust resistance, resistance to black point and resistance to barley yellow dwarf virus.</p> <p>Prioritisation of traits for marker development, validation and implementation has been achieved.</p>
<p>GBA00002: Implementation, Grain Biotech Australia</p>	<p>Three priority markers were used to screen single plants; double haploid lines were marker genotyped for waxy starch; selected lines are now parents.</p> <p>Cost benefit study on markers undertaken.</p> <p>Of the test traits validated and implemented, some will now be screened on a routine basis.</p> <p>Marker assisted selection has been successfully implemented to advanced segregating populations in the GBA wheat</p>

	breeding program.
DAN00041: Implementation, Validation and Development of Markers in EGA – NSWA Node	<p>Allelic diversity in 150 parental lines of bread and 160 lines of durum wheat was determined with markers linked to various traits.</p> <p>Molecular markers linked with aluminium tolerance and resistance to <i>Septoria tritici</i> blotch were also identified or validated in double haploid populations.</p> <p>Progress was made in developing more efficient methods for high throughput DNA extraction and marker screening.</p> <p>Further advances were made in developing, implementing and validating markers.</p>
DAW00068:Validaton /Implementation – Barley, Western Region	<p>Markers were used to accelerate backcrossing, intercross various target traits, improve genetic value of double haploid lines by screening donor plants and improve genetic gain by post screening DH lines.</p> <p>High throughput genetic analysis was developed and adopted.</p> <p>New barley lines with high thermostable beta-amylase genes show significant improvement of malting quality.</p> <p>New breeding barley germplasm with various combinations of disease resistance and malting quality is under evaluation.</p>
DAN00040: Implementation, validation and development of markers in barley at NSW Agriculture	<p>Markers for net blotch, blue aleurone colour and aluminium tolerance were validated.</p> <p>Development of protocols for high throughput marker screening in barley, as well as protocols for high throughout genotyping.</p> <p>Information on allele size has been generated and is being used for selecting markers for routine implementation in barley breeding.</p> <p>Markers linked to scald resistance, BYDV and aluminium tolerance have been implemented to screen for lines carrying the resistance/tolerance genes; early generation material has now been selected.</p>
DAQ00046: Molecular biology support for barley improvement - North	<p>Developed further capacity for molecular marker throughput (e.g. DNA extraction).</p> <p>Increased marker assays conducted on targeted breeding populations regarding disease resistance and malting quality.</p>

	<p>Marker assisted selection has been implemented on targeted breeding populations in conjunction with pathology and quality selection screens such as NIR, seedling screening and hillplots, so increasing the probability of producing elite lines.</p> <p>The generation of a genotype data set of 93 selected barley lines has facilitated the development of significant genomic regions and therefore opportunities for validation of selected markers in northern barley germplasm.</p>
<p>GG00001&GG00003: Implementation of molecular markers for key agronomic and quality traits in wheat and barley using simple high throughput technologies</p>	<p>Developed increased throughput at low cost for DNA extraction and PCR.</p> <p>Improvements in the visualisation of PCR products.</p> <p>Workshops with laboratories within the AWCMMMP.</p> <p>Increased efficiency of marker assisted breeding through use of high throughput technologies, resulting in time and cost savings.</p>

4. Outcomes

Very few molecular markers had been used successfully by wheat and barley breeders prior to the AWCMMMP investment. However, barley variety with cereal cyst nematode resistance was released in 2002 using extensive use of molecular markers. Given the late adoption by breeders and the long time it takes to take a trait through into a new variety, the mainstream impact and capture of benefits by the industry, particularly with wheat breeding, is deferred by many years.

In a previous economic evaluation of the benefits from barley breeding that released varieties over the period 2002 to 2008 (Agtrans, 2008), the view of barley breeders was that pre-breeding research such as molecular marker development would have made only a modest contribution to the releases up to 2008. Hence, the significant impact of molecular markers in Australian cereal breeding (before the AWCMMMP commenced) is likely to be with varieties released post 2007/08.

As markers are used most efficiently in the early years of a breeding cycle, their contribution will be mainly in future releases, perhaps 10 years or more after first being usefully employed. Further, the quality of the information concerning the linkage of the trait to the marker has increased considerably in recent years.

However, many of the markers being used do not reside within the gene of interest, however, their use is increasing the chances of improvement. Markers have been used in screening donor plants (parents) before making crosses, in enrichment of early generation breeding material, in backcrossing, and by allowing pyramiding of multiple sources of resistance.

The traits where molecular markers have assisted /are assisting wheat breeders include pre-harvest sprouting resistance, resistance to root lesion nematode

(*neglectus*), leaf, stem and stripe rust, and quality traits (polyphenyl oxidase) (Haydn Kuchel, pers. comm., 2009). Molecular markers' contribution most to barley breeding to date has mostly been with respect to quality (e.g. increased malt extracts and diagnostic markers for beta amylase) and in the future they could contribute most to adaptation traits (Jason Eglinton, pers. comm., 2009). Breeders consulted expect a higher rate of genetic gain with the use of markers over what could be expected from a traditional wheat or barley breeding program.

The costs of using molecular markers in breeding programs can either increase or decrease in relation to phenotypic evaluation. Discussions held with cereal breeders indicate that any increase is not likely to be very significant.

Breeders are using markers more frequently and more effectively than even five years ago. For example, one cereal breeding company carried out 15,000 molecular marker assays for selection purposes in 2002 but this had increased by 2007 to over 60,000 assays. Another breeding company increased its assays from 2,000 in 2001 to 100,000 in 2006.

The contribution of the AWCMMMP investment being evaluated to the identification and application of molecular markers in Australian cereal breeding has been significant, but it is difficult to separate out its contribution to specific variety releases or pending releases. However, it was confirmed by two cereal breeders that the investment made an extremely valuable contribution, particularly in the technology of application of markers in breeding programs. In fact, the increase in marker uptake by breeders was perhaps the most important achievement of the AWCMMMP.

A critical function of the program was to provide fully funded marker implementation to each of the breeding programs in Australia for five years. This allowed each program to develop local systems, processes, and knowledge required for successful implementation (Haydn Kuchel and Jason Eglinton, pers comm., 2009).

The cereal breeding programs now fund the application operations from their breeding budgets. This has been a positive outcome with most breeding programs now spending more on marker assisted selection than when GRDC was supporting the applications (Jason Eglinton, pers. comm., 2009).

In summary, the principal outputs and outcomes from the AWCMMMP investment were:

- The identification, validation, and application of genetic markers for cereals for a range of traits of importance has led to their increasing use in breeding programs for a range of purposes.
- Breeders are making selection decisions earlier and with more confidence as the quality of the information improves regarding the linkage between the marker and the trait.
- The cost-effectiveness of markers has been increased due to the advent of high throughput DNA extraction methods in a number of laboratories.
- The release of new varieties occurs about 6-10 years after the use of the markers in routine selection strategies and activities, compared to 8-12 years with traditional breeding.
- The use of the markers in Australian cereal breeding programs will have impacts on the characteristics of varieties that are released in future. These impacts will be in the form of being able to more quickly build improved disease and pest resistance, adaptation to water and soil constraints, and

- enhanced quality traits into new varieties of wheat and barley that is in line with consumer and market requirements.
- Beneficial linkages and coordination resulted from the AWCMMMP between the projects carried out by different research organisations in the three grain agro-ecological regions.
 - Beneficial coordination was achieved within each grain region, for example, between the four northern region partners of Queensland Primary Industries and Fisheries, CSIRO Plant Industry, University of Southern Queensland and CIMMYT.

5. Benefits

Breeding programs are producing new varieties of cereals whose properties are enhanced relative to existing varieties they replace. These advantages can be in the form of, for example, disease and pest resistance, tolerance of environmental factors such as waterlogging and aluminium toxicity, and reduced pre-harvest sprouting, all of which can result in an increased harvested yield as well as a reduced variability in yield from year to year.

Increased disease resistance in cereals can reduce costs of control and impact on the chemical regime that is utilised in production systems, with the outcome being reduced and more strategic use of chemicals. This is beneficial to grain producers, their neighbours and the general environment.

Breeding programs also produce improved milling characteristics and flour and final product quality that can provide increased profitability for producers and more closely match consumer requirements.

Given the set of benefits that already exist from investment in traditional breeding programs, the AWCMMMP investment has, and potentially will, impact firstly on how breeding programs are conducted resulting in a shorter time period to produce a variety with a given set of improved properties. This means that improved varieties can be adopted sooner and benefits to grain producers flow earlier than otherwise. This means that real increases in the rate of genetic gain can be expected.

Other benefits that have been derived from the current investment include the increased coordination and interactions between Australian scientists within the program, and between Australian scientists and those overseas. In addition, the program has built an increased Australian scientific capacity in the area of molecular biology.

There are likely to be some spillover public benefits from molecular biology from this investment in molecular markers for cereals including the increased skill capacity built in the area of molecular biology.

Summary of Benefits

A summary of benefits in a triple bottom line categorisation is shown in Table 7.

Table 7: Categories of Benefits from the Investment

Levy Paying Industry	Spillovers		
	Other Industries	Public	Foreign
<u>Economic Benefits</u>			
1. Increased rate of genetic gain in wheat and barley 2. Earlier benefits generated from reduced chemical control costs 3. Access to knowledge generated overseas	6. Private breeding company intellectual property (end point royalties)	7. University and state agencies intellectual property (end point royalties)	
<u>Environmental Benefits</u>			
4. Reduced chemicals in the farm environment		8. Reduced chemicals in the community environment	
<u>Social Benefits</u>			
5. Reduced risk of toxic contamination from chemicals		9. Increased molecular biology capacity in the scientific community 10. Consumer needs better met	11. International scientific collaboration and capacity building

Public versus Private Benefits

The benefits identified from the investment are predominantly private benefits, namely benefits to cereal producers in all regions of Australia. There also will have been some lesser public benefits produced, mainly associated with a reduced need for chemicals in controlling insects and disease, resulting in a reduced risk of chemicals reaching the off-farm environment. Public benefits have also been delivered in terms of capacity building in the molecular biology area, science advancement in knowledge about key traits, and development of technology platforms such as Multiplex Ready and DARt.

Benefits to other Primary Industries

More profitable cereal production systems will influence mixed farming systems that contain cereal rotations.

Distribution of Benefits Along the Grains Supply Chains

Some of the potential benefits from increased grain producer profitability will be passed along the grain supply chain to processors, exporters and consumers. For the variety production chain, cereal breeding companies benefit from new varieties through end point royalties.

Match with National Priorities

The Australian Government's national and rural R&D priorities are reproduced in Table 8.

Table 8: National and Rural R&D Research Priorities 2007-08

Australian Government	
National Research Priorities	Rural Research Priorities
1. An environmentally sustainable Australia	1. Productivity and adding value
2. Promoting and maintaining good health	2. Supply chain and markets
3. Frontier technologies for building and transforming Australian industries	3. Natural resource management
4. Safeguarding Australia	4. Climate variability and climate change
	5. Biosecurity
	<i>Supporting the priorities:</i>
	1. Innovation skills
	2. Technology

Table 9 identifies the rural research priorities that each of the benefits address.

Table 9: Categorisation of Benefits by Priorities

Benefit	National Research Priority Addressed	Rural Research Priorities Addressed
1. Increased rate of genetic gain in cereals		Priority 1 *** Priority 2 ***
2. Reduced chemical control costs	Priority 1 *	Priority 1 *
3. Access to knowledge generated overseas		
4 and 8. Reduced chemicals in the farm and off farm off-farm	Priority 2 *	Priority 3 *

environment		
5. Less handling of chemical by grain producers	Priority 2 *	
6. Private breeding company IP		
7. Public sector IP		
9. Scientific capacity building	Priority 3 **	Supporting Priority 1 and 2 **
10 Meeting consumer needs		
11. International scientific collaboration		

*** Strong contribution **Some contribution * Marginal contribution

Additionality and Marginality

The investment in this cluster was targeted principally towards benefits to cereal producers. As breeding programs are central to technology advancement in grain production, enhancement of breeding strategies and technologies can be seen as a critical investment. On the other hand the payoff to this research investment can be considered somewhat risky and long term. While probably regarded by many as high priority, in the event that public funding was restricted, it is likely that the investment would have been reduced substantially.

With reduced public funding, less of the public spillovers that have been identified would have been delivered. If no public funding at all had been available, it is likely that the investment would have been curtailed to about 25% of what GRDC actually funded. This would have been associated with a slower rate of genetic progress. Further detail is provided in Table 10.

Table 10: Potential Response to Reduced Public Funding

1. What priority were the projects in this cluster when funded?	Medium to High
2. Would industry have funded this cluster if less funds were available?	No, or only with significant time delays
3. Would industry have funded this cluster if only industry funds were available and no public funds?	No, or only with significant time delays
4. If the answer to Q3 is no or reduced, why?	Risk and long-term payoffs

6. Pathway to Adoption

One of the benefits of the AWCMP has been the sharing of knowledge of markers and genetic maps between molecular biologists and the relationships of the molecular biologists with cereal breeders. Hence, the adoption by plant breeders of identified and validated markers has been apparent and effective.

Varieties produced in breeding programs enter the National Variety Trials, not considered a part of the breeding activities. A central objective of the National

Variety Trials program (NVT) is to accelerate the adoption of superior varieties from breeding programs. Superior refers to varieties with improved yield, quality, disease resistance or combinations of these attributes.

Information on the expected performance of new varieties is usually plentiful and available so that adoption of improved varieties produced using marker assisted selection is likely to be as rapid as it is currently. New varieties will be available sooner and therefore adopted sooner.

Breeding companies now have processes and systems for application of molecular markers as they become available in the future. Jason Eglinton (pers. comm.,2009) comments:

“In Europe, programs have typically adopted markers only when there is a direct cost saving (e.g. replace viral resistance testing). North America has had major national genetic programs that generated at least as much genetic knowledge as the Australian efforts, but they did not fund implementation within the breeding programs. Consequently, there has been lower adoption rates and lower total level of marker assisted selection. The creativity and aggressive strategies of the Australian marker selection activity would not have been developed had the breeding programs been left to their own devices”.

7. Measurement of Benefits

There are a number of difficulties in valuing the benefits derived from this investment. These include:

- The indirect rather than direct use of the end products aligns part of this investment more with strategic research. Therefore it is difficult to trace the linkages between the identification of a marker and its validation and use, and the benefits it ultimately provides.
- The various markers addressed in the period of investment are at different stages of development and application in breeding programs.
- Markers identified in previous investments have been used in the past decade of breeding programs so that assumptions are required about the difference the new information generated by the defined investment will make in the future.
- There are many different production and quality traits in different cereals that potentially could be improved by the use of the markers identified, so that generalisations are necessary to value the expected benefits.

Nevertheless, an attempt has been made to value the benefits through a set of broad assumptions about the impact of molecular markers.

General Assumptions

1. The first assumption is that the use of genetic markers will increase the rate of genetic gain from wheat and barley breeding programs compared with traditional breeding methods.
2. Markers developed or improved during the period of the investment will add to the suite of markers available to cereal breeders. It needs to be recognised that the development and application of markers is a continuing process, especially in the

area of plant disease. The current investment has contributed significantly to the application of markers in cereal breeding programs.

3. Although molecular marker technologies have been available in various forms for some time breeders had been slow to adopt and implement them. It is assumed that variety development commencing around 2008/09 and thereafter will be the principal beneficiaries of the use of molecular markers.

4. Identification, validation and application of genetic markers as a result of additional investment occurring after that defined here (investment after 2007/08) are excluded from the current evaluation.

Approach

The approach to the evaluation is to estimate the benefits of cereal breeding programs commencing in 2008/09 using an assumption of the expected rate of genetic gain with and without molecular markers.

Estimating the benefits from the impact of the additional rate of genetic gain needs to allow for any additional costs of employing marker assisted selection in the breeding programs.

The marker net benefits are then partly attributed to the current investment through an estimate of its additional contribution to the rate of genetic gain commencing in 2014/15 and continuing thereafter.

The resulting benefit cash flow difference (with and without the impact of the AWCMMMP investment) is then related to the cash flow of the cost of the investment made in the AWCMMMP as defined earlier.

Reduced or Additional Costs

One study (Kuchel et al, 2005) has demonstrated that marker assisted selection may not only provide genetic gain but also reduced costs. In fact, any additional costs of molecular marker application are generally small relative to additional benefits and small relative to traditional breeding costs. One estimate is that use of markers can add about 8% to breeding costs (Jason Eglinton, pers comm., 2009).

Brennan et al (2005) assessed also the value of molecular markers in plant breeding programs. Regarding costs of applying markers compared with phenotypic evaluation, they conclude that markers can lead to cost savings in some situations but they can also lead to cost increases. Hence the assumption is made in the current analysis that, on the whole, the use of markers will incur no net change in total costs per annum.

Rates of Genetic Gain

The rate of genetic gain without application of molecular markers is assumed to be 0.5% yield gain per annum across Australia. This is based on the study by Black et al (2008) where it was estimated that new wheat varieties in South Australia had contributed 0.5% per annum yield gains of a total of 1.7% per annum yield gains from all sources in that State. A similar level of gain is assumed for conventional barley breeding.

Also, Brennan et al (2004) estimated that wheat breeding in NSW had increased the value of wheat per hectare (incorporating both yield and quality) in southern NSW by

approximately 0.50% per year. Agtrans Research (2008) estimated the yield increase for barley breeding from 2002 to 2013 would be about 0.75% per annum.

However, breeders estimate the value gains from traditional breeding would average around 1% per annum compared with no breeding program as existing yields and quality are being maintained as well as improvements being made. A base 1% gain in value is therefore used for both wheat and barley.

The assumption is made that without the AWCMMMP, the rate of genetic gain with the employment of markers would have increased the rate of value gain from 1% to 1.05% commencing 2008/09. This would increase due to the AWCMMMP investment to 1.10% in 20014/15, largely due to the more effective application processes and knowledge generated by the investment.

The development of these assumptions was assisted by discussion with two plant breeders. These discussions led to an Agtrans assumption of 0.10% per annum gain (10% increase) due to the use of molecular markers including the contribution from the AWCMMMP. The breeders thought that the 10% was reasonable. While the AWCMMMP did not in itself identify any significant new markers, its contribution to the application of all molecular markers meant that the additional rate of genetic gain due to markers was actually doubled due to the program (0.05% per annum gain assumed without the AWCMMMP). It should be noted that these gains are cumulative. Also, this uncertain assumption of the added gain was tested using sensitivity analysis (See results later).

Summary of Assumptions

A summary of the key assumptions made is shown in Table 11

Table 11 Summary of Assumptions

Variable	Assumption	Source
Value gains from traditional breeding for wheat and barley	1.0% per annum	Agtrans Research after discussions with cereal breeders
Value gains from use of molecular markers without the AWCMMMP investment	1.05% per annum commencing 2008/09	Agtrans Research after discussions with cereal breeders
Value gains from use of molecular markers with the AWCMMMP investment	1.10% per annum commencing 2014/15	Agtrans Research after discussions with cereal breeders
Base wheat production from 2008/09	Five year average of 19.4 million tonnes per annum	ABARE (2008)
Base barley production from 2008/09	Five year average of 7.6 million tonnes per annum	ABARE (2008)
Wheat value	Five year average of \$277 per tonne	ABARE (2008)
Allowance for farm gate to port costs for wheat	\$60 per tonne	Based on Wilkinson (2006)
Barley value	Five year average of \$242 per tonne less \$20 transport costs	ABARE (2008), Agtrans Research

Results

All past costs and benefits were expressed in 2008/09 dollar terms using the CPI. All benefits after 2008/09 were expressed in 2008/09 dollar terms. All costs and benefits were discounted to 2008/09 using a discount rate of 5%. The base run used the best estimates of each variable, notwithstanding a high level of uncertainty for some of the estimates. All analyses ran for the length of the investment period plus 30 years from the last year of investment (2007/08) to the final year of benefits assumed (2038/39).

Investment criteria were estimated for both total investment and for the GRDC investment alone. Each set of investment criteria were estimated for different periods of benefits. The investment criteria were all positive after 20 years as reported in Tables 12 and 13.

Table 12: Investment Criteria for Total Investment and Total Benefits for Each Benefit Period (discount rate 5%)

Criterion	0 years	5 Years	10 years	20 years	25 years	30 years
Present value of benefits (m\$)	0	0	21.72	178.32	286.23	401.77
Present value of costs (m\$)	39.30	39.30	39.30	39.30	39.30	39.30
Net present value (m\$)	-39.30	-39.30	-17.58	139.02	246.93	362.47
Benefit cost ratio	0	0	0.55	4.54	7.30	10.22
Internal rate of return (%)	negative	negative	0.2	13.9	15.4	16.2

Table 13: Investment Criteria for GRDC Investment and Benefits to GRDC for Each Benefit Period (discount rate 5%)

Criterion	0 years	5 years	10 years	20 years	25 years	30 years
Present value of benefits (m\$)	0	0	9.51	78.03	125.25	175.81
Present value of costs (m\$)	17.15	17.15	17.15	17.15	17.15	17.15
Net present value (m\$)	-17.15	-17.15	-7.65	60.88	108.10	158.66
Benefit cost ratio	0	0	0.55	4.55	7.30	10.25
Internal rate of return (%)	negative	negative	0.2	14.0	15.5	16.2

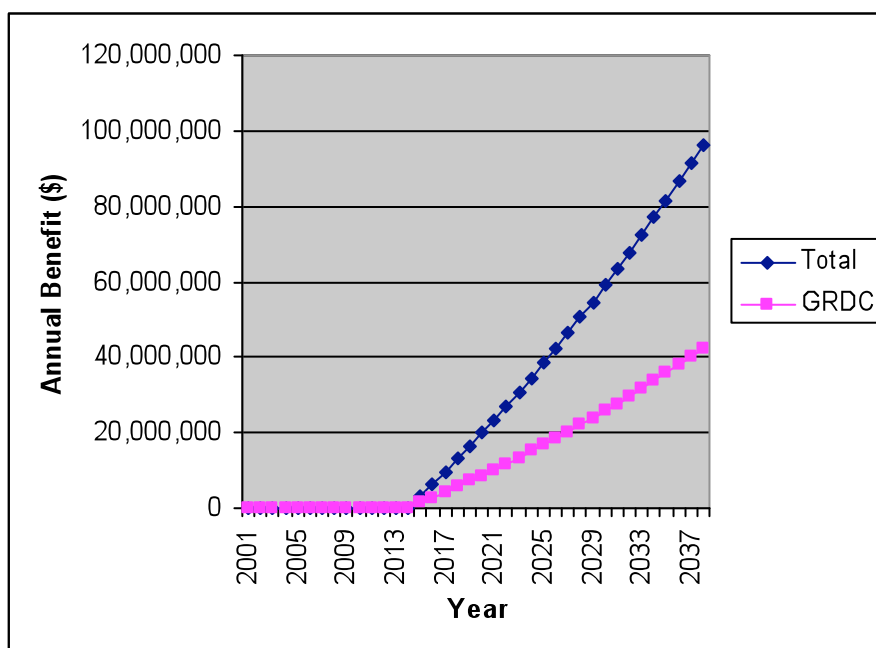
The quantified benefits are allocated to the Rural Research Priorities as expressed in Table 14.

Table 14: Allocation of Quantified Benefits to Rural Research Priorities

Rural Research Priority	Allocation
1. Productivity and adding value	100%

The annual net benefit cash flows for both total investment and GRDC investment for the 30 year period from the year of first investment are shown in Figure 1.

Figure 1: Annual Benefit Cash Flow



Sensitivity Analyses

Sensitivity analyses were carried out on several variables and results are reported in Tables 15 and 16. All sensitivity analyses were performed on the GRDC investment criteria using a 5% discount rate, with benefits taken over the life of the investment plus 30 years from the year of last investment. All other parameters were held at their base values.

Table 15 shows the sensitivity to the additional rate of gain assumed due to the current investment being analysed.

Table 15: Sensitivity of Investment Criteria to Additional Rate of Gain due to AWCMMMP
(GRDC investment, 5% discount rate, 30 years)

Criterion	Additional Yield Gain		
	0.025% pa	0.05% pa (Base)	0.1% pa
Present value of benefits (m\$)	87.76	175.81	352.85
Present value of costs (m\$)	17.15	17.15	17.15
Net present value (m\$)	70.60	158.66	335.70
Benefit cost ratio	5.12	10.25	20.57
Internal rate of return	12.6	16.2	20.2

Table 16 shows the sensitivity of the investment criteria to changed assumptions regarding the year of first impact of the investment provided by AWCMMMP.

Table 16: Sensitivity of Investment Criteria to Year of Initial Benefits Delivered from AWCMMMP
(GRDC investment, 5% discount rate, 30 years)

Criterion	Year of First Impact		
	2012/13	2014/15 (base)	2016/17
Present value of benefits (m\$)	212.08	175.81	143.9
Present value of costs (m\$)	17.15	17.15	17.15
Net present value (m\$)	194.87	158.66	126.75
Benefit cost ratio	12.36	10.25	8.39
Internal rate of return	18.1	16.2	14.6

8. Confidence Rating

The results produced are highly dependent on the assumptions made, many of which are uncertain. There are two factors that warrant recognition. The first factor is the coverage of benefits. Where there are multiple types of benefits it is often not possible to quantify all the benefits that may be linked to the investment. The second factor involves uncertainty regarding the assumptions made, including the linkage between the research and the assumed outcomes

A confidence rating based on these two factors has been given to the results of the investment analysis (Table 17). The rating categories used are High, Medium and Low, where:

- High: denotes a good coverage of benefits or reasonable confidence in the assumptions made
- Medium: denotes only a reasonable coverage of benefits or some significant uncertainties in assumptions made
- Low: denotes a poor coverage of benefits or many uncertainties in assumptions made

Table 17: Confidence in Analysis of AWCMMMP Investment

Coverage of Benefits	Confidence in Assumptions
High	Medium

9. Conclusions and Lessons Learned

The investment in the two themes of the AWCMMMP will deliver benefits to the industry via the wheat and barley breeding programs to which the program has contributed significantly. While some breeding companies have benefited more so than others, the cereal industry will benefit from the increased rate of genetic gain delivered by the use of marker assisted selection in breeding with little, if any, additional costs.

The traits where molecular markers have most assisted /are assisting wheat breeders include pre-harvest sprouting resistance, resistance to root lesion nematode (*neglectus*), leaf, stem and stripe rust, and quality traits (polyphenyl oxidase). Molecular markers have contributed most to date in barley breeding in the area of barley quality.

An important outcome of the AWCMMMP is in the area of breeder implementation GRDC provided fully funded marker implementation to each of the breeding programs in Australia for five years. This allowed each program to develop local systems, processes, and knowledge required for successful implementation of all markers available. The cereal breeding programs now fund the application operations from their own breeding budgets. The investment has facilitated increased use of markers with most breeding programs now spending more on marker assisted selection than when GRDC was supporting the applications.

There are two associated lessons of significance apparent in this evaluation:

1. GRDC no longer directly funds cereal breeding and has now focused strategically on pre-breeding. However, the current investment analysis demonstrates the value of linking pre-breeding outputs to product applications, much like most RDCs focusing on on-farm adoption on the principle that an increase in adoption can generate higher and earlier returns to investment in the original innovative technologies.
2. It is unlikely that this investment would have been funded at the scale reported if public funding of GRDC had not been available and funding had been reliant on industry funds alone. This stresses the importance of public funding being available for long term strategic and higher risk research, as well as capacity building. It is quite probable that the outcome of this investment would not have been achieved if GRDC had not been supported by public funding.

Given the assumptions made, the total investment in this investment cluster of \$39.3 million (present value of costs in 2009 \$ terms) has been estimated to provide a net present value of \$362 million and a benefit-cost ratio of 10 to 1 (analysis over 30 years and at a 5% discount rate).

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