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MAJOR ACHIEVEMENTS AND OUTCOMES

PROGRAM 1

- A new method for detecting molecular markers to accelerate wheat breeding.
- New wheat germplasm with major benefits for processors and consumers.

PROGRAM 2

- Commercial launch of the WheatRite test for rain damage.
- Improved quality at harvest and receival: agronomy and storage procedures developed for growers and users.

PROGRAM 3

- Aids for the management of microbe contamination in wheat and flour mills.
- Enhanced process control in bakeries leading to cost savings and superior products.

PROGRAM 4

- Methods for the rapid assessment of the shelf-life of frozen dough products.
- Product quality improvements; knowledge of the effects of different starches and other ingredients on bread, pasta and noodles.

PROGRAM 5

- New equipment and methods to evaluate wheat and flour properties.
- Quality tests to accelerate wheat breeding.

EDUCATION & TRAINING

- Multiple advisory aids provided to growers. Great Grain quality assurance scheme piloted.
- Tertiary educated scientists and technologists enter the industry,

Develop new wheats and new products.

Develop improved diagnostic techniques.

Develop wheat production, handling and processing technology.

Improve product consistency and reduce processing costs.

Increase the supply of highly trained and skilled people in the industry and the organisations servicing it.

Enhance the competitive ability of the wheat industry research and technological services sectors.

Quality Wheat CRC operates within the framework of the Commonwealth Cooperative Research Centres Program with Participants' cash and in-kind funding for the Centre supplemented by financial assistance from the Commonwealth for a period of seven years. Its aim is to achieve a sustainable increase in the contribution of the wheat production, processing and related service activities to Australia. We will do this by generating scientific, technical and business systems knowledge that add value at each point in the production chain.

The Centre comprises representatives from manufacturers of wheat-based products and the major agricultural and research bodies.

The four manufacturers are:

Arnott's Biscuits Ltd;
Bunge Defiance Mills Ltd (merged with Goodman Fielder Ltd during 1998/99);
George Weston Foods Ltd and Goodman Fielder Ltd.

The other organisations involved are:

Grains Research and Development Corporation;
AWB Limited;
NSW Agriculture;
Agriculture Western Australia;
Crop and Food International;
BRI Australia Ltd;
CSIRO Plant Industry and
The University of Sydney.

A senior representative from each of these organisations sits on the CRC's Board of Directors.

The Quality Wheat CRC mission is to support the commercial development of the wheat growing and products industry - the 'grower to consumer' perspective. The CRC's goals reflect this industry-wide view, while focusing on those specific areas where the CRC has particular value to add to the industry's development.

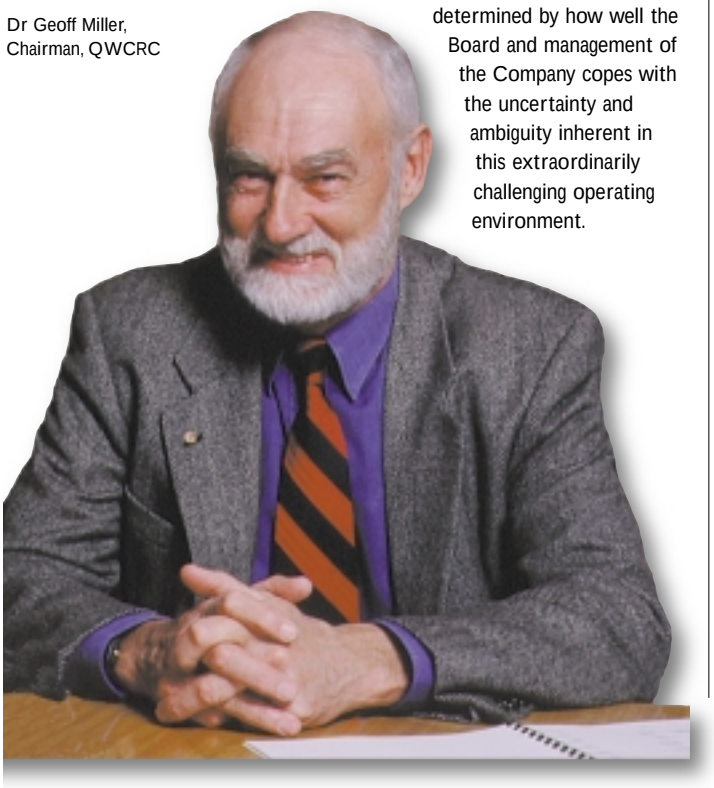
The CRC's goals are to:

1. Develop new wheats and new products (food ingredients, feed and alternative use) that provide consistency and meet the quality requirements of domestic and export markets.
2. Develop improved diagnostic techniques to accurately identify wheat and product quality consistency at different points in the value added chain.
3. Develop wheat production, handling and processing technology to improve industry capacity to utilise wheat of varying characteristics, thus improving the product performance of these wheats.
4. Improve product consistency and reduce processing costs through accelerated adoption of efficient technology with Quality Management systems.
5. Increase the supply of highly trained and skilled people in the industry and the organisations servicing it.
6. Enhance the competitive ability of the wheat industry research and technological services sectors to build (pre-competitive) knowledge to service Australian and overseas firms.

During its fourth year, Quality Wheat CRC Ltd (QWCRC) has continued to exceed performance expectations. These results have been achieved despite the tumultuous change beginning to engulf the Australian wheat and related-food industries.

There is no doubt that the industry rationalisation, now snowballing, will reshape this Company. Whatever the industry outcomes, however, the new research culture developed in QWCRC, the intellectual property emerging from it and the innovations that it will spawn, will all be part of the new industry architecture.

Exactly where QWCRC will fit into that architecture, will be determined by how well the Board and management of the Company copes with the uncertainty and ambiguity inherent in this extraordinarily challenging operating environment.



Dr Geoff Miller, Chairman, QWCRC

In the Managing Director's Report, the achievements of the joint venture have been listed against the eight success criteria set at the beginning of the life of the CRC. Readers can judge these for themselves. In terms of commercial industry outcomes, four developments worthy of particular note are:

- The uptake of the Quality Assurance (QA) systems work of the Company into the "Great Grain" program being marketed in the field by Pulse Australia. While the systems and commercial entities will undergo further metamorphosis, as rival schemes are offered to the industry, the application of QA in the industry is now assured;
- The early emergence of a "hi-tech diagnostics" business from the work of the Company, exemplified by the successful development and commercial testing of the WheatRite® rain-damage test kit. Commercial interest in this and other diagnostic products is beginning to gain momentum;
- The stream of commercially-valuable germplasm, and new insights into breeding technology, now in the pipeline, flowing from the Company's biotechnology program; and
- The increasing confidence that the commercial outcomes emerging to date will be surpassed, in terms of their overall impact, by those yet to come.

During the year, Bunge Defiance was taken over by Goodman Fielder; the privatisation of statutory grain marketing and handling organisations gathered momentum; and the emergent commercial businesses began to align themselves to others, in order to grow and prosper in the new more-competitive environment.

The changes have not been confined to handling and marketing. New technology companies and ventures are also germinating. More recently, in an initiative destined to reshape the wheat-breeding industry, the GRDC has invited expressions-of-interest in developing new structures and approaches, including proposals involving private-sector businesses.

This activity is but the early stages of the rationalisation and development yet to come. In the new environment, participants are already looking to shift the focus of much of their business from the horizontal to the vertical – branching out into "through-chain" activities, from supplying farm inputs to marketing value-added food products. As anticipated in the first Annual Report of Quality Wheat CRC Ltd, this shift is creating new alignments of business interests.

All these changes constitute both threats to and opportunities for the suppliers of research and technological services to the industry, including this Company. Our goal is to make the most of the opportunities. To achieve that, we have to meet two requirements:

- The first is to continue to create value for our existing shareholders, comprising as they do a substantial proportion of the industry, covering most of the value-adding activities. If we manage to do that, then whatever industry configurations and alliances emerge, the CRC's science, and the people who undertake it, will be highly valued and sought-after; and

- The second is to position the company, its structure and its commercial relationships, so as to best realise the value created by the science, in the context of a fast-evolving industry; a remaining known period of only three further years of public funding.

Meeting both of these requirements concurrently is quite a challenge to the management team and the Board. It will be necessary to nurture and enhance the alignment of interests between the scientists and their employers, on the one hand, and between the participants as individual commercial entities and as shareholders in the Company, on the other.

Maintaining a community of interest among the shareholders in QWCRC may require some changes in its structure, even prior to the end of its first seven-year period of public funding. It will certainly require the development of new commercial relationships.

Challenging as these strategic issues are, there is no reason to expect that they will not be handled by management and the Board with the same commitment and competence that has characterised the Company during the first four years of its life.

I would like to thank Bill Rathmell and his team, for continuing to excel at a challenging assignment, and the Executive Committee and Board, for their persistently constructive approach to governing the Company. Finally, on behalf of the Board, I congratulate the scientists for continuing to exceed expectations in creating value for the shareholders, the industry and the national economy.

Geoff Miller
Chairman

The fourth Annual Report of Quality Wheat CRC Ltd records yet another year of solid research progress and excellent science.

It's the people who make up an organisation that determine its success, and all the secondees and employees of Quality Wheat CRC have contributed to this considerable list of achievements - special thanks to all of them.

Dr Bill Rathmell,
Managing Director, QWCRC

The fourth Annual Report of Quality Wheat CRC Ltd records yet another year of solid research progress and excellent science. There are clear outcomes for the wheat industry, new intellectual property and steady movement towards commercialisation and application in the wheat industry. Our education and training programs have developed well this year, particularly in technology transfer to growers. It is appropriate to review our progress this year in terms of the criteria for success that we set ourselves at the beginning of the life of the CRC. I believe this list makes impressive reading:

Increased interactions between groups (commercial and research)

- Many new projects with cross-site interaction between Participants have been started. This year, for example, such projects generating new wheat germplasm, controlling wheat quality in storage and improving mill performance have begun.
- New research projects have been developed or have been started with the non-Participant wheat-growing States (Queensland, Victoria and South Australia).
- In the development of our strategies for the commercialisation of our breeding material (germplasm) we have made research links with commercial organisations like Hybrid Wheat Australia/Sunprime Seeds and with Monsanto (USA).
- Overseas research projects are now also established with agencies in Mexico and in Hungary.
- Expressions of interest in the WheatRite rain-damage test kit have been received from all over the wheat world.
- The Quality Farms Australia quality assurance (QA) activity links us to Pulse Australia, the Australian Oilseeds Federation, the Australian Cotton Industry Council and the Grains Council of Australia.

Commercially important outcomes

- Growers throughout the country evaluated the WheatRite rain-damage test kit successfully and extensively.
- The number of diagnostic tests supplied to Australian and overseas wheat breeders rose to nearly nine thousand.
- The WheatRite rain-damage test kit was also used by breeders to eliminate germplasm showing the "late maturity α-amylase" defect.
- Cost reductions from the use of our process control hardware and software in a single bakery were estimated at a $75,000 per annum reduction in product waste and "give away".
- Our quality assurance (QA) system was developed with others into a pilot "Great Grain" program that was evaluated by leading growers.
- Food companies within and outside the CRC tested our waxy wheat as an ingredient with important benefits to processors and in the creation of novel foods.
- Despite adverse climatic conditions AWB Ltd and growers enthusiastically supported the development of the "Prime Hard in the South" concept, and there was much input from fertiliser manufacturers.
- Our research in the south showed how to recover grain with high quality characteristics by grading following frost damage - an outcome of direct value to growers that was achieved as a result of a rapid response by Centre scientists to the adverse weather.

An increasing intellectual property (IP) portfolio

- In the year we filed domestically and internationally (Canada, Europe, Japan and the USA) on one patent (food colouring), and also filed two new patents covering the WheatRite kit and antibodies that discriminate quality-determining wheat proteins.

- We instructed our patent agents on two other pieces of intellectual property - a novel food product from waxy wheat and a new method to enhance the use of molecular markers in wheat breeding.
- We registered the trademark WheatRite in Australia, Canada, Europe, the USA and in other countries.
- Important research projects provided genes and breeding material (germplasm) with a number of valuable benefits to farmers, processors and consumers such as resistance to rain damage, improved bread, noodles and biscuits and improved factory efficiency. The potential gross value of some of these benefits is large (in the $2-$60M per annum range in Australia alone).

Commercialisation of Centre outcomes

- The strategy based on the creation of a company, QW Investments Pty (QWIP), to attract outside investment to, and manage, the development and commercialisation of Centre inventions has continued.
- The Board approved the use of Centre funds to progress the WheatRite kit. An agreement was signed with the national distributor of the kit, and negotiations have continued on a manufacturing agreement. Production of the first batch of kits has been completed following receipt of an order from the distributor.
- The Board of the Company also approved a continuing strategy for the commercialisation of the Centre's intellectual property (IP) outcomes that are in the form of germplasm (wheat genetic material). This is further discussed below.
- The progress of Quality Farms Australia (QFA - which includes Quality Wheat CRC) was described at Grains Week in Perth where there was general support shown for the adoption of QA on-farm. To speed up delivery to interested growers, Pulse Australia is marketing and supporting our Wheat QA program through their "Great Grain" concept. A per capita payment will be made to QWCRC for the use of our source materials. A contract with Pulse Australia has now been signed.

Increased technology transfer within the wheat industry

- We held a workshop, "Late Maturity α-amylase in Wheat", to report on the occurrence of this problem in Australian breeding material. Senior representatives attended this from all the Australian wheat breeding programs.
- Representatives of all four manufacturing Participants attended a forum organised by two of the major research provider Participants to describe the latest results and industry application of the dough rheology work.
- Another workshop, "Tools for Achieving Wheat Quality Targets", was used to promulgate major agronomic outcomes to all Participants' staff.
- The Centre co-supported (with Topcrop Australia) materials on quality produced by SARDI for farmers in South Australia. We also supported (with Participants and fertiliser distributors) a brochure on quality for growers in the northern part of the southern wheat belt.
- We published our second industry newsletter during the year and also a suite of articles on wheat quality issues in Farming Ahead.

Financial commitment from industry

- A number of new proposals for additional complementary research have again been accepted by the GRDC. These added a further $430,000 to the value of the research under the management of the Company.
- In addition, the budget developed for the core activities of the Centre is about $400,000 above the original Commonwealth Agreement.

Increased impact of the Centre's education and training programs

- The number of postgraduate students has risen to eighteen, four finished during the year under review. Seven new ones will start next year. Six of the recent finishers are now working in the wheat industry.
- Increasing numbers of Quality Wheat for Quality Foods courses have been given, and a version of the course has been prepared for using at smaller growers' assemblies.
- We co-sponsored an "Asian Wheat Users and Markets" course for (Western) Australian Farmers.
- Eight vacation students were given projects this year: three worked in industry and one subsequently negotiated employment in a Participant's laboratory.
- A total of 63 industry managers, staff and students attended two workshops, "Wheat Proteins and Dough Properties" and "Molecular Techniques for Rapid Wheat Breeding".
- Our Wheat Quality fact sheets proved valuable to extension officers.
- A grain storage CD was prepared for release in spring.

Provision of an efficient and selective research management infrastructure

- Again we had a successful Audit of the Company and we met all Board-required and Commonwealth-required corporate governance standards and laws.
- The preliminary report of the economic evaluation of the Centre's program was received. This study, jointly done by the Centre and GRDC, is now the subject of further research involving participants, both commercial and research providers.
- Staffing levels at head office have remained as last year, and existing staff have dealt with communication and commercialisation activities.

Impressive as this list is, we continue to work towards attracting additional investment from the private sector that will enable us to commercialise more efficiently the Company's outcomes, especially those that are in the form of wheat germplasm. These outputs from QWCRC research will form the basis of some of the first wheats available anywhere in the world with benefits such as these:

- improved food processing quality, reduced wastage and costs - (wheats with high amylopectin starch, special biscuit wheats),
- more desirable natural ingredients, fewer undesirable additives and wastes - (wheats with enhanced natural pigments and improved milling yield),
- industrial starch manufacture with reduced environmental impact - (uniform starch granule size) and
- increased farmer revenues - (white wheats with dependable resistance to rain-damage).

These benefits (some of which, as stated earlier, have a large potential value) need to be delivered to growers, handlers and manufacturers by being incorporated into adapted wheat varieties. The wheat varieties have to be bred so that they are suitable for farmers in different climates and for manufacturers of different products and, as such, provide the opportunity for global sales.

Management has had extensive discussions with companies about suitable strategic alliance(s) to achieve this. Many companies in Australia and worldwide are trying to position themselves for the introduction of identity-preserved, biotechnology based wheat products. There is a need for a commercially run wheat-breeding programme in Australia with the resources to bring QWCRC's germplasm (and that of other germplasm providers) to the market. QWCRC is strategically positioned to be involved in these changes in Australia, with its focus on products ready for the market in the next few years.

In closing this year's report I would like to offer congratulations and thanks to the following people. Congratulations to Dr Kevin Sheridan, a Director, who was awarded an AO in the 1999 Queen's Birthday Honours. Dr Chris Hudson, also a Director, was appointed Adjunct Professor in the Faculty of Natural Resources (Department of Agriculture and Veterinary Science) at the University of Queensland. He was also appointed to the Board of the Australia and New Zealand Food Authority (ANZFA). Dr John Skerritt, Program five Manager, was appointed Deputy Director of the Australian Centre for International Agricultural Research (ACIAR) and received the American Association of Cereal Chemists' (AACC) "Young Investigator" award. He and three other CRC secondees from CSIRO Division of Plant Industry (Rudi Appels, Frank Békés and Peter Gras) received awards from the Chief of the Division. Bob Cracknell became president of the International Association for Cereal Science and Technology (ICC) and became a Director of AACC. Fin MacRitchie, formerly seconded to the Centre from CSIRO Plant Industry, and now professor in Kansas State University Department of Grain Science and Industry, received the Thomas Burr Osborne medal from AACC.

Personal thanks to the Company's headquarters staff, Alan Ellis, Helen Warwick, Clare Johnson and Maria Foster and to the Senior Management Group.

I'd particularly like to record the contribution that John Skerritt made to the CRC before he moved on. Not only did he keep abreast of the science, but he also contributed to the education program, the IP portfolio and the commercialisation endeavours with energy and effectiveness. It's the people who make up an organisation that determine its success, and all the secondees and employees of Quality Wheat CRC have contributed to this considerable list of achievements - special thanks to all of them.

Dr Bill Rathmell
Managing Director

Mr Alan Ellis
Business Manager

The Centre was established in July 1995 under the Commonwealth Government's Cooperative Research Centres program by agreement between the Participants (Centre Agreement) and with the Government (Commonwealth Agreement). In the first two years of operation the research was managed under a three program structure. However, it was felt that more effective program management could be achieved by establishment of a five program structure whereby the education program (coordinated by the Centre's Education and Training officer) was absorbed within the relevant programs. This structure has been operational since 1997 and the merits of this decision have been confirmed.

The Participants

Six commercial and six non-commercial organisations.

Industrial	Non-Industrial
Arnott's Biscuits Ltd	Agriculture Western Australia
AWB Ltd	BRI Australia Ltd
Bunge Defiance Pty Ltd*	CSIRO Plant Industry
George Weston Foods Ltd	NSW Agriculture
Goodman Fielder Ltd	Crop & Food International
Grains Research & Development Corp.	University of Sydney

* during 1998-99, Bunge Defiance merged with Goodman Fielder

Ms Helen Warwick
Executive Assistant and
Communications Coordinator

QWCRC Board

The CRC Board of Directors comprises representatives of the CRC participants, the Managing Director and an independent Chairperson.

The Board determines the strategic direction the Centre will take and sets specific performance milestones for the core research programs. It also oversights management of the CRC (in particular management of program outcomes), the Centre's staff, researchers and financial matters and approves the Centre's Annual Operating Plan and the Annual Report.

Board membership comprises (as at 30/6/99):

Members	Representing
Dr G Miller	Chairman
Dr W Rathmell	Managing Director
Dr G Robertson	Agriculture Western Australia
Mr R Wotzak	Arnott's Biscuits Ltd
Mr J Crosbie	AWB Ltd
Mr N Marran	BRI Australia Ltd
Dr J Huppatz	CSIRO Plant Industry
Dr M Dunbier	Crop & Food International
Mr P Loneragan	George Weston Foods Ltd
Dr C Hudson	Goodman Fielder Ltd
Prof J Lovett	Grains Research & Development Corporation
Dr L Cook	NSW Agriculture
Prof R Tanner	University of Sydney

The Executive Committee

The Board is assisted by an Executive Committee comprising the Chairman, Managing Director, and three other Board members.

The Executive Committee:

- manages the various aspects of the activities of the CRC as determined by the Board from time to time and
- carries on the business of the Board between Board meetings.

The Managing Director

The Managing Director is a member of the Board and is responsible for management of the Centre.

The Managing Director:

- provides leadership to the Centre;
- ensures that Centre funds are used in accordance with the budget in the Annual Operating Plan;
- monitors and keeps the Board informed of the Centre's performance;
- supervises the Program Managers and
- identifies new research opportunities.

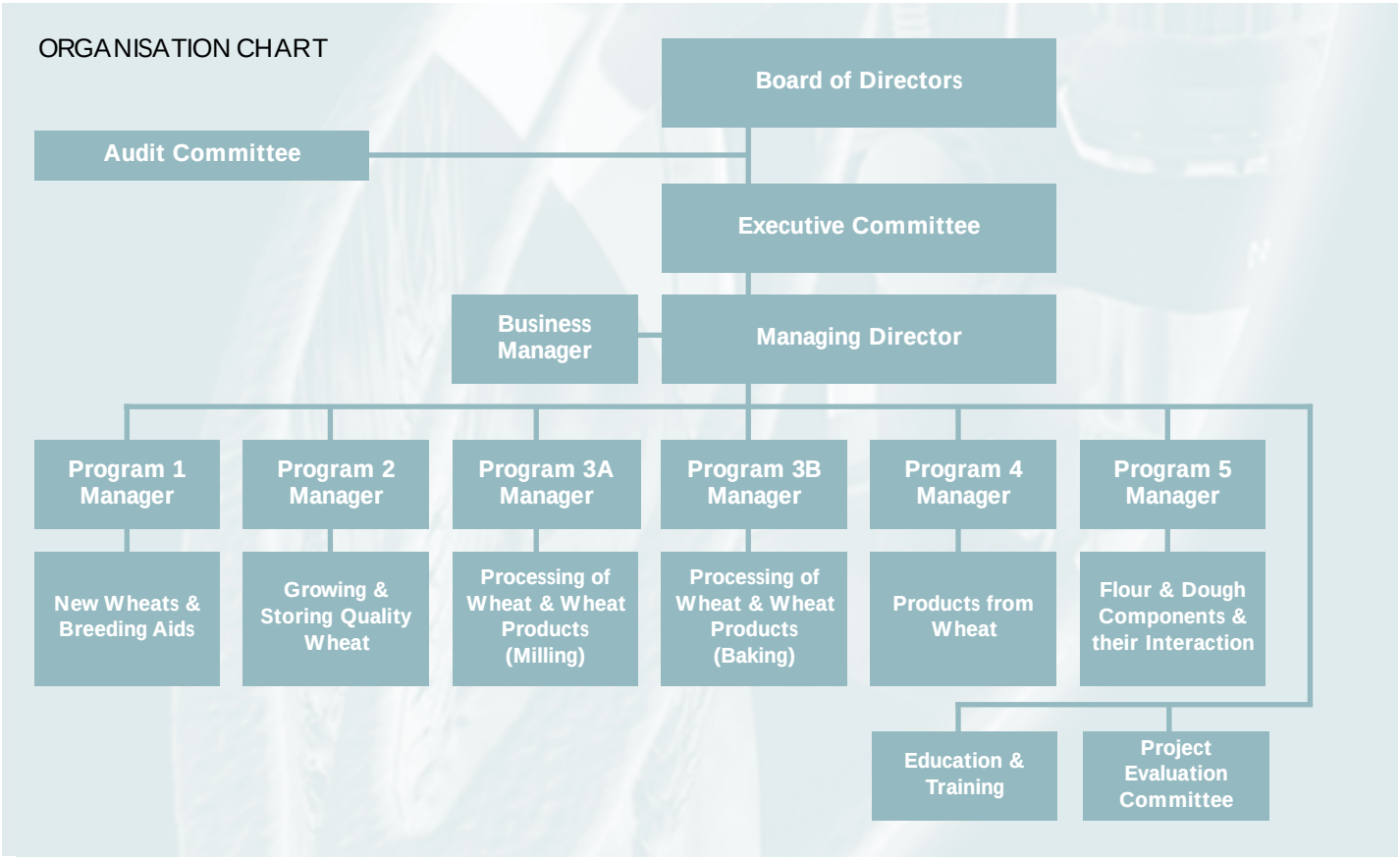
The Senior Management Group

A Senior Management Group (SMG), comprising the Managing Director, the Program Managers and the Business Manager, plus representatives from any research provider not otherwise represented on the Committee, oversees management and evaluation of the Centre's total operations through:

- identification and prioritising activities against industry needs;
- monitoring program performance;
- developing administrative policies and procedures for the Centre as a whole and
- assisting the Managing Director in development of annual budgets, and performance reporting for the Centre, advising the Managing Director on issues to be raised with the Board, and on effective means of responding to specific concerns or requests.

Project Evaluation

During the year, projects in the Quality Wheat CRC program were evaluated along with GRDC projects in the GRDC Quality Wheat program . Professor Gordon MacAulay (professor of Agricultural Economics, Sydney University) in conjunction with consultants from The Centre for International Economics (CIE) conducted a two-phased project with the first phase reporting on the economic model of the grains industry to be used for the analysis.



Dr Douglas Graham
CRC Visitor

This study, done jointly by the Centre and GRDC also involved staff from most of the other commercial Participants of the Centre as well as the research providers. The analytical work was completed in the year under review and the conclusions will be discussed and implemented during 1999-2000.

CRC Subsidiary

To help exploit and commercialise R&D outcomes Quality Wheat CRC established, during the year under review, a fully owned subsidiary QW Investments Pty Ltd. The Directors of this company are Dr William Rathmell and Mr Alan Ellis.

The CRC's management structure is illustrated above.

Dr Geoff Miller
Chairman
Quality Wheat CRC

Dr Bill Rathmell
Managing Director
Quality Wheat CRC

Mr John Crosbie
General Manager
Agrifood Technology

Dr Graeme Robertson
Chief Executive Officer
Agriculture Western
Australia

Mr Norman Marran
Chairman,
BRI Australia Ltd

Dr Geoff Miller AO

Chairman
Quality Wheat CRC Ltd
Riverside Corporate Park
51 Delhi Road
NORTH RYDE NSW 2113

Geoff Miller is a corporate adviser in agribusiness and a company director. He is Executive Chairman of GCM Strategic Services Pty Ltd and Chairman of the Board of Quality Wheat CRC Ltd. He is also a Director of the Queensland Sugar Corporation, Nemair Cotton Coop. Ltd and JEM Boards Ltd; a member of the Board of Trustees of the International Food Policy Research Institute; and adjunct Professor of Agribusiness at the University of New England. In the past, he has served (inter alia) as Chairman of the Primary Industries and Energy Research Council; a member of the CRC Council; a member of the Policy Advisory Council of ACIAR Ltd and of the Australian Wheat Board. He had a distinguished research career with the (then) Bureau of Agricultural Economics, including important work on wheat marketing.

Dr Bill Rathmell

Managing Director
Quality Wheat CRC Ltd
Riverside Corporate Park
51 Delhi Road
NORTH RYDE NSW 2113

Bill Rathmell joined Quality Wheat CRC as its Managing Director at the end of 1995. Between 1991 and 1995 Bill was Research & Development Director of SES Europe, a supplier and breeder of agricultural seeds based in Belgium. Prior to that, he was Exploratory Plant Science Manager at ICI's Agricultural Research Station in the UK. He is adjunct Professor in the Faculty of Agriculture in the University of Sydney. He has also held a number of academic posts in the USA and Europe.

Mr John Crosbie

General Manager
Agrifood Technology
260 Princes Hwy
WERRIBEE VIC 3030

John Crosbie has been General Manager of Agrifood Technology (formerly the Academy of Grain Technology or AGT) since December 1995. Agrifood Technology is the technical services division of AWB Limited, and is responsible for AWB Limited's quality assurance program. Other major Agrifood Technology activities include providing technical marketing support, market-focussed R&D, seed testing services and commercial analytical, training and consulting services to Australian agribusiness. He joined AWB Ltd in 1979, and has been a member of the Executive since May 1992. Between 1991 and 1995, he held the position of Senior Manager of AWB Limited's State Office network. He was WA State Manager between 1987 and 1991, and NSW Operations Superintendent between 1983 and 1986. He has had broad experience in servicing Technical Markets in Sri Lanka, Egypt, the Middle East and Asia.

Dr Graeme Robertson

Chief Executive Officer
Agriculture Western Australia
3 Baron-Hay Court
SOUTH PERTH WA 6151

Graeme Robertson has held this present post since August 1995. His career has involved a wide range of research, development and management activities in agriculture, including a period as officer in charge of the Kimberley region, Director of Resource Management and Commissioner of Soil Conservation, before being appointed Deputy Director General of the Department in 1990. He has been involved in a number of national and state activities involving agriculture and resource management, including 6 years as the inaugural chair of Land and Water Resources Research and Development Corporation.

Mr Norman Marran

Chairman
BRI Australia Ltd
Riverside Corporate Park
51 Delhi Road
NORTH RYDE NSW 2113

Norman Marran has wide experience in agribusiness and has spent most of his working life in agriculture, initially a pioneer of the Australian cotton industry as Chairman and CEO of Auscott Ltd and director of Cargill Oilseeds Australia Ltd, subsequently in the grains industry as a director of the Australian Wheat Board, member of the Wheat Research Council and graingrower in North Central NSW. He is currently Chairman of the Northern Regional Panel of GRDC, Chairman of BRI Australia Ltd and director of Combined Rural Traders Ltd.

Dr Michael Dunbier

Chief Executive Officer
Crop & Food International
Gerald Street
LINCOLN NEW ZEALAND

Michael Dunbier is Chief Executive of Crop and Food International based in Christchurch, New Zealand. He was formerly a Director of the Grains Research and Development Corporation and the New Zealand Foundation for Research, Science and Technology.

Professor John Lovett

Managing Director
Grains Research and Development Corporation
40 Blackall Street
BARTON ACT 2604

Appointed Managing Director of the Grains Research & Development Corporation in September 1994, John Lovett was formerly Professor of Agronomy in the University of New England. He has experience in science and technology, communications, environmental matters and the management of research and development. He served as Chairman of the Oilseeds Research Council, becoming Deputy Chairman of the Grains Research & Development Corporation in October 1990.

Dr Chris Hudson

Director Research and Development
Goodman Fielder Ltd
2 Smith Street
SUMMER HILL NSW 2130

Chris Hudson is Research and Development Director of Goodman Fielder Ltd. He has worked in the food industry in Australia, USA and South East Asia for 26 years. He is a Fellow of the Australian Institute of Food Science and Technology and a Fellow of the Academy of Technological Sciences and Engineering. He was President of the Australian Industrial Research Group (1995-96) and is a Director of the CRC for Plant Science. He is currently President-elect of the Australian Institute of Food Science and Technology.

Dr Michael Dunbier
Chief Executive Officer,
Crop & Food
International

Professor John Lovett
Managing Director
Grains Research &
Development Corporation

Dr Chris Hudson
Director Research and
Development
Goodman Fielder Ltd.

Mr Robert Wotzak
General Manager -
Technical Development
Arnott's Biscuits Ltd

Professor Roger Tanner
P N Russel Professor of
Mechanical Engineering
The University of Sydney

Mr Robert Wotzak

General Manager - Technical Development
Arnott's Biscuits Ltd
11 George Street
HOMEBUSH NSW 2140

Robert Wotzak is currently the General Manager - Technical Development for Arnott's Biscuits Limited. In the past 10 months, Robert has provided the leadership for the Product Development, Applied Research and Packaging Development functions. He has also established and currently manages Arnott's newly created Consumer Contact Centre. Prior to joining Arnott's, he was the Regional Research and Development Director - Asia Pacific for Campbell Soup in Melbourne. Robert's responsibilities in this position included the direct management of the R & D functions for Campbells - Australia, Hong Kong, Malaysia, Spring Valley and Campbells Mushrooms.

Professor Roger Tanner

P N Russell Professor of Mechanical Engineering
University of Sydney
SYDNEY NSW 2006

Roger Tanner began his career in England in the aero-engine industry. Subsequently he has held academic appointments as Professor of Engineering in England, USA, France and Australia. His personal research is in rheology, which is the science of deformation and flow of materials, and especially in the application of large computing efforts to solve practical problems in shaping materials. Professor Tanner has been a director of several CRCs and companies. He has served as the Pro-Vice-Chancellor (Research) at the University of Sydney and also as the Foreign Secretary of the Australian Academy of Science.

Dr John Huppatz

Assistant Chief
CSIRO Plant Industry
GPO Box 1600
CANBERRA ACT 2601

John Huppatz is a graduate of the University of Adelaide with a Ph.D. in organic chemistry. His research career with CSIRO Plant Industry involved structure/activity relationships and mechanisms of action of chemicals affecting plant growth, in particular herbicides and plant growth regulators. His broader interests include the biochemistry and molecular biology of plant growth and development. He is currently Deputy Chief of CSIRO Plant Industry.

Mr Paul Loneragan

Divisional Chief Executive
Weston Cereal Industries
1 Braidwood St
ENFIELD NSW 2136

Paul Loneragan has spent his working life in the Flour Milling and Baking industries. He joined George Weston Foods Limited in 1986 and is currently the Divisional Chief Executive of Weston Cereal Industries (Cereals Division) which covers the flour milling, stockfeed manufacturing and food ingredients business in both Australia and New Zealand.

Dr Lindsay Cook

Director General
Agriculture NSW
161 Kite Street
ORANGE NSW 2800

Lindsay Cook obtained a B.Ag Science from Melbourne and a PhD from New England. He spent a post doctoral year at Oregan State University. He researched pasture seed production problems in the Victorian Department of Agriculture before moving to New South Wales to lead the seeds section for NSW Agriculture. In this position he was responsible for seed certification and registration schemes and the seeds laboratory. Subsequently, he was appointed Principal Agronomist (Cereals) and Director of Plant Production Research. He currently holds the position of Chief, Division of Plant Industries. This division undertakes NSW Agriculture's research and extension programs for all field crops, pastures and rangelands, annual and perennial horticulture, and in soil management, irrigation water management and land use planning.

Mr Paul Loneragan
Divisional Chief Executive
Weston Cereal Industries

Dr John Huppatz
Assistant Chief
CSIRO Plant Industry

Dr Lindsay Cook
Director General
Agriculture NSW

An important success criterion for the Centre is that it promotes research linkages and co-operation amongst its own Participants as well as with outsiders (commercial and researchers). There are many examples mentioned throughout this report, and these are summarised here.

1. Most of the projects with cross-site interaction initiated in previous years have continued (see the Performance Indicators section). Particularly noticeable have been the links with Agriculture WA through the quality assurance, education and agronomy projects, and with the NZ Institute for Crop and Food Research in processing projects. There are also several new projects with cross-site interaction that have started in the year under review:

- A project (1.4.1) to extend the soft wheat breeding program to the Southern region, (this has cash and in-kind support from Arnott's Biscuits, involvement from Bunge/Defiance (now Goodman Fielder) and George Weston Foods, and the research is being conducted by the University of Sydney and NSW Agriculture).
- A project (2.1.6) widely supported by industrial Participants to evaluate practical solutions to the control of wheat quality in storage. Bunge/Defiance, Goodman Fielder and George Weston Foods have been active in this project which has also involved staff from CSIRO Plant Industry and from CSIRO Entomology (Stored Grains Research Laboratory)
- A project (3.1.5) also widely supported, which came out of a brainstorming session, to study novel approaches to the control of mill performance. This is being conducted between commercial laboratories (Goodman Fielder) and BRI Australia.

2. Projects within the Centre that involve scientists from non-Participant organisations have continued this year. The list now includes:

- significant new links with CSIRO Entomology Division (Stored Grains Research Laboratory) in the above grain storage project (2.1.1/6);
- the mill microbiology project (3.1.4) - this project involves Food Science Australia staff; which was the first example of a wholly Centre-funded project employing scientists not part of any Participant organisation and
- the "Prime Hard in the South" project which, though not new, received this year very high levels of interest across all Centre Participants, as well as external organisations. Most notable were CSIRO, NSW Agriculture, GRDC, AWB Ltd, Weston's, Incitec fertilizers, Pivot Agriculture, and agencies from Victoria and South Australia.
- We have supplied immunoassay-based test-kits to wheat breeders at the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT - Mexico City) as well as Australian wheat breeders for their use in rapid identification of a quality character (for the rye chromosome translocation "1B/1R") in early breeding lines. The total number of tests rose to nearly 9000 (5.1.4).
- In addition, our links with the CRC for Molecular Plant breeding have developed, with new research collaborations under discussion, and the Managing Director serving on the Industry Advisory Committee of the Adelaide-based Centre.

3. Links with research groups outside Quality Wheat CRC have also been established through GRDC-funded research projects complementary to CRC-funded work. In the year under review we have been involved in the following projects, drawing in the groups indicated from outside the Centre:

- Amelioration of Genetic Factors which Result in Downgrading of Wheat at Receival (1996 application for funding by CRC project leader Dr Daryl Mares involving scientists from Queensland DPI; project now in progress);
- The Chemical and Genetic Basis of Noodle Quality (Project in progress, co-ordinated by CRC program manager Dr Ken Quail and involving scientists from Victorian Institute for Dryland Agriculture (VIDA) and from SA);
- Flexibility of Wheat Use (1996 application co-ordinated by CRC secondees Drs John Oliver and Colin Wrigley, contracted through the Centre, also involving scientists from VIDA, Agriculture Victoria, SARDI, University of Adelaide, and from Queensland DPI. This project is now in progress as 2.1.5).
- A project to develop high-protein wheat genotypes for S and W regions (co-ordinated by a scientist from SARDI successfully applied for during 1997/8 and now on-going).

- An extension to the "Prime Hard in the South" project, which has involved a wide range of groups (project 2.1.2) was successfully run last year.
- The newly accepted (in 1998/9) GRDC project to identify key quality characteristics required by bread manufacturers using the sponge and dough process (to which the Centre will contribute $23K, Program 4). This involves extensive collaboration with the Leslie Research Institute, Queensland DPI.

4. There has been a marked increase this year in the number of workshops, seminars and publications specifically designed to enhance technology transfer between Participants and to outside commercial and research entities, for example:

- A workshop, "Late Maturity α-amylase in Wheat", to report on a study of Australian breeding material (August 1998 - Program 1). Senior representatives attended this from all the Australian Wheat Breeding programs.
- In October 1998, representatives of all four manufacturing Participants attended a forum organised by two of the major research provider Participants to describe the latest results and industry application of the dough rheology work.
- In February 1999 we held a workshop "Molecular Techniques for Rapid Wheat Breeding" which a total of 46 industry managers, staff and students attended.
- In March 1999, the workshop, "Tools for Achieving Wheat Quality Targets", was used to promulgate major outcomes of Program 2 to all Participants' staff.
- The Centre co-supported (with Topcrop Australia) the "Managing Wheat for Quality" and "Nitrogen Management for Wheat….." guidelines materials produced by SARDI for farmers in South Australia.
- We also supported (with Paricipants and fertiliser distributors) "Increasing Grain Protein in Southern Crops with Topdressed Nitrogen" - a brochure for growers in the Northern part of the Southern wheat belt.
- This year there has been a series of six articles in Farming Ahead, two in Australian Grain, and others in publications as diverse as Rural Weekly and Central and North Burnett Times (Queensland).
- We also published our second industry Newsletter during the year. This document was widely circulated and described outcomes from several Centre projects.

5. Links with groups outside the Centre and overseas have been strengthened by our commercialisation endeavours.

- In the development of our strategies for commercialisation of our germplasm we are discussing links with several commercial entities, and have made new research links with Hybrid Wheat Australia/Sunprime Seeds and Monsanto (USA).
- Evaluation of a larger sample of "waxy" wheat (Programs 1 and 4) was conducted by a non-Participant company as well as by Participants in the CRC and this provided evidence of new processing benefits to be derived from this type of product.
- The WheatRite rain-damage test kit was evaluated successfully and extensively by growers throughout the country and also used by breeders around Australia to detect germplasm showing the "late maturity α-amylase" defect. Agreement has now been reached with a national distributor, Graintec of Toowoomba and negotiations have continued with Amrad-ICT to complete a manufacturing agreement. Interest in the test has been received from all round the world.
- International interest has also been expressed in the new type of small-scale dough mixing machine we have built in a research project (5.1.6) with the Hungarian Institute for R&D (OMFB).
- The Quality Farms Australia initiative now includes Pulse Australia, the Australian Oilseeds Federation, the Australian Cotton Industry Council and the Grains Council of Australia as well as QWCRC. A quality assurance scheme, "Great Grain - Quality Assurance for Grain Growers", has been produced in a joint initiative with Pulse Australia. It is being piloted by a number of grower groups around the country so that refinements can be made.

PROGRAM 1: NEW WHEATS AND BREEDING AIDS

Program Manager: Professor D.R. Marshall

Professor Don Marshall
Program Manager

PROGRAM 1 OBJECTIVES

Identification and characterisation of novel sources of variation for a range of wheat quality attributes.

Tagging of the genes responsible for variation in wheat quality traits.

Development of rapid breeding protocols.

Using these protocols to develop new cultivars for specialty quality markets.

The development of new wheat varieties with novel processing and manufacturing qualities is a key component of the CRC research and development program. Such wheats are important, first, in improving and expanding the production and value adding opportunities for the Australian wheat industry, and second, in delivering the benefits of research and development in wheat quality to both producers and the processing industries. They are also important in the commercialisation of a significant proportion of the intellectual property of the Quality Wheat CRC, nationally and internationally.

In this process, particular emphasis is given to ensuring that the research findings of the CRC and its partners, which can be delivered to industry via breeding, are made available for commercial use as quickly as possible. We are seeking to do this directly by the joint development of new wheats with breeders, or indirectly, through the development of more efficient breeding technologies.

Program Objectives

The objectives of the program, focusing breeding on industry requirements, are thus to identify new and novel sources of variation in economically important wheat quality and processing traits to develop and deploy molecular genetic markers for this novel variation to allow its rapid incorporation into breeding programs and to develop, through strategic alliances with breeding programs, new commercial cultivars with improved processing qualities.

The research objectives of Program 1 are being pursued by means of a four-pronged strategy:

- identification and characterisation of novel sources of variation for a range of wheat quality attributes such as starch, protein and pentosan content and composition;
- tagging of the genes responsible for variation in wheat quality traits using cutting edge molecular marker techniques;
- development of rapid breeding protocols using molecular markers and doubled haploid technology and
- using these protocols to develop new cultivars for specialty quality markets including new soft wheat cultivars for biscuit and cake production, and wheats with waxy starch.

These outputs from QWCRC research will form the basis of some of the first wheats available anywhere in the world with benefits such as these:

- improved food processing quality, reduced wastage and costs – (Wheats with high amylopectin starch, special biscuit wheats);
- more desirable natural ingredients, fewer undesirable additives and wastes – (Wheats with enhanced natural pigments and improved milling yield);
- industrial starch manufacture with reduced environmental impact – (Uniform starch granule size) and
- increasing farmer revenues – (White wheats with dependable resistance to rain-damage).

The potential gross value of some of these benefits is large (in the $2-$60M per annum range in Australia alone), impacting directly on processor profits. For instance, the environmental costs of disposing of effluent containing small granules has been estimated at $25-40 per tonne of wheat used in industrial starch manufacture (half a million tonnes per year in Australia).

The above benefits need to be delivered to growers, handlers and manufacturers by being incorporated into adapted wheat varieties. The wheat varieties have to be bred so that they are suitable for farmers in different climates and for manufacturers of different products and as such provide the opportunity for global sales.

At present only a small minority of the germplasm projects of QWCRC Ltd involve transfer of genes by genetic engineering into the new wheats (genetically modified organisms or GMOs). In the longer term more such projects could be included. This could occur when there is demand from the market and when the technical capability exists, also provided there is public and government acceptance of such projects.

Project 1.1.1 - Exploiting new variants in starch B granule content

Project Leader: Dr. F. Stoddard

Background and Objectives

In the developing wheat endosperm, starch is deposited in two main sizes of granule, type A with diameter of about 25 µm and type B with diameter of about 5 µm. This project was started because starch/gluten manufacturers reported that B granules were lost during processing, necessitating additional treatment of the waste water. Starch end-users also have expressed a requirement for a unimodal granule size distribution, and biscuit manufacturers wanted reduced water absorption, which could

also be achieved by reducing B-granule content. Our objectives are therefore to establish the genetic basis for variation in B-granule content and then to use that knowledge in the efficient production of new wheat cultivars with greatly reduced B-granule content.

Progress

In the three previous years of this project, we have determined the range of B-granule content available in a range of wheat and related species. One soft wheat was much lower in B-granule content than any other cultivar and this line, which we call "Outlier 67", is an important source for further development. We also investigated the expression of B-granule content in the cross of cv Sunco with Iraq landrace ME71 and found that it was determined by several genes. Both additive and dominant forms of gene expression were found and epistatic interaction was also significant, indicating that this trait is complex in its inheritance. In addition, we showed that the B-granule content of an endosperm was determined by its own genotype, not that of the mother plant.

This year we have examined the expression of B-granule content in detail in several crosses. In every case, additive, dominant and epistatic expression were all significant. In addition, cytoplasm often played a small but significant role. These results show that we are dealing with a typical quantitative trait. We have therefore had a doubled-haploid population produced from the cross of Vulcan x Kewell, representing the greatest extremes of B-granule content available in Australian germplasm. This population of 400 lines has been grown in controlled environment chambers, to produce reliable data on B-granule content, and also in the field at Narrabri, to produce larger quantities of grain for testing. We are in the process of seeking molecular markers that will co-segregate with B-granule content in this population. Such markers will enable more efficient tracking of genes lowering B-granule content.

We have previously found wild wheat relatives with no apparent B granules. We are attempting to transfer this trait to domesticated wheats. Grains from a second backcross of one species to cultivar Kewell showed a broad range of B-granule contents that was not correlated with grain filling. This result clearly refutes the argument that B granules are produced to "fill space" in a nearly full endosperm.

Outlier 67 has been crossed to Vulcan to produce an experimental population for further genetic studies. We have consulted with several potential end-users to determine what other attributes are desirable in a low B-granule cultivar. On this basis, three recent cultivars have been selected for crossing to Outlier 67.

Project 1.1.2 - Manipulation of the yellow colour of Asian alkaline noodles

Project Leader: Dr. D. Mares

Background and Objectives

Colour is an important component of quality in yellow alkaline noodles (YAN) and plays a major role in determining consumer acceptance and market access. A number of independent genetic factors control colour and these are affected by the growing environment and the flour milling process in different ways. This is particularly important for some of the flour constituents involved in the development and stability of colour that derive from grain tissues other than the starchy endosperm. Critical factors include: the initial brightness of flour and noodles, the degree of bran and germ contamination of flour, the xanthophyll and flavonoid content of the flour, and the stability of brightness and the yellow colour. In addition there may be interactions between these factors. There is considerable potential to improve all of the components of YAN colour and in so doing to increase the competitive advantage of Australian wheat in this important export market, to reduce the need for artificial colour additives, and to develop speciality wheats for existing or new products. The focus of this project is on improving the yellow colour of YAN both directly, by manipulating xanthophylls and flavonoids, and indirectly by reducing deleterious interactions with other factors such as oxidative darkening.

Progress

Stability of flavonoids in noodles

The apigenin diglycosides which are the major flour constituents responsible for the alkali-induced yellow colour of YAN, appeared to be very stable chemically during 2 days storage of raw noodles. A series of experiments involving the use of specific inhibitors, heat treatments and germplasm with extreme diffences in enzyme levels, indicated that these compounds were unlikely to be oxidized by polyphenol oxidase (PPO). By contrast, an as yet unidentified minor constituent was rapidly degraded in raw noodles, in noodles that had been heated to denature enzymes, and in aqueous solution. Degradation of this component of yellow colour is therefore non-enzymic and presumably contributes to

the slight loss in yellow colour that occurs in raw noodles over time. Whilst PPO does not directly affect the yellow compounds, the dark oxidation products produced by PPO and possibly other oxidases can mask the yellow colour and cause an apparent loss in b*. This effect was quantified by adding black indian ink to noodle sheets thereby enabling the development of a mathematical relationship between change in L* (brightness) and b* (yellowness). The practical significance of this interaction was demonstrated by ranking a set of doubled haploid lines in order of increasing final b*. High and stable b* was associated with lines that had low PPO. As a consequence, selection for high flavonoid content would be of little practical use unless darkening is also reduced.

Variation in flavonoid content

A survey of genetic variation for flavonoid content in wheat and wheat relatives continued. Flavonoid content in 225 *T.tauschii* accessions varied from 0.075 to 0.57 OD units/g grain weight compared with ranges of 0.16 - 0.22 for durums and 0.22 - 0.36 for bread wheat of Australian, Japanese and US origin. Within the *tauschii* set, flavonoid content was strongly correlated with grain size. This was not unexpected given reports in the literature that embryo size is related to grain size and the results of our earlier work that identified the germ tissue as the source of grain flavonoids. For this reason, flavonoid contents were converted to units/g rather than units/grain. To this point there has been no evidence of flavonoid synthesis in the endosperm of wheat or its relatives. Current strategies for increasing flavonoid content in flour are therefore based on increasing the content in the germ and the assumption that a proportion of this increased content will be carried into flour. Further survey work on synthetic wheats is planned before a decision is made regarding utilization of the variation detected in the *tauschi* group.

Variation in xanthophyll content

Xanthophylls impart a yellow or creamy colour to flour and flour products irrespective of pH. High xanthophyll content is an advantage for YAN, but at levels that give yellowish flour there are deleterious effects on the colour of other end-products. Populations derived from sources of very high xanthophyll and genotypes with good noodle colour stability/low PPO, were screened in 1998/99. Several lines were recovered that recombine xanthophyll levels typical of durum wheats with low PPO. These lines will be further assessed in 1999/2000 and will go into a back-crossing program to recover all the good noodle-making characteristics and agronomic features of the adapted parent. This novel germplasm will give very yellow flour and would not be suitable for pan or steamed bread. The target would be an ingredient wheat/flour, that would allow noodle manufacturers to manipulate the yellowness of YAN, or a flour for specialty products where yellow colour might be an advantage.

Time course of synthesis of flavonoids and xanthophylls in developing wheat grains

Ear samples were harvested at 5 day intervals between flowering and maturity and grain analysed for xanthophyll content, flavonoid content and total phenolics. Flavonoid content, specifically the flavonoids responsible for the alkali-induced component of yellow colour in YAN, reached a peak at 30 - 35 days after anthesis and the showed a small decline up to maturity. Levels at maturity in Sunco, for example, were approximately 75% of levels at the peak. By contrast, total phenolics were already high at the earliest stage examined and declined steadily up to maturity. Similarly xanthophylls (lutein and its esters) were high at day 20 and declined to about 5% of this level at maturity. These different patterns of accumulation and degradation presumably reflect differences in the physiological function of the particular compounds and the grain tissue involved in synthesis. In the case of xanthophylls, the amount remaining in the mature grain was very much a remnant of compounds present at the very early stages of grain development.

Project 1.1.3/5 - Genetic dissection of flour processing properties

Project Leaders:
Dr. R. Appels and Dr. I Batey

Background and Objectives

The project, in association with the National Wheat Molecular Marker program, will provide:

- intellectual property relating to the identification of DNA markers linked to specific starch functional properties;
- acceleration of breeding, using DNA markers, for aspects of starch swelling volume (and noodle quality) which are not accounted for by the presence or absence of granule bound starch synthase (GBSS) on chromosome 4A;
- new DNA markers, and functional quality tests, for defining starch quality attributes for Plant Breeders Rights and for marketing and

TABLE 1.1 GELATINISATION PROPERTIES OF WHEAT STARCHES

Sample	GBSS	Onset Temp. (°C)	Peak Temp. (°C)	End Temp. (°C)	Delta-H (J/g)
Survey wheats	-	50.9 - 59.2	56.2 - 65.3	61.7 - 72.5	2.8 - 4.1
Survey wheats	Null-4A	51.1 - 58.6	56.9 - 65.2	61.7 - 72.5	2.8 - 4.1
Survey wheats	Normal-4A	50.9 - 59.2	56.2 - 65.3	61.7 - 71.9	2.8 - 4.1
Reeves X Kulin progeny	Null-4A	51.2 - 56.2	57.6 - 61.6	62.3 - 67.4	2.9 - 3.8
Reeves X Kulin progeny	Normal-4A	51.0 - 56.4	56.5 - 61.8	62.8 - 67.7	2.9 - 3.5

- improvement in the consistency of supply of specific starch qualities in wheat flour through improved technology for defining appropriate wheat lines.

The wheat quality objectives group established by the GRDC has provided key guidelines as to quality attributes that require particular attention in Australian wheat breeding. Ranked in the top five attributes is starch functionality and, in particular, there is the constant need to improve starch viscosity in combination with other quality traits. Based on the requirement to provide accurate information about the genetic control of starch functionality, the project initially examined a number of crosses to identify ones that were suitable for more detailed analyses as well as developing and validating small-scale tests for starch functionality. As the doubled haploid lines from the GRDC- National Wheat Molecular Marker program (NWMMP) have started to become available, the focus has turned to this material as a means of combining the expertise acquired in the assay of starch functionality with a detailed genetic analysis.

Progress

Preliminary studies to establish techniques and assess the key variables of starch functionality

The preliminary study of variation in starch properties utilised progeny from the crosses:

- Weaver x Sun234A;
- Sunbri x Sunco and
- Reeves x Kulin

In addition to providing the basis for validating a number of small-scale starch functionality tests, these studies showed that while the presence or absence of granule bound starch synthase on chromosome 4A (4A-GBSS) had dramatic effects on starch viscosity, this was clearly only part of the control on starch functionality. In the Weaver x Sun234A the presence or absence of the GBSS allele was not a variable (since both parents were null for the 4A-GBSS) and progeny lines showed a 2502 to 3757 centripoise range in starch viscosity (peak viscosity in RVA).

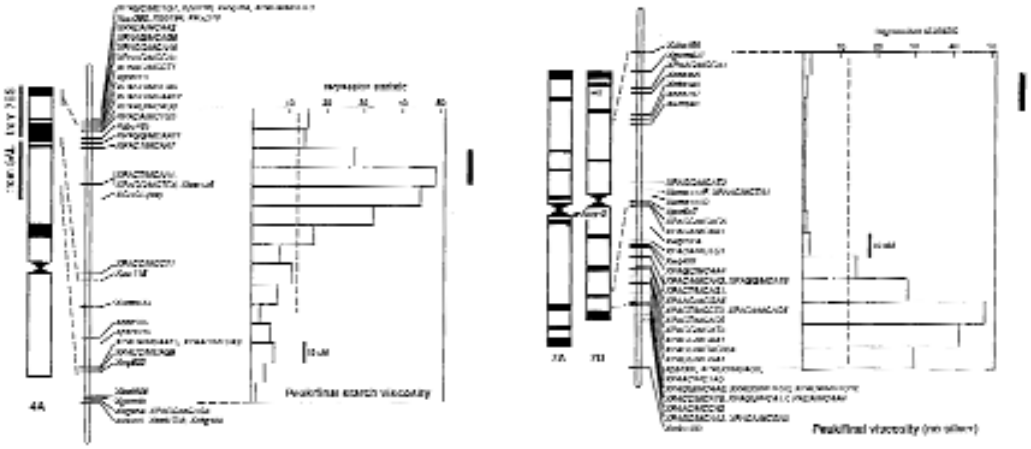
The availability of a Perkin-Elmer differential scanning calorimeter (DSC) provided a new, and very small-scale, procedure for assessing the functional properties of starch. An extensive study of Australian cultivars, as well as progeny from the crosses noted above, indicated that onset of gelatinisation could be measured accurately and showed variation that was independent of the presence or absence of the 4A-GBSS allele. The data in Table 1 shows clearly that the variation in onset of gelatinisation temperature was significant among wheat lines, in both the "survey" and Reeves x Kulin groups of lines, whether or not the GBSS allele on chromosome 4A was present.

These results were confirmed with limited studies of double null-GBSS and triple null-GBSS (waxy) lines from projects 1.1.7 and 1.1.11. Starch from Japanese lines has also been studied and included Kanto 107 (double null) and a waxy triple null line derived form Kanto 107.

Genetic analysis of variation in starch functionality

The preliminary studies described above established technologies that could be used to assess starch functionality. These technologies include RVA viscosity measurements in the presence of silver nitrate to inhibit α-amylase activity, and measurement of onset of gelatinisation temperature in DSC. As this preliminary phase was nearing completion, the material from the doubled haploid lines in the NWMM program became available (during 1998) and the analysis of this material has dominated the project. The first of the 173 lines derived from the

FIG 1.2 - DNA Markers linked to peak/final starch viscosity (RVA Measurement)



Cranbrook (contains all three GBSS alleles) x Halberd (missing the GBSS allele on chromosome 4A) have been extensively studied. A total of 5 crosses are being targeted for analysis in the NWMM program, for completion by 2002. The flour samples for CD87 x Katepwa and Sunco x Tasman (180 samples each) are coming through this month (June, 1999). Our experience to date suggests that the following characteristics need to be analysed:

- RVA (peak/final viscosity);
- starch swelling volume;
- onset of gelation temperature (DSC);
- grain weight and hardness (single kernel analyser) and
- characteristics of molecular size and shape (field flow fractionation).

The data illustrated in Figure 1.1 indicates that the first steps in identifying DNA markers for characteristics that define starch content and functionality can be achieved in the populations being studied. They illustrate the depth of analysis of the Cranbrook x Halberd cross which is now nearing completion in preparation for the analysis of the other crosses coming through the program. The compilations below were achieved through a close collaboration within the NWMM program, in particular with Angelo Karakousis (the coordinator of the genetic maps).

DNA markers linked to peak/final starch viscosity (RVA measurement)
In the Cranbrook x Halberd cross, starch peak viscosity, final viscosity and swelling volume map predominantly to the region of chromosome 4A where the GBSS in the cross is either present or absent. The profound effect of the presence or absence of the GBSS allele on chromosome 4A is striking and raises the question as to whether other genes, close to this GBSS gene, are also missing in the deletion that characterises Australian udon noodle quality wheats.

A consistent trend maps milling yield to the terminal region of the short arm of chromosome 7A/7D. Other regions of the genome influence this character but insufficient data are available to clearly assign genetic influences in the Cranbrook x Halberd cross.

A key finding during the course of this study was the contrasting results obtained in the presence or absence of silver nitrate in the RVA studies, reflecting the contamination of starch preparations with α-amylase (from the Cranbrook parent). The presence of silver inhibits the action of α-amylase.

Both Cranbrook and Halberd are classified as "hard". It was of interest therefore that the relatively small difference in degree of hardness that segregates in the cross is clearly controlled by the classic *Ha* locus on 5DS. It seems possible that the *Ha* locus contains a cluster of genes that account for different levels of hardness in the grain.

TABLE 1.3 EFFECT OF COMMERCIAL GLUTENS ON INDIVIDUAL STARCHES FROM THE CRANBROOK X HALBERD LINES (measurements in RVA units)

	Starch from Cranbrook x Halberd progeny	After addition of a single preparation of commercial gluten	Difference
RVA-Peak	249 to 403	228 to 417	-71 to +32
RVA-Trough	141 to 221	114 to 193	-4 to -49
RVA-Final	281 to 459	227 to 403	-10 to -91

TABLE 1.4 EFFECT OF ISOLATED GLUTEN (FROM CRANBROOK X HALBERD LINES) ON A SINGLE COMMERCIAL STARCH (measurements in RVA units)

	A single commercial starch	After addition of the gluten from Cranbrook x Halberd progeny	Difference
RVA-Peak	237	256 to 329	19 to 92
RVA-Trough	155	155 to 188	0 to 33
RVA-Final	306	312 to 358	6 to 52

Variation in flour paste viscosity due to interactions with protein

During the course of validating the measurements of starch viscosity in the Cranbrook x Halberd derived progeny, the effect of gluten on starch viscosity was measured. Starch and protein (gluten) were isolated from 40 lines of the Cranbrook x Halberd population of progeny. Each starch was mixed with a common gluten (commercial gluten was used for this purpose) and each of the glutens was separately mixed with a common starch (commercial wheat starch). The viscosity of pastes from these "flours" was measured in the Rapid Viscoanalyser (RVA).

The gluten had a variable effect on the RVA viscosity of the different starches. The results are shown in Table 1.3. The commercial gluten being added to the different starches caused a reduction in peak viscosity with some starches, but an increase with others. There was a decrease in the final viscosity with all starches but there was a large variation in the size of this variation.

The effects of varying the gluten component are shown in Table 1.4. Similarly, there was a significant variation in the size of the change in viscosity. An interesting suggestion from the data was that the size of the variation may be dependent on the HMW glutenin sub-unit composition; this needs further study. The results of this analysis should assist in defining the influence of protein on flour qualities targeting products such as udon noodles.

Project 1.1.4 - Genetic factors affecting Udon noodle quality

Project Leader: Dr. P. Sharp

Background and Objectives

This report summarizes the main points of three years of postgraduate research aimed at identifying genetic factors that affect white salted or Udon noodle quality. Secondary objectives were the development of novel methods for discovering microsatellite (SSR) markers and the cloning of the structural genes for polyphenol oxidase (PPO), an important class of enzyme implicated in discolouration of all classes of noodles.

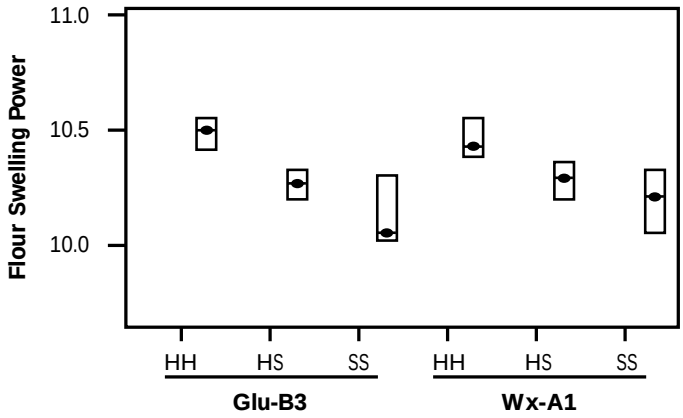
Progress

Australian Standard White (and the noodle segregation of this class) is the preferred source of flour for Udon noodle production in Asian countries, a preference that is largely conferred by the highly desirable pasting properties of this flour. These properties result from a well-characterized null mutation at the waxy locus located on chromosome 4A, which encodes one of the proteins involved in amylose synthesis. However, significant variation in noodle-making quality exists between wheats that are fixed for this mutation, indicating that there are also other important genetic factors. In this work, several of these genes were identified by analysis of an F_2 mapping population derived from a cross between the null 4A wheat cultivars Halberd and Stiletto. Using candidate gene and Quantitative Trait Loci (QTL) mapping strategies, chromosomal regions explaining approximately 50% of the phenotypic variation associated with flour swelling power were identified. This trait is highly correlated with the three important noodle textural parameters: elasticity, smoothness and softness, the latter of which is the most reliably predicted. The cloning of PPO genes was unsuccessful because of technical problems with the probes used.

Traditional approaches for developing microsatellite (SSR) markers are time-consuming and expensive. Consequently, considerable effort was devoted to the development of a novel method that enables discovery of SSR markers without the prior requirement of DNA sequence information. The method developed allows the rapid generation of a virtually unlimited supply of markers, whose usefulness and chromosomal location can be determined prior to the design of sequence-specific Polymerase Chain Reaction (PCR) primers. The utility of this method was demonstrated with

FIG 1.5 - Effect of the allelic constitution at *Glu-B3* and *Wx-A1* on flour swelling power (FSP) in the Halberd x Stilleto mapping population.

Shown is the average FSP over four sites for F2 progeny grouped by their allelic constitution at Glu-B3 and Wx-A1. The central black dot represents the median and the grey rectangle the 95% confidence interval of the median. Allele effects were significant at the 0.001 significance level and explained 22.8% and 12.6% of the total phenotypic variation, respectively.



the genetic mapping of 72 random SSR markers, 18 of which were converted to locus-specific SSRs. In addition, the method was employed as a strategy for rapid discovery of chromosome-specific SSRs, six of which were converted to specific PCR markers. While several technical aspects of the method require further development, this technique offers a useful alternative to traditional approaches for SSR marker development.

Project 1.1.6 - Development and application of new antibody probes for mapping and selection of wheat phenotypes

Project Leader: Dr. J. Skerritt

Background and Objectives

The main aim of the project was to establish a library of antibodies that can distinguish the several loci on each chromosome arm and to develop rapid and simple assays to target specific quality and other attributes in wheat. To achieve the targets, the water-and salt-soluble proteins were mapped on chromosomes and monoclonal antibodies to these proteins were raised.

Progress

The chromosomal control of water and salt-soluble proteins established in previous years was confirmed by analysing some genetic lines on two dimensional electrophoresis at two different isoelectric point (pI) ranges. Additionally, the proteins which eluted in high performance liquid chromatography (HPLC) fractions were collected and analysed by SDS-gel electrophoresis and several proteins which were separated by different techniques were correlated. In this way, a precise map of water-soluble proteins has been produced. Some proteins purified by HPLC were characterised by N-terminal amino acid sequencing in order to establish the identity of non-gluten proteins.

A polymorphic water-soluble protein (pI 7.1) mapping to the short arm of chromosome 3B has been further analysed by screening 172 lines of Halberd x Cranbrook population by isoelectric focusing. It has been confirmed that this protein is present on chromosome 3BS. The analysis of another population obtained from a Synthetic x Opata cross is underway in order to find out the precise locations and map distances of genes controlling this protein on the chromosome.

The library of monoclonal antibodies to water-and salt-soluble proteins developed last year has been screened for the specificity of antibodies to non-gluten proteins. Many cell lines were screened in immunoblots, and lines showing narrow specificity have been subcloned. The most specific cell lines have been used for ascites development for producing antibodies with higher concentrations. Ten antibodies were purified and used in immunoaffinity procedures.

The antibodies to lysine rich proteins were used to map the genes controlling these proteins on wheat chromosomes. Genetic control of lysine rich proteins was found to be on chromosome groups 2, 3, 5 and 7.
This project is now completed.

Project 1.1.7 - Development and evaluation of waxy wheat

Project Leader: Dr. P. Sharp

Background and Objectives

The amylose content of wheat grain is an important determinant of the quality of wheat flour and is largely determined by the amount of the "waxy" protein, or granule-bound starch synthase (GBSS), expressed in the endosperm. The waxy protein in bread wheat is controlled by null alleles of three waxy genes. Introducing the null allele from the three genes into one line will results in wheat with amylose-free (waxy) wheat, which is attractive for certain industries, such as noodle and biscuit manufacturers. DNA markers are now widely used for different purposes, including marker-assisted selection in breeding programs. We have constructed a breeding program utilising marker-assisted selection to produce waxy wheat cultivars. In this program, DNA markers are being developed and used for introgression of waxy genes from a donor line into commercial cultivars. A marker-assisted selection approach is also being used for the selection of the recurrent parent genotype, in

order to reduce the number of backcross generations.

Progress

Breeding and marker-assisted selection in backcross materials

Third generation backcross progeny (BC3) seeds resulting from crosses of DHWx-12 (the donor of the waxy genes) with four different recurrent parents, namely Goldmark, Janz, NP150 and Silverstar, have been sown for the winter generation. These BC3 seeds are carriers of the null allele of the three waxy genes. DNA markers developed in the program, including a microsatellite within one of the waxy genes, enables these genes to be detected. In addition, during the backcross generations, a marker-assisted approach was used to select for concurrent maintenance of the background genetics of the recurrent parents. A total of 15-20 microsatellites were used in each generation to select for recurrent parent genotype, and 2-4 families were selected from each of the 4 crosses. These seeds are being grown for doubled-haploid (DH) production of waxy seeds and possibly for further backcrossing. From each family, 5-40 seeds have been sown and are in seedling stage.

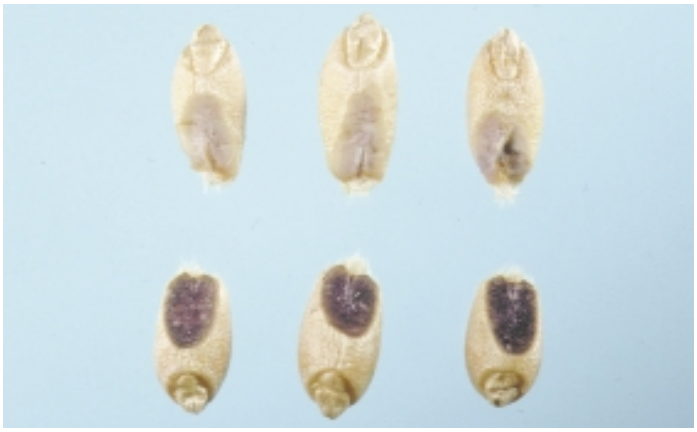
Winter increase of doubled-haploid seeds of waxy-NP150

A small number (15) of doubled-haploid seeds of waxy NP150 derivatives was sown for winter increase of the lines. These lines were produced over the summer, from second-generation backcross (BC2) plants of DHWx-12 X NP150, using the wheat X maize DH production system.

Breeding waxy Janz lines

About 2000 waxy lines belonging to 50 F4 (4th generation) families from a cross between a waxy genotype and the cultivar Janz,

FIG 1.6 - Staining with iodine solution reveals the cut surface of normal starch wheat grains stained dark blue-black while waxy starch grains stain light tan in colour.



were sown in the field at Narrabri for further selection of morphological, agronomic and quality characters. These lines were selected to resemble Janz for seed coat colour, rust resistance (especially *Sr24/Lr24*), and for morphological and phenological traits. Selection for these characteristics was done under microclimate conditions in the F2 and F4 generations, and in field conditions in the F3 generation.

Production of waxy grain for testing

The 1998 harvest produced a one tonne grain sample of a waxy genotype, as well as kilogram amounts of three other waxy genotypes. These were supplied (some after milling) to the CRC commercial partners for evaluation. A workshop reporting the results of this testing provided valuable information to guide the breeding program.

Future work

We plan to examine lines derived from a different cross, CD87 and Katepwa, starting in June 1999. CD87 and Katepwa are two lines with the same 4A-GBSS alleles, so any variation in viscosity will result from other differences.

Project 1.1.8 - Development and application of wheat microsatellite markers

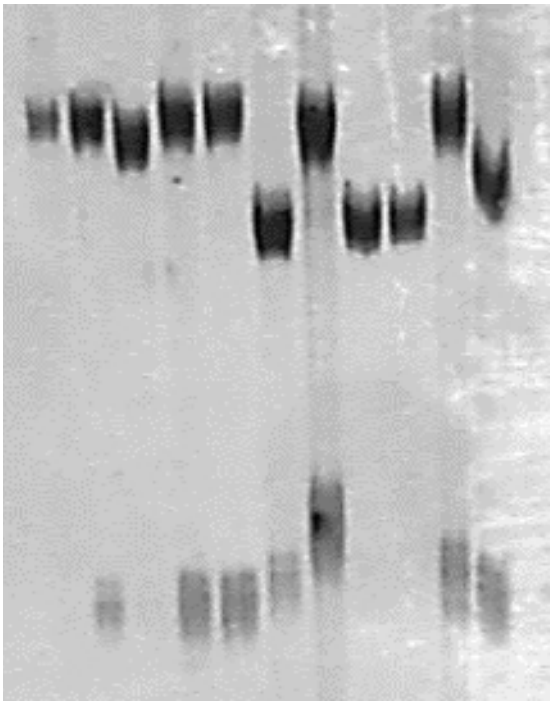
Project Leader: Dr. P. Sharp

Background and Objectives

DNA markers are becoming critical tools in breeding wheat for many different purposes including construction of genome maps, parentage testing, variety identification and to aid selection in breeding programs. Microsatellites are at present the most attractive markers, because of hyper-variability, abundance and even distribution throughout the genome, and easy detection with Polymerase Chain reaction (PCR) techniques. Microsatellites are being progressively developed worldwide. The objective of this program is to evaluate microsatellite markers in Australian wheats and to utilise them as DNA markers for quality traits in breeding programs, genome mapping and variety identification.

Fig 1.7 - A multiplex PCR using two sets of WMC primers.

Samples analysed are (left to right), Cranbrook, Egret, a Waxy line, Goldmark, Janz, NP-150, Silverstar, Halberd, Stiletto, Opata85, and Synthetic.



Progress

Evaluation of polymorphism of microsatellites

GRDC parental lines

In collaboration with the GRDC National Wheat Molecular Marker Program (NWMMP) the 12 GRDC parental lines are being evaluated for microsatellite polymorphisms. This program is to identify polymorphic markers in the mapping populations in order to construct genetic linkage maps from the doubled haploid progeny. In cooperation with the International Wheat Microsatellite Consortium (WMC) a total of 353 primers obtained from the consortium was divided amongst three groups, namely University of Sydney, Southern Cross University and CSIRO Plant Industry. Each group was allocated about 118 primers which were tested on the GRDC parental lines. In addition, 64 primers from the WMS set of Roder *et al* (1998) were also tested on the GRDC parental lines. The level of polymorphism was 37% for WMC primers and 70% for WMS primers. The different level of polymorphism observed is because the WMS primers were already screened and only polymorphic ones were reported in the literature. In contrast, the whole group of WMC primers (without any pre-selection) was scored for the first time and therefore a lower level of polymorphism was to be expected.

Waxy parental lines

A total of 334 primers was evaluated on the 5 waxy parental lines of project 1.1.7. The aim of this evaluation was to search for markers linked to the waxy genes and to find polymorphic markers for selection of recurrent parent background in the waxy breeding program of project 1.1.7.

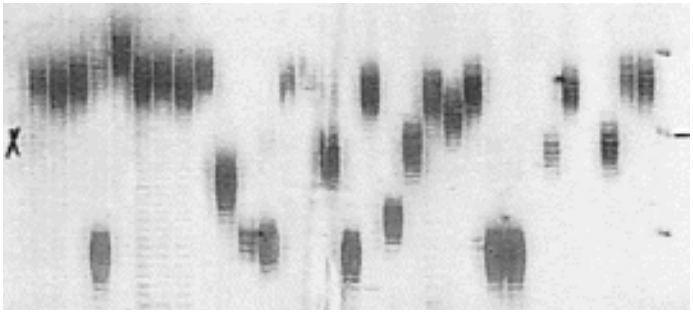
The level of polymorphism in the waxy breeding materials was about 13% for the WMC primers and 56% for the WMS primers. The level of polymorphism in this population was much less than that observed in the GRDC lines. This can be explained with the smaller number (5) of waxy breeding lines coupled with the fact that Goldmark and Silverstar have the same parents, compared with the larger number (12) of GRDC parental lines. Nevertheless there is a sufficient number of polymorphic markers for selection of background genetics in the waxy breeding material, and this is being implemented during the backcross generations, as reported in program 1.1.7.

In search for possible linked markers, the primers were also tested on two F_2 populations, from crosses of DHWx12 X Janz and of DHWx12 X NP150, and were fixed for the null alleles of all three waxy loci. None of these markers were found to link to the waxy genes. Therefore, the waxy microsatellite already developed in this program is still the only marker known to be linked to the waxy genes.

Wheat variety identification

In this project, in collaboration with three other Australian groups in a GRDC wheat variety identification project, 4 microsatellite markers were evaluated on 32 selected cultivars. The joint results were evaluated for the quality of PCR products and for the level of polymorphism. From this, 4 microsatellite markers were selected for scoring on 95 Australian cultivars. This experiment is in progress and the results will be analysed to decide on a final small number of microsatellites suitable for cultivar identification.

Fig 1.8 - Polymorphism at a microsatelite locus in 32 wheat cultivars



Project 1.1.9 - Marker assisted selection for sprouting tolerance and late maturity α-Amylase (LMAA)

Project Leader: Dr. M-K. Tan

Background and Objectives

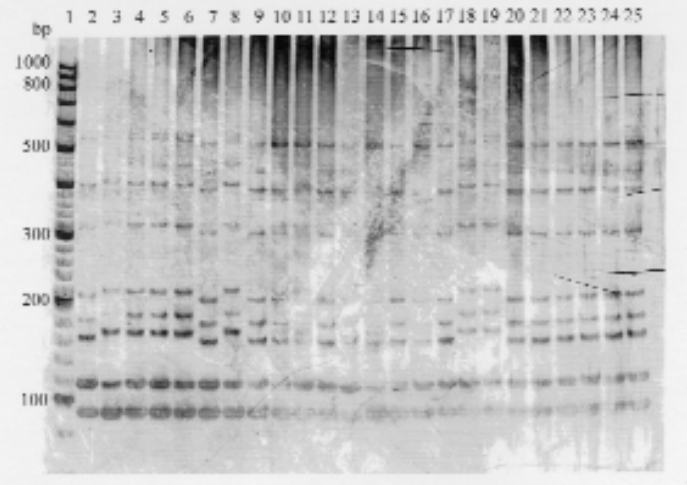
The major source of sprouting tolerance used in Australian breeding programs, AUS1408, shows a consistent level of grain dormancy at harvest-ripeness which is useful in practice. The dormancy in this genotype is controlled by two recessive genes located on chromosome 3D. One of these genes is associated with embryo-sensitivity to abscisic acid (ABA), the other with a seed coat factor that is effective only in the presence of embryo sensitivity. A population derived from Janz/AUS1408 was treated with ABA to develop a sub-population that was homozygous for the embryo sensitivity gene but still segregating for the seed coat gene. Subsequent progeny testing of the individual lines enabled the seed coat genotype to be determined. This material is being used to develop molecular markers for the seed coat factor. A few breeding lines and another Janz/AUS1408 population which is thought to come from lines that are heterozygous for the seed coat factor were also used in this work. The second population showed a range in dormancy phenotype from dormant to non-dormant.

Progress

Initial studies utilizing some chromosome 3-specific probes for restriction fragment length polymorphism (RFLP) analysis revealed no polymorphism between the parents, Janz and AUS 1408. Similarly, amplification of flanking regions for the R-genes, followed by restriction analysis did not uncover any length polymorphism between the parents. The primers for the flanking regions of the R-genes had been developed at the John Innes Institute, UK.

Fig 1.9 - Electrophoresis of microsatellite marker fragments on a 12% non-denaturing polyacrylamide gel.

The marker fragments for Opata 85 and W7984 are 182bp and 171 bp respectively. Molecular size markers were in lane 1; parents, Janz (2X) and AUS1408 were in lanes 2, 13 and 3 respectively; breeding lines, SUN 325B, SUN 325C, SUN 325F, QT7475 and SA1166 were in lanes 4-8; progeny lines 2.1 to 2.4 were in lanes 9-12, progeny lines 2.5 to 2.10 were in lanes 14-19; and progeny lines 9.1 to 9.3 were in lanes 20-25.



A total of eight group 3 microsatellite markers were found to be polymorphic for Janz/AUS1408. Of these, four were chromosome 3DL-specific and were found to be particularly useful for correlation of the molecular data with the dormancy phenotype. One marker was found to be linked to the gene associated with embryo sensitivity to ABA. Results from the 2 populations suggested that another microsatellite, 314 has some linkage to the gene for the seed coat factor. This linkage was weakened by the fact that the second population used to deduce the relationship was heterozygous for this gene. It was thus hypothesized that this linkage will be significantly strengthened if populations that are homozygous for the seed coat gene are used. Results from four non-dormant families that segregate for the four markers showed that this second locus is linked to the seed coat factor gene. It would be necessary to have dormant lines that are homozygous for the seed coat gene and segregate for the four markers to establish clearly the other side of the linkage.

The second marker is in the vicinity of the seed coat locus with the first marker at 44.6 centimorgan (cM) from the centromere. Hence, the seed coat gene is estimated to be more than 44.6 cM from the centromere. The first locus appears to be more than 10 cM from the centromere. Estimates of recombination frequency and conversion to map units could be made to estimate the approximate location of the embryo sensitivity gene and the seed coat factor gene. The loci will be mapped more precisely as more data become available.

Project 1.1.10 - Breeding soft wheats of Northern Australia

Project Leader: Dr. L. O'Brien

Background and Objectives

New rust resistant soft wheats are being developed for the northern region to provide a supply of soft wheat in the same region as milling and biscuit production and to improve its reliability by having production in northern and southern regions.

Progress

Commercialisation of a new soft wheat for the northern region is imminent, bringing this project to successful fruition within the lifetime of the CRC.

Testing in the 1998 season, resulted in the identification of a number of rust resistant breeding lines with high yield potential across an area from northern Victoria to the Queensland border.

Quality testing of these lines by industry partners indicated that they had the desired low protein content, flour water absorption and weak dough characteristics needed for use in soft biscuit production.

Biscuit test baking conducted by Arnotts Biscuits confirmed that the test-bake performance of all lines was superior to the current commercial flour used by the Company. All lines yielded better packet length, baked dough weight and biscuit hardness parameters, compared with the commercial flour.

Seed from large scale production blocks of some of the best lines was commercially milled by Goodman Fielder and used in factory scale evaluations. All lines tested gave satisfactory performance.

The best lines are in seed production with a view to commercialisation early in 2000-2001.

Project 1.1.11 - Genetic variants for soft wheat quality

Project Leader: Dr. L. O'Brien

Background and Objectives

Flour chlorination is widely used in the production of cake flours, and chemical dough conditioners are used in biscuit production. Increasing consumer concern over such treatments means alternative strategies need to be pursued.

Through this project we aim to use genetic variation at the high and low molecular weight glutenin loci and the waxy locus to develop novel breeding lines. Suitable characteristics developed could improve processing quality of soft wheat cultivars for biscuit and cake manufacture without the need for dough conditioners, flour treatment or additives.

Progress

This project is approaching the stage where the hypotheses that altering protein and starch composition can be used as replacements for the use of flour chlorination and dough conditioners may be tested.

Doubled haploid populations of lines varying in protein composition will be increased during the 1999 season.

Lines varying in starch quality via genetic variation at the granule bound starch synthase loci are now available in sufficient quantity for evaluation by commercial partners of the CRC.

Project 1.1.12 - Soft wheat breeding for South Eastern Australia

Project Leader:
Dr. L. O'Brien / H. Allen

Background and Objectives

Through this project we aim to increase soft wheat breeding activity on quality testing of soft wheat lines and to facilitate collaboration with the existing CRC soft wheat breeding project, so as to release suitable new soft wheat varieties.

The Wheat Improvement program at Wagga Wagga released Snipe, a new biscuit wheat in 1997. Snipe was commercially grown in 1998, and has very good biscuit baking quality, however, in 1998 it had a high level of blackpoint. Blackpoint was particularly high in any susceptible varieties because of the moist conditions in 1998.

Lines for release 1999 include two lines evaluated in the last 12 months. These were M5635 (LR_21, SRX/3*M3087), and Bowie, a South Australia bred variety.

M5635 has very good grain quality, high flour extraction, high starch paste viscosity, very good extensibility and good biscuit baking quality.

Bowie is a suitable biscuit quality wheat as a replacement for Tatiara, even though Bowie is slightly stronger in dough strength.

Progress

Late generation

Stage 3 biscuit trials currently being quality tested are WW2536, WW2436, WW2433, DH3358 and DH3506. VH302 has similar quality and yield to Wyuna but better stripe and leaf rust resistance. In testing the dough strength of VH302 is stronger than other biscuit lines. The other lines are being tested by WWAI.

Early Generation

A new Stage 1 early generation biscuit trial conducted in 1998, included only potential biscuit quality soft wheat. These lines were yield tested and screened for disease resistance, and some preliminary quality analysis was conducted. Lines were subjected to the normal set of quality evaluation tests, including flour yield, grain tests, and physical dough parameters using the probe test for dough strength and extensibility. Only lines with soft grain and weak dough strength were promoted into the more advanced trials for evaluation. A series of doubled haploid lines have been tested in the early generation trials and the best quality lines from this material will be promoted into the Stage 3 trials in 1999/2000. Lines for a special Stage 1 biscuit trial was grown in 1998 and these lines are now being processed through the quality laboratory. Some promising Triller selections with improved quality were rejected because of the breakdown of rust resistance, gene Lr 26.

Research

To improve testing for biscuit baking quality at an early stage in the breeding program research has been conducted using the probe test. The test measures dough strength and gives an indication of extensibility. In addition, research will be conducted to improve all small scale tests to identify high biscuit quality early in the program.

A laboratory assistant was appointed in 1998 to assist with quality evaluation and some field work.

Project 1.1.13 - Hybrid Wheat

Project Leader: Dr. D. Bonnett

Background and Objectives

Hybrids offer an effective means of intellectual property protection and of increasing grain yield. Sunprime R&D, of which the University of Sydney is half owner, operates a commercial hybrid wheat program. Its hybrids offer yield advantages of around 10% over the best conventional varieties. The parents of these hybrids are agronomically adapted lines with good hybrid production characteristics into which novel quality traits identified by the CRC could be introgressed for commercial exploitation.

The commercial hybrids are produced using the Triticum *timopheevi cytoplasmic* male sterility system, a system requiring a cytoplasmic male sterile line, a maintainer for the sterile line and a restorer line carrying 2 to 3 genes for fertility. Breeding restorer lines is inefficient due to the difficulty of selecting for fertility restoration. RFLP markers for some of the fertility restoration genes likely to be present in the Sunprime hybrids have been identified (in overseas laboratories) and could simplify the development of restorer lines with novel quality traits.

The *T.Timopheevi* system is not amenable to the production of large numbers of new hybrid combinations due to the need to breed male sterile and restorer lines for each combination. The production of large numbers of combinations is important in identification of such heterotic groups. Effective pollen killing chemicals (gametocides) which allow efficient production of large numbers of new hybrids have been developed by a number of private companies (eg Monsanto and Du Pont). The CRC has negotiated access to the Monsanto gametocide for use in the identification of heterotic groups.

These groups would be targets for the introgression of characteristics constituting CRC intellectual property for commercialisation.

Progress

Identification of Heterotic Groups.
Hybrid production blocks have been planted. These will result in the production of hybrids between existing parental lines from the hybrid program, representative cultivars from major Australian hard and soft wheat families and elite CIMMYT material.

Development of Molecular Markers.
Genetic populations segregating for fertility have been planted at Cobbitty for assessment of fertility and DNA extraction. F3 SSD populations have been planted at Narrabri for development of recombinant inbred lines.

Introgression of Novel Quality Traits into Potential Heterotic Groups
Crossing blocks have been planted at Narrabri to initiate introgression of novel quality traits into potential heterotic groups.

MAJOR RESEARCH MILESTONES ACHIEVED IN PROGRAM 1

- Identification of exciting new sources of low B-granule content in breed wheat and a greater understanding of the genetic basis of this character.
- Progress toward understanding the molecular genetic basis of B-granule content and the development of Australian cultivars with lower B-granule content.
- Analysis of changes in flavonoid content in raw yellow alkaline noodles with time. The major components of yellow colour (the apigenin diglycosides) were shown to be relatively stable during storage of noodles and not oxidized by polyphenol oxidase.
- Survey of wild relatives for flavonoid content. Variation in *T.tauschii* appeared to exceed the range present in durum wheat and bread wheats.
- Determination of time course of synthesis of flavonoids in developing wheat grains. Flavonoid content reached a peak at 30-35 days after anthesis and then declined. This pattern contrasted with total phenolics and xanthophylls that were high in the early stages of grain development and then decreased steadily until maturity.
- New albumins which are polymorphic in bread wheat have been identified. A polymorphic water soluble protein has been mapped to chromosome 3BS.
- Identification of chromosomal regions controlling flour swelling power related to udon noodle quality and a range of other starch quality traits.
- Assessment of the utility of 250 microsatellite marker primers provided by Agrogene (France) and the mapping of those polymorphic in local cultivars.
- Development of a novel method for the detection of microsatellite markers in wheat.
- Demonstration that two microsatellite markers are linked to the embryo sensitivity gene and the seed coat factor gene, respectively, of the dormancy trait in AUS 1408.
- Identification and industry assessment of several promising new lines of soft wheat adapted to both northern and southern Australia.

PROGRAM 2: GROWING AND STORING QUALITY WHEAT

Program Manager: Dr Bob Cracknell
Deputy: Dr Colin Wrigley

Bob Cracknell
Program Manager

PROGRAM 2 OBJECTIVES

Research conducted at all stages of the growing and storing of wheat to elucidate the causes of grain-quality variations.

Implications of environmental conditions evaluated throughout the continuum of growth, harvesting and storage.

Current wheats studied for their quality attributes in diverse environments.

Effective use of quality directed strategies.

Consistency of grain quality is an ongoing requirement of the wheat-marketing and processing industries of Australia. This is matched by the need for the wheat-growing sector of the industry to achieve quality-related premiums. For the requirements of all these sectors, more information is needed about how growth conditions affect specific aspects of grain quality, and thus how targeted quality attributes may be achieved.

In practice, the combination of varietal identity, protein content and grain soundness provides a reasonable guide to processing quality, different combinations of these being appropriate to the various marketing and manufacturing specifications. But there still remain unexpected and unexplained fluctuations in quality, the causes for which we need to understand.

As a result of Program 2 projects significant successes are now being achieved in elucidating some of the causes of quality fluctuations. More importantly, solutions are being developed to provide tools with which growers can increase their opportunities for premium returns, and processors may have better assurance that quality specifications are met when they buy.

These advances include the provision of on-farm testing for sprout damage (enabling damaged grain to be excluded during harvesting), the demonstration of success with farm management strategies to achieve premium-attracting levels of protein content, improved storage methods (providing stability of dough-processing properties), and elucidation of the results of blending wheats that differ in dough quality.

These research advances are matched, in Program 2, by training and quality-assurance programs to ensure these and other new knowledge in grain production are applied in practice.

Program Objectives

Research is being conducted at all stages of the growing and storing of wheat to elucidate the causes of grain-quality variations, and thus to develop appropriate strategies to achieve improved outcomes for both growers and processors.

The quality implications of environmental temperature and moisture are being evaluated throughout the continuum of growth, harvesting and storage, with novel management strategies being developed to improve grain quality.

At sowing, choice of variety is a major determinant of quality outcome, both due to intrinsic quality attributes and tolerance to environmental factors. For this reason, current wheats are being studied for their quality attributes in diverse environments (both in the field throughout the wheat belt, and under controlled conditions). In association with breeders and geneticists in Program 1, we are pursuing the aim of conferring better tolerance to environmental effects.

Through our training program, including development of a system of quality assurance suited to Australian wheat farming, effective use of quality-directed strategies is being pursued.

Project 2.1.1 - Protein composition during grain filling and post-harvest storage

Project Leader: Dr Ferenc Békés

Background and Objectives

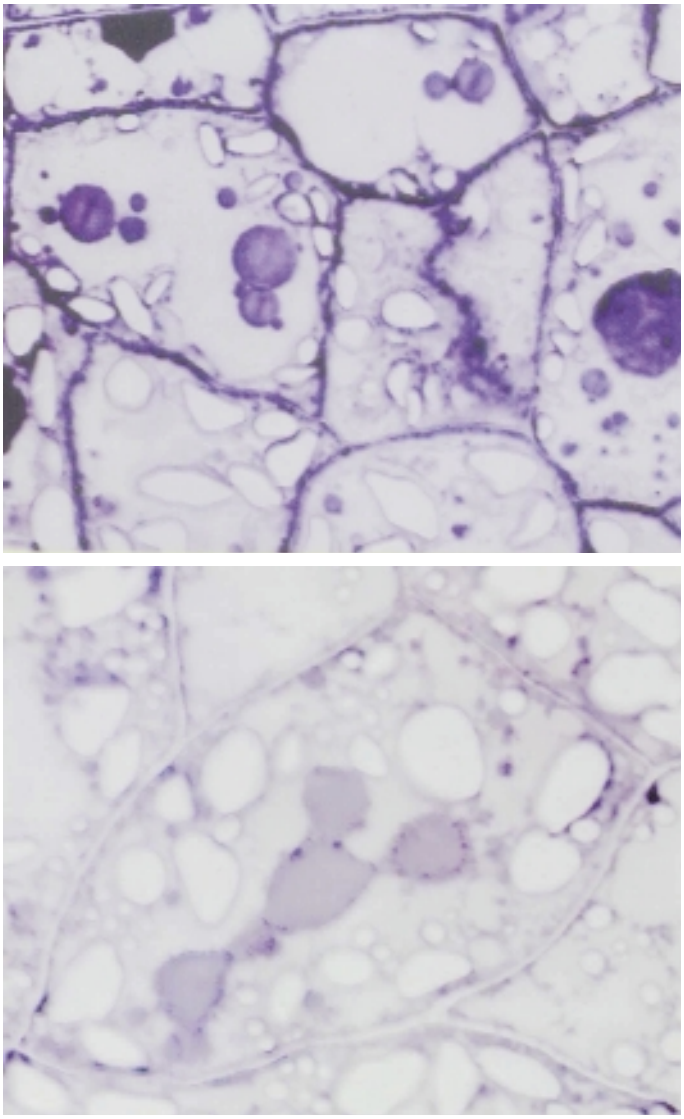
The structure of the major storage protein, glutenin, is the most important factor in determining dough strength. The functional properties of this important component of gluten are determined by the composition of its polypeptides (largely a part of its genetic constitution) and the manner by which they are linked together by disulphide bonds. More extensive cross-linking produces larger glutenin polymers, and thus greater dough strength. This process begins following protein synthesis in the developing grain. Much of the process is completed by maturity, but it can continue during storage, depending on conditions.

The aim of this project is to elucidate the changes that occur in grain proteins throughout grain filling and post-harvest storage. For a clear understanding of the dynamics of glutenin structure and function, an integrated approach is required. The project thus includes monitoring the formation of the key protein components during grain development, combined with investigation of changes during post-harvest storage.

Progress

The accumulation of the major classes of wheat endosperm proteins has been studied, in relation to grain growth, cell division and cell enlargement, and gene transcription and accumulation of mRNA. Microscopy has proven to be a useful tool in defining the stages of development, as well as providing new insights into the manner in which the gluten proteins are laid down in the developing grain (Figure 2.1).

Fig 2.1 - Microscopic examination of gluten proteins



We found that RNA transcription, for the proteins involved in gluten formation, is initiated at different times depending on which wheat cultivar is under study. For example, major expression of the HMW glutenin subunits is not achieved until 15 days after flowering in the variety Wyuna, whereas significant expression is observed from 8 days for a Gabo/Olympic cross. Nevertheless, the number of days after flowering is not proving to be so reliable a guide to the stage of development as is the size of the developing grain, according to microscopic studies. Using this approach to stage determination, we are identifying the earliest stages at which protein bodies and starch grains are first observed during grain formation.

Storage experiments involving 72-kilogram quantities of grain have continued in the laboratory, using conditions that simulate those in aerated and in non-aerated storages at country stations. Grain in storage has been adjusted to temperatures reflecting those 'in the field', namely maintenance of a temperature for control grain of 27º C, and simulation of aerated storage by gradually reducing this temperature to 23º C over 70 days; additional control samples are stored at the constant temperatures of 4º C, 23º C , and 40º C.

The ongoing aim of the laboratory studies will be to develop a quantitative model to describe (and predict) quality changes, based on temperature and moisture data, also considering variations due to variety. As a result of the successes of the laboratory-scale simulations, pilot-scale storage has commenced in paired silos at Narromine. The details of these experiments are provided later in this report in Project 2.1.6.

Project 2.1.2 - Improved consistency and continuity of supply for markets

Project Leader: Helen Allen

Background and Objectives

The achievement of quality-related premiums is an important goal for growers in regions of the wheat belt where premium payments are not traditionally available. It has thus been the overall aim of this project to develop farm-management systems that would assist in the production of premium-attracting wheats. The main focuses have been the production of Prime Hard wheat in southern Australia, and a range of premium grades in Western Australia.

Additional aims have been the development of tests for the pre-harvest prediction of final-grain protein composition, and elucidation of the range of factors affecting wheat quality and yield.

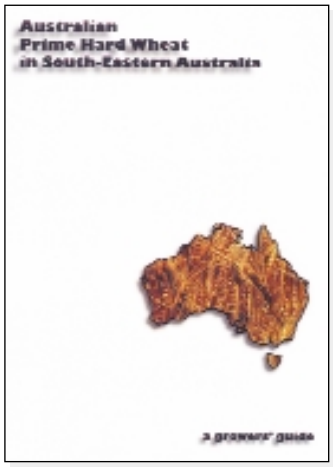
Expected outcomes are increased areas of production of premium-attracting wheats, increased protein levels for Australian wheat production, and better diagnostic and management systems to achieve improved consistency and continuity of supply of grain that meets specific quality targets.

Progress

Analyses on all grain samples from the three years of trials in the 'Prime Hard in the South' project have been completed. The results showed overall that when quality is assessed at the same grain-protein content, grain quality and dough made from grain produced in areas to the south of the current Prime Hard zone, were similar to that from grain grown in the traditional northern areas. The growing of Australian Prime Hard wheat is thus not only achieved as a result of dry seasons, but it can be managed and grown on a regular basis. There are risks with unpredictable dry springs, but the risks can be minimised, by adopting a staged decision-making approach to growing high-yielding, high-protein wheat.

On a commercial scale, the research has already proved its success. An initial segregation operated at five sites in the 1997/98 season; this resulted in

Fig 2.2 - The growers manual on farm management practice to achieve premium targets was launched at the GRDC Temora Expo on July 19th and at Condobolin Expo on July 23rd, 1999.



the segregation of some 33,000 tonnes of Prime Hard wheat which was successfully marketed to south east Asia, as an integral part of the national Prime Hard pool. The segregation was further expanded in 1998/99 but due to unfavourable seasonal conditions, deliveries were much reduced. However, some good quality grain was received and for the first time, this wheat was included in the annual crop quality presentation to Japanese buyers.

As a result of the experimental and commercial trials in southern NSW, a handbook (Fig 2.2) has been prepared recommending agricultural practices to achieve Prime Hard quality. The handbook was launched at a farmers meeting in July, 1999. Growing commercial Prime Hard wheat in southern Australia requires intensive management and a large input of nitrogen, either from high soil fertility or fertiliser. Because of the resources required, a good risk strategy is to manage only a small proportion of wheat on a farm for Prime Hard production. A suggested strategy is first to target the most fertile paddocks to produce Australian premium white or Australian Hard wheat, and then to top-dress with additional nitrogen fertiliser to produce Prime Hard wheat if the seasonal conditions, crop condition and price premiums are all suitable.

Fig 2.3 - The WheatRite test card, developed to determine the degree of rain damage to wheat, on-farm prior to harvest or at the silo on delivery.

The test involves shaking coarsely ground grain with buffer solution, and placing two drops of this extract onto the upper pink pad. A drop of another solution (supplied in the kit) is added to the lower porous pad (white), and the card is closed. This brings the two pads into contact, allowing the test sample to flow up to contact the antibody-impregnated reaction lines, which develop colour in proportion to the concentration of α-amylase in the extract. The colour intensity can be related to Falling Number by visual comparison between test and reference lines or by using a portable reader device.

Project 2.1.3 - On-farm diagnostics for maximising grower returns

Project Leader: John Skerritt

Background and Objectives

Rain at harvest presents the risk that wheat grain will be downgraded due to the development of excessive alpha-amylase in the grain, despite the absence of obvious signs of sprouting. If this damaged grain could be readily identified prior to harvest, it would be possible to harvest the sound grain without inadvertently including sprouted grain and thus downgrading the rest of the crop.

With the aim of providing for this situation, a simple test card (the WheatRite kit) has been devised to permit amylase to be quantified under field conditions. In parallel with the commercial development of the test kit, it has been necessary to devise strategies for its effective use, as well as providing for consumer evaluation and training and publicity activities to ensure its acceptance.

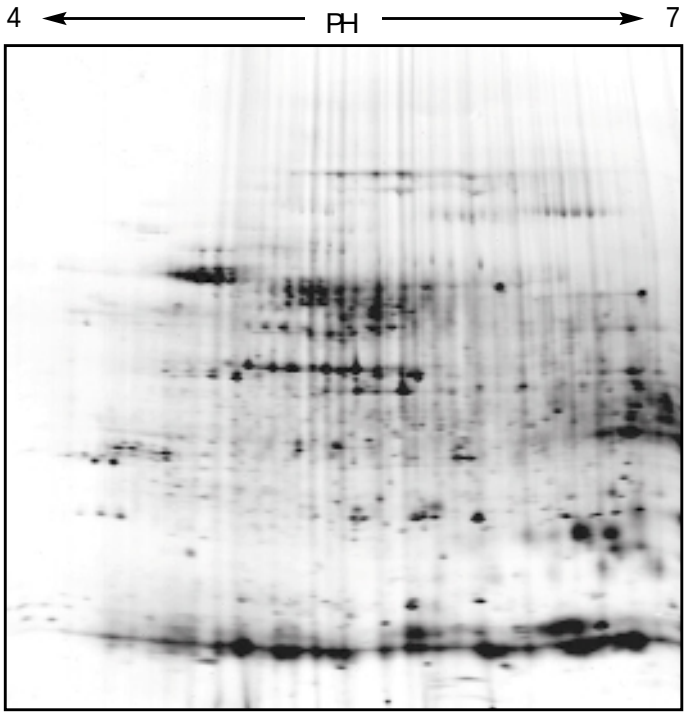
Further diagnostics are being developed to improve on-farm management of grain quality. The next is a procedure for the rapid determination of grain protein content. This will allow growers to maximise opportunities for premium returns by arranging a harvest strategy to utilise variations in protein content across the paddock.

Progress

The WheatRite test card has been evaluated successfully in demonstrations with many groups of potential users, particularly wheat growers and silo operators. The precision of the test card was shown to be as good as the Falling Number test (the standard laboratory procedure for evaluation of sprouting). Field trials, conducted during the 1998/99 harvest, showed that the extent of pre-harvest sprouting after rainfall varies markedly between and within fields. Farmers, who tested grain from different fields or areas before maturity, could harvest damaged grain separately from sound grain, thus minimising financial losses that would have resulted without this form of segregation. A sampling system has been established to assist in developing such a strategy. As well as being suited for rapid screening on-farm prior to harvest, the test kit is proving valuable for testing when grain is received at a mill or grain elevator, and also as a rapid laboratory test.

The test card (Fig 2.3) has been demonstrated at Australian conferences and at an international Cereal Chemistry Conference in Spain. Collaborative evaluation for European potential, undertaken in Sweden, has indicated the general suitability of the test system for European requirements, which may also require greater sensitivity to detect much lower levels of sprout damage than those normally encountered in Australia. The effectiveness of the test for barley grain has been demonstrated, further extending its potential.

Fig 2.4 - Two dimensional "proteome" analysis of the composition of proteins in immature grain of the heat-susceptible variety Wyuna.



Wyuna (17 DPA)-Endosperm proteins
pH4-7, L, 18 cm IPG 8-18% T SDS-PAGE Silver-stain

Project 2.1.4 - Reducing the dough-weakening effect of heat stress

Project Leader: Colin Wrigley

Background and Objectives

Variation in growing conditions is the main source of inconsistency of grain quality about which we still have only a sketchy understanding. Improved strategies of farm management, such as those being developed in the Project 2.1.2, are helping to achieve quality targets, but other aspects, particularly temperature fluctuations, cannot be controlled.

In particular, a few very hot days during grain-filling can cause reduced starch synthesis, higher protein content, and a deterioration of protein quality, resulting in poor dough quality. Systematic evaluation of many wheat lines has led to the identification of some Australian wheats that are reasonably tolerant to this dough-weakening effect. A promising strategy to provide for more consistent grain quality is to assist wheat breeders in selecting heat-tolerant varieties. To this end, we are developing molecular markers, for use in breeding for heat tolerance. An understanding is developing of the changes in protein composition that accompany heat stress, providing a basis for use in selecting tolerant varieties.

Progress

Wheat responds best to much lower temperatures (15-20º C daily maxima) than are generally experienced in the Australian wheat belt during grain filling (October to December), with the likelihood of further complications in the field due to short periods of heat shock (e.g. >32º C). To simulate combinations of these more moderate and extreme conditions, wheat was grown in controlled-environment facilities at each of several set temperatures throughout grain filling, namely, at daily maxima of 18º, 21º, 24º, 27º and 30º C. In addition, plants otherwise maintained at 21º C were subjected to one of ten heat-shock treatments, each being approximately equivalent in terms of heat load, ranging from longer periods at only moderately high temperatures (e.g. 7 days at 27º C) to shorter periods at considerably higher temperatures (e.g. 3 days at 39º C). Kernel weights at maturity (an indicator of grain yield) were progressively lower with increasing temperature, with the higher heat-shock temperatures causing greater losses, despite their equivalence as measured by heat load. Dough properties showed greatest sensitivity to stress treatments above 36º C, these higher stresses causing considerable losses of dough strength and reductions in the proportion of very large glutenin polymers.

Results implicating the size distribution of the glutenin proteins have been obtained by fractionation and reconstitution of flour proteins from control and heat-stressed grain. Evaluation of their function in a 'model-dough system' showed that the main change in dough function correlated with the glutenin fraction from the heat-stressed sample. This fraction was shown to have a reduced proportion of large polymeric glutenin by size-exclusion HPLC and field-flow fractionation. In addition, the starch prepared from the heat-stressed grain exhibited a significantly lower peak viscosity in the Rapid ViscoAnalyser.

These heat-induced changes in the structure of the glutenin proteins are presumed to occur in the immature grain under the influence of 'chaperone' proteins. Their presence during heat stress has been investigated by applying a 'proteome' approach. This has involved the development of novel extraction methods and analysis by two-dimensional electrophoresis (Fig 2.4). Over 200 polypeptides have been separated, and many of these have been characterised by mass spectrometry and N-terminal amino-acid sequencing. Specific differences in protein composition have been identified as a result of heat-stress. Heat-tolerant and susceptible varieties are now being compared by these methods, in search of differences in their proteome (protein composition) that may explain the diversity of reactions to temperature fluctuations

Project 2.1.5 - Flexibility of wheat use

Project Leader: Helen Allen

Background and Objectives

The objective of this set of projects is to provide improved flexibility and management in producing quality wheats. The projects involve 'benchmarking across Australia' (to compare the quality and molecular composition of premium wheats), study of the 'genetic and biochemical basis for varietal interchangeability','managing within paddock variation in grain quality' and the development of procedures for 'blending quality types' to meet market specifications. These projects were developed as a result of grower initiatives and workshops involving all branches of the industry. All current aspects of this group of projects were reviewed at a one-day workshop held at North Ryde on March 17th. A report of the day's proceedings has been published, containing a summary and copies of the overhead films used by speakers. One of the original five projects has already been completed. The remaining projects are well advanced, being scheduled for completion within the next few years.

Progress

The first of these sub-projects ('bench-marking varieties across Australia'), involves quality testing grain from 12 sites around Australia for a set of 15 varieties, including 11 hard and 4 soft wheats, from each Australian breeding program. Grain from all sites was obtained in good condition from the 1997 harvest, but only from 9 sites from the 1998 season. Grain characteristics of the samples were determined as % screenings, incidence of blackpoint, test weight, 1000 kernel weight, hardness and protein content. Milling quality was determined by flour extraction and flour colour index. Starch pasting properties were determined using the Rapid Visco Analyser (RVA). Sub-samples were sent to SARDI (Adelaide), where physical-dough characteristics were determined using the Farinograph and Extensograph.

Buhler flour extraction results were comparable between all sites, except for Western Australia, where small, pinched grain had the effect of lowering the flour extraction rates. Uniform flour colour was detected across all sites. Flour colour results for all regions demonstrated high b* (yellowness) values for Krichauff. RVA parameters for each site appeared to be comparable, although the peak heights for the hard varieties from Narrabri were slightly lower than for the other sites.

Physical dough tests highlighted the differences between the sites, although no one site was consistently better than any other for all of the parameters tested. Farinograph water absorption values varied slightly between the sites. From the Extensograph data, Narrabri samples appear to be the most extensible, but this again can be attributed to the high protein content of the samples. When extensibility is expressed per unit of protein for each sample, there is very little difference between all sites for both the hard and soft varieties.

Fig 2.5 - The results of blending pairs of flour samples differing in time to peak dough mixing.
The results depends largely on the compatability of HMW glutenin alleles shown for each A and B pair varieties. A straight line is included connecting the values for the pure samples, for comparison with the lines connecting the experimental points.

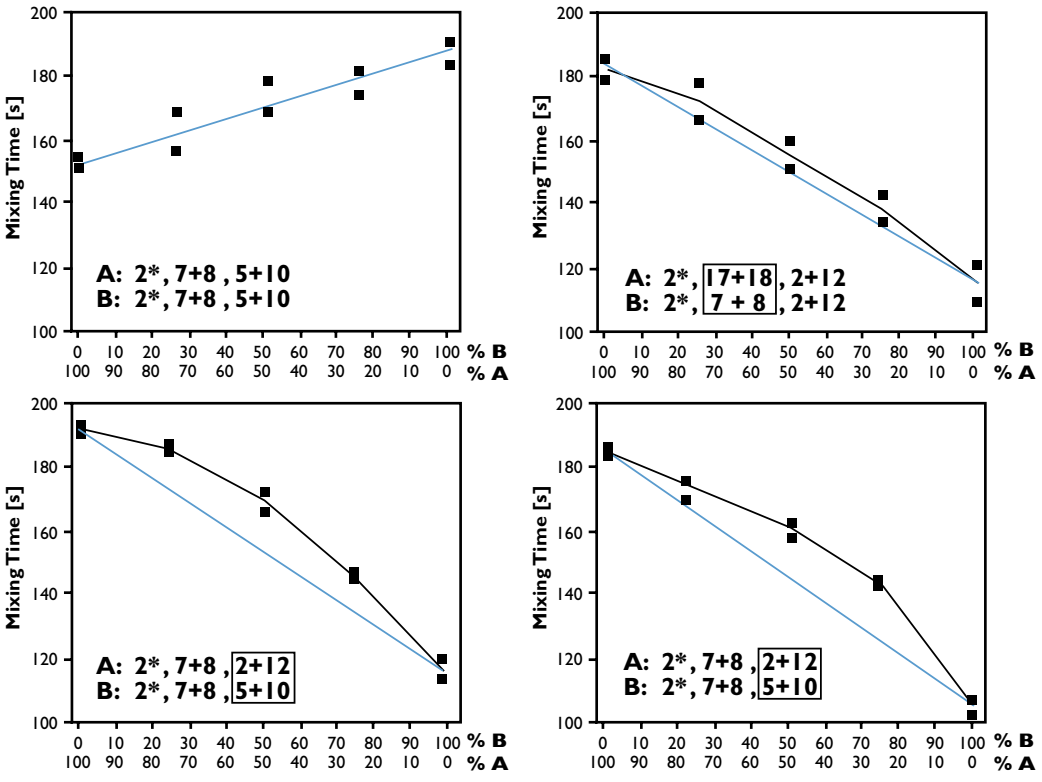


Fig 2.6 - Pilot-scale experiments on aeration to prevent the deterioration of dough properties of wheat during storage.

With the physical dough testing completed, samples will now be sent to SARDI for flat bread analysis. Yellow alkaline noodle quality testing will be carried out at VIDA (Horsham) for all of the hard varieties. Agriculture WA (Perth) will produce white-salted noodles from the soft-variety samples. Pan bread and steamed bread will be produced at Wagga Wagga.

In a related study conducted at the Wagga Wagga Agricultural Institute, frosted grain from the 1998 harvest was examined to determine if it was feasible to separate this type of sample into different fractions, thus removing the badly frosted grain. Previously, it was thought that frosted grain was suitable only for feed. Small, pinched grain, poor milling results, weak dough characteristics and poor baking results are some of the properties of frosted samples. By grading the frosted samples, the small, shrivelled grain was removed, leaving large grain with high quality characteristics.

Through baking trials we verified that this grain could then be used for normal processing. Acceptable germination rates for frosted wheat are also achieved after grading. These results have been of considerable value to growers, because the severe late frost in October 1998 resulted in considerable losses in grain quality.

The project on genetic interchangeability is a follow-up to the Prime-Hard-in-the-South studies, with the aim of obtaining information about 'north-south' variations for a much wider range of genotypes than could be tested in the main field trials. In the most recent trials of these many genotypes, quality did not differ systematically between north and south, though there were differences between sites. A related project in this set is a study of quality variations within a paddock, such as are relevant to 'precision agriculture'. Most significantly, there was no indication of the expected inverse relationship between grain yield and protein content in the analyses of numerous paddock samples.

Another potential tool for tailoring quality to market needs involves the blending of wheats (or of flours after milling). Good progress has been made towards predicting the qualities of blends for attributes that are not linearly related, particularly dough properties. Non-linearity was most pronounced for genotypes that differed considerably in their glutenin-subunit composition. In addition, the outcome of blending was found to be affected by the milling process itself. Current research is directed towards modelling multiple-component mixtures. Blending studies on noodle quality relate particularly to product colour. Noodle colour could be predicted, based on Minolta assessment of slurries of flour samples from small-scale milling. These studies currently aim to determine the feasibility of upgrading low-protein noodle wheats, by blending them with other grades of wheat having higher protein contents.

Project 2.1.6 - Field trials of temperature-controlled grain storage

Project Leaders:
Jonathan Banks and Peter Gras

Background and Objectives

There are progressive and significant changes in the quality of grain stored at temperatures above 30º C, according to the results of the past few years of work in the QWCRC project 2.1.1. Most of these changes make the grain less suitable for the milling and baking industries. These findings point to significant causes of quality variation, because most of Australia's wheat is delivered at temperatures exceeding 30º C (even in southern regions), and because these high temperatures are maintained unchanged during many months for a large mass of grain.

Aeration is the cheapest and most efficient means of reducing the temperature, and also reducing insect multiplication. Laboratory studies imply that aeration to temperatures near 20º C has the potential to minimise quality variation during storage. The aim of this new project was to determine the effectiveness of aeration in preventing quality loss in an actual silo situation.

Progress

This new project (commenced during 1998/99) is based on laboratory experiments (Project 2.1.1) which showed that high-

temperature storage causes a progressive increase in the mixing requirement of flours milled from the stored grain. This is accompanied by changes in the properties of dough with storage as measured by the Extensograph, namely, increased resistance to extension and decreased extensibility. The sum of these changes leads to a reduction in bread quality.

These changes are in accordance with 'anecdotal' observations of millers and bakers in the industry. The laboratory-scale experiments also demonstrated that these changes could be slowed greatly by reducing the storage temperature. Such improvements in storage conditions could be achieved by the more widespread use of aeration in bulk storage. This strategy would cool grain to temperatures at which the rate of quality change is much reduced. This strategy also offers the advantage of reducing the risk of insect growth, and potential mould development.

To gain industry acceptance of the need for aeration, practical demonstrations were needed to complement the laboratory experiments, thereby showing that differences in quality are obtained for bulk grain, stored under aerated and non-aerated conditions. To achieve this aim, a pair of matching storages of wheat at Narromine were compared during 1999 (following the 1998/99 harvest), one being aerated and the other not aerated. Both consisted of 800 tonnes of Prime Hard wheat, initially at 30º C.

Grain samples have been taken from both silos after 70 days' storage, for comparison with the grain as initially placed into storage and since kept under refrigeration). After only 20 days' aeration, the temperature of the aerated grain had fallen to 24º C, whereas the non-aerated grain still had a temperature of over 27ºC after 70 days' storage. Quality analysis of the resulting grain samples is continuing.

Training and Education

Part two of this program relates to training initiatives that are detailed in the relevant section of this Annual Report. These projects are designed to provide extension of the research outcomes of the CRC for the benefit of the wheat-growing industry, as well as increasing quality consciousness among producers, their advisers, grain handlers and marketers. These objectives are being achieved through the development and delivery of literature, workshops, seminars, displays and resource materials.

Project 2.2.1 - Value Added Training for Key Influencers.

Project Leader: Jim Vandore

Outcome:

- New understanding of wheat processing by key influencers in the value-adding chain

Project 2.2.2: Quality wheat for quality manufactured products

Project Leader: Jim Vandore

Outcome:

- Progressive personnel in farming who know about the processor's needs

Project 2.2.3 - Wheat quality information for producers, agronomists and grain marketers

Project Leader: Clare Johnson

Outcomes:

- Aids to educate key individuals and groups through lectures and demonstrations.
- Growers and agronomists who are more:
  (i) familiar with the wheat quality attributes sought by particular processors and consumers
  (ii) better able to manage their crop to provide, in a cost-effective manner, grain of the required quality.

Project 2.2.4: Maintaining grain quality during on-farm storage

Project Leader: Graeme Matheson

Outcome:

- Maintenance of grain quality with significantly less spoilage/wastage of on-farm stored grain due to inappropriate storage practices.

Project 2.2.5 - National quality assurance on-farm

Project Leader: Di Miskelly

Outcome:

- Assurance of grain quality throughout the value-added chain from paddock to plate

Wheat storage silos at Narromine

MAJOR RESEARCH MILESTONES ACHIEVED IN PROGRAM 2

- Commercial evaluation and release of WheatRite test card for rapid estimation of sprout damage on-farm and at grain receival.
- Understanding how to achieve premium-grain quality in areas that have not previously achieved quality premiums; recommendations provided to growers.
- Extension of laboratory-based grain-storage experiments to pilot scale in country silos.
- Identification of factors responsible for quality loss following heat stress in the field.
- Application of advanced methods of protein fractionation and characterisation (proteome analysis) to further elucidate grain-protein composition.
- Completion of 'Precision Agriculture' project, providing data on variation in protein content within a paddock.
- Development of a preliminary model to describe the results, for dough properties, of blending grain or flour samples.

PROGRAM 3A: PROCESSING OF WHEAT AND WHEAT PRODUCTS (MILLING)

Program Manager: Ms Di Miskelly

Di Miskelly
Program Manager

PROGRAM 3A OBJECTIVES

Provide a scientific basis for technical information used in flour milling in the domestic and overseas markets, as well as providing feedback to breeders and other researchers.

Use new technologies to modify the milling process, and provide the commercial partners with timely and useful information for further application.

The initial step in the wheat processing chain is flour milling. Milling performance and flour extraction rate are of major economic importance to flour millers and wheat marketers. Opportunities may exist to maximise extraction rate, without sacrificing flour quality, by using new milling technologies which are under investigation in this program.

Flour mill customers depend on flour mills to supply flour of appropriate quality for end product processing. Quality in this context includes not only the normal chemical and physical characteristics, but also microbiological specifications. The microbiological status of milled products depends on the microbiological status of the incoming wheat, and Australia, with its dry harvests and low wheat intake moisture contents, is favourably placed in this regard.

This program operates with the active collaboration of the QWCRC commercial partners.

Program Objectives

Through Program 3a Quality Wheat CRC seeks to provide a scientific basis for technical information used in flour milling in the domestic and overseas markets, as well as providing feedback to breeders and other researchers. Other research projects in the program focus on the use of new technologies to modify the milling process and to monitor the distribution of the wheat microflora through the milling process. An important objective of the program is to provide the commercial partners with timely and useful information for further application.

Project 3.1.3 - Pilot Milling Studies

Project Leader: Michael Southan

Background And Objectives

The overall aim of this project is to provide information on the milling and end-product quality of specific wheat varieties and grades of particular interest to breeders (Agriculture WA, NSW Agriculture, University of Sydney), processors (Arnotts, Defiance, Goodman Fielder, Westons) and marketers (AWB Ltd). All of the AWB's customer surveys confirm that soundly-based and credible technical milling advice is an essential marketing tool. To be effective, the Advisers need to be constantly generating new and useful information with which to impress the customer and this represents the true value of the main outcomes of the work. While the AWB is the immediate beneficiary, the ultimate beneficiaries are the grain growers so this can be viewed as a return on the GRDC investment in the CRC.

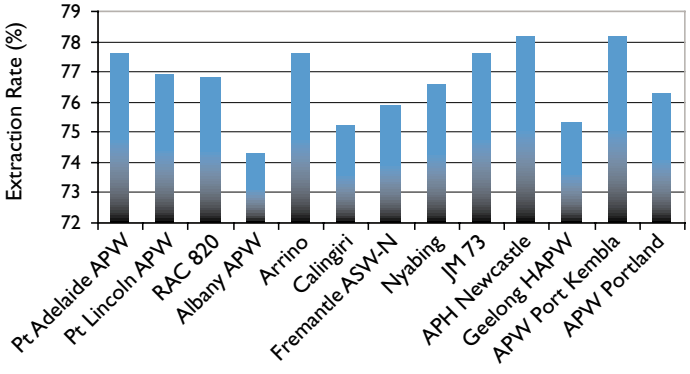
Specifically, the pilot milling trials provide AWB Ltd with:

- data and hands-on experience for the AWB Senior Milling Adviser on the milling performance of key grade samples. This provides great assistance to the AWB Senior Milling Adviser on overseas technical missions and forms the basis for advice and recommendations to AWB's milling clients;
- the pilot milling results which enable AWB Ltd to identify the commercial milling characteristics of each season's samples and identify any potential problems or changes in performance compared with samples from the previous season or samples of similar grades between states and
- commercial quality flour for supply to potential clients for their evaluation.

Progress

Fourteen wheat samples were pilot milled in the 1999 Pilot Milling Studies Program. These comprised three varieties, Arrino, Calingiri and Nyabing; one Prime Hard sample, APH Newcastle; one Prime Hard 5 sample, PH5-Newcastle; six Australian Premium White samples, APW Port Adelaide, APW Port Lincoln, APW Portland Victoria, APW Albany, HAPW Geelong and APW Port Kembla; one Australian Standard White - Noodle sample, ASW-N Fremantle and two advanced crossbred lines RAC 820 and JM 73.

Fig 3.1 - Pilot Milling Flour Extraction Rates



Straight run flour was collected from all samples, 60% extraction flours from Arrino, Calingiri, Nyabing, ASW Noodle, APW Geraldton and APW Albany and 82% extraction flours from APW Port Lincoln, APW Port Adelaide, APW Port Kembla and APW Portland. All flour samples have been distributed to the CRC partners who requested them. Flour and wheat quality data were supplied by AWB Ltd and end product quality data by Bunge Defiance, Goodman Fielder and Westons.

Extraction rates ranged from 74.3% for the Albany APW sample to 78.2% for both the APH Newcastle and Port Kembla APW samples. The APH sample from Newcastle did not yield as much flour as might be expected and this most likely reflects the poor quality of this wheat crop in the north of NSW. On the other hand, the APW from Port Kembla had a good extraction rate which did not reflect the quality problems experienced in the south of NSW. Interestingly, the APW from Port Adelaide had a good extraction rate as did the Arrino from WA. JM 73 had a similar extraction rate (77.6%) but was lower than might be expected for a Sunco backcross. The APW from Albany had the lowest extraction rate followed by Calingiri, also from WA, and the HAPW sample from Geelong. In very general terms from the limited number of samples milled in this project the NSW and SA wheats had the better flour extraction rates while the WA and Victorian wheats had the lower flour extraction rates.

The final report will be published shortly.

Project 3.1.4 - Microbiology and the flour milling process

Project Leader: Ailsa Hocking

Background And Objectives

Flour millers are under increasing pressure from their customers to provide flour and other mill products to particular quality and microbiological specifications. In addition to this, changes in food hygiene regulations will require all food producers and food handlers to have Hazard Analysis Critical Control Points-based (HACCP) food safety plans to ensure the microbiological, physical and chemical safety of all their food products. This project was initiated in response to these pressures. The aims are to study the distribution of pathogenic microorganisms, and those causing spoilage through the various milling procedures and to assess the fate of microorganisms entering the mill on the incoming grain. An extensive survey of flour mills over a two year period will establish a scientific basis for the setting of microbiological specifications for flour and other mill products.

Progress

Mill sampling:

Sampling from the nine participating flour mills continued during the year. We continued to have excellent cooperation from the mill staff and from the CRC partners. Consolidated reports from Rounds 3, 4, 5 and 6 were sent out during the year to participating mills, technical and management personnel in the parent companies, and CRC participants. Very positive feedback was received from a number of recipients of these reports. The seventh (final) round of sampling was interrupted by the late arrival of some samples, and the commencement of the pilot millings at BRI. The consolidated report for Round 7 was sent out in July 1999.

Pilot milling:

During December, January, February and March, a significant number of downgraded wheat samples was tested microbiologically to assess the suitability of the samples for pilot milling. Test weight and falling number assessments were done by BRI. Many samples that were deemed microbiologically suitable were ruled out by their low falling number and test weight results. Suitable grists were finally sourced from Queensland, with the assistance of John Dines (Bunge Defiance). Pilot milling commenced in May, in conjunction with some trials using the Satake Peritec Debranner to assess the effect in lowering the microbiological load. Control grists of both hard and soft wheat were also milled. Microbiological testing on all these samples was completed in July.

The project has been given a three month extension to enable full analysis of the results. The final report will be available in September, 1999.

Project 3.1.5 - Use of new technology to aid mill process control

Project Leader: Michael Southan

Background And Objectives

Flour mill efficiency is usually expressed in terms of grist rate, that is, the amount of wheat required to produce one tonne of flour. Even small improvements in grist rate are of high commercial value, but run the risk of increasing bran contamination with consequent effects on product quality. The main bran components can now be

measured using commercial image analysis systems such as the Dipix, Branscan and Maztech. Using the Satake/Peritec debranning machine, bran components can be removed selectively during the milling process to produce flours with a range of yields, aleurone and pericarp concentrations.

Through this project we aim to understand the effects on end product quality of increased concentrations of bran components in flour, and to provide the scientific basis for bran component concentration specifications which could routinely allow higher flour yields than the current quality specifications based on ash content and colour grade.

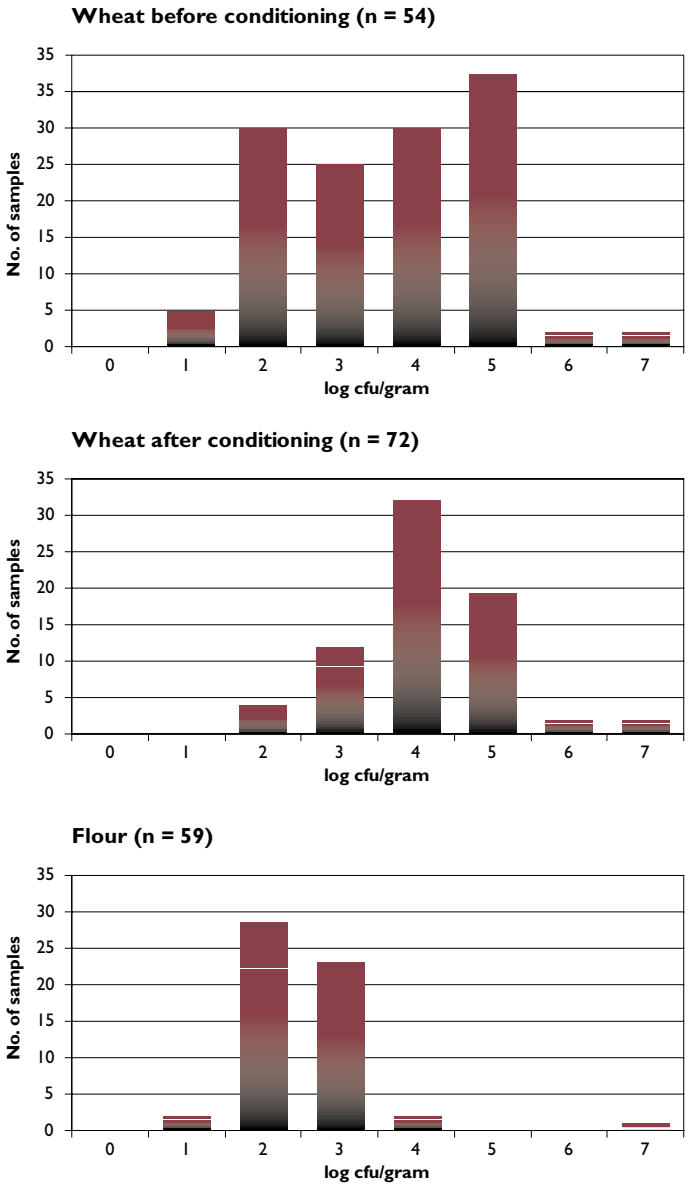
Progress

Samples of commercial flour from Australia and New Zealand were benchmarked to determine the range of bran components (aleurone and pericarp) and ash content. The ash contents of flours from WA, Qld and NZ were higher than those from SA, NSW and Vic, but the measurement of the bran component concentrations showed that SA flours had the highest concentrations, with NZ having the lowest. This demonstrates that ash content per se can be a highly misleading indicator of bran content of flours of diverse origins.

In a further experiment, streamed samples from a commercial flour grist were tested for Branscan (specks and bran content), ash, colour grade and Minolta Colour Meter values. All the traditional measures of flour cleanness correlated significantly with Branscan results.

Fig 3.2 - Distribution of Standard Plate Counts for wheat, conditioned wheat and flour.

0 = Samples with less than 10 colony forming units per gram (cfu/g). 1 = Samples with 10-99 cfu/g. 2 = Samples with 100-999 cfu/g, etc. Before conditioning, 44% of wheat samples were in the lower count range ($<10^4$), but after conditioning, only 22% of wheat samples were below 10^4 cfu/g. 97% of flour samples had counts < 10^4 cfu/g.

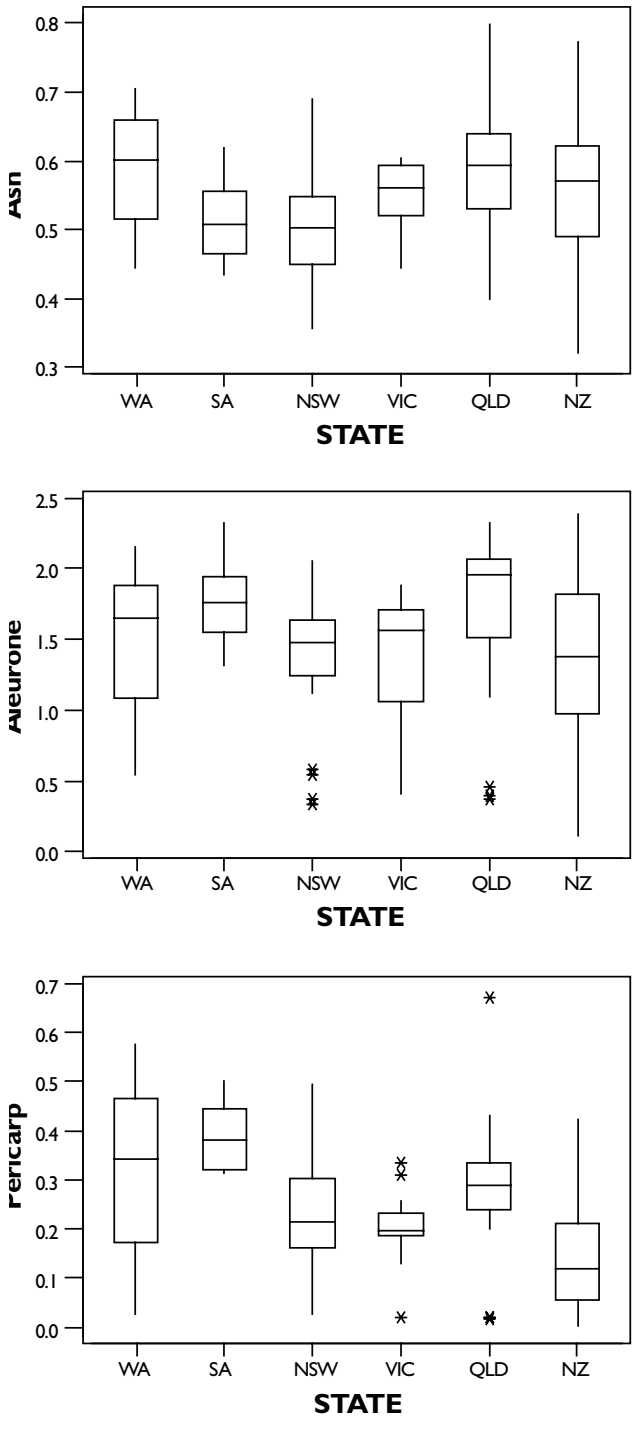


Pilot milling trials were carried out on hard and soft grists using the Peritec Debranning at two levels of abrasion. Early results indicate that there are differences between corresponding mill streams from the different millings in terms of number and area of bran specks, with debranned wheats generally having fewer specks in the cleaner flour streams.
End products will made from these flours so as to assess the effects of different bran components.

MAJOR RESEARCH MILESTONES ACHIEVED IN PROGRAM 3A

- Millings for the 1998/99 pilot milling studies program have been completed.
- Analytical testing has been completed on samples from the 1998/99 pilot milling studies.
- The level, nature and distribution of the microflora in selected commercial flours from all Australian States has been established.
- The effects of milling variables, including debranning, on the distribution of microflora in selected mill flows have been investigated.
- Pilot milling has been carried out on downgraded wheat and control premium grade wheat from the same area.
- Pilot Millings using debranning at different levels of abrasion prior to milling have been carried out.

Fig 3.3 - Ash and Dipix (aleurone and pericarp) analyses from commercial Australian and New Zealand flours.
The data is shown in the form of boxplots. The box extends from the first to the third quartile of data, with the median shown by the line drawn across the box. Outliers are plotted with asterisks (*).



PROGRAM 3B: PROCESSING OF WHEAT AND WHEAT PRODUCTS (BAKING)

Program Manager: Dr Nigel Larsen

Dr Nigel Larsen
Program Manager

PROGRAM 3B OBJECTIVES

To understand the relationships between industrial scale and laboratory scale dough processing and baking, and the effects of processing on a range of baked-product quality attributes.

Through understanding, develop new integrated control systems for commercial bakeries, including systems that will enable remote monitoring and management of bakeries.

To maximise food product quality and value, the grain foods processing industry needs modern systems for real time measurements, during processing, of product properties and processing parameters. This will lead to more fully automated food manufacturing, more consistent higher quality products, and greater efficiency and profitability.

This program comprises three projects. "Process measurement and control for dough mixing and makeup plants" involves studies of the mixing of dough and what happens to it as it passes through the makeup plant. Our studies on the makeup plant have been extended this year to include sheeting processes that are important not only in bread dough moulding, but also in the manufacture of a variety of products such as flat breads, pastry, biscuits, noodles and tortillas. "Oven technology to optimise product quality and improve efficiency" involves researching the development of a complete process control system for baking, using existing and newly developed technology to measure process variables and product quality. "Rheology of yeasted doughs" is a PhD project, developing new ways to measure the fundamental physical properties of full-formula doughs so that the effects of all ingredients, including yeast, are accounted for when making these measurements. Use of these new methods will allow us to understand how yeast contributes to the development of dough, and will ensure that measurements and predictions of dough properties will be more industrially relevant.

Program Objectives

The objectives of Quality Wheat CRC researchers in this program are to understand the relationships between industrial scale and laboratory scale dough processing and baking and the effects of processing on a range of baked-product quality attributes. At the dough stages of bakery processing we can do this through monitoring systems such as power consumption, load cells and torque sensors suitable for a range of mixer types and makeup equipment. We can also measure changes in dough properties at stages after mixing and relate these to product quality (this includes fundamental rheological measurements). At the baking stages we can define optimum baking conditions for various products and reduce energy costs by optimising the use of heat and humidity. Through understanding these we can then develop new integrated control systems for commercial bakeries, including systems that will enable remote monitoring and management of bakeries.

Project 3.4.1 - Process measurement and control for dough mixing and makeup plants

Project Leader: Nigel Larsen

Background And Objectives

The goal of this project is to facilitate the ability of the Quality Wheat CRC's food manufacturing partners to add value to cereal-based food products, by defining, predicting and reducing the industrial processing requirements, and improving the quality of these foods. We can do this through research to understand the relationships between laboratory scale and industrial scale mixing and define how dough rheological properties affect the outcomes of mixing and makeup plant (eg sheeting) processes.

It is important to the baking industry that small scale testing is able to predict industrial processing requirements. Wheat breeders rely on small scale testing to provide "industrial relevance" in the selection of new wheats for release into commercial production. Millers use some form of small scale dough testing (eg Farinograph and Extensograph) to meet flour specifications and bakers have to use these measurements to make empirical judgements and subsequent adjustments to processing parameters (eg, water addition and mixing time or work input). However, the baking industry has long been saying that most current tests for flour quality do not predict industrial processing performance. This costs bakeries in poorer quality and inconsistent products and loss of efficiency and profitability.

Progress

To find solutions to these problems, Quality Wheat CRC's new approach has been to measure and compare doughs produced on industrial and laboratory scale mixers and dough sheeting systems, using a variety of methods. This has never been done before, to any great extent, by either industry or researchers. During 1998-99 we made excellent progress towards understanding what happens during the sheeting of dough.

The aim of the first part of our research was to compare large deformation rheological properties of a dough sheet with baking quality of dough from the same sheet. Apparent viscosity at large deformation appeared to be the best predictor of the minimum sheeting requirement to obtain high loaf volume. This is similar to mechanical dough development (MDD) mixing of dough where the mixing curve

(apparent viscosity) is used to determine mixing requirement. Baking tests showed that loaf quality of bread made with sheeting (volume and crumb texture) was different from that of bread made with MDD mixing, particularly when dough was developed beyond the minimum sheeting requirement.

We then investigated these differences and included measurements of protein composition by SE-HPLC and quantified the thiol groups exposed during sheeting. That is, we looked at the relationship between the physical and chemical properties of dough sheets.

The weak flour we used required only about 15-20 sheeting passes to develop fully, whereas the strong flour required 50 passes. This is analogous to longer mixing times for strong flours developed by conventional mixers. The SE-HPLC analyses showed what happened to the various protein fractions as the dough was developed by sheeting. The results were similar to mixer-developed dough in that insoluble HMW glutenins are solubilised during sheeting dough development. However, the numbers of thiols generated by the physical forces exerted on the dough were only about a quarter of those generated by mechanical dough development of dough. Hence sheeting is a much more gentle process than mixing in our small scale process simulation studies. These results may have significance for minimising the use of dough oxidants in bakery products.

Project 3.4.2 - Oven technology to optimise product quality and improve efficiency

Project Leader: Thomas Adamczak

Background and Objectives

The goal of this project is to develop a complete process control system using newly developed technologies to measure process variables and product quality. To develop equipment and strategies for the optimisation of baking and proving a range of hardware options has been tested. During 1998-99, we also did a lot of work on weight loss of products during production, humidity control of the oven and looked at the effect of baking on crumb softness and texture analysis. Ultimately, a bakery that has on-line monitoring and process control software and hardware will require little operator input and would result in more consistent and higher quality loaves for the consumer, and higher profitability for the baker.

Progress

Colour meter

The Hunter lab HT Colour Meter has been used during extensive trials in a commercial bakery to evaluate it as an objective continuous assessment system for composite crust colour/seed cover of bread buns. The results collected confirm that the instrument can be reliably used as a quality control tool and be a part of the total bakery quality control system for bread and bread roll plants. From this work it would be possible to develop an online system for quality evaluation.

Humidity control during baking

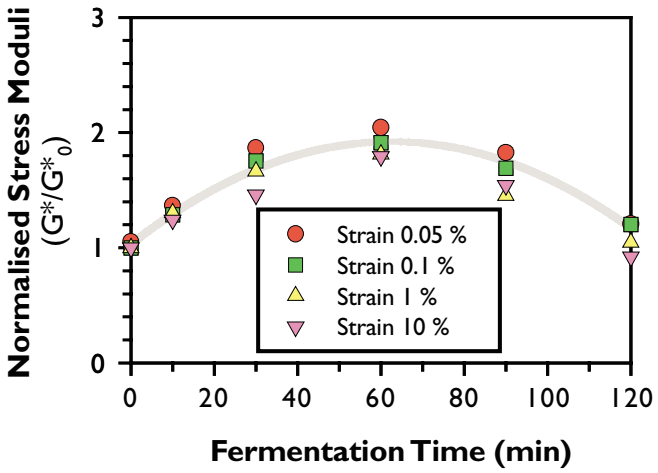
Baking tests in the pilot bakery indicated that crust characteristics are influenced by the combination of humidity and temperature on the surface of the product during the first 3 - 5 min of baking. No influence on the crust was recorded by applying any levels of humidity in the later stages of baking. This information can be used to optimise the desired crust characteristics through humidity control. It may also be applied to enhance oven design.

Process quality parameters - display and control system

Our work progressed software development for a Colour Monitoring System and Weight Loss Monitoring System for commercial bakeries. Industrial trials with our commercial partners, using software we developed, showed that the total weight loss fluctuated by up to 20 grams. Weight loss is a critical quality control parameter. It is an excellent indicator of production consistency and is a direct indicator of expected yields.

Weight loss monitoring ensures that the product is not in breach of the Trade Measurements Act (packaged articles regulation). The Act stipulates that not one sample be more than 5% lighter than the stated net weight of the packaged product. The average of 12 loaves must also not be under the stated weight. Hence, if these fluctuations of up to 20 grams can be reduced and the divider dough piece weight can be lowered by only 10 grams, the benefit to the bakery should be in the order of tens of thousands of dollars each year in ingredient costs alone. The total operation and marketing benefits should be significant as well. If these calculations are applied across the whole Australian baking industry, the benefits could represent over $2M saving in ingredients.

Fig 3.4 - Normalised, or standardised, dynamic stress moduli of doughs fermented for various periods.
The maximum behaviour is observed at several different strain levels, including those above the linear limit to standard viscoelastic rheological theory.



We are also studying the correlation between weight loss fluctuation and other baking parameters and will attempt to develop a system to reduce these fluctuations in industry.

Bread Weighing Machine

To obtain weight loss data at any location on a production line, a portable bread weighing machine was designed and constructed. The machine removes a loaf of bread from the conveyor, weighs it, logs the weight in a computer and then returns the loaf to the conveyor. In commercial bakery trials one loaf in every group passing was weighed. This is enough to monitor the general trends in final weight and weight loss of various products, particularly at bakeries not equipped with weight checkers at the slicers.

Future uses for the bread weighing machine may include measuring core temperature and facilitating taking digital photographs of loaves that are out of specification.

Bread Softness Analysis

The aim of this work was to compare four methods of bread texture analysis using the TA.XT2 texture analyzer, as indicators for consumer preference as a function of degree of baking. Approximately ten people participated in the sensory evaluation. Bread samples were tested using the texture analyzer and sensory analysis on the same day. There was significant correlation between sensory evaluation of the texture of the bread and the results from the texture analyser. However the baking and slicing experimental procedure needs improvement to reduce the variance of the results before one of the testing methods can be recommended as a good indicator of consumer preference for bread.

Project 3.4.4 - Rheology of Yeasted Doughs

Project Leader: Marcus Newberry

Background and Objectives

Despite the central importance of yeast in producing the distinctive aerated structure of many baked products most rheological studies of doughs ignore the effect of yeast. Thus focussing on yeasted doughs will help to provide more industrially relevant dough rheology information. This project's central aim is to measure the rheology of fermenting doughs using fundamental shear and extension rheological tests. Unlike the few previous rheological studies on yeasted doughs, in this work the yeast is inactivated prior to measuring, to avoid confounding of the results by yeast fermenting during collection of data. Rheological changes during fermentation will be quantified; the affect of density and gas cell size will be determined. Once a fuller understanding of the influence of fermentation on dough rheology is obtained the affect of post-mixing operations in the make-up plants on dough rheology will also be investigated.

Progress

There are few published rheological studies of yeasted dough, but in all the yeast was allowed to ferment as the rheological data were collected. There are several problems with leaving the yeast active during measurement. Firstly there is no way of determining whether the measured properties are due to prior fermentation of the dough or to fermentation that occurred during the measurements. Secondly the techniques used at Sydney University involve long resting periods and, particularly for some tests, long measurement times during which significant fermentation can occur. Thus investigations into ways of inactivating the yeast within mixed bread doughs using a variety of freezing processes were made. The most effective means of reducing yeast fermentation, as measured by dough volume expansion at 37 ºC, was rapid freezing followed by very slow thawing of the sample.

Initial studies of the affect of fermentation on the shear and extensional properties of inactivated fermented yeasted doughs have revealed significant rheological changes during the fermentation. Firstly, under uniaxial extension the peak viscosity, or viscosity at failure, of the dough decreases with fermentation. Likewise, the strain at which the extended sample breaks, a measure of extensibility, decreases with fermentation. One possible, and very tentative, interpretation of these findings is that they are a measure of what bakers describe as "dough mellowing". Oscillatory shear

The On-Line Colour Meter

measurements, under increasing strain, revealed a maximum stress response after around 60 minutes of fermentation (Fig 3.4). An encouraging finding from the shear rheology experiments is that the optimum pattern is observed at a range of strain levels, including strains above which standard viscoelastic rheological theory collapses (known as the linear viscoelastic limit). The very low linear viscoelastic limit (at around 0.1% strain) is a major limitation to applying existing rheological theory to dough rheology.

Thus this observation of consistent behaviour over a range of strains raises hopes of developing a rheological model to explain the changes in dough rheology during fermentation.

Verification of these initial findings has had to wait until the recent development of pre-conditioning methods to reduce the inherent data variation in the rheological readings to acceptable levels.

MAJOR RESEARCH MILESTONES ACHIEVED IN PROGRAM 3B

- A new pilot-scale dough sheeter with interchangeable rolls was custom built to enable simultaneous measurements of roll speeds, gaps, separation forces between rolls, torque reaction on each roll and dough sheet thickness during sheeting studies.
- The relationships between the physical and chemical properties of sheeted doughs from a weak and a strong flour were established and correlated with the baking quality of breads baked from these doughs.
- On-line Hunter Lab colour measurement was confirmed as a reliable quality control tool for integration into bakery quality control systems.
- A portable bread weighing machine was designed and constructed to remove a loaf of bread from the conveyor, weigh it, log the weight in a computer and then return the loaf to the conveyor.
- Measurements of weight loss indicated that annual savings of over $2M could be made by reducing divider fluctuations to less than 10 g per dough piece and oven losses to less than 20 g per loaf.
- A method was developed for inactivating yeast in fermented dough to remove the problem of yeast fermention during rheological measurements.
- Methods were developed for performing uniaxial extension and shear sweep rheological measurements on these doughs.
- A highly promising method for pre-conditioning dough before rheological tests was developed to lower the variation in rheological readings to more acceptable levels.

PROGRAM 4: PRODUCTS FROM WHEAT

Program Manager: Dr Ken Quail

Dr Ken Quail
Program Manager

PROGRAM 4 OBJECTIVES

To develop raw material specifications and processing knowledge for major wheat based products.

Enable the Australian wheat industry to better meet consumer demands for product quality.

Enable sale by specification and the targeting of more discerning markets.

There is an international trend towards convenience foods. These new products must be simple and rapid to prepare. Often they must be available in take away forms or suitable for microwave reheating. Fortunately many wheat based products have been adapted to suit this trend to convenience. Demand for Asian style noodles has grown enormously throughout the world. Instant noodles have been the fastest growing convenience food in the last five years with over 40 billion packs to be consumed this year. We have also seen the recent emergence and success of precooked long life noodles and frozen and chilled noodles, which have revitalised traditional markets and opened new opportunities. Pasta products have also seen growth, and there is a trend towards greater diversity of bread markets, which has generated some increases in bread consumption even in mature markets such as Australia.

Behind these market trends there is a need to deliver finished products to meet tighter quality specifications. To meet these requirements food manufacturers are demanding tighter raw material specifications. The aim of this program is to understand wheat based products from the perspective of consumers and food processors. What is important to the consumer and what must the food processor do to achieve these products? This means looking at the effect of processing and raw materials on finished product quality. The information must then be distilled to determine which wheat quality traits are most important to the food processor.

The wheat specifications developed by this program can be used to target wheat for discerning markets. Delivering the quality demanded by markets increases our competitiveness and potential to attract higher prices. These specifications can also be used as targets for wheat breeders to develop new wheats, which better meet market requirements. Understanding the food manufacturing process and interactions between the raw material and the process can also be extremely helpful in supporting processors using our wheat. This enables Australia to meet quality requirements and effectively support our product in the market.

Program Objectives

The objectives of this program are to develop raw material specifications and processing knowledge for major wheat based products. This will enable the Australian wheat industry to better meet consumer demands for product quality and will also improve efficiency for food manufacturers. Development of raw material specifications will enable sale by specification and the targeting of more discerning markets, and will greatly assist the development of wheat breeding targets for enhanced quality.

Project 4.1.1 - Defining starch quality for enhanced performance of baked products.

Project Leader: Dr Hon Yun

Background and Objectives

Starch forms the major component of wheat flour and makes an important contribution to bread character. In this project we are seeking to identify how changes in wheat starch characteristics affect baked products.

Results reported in earlier CRC reports indicated that the proportion of A granules had only a minor impact on starch physical properties such as starch viscosity or flour swelling volume. The effect of starch granule ratio has now been assessed for its impact on baking using a specifically designed small scale baking test. In addition we have used the waxy wheat material developed in Program 1 to explore the impact of amylose to amylopectin ratio.

In addition to this work on bakery products, Dr Hon Yun has now linked into a GRDC project seeking to characterise the role of starch components for Asian noodles. This has achieved a number of synergies, as the sample preparation methods are similar.

Progress

A and B granules

Flour was first separated into gluten, starch and water soluble fractions. The starch was then separated as tailing and prime starch. The prime starch component was separated into A (>10 microns) and B (<10 microns) granules using a sedimentation procedure which achieved effective resolution.

Once adequate quantities of the components were created, a base flour was formed, which consisted of gluten, water solubles and tailing starch in their original proportions. The prime starch component was then made up of the following A:B granule ratios: 100% A, 50%A: 50% B and 100%B based on weight. When preparing the bread doughs from the reconstituted flours. B granules significantly increased the amount of water required to form a dough. A higher water addition is considered desirable by bakers as it increases their bread yield. Intact starch granules tend to hold water on their surface during dough formation. For the same weight of starch, a sample of B granules has a much higher number of granules with a greater

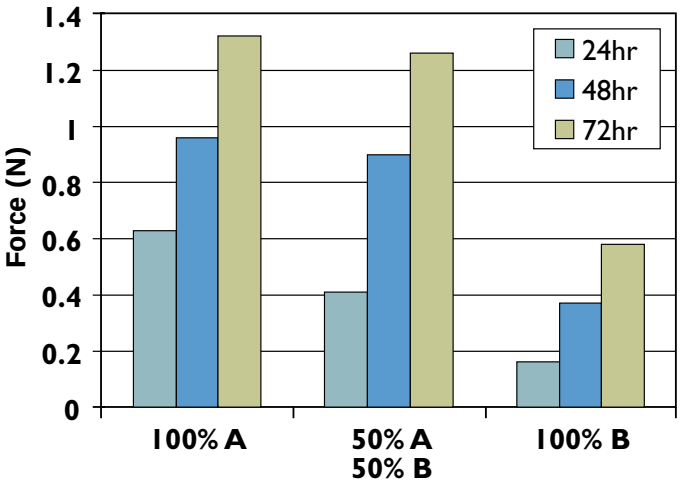
Fig 4.1 - Granule Reconstituted Bread

total surface area than for a sample of A granules. The higher water absorption values obtained appear to be consistent with the increase in surface area associated with the B granules. Other features of the dough such as mixing time did not appear to be significantly affected by the ratio of A to B granules.

The samples were baked into high top and square sandwich loaves (Fig 4.1). This was done on a miniature scale using only 40g of flour for each loaf. The miniature scale was used due to the difficulty in obtaining adequate quantities of B granules. The sample with 100% B granules had a significantly higher loaf volume and produced softer breadcrumb (Fig 4.2). The effect of B granules on crumb softness was also found using the square bread samples). It is possible that the softer breadcrumb was in part due to the higher water addition required for the B granules.

Higher water absorption and increased bread crumb softness are both desirable features for bread production and it may be worth considering the target of higher B granule compositions for bread making.

Fig 4.2 - The effect of granule composition on crumb firmness.



Whole starch was separated from the CRC's waxy wheat samples and reconstituted with gluten and water solubles extracted from a bread making flour. This was important as the waxy wheat did not have good gluten quality and assessment of the whole flour milled from this sample did not represent the potential of the starch properties. Similar assessment criteria to those used in the A:B granule work described above were used to assess these flours. When the ratio of waxy wheat starch was increased, the water required to make a bread dough increased by approximately 2% for each 25% increase in the proportion of waxy starch.

The specific loaf volume of bread did not show any clear trend with an increase in the ratio of the waxy starch. A major problem of loaf shrinkage at the high levels of waxy substitution occurred, which appears to be related to the high levels of water addition required. At high levels of substitution the waxy starch also made the bread crumb sticky and unacceptable. At lower levels it improved the softness and elasticity of the crumb which was desirable.

Similar tests were performed for Japanese white salted noodles. In this case the noodles became softer as the ratio of waxy wheat flour increased. It was also apparent that noodle elasticity increased at low levels of substitution, however this trend was less clear than the results for noodle firmness.

Results for the bread and noodles indicate benefits from the use of waxy wheat. This work will need to be reviewed continually, to determine the optimum levels for substitution, as more samples of waxy wheat become available.

Project 4.1.2 - Improvement of frozen and par baked products

Project Leader: Ken Quail

Background and Objectives

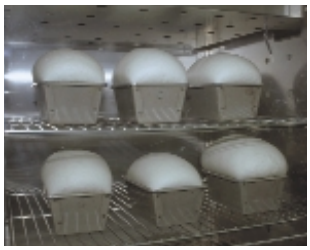
Frozen dough for bread and pastry products offers the convenience of fresh bake-off that has appeal in both domestic and export markets. The major limiting factor is the shelf life of the frozen dough. These products lose viability during storage due to deterioration of yeast activity and damage to the gluten structure by ice crystals, chemicals leached from yeast cells and moisture migration.

Industry is targeting a frozen shelf life of up to six months. The time taken to evaluate the effects of processing changes and ingredients on shelf life over six months restricts progress. This program is aimed at establishing methods to provide a rapid storage test and to provide more effective measures of the changes taking place during storage.

Progress

The deterioration of frozen bread dough appears to be quite linear at constant temperature. A major proportion of this deterioration is accounted for by the loss of gassing power or yeast activity. Work on the cycling of storage temperatures indicated that both the disruption of the dough structure and yeast activity were accelerated by this treatment. In this phase of the project we have attempted to match the rate of deterioration between doughs stored at constant temperature and through a temperature cycling regime. When dough is stored at minus 20ºC, ice crystals gradually grow and components such as the gluten lose water to these crystals. By raising the temperature and then lowering it again the rate of this process is increased. A range of times and

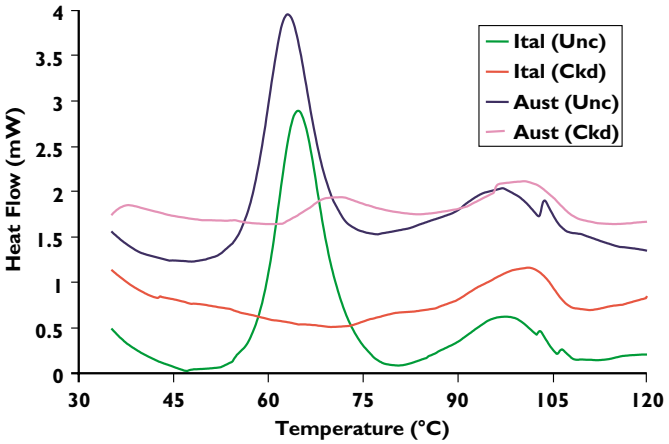
Fig 4.3 - Frozen bread doughs proving - loss of yeast activity.



temperatures were trialed to obtain a rate that could be related to the rate of deterioration at constant storage temperature. The initial temperatures and times trialed for cycling, tended to disrupt the dough structure more than during constant storage and it appeared that the rates were too high for an effective rapid storage test. Further testing showed that the cycling worked best when three temperatures were used and there were adequate storage times at minus 20ºC to allow equilibration of the dough at this temperature. The rate of deterioration under the selected cycling regime could be related to deterioration at constant storage temperature using loaf volume and gassing power as measures of quality. Thus, a six month storage trial can now be completed in approximately 3 weeks.

To contrast with the work on bread doughs a benchmarking study using commercially manufactured frozen croissant doughs was conducted. Samples of frozen croissants were obtained from five manufacturers and stored for six months. Two out of the six samples stood up to the storage extremely well and had similar quality, whether baked off at the start of the trial or after six months. The other three samples were not as good at the start of the trial and deteriorated further over the six months. This indicates that the technology is available to achieve a commercially viable shelf life with croissants. The extra fat between the layers of dough forms a barrier to water migration and effectively reduces the impact of freezing. The challenge remains, how to achieve a similar outcome for bread doughs that have significantly less fat.

Fig 4.4 - DSC thermograms of uncooked pasta from Australian and Italian manufacturers.



Project 4.1.3 - Better durum grain for premium pasta

Project Leader: Dr Mike Sissons

Background and Objectives

Australia exports about 200,000 tonnes of durum wheat per annum with about half of this going to Italy. Opportunities to export grain and finished products into East Asia in the future also exist e.g. Japan currently uses about 2,000,000 tonnes grain each year. Australian production should target the high quality, lucrative export market, towards which the current breeding and research effort is directed.

The aims of this project are to determine the role of starch properties and interactions between starch and protein in determining pasta eating quality, the most appropriate starch and protein properties for durum improvement using small-scale pasta making and reconstitution techniques to identify the molecular basis of quality differences, and the value of novel germplasm introductions into a durum background.

Progress

Using a unique design, a small-scale pasta extruder was developed to allow the preparation of pasta from as little as 25g of semolina. A suitable method was developed so that the pasta prepared with this equipment had the same cooked pasta firmness as that prepared from a commercial 2kg extruder. The method will be useful for reconstitution studies and to assess breeders' early generation lines for pasta-making quality. Gluten, starch and soluble protein have been isolated from semolina and recombined in their original proportions and shown to have equivalent dough rheology (mixograph curves) cooked pasta firmness, stickiness and cooking loss. In future studies we will examine the effect of variations in protein and starch quantity, composition and proportion on mixing and pasta-making quality. This information will provide the molecular basis for a "good" pasta product to be defined and will be used to develop diagnostics for the breeding, processing and marketing of pasta products.

A collection of 32 tetraploids evaluated for novel quality in last year's report were again grown this year and analysed for quality, protein and starch composition. Species that show consistently desirable quality attributes will be identified and crossed with adapted durums.

The recently developed semolina mill yield calibration for the single kernel characterisation system will be applied to screening durum lines with known Buhler mill yield to evaluate the utility of the method in a breeding program.

Commercial pasta has been examined using a differential scanning calorimeter. There are distinct differences between most Italian and Australian pastas after cooking. Pastas were also cooked for varying lengths of time, ranging from one third optimum

cooking time to ten minutes over the optimum cooking time. As cooking time increased, the starch gelatinisation peak became smaller and occurred at a higher temperature until optimum cooking time was reached. At optimum cooking time, there was a residual peak in most Australian pastas, but it was absent in most Italian pastas (Fig 4.4).

Project 4.1.4 - Optimisation of the Processing Strategy for Utilising Australian Wheat in Instant Noodles

Project Leader: Dr Nasir Azudin

Background and Objectives

The current world consumption of instant noodles is over 40 billion packs per year. This constitutes a total wheat requirement in excess of 4.6 million tonnes, representing a highly significant market, which is still growing. The aim of this project is to address the current technical problems faced by flour millers and instant noodle manufacturers when using Australian wheat in the production of instant noodles. The project forms an extension to the initial project, which established the wheat quality requirements for instant noodle production.

Progress

Starch work:

Starches were isolated from a total of 28 samples (14 varieties) grown at two different sites (Horsham and Yeelanna) during the 95/96 planting trials. The total amylose content in the prime starches ranged between 24.7% and 30%. The gelatinisation temperatures were measured by differential scanning calorimetry (*Perkin-Elmer DSC 7*). Considerable differences in gelatinisation temperature (Tp), onset temperature (To) and conclusion temperature (Tc) were observed between starches. The enthalpy of gelatinization ($-\Delta H_G$) associated with the transitions varied between 3.31 and 4.78 J/g. To ranged between 60.58 and 64.5ºC, Tp between 65.3 and 69.2ºC, and Tc was between 70.9 and 75.3ºC. Significant positive correlations were observed with Tp ($r = 0.7$, $P<0.01$) and Tc ($r = 0.798$, $P<0.001$) of the same variety grown at two different sites. Other physical properties such as starch paste peak viscosity and starch granule distribution were measured. The physicochemical properties of prime starches and the relationship to texture characteristics of instant noodles and Japanese Udon noodles is currently being investigated. A significant positive linear correlation ($r = 0.54$, $P<0.05$) was observed between the percentage A type starch granules (prime starches with tailings) and the firmness (maximum load) of instant noodles. In addition, a significant positive linear correlation ($r = 0.86$, $P<0.001$) was observed between the firmness of instant noodles of the same wheat variety grown at two different sites.

Addition of commercial starches in instant noodles

The use of commercial starch as partial replacement to flour for instant noodle production was investigated. Two common types of starches used in commercial instant noodle manufacture were looked at, namely tapioca and potato starch. Four types of tapioca starches used were: Native Tapioca, National 7, Purity 90 and Amioca (the last 3 being modified starches), and the three types of potato starches were Native Potato, Avebe NS-450 18% and Perfectamyl AC (the last 2 also being modified starches). Levels of addition investigated were 5%, 10%, 15% and 20% for each starch type.

It was observed that the addition of starch contributed to higher sheet brightness, lower redness and lower yellowness and there was a good correlation between flour brightness and sheet brightness and a strong correlation between flour yellowness and sheet yellowness. For both types of starches, the native ones seemed to contribute to lower sheet brightness and higher sheet yellowness than the modified ones.

As for noodle block colours, there was a good positive correlation between flour yellowness and noodle block yellowness however, correlations between brightness of flour and noodle block were poor. There was no specific trend for the noodle block colours and cooked noodle colours and this could to due to the effect of the amount of fat absorbed (as there is a positive relationship between fat content, noodle block yellowness and cooked noodle yellowness as established by the previous study).

Various texture parameters (firmness, hardness, springiness, cohesiveness and chewiness) were measured using the Lloyd Texturemeter LXR 2K5. Noodles were cut across 7 strands on a plate with a probe for the measurement of firmness. For the tapioca starches, firmness of noodles increased and peaked at between 5-10% addition. The modified tapioca starches did not seem to be as firm as the native one. However for the potato starches, the modified ones were firmer than the native one at all addition levels. At 5% addition, firmness was very similar to the sample without starch and decreased as the level of addition increased. There were no specific trends observed for the remaining texture measurements for either tapioca or potato starches.

Fig 4.5 -
Frying Instant Noodles

Project 4.1.5 - Wheat and flour properties affecting the quality, processing and shelf life of fresh long life noodles

Project Leader: Dr Nasir Azudin

Background and Objectives

Long life noodles have become extremely popular in Asian countries. They are a pre-cooked product which is shelf stable and only requires reheating by consumers before serving. Through this project we are seeking to determine methods to evaluate shelf stability and to assess wheat quality requirements. The major challenges of this product are maintaining its freedom from microbial spoilage at room temperature, and the achievement of acceptable texture after the high temperature treatment required for shelf stability.

Progresss

Following up last year's work, the results from the microbiological testing showed that using the current processing technique, the long life noodles can be classified as commercially sterile, being guaranteed a shelf life of at least 6 months at ambient temperature. Following the work that was done with acetic acid, lactic acid was trialled to see if the same results could be obtained. Microbiological testing revealed that long life noodles made using lactic acid were commercially sterile. Lactic acid is the preferred acid due to the fact it is both colourless and odourless. Acetic acid gave off a slightly offensive odour when the noodle packets were opened. It was found that a concentration of 5M lactic acid worked well with 10M being a little too strong and causing some surface pitting. As had happened in the acetic acid trials, the lactic acid also caused the whitening of the product over time, at both concentrations.

With the process for manufacturing this product now documented, various other parameters were looked at in more detail. Water content is an important part of controlling textural longevity in long life noodles, in terms of both firmness and elasticity. This product is preferably soft and chewy and increased water levels are thought to stabilise these parameters. Water contents between 35 - 45% were trialled for this product. It was found that without a vacuum mixer, higher water content could cause processing problems, such as large dough crumbs, sticky dough sheets and poorly shaped noodles. Due to the increased water levels the cut noodles became sticky and required vigorous agitation to separate during the parboiling stage, causing twisting and breaking of strands. Results indicated that there was a slight increase in the springiness of the samples with higher water content, however this levelled out over time, as did chewiness. No extensive advantage for increasing the water content in the formulation was found.

The use of commercially available starches is becoming quite common in noodle manufacture. Various commercial starches were tested to see the impact that they would have on this type of product as well as the fresh noodles. Current Japanese and Korean blends were manipulated and had starch added to quantify the effect of added starch. Starch levels used were 0, 10% and 20. Although good correlation was found between results for the fresh noodles, these correlations were not as strong or were non-existent in the long life noodles. Both native and modified starches were tested, and it appeared that the native starches actually performed better than the modified ones. The pasteurisation process used to sterilise this product appeared to even out any differences that were noticeable in the fresh noodles. It was concluded that the use of native potato and tapioca starch appears to be more beneficial in long life noodle manufacture than the use of some modified starches.

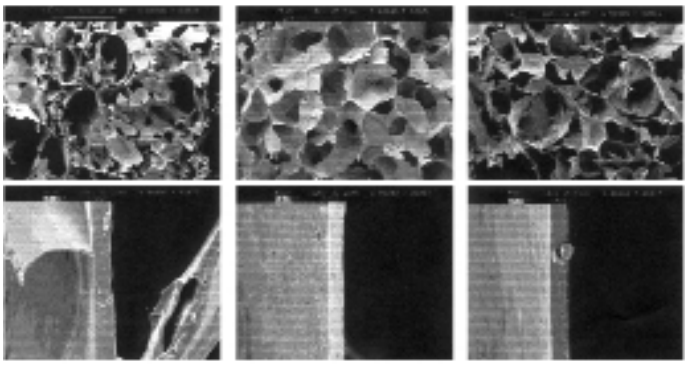
Project 4.1.9 - A specification of wheat quality and processing requirements for extruded products

Project Leader: Di Miskelly

Background and Objectives

The extrusion process is widely used in the food industry because of its versatility and reduced costs. Snack foods made using the extrusion process (either single or twin screw) are increasing in popularity worldwide. Typically, extruded snack foods are made with maize and rice because of their higher expansion properties compared with wheat. Some wheat is used in extruded snack products, and where this occurs, there is a preference for low protein soft wheats. However, little information is available on the wheat and flour quality attributes, which influence product and processing quality in snack food manufacture, or whether low protein hard wheat can be used to make an acceptable product. If strategies can be developed to use low protein hard wheat in snack foods, there is a major opportunity to add value to Australian wheats. The information generated in this project should assist wheat marketers, and have an application in the domestic market.

Fig 4.6 - Scanning Electron Micrographs of three wheat types as extruded products.



LOWPRO Soft | LOWPRO Hard | HYPRO Hard

Progress

Commercially milled flour from high protein hard wheat, low protein hard wheat and low protein soft wheat were used to produce expanded snacks. These trials were carried out in the Food Science Australia APV Baker twin screw extruder operating with no external heat input (adiabatic conditions) or with a range of external heat input (non-adiabatic conditions). Expanded snack products were analysed for degree of expansion, specific volume, pasting properties, texture, structure and textural properties.

Product characteristics were found to vary with the extruder operating conditions (mainly barrel moisture content), flour protein content and grain hardness. High protein hard wheat was found to require higher levels of energy compared with low protein hard and soft wheats. Overall, the difference in texture score of the three wheat types appeared to be minimal in both adiabatic and non-adiabatic conditions using the twin screw extruder. Sensory analysis showed that extruded snacks made from low protein hard wheat had stronger flavour and aroma, more toothpacking and a drier mouthfeel compared with snacks made from low protein soft wheat. The low protein hard wheat appeared to have a higher potential for producing better texture if external heat was applied. Scanning electron microscopy showed that thinner cell walls were formed in expanded products using low protein hard wheat.

As wheat flour is normally used in combination with other ingredients to increase expansion, a fully commercial snack product was produced under optimised operating conditions. The extruder was operated under adiabatic conditions and adjustments were made to the barrel moisture. Both low protein hard wheat and low protein soft wheat flour were used in this trial. The final product was produced with 70% wheat flour and 30% maize flour. The products had similar physical characteristics, and a sensory panel was unable to distinguish between snacks made from hard and soft flour.

MAJOR RESEARCH MILESTONES ACHIEVED IN PROGRAM 4

- Assessment of the impact of starch granule ratio on baking completed.
- Assessment of the impact of starch isolated from new waxy wheat cultivars on baking and noodle making completed.
- Rapid test for the evaluation of frozen storage shelf life available for bread doughs.
- Benchmarking study to compare the frozen shelf life of commercial croissants completed.
- Assessment of the impact of commercial starches on instant noodle manufacture initiated.
- Evaluation of starch properties for their impact on instant noodle quality initiated.
- A method for the evaluation of long life noodles based on a lactic acid treatment established.
- Assessment of commercial starches to improve the quality of long life noodles completed.
- Small-scale pasta extruder developed as a tool for studying the biochemical basis of pasta quality using small quantities of semolina.
- Differences between Italian and Australian pastas observed by differential scanning colorimetry.
- Four tetraploids, identified from the 32 that were extensively tested, have been crossed with adapted durums and are at the F1-F4 stages.
- Extrusion testing and evaluation of optimum processing conditions for production of extruded wheat snacks using a twin screw extruder completed.

PROGRAM 5: FLOUR AND DOUGH COMPONENTS AND THEIR INTERACTION

Program Manager: Dr Ferenc Békés
Deputy: Ms Amanda Hill

Dr Ferenc Békés
Program Manager

PROGRAM 5 OBJECTIVES

Provide a basis for breeding for quality by understanding the relationship between flour composition and dough processing properties.

To study the products of genes from sources outside cultivated wheat for novel effects on dough function.

To better predict commercial bakery performance of flours.

To attract talented students and to provide industry-relevant continuing education for postgraduate students and industry professionals.

The focus of Program 5 on flour and dough components and their interaction underpins much of the research elsewhere in the CRC. Its purpose is to provide a basis for breeding for quality by understanding the relationship between flour composition and dough processing properties. Much of the enhanced understanding generated can be used to develop breeding targets, or for development of diagnostic tests using antibodies and DNA probes (interactively with Program 1).

Given the variable concentrations and high sequence homologies of many of the flour proteins which are targets of these diagnostics new methods based on antibody engineering are being used to manipulate the specificity and sensitivity of assays. Several assays for products of key genes are already being provided to breeding programs for routine screening. The techniques developed in the Program provide research methods to use in a variety of applications. These include studies on developing molecular markers for dough quality traits (with Program 1), on the effect of environmental growing conditions and grain storage conditions on processing quality, on monitoring the changes in protein composition during endosperm development and on developing a mathematical model to estimate the quality attributes of flour blends, as well as providing diagnostic methods for on-farm segregation (with Program 2).

The ability to understand the role of individual flour polypeptides and starch components comes about from the development of small-scale equipment for dough mixing, extension and baking. This development, together with research aimed to understand and differentiate dough behavior in fundamental rheological parameters, should allow the results of laboratory screening tests to better predict commercial bakery performance of flours, and enable processing conditions to be more objectively manipulated to suit different end-products.

Finally, professional education in cereal science is provided.

Fig 5.1 - The effect of protein content (A, C) and the glutenin to gliadin ration (B , D) on the viscosity of flours of cv Banks (A, B) and Rosella (C, D)

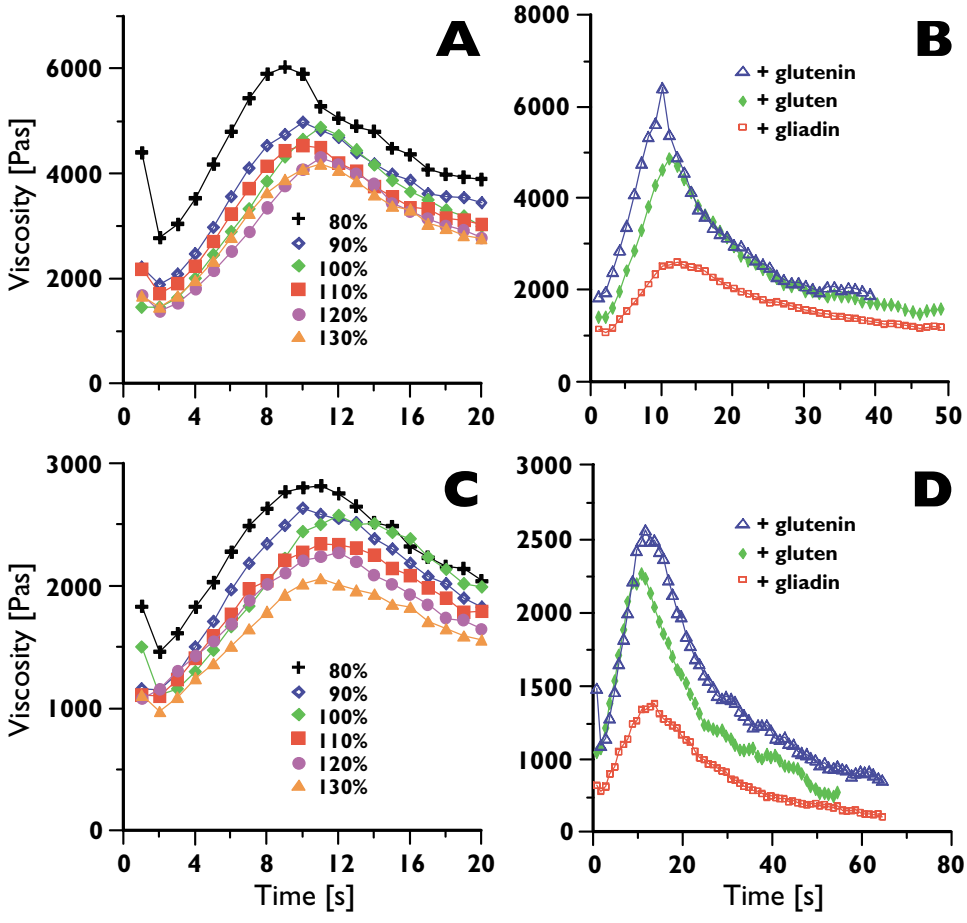


Fig 5.2 - Stages of an extension experiment investigating the effects of altering flour protein composition on rheological characteristics of the dough.

Program Objectives

The objectives of the program are four-fold. The first is to provide a basis for breeding for quality by understanding the relationship between flour composition and dough processing properties. The second, to study the products of genes from sources outside cultivated wheat, such as from the primitive wheat, *Triticum tauschii*, and novel antifreeze proteins, for novel effects on dough function. Thirdly, to better predict commercial bakery performance of flours, allowing processing conditions to be tailored appropriately for different end products. The final objective, interactive with other research programs, is to attract talented students and to provide industry-relevant continuing education for postgraduate students and industry professionals.

Project 5.1.1 - Functional properties of individual flour components

Project Leader: Ferenc Békés

Background and Objectives

Existing approaches used to relate flour composition to dough and baking properties have major limitations. Statistical correlations between dough parameters and genetic composition have been developed, but their reliability depends on the particular sample set. There have also been difficulties in detecting quantitative relationships, and the mechanism of effects of particular gene products is not explained. In this project, two different approaches are utilised. In the incorporation/addition test, the composition of a base flour is altered systematically by enriching the flour with well-characterised individual flour components, while in a new "model dough" approach, we have been developing the methodology for building up flours from a minimum number of individual components. Another aim of the project is to improve the quality of frozen dough products by applying novel antifreeze polypeptides in the dough formulation.

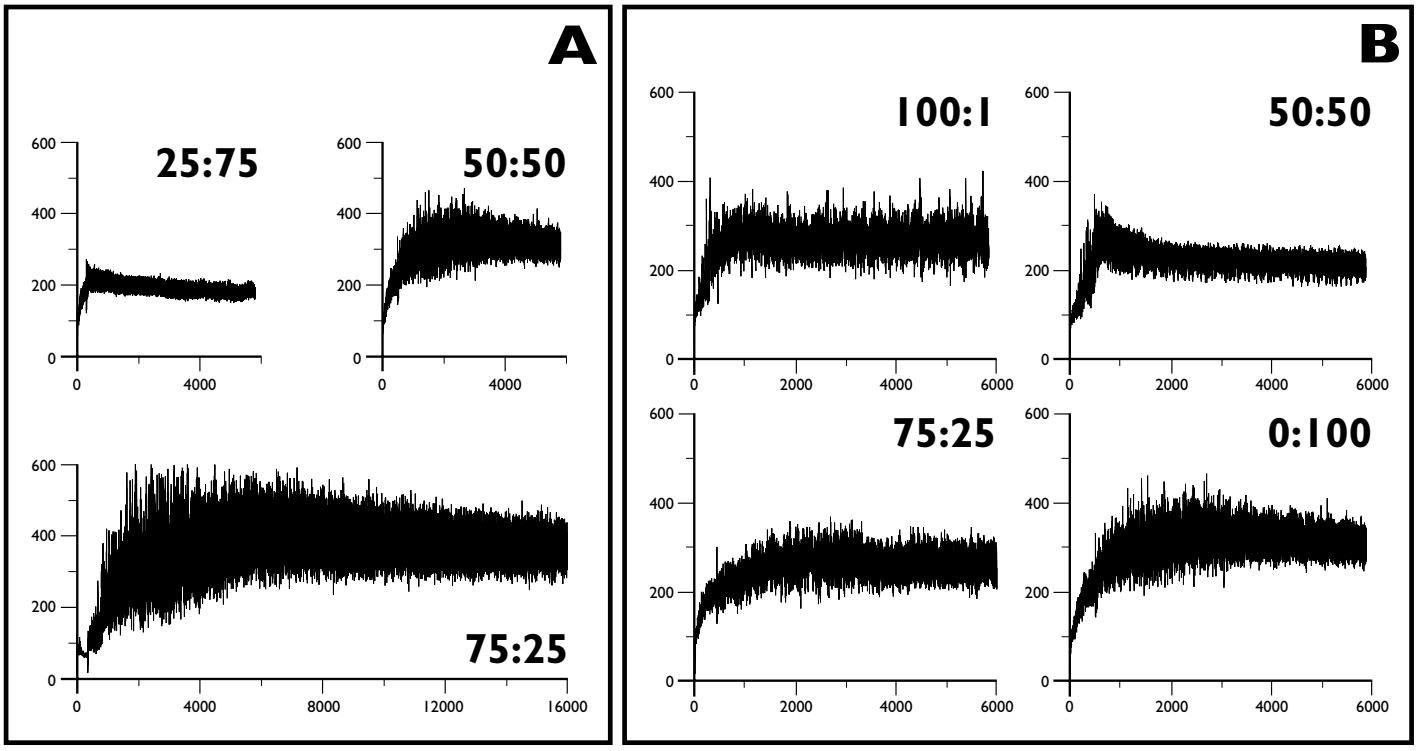
Progress

Surjani Uthayakumaran has completed her studies and submitted her PhD thesis on monitoring the changes in functional properties (small-scale mixing, extension and baking studies) and fundamental rheological parameters caused by systematically altering the protein composition to flour samples. For the continuation of Surjani's successful work on relating chemical composition and basic rheological properties of wheat dough, Tasir Hubraq has been selected to work on a new PhD project (5.1.6.)

In the model dough approach protein fractions have been isolated, either from flour from special null wheat lines, or from *E. coli* expressing cloned glutenin subunits, and the subunits have been polymerised *in vitro* before dough formation. Using bulk glutenin and gliadin protein fractions isolated from several wheat varieties, representing a wide range of allelic composition in the starch-solubles-glutenin-gliadin system, it was found that the model dough system is an excellent method to compare the effects of proteins on dough functionality.

In similar experiments, starch, solubles, gliadin and glutenin fractions were isolated from control and heat-shocked samples and flours were reconstituted, systematically altering the components. Dough weakening caused by the heat treatment was clearly related to

Fig 5.3 - Mixing curves of dougs, altering the glutenin to gliadin (A) and the HMW to LMW glutenin subunit (B) ratios in model dough experiments.



the glutenin fraction of the samples. In experiments to optimise the conditions for the *in vitro* polymerisation of HMW-GS, LMW-GS (high and low molecular weight glutenin subunits), and mixtures containing different ratios of these subunits, it was found that polymer size distribution mimicking the size range of native glutenin polymers can only be produced in the presence of special compounds with chain-terminating characteristics. For the production of sufficient amounts of individual glutenin subunits, clones of HMW-GS *Dx5, Dx10, Dy2 and Dy12* were expressed in *E. coli*. The bacterial expression has been successfully scaled up to 2 litre fermentation and a protocol was developed to purify HMW-GS from lysates using a combination of selective extraction and chromatography using the highly effective POROS system.

The effects of eight anti-freeze proteins containing cysteine residues to promote oxidative polymerisation were assayed by cryomicroscopy and by small-scale dough mixing and extension testing. Oxidation of the proteins to cysteine-linked polymeric form had little effect on their antifreeze activities, compared to either the reduced state or the wild-type protein. When incorporated into the dough using a reduction/oxidation protocol, no effect on the mixing properties of doughs was seen. Addition of the recombinant antifreeze proteins to frozen doughs at low levels (0.1% of flour mass) generally had little effect on the extension properties of simple non-yeasted dough pieces.

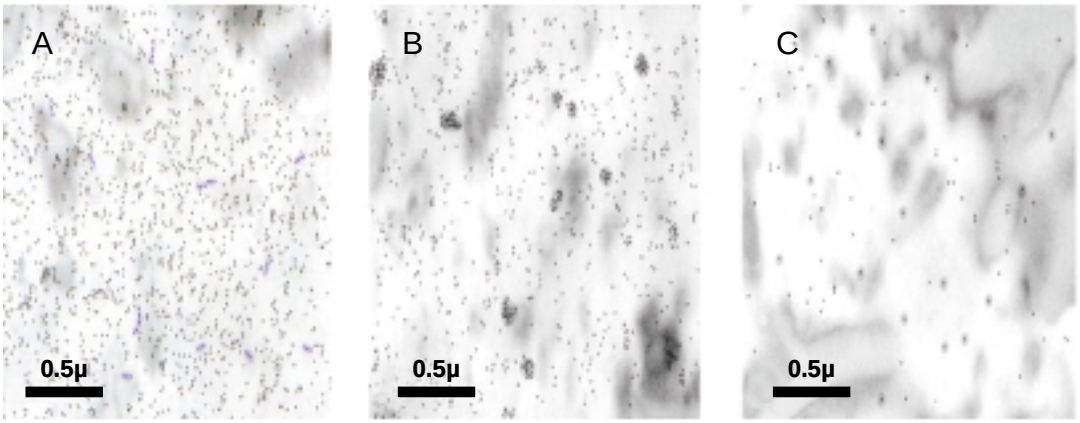
Project 5.1.2 - Molecular interactions between flour components

Project Leader: John Skerritt

Background and Objectives

The extremely high molecular weight of the glutenin macropolymer in flour and doughs has been the major limitation to studying and understanding its central role in determining dough-processing behavior. In this project we are utilising two approaches to study the polymer and its changes during processing. These are the development and application of Field Flow Fractionation (FFF), a technique from particle analysis, in addition to biochemical studies and microscopical analyses on changes in the structure of this polymer during dough processing.

Fig 5.4 - Distributions of HMW-GS (A), LMW-GS (B) and gliadins (C) in dough shown by transmission electron microscopy, with immunocytochemical detection.



Progress

FFF proved to be extremely useful in the characterisation of native glutenin polymers, and in studies on the effects of reaction conditions for *in vitro* polymerisation of glutenin subunits. This was specifically needed in the development of the model dough system (project 5.1.1). Studies on reaction parameters such as monomer concentration, the concentrations of different oxidisers (KIO_3, $KBrO_3$, $H2O_2$), reaction time, pH and temperature have been completed. FFF was found to be an excellent tool for the determination of the size distribution of polymeric proteins.

A protocol and computer software has been developed to calibrate FFF data to molecular size data using proteins of known molecular size. At present, a reliable calibration curve has been developed for proteins of molecular weights up to 890,000, and a procedure is available to estimate larger sizes. To get more precise data for the larger size interval, work was initiated using DNA standards to calibrate FFF separations in larger sizes. To continue studying the role of the size and shape of biopolymers in cereal processing, a new PhD project (5.1.9) has been established.

Megan Lindsay has completed her studies and submitted her PhD thesis on investigating the molecular structure of the glutenin macropolymer (GMP), the main protein component responsible for the viscoelastic functional properties characteristic of a dough. Biochemical studies have shown that the GMP in doughs has a defined structure and specific changes in structure occur during dough mixing.

During the last quarter, the structure of the GMP was examined. Several microscopical approaches were pursued to test hypotheses on the structure of the glutenin macropolymer. Initial transmission electron microscopy (TEM) studies were conducted using immunolocalisation techniques to study the structure of the GMP. The pattern of gold labelling suggested that HMW-GS form chains that develop into a network structure. According to this structural arrangement, it is possible that HMW-GS form the "backbone" of the gluten macropolymer. The distribution of LMW-GS was markedly different, which may account for differences in the contribution of LMW-GS to dough properties. LMW-GS were evenly distributed in gluten, however, they were localized in discrete regions, forming clusters that varied in size. The LMW-GS is predicted to be located on branched structures of the HMW-GS backbone. To utilise the theoretical and methodological achievements of this project, a new PhD project was established recently (5.1.7) aiming to investigate the role of changes to the structure of glutenin macropolymer in commercial bread and low-water (noodle) doughs and products.

Project 5.1.3 - Differentiating dough behavior at the small-scale or fundamental level

Project Leader: Nhan Phan-Thien

Background and Objectives

Despite its obvious commercial relevance, we know rather little about the behavior of doughs in precise rheological terms. Laboratory equipment such as the Mixograph, Farinograph and Extensograph provide empirical rheological information on dough behavior, but the lack of understanding of fundamental rheology of the doughs can lead to inconsistencies in dough behavior between these instruments (complicating selection in breeding programs), inconsistencies in results between the laboratory and the bakery, and difficulties in understanding relationships between flour composition and rheological behavior. We are tackling this in two ways, firstly by developing and utilising equipment for small-scale dough testing, and secondly by undertaking an extensive investigation of the fundamental rheological analysis of dough.

Fig 5.5 - High resolution mixing curve for mathematical modeling of the mixing action Z-mixer traces.

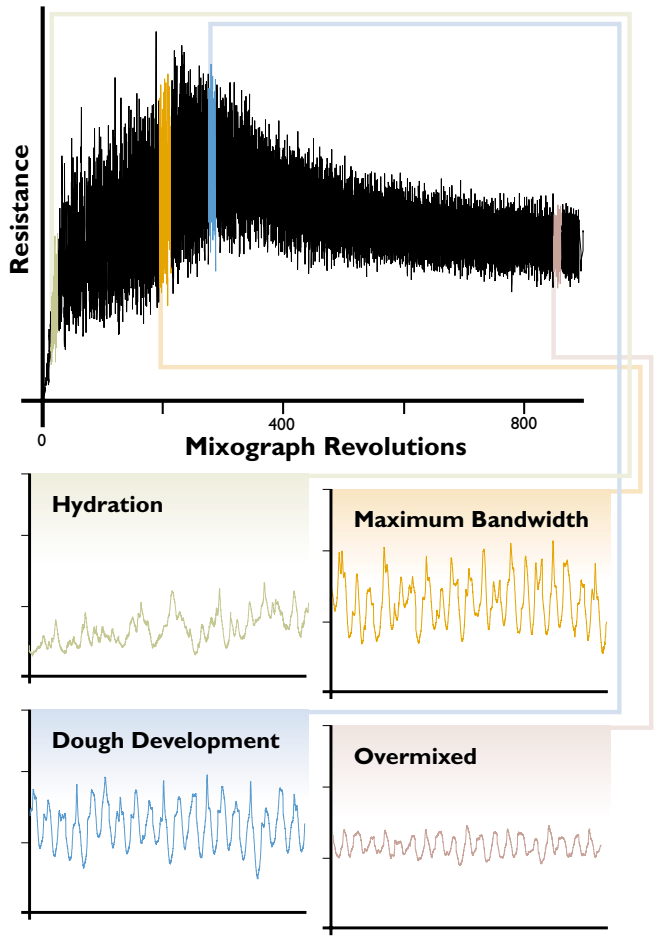
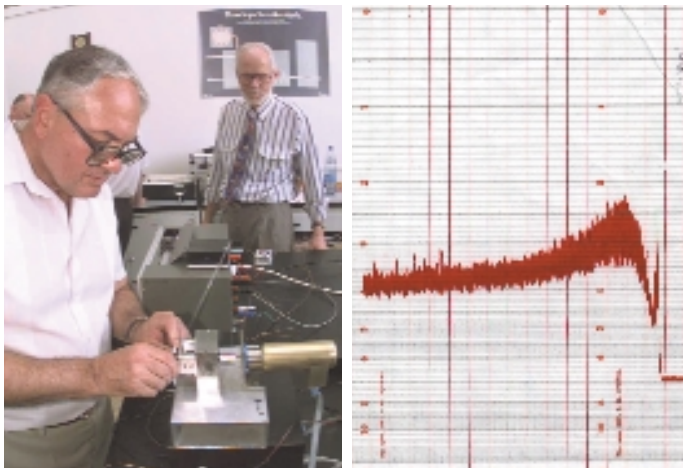


Fig 5.6 - Developing the small scale Z-armed mixer:
Janos Varga (TUB, Budapest) and Chris Rath working on the prototype machine (left) and a mixing curve obtained using the new equipment (right),



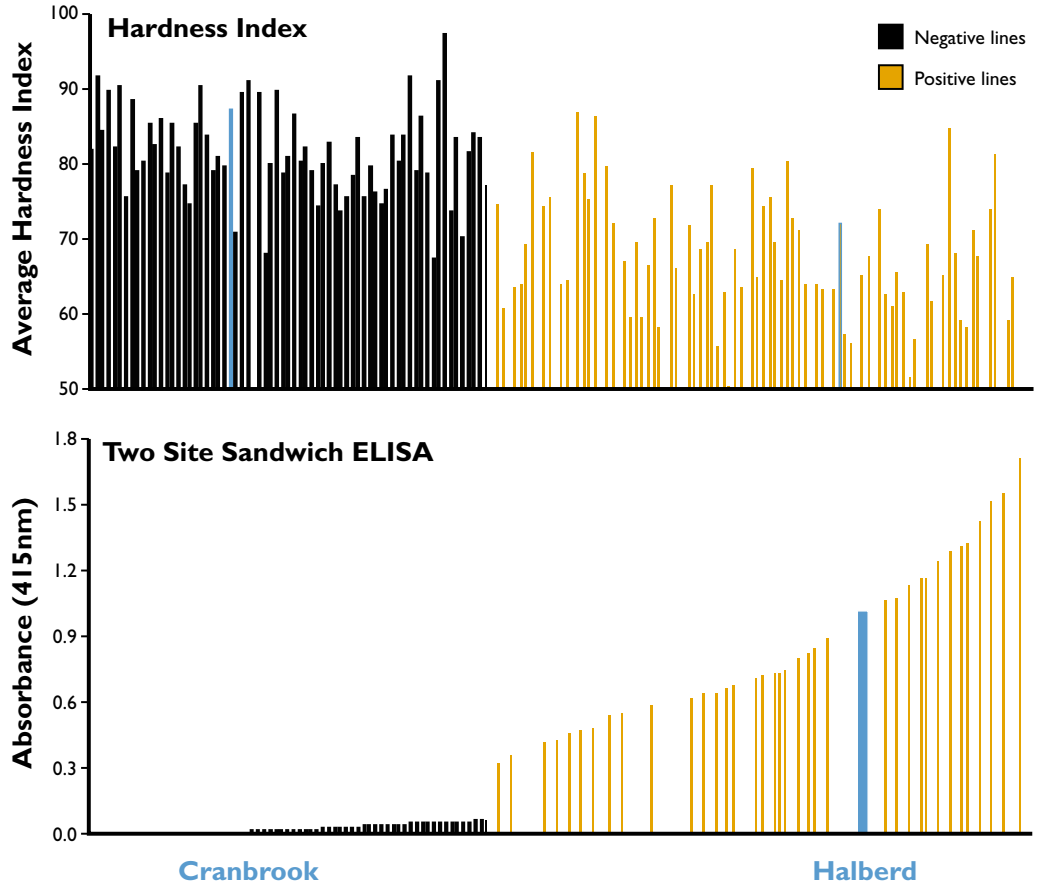
Progress

A series of samples was selected and investigated to allow direct comparison of the results of micro-extension tests, conducted under conventional fixed-speed conditions, with those from tests emulating the strain regimen used in the conventional Extensograph, and with those from extension tests using constant Hencky strain. Rheological measurements on two sets of flour samples provided by Weston Food Laboratories have been completed. These measurements were aimed at verifying the performance of the tensile testing machine (United Test Machine) at high strain rates and the suitability of the image analysis system for measuring the sample diameter. Load and extensional stress were measured as a function of time at three different strain rates (0.01, 0.1 and 1 s^{-1}). The usual strain-hardening behaviour was observed. Results show that under extensional testing, the sample diameter follows an interesting double exponential with time, and this will be investigated further.

In another sample set, bread doughs were made at standard water absorption, and oscillatory shear, creep and yield stress measurements, penetrometer testing, and extensional testing on the United Tensile Tester were carried out. For the tensile testing, load and extensional stress were measured as a function of time at two different strain rates (0.1 and 1 s^{-1}): the usual strain-hardening behavior was observed. These measurements show that it is possible to distinguish strong flours from weak ones on the basis of the extensional viscosity and related properties, and also on the basis of creep compliance (a new finding). In addition, the fundamental rheological properties are being clarified with a view to mathematical modeling of bread dough. A new penetrometer has been commissioned and is in use as part of the rheological characterisation of bread dough, mentioned earlier. Penetrometer testing may offer other avenues of testing and measuring the rheology of bread dough, not previously considered in this group.

The development of a new Z-arm Mixer has reached a major milestone: in collaboration with the Hungarian partners, two machines have been manufactured which give stable base lines and mixer curves that resemble those from larger machines. The causes of some intermittent noise observed previously on the recorded traces were identified and rectified. The two new instruments perform in parallel, and both show excellent performance: compared to the traces of a full-sized Valorigraph, the instruments are able to distinguish all common quality types of European wheat flours. The development of the prototype electronics package and computer software of the equipment and the intensive evaluation of the performance of the machine on Australian wheats are in progress.

Fig 5.7 - Hardness test and two site sandwich ELISA on the Halberd x Cranbrook doubled haploid population.



Project 5.1.4 - Molecular diagnostics for wheat quality

Project Leader: Amanda Hill

Background and Objectives

The aim of this project is to capture the results of research elsewhere in the CRC through development of simple methods for rapid and objective testing of quality attributes by breeding programs, grain growers, handlers and processors. The targets of the assays include polypeptides that mark the presence or absence of linked resistance genes, detection of chromosome arms and genes determining grain characteristics as well as products of specific gliadin and glutenin alleles or subunit types.

Progress

We have isolated monoclonal antibodies discriminating high molecular weight glutenin Band D genome alleles related to bread making quality. The 2+12/5+10 antibody test has been optimized and can now be delivered to breeding programs in a similar format as the 1BL.1RS translocation test.

In Michael Partridge's PhD project, monoclonal antibodies to unreduced glutenin and primitive wheat antigens have been raised, adding to the panel of available antibodies which cover a range of specificities for HMW and LMW glutenin subunits, and the major subclasses of gliadin. During development of the sandwich immunoassays, unusually large differences in absorbance were observed with one antibody combination. This marked discrimination, with zero absorbance for negative samples, was not linked to HMW or LMW-GS loci. The protein detected by the antibodies has been mapped using the Halberd x Cranbrook Doubled Haploid population, and Chinese Spring aneuploid lines, to the distal end of chromosome 5DS (Figure 5.7). The antibody combination binds to a 66,000 Da albumin purified by immunoaffinity chromatography. The N-terminal sequence of the protein matches sucrose synthase from wheat, barley, rice and maize as well as serum albumins. Chromosome 5DS encodes the *Ha* complex locus, which controls grain texture. Detection of the protein in enzyme-linked immunosorbent assays (ELISAs) correlated with a significant difference in hardness index, particle size index and water absorption in the Halberd x Cranbrook population. The protein is expressed in all soft wheats, including those from Heron and Falcon crosses, and *Triticum tauschii* accessions. This finding may represent another step in understanding the complex biochemistry involved in kernel texture and it will be valuable in breeding programs where parents of a cross have different ELISA phenotypes. The assay also provides an excellent tool for varietal identification.

The antibody engineering research was focussed on the construction of cDNA expression libraries and the optimisation of antibody selection and screening methods. These methods for expression of antibody genes in bacteria are required for isolation of antibodies with new specificities, using cDNA libraries

from both hybridomas and spleen cells from immunised mice. In addition, a "colony lift" method has been optimized for specific isolation of single-chain antibodies (scFv) that are expressed in bacteria at reasonable levels and are functional. In this assay, secreted soluble scFv are trapped on HMW-GS- coated membranes, allowing individual bacterial clones expressing scFvs which bind to HMW-GS to be detected on the membrane with enzyme-labelled antibodies to a peptide tag that is co-expressed with the scFv. A number of clones have been characterised from two cDNA libraries and we have isolated one scFv which binds specifically to HMWGS 7/8. Research to remedy the apparently broader specificity of the bacterially expressed scFv antibodies by expression of these clones in a mammalian system has given promising results.

Kym Turnbull's PhD project, developing molecular markers for grain hardness and water absorption, involved working with Bacterial Artificial Chromosome (BAC) clones to attempt to isolate the true hardness locus and to differentiate it from genes for other characters such as puroindoline synthesis and GSP. A successful procedure has been developed to purify BAC clones to enable them to be sequenced. Sequence data from the ends of three of these clones, containing combinations of the known *Ha* locus markers, have been used for construction of a BAC contiguous construct to screen a mapping population, to examine linkage of the different markers with the hardness trait.

Project 5.1.5 - Characterisation and introgression of novel storage protein genes

Project Leader: Peter Sharp

Background and Objectives

Triticum tauschii (goat grass) is the progenitor to the D-genome in wheat. However, in the domestication of wheat, a significant proportion of the genetic variation in the seed storage proteins derived from this wild grass was lost. This species is thus a potentially valuable source of novel genetic variation as several gliadin and glutenin subunits with unusual characteristics have been identified. These may be potential sources of novel dough properties. Since genes from *T. tauschii* can be introgressed into wheat either directly by wide crossing, or through the development of synthetic hexaploids, the use of these lines may provide new proteins with novel dough properties without resorting to wheat transformation technologies. This would avoid the accompanying concerns about transformation efficiency and acceptance of genetically-modified foods.

The project has several components, involving the further identification of potential target proteins through protein electrophoresis, HPLC and biochemical analyses of protein polymer size distribution, and the introgression of desirable lines into selected, elite bread wheats through a backcrossing strategy.

Progress

The T1 protein of one accession of *Aegilops tauschii* is an unusually high molecular weight ϖ-gliadin. The aim of cloning and sequencing the gene was developed because such an unusual protein may have some attributes that could be utilised to modify the processing properties of wheat flour. The synthetic hexaploid with the *Triticum tauschii* donor (AUS18913 x Langdon) was available for the introgression of this protein, and was backcrossed twice with Kite as recurrent. This BC1 (first generation backcross progeny) material was crossed to produce Kite BC2 material, F1s with RAC704 and RAC746, and BC1F2 material. This material is growing in the field for further crossing and selection.

The determination of the N-terminal sequence of the protein required modification of the isolation technique. The sequence was finally determined as being significantly different from the sequence determined earlier. Interestingly, both the sequences align, in a sequence database analysis, with the few ϖ-gliadin protein sequences that exist in the literature (ϖ-2 and ϖ-3 gliadins respectively). Since the proteins were prepared by different procedures it is possible that more than one protein exists at a particular molecular weight and that the different isolation procedures have been biased toward one or the other. Primers designed from the N-terminal sequence in the present study (T1-ϖ2), plus a primer from a consensus C-terminal sequence based on data from the literature, allowed PCR to be used to amplify a DNA sequence from the *A. tauschii* in which the T1 protein occurs. Although proof still needs to be obtained that the sequence below actually belongs to the T1 protein(s) class, it is evident that this study is now identifying a unique seed storage protein. Further work is now underway to differentiate among the PCR products based on molecular weight, and select sequences that are 2,000 bases or longer, in order

to isolate the gene(s) encoding the T1 protein.

For the introgression of the T12.4 protein, the parent *Triticum tauschii* (CPI110750) was crossed with bread wheat Baxter, and to two durum lines. An amphiploid from the Baxter cross was produced. It was slightly late so that it could not be backcrossed to Baxter. It is now being re-grown, to be available for backcrossing to Baxter, Sunvale and Sunbrook. PCR products from two different primer combinations were isolated. Incomplete DNA sequence of one of these confirmed that protein T21.4 is a HMW glutenin-type gene, but does not yet enable the complete characterisation of the protein.

Project 5.1.6 - The effects of protein composition on basic and applied rheological parameters

Project Leaders:
Roger Tanner and Nhan Phan-Thien

Background and Objectives

Novel theoretical and methodological knowledge achieved to date in different projects is being utilised in this newly established project.

The first component of this project involves the fundamental rheological analysis of dough. A range of sophisticated equipment is available, and has been specially adapted for dough analyses, including: Bohlin strain-controlled rheometer with two torsional heads; Carrimed stress-controlled viscometer; United SSTM-5000 Universal Tension and Compression Testing machine and a Micro-Fourier Rheometer. The research on modeling of dough behavior has three aims. The first is to implement a numerical model of the dough mixing process, using the constitutive equation developed for bread dough, with a view to exploring the effects of parameter variations on the performance of the process. The second is to simulate the drawing (extension) process in the tensiograph, and the third, to implement transient, and three-dimensional computer codes dealing with bread dough mixing processes.

The second part of the project is a continuation of research based upon methodology to alter the protein content and composition of the dough by supplementing the flour during mixing studies with purified protein components developed in project 5.1.1. The newly established PhD project of Taisir Hubraq is aimed at defining direct relationships between the chemical composition of the flour and basic and applied rheological properties of the dough. In this part of the project there will also be systematic comparison of doughs produced by the small-scale and the standard or traditional pin- and Z-armed mixers. The 2g Mixograph and the prototype equipment developed in project 5.1.3 will be applied in these studies to produce doughs with altered chemical composition for rheological studies. Development of novel, small-scale methods for constant strain-rate dough testing is also planned. This will entail determination of dough parameters on established, larger scale equipment and on the new, constant strain-rate micro-extension tester.

Project 5.1.8 - Field diagnostics for wheat varietal identification

Project Leader: Kevin Gale

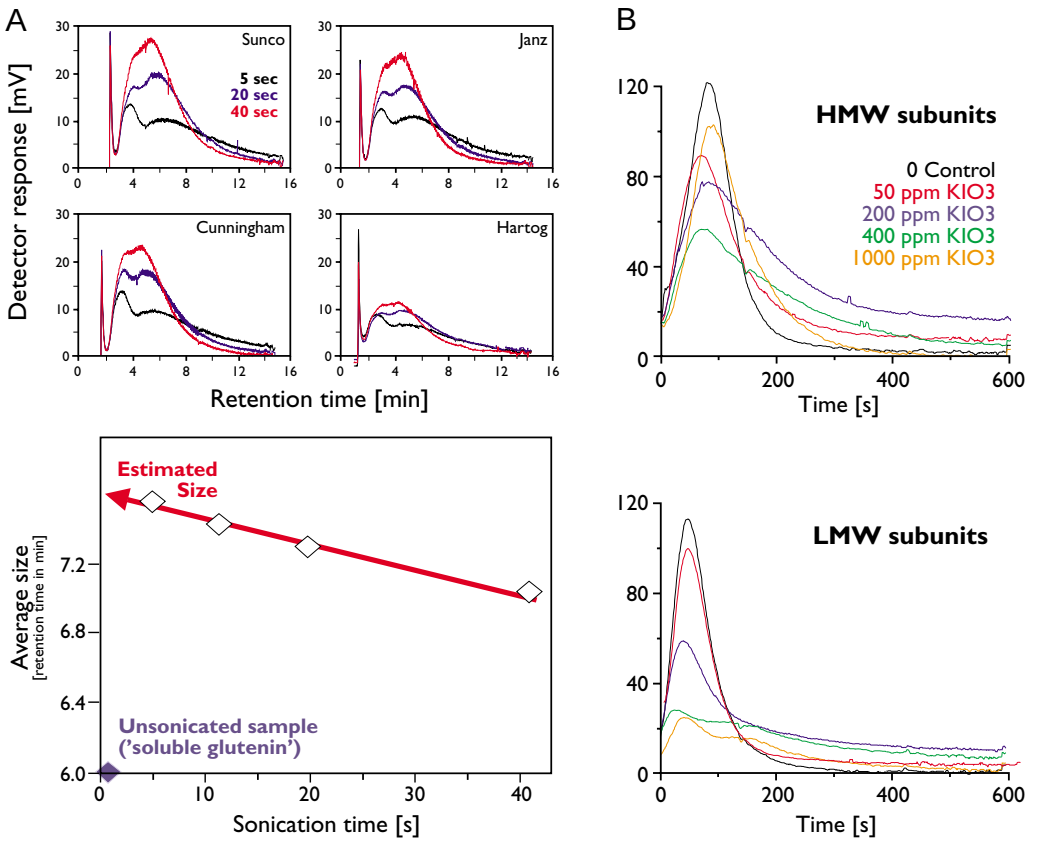
Background and Objectives

Last year in Australia, 91 different wheat varieties were grown in significant quantity. There is a wheat industry requirement for a rapid, high throughput test for identification of these varieties. This will aid in the verification of cultivar identity for royalty payment purposes and facilitate improved receival segregation according to end-use suitability.

Antibodies are at present the best diagnostic tools to facilitate rapid and accurate field-based discrimination of proteins differing by as little as one amino acid. It is not envisaged that separate diagnostic antibodies specific for all wheat varieties will be required for wheat varietal identification. Instead, a panel of antibodies which react with some, but not all varieties will be developed. If each antibody gives either a positive or negative result for each variety, then for 8 different antibodies, 2^8 (256) distinct patterns of reactivity are possible. It is envisaged that the final format of the test will be the immuno-chromatography test strip, the format used successfully for the rain damage test kit. The results of the test would be a series of bands (a specific bar-code) for each variety, which would be read by an automated bar-code reader.

The proteins targeted will preferably be present in the mature grain and not be subject to change due to environmental effects. The process for extraction will be simple and rapid. Many antibodies currently available will not give plus/minus discrimination and may in fact give intermediate signal levels for

Fig 5.8 - Method development and application of Field Flow Fractionation:
A - estimating native molecular size of polymeric glutenin by extrapolating date to zero time sonication;
B - the effect of iodate concentration on the size distribution of in *vitro* polymerised glutenins.



some varieties. This could be advantageous in the laboratory high-throughput ELISA test format. Varieties could be ranked, according to the magnitude of their reaction, thus greatly increasing the discriminating power of each antibody. However, for a robust, field-based test system, a plus/minus discrimination (band present or absent) is preferable.

Initially, the extensive CSIRO Plant Industry library of anti-wheat storage protein antibodies will be screened for those that detect varietal polymorphism. This approach has already shown great promise. In addition, novel protein targets will be studied with the aim of developing new antibodies that give plus/minus discrimination of varieties. For example, approximately 40% of Australian wheat varieties lack the 4A allele of granule bound starch synthase (GBSS). Using information available in sequence databases, synthetic peptides specific for this isozyme have been designed. A further approach to the identification of novel targets is through the mining of expressed sequence tag (EST) libraries available through CSIRO I.P. development. For example, identification of novel polymorphic gene families may be useful for cultivar identification.

One outcome of this project is likely to be a high throughput, laboratory-based ELISA for wheat variety identification. This will then be adapted in collaboration with AMRAD-ICT to the immuno-chromatography test strip format. In addition, the diagnostic antibodies may have other applications. For example, the GBSS 4A null allele is indicative of wheat suitable for quality noodle production. The identification of the targets of the diagnostic antibodies is therefore important in determining the scientific basis for variety discrimination and defining quality trait links with the expression of the target proteins.

Project 5.1.9 - Polymer size and shape in cereal processing

Project Leader: Ferenc Békés

Background and Objectives

Results from project 5.1.2 indicate that Field Flow Fractionation (FFF) provides information on the full molecular weight distribution of polymeric glutenin. The size distribution of glutenin is important for quality bread making. However, in this recently established PhD project, student Laila Daqiq is seeking experimental evidence to determine whether size distribution alone, or the actual three-dimensional structure of glutenin, is involved in wheat product quality.

Initial results suggest that, for standard sets of carbohydrate polymers of determined molecular mass, there is a linear relationship between mass and FFF retention time. Furthermore, carbohydrate polymers with different bond types between glucose units may have different retention times over the same molecular mass range. This is the first evidence that FFF can distinguish differences in

biopolymers of the same mass but of different shape. It is proposed that FFF will be used to relate the shape, or the degree of branching of amylopectin, to starch properties such as starch paste viscosity and gel stability, which are important for quality.

Progress

Because of the extremely large size of the polymeric glutenin proteins, one of the most difficult technical problems in cereal science is to extract/solubilise the total amount of endosperm proteins from the grain without altering their "native" chemical structure and functionality. Techniques developed to date either result in low extraction yield, not being able to solubilise the large polymeric proteins, or significantly reduce the size of the proteins extracted. Using new approaches, we aim for the development of methods for extraction of the total amount of endosperm proteins from wheat flour and grain with no alteration in polymeric size. A set of detergent systems with novel chemical composition has been applied, for comparison of their efficiency extracting wheat endosperm proteins. It seems, however, that even the most sophisticated extraction systems, used successfully in different areas in biochemistry, are not able to solubilise wheat glutenins fully. Method development was therefore initiated, to estimate the "native" size distribution of polymeric glutenin fractions of samples by using different sonication time treatments, and then extrapolating the apparent average molecular weights to zero sonication time. The preliminary results indicate that use of this indirect methodology will enable characterisation of the size distribution of polymeric glutenin proteins.

Preliminary experiments showed that DNA standards of known molecular weight could be used for calibration of FFF in the very large molecular size range where no suitable protein standards are available. Different fractions from the FFF separations have been collected and re-injected, to study the effectiveness of separation using different parameters, and to provide data to calculate the theoretical plate number for the FFF separation.

Project 5.2.1 - University-based training for the cereal industry

Project Leader: Les Copeland

Professional education in cereal science, provided through this project, is achieved by coordinating postgraduate programs within the CRC, developing mechanisms for attracting outstanding undergraduates to cereal science and by hosting short courses for professionals already working within the industry. This is described in more detail under Education.

MAJOR RESEARCH MILESTONES ACHIEVED IN PROGRAM 5

- Effects of protein content and glutenin to glutenin ratio on basic rheological parameters defined.
- Model doughs reconstituted with systematically altered glutenin to gliadin and glutenin subunit ratios.
- Glutenin subunits produced in bacteria on a large scale for model dough experiments.
- Effects of novel antifreeze proteins on frozen dough quality evaluated.
- Relationships between reaction conditions for in vitro polymerisation and the size distribution of the resulting glutenin polymers established by using improved Field Flow Fractionation procedures.
- A method to estimate "native" size distribution of polymeric glutenin fractions developed by using different sonication times and then extrapolating the apparent average molecular weights to zero sonication time.
- Improved understanding of the polymeric structure of native glutenin by the combined application novel biochemical and microscopic techniques.
- Micro-extension tester emulating a range of constant-strain extensions applied successfully in functional characterisation of flour samples.
- Discrimination of strong flours from weak ones on the basis of the extensional viscosity and related properties, and also on the basis of creep compliance.
- Significant progress with the development of the Z-arm mixer: compared to the traces of the full-sized Valorigraph, the instrument is able to distinguish all common quality types of wheat flours.
- Isolated monoclonal antibodies discriminate high molecular weight glutenin B and D genome alleles related to bread making quality.
- Results of an ELISA applying a novel antibody combination, specific to a 66,000 Da albumin, correlated hardness index, particle size index and water absorption.
- Isolated a single chain antibody which binds specifically to a quality-determining glutenin subunit.
- Developed a successful procedure to purify bacterial artificial chromosomes clones, to enable them to be sequenced.

EDUCATION AND TRAINING

Program Co-ordinator: Clare Johnson

Clare Johnson
Program Coordinator

OBJECTIVES

To develop a well-trained and high quality technical and professional workforce that can contribute effectively to the wheat industry.

To grant postgraduate scholarships and vacation studentships to attract new researchers to the industry across diverse fields, including agricultural and food services, and molecular and mechanical engineering.

The Education and Training Program spans projects across the Research Programs, particularly Programs 2 and 5. Several of these projects are aimed at increasing awareness of the importance of wheat quality, of its management, and of developments in wheat-quality research. To this end, workshops, seminars, displays and resource materials are developed and delivered to target audiences including producers, their advisers, grain handlers and marketers. QWCRC also sponsors the attendance of key influencers in the wheat industry at Milling for non-Millers courses run by BRI Australia Ltd. Several of these key influencers have been instrumental in setting up Wheat Quality courses for growers in WA. The Quality Wheat for Quality Foods course developed independently and staged at locations in SA, Vic., rural NSW and Qld has been so well received that expansion will be necessary. It serves as excellent preparation for the extension packages being developed to communicate the outcomes of the CRC's research.

The consumer-driven requirement for quality assurance of produce will also be served well by the grower awareness we are raising through these courses. A nationwide project on quality assurance on-farm has commenced, and our CD-ROM on grain storage on-farm, which promotes Hazard Analysis Critical Control Points (HACCP) -based management practices, is due for release in spring 1999.

Industry-relevant postgraduate and continuing education helps to attract researchers and maintain their focus. In support of this aim, we also conduct a program of workshops and symposia for undergraduates and graduates in science/ agricultural science, and employees in the cereal industry with an appropriate technical background and experience.

Program Objectives

Quality Wheat CRC aims to develop a well-trained and high quality technical and professional workforce that can contribute effectively to the wheat industry. This means ensuring information on best practice, research outcomes and market awareness is available to growers, advisers, handlers, processors, manufacturers and researchers. It is a two way process and involves monitoring developments across the industry, distilling relevant resource materials, and most importantly, building an effective trainer and adviser network for effective information flow. QWCRC grants postgraduate scholarships and vacation studentships to attract new researchers to the industry across diverse fields including agricultural and food sciences, and molecular and mechanical engineering.

Grower and Adviser Training Program:

Program 2: Growing And Storing Quality Wheat

Program Manager: Bob Cracknell
Deputy: Colin Wrigley

Project 2.2.1: Value added training for key influencers

Project Leader: Jim Vandore

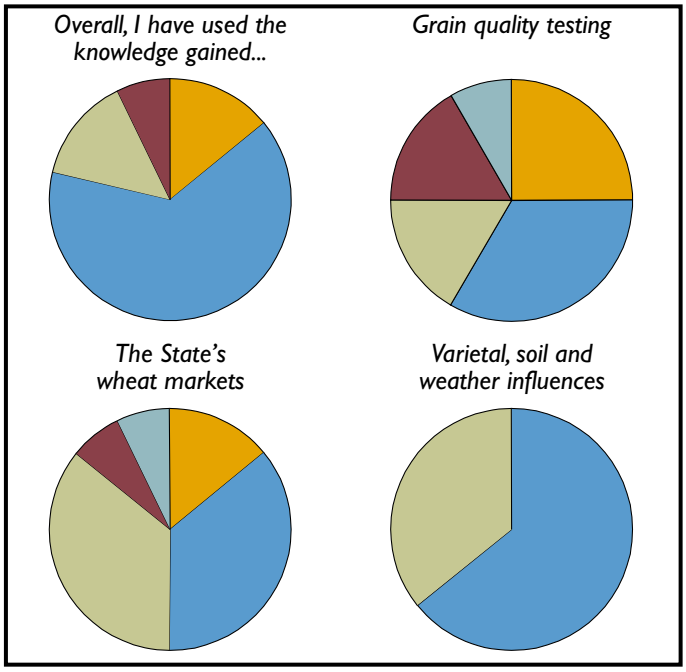
Background and Objectives

Wheat quality information will be disseminated better through the industry if key influencers in the value-adding chain understand the total process from grower to consumer. To expose such key influencers to the demands of the market place in terms of the needs and requirements of flour millers and manufacturers of consumer products, the CRC sponsors places on BRI's Milling for non-Millers course. Milling for non-Millers is designed to familiarise participants with wheat quality evaluation and how differences in wheat quality influence the milling process. Different quality specifications exist for various products, and awareness will assist producers and breeders to target appropriate goals. Having developed the network of key influencers, Quality Wheat CRC aims to maintain contact with them to enhance the effectiveness of information flow for new developments across the industry. The resources developed to date and the delivery methods will be

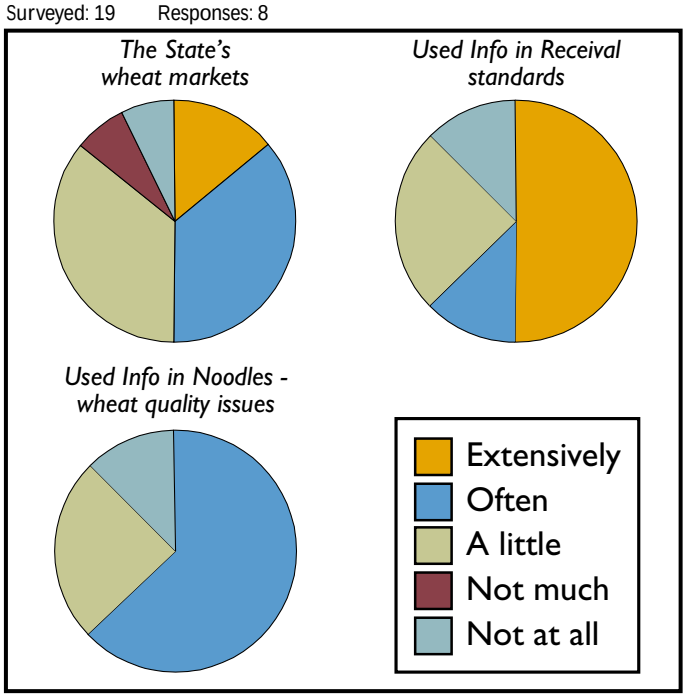
Testing Dough Strength

Fig 6.1 - Pooled Survey Results:
Quality Wheat For Quality Foods Courses
To what extent have you used training from the following modules of the course in your work?

Wagga Wagga 10-11 June 1998 and Adelaide 25-26 June 1998
Surveyed: 32 Responses: 14



Wheat Quality Course: Northam 28-29 July 98
Surveyed: 19 Responses: 8



described under the following projects in this section.

Progress
Quality Wheat CRC sponsored the attendance of 10 "key influencers" on BRI Australia's Milling for non-Millers course run in May 1999. Attendees included staff of AWB Ltd, NSW Agriculture, Agriculture Western Australia, the Leslie Research Centre, Toowoomba, Victorian Institute for Dryland Agriculture, and the South Australian Research and Development Institute.
Supervisors of two PhD students of the CRC, Andrew Verrell and Kym Turnbull, requested that they also attend. As the course is of direct relevance to their research into wheat quality and grain hardness, respectively, an additional two positions were supported.

The opportunity for hands on experience is one of the key attractions of the course. It makes the reasons for millers' grain quality requirements clear to course participants, not only for bread, but for a variety of end products. This can have ramifications for growers in the varieties chosen, and the way the crop is managed.
As is usual for this course, which is regarded highly in the industry, excellent feedback was received from attendees. For Steven Penny of Agriculture WA, for example, the content will provide more detail for the Wheat Quality Courses in which he assists (see project 2.2.2). Now that a suite of resource materials has been produced through project 2.2.3, there will be more emphasis on delivering the information through networks of farm advisers. Those key influencers Quality Wheat CRC has supported on this course will form an important part of this process.

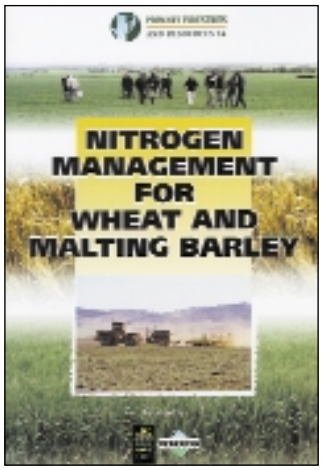
Project 2.2.2: Quality wheat for quality manufactured products

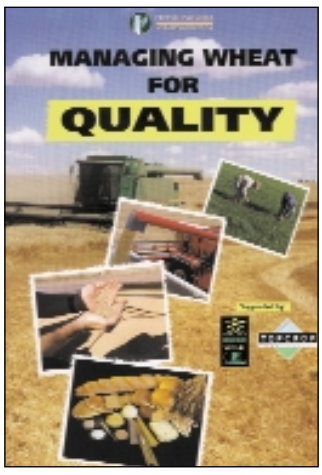
Project Leader: Jim Vandore

Background and Objectives
Progressive personnel in farming who know about the processor's needs can therefore make decisions based on an appropriate level of knowledge. Through short courses in wheat processing, wheat farmers and staff from associated industries are shown how and why wheat quality factors influence end product quality. Around 20 growers, bulk handlers and farm advisers attend each course, which includes 'hands-on' training in wheat quality evaluation relating to particular end products. The value of this to growers is that they can see what markets their wheat ends up in and the reasons for certain receival standards. Most growers are surprised to learn that only 20% of total production remains in the domestic market. The rest of Australian wheat ends up in everything from middle eastern flat breads, to Chinese steamed breads and Japanese noodles. Variety plays a large part in determining the end use for the grain produced. The importance of this decision for marketing becomes clear to wheat growers.

Progress
Word is spreading on the highly relevant courses for progressive farmers, advisers and grain handlers, "Quality Wheat for Quality Foods" and "Wheat Quality - Understanding Market Requirements" – so much so that the number of courses to be offered over the next year will almost double, with a more portable version now travelling to even more regional centres.

Demonstration of bread quality obtained from different grades of wheat and from rain damaged wheat; Weston Milling Test Bakery





Michael Wurst Booklet Covers

This year, courses have been held in Northam (July 28-29, 1998 and Feb 25-26, 1999) Adelaide (March 17-18, 1999), Wagga Wagga (June 23-24, 1999) and are planned for venues including Northam (July 29-30, 1999), the Eyre Peninsula (July 8-9, 1999), Walgett (July 29-30, 1999), and also Horsham, Tamworth, Toowoomba, Condobolin, and Coonamble, at dates to be determined. Staff from local mills, Agrifood Technology, AWB Ltd, the state agriculture departments and BRI Australia Ltd contribute presentations and organisation to these courses.

In follow up surveys, course attendees said they appreciated most the opportunity to gain an understanding of their state's wheat markets, end-user requirements, the relevance of testing, and varietal, soil and weather influences.

Excellent tours conducted by the staff of facilities such as Westons' Mill in Northam are a real help to growers' understanding of the quality the end users are looking for.

Resources developed under project 2.2.3 are enhancing the courses. As the new milling video is now available for use, we can overcome the difficulty hearing explanations due to the high noise levels on mill tours, and it has also become possible to conduct the courses in locations where there is no mill. Questions of best agronomic practice to achieve desired protein levels are addressed in part by distributing the excellent QWCRC-supported publications by Michael Wurst, PIRSA: Managing Wheat for Quality, and Nitrogen Management for Wheat and Malting Barley, to attendees. Fact sheets explaining issues to do with receival standards and recent developments from QWCRC are also distributed at these courses.

Project 2.2.3: Wheat quality information for producers, agronomists and grain marketers

Project Leader: Clare Johnson

Background and Objectives

Through this project we aim to provide growers and agronomists with information on wheat quality and receival testing, and to provide them with CRC research outcomes so that they are better able to manage crops to produce, in a cost-effective manner, grain of the quality required by their end users. Grain growers are contacted directly and through farm advisers, agronomists and special interest groups. Methods include development of booklets summarising agronomic information, particularly resulting from QWCRC-supported research. Displays and brochures are also designed for use at field days and GRDC grower education days, and for distribution in the courses and focus groups in projects 2.2.2 and 2.2.5. Development of slide sets, videos and the web site assist agronomist education on specific quality issues. Articles published in farm journals are an important means of reaching both growers and advisers. Attention is also paid to building an effective network of farm advisers for effective information flow.

Progress

It has been a very productive year, with a suite of extension resources developed and more planned. The factsheets providing answers to frequently asked questions on quality testing have been in demand by growers and agronomists on courses and at open days and field days around the country, as interest in quality increases. The excellent QWCRC-supported publications by Michael Wurst, PIRSA: Managing Wheat for Quality, and Nitrogen Management for Wheat and Malting Barley, are also in demand, as they provide critically evaluated details of best agronomic practice to achieve desired protein levels. Fact sheets explaining recent developments on Prime Hard in the South and Grading Frost-damaged Wheat for Profitability are being produced.

The video The Art and Science of Flour Milling has been completed and provided to extension staff and BRI experts for use in training courses. Sales through industry and educational institutions are contributing to cost recovery. Slide sets nearing completion describe laboratory test methods for the evaluation of wheat quality. Each test is described, with photos of the equipment. There are also slide sets defining the product, major markets, production methods and wheat quality requirements for Asian noodles, pan breads and flat breads.

At Field Days in WA, agronomists featured a QWCRC-supported noodle wheat package. The WA team will expand over the next year. NSW Agriculture agronomists coordinated completion of the Prime Hard in the South package, due for release in spring, and have also coordinated groups for quality awareness and quality assurance. PhD student and agronomist, Andrew Verrell, was an invited speaker on an AGnVET series of nitrogen management workshops in Northern NSW. The GRDC northern update at Dubbo was attended to network and to balance the focus.

The web site (www.wheat-research.com.au) has been updated to contain

Managing on-farm grain storage CD-ROM: Effective practices for the delivery of quality assured products, a valuable new resource for growers and advisors.

much more information about the research, publications and products of QWCRC, in addition to education and training information and answers to frequently asked questions on receival testing.

Publications

An integrated series of articles was published in Kondinin's farm journal, Farming Ahead. Kondinin, with a membership exceeding 20,000, maintain a reputation for impartial critique of agricultural industry resources and services. This series provides a valuable archive of QWCRC's current wheat quality information. More recent developments are also being publicised in industry journals such as Australian Grain which will assist us in reaching all TopCrop members.

Project 2.2.4 - Maintaining grain quality during on-farm storage

Project Leader: Graeme Matheson

Background and Objectives

Increasingly, growers are storing grain on farm, whether for short, or for extended periods of time. This may be for seed, feed or harvest efficiency, and it can also be a way of adding value to the farm business, giving growers the option to sell some of their grain when prices are favourable. Grain must be maintained in peak condition, with little wastage due to inappropriate practices, if storage is to be worthwhile. Food safety standards of end users must also be met. There is a lot of scope to control critical levels through best practice grain storage and transport. With Orange Agricultural College, QWCRC is producing a CD-ROM for growers, advisers and educators, offering the necessary information on storage management for maintenance of grain quality. In line with the QA principles defined by Quality Farms Australia, food safety issues in storage are dealt with on the CD, and a grain storage risk management process based on HACCP principles is promoted. Current Rural training Council of Australia (RTA) competency standards are also listed to assist course design.

INTEGRATED SERIES OF ARTICLES IN KONDININ'S FARMING AHEAD

1. Pre-harvest Test can Help Boost Returns (WheatRiteRain Damage Test Kit) (Sept 98 FA 81:57-58)
2. Choosing Wheat to Meet Market Demands (Jan 99 FA 85: 47-48)
3. Prime Hard Wheat - Increasing Grain Protein Levels for Export; (Feb 99 FA 86: 46-47)

4a. Nitrogen- Early nutrition builds grain protein; (April 99 FA 88: 55-57) and

4b. Simplified nutrient budgeting in northern regions (April 99 FA 88: 58)

5. New releases - Wheat varieties target niche markets (May 99 FA 89: 59-60)
6. Manage on-farm storage for a market edge (June 99 FA 90:59- 63)

Progress

The CD-ROM, Managing on-farm grain storage - Effective practices for the delivery of quality assured products, was assembled by principle author David Webley, a consultant with AWB's Agrifood Technology, in collaboration with staff of Orange Agricultural College, who also provided the IT architecture and instructional design. The modules comprising the CD provide background information on all practical aspects of grain storage: from receival standards, storage structures, pest identification and control alternatives, to inspection and sampling, grain hygiene, on-farm safety, grain quality management on-farm, market requirements and storage economics.

The CD also gathers together lists of industry contacts and regulatory information, to make things as smooth as possible for interested growers. Use of HACCP principles (a risk management process used in QA for food safety) is suggested as a basis for designing best practice grain storage, taking conditions on the particular farm into account. A series of quizzes is provided throughout the CD to help growers to check what they have learned, so as to help them plan their grain storage strategy for their own circumstances. Updates and useful sites are available by hotlink for those users who have an Internet connection.

In the interests of providing the best possible resource, many organisations and individuals generously provided material for inclusion on the CD. Once a beta test version had been assembled, copies were circulated to a group of 20 industry specialists nationwide for review. Their comments and suggestions were catalogued and responses were incorporated systematically into the CD by the team at QWCRC, OAC and the author. Navigation aids, an index and a glossary were added, a cover booklet containing use notes was designed and promotional flyers and a poster were produced. A detailed article was published in Farming Ahead in June 1999.

Coordinators of the GRDC grain storage extension workshop, held in March 1999, invited a demonstration of the CD. This QWCRC resource, due for release in spring, will provide consistent, detailed information for the national strategy for safe and effective grain storage.

Project 2.2.5 - National Quality Assurance on-Farm

Project Leaders:
Di Miskelly and Bob Cracknell

Background and Objectives

Quality assurance programs are becoming an accepted part of food processing. This has followed from the changes in food hygiene regulations put in place by Australian and New Zealand Food Authority (ANZFA), which will require everyone involved in food manufacture and food handling to have in place food-safety plans based on HACCP (Hazard Analysis Critical Control Points). Implementation of HACCP plans is necessary to ensure the chemical, physical and microbiological safety of all food products. As a consequence of the increasing emphasis on food safety, food processors are now beginning to require quality assured raw materials, which passes some of the requirements for food safety back down the food chain to primary producers.

In 1997, the QWCRC completed the major report of the Quality Wheat project, which was funded by DIST (Department of Industry, Science and Tourism) and co-ordinated by SGS Australia Pty Ltd and the Meyers Strategy Group. This project developed systems for quality assurance across all sectors of the wheat industry, from growing to milling. The current project builds on this work, with the aim of tailoring systems to quality-wheat production in specific regions, and implementing quality-assurance programs by pilot grower groups.

Progress

A number of planning meetings were held with project collaborators, with the aim of setting up pilot grower groups in 1999. As an outcome from the meetings, it was agreed that there was a need for a clear and consistent message to growers regarding the advantages to be gained from quality assurance on-farm. The initial impetus for adoption will come from domestic buyers and millers. The Flour Millers Council of Australia has come out strongly in favour of both the quality and food-safety aspects of quality assurance. Growers delivering to the export market will also be encouraged adopt on-farm quality-assurance systems.

The initial quality-assurance manual, developed in conjunction with Agriculture WA, has been extensively revised and simplified. The "Great Grain" program has been developed by Quality Wheat CRC, Pulse Australia and the Australian Oilseed Federation to provide a co-ordinated approach to the implementation of on-farm quality-management practices in the grains industry. The "Great Grain" manual is structured to enable the adoption of quality practices by grain growers at the appropriate level required. These include food safety, delivery quality and customer quality requirements. The revised QA system is concise and very streamlined, predominantly using documentation growers already keep, and tying it together, so those who follow best practice will find that QA accreditation is largely simply getting recognition for what they are doing already.

Key collaborators within the project have attended a training course on implementation of the "Great Grain" quality program, conducted by Pulse Australia. This will facilitate implementation of programs being run with pilot grower groups this season. An important part of the project has been liaison with Quality Farms Australia through attendance at meetings of their Operations Committee. This committee was chaired by QWCRC Business Manager Alan Ellis, and resulted in the formation of three working groups to report on issues of implementation, training and auditing. The total exercise has brought together all relevant parties in production and processing to advance the adoption and harmonisation of national on farm quality assurance.

University-Based Education and Professional Development Program:

Project 5.2.1: University-based training for the cereal industry

Project Leader: Prof. Les Copeland

Background and Objectives

Industry-relevant postgraduate and continuing education is necessary, to attract and maintain a well-trained and high quality technical and professional workforce who can contribute effectively to the wheat industry. The target groups of this education project are undergraduates and graduates in agricultural science or science, and employees in the cereal industry with an appropriate technical background and experience.

Progress

Undergraduate Programs

An undergraduate scholarship of $6000 per annum awarded to Ms Sarah Peel assists with her study towards a BSc in Agriculture at Sydney University. She has remained the top student in her year.

TABLE 6.2 SUMMER STUDENTS 1998/99

Student	Project Title	Supervisor	Location
Bradley Schultz	Portable automatic bread weighing machine and weight tracking system for commercial bakeries.	Thomas Adamczak	BRI Australia Ltd
Ayla Pelit	Texture analysis of baked products.	Di Miskelly	Goodman Fielder
David Appels	The effects of freezing on noodle quality, and determining factors.	Naz Azudin	Agrifood Technology
Wendy Leung	Investigation of biaxial stretching of bread dough: (a) Effects of lubrication in biaxial extension measurements; and (b) Computer simulation of squeeze film flow.	Roger Tanner	University of Sydney
Keith Leong	(a) Dough rheology of heat treated flours; and (b) High speed dough tester trial	Elizabeth Hocking	Weston Food Laboratories
Vanessa Yu / Kate McDonald (Combined)	WheatRite: (a) Analysis of within and between paddock variation in sprouting; (b) Suitability of WheatRite test to monitor preharvest sprouting in barley; and (c) Assessing grower responses to new test for pre-harvest sprouting.	John Skerritt / Russell Heywood	CSIRO Plant Industry
Chris Moore	Breeding soft biscuit wheats for the northern wheatbelt.	Lindsay O'Brien	I.A. Watson Grains Research Centre, Narrabri

Summer Students 1998/99

Following a competitive application process, QWCRC awarded vacation scholarships to 8 students this year (Table 6.2). All of the projects had a strong industry focus. The students achieved excellent results and produced impressive reports which were distributed to interested project managers within QWCRC. This scheme is an excellent means of attracting students to the industry, and provides an opportunity for exploratory work or completion of data analysis to be done for the host organisations.

A call for projects usually occurs in August, and studentships are advertised on the Web site (www.wheat-research.com.au) and by flyer distribution in September.

Postgraduate students

During 1998/99 there were fifteen postgraduate students in the CRC (Table 6.3) as three new students commenced. The number of externally funded students supervised by CRC secondees dropped to three, as two had completed their studies (Table 6.4). Nine students have just completed, or are due to complete their studies in the near future. Four new GRDC-sponsored students studying pentosan content and water absorption, protein glycation, and genetic variation and large-grained wheat for high milling yield are due to commence in July 1999, and three studentships in rain damage modelling, micronutrient effects on wheat flour quality and novel storage proteins were approved in the current annual operating plan.

Matt Hayden will remain in QWCRC on a GRDC postdoctoral scholarship and Surjani Uthayakumaran will also remain, having commenced a one year postdoctoral position with Prof. Roger Tanner at Sydney University. Those students currently due to complete their work are also negotiating postdoctoral positions.

Postgraduate Workshops and the Professional Education Program

The postgraduate workshop organised for July 1998 was combined with a symposium, entitled "Wheat Proteins and Dough Properties", attended by several industry participants in addition to Quality Wheat CRC staff and students. In the remainder of the workshop, the focus was on communications, grant applications, student presentations and feedback. Students found the assistance valuable for their presentations at seminars and conferences, and for written presentation, research record management and personal management skills.

A similar workshop, focussing on dietary fibre is planned for July 1999. Industry staff have shown strong interest in this subject, and will be referred to expert sources to keep up to date after the workshop. A session on intellectual property will also be included for the postgraduate students.

Quality Wheat CRC co-sponsored a Masterclass, Biotechnologies in food processing and their impact on crop production, held over three weeks in July 1998. It provided extensive coverage of relevant biotechnologies, and their potential in food processing and breeding, production and marketing programs. Hands-on experience in areas of DNA and

TABLE 6.3 POSTGRADUATE STUDENTS

Student	Degree	University	Project	Supervisor	Date Due
Patricia Chong	PhD	ANU	Structure of glutenin macropolymer in bread / noodle doughs and products	Dr Ferenc Bekes & Prof. Adrienne Hardham	06/2002
Laila Daqiq	PhD	Sydney	Polymer size and shape in cereal processing	Dr Ferenc Bekes & Dr Fred Stoddard	01/2002
Taisir Hubraq	PhD	Sydney	The effects of protein composition on basic and applied rheological parameters	Dr Ferenc Bekes & Prof. Roger Tanner	01/2002
Matt Hayden	PhD	Sydney	Udon noodle quality: genetic factors	Dr Peter Sharp	02/1999 Thesis submitted
Megan Lindsay	PhD	Sydney	Protein-protein interactions in doughs	Dr John Skerritt & Dr Robyn Overall	02/1999 Thesis submitted
Kevin Liu	PhD	Sydney	Fluid mechanics and dough rheology	Dr Nhan Phan-Thien	06/1999
Dennis Murray	M.Ag.	Sydney	Role of hydrogen bonds in dough rheology	Dr Ferenc Bekes & Prof. Les Copeland	11/1999
Marcus Newberry	PhD	Sydney	Dough process control	Dr Nigel Larsen & Dr Nhan Phan-Thien	02/2001
Michael Partridge	PhD	Sydney	Development of antibody probes for glutenin subunits	Dr John Skerritt & Dr Daryl Mares	03/1999 +3 mth ext.
Jaswinder Singh	PhD	Sydney	Probe for water- and salt-soluble grain proteins	Dr John Skerritt & Dr Peter Sharp	03/1999 +3 mth ext.
Daniel Skylas	PhD	Sydney	Reducing effects of heat stress on wheat quality	Dr Caron Blumenthal & Prof. Les Copeland	10/2000
Kym Turnbull	PhD	Sydney	Molecular markers for grain hardness and water absorption	Dr Sadiq Rahman & Dr Peter Sharp	07/2000
Surjani Uthayakumaran	PhD	Sydney	Function of individual flour component in processing	Dr Ferenc Bekes & Prof. Don Marshall	03/1999 Thesis submitted
Andrew Verrell	PhD	Sydney	Wheat quality and yield in Northern Australia	Dr Lindsay O'Brien	02/2001
Steven Zounis	PhD	NSW	Frozen dough products	Dr Ken Quail & Dr Mike Wootton	06/1999

TABLE 6.4 EXTERNALLY FUNDED POSTGRADUATE STUDENTS SUPERVISED BY CRC SECONDEES

Student	Degree	University	Project	Supervisor	Date Due
Nicole Kerr	M. Ag.	Sydney	Prime Hard Quality	Dr Lindsay O'Brien	*Chose not to complete*
Gasiram Rema	M. Ag.	Sydney	Effects of starch granule size distribution on noodle quality	Dr Hon Yun & Dr Bob Caldwell	12/1999
Zhao Xiaochun	PhD	Sydney	Waxy wheat lines	Dr Peter Sharp	07/1998

antibody technologies, cereal chemistry, instrumentation and computer analysis featured on the course. Nominees were selected partly on the criterion that they should be in a position to recommend and implement such technologies in various aspects of the industry. Several QWCRC nominees attended, including Dr Fred Stoddard, University of Sydney, Dr Nasir Azudin, Agrifoods Technology, Ms Kathy Haigh, Weston Food Laboratories, and Ms Monica Solichien, nominated by the Director, Corp R&D, Indofood.

An additional workshop, Molecular Techniques for Rapid Wheat Breeding, held in February 1999, was presented by QWCRC staff and secondees, with guest speaker Brad Walsh from the Australian Proteome Facility. This workshop was extremely well received by students and staff attending. A total of 46 staff and students attended (5 from Agriculture NSW, 3 each from Arnotts, BRI and Sydney University, 17 from CSIRO, 9 postgraduate students, an Honours student and a summer student, and 3 staff from QWCRC Centre). The course notes have subsequently been requested by senior staff of Agriculture WA.

Future plans include a rheology workshop, site visits to Goodman Fielder plants for pasta and buns, and a workshop on enzymes relevant to wheat products.

MAJOR MILESTONES ACHIEVED IN EDUCATION AND TRAINING PROGRAM

Grower and Adviser Training Program

- Attendance of 10 key influencers and several postgraduate students at the Milling for Millers Course.
- Five wheat quality courses held at regional centres in WA, SA and NSW, with a further two planned for early July.
- Published integrated series of 6 articles on wheat quality issues in Kondinin's Farming Ahead.
- Expanded and distributed suite of resources to industry and growers; includes flour milling video, booklets on wheat quality and nitrogen management (PIRSA), noodle wheat package (WA), and updated factsheets and posters. Expanded network of farm advisers and influential grower groups in several states.
- Booklet on producing Prime Hard in the South ready for publication.
- Participated in GRDC grain storage extension work party and in several GRDC Grower Education programs and field days/agricultural shows in WA and NSW.
- Updated web site, including current Annual Report, commercialisation and educational and scholarship information.
- Grain storage CD-ROM compiled with assistance of Orange Agricultural College, reviewed by industry experts nationwide; revised version for release in spring 1999.
- Industry workshops held to discuss common approach to on-farm quality-assurance systems.
- "Great Grain" manual on quality assurance for grain growers has been completed.

University-based and Professional Education Program

- Provided 8 vacation scholarships this year, exceeding the minimum requirement of 5 scholarships.
- Conducted workshops on Wheat Proteins And Dough Rheology, and Molecular Technologies For The Wheat Industry.
- Conducted postgraduate symposium and workshop on communication skills in the context of the cereal industry.
- Sponsored Crawford Fund Masterclass on Biotechnologies in food processing and their impact on crop production.

The creation of the CRC was partly a response to perceptions of fragmentation in research and education services; a product of distance, focus and culture which are particular to the wheat industry in Australia. The structure of the Centre is designed to overcome this fragmentation by establishing a co-operative culture between the participants, whilst retaining a focus on commercially valuable outcomes.

To achieve its goals, the CRC is stimulating fundamental improvements in the collaborative arrangements covering research, education, technology transfer and commercialisation throughout the industry. Without wishing necessarily to expand the scope of its own activities, the CRC must act as a catalyst to improve contacts, information flow and collaboration between scientific and industrial groups.

Use of the research by Participants.

A good indication of our progress in this area has been the increased involvement of industry scientists and technologists (ie the users of the science) in managing the progress of Centre projects. CRC secondees and other staff from all of our company Participants - Arnott's, Goodman Fielder and Weston's, as well as from AWB Ltd and the GRDC were involved in steering the following projects, for example:

- the soft wheat breeding project and the project to devise testing procedures for breeders to use in all stages of biscuit wheat breeding (project 1.1.4);
- a new project (1.1.12) to extend the soft wheat breeding program to the Southern region has cash and in-kind support from Arnott's Biscuits, involvement from Bunge/Defiance (now Goodman Fielder) and George Weston Foods;
- the evaluation of the "waxy" wheat (Programs 1 and 4);
- the project to determine the grain storage factors that influence flour quality (project 2.1.1/6) - Bunge/Defiance, Goodman Fielder and George Weston Foods have been active in this project;
- the "Prime Hard in the South" project (project 2.1.2) which has involved, inter alia, a number of fertiliser distributors;
- the WheatRite project (2.1.3);
- the flour blending part of the Flexibility of Wheat Use project (2.1.5);
- the mill microbiology project (3.1.4) - this project involves Food Science Australia staff; the first example of a wholly Centre-funded project employing scientists not part of any Participant organisation;
- an on-going project (3.1.5), also widely supported by industry Participants, to study novel approaches to the control of mill performance;
- the oven technology project (3.4.2). Cost reductions from the use of our process control hardware and software in a single bakery were estimated by its managers at a $75,000 per annum reduction in product waste and "give away";
- the newly accepted GRDC project on strategies to replace cake flour chlorination (to which the Centre has contributed $30K, Program 4) - this project has strong industry participation and
- the fundamental dough rheology project (project 5.1.3).

This list is longer than last year's. The continued improvement has resulted in part from the continued participation by more senior research managers from industry. Of the eleven managers and deputies in the Senior Management Group three are currently employed in commercial Participants' businesses. This includes a senior industrial scientist who is giving 50% of her time to the management of the Centre.

Use of the research by groups outside the Centre and overseas.

We have significant new links with CSIRO Entomology Division (Stored Grains Research Laboratory) in the grain storage project (2.1.1/6). In the development of our strategies for commercialisation of our germplasm we are discussing links with several commercial entities, and have made new research links with Hybrid Wheat Australia/Sunprime Seeds and Monsanto (USA). Evaluation of a larger sample of "waxy" wheat (Programs 1 and 4) was conducted by a non-Participant company as well as by Participants in the CRC and this provided evidence of new processing benefits to be derived from this type of product. We have supplied immunoassay-based test-kits to wheat breeders at the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT - Mexico City) as well as Australian wheat breeders for their use in rapid identification of a quality character (for the rye chromosome translocation "1B/1R") in early breeding lines. The total number of tests rose to nearly 9000 (5.1.4). The WheatRite rain-damage test kit was evaluated successfully and extensively by growers throughout the country and also used by breeders around Australia to detect germplasm showing the "late maturity a-amylase" defect. Interest in the test has been received from all round the world. International interest has also been expressed in the new type of small-scale dough mixing machine we have built in a research project (5.1.6) with the Hungarian Institute for R&D (OMFB). Increasing numbers of Quality Wheat for Quality Foods courses were given in the wheat-producing States not represented in the CRC – Queensland, Victoria and South Australia (2.2.2). The Quality Farms Australia initiative now includes Pulse Australia, the

Australian Oilseeds Federation, the Australian Cotton Industry Council and the Grains Council of Australia. A quality assurance scheme,"Great Grain - Quality Assurance for Grain Growers", has been produced in this joint initiative. It is being piloted by a number of grower groups around the country so that refinements can be made. The Wheat Quality Assurance project (2.2.5) will continue to validate and improve the above program material where appropriate over the course of the 1999/2000 season.

Links with research groups outside Quality Wheat CRC have also been established through GRDC-funded research projects complementary to CRC-funded work. In the year under review we have been successful in applying for and/or setting up and/or running the following projects, involving groups from outside the Centre. This again is a longer list than last year:

- Amelioration of Genetic Factors which Result in Downgrading of Wheat at Receival (1996 application for funding by CRC project leader Dr Daryl Mares involving scientists from Queensland DPI; project now in progress);
- The Chemical and Genetic Basis of Noodle Quality (Project in progress, co-ordinated by CRC program manager Dr Ken Quail and involving scientists from Victorian Institute for Dryland Agriculture (VIDA) and from SA);
- Flexibility of Wheat Use (1996 application co-ordinated by CRC secondees Drs John Oliver and Colin Wrigley, contracted through the Centre, also involving scientists from VIDA, Agriculture Victoria, SARDI, University of Adelaide, and from Queensland DPI. This project is now in progress as 2.1.5).
- A project to develop high-protein wheat genotypes for S and W regions (co-ordinated by a scientist from SARDI successfully applied for during 1997/8 and now on-going).
- An extension to the "Prime Hard in the South" project, which has involved a wide range of groups (project 2.1.2) was successfully run last year.
- The newly accepted (in 1998/9) GRDC project to identify key quality characteristics required by bread manufacturers using the sponge and dough process (to which the Centre will contribute $23K, Program 4). This involves extensive collaboration with the Leslie Research Institute, Queensland DPI.

Commercialisation of the research.

The strategy based on the creation of a company, QW Investments Pty (QWIP), to attract outside investment to, and manage, the development and commercialisation of Centre inventions has continued in a modified form. In the absence of outside funding, the Board approved the use of Centre funds to progress the WheatRite kit (maximum exposure $135,000). There has been a successful field trial (test marketing) of the kit. News about the test has travelled widely and it is generating a great deal of interest. A survey of growers gave a 20% response rate with more than 82% saying they would use the test and pay at least $6-10 for it. An agreement has now been signed with the national distributor of the WheatRite kit, Graintec of Toowoomba. Negotiations have continued with Amrad-ICT to complete a manufacturing agreement. Production of the first batch of kits has been completed following receipt of an order from the distributor. There have been lengthy delays in the provision of the prototype reader from the United States.

The Board of the Company has approved a continuing strategy for the commercialisation of the Centre's intellectual property (IP) outcomes that are in the form of germplasm (wheat genetic material). This IP needs to be incorporated into new wheat varieties. The Board mandated management to discuss with companies suitable strategic alliance(s). Many discussions have taken place with a wide range of companies. Many companies in Australia and world-wide are trying to position themselves for the introduction of identity-preserved, biotechnology based wheat products. There is a need for a commercially run wheat breeding programme in Australia with the resources to bring QWCRC's germplasm (and that of other germplasm providers) to the market. QWCRC is strategically positioned to be involved in these changes in Australia, with its focus on products ready for the market in the next few years.

Quality Farms Australia (QFA) includes Quality Wheat CRC, Pulse Australia, the Australian Oilseeds Federation, the Australian Cotton Industry Council and the Grains Council of Australia. QFA has discussed and agreed on the major topics concerning the implementation of uniform quality assurance (QA) protocols. The progress of QFA was announced by Tom Bolton (Chairman) at Grains Week in Perth (mid-April) where there was general support shown for the adoption of QA on-farm. The accelerated update of our QA program has now been completed. Interested growers will now have access to a complete QA program for the forthcoming season. To speed up delivery, Pulse Australia will market and support the Wheat QA program through their "Great Grain" concept. A per capita payment will be made to QWCRC for the use of our source materials. It is anticipated that one thousand growers will adopt the program within the next twelve months. A contract with Pulse Australia has now been signed.

The Centre continues to attract and retain high quality staff. As at 30 June 1999, the Centre had 4 full-time and 1 part-time Headquarters staff. In addition, there are some 145 professional research staff seconded from their employers or paid for by the Centre. Their work is central to the activities of Centre. The percentages of each of these researchers' time allocated to the Centre is listed in Fig 7.1.

CRC Headquarters Staff

Research

Six Program Managers supported by deputy program managers continue to efficiently manage the day to day running of the Centre's five research programs.

Education, Training and Communication

The Centre's Education and Training program which is spread across all five programs is coordinated by Clare Johnson whilst the Communications function is coordinated by Helen Warwick.

Business Management

Alan Ellis is responsible for the financial function, company secretarial duties, commercialisation of Centre I.P. and management of the wheat quality assurance program.

PROGRAM MANAGERS

Program 1	Professor Don Marshall
Program 2	Mr Bob Cracknell
Program 3a	Ms Di Miskelly
Program 3b	Dr Nigel Larsen
Program 4	Dr Ken Quail
Program 5	Dr John Skerritt

DEPUTY PROGRAM MGRS

Program 1	Dr Lindsay O'Brien
Program 2	Dr Colin Wrigley
Program 3b	Ms Kathy Haigh
Program 4	Dr Mike Sissons
Program 5	Dr Ferenc Békés

The QWCRC Website can be found at:
www.wheat-research.com.au

FIGURE 7.1 SPECIFIED PERSONNEL

Name	Contributing Organisation	% of working time	Role in Centre
Dr William Rathmell	CRC Wheat Quality Products and Processes	100%	Managing Director
Prof. Don Marshall	The University of Sydney	50%	Program 1 Manager
Mr Bob Cracknell	AWB Ltd	20%	Program 2 Manager
Dr Nigel Larsen	Crop & Food International	80%	Program 3B Manager
Ms Di Miskelly	Goodman Fielder Ltd	60%	Program 3A Manager
Dr Ken Quail	BRI Australia Ltd	80%	Program 4 Manager
Dr John Skerritt	CSIRO Plant Industry	90%	Program 5 Manager
Dr Ferenc Békés	CSIRO Plant Industry	90%	Deputy Manager Program 5
Dr Colin Wrigley	CSIRO Plant Industry	20%	Deputy Manager Program 2
Dr Lindsay O'Brien	The University of Sydney	45%	Deputy Manager Program 1
Dr Mike Sissons	NSW Agriculture	60%	Deputy Manager Program 4
Dr Daryl Mares	The University of Sydney	80%	Sub-program Leader

PUBLICATIONS

Publications, Public Presentations, Public Relations and Communication.

SCIENTIFIC JOURNALS

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Journal of Cereal Science 28: 273 - 280.

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Cereal Chemistry 76: 145 - 149

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Farming Ahead, 90: 59 -63

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Farming Ahead, 89 : 59 - 60

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PATENT PORTFOLIO

Title	Application No	Country	Filing Date
Discrimination of glutenin subunits	PP5548	Australia	28/08/98
Detection of preharvest sprouting in cereal grains	PP7058	Australia	11/11/98
Method for identifying useful polymorphic markers		Australia	Waiting
Food colouring and method for producing same	PCT/AU99/00193	International	19/03/99

TRADE MARK PORTFOLIO

Title	Application No	Country	Filing Date
WHEATRITE in Class 1	771211	Australia	24/08/98
WHEATRITE in Class 1	1004419	Canada	05/02/99
WHEATRITE in Class 1	1063858	European	03/02/99
WHEATRITE in Class 1	75/637035	USA	10/02/99

© Quality Assurance Program

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AWARDS

During the year under review the Centre or Centre staff/secondees received the following awards:

- Mr Bob Cracknell, Manager of Program 2, became president of the International Cereal Chemists Association.
- John Ronalds received the RACI Cereal Chemistry Division Founders Award in recognition of meritorious service to the cereal industry.
- Dr Kevin Sheridan, Director, was awarded the AO in the 1999 Queen's Birthday Honours.
- Dr Chris Hudson, Director, was appointed Adjunct Professor in the Faculty of Natural Resources (Department of Agriculture and Veterinary Science) at the University of Queensland. He was also appointed to the Board of the Australia and New Zealand Food Authority (ANZFA).
- Mr Chris Rath, Dr Rudi Appels, Dr Ferenc Békés and Dr Peter Bras from CSIRO Division of Plant Industry jointly received an award for Excellence in Research from the Chief of the Division.
- John Skerritt was chosen as the 1999 recipient of the Bruce Wasserman Young Investigator's Award presented in recognition of outstanding contributions to cereal science in the area of bioechnology.

GRANTS

Additional grant monies were provided by GRDC during the year for research on:

- Flexibility of Wheat Use
  $288,611

  and

- Amelioration of genetic factors which result in down-grading of wheat at receival
  $167,581

Quality Wheat CRC is clearly meeting and exceeding the performance indicators required by the Commonwealth Agreement that set up the Centre. Progress is reported below against each indicator for the first four years. More detail of progress made in the last year is, of course, to be found in the relevant section of this Annual Report. (The indicators have been grouped together where they have overlapping scope. New criteria - indicated with an asterisk - have also been added to reflect the Corporate Strategy drawn up in 1998. The first three years' progress reports are as they appeared in last three Annual Reports.)

1. COOPERATIVE ARRANGEMENTS

An appropriate mix of staff, in terms of disciplines and sub-disciplines, function etc and a mix from the participants, particularly at the North Ryde, Canberra and industry sites. The interchange of personnel among different sites within the Centre.

- Year 1: Particularly good examples of cross-site and cross-discipline mixing are to be found in sub-programs 1.7 (NZ Crop & Food, Weston's, BRI and other participants' staff) and 2.3 (Small-scale mixing and baking research at CSIRO N Ryde interacting with the breeding program in Sydney University - sub-program 1.3 - and with Arnott's).
- Year 2: A major example of cross-site and cross-discipline interchange is in project 1.3.2 (the soft wheat germplasm project) which involves staff from all four company Participants' sites, CSIRO North Ryde and two sites in Sydney University. Other examples are too numerous to list fully; the project to develop mill systems to control starch damage (and hence water absorption and ingredient cost - project 1.6.2) and the project to determine the grain storage factors that influence flour quality (project 2.3.3) also involved multiple discipline and site collaboration; in the latter case from three CSIRO sites, Sydney University and several industrial sites.
- Year 3: The above examples are continuing; prominent new projects with such cross-site interaction are:
  - Mill microbiology (Project 3.1.4 involving Food Science Australia, BRI Australia, Goodman Fielder, Bunge Defiance and Weston's);
  - Extruded products (Project 4.1.9 involving Food Science Australia, Goodman Fielder and AWB Ltd) and
  - Quality Wheat for Quality Products Course (Project 2.2.2 involving AWB Ltd, Agrifood Technology, BRI Australia, Agriculture WA, the Centre for Agribusiness Marketing, NSW Agriculture, Weston's, among others). The examples continue to be too many to list fully.
- Year 4: Again there are several prominent new projects with cross-site interaction that have been included in the budget. Meanwhile most of those initiated in previous years have continued:
  - A project (1.4.1) to extend the soft wheat breeding program to the Southern region, (this has cash and in-kind support from Arnott's Biscuits, involvement from Bunge/Defiance (now Goodman Fielder) and George Weston Foods, and the research is being conducted by the University of Sydney and NSW Agriculture).
  - A project (2.1.6) widely supported by industrial Participants to evaluate practical solutions to the control of wheat quality in storage. Bunge/Defiance, Goodman Fielder and George Weston Foods have been active in this project which has also involved staff from CSIRO Plant Industry and from CSIRO Entomology (Stored Grains Research Laboratory)
  - A project (3.1.5) also widely supported, which came out of a brainstorming session, to study novel approaches to the control of mill performance. This is being conducted between commercial laboratories (Goodman Fielder) and BRI Australia.
  - Special mention should be made of the "Prime Hard in the South" project which, though not new, received this year very high levels of interest across all Centre Participants, as well as external organisations. Most notable were CSIRO, NSW Agriculture, GRDC, AWB Ltd, Weston's, Incitec fertilizers, Pivot Agriculture, and agencies from Victoria and South Australia.
  - Quality Assurance on farm (2.2.5) involves staff from Agriculture NSW, Goodman Fielder, Agriculture WA, Queensland DPI, NRE Victoria; in addition to interaction with Quality Farms Australia and its member organisations.

The level of participation by industry and research providers in the functioning of the Centre, including the Board and Program Management Committees in project generation, education, technology transfer and applications.

The involvement of researchers and research managers from commercial Participants in steering Centre projects. *

- Year 1: Participation has been widespread across the management of all programs, as foreseen in the 1994 CRC Application and in the Commonwealth Agreement.
- Year 2: One current and one former industrial scientist became members of the Centre's expanded Senior Management Group. Company Participants renewed their commitment despite changes in their organisations such as take-overs, budget cutting and management reorganisations. Research providers pledged to maintain in-kind contributions.
- Year 3: Scientists working for commercial Participants who are in the Senior Management Group now number three. One senior commercial scientist is seconded for 50% of her time to the Centre at this level. High level of representation on the Board by commercial Participants maintained.
- Year 4: The previous years' level of commitment to the management of the Company by the commercial Participants has continued, despite the merger of two of them. All participants remain committed to the overall level of in-kind in the Commonwealth Agreement, and to recovering the earlier shortfall.

The effectiveness of the Centre (and its component research and educational groups) in interfacing with industry, university and government users of the Centre outcomes.

- Year 1: Industry and university participants and non-participants (overseas companies) are being involved in the development of research and business plans. Examples are the creation of speciality wheat varieties (industry participants and Sydney University), research on process control of starch damage in mills and machinery for wheat processing (overseas machinery manufacturers and BRI). The Centre also participated in the GRDC-funded NIR Centre.
- Year 2: Again the examples have multiplied. During the past year we have managed the scientific part of a DIST- and wheat industry-funded Wheat Quality Assurance program. It has involved states and groups not part of the Centre such as the Grains Council of Australia, Queensland DPI, Pulse Australia and the bulk grain handlers. Quality Wheat CRC Ltd is working with the newly

established Co-operative Research Centre for Molecular Plant Breeding centred on the Waite Institute in the University of Adelaide. Further links with research groups outside Quality Wheat CRC have also been established through GRDC-funded research projects complementary to CRC-funded work. Apart from a Wheat Molecular Marker project, we have been successful in applying for and setting up three projects, involving other groups from outside the Centre - the Victorian Institute for Dryland Agriculture (VIDA), and SARDI. Another aspect is the linkage of CRC-funded research with overseas scientists and technologists. In the year under review we have, for example undertaken to supply immunoassay-based test-kits to wheat breeders at the Centro Internacional de Mejoramiento de Maiz y Trigo (CIMMYT - Mexico City) as well as Australian Wheat Breeders for their use in rapid identification of quality characters in early breeding lines.

- Year 3: Virtually all the above two years' examples have continued, and there are now significant additional interactions with old and new collaborators including Food Science Australia, Queensland DPI and GRDC. The continuing QA activity through Quality Farms Australia, assures a high profile involvement and uptake of Centre science by the industry at large, and the increased momentum of our grower training programs has increased use of our output by Agriculture Western Australia.
- Year 4: Again the above examples continue unabated. We have significant new links with CSIRO Entomology Division (SGRL), and new GRDC projects including one on high protein wheat genotypes which is a collaboration with the South Australian Research & Development Institute (SARDI). In the development of our strategies for commercialisation of our germplasm we are discussing links with several commercial entities, and have made research links with Hybrid Wheat Australia/Sunprime Seeds and Monsanto (USA). Two scientific projects this year have resulted in increased use of our outcomes by NSW Agriculture. The Quality Farms Australia involvement now includes Pulse Australia, the Australian Oilseeds Federation, the Australian Cotton Industry Council, GRDC, grain handlers and the Grains Council of Australia.

The extent of PhD and Honours candidate involvement in the research activities of the Centre.

- Year 1: Eight new postgraduate studentships started and three undergraduate vacation students appointed.
- Year 2: The number of postgraduates working in the CRC has increased, and Centre staff supervised fifteen. The number of CRC Vacation Scholarships enabling undergraduate students to conduct a small research project in cereal science was increased to five. The proportion carried out in industrial laboratories was also increased (60%). The Centre sponsored an Undergraduate Scholar in Agriculture in the University of Sydney.
- Year 3: Four former PhD students associated with the Centre have moved into related work in industry. The number of postgraduate students is still fifteen.
- Year 4: The number of postgraduate students has risen to eighteen (fifteen fully funded by the Centre), and two have had their theses accepted during the current year. Recruitment and financing for at least four new students to start July-December 1999 has been obtained during the year.

2. RESEARCH & RESEARCHERS

An appropriately balanced portfolio of longer term strategic and applied research developed in close association with industry.

- Year 1: The longer-term research goal (number 6) has the heaviest allocation of sub-programs contributing to it, and roughly represents one-third of the Centre's current activity by this measure.
- Year 2: In agreement with industry, we defined projects whose basic justification is to enhance background knowledge as "long-term", and concluded that 24% of the resources of the centre are actually so deployed, and that the proportion was right.
- Year 3: The Board and the CRC Committee (at the Second Year Review) have approved the balance implicit in the above ratio, which has been maintained.
- Year 4: Consistent with policy, support for the longer-term part of the portfolio has been maintained. Industry Participants have taken an increasingly active role in steering the shorter-term part, as a result of their higher representation on the Senior Management Group. Periodic updates on project progress have been given to groups of managers and employees from individual commercial Participants.

Invitations to present keynote addresses, invited papers and workshops at influential conferences.

- Year 1: The Centre Director has made invited presentations on the work of the CRC to the AIFST Annual Conference, and is currently preparing presentations to three other conferences. Invited presentations have been/are being made to research bodies outside the CRC and internationally. Centre secondees and the Director have participated in farm advisory workshops and in workshops designed to help the allocation of GRDC funding.
- Year 2: Levels of such activity increased, with the Centre playing a high-profile role in the group of international conferences that occurred in Sydney during August and September and Canberra in October, namely Cereals '96 and Gluten '96, the International Triticii Mapping Initiative, and the Eighth Australian Wheat Breeding Assembly. The Centre was represented at the International Wheat Quality Conference, Kansas City, USA in May 1997. A CRC program manager gave radio interviews about the growing of Prime Hard Wheat in the southern wheat belt. CRC program and project managers as well as the Director again participated in several GRDC workshops.
- Year 3: The Centre played a high profile role at the 47th RACI Cereal Chemistry Conference in Perth (September 1997), the Managing Director addressed the conference, and numerous other papers and posters were given. Two Centre students (Surjani Uthayakumaran and Steven Zounis) were given bursaries to attend the conference by the Organisers. The Managing Director was invited to share a platform with Norman Borlaug at the ICC Symposium "Genetic Engineering in Cereals", Vienna, May 1998 (his place was eventually taken by Frank Bekes, representing the Centre), and to address the Flour Millers Council Conference in Victoria in September 1997. Alan Ellis (Business Manager) played a major role in the Grains Council of Australia Workshop "Quality Assurance in the Grains Industry" (July 1997). One project leader (Rudi Appels) and the Managing Director participated in the strategy workshop of the CRC for Molecular Plant Breeding in June 1998; the MD was invited to be a member of the Industry Advisory Committee of that Centre.
- Year 4: The Managing Director was invited to address the GRDC-sponsored "Research Horizons for Grain Policy Leaders" course in July. He also chaired a session at, and the

Centre generally played a major role in "Cereals '98" in Cairns (August). Other prominent CRC people were involved – John Ronalds (received an award) Bob Cracknell (became president of the ICC and a Director of AACC) and Lindsay O'Brien (co-chair of the organising committee), and two CRC students received awards. Also in August we presented several papers and organised (Colin Wrigley) a symposium at the Annual Meeting of the AACC. The Managing Director was invited to address the GCA/GRDC conference: "Progressing Grain Crop Improvement for a New Millenium" in September and the South Australian Field Crops Development Board in November 1998. Colin Wrigley contributed to a conference organised by the European Union in Sweden (March 1999) to discuss the commercialisation of food industry research. In the same month Clare Johnson was invited to participate in the GRDC's Grain Storage Extension Working Party. We also submitted many papers and posters to the Australian Plant Breeding Conference in Adelaide (April).

The number and importance of honours and awards bestowed upon Centre staff. Promotions of Centre secondees to more senior positions within or outside their organisations*.

- Year 1: Professor D Marshall (Program 3 leader) and Dr G McMaster were elected fellows of the Australian Academy of Technological Sciences and Engineering in 1995.
- Year 2: The Chairman was appointed adjunct Professor in the Department of Agricultural Economics of the University of New England. The Managing Director was appointed adjunct Professor in the Faculty of Agriculture at Sydney University. Dr Graeme Robertson, a Director, was elected Fellow of the Australian Institute of Agriculture, Science & Technology.
- Year 3: The Council of the University of New England conferred the title of Emeritus Professor on a Centre Director, John Lovett in recognition of his distinguished academic career. Dr Lindsay O'Brien (Program 1 deputy manager and project leader) received the F B Guthrie award at the 47th RACI Cereal Chemistry Conference in Perth (September 1997) for his outstanding contributions to the science. John Oliver, formerly Program 2 manager in the Centre was promoted to Program Leader (cereal products) in NSW Agriculture.
- Year 4: Dr Kevin Sheridan, a Director was awarded the AO in the 1999 Queen's Birthday Honours. Dr Chris Hudson, also a Director, was appointed Adjunct Professor in the Faculty of Natural Resources (Department of Agriculture and Veterinary Science) at the University of Queensland. He was also appointed to the Board of the Australia and New Zealand Food Authority (ANZFA). Dr John Skerritt, a Program Manager, was appointed Deputy Director of the Australian Centre for International Agricultural Research (ACIAR). He and three other CRC secondees from CSIRO Division of Plant Industry (Rudi Appels, Frank Bekes and Peter Gras) received awards from the Chief of the Division. Dr Nigel Larsen, a Program Manager, was promoted to Team Leader, Food Quality and Safety, at the NZ Institute for Crop and Food Research. Dr Michael Southan, a Centre postdoctoral fellow joined the milling and baking science group of BRI Australia.

Increase in the number of articles accepted for publication in leading scientific journals such as: Cereal Science, Cereal Chemistry, Australian Journal of Agriculture Research, Plant Molecular Biology.

- Year 1: Publications are in line with the activities of the participants before the formation of the centre, but in one or two areas (eg dough behaviour modelling in CSIRO) new activity has been stimulated which is in press.
- Year 2: Greatly increased publication activity is reported for the year.
- Year 3: Fourteen fully refereed publications appeared or went to press during the year. This is a sharp increase on last year.
- Year 4: The rate of publication in refereed Journals has doubled relative to last year's level.

Increase in the number of farmers, companies, agencies or institutions using Centre developed concepts and technology.

- Year 1: Centre participants and non-participants (companies, institutes and research providers) are planning new research programs in marker-assisted wheat breeding and noodle quality, modified and/or stimulated by Centre activity. A through-chain quality assurance system for the wheat industry is being developed.
- Year 2: All the above examples have turned into actual work programs. New examples (again, this is a random selection from a long list) are in the use of centre-derived knowledge by one industry participant for improving performance of its bakery ovens, and by another for identifying flour batches with cake-processing problems.
- Year 3: Again the above examples have continued and the new ones have multiplied even more. As a direct result of QWCRC-managed research, AWB Ltd has encouraged exports of prime hard wheat from the Port Kembla zone. We have produced and supported new targeted training courses for growers in Eastern and Western Australia during 1997/8. We have completed research on new methods for controlling water absorption in bakers' flours (ie reducing ingredient costs); some of this produced commercially-valuable information being used by Industrial Participants. Our pilot milling project generated useful data for the classification of the new variety Diamondbird. Improvements in flourmills' quality assurance (QA) procedures were stimulated by CRC science, resulting in a workshop attended by large numbers of site-based practitioners. We contributed to the Grains Council of Australia's workshop in July 1997, and joined with other grains industry groups in establishing Quality Farms Australia, to further aid the implementation of QA systems on farm. Centre commercial Participants joined in the evaluation of one of the world's first samples of "waxy" wheat. The uptake, by Australian and overseas wheat breeders, of our diagnostic test (for the rye chromosome translocation "1B/1R") has been good and they have reported it reliable.
- Year 4: Again there has been a continuation of the previous examples, and a raft of new ones, the following being typical. Despite adverse climatic conditions for the 1998 season AWB Ltd and growers enthusiastically supported the development of the "Prime Hard in the South" concept, and there was much input from fertilizer manufacturers. The program of grower-oriented training courses and the quality assurance program was expanded. Evaluation of a larger sample of "waxy" wheat was conducted by Participants in the CRC and by non-Participant companies, and this provided evidence of new processing benefits to be derived from this type of product. The number of diagnostic tests (for the rye chromosome translocation "1B/1R") supplied to Australian and overseas wheat breeders rose to nearly

9000. The WheatRite rain-damage test kit was evaluated successfully and extensively by growers throughout the country and also used by breeders to detect germplasm showing the "late maturity α-amylase" defect.

Increase in the number of articles reporting on wheat quality and advanced processing technologies.

- Year 1: Television, radio and rural press articles on the CRC at the time of opening; national and international newspaper articles on dietary aspects of wheat quality.
- Year 2: Continued coverage in newspapers, radio and non-learned periodicals, eg Food Australia, Ground Cover.
- Year 3: This year's coverage included the cropping section of the Stock Journal and Leading Edge bakery and food service journal and the Annual Wheat Newsletter.
- Year 4: This year there has been a series of six articles in Farming Ahead, two in Australian Grain, and others in publications as diverse as Rural Weekly and Central and North Burnett Times (Queensland). Also in Food Australia and Cereal Foods World (USA). Support for articles and booklets on wheat quality and relevant agronomy has resulted in articles widely circulated to growers in the Southern and Western wheat belts.

Increase in the number of eminent scholars undertaking visits to the Centre.

- Year 1: One visiting research fellow from UK (sub-program 1.6).
- Year 2: Obtained a GRDC Visiting Fellowship Award to finance the visit of Professor Z Plaut of the Volcani Institute, Israel.
- Years 3 and 4: The Centre has subsidised the activities of the Royal Australian Chemical Institute's (RACI) Cereal Chemistry Division, thereby facilitating the visits of several prominent scientists from overseas. Wim S. Veraverbeke, a visiting PhD student from the Laboratory of Food Chemistry, Katholieke Universiteit, Leuven, Belgium spent 2 months at North Ryde, optimalising the conditions of the in vitro polymerisation of glutenin subunits (5.1.1).

3. EDUCATION & TRAINING

Increase in the number of PhD and/or Masters candidates conducting their research within the Centre, or through universities associated with the Centre. A future indicator will be the number of PhD and Masters degrees awarded.

Increase time spent by Centre Participants and their staff in supervising/co-supervising/advising students and the value placed by employers on Centre PhD, Masters and Honours graduates.

- Year 1: Eight new postgraduate studentships started and three undergraduate vacation students appointed.
- Year 2: The number of postgraduates working in the CRC increased, and fifteen are supervised by Centre Staff.
- Year 3: Four students who have completed their studies are now working in the industry. The number of postgraduate students associated with the Centre is fifteen.
- Year 4: The number of postgraduate students has risen to eighteen (fifteen fully funded by the Centre), and two have had their theses accepted during the current year. Recruitment and financing for seven new students to start July-December 1999 has been obtained during the year. Of the recent finishers, three are now working at the University of Sydney (on Centre related research for which part of the money was raised by us), one is in Agriculture WA, one is at CSIRO Plant Industry, and one at Arnott's Biscuits. A number of students have been granted short (3-6 month) extensions to their scholarships to enable them to complete their research. The managing Director has joined the extensive list of Centre Staff who spend time supervising and examining theses.

Increase in the number of grain producers and handlers undertaking short courses and workshops developed and/or sponsored by the Centre.

- Year 1: Twelve NSW district agronomists and a key agronomy researcher from WA trained through CRC sponsorship.
- Year 2: Fourteen district agronomists and other growers' advisers (from NSW Agriculture, Agriculture WA and from other State departments) were sponsored to attend the Milling for Non-Millers course at BRI Australia. Quality Wheat for Quality End Products Courses were prepared and/or presented to give a wider appreciation of the influence of growing conditions on wheat quality to farmers in WA, SA, Queensland and Victoria.
- Year 3: We have produced and supported new targeted Quality Wheat for Quality End Products training courses (Called Quality Wheat – Understanding Market Requirements in the West) for growers throughout Australia during 1997/8, and they have received excellent feed-back from those attending.
- Year 4: The earlier initiatives have continued, increasing numbers of Quality Wheat for Quality Foods courses being given, and a version prepared for using at smaller growers' assemblies where there are less resources available. This course has now been in all wheat-growing States, including those not represented in the CRC – Queensland, Victoria and South Australia. There is now a waiting list for the Western Australia course, which has become practically self-supporting. We also co-sponsored an "Asian Wheat Users and Markets" course for (Western) Australian Farmers in August, and have grower groups involved in the QA on-farm project.

Increase in the number of Honours students undertaking research projects in the Centre research programs and/or in laboratories of industry partners.

- Year 1: Three undergraduate vacation students appointed.
- Year 2: The number of CRC Vacation Scholarships enabling Honours students to conduct a small research project in cereal science was increased to five. The proportion carried out in industrial laboratories was also increased.
- Year 3: There were seven CRC Vacation Scholars this year (two worked in industrial laboratories), and there was also an (honours listed) Undergraduate Scholar at the University of Sydney.
- Year 4: Eight vacation students were given projects this year: three worked in industry labs (Goodman Fielder, Agrifood Technology and Weston's). One was at BRI Australia in a project for commercial bakeries and two were working on WheatRite field trials for commercial validation. The other two had a strong industry focus; one of them subsequently negotiated work in a Participant's laboratory. The undergraduate scholarship was continued.

Increase in the number of current or potential industry employees undertaking training programs developed with Centre involvement.

- Year 1: One industry employee has submitted a Master's.
- Year 3: Five Industry Employees attended a week-long course "The Chemistry and Biochemistry of Grains" organised by the Centre and Sydney University.
- Year 4: Four industry employees and thirteen students attended the "Wheat Proteins and Dough Properties" course in July 1998. We co-sponsored the Crawford Fund "Master Class" on biotechnology in agriculture, attended by influential industry staff. In February 1999 we held a workshop "Molecular Techniques for Rapid Wheat Breeding" which was extremely well received. A total of 46 industry managers, staff and students attended (including five from Agriculture NSW, three from Arnott's, and three from BRI Australia). In March 1999 the workshop "Tools for Achieving Wheat Quality Targets" was used to promulgate the outcomes of Program 2 to all Participants' staff. We have prepared a workshop for July 1999 at which seven industry employees have made bookings. The Managing Director provided a segment in the GRDC-sponsored course "Research Horizons for Grain Policy Leaders" (July 1998).

Increasing relevance and accessibility of industry targeted training programs.

- Year 1: A National Certificate Course and an Advanced Certificate Course in areas relevant to the centre are in advanced stages of preparation.
- Year 2: Agreement was reached with the University of Sydney to use Centre-designed modules as part of a MAgr degree which will be attractive to industrial employees for whom study time is at a premium. The drawing up of the competency standards for plant bakery operatives was completed in collaboration with the National Food Industry Training Council and DEET.
- Year 3: Accessibility has been increased by the recruitment of an effective Education and Training coordinator in the Centre during the year. A National Certificate in Food Processing – Plant Baking is now available. An Advanced Certificate in Cereal Science for Technical Laboratory Personnel is available by distance learning.
- Year 4: Concerted effort has been devoted by the Education and Training coordinator in building a suite of resources and effective links with a broad network of farm advisers. Our web-site is now up and running and the Wheat Quality factsheets have proved valuable to extension officers. A grain storage CD has been prepared for release in spring and was received most enthusiastically by reviewers nationwide. A revised booklet, "Great Grain - Quality Assurance for Grain Growers", has been produced in a joint initiative of Quality Wheat CRC, Pulse Australia and the Australian Oilseed Federation. It is being piloted by a number of grower groups around the country so that refinements can be made.

4. APPLICATION OF RESEARCH

The degree of adoption and diffusion of concepts developed within the Centre into industry, universities and government users of the research.

- Year 1: Centre participants and non-participants (companies, institutes and research providers) are planning new research programs in marker-assisted wheat breeding and noodle quality, modified and/or stimulated by Centre activity. A through-chain quality assurance system for the wheat industry is being developed.
- Year 2: Again the examples have multiplied. Conceptual areas we have influenced have included the following, in addition to the above: Research to increase the flexibility of wheat use; research to understand and manage the effects of growing and storing conditions on flour quality.
- Year 3: The above examples continue to be important, but new ones have risen to prominence. As a direct result of QWCRC-managed research, AWB Ltd has encouraged exports of prime hard wheat from the Port Kembla zone. We have completed research on new methods for controlling water absorption in bakers' flours (ie reducing ingredient costs); some of this produced commercially-valuable information being used by Industrial Participants. Our pilot milling project generated useful data for the classification of the new variety Diamondbird. Improvements in flourmills' quality assurance (QA) procedures were stimulated by CRC science, resulting in a workshop attended by large numbers of site-based practitioners. We contributed to the Grains Council of Australia's workshop in July 1997, and joined with other grains industry groups in establishing Quality Farms Australia, to further aid the implementation of QA systems on farm.
- Year 4: Most of the above examples have again continued, strongly in the case of most examples. New or extended initiatives have included a workshop, convened by Daryl Mares, "Late Maturity a-amylase in Wheat", to report on his study of Australian breeding material (August 1998 - Program 1). Senior representatives attended this from all the Australian Wheat Breeding programs. In October 1998, representatives of all four manufacturing Participants attended a forum organised by two of the major research provider Participants to describe the latest results and industry application of the dough rheology work. In March 1999, the workshop, "Tools for Achieving Wheat Quality Targets", was used to promulgate major outcomes of Program 2 to all Participants' staff. The Centre co-supported (with Topcrop Australia) the "Managing Wheat for Quality" and "Nitrogen Management for Wheat….." guidelines materials produced by SARDI for farmers in South Australia. We also supported (with Paricipants and fertiliser distributors) "Increasing Grain Protein in Southern Crops with Topdressed Nitrogen" – a brochure for growers in the Northern part of the Southern wheat belt. We also published our second industry Newsletter during the year. This document was widely circulated and described outcomes from several Centre projects.

The number of CRC developed methods and technologies (eg diagnostic kits) used by the wheat and related food processing industries.

- Year 1: CRC activities in commercial bakeries are beginning to provide management aids to process control (sub-program 1.7). New lines of soft wheat are being made available for commercial evaluation and a direct contribution is being made to the development of suitable test equipment for use in industry (sub-program 1.3). Possible diagnostic kits for rain damage are being studied with a possible commercial partner (2.1).
- Year 2: The progress in the above projects has continued with the development of prototypes of the rain damage kits and the oven probe. The development of the Centre's Intellectual Property portfolio includes genes for use in wheat breeding programs, and there are important advances on early generation screening techniques for use by breeders.

- Year 3: We have continued development of the rain-damage kit to a simple credit-card format. The uptake, by Australian and overseas wheat breeders, of our diagnostic test (for the rye chromosome translocation "1B/1R") has been good. We have seen some further progress towards the commercialisation of the oven probe, and marked development of process control concepts and diagnostic services to reduce costs in Partners' bakeries. Our science was used by one commercial Participant in setting up a new oven installation.
- Year 4: Growers throughout the country evaluated the WheatRite rain-damage test kit successfully and extensively. It was also provided for evaluation to scientists in France, in Sweden and in the USA. The number of diagnostic tests (for the rye chromosome translocation "1B/1R") supplied to Australian and overseas wheat breeders rose to nearly 9000. The WheatRite rain-damage test kit was also used by breeders to detect germplasm showing the "late maturity a-amylase" defect. Cost reductions from the use of our process control hardware and software in one bakery were estimated as a $30,000 per annum reduction in product waste and a $45,000 per annum reduction in product giveaway. Our Quality Assurance System was developed with others into a pilot Great Grain program that is being evaluated by leading growers. Food companies within and outside the CRC tested our waxy wheat as an ingredient in the creation of novel foods.

Establishment of effective mechanisms for protecting and commercialising Centre Intellectual Property*

- Year 3: We have filed two new Australian provisional Patents (one withdrawn) and are working towards several others. We have established QW Investments Pty Ltd (QWIP) to be a partially (minority) owned subsidiary of the Centre to attract investment into the commercial development of Centre Outcomes, and we have reached advanced stages in drawing up contracts for such investment with potential investors. We have developed a business plan for the protection and commercialisation of speciality wheats emerging from Centre science.
- Year 4: In the year we filed domestically and internationally (Canada, Europe, Japan and the USA) on one patent (food colouring), and filed two new patents covering the WheatRite kit and antibodies that discriminate quality-determining wheat proteins. We have instructed our Patent agents on two other pieces of intellectual property – a novel food product from waxy wheat and a new method to enhance the use of molecular markers in wheat breeding. We have registered the trademark WheatRite in Australia, Canada, Europe, the USA and in other countries. QWIP is now operating to commercialise the WheatRite kit, using Centre funds at present. The first actual sales of this kit were made during the year. Activity to seek routes for the commercialisation of the biscuit and waxy wheats, plus other speciality wheats from Centre science has intensified. We have started to distribute our quality assurance system through Pulse Australia. The series of confidential project reports (containing know-how IP accessible only to Participants) has grown markedly this year.

Increasing level of funding, particularly from industry, for Centre projects. Funding from Participants and from external investors for the technical and commercial development of Centre projects*.

- Year 1: Additional commitments of >$1M have been obtained from industry and Government to a new wheat quality assurance program. There is increased financial commitment from an industry participant to a speciality wheat-breeding program in the CRC. A grant of $200000 was obtained from NSW State Development for equipment purchase and for the development of the Centre. These items represent an overall increase of funding of around 10% relative to the Commonwealth Agreement.
- Year 2: Quality Wheat CRC Ltd has again been able to increase the cash and in-kind funding available to it, which has enabled it to strengthen links with bodies other than its twelve Participants. In terms of cash, GRDC monies and the DIST/industry contributions to the Wheat Quality Assurance Program amounted to about $591,000 and $525,000 respectively.
- Year 3: The funding under management in the Centre was increased by commitments from GRDC grants for research complementary to that already going on. Notably this was for a program to develop high-protein wheat genotypes for S and W regions ($290,000), for an extension to the "Prime Hard in the South" project ($15,000) and for a project entitled "Amelioration of Genetic Factors which Result in Downgrading of Wheat at Receival" ($873,286). In addition we extended our rôle in the National Wheat Molecular Marker program (a strategic initiative of GRDC) by matching a salary component in Program 1 to a GRDC commitment of $147855 to commence in 1998 to pay for a technician working on marker validation. Year 3 saw the commencement of the "Flexibility of Wheat Use" project representing a commitment of $1,208,617 (like most of the aforementioned projects, over 5 years) by the GRDC. The QA program with DIST was finally completed during the year, with a final funding of $72,000 being obtained to ensure the uptake of the procedures developed in industry.
- Year 4: A number of new proposals for additional complementary research have again been accepted by the GRDC. These add a further $430,000 to the value of the research under the management of the Company next year. In addition, the budget developed for the core activities of the Centre is about $400,000 above the original Commonwealth Agreement.

Increases in the number of articles published in industry and farming journals such as: Food Australia, Food Manufacturing News, Food Engineering, Australian Farm Journal, Australian Grain, Ground Cover.

- Year 2: Coverage in rural newspapers and non-learned periodicals, eg Food Australia, Ground Cover has taken place with increased coverage planned.
- Year 3: This year's coverage included the cropping section of the Stock Journal and Leading Edge bakery and food service journal.
- Year 4: This year there has been a series of six articles in Farming Ahead, two in Australian Grain, one each in Food Australia and Cereal Foods World and others in publications as diverse as Rural Weekly and Central and North Burnett Times (Queensland).

5. MANAGEMENT AND BUDGET

Increasing coherence, clarity and effectiveness of management and financial systems and procedures.

The timeliness and quality of Centre accountability documents and processes.

- Year 1: Complete financial reporting system put in place to satisfy internal and external reporting requirements of the Company. Reporting timetables all met, and recipients satisfied, by the end of the year.
- Year 2: Successful first Audit of the Company and its first Annual Report and Annual Operating Plan published, meeting all required corporate governance standards and laws.
- Year 3: Successful two phase Second Year Review with a panel of distinguished scientists external to the Centre and with the CRC Committee chairman, Dr Geoffrey Vaughan and Secretariat. Successful second Audit of the Company and its second Annual Report and Annual Operating Plan published, meeting all Board-required corporate governance standards and laws.
- Year 4: Again we had a successful third Audit of the Company and its third Annual Report and Annual Operating Plan were published, meeting all Board-required and Commonwealth-required corporate governance standards and laws.

The level of transparency and timeliness of resource allocation and management decisions.

- Year 1: Budgetary allocations for the second year of the Centre's life established by Program Leaders, modified and then agreed at Board level (as the Annual Operating Plan) essentially within a three-month cycle.
- Year 2: New program structure increases transparency of decision making process, by putting related projects under the same manager. Project priorities and new project proposals were debated in open forum involving most Centre secondees, and finalised by the Centre's expanded Senior Management Group. An individual economic evaluation of projects was begun. Annual Operating plan finalised and approved by the Board in time for new budgetary cycle.
- Year 3: Project priorities and new project proposals were debated by an expanded Senior Management Group (including Program Managers' deputies), and finalised by the Centre's management. An individual economic evaluation of projects was continued. The Annual Operating plan was finalised and approved by the Board in time for the new budgetary cycle.
- Year 4: The preliminary report of the economic evaluation of the Centre's program was received. This study, done jointly by the Centre and GRDC, involved staff from most of the other commercial Participants of the Centre as well as the research providers. The Senior Management Group and the Board debated new project proposals and project priorities in time for the new budgetary cycle.

An increasing sense of ownership of management outcomes by Centre staff and participants.

- Year 1: Approval from Program Leader to Board level of the first Corporate Strategy document. Research provider participants agree to substantial reallocations of in-kind resources to facilitate Centre objectives, for example wheat breeder and Consortium personnel from NSW Agriculture and Sydney University, Intellectual Property searching facilities from industrial participants. Ready acceptance of redirection of specific programs in response to Centre management (examples; sub-programs 1.3, 1.5, 2.3, 2.4, 3.1).
- Year 2: New program structure increases transparency of decision making process, by putting related projects under the same manager. Project priorities and new project proposals were debated in open forum involving most Centre secondees, and finalised by the Centre's expanded Senior Management Group. An individual economic evaluation of projects was begun.
- Year 3: The new program structure is now fully in place, which increases the transparency of decision making process, by putting related projects under the same manager (who is now provided with a deputy). Project priorities and new project proposals were debated by an expanded Senior Management Group, and finalised by the Centre's management. This process was faster than last year's, yet there were no significant problems of transparency.
- Year 4: Research providers and other Participants have shown increased commitment to achieving the in-kind budgets of the Centre. The Senior Management Group and the Board debated new project proposals and project priorities in time for the new budgetary cycle. Members of the Senior Management Group made visits to commercial Participants to present outcomes and discuss research priorities.

The cost effectiveness of the provision of Centre leadership and management services.

- Year 1: Management costs and staffing levels below those foreseen in Commonwealth Agreement and below 5% of overall budget.
- Year 2: Staffing levels remain as low as before, and inadequate for communication and commercialisation activities. Consideration of increased resourcing to cover these is begun. New project structure implemented which removes two tiers from Centre management structure.
- Year 3: Management staffing has remained as last year, and communication and commercialisation activities have been dealt with as before. Plans have been made to expand staffing levels as part of QWIP (when investment is in place) without adversely affecting Centre overheads.
- Year 4: Staffing levels at head office have remained as last year, and existing staff have dealt with communication and commercialisation activities. We have had an Education and Training co-ordinator working for the full year for the first time.

THE OVERALL CENTRE

The strength of the Centre identity and the commitment of the people who are involved in it.

- Year 1: High attendance by all participants' staff at CRC workshops and meetings and support for the CRC by their Board representatives indicates strong continuing commitment to the Centre.
- Year 2: The same continues. Commercial Participants renew their commitment despite take-overs, budget cutting and management reorganisations. Research providers pledge redistributed and maintained in-kind contributions again.
- Year 3: Quantitative measures of the commitment of Participants to the Centre remain high at all levels. We have budgeted

for increased in-kind contributions again, and Board, management, and program meetings continue to be well attended. Overall cash from participants is also increased, relative to the Commonwealth agreement.

- Year 4: The above measures continue to show that levels of identity and commitment remain unabated. Increased publicity through articles, newsletters, distribution of videos etc has improved the profile of the Centre in the wider community.

The esteem with which the CRC for Quality Wheat Products and Processes is held nationally and internationally.

- Year 1: Renewed interest in participating in CRC programs has been expressed by a number of research providers in States not currently taking part (Victoria, Queensland).
- Year 2: Above organisations now working in Centre projects. The CRC and GRDC secretariats encourage the Centre to work closely with other CRC's on projects that they sponsor. Overseas companies, research organisations and scientists express interest in collaboration with the Centre.
- Year 3: We initiated closer collaborations with the CRCs for Molecular Plant Breeding and International Food Manufacture and Packaging Science, and have received initial inquiries about research collaboration from three multinational companies (Europe and United States-based).
- Year 4: Contracts for research collaboration have been signed with an United States-based multinational. New research programs have been developed or have been started with the non-Participant States (Queensland, Victoria and South Australia). The Managing Director has been appointed to the Industry Advisory Committee of the CRC for Molecular Plant Breeding. The Managing Director was invited to address the GRDC-sponsored "Research Horizons for Grain Policy Leaders" course, the GCA/GRDC conference: "Progressing Grain Crop Improvement for a New Millenium" and the South Australian Field Crops Development Board. Farmer groups around the country are seeking closer interaction with the Centre.

The improved capacity of the wheat and related food industries to produce products of specific quality and increased value for domestic and international markets.

- Year 2: Specific quality germplasm and genes identified and means for introducing them into varieties rapidly established. Development of prototypes of the rain damage kit and the oven probe. CRC activities in commercial bakeries are beginning to provide management aids to process control (sub-program 1.7).
- Year 3: We have continued development of the rain-damage kit to a simple credit-card format. The uptake, by Australian and overseas wheat breeders, of our diagnostic test (for the rye chromosome translocation "1B/1R") has been good. We have seen some further progress towards the commercialisation of the oven probe, and marked development of process control concepts and diagnostic services to reduce costs in Partners' bakeries. One commercial Participant in setting up a new oven installation used our science. We developed plans for launching new wheats with improved properties in the period 2000 - 2005. In terms of grower benefits these projects mean better quality wheats for specific products, such as noodles, biscuits etc., reduced risk of rain damage.
- Year 4: Again there has been a continuation of the previous examples, and a raft of new ones, the following being typical. Despite adverse climatic conditions AWB Ltd and growers continued to support the development of the "Prime Hard in the South" concept. The program of grower-oriented training courses and the quality assurance program was expanded. Our quality assurance system was developed with others into a pilot "Great Grain" program that was evaluated by leading growers. Evaluation of a larger sample of "waxy" wheat was conducted by Participants in the CRC and by non-Participant companies. This provided evidence of new processing benefits to be derived from this type of product and its potential as an ingredient in the creation of novel foods. The number of diagnostic tests (for the rye chromosome translocation "1B/1R") supplied to Australian and overseas wheat breeders rose to nearly 9000. The WheatRite rain-damage test kit was evaluated successfully and extensively by growers throughout the country and also used by breeders to detect germplasm showing the "late maturity a-amylase" defect. Cost reductions from the use of our process control hardware and software in one bakery were estimated as a $30,000 per annum reduction in product waste and a $45,000 per annum reduction in product giveaway.

The extent to which industry supported research in the Centre is integrated with education and the extent to which project material is used in teaching and training.

- Year 1: Sub-program 2.6 and related work are producing data which will be directly applied to the grower education parts of program 3 (3.1).
- Year 2: In the program reorganisation, all education and training projects are co-managed with the scientific work of the Centre (in new Programs 2, 4 and 5).
- Year 3: There has been progress especially with the outcomes from the QA work and the Prime Hard in the South project, in establishing specific programs to transfer the technology to the users as part of the Education and Training function.
- Year 4: New or extended initiatives have included a workshop, convened by Daryl Mares, "Late Maturity a-amylase in Wheat", to report on his study of Australian breeding material (August 1998 - Program 1). Senior representatives attended this from all the Australian Wheat Breeding programs. In March 1999, the workshop, "Tools for Achieving Wheat Quality Targets", was used to promulgate major outcomes of Program 2 to all Participants' staff. The Centre co-supported (with Topcrop Australia) the "Managing Wheat for Quality" and "Nitrogen Management for Wheat….." guidelines materials produced by SARDI for farmers in South Australia. We also supported (with Paricipants and fertiliser distributors) "Increasing Grain Protein in Southern Crops with Topdressed Nitrogen" – a brochure for growers in the Northern part of the Southern wheat belt. Our quality assurance system was developed with others into a pilot "Great Grain" program that is being evaluated by leading growers. Outcomes from the storage and frosted wheat projects, for example, are providing enhanced extension information.

The extent to which the Centre is keeping pace with or, indeed, leading international scientific and technological progress.

- Year 1: The majority of sub-programs in the Centre appear to have few, if any, national or international competitors and are thus largely "front-runners". Equivalent programs exist in other countries corresponding to sub-programs 1.1-4 and 2.1 and 2.3-6 but they are not focussed on Australian Wheat.
- Year 2: The following new or developing collaborations with international groups indicate our level of international competitiveness: Work with European based scientists on dough protein components; agreement with a Japanese machinery manufacturer to install an instrument in the BRI Australia Pilot Mill; negotiations with a European machinery manufacturer about a joint project to develop new equipment; supply immunoassay-based test-kits to CIMMYT, Mexico City for use in early breeding lines; research agreement with the Hungarian Institute for R&D to build a small-scale mixing machine; visit of Professor Z Plaut, Volcani Institute, Israel. Also, Crop and Food International increased its in-kind commitment as a participant in the Centre.
- Year 3: Nearly all of the above collaborations have all been developed during the year and they have been augmented by interest from European and USA-based agribusiness multinationals with high levels of wheat quality scientific work and expertise. Two of these have commenced negotiations for specific research collaborations with Quality Wheat CRC Ltd.
- Year 4: Actual research programs are now well established with agencies in the United States (Monsanto), Mexico (CIMMYT) and Hungary (OMFB). Expressions of interest in the rain-damage test kit have been received from several countries in all the wheat-exporting continents.