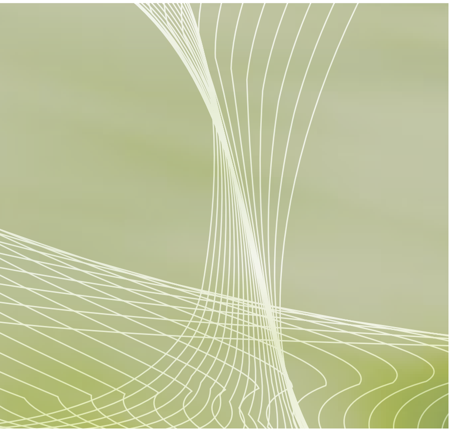

Taking the stress out of agriculture

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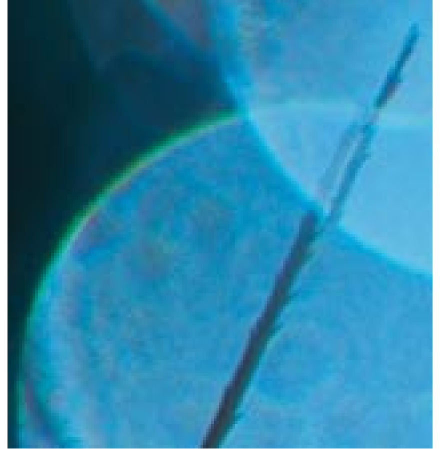
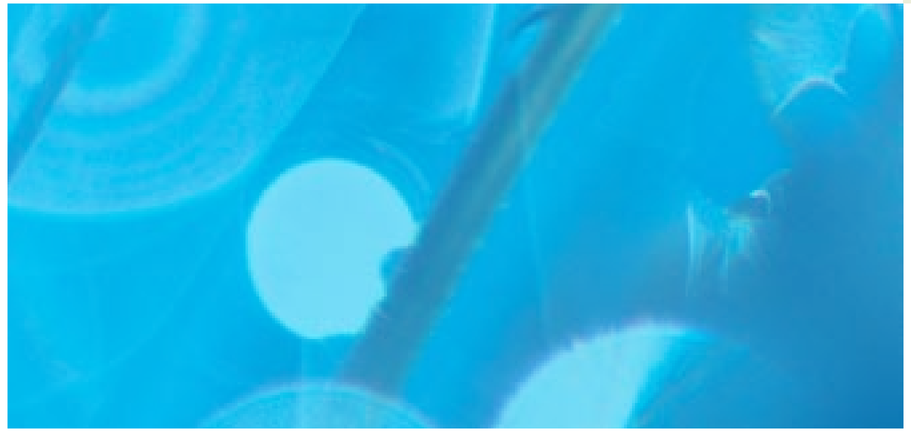


According to the Australian Bureau of Statistics, the area of land sown to crops in Australia has more than doubled in the past 40 years. In 2004/2005, 13.4 million hectares of wheat was grown in Australia, along with 4.6 million hectares of barley.

Wheat and barley are among Australia's most valuable agricultural commodities.

The Australian Centre for Plant Functional Genomics is working towards better wheat and barley varieties for Australian farmers.

Why does ACPFG focus research on wheat and barley?



Wheat

The Australian Department of Foreign Affairs and Trade lists wheat as Australia's most important grain crop, with exports worth more than $4 billion annually. This accounts for 17% of the world's export demand.

Wheat is the most widely cultivated cereal crop in the world. Australia is the seventh largest producer and third largest exporter of wheat.

Most of Australia's wheat is exported for human consumption, while lower quality grain is used as stock feed.

People eat around 595 million tonnes of wheat each year globally, with 5 to 6 million tonnes consumed in Australia.

Barley

Barley is Australia's second largest grain crop. Australian exports account for approximately 18% of world barley trade. Barley was worth $1.8 billion in 2003/2004 to the Australian economy.

Barley grain is sold for malting and beer production, or crushed into meal for animal food.

Australia produces about 6.6 million tonnes of barley per year. 2.5 million tonnes is used as malting barley both here and overseas, and around 4.1 million tonnes is used as animal feed.

Barley is an important staple food in several developing countries, with Morocco being the largest consumer.

It is a hardy cereal crop, grown over a wider environmental range that any other cereal; from 70°N in Norway to 46°S in Chile.

Why does ACPFG research focus on abiotic stresses?

ACPFG HAS TAKEN a targeted approach to its research. Prior to establishing the centre, ACPFG facilitated a market evaluation of Australian farms which was conducted by external consultants. This review concluded that salinity, drought, frost and nutrient deficiencies or toxicities were the main abiotic stresses that reduced yield and quality of cereal crops. With this information ACPFG could ensure that its core research programs were relevant to the needs of farmers and provide them with direct benefits.

ABIOTIC STRESS refers to environmental problems, like salinity, drought, too much or too little light, mineral deficiencies or toxicities and frost. These stresses are a major cause of crop yield and quality loss throughout the world.

- Between 1991 and 1995, drought cost the Australian economy $5 billion. In 2002/03, drought affected nearly all grain producing areas in Australia and in 2006 over 60% of the yield was lost to drought.
- About 32 million hectares of cropland in Australia are affected by salt. Salinity in Australia causes agricultural production losses of about $130 million each year.
- Boron toxicity can cause grain losses of about 17% in both barley and wheat.
- In Victoria and South Australia, the annual cost of frost damage to crops is estimated at around $33 million. In Western Australia $90 million worth of wheat was lost to frost in 2005, and the 2001 frost in New South Wales caused $90 million worth of damage to crops.

SOME PLANTS, including wild relatives of modern cereals, have adapted to abiotic stresses. Understanding these mechanisms of adaptation and identifying the genes responsible will help lead to the development of commercially important cereal varieties.

Adapted plants have increased tolerance to abiotic stresses through physical, molecular and cellular changes that can be triggered by the stress.

Stress can alter gene activity, with consequent changes in proteins, enzyme activity and metabolic pathways.

Why does ACPFG use functional genomics?

The Australian Centre for Plant Functional Genomics is using functional genomics technologies to understand how wheat and barley respond to abiotic stresses.

Molecular markers are easily identified pieces of DNA that breeders can use to follow specific genes through a breeding program.

1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16

Functional genomics refers to new automated testing technologies that produce large amounts of data on genes, proteins and metabolites that arise through altered gene activity. Once genes have been discovered, their function and structural characteristics can be defined.

In the past, genetic experiments were usually conducted with an hypothesis in mind. Now, with the use of functional genomics technologies scientists have a new approach to research. No preconceived ideas are required about which genes are involved or what these might do, as thousands of genes can be investigated at the one time in an experiment. Functional genomics takes into account that genes seldom act alone and acknowledges the complexity of cellular networks. It allows comparisons to be made between plants under normal growth and development or in response to different environmental stresses. This helps us understand the genes involved in the tolerance mechanisms.

For example, a particular stress such as salt can be applied to a plant, and data on changes in the expression of a multitude of genes (in some cases every gene in the plant) can be gathered. Genes that respond to the salt stress can then be identified, and scientists can infer why and how the genes' expression has changed in response to the stress. This information can help scientists to develop varieties of wheat and barley that are more tolerant to salt stress.

Once genes involved in stress responses have been isolated, and their function defined, this knowledge can be passed on to conventional breeding programs. These genes can then be moved into elite varieties of wheat and barley using either transgenics or conventional breeding techniques which makes use of molecular markers.

To put into perspective the magnitude of the work, a wheat plant has around 100,000 genes and a barley plant has around 30,000. Finding the single gene or group of genes involved in a stress response is an enormous task.

ACPFG is generating drought-tolerance markers for the selection of adapted lines in conventional breeding programs, and developing transgenic cereal lines carrying genes for adaptation to drought from a range of drought tolerant sources.

The development of salt tolerant crops is also a major focus. Genes have been identified that help move sodium out of cells, preventing toxic levels of accumulation. Using cell specific expression coupled with transgenics and conventional breeding approaches, researchers will express this gene within certain cells leading to the development of more tolerant lines.

Scientists are using genomics and associated technologies to investigate the mechanisms cereal crops employ to tolerate toxic levels of soil boron. One of the main genes involved in boron tolerance has now been identified. This will enable breeders to enhance the efficiency of breeding for boron tolerance in wheat and barley, either through conventional or transgenic breeding programs.

A gene discovery and functional genomics program is investigating the role of ice recrystallisation proteins in improving cereals tolerance to frosts. The gene responsible for the production of this protein has been isolated and experimental work is now assessing the ability of these proteins to enhance freezing tolerance in sensitive plants.

The mechanisms plants use to tolerate high levels of aluminium is also on the ACPFG research agenda. Specifically, research is focused on investigating new techniques that plants can employ to ensure aluminium equilibrium is retained.

Using comparative genomics, scientists at ACPFG have identified a gene family, CslF, implicated in the synthesis of (1,3;1,4)-ß-D-glucans (beta glucans) in cereals. This means that scientists now have the ability to modify the amount of beta-glucan present for different markets. Such modifications include increasing levels for increased dietary fibre in cereals which could help prevent colorectal cancer and cardiovascular disease.

Wheat and barley breeding

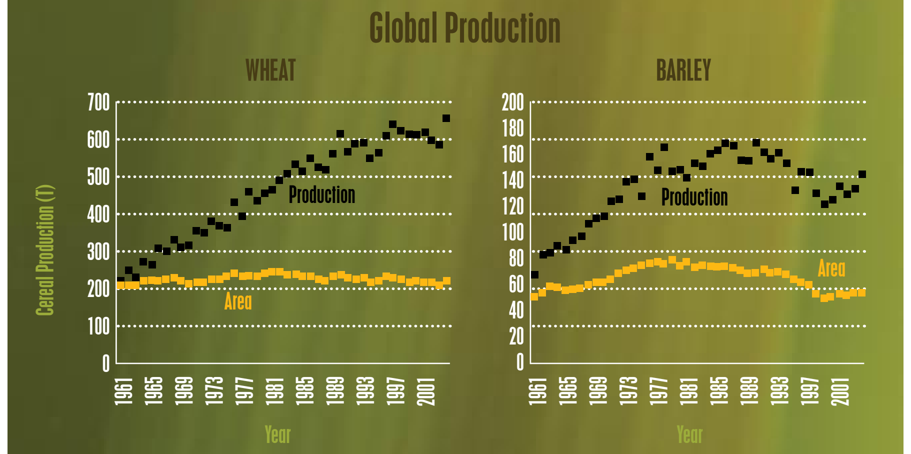
Conventional plant breeding has helped crop productivity keep pace with world demand. However, as the human population continues to grow, increases in productivity will need to be maintained.

Plant breeding began after the domestication of wheat and barley thousands of years ago. The most significant crop yield increases have happened since the start of systematic plant breeding in the late 1800's, and particularly since the 1960's Green Revolution era.

This increase was due to plant breeders progressively adopting new technologies, such as selective and mutation breeding and marker assisted selection. At the same time, farmers were improving farm management. This was accompanied by better agricultural infrastructure, such as irrigation, and greater inputs, including fertilisers and pesticides.

Selective breeding led to varieties of wheat and barley with improved yield, disease resistance and quality. These new conventionally bred varieties have different traits from their wild relatives. Traits for accelerated development, semi-dwarf size and enhanced disease resistance have contributed to dramatic yield increases.

While yields and quality of grain continue to improve, global cereal production is beginning to decline. Research suggests this is due to several factors, including land degradation from intensive cultivation, less sustainable use of irrigation, increasing labour costs and less investment in agricultural infrastructure and research. Biotechnology and continual developments in cereal breeding programs will help to reverse the decline in production.



2004	Production (Ml)	Area (Mha)	Yield (t/ha)
Maize	721	147	4.9
Wheat	627	216	2.9
Rice	606	151	4.0
Barley	154	57	2.6

Source: FAO 2005

The Australian Centre for Plant Functional Genomics is investigating how wheat and barley respond to abiotic stresses, and using this information to improve crops' productivity.

What is ACPFG striving to achieve?

ACPFG uses many different research tools including biotechnology and functional genomics. These technologies help scientists increase the speed and efficiency of conventional and transgenic breeding programs.

Our research outcomes include:

- An increased understanding of the mechanisms plants use to survive in stressful environments
- Improved genetic manipulation technologies
- New screening procedures that allow more rapid analysis of germplasm
- Markers for stress tolerance traits
- New positional cloning tools to help assess genes controlling specific traits related to abiotic stress
- Tools that allow candidate proteins involved in stress tolerance to be identified
- Improved understanding of the root and leaf metabolites of tolerant lines
- Identification of novel stress tolerance genes
- Plants with inbuilt mechanisms to survive under tough environmental conditions.

In the second half of the 1900's, there were major improvements in the yield of wheat and barley worldwide, while the area sown to these crops remained fairly constant. This is indicative of advances made in both farming practices and the adoption of new technologies.

The origins of wheat and barley

Wheat

The term 'wheat' covers a group of grain crops belonging to the genus Triticum. Bread wheat, *Triticum aestivum*, and pasta wheat, *Triticum turgidum*, are the most common varieties grown today. These modern Triticum varieties have come a long way since the domestication of wheat. This is a result of a series of events.

Wheats evolved in the Fertile Crescent of the Middle East. Einkorn wheat, *Triticum monococcum*, was probably the first wheat species to be cultivated widely in the Fertile Crescent, some 9,000 years ago. This primitive wheat species is diploid, carrying two copies of the seven chromosomes common to all wheats. Einkorn is still grown for animal feed in parts of Europe.

The first domestication event occurred some 9,000 years ago in the Middle East, when two diploid wild grasses, *Triticum urartu* and *Aegilops speltoides*, spontaneously crossed, merging their genetic information. This fertile tetraploid became a species in its own right and was domesticated as emmer wheat, *T. turgidum*, which we now use to make pasta.

A second evolutionary event leading to bread wheat occurred in the region south of the Caspian Sea. Here, tetraploid emmer wheat hybridised with another wild diploid species, 'goat grass' or *Triticum tauschii*. This cross gave rise to a fertile hexaploid species known as *Triticum aestivum*, or bread wheat. This hexaploid species first emerged in cultivated wheat fields some 7,000 years ago. The genome contributed by *T. tauschii* made bread wheat more versatile. This wheat is suited to the production of leavened bread as it contains proteins that trap carbon dioxide during yeast fermentation. Currently, hexaploid bread wheats account for around 90% of wheat production worldwide.

Therefore, the development of wheat came from hybridisation between diploid species, each possessing a distinct version of the seven basic chromosomes and led to the formation of polyploids bearing four or six sets of the seven chromosomes. This process was fundamental to the development of modern wheat varieties.

Barley

Barley, or *Hordeum vulgare*, is believed to be even older than wheat. Archaeological remains reveal that the crop was first domesticated in the Fertile Crescent some 10,000 years ago.

Barley is used for malting, to make beer, spirits and confectionary. In many poor regions of the world it is the main food of humans. Feed quality barley is also used for animal feed.

The taxonomy and evolution of barley is uncomplicated when compared with wheat, the term barley being used to describe a single species, *H. vulgare*.

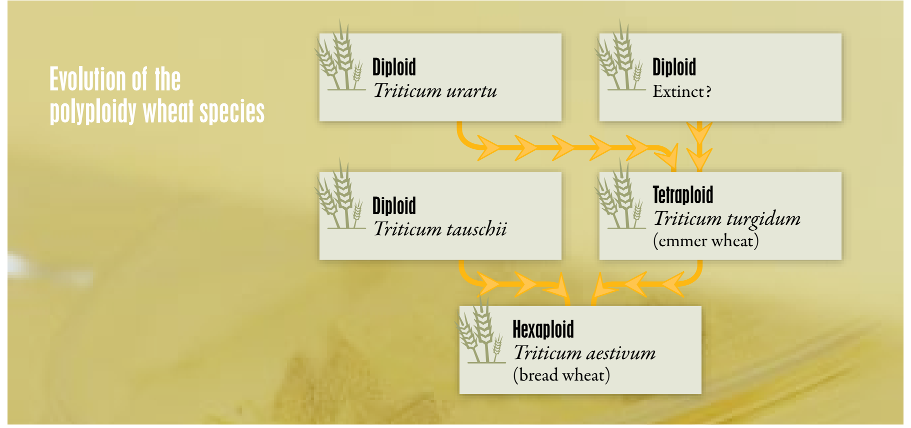
The use of barley as a food source has varied over time. In Neolithic cultures, barley was the staple food source.

The training diets of the Gladiators of the Roman Empire were also high in barley due to its reputation for building strength. In fact, barley was so important to the Gladiators that they were known as '*hordearii*' or barley-men.

There was a shift to consuming more wheat than barley in the classical times. Wheat was preferred due to its beneficial properties for milling and high energy.

However, over the past two decades there has been a renewed interest of barley as a food source. Barley is high in dietary fibres such as beta-glucan. A diet high in this type of fibre helps to protect against diseases like colorectal cancer, obesity, non-insulin dependant diabetes and cholesterol and cardiovascular disease.

A diploid cell or organism contains two complete sets of chromosomes.
A polyploid cell or organism contains three or more complete sets of chromosomes.



References and further reading

- ABARE, 'Agricultural biotechnology: *potential use in developing countries*,' eReport 03.17, **October 2003**
- ABARE Australian Crop Report, **February 2003 & December 2006**
- Australian Bureau of Statistics, *'Year Book Australia,'* catalogue number 1301.0, **2005**
- Australian Bureau of Statistics, *'Agricultural Commodities, Australia, 2004–05,'* catalogue number 7121.0
- Australian Centre for Plant Functional Genomics, *'Market Demand Analysis for New Cereal Crop Varieties,'* **July 2003**
- Australian Department of Foreign Affairs and Trade website, *'Australian agriculture, fisheries and forestry,'* **http://www.dfat.gov.au/facts/affaoverview.html**
- AWB website: **www.awb.com.au**
- AWB, *'Industry Overview, Australian Grains Industry,'* **2005**
- AWB, *'Industry Overview, Australian Grains Industry,'* **2003**
- Barley Australia website: **www.barleyaustralia.com.au**
- Cartwright B, Zarcinas, BA and MayField, AH *'Toxic concentrations of boron in a red-brown earth at Gladstone, South Australia,'* Australian Journal of Soil Research, **Volume 22, 1984**
- Food and Agriculture Organisation of the United Nations FAOSTAT Statistical Databases: **http://faostat.fao.org/**
- Global Network on Integrated Soil Management for Sustainable Use of Salt-affected Soils, *'Extent and Causes of Salt-affected Soils in Participating Countries,'* **November 2000**
- Goklany IM, *'Applying the Precautionary Principle to Genetically Modified Crops,'* Center for the Study of American Business, policy study number 157, **August 2000**
- Grain Research and Development Council Go Grains website: **www.gograins.grdc.com.au**
- Grain Research and Development Council, *'Frost tolerance breakthrough in barley,'* **June 2004**
- Grando, S (2005). *'Food Uses of Barley'*, In: Proceedings of the 12th Australian Barley Technical Symposium [CD ROM]. 10–13 September 2005, Hobart TAS: Conference Organising Committee for the 12th Australian Barley Technical Symposium
- National Dryland Salinity Program, *'Assessing salinity hazards in cropping areas,'* **July 2000**
- Pingali PL and Heisey PW, *'Cereal Crop Productivity in Developing Countries: Past Trends and Future Prospects,'* CIMMYT Economics working paper 99–03, **1999**
- Saxena MC and Yau SK, *'Variation in growth, development, and yield of durum wheat in response to high soil boron,'* Australian Journal of Agricultural Research, Volume 48, **1997**

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