A Report for the Nuffield Farming Scholarships Trust

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The scope for adding value in UK wheat food chains through plant breeding

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Foreword

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The views expressed in this report are entirely my own and do not necessarily represent the views of the Nuffield Farming Scholarships Trust, or my sponsor or of my employers, or any other sponsoring body.

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List of Abbreviations

Abbreviation	In full
AFGC	Australian Food and Grocery Council
AWB	Australian Wheat Board
BRI	(Australia) Bread Research Institute
BSPB	British Society of Plant Breeders
CRC	(Australia) Co-operative Research Centre
CSIRO	(Australia) Commonwealth Scientific & Industrial Research Organisation
CIMMYT	(English translation) International Maize and Wheat Improvement Centre
DAFF	(Australian government) Department of Agriculture, Fisheries and Forestry
DUS	Distinctness Uniformity and Stability (pertaining to a plant variety)
FCB	Farmer Controlled Business
FIG	(Australia) Food Innovation Grant
FSS	Farm Saved Seed
HFN	Hagberg Falling Number
HGCA	Home Grown Cereals Authority
GFCRC	(Australia) Grain Foods Co-operative Research Centre
GI	Glycemic index
GM	Genetically Modified
GRDC	Grains Research and Development Corporation
IP	Intellectual Property
ISB	In Store Bakery
MAS	Marker Assisted Selection
MPBCRC	(Australia) Molecular Plant Breeding Co-operative Research Centre
NABIM	National Association of British & Irish Millers
NFIS	(Australia) National Food Industry Strategy
NIAB	(formerly) National Institute of Agricultural Botany
NL	National List(ing)
NSW	New South Wales
PBI	(formerly) Plant Breeding Institute
PVR	Plant Variety Rights
RL	Recommended List(ing)
SA	South Australia
VAWCRC	(Australia) Value Added Wheat Co-operative Research Centre
VCU	Value for Cultivation and Use (pertaining to a plant variety)
WGIN	Wheat Genetic Improvement Network
WA	Western Australia

1.0 Executive Summary

My study focused on examining the role and attitude of stakeholders across chains and the impact on plant breeding strategies. Defining barriers to exploiting new opportunities to add value, especially those of potential relevance to consumers, in wheat food chains through breeding in the UK was a key objective. The study was funded by the Farmers Fund and involved travel in the UK, Australia, France and Germany.

In terms of defining key issues for UK wheat food chains I established that demand in theory exists for improved agronomics, for instance sustainable varieties to produce more from less and traits for novel markets. Demand also exists for improved processing quality such as more stable protein and HFN across seasons or improved processing efficiency. Some interest may exist further up chains in delivering attributes relating to consumer health and taste in wheat food products. On the supply side, breeders would be technically able to deliver the desired traits in new varieties. But, the reality in the UK is that wheat is viewed across the food chain as a commodity (full stop!). Commercial plant breeders who remain active in the UK will restrict investment to targets most likely to deliver the greatest market share for their varieties. This will exclude small, unproven markets.

In France I found evidence that it is possible to select for niche markets from what already exists in breeding programmes and that efficient co-operation and innovation can operate across international borders. The Limagrain group demonstrates that an FCB can lead the way and capture value added through breeding in wheat food chains. Vertical integration with the use of closed loop supply is one way to achieve these benefits, but there may be others. The challenges in adding value in commodity cereals through plant breeding are complex and difficult. Key to the Limagrain group business model is the use of R&D to deliver added value to meet the needs of their customers in the food industry.

In Germany I found that the attitude towards wheat as a commodity was similar, but even more marked than in the UK. Although the German variety testing system emphasises quality, this does not drive improvements in end-use quality because market demand remains weak. Also, the larger variety lists in Germany do not benefit farmers or the industry. Regulation on mycotoxins in Germany has acted to distort the drivers for breeding programmes. In Germany, the development of niche markets via innovations in plant breeding is likely to be particularly difficult because industry attitudes are strongly Luddite.

The Australian wheat industry has not yet gained commercial benefit from the exploitation of molecular based research to add value in wheat through plant breeding. But examples closer to market were more easily available than in the UK. There are many structural and historical reasons for this contrast, but I believe that the main reasons lie in differences in attitude and experience. For example, the overall sense of optimisim in Australia is higher than in the UK and attitudes to risk and long term efforts to integrate across industry chains seem more broad minded than in the UK. There is a clear appreciation of markets and customers and a greater acceptance and willingness to adapt to change. Australia does not have a better science base than the UK, but does have a firm linkage between research, plant breeding and technology transfer across chains. This is important for future innovation in wheat food chains.

Mechanisms to promote commercial awareness among researchers are seen as critical to ensure delivery of what the market needs. The same is true for processors and manufacturers accepting a role in the improvement of raw material into the future. Co-operation between industry players, researchers and breeders is seen as desirable and possible in Australia.

A final point of interest from Australia is that rather than subsidy to support agricultural businesses today, farmers in Australia will benefit 'tomorrow' from a large and varied portfolio of investment in research and development through the GRDC. This investment extends to plant breeding programmes.

Pig breeding may seem some distance away from wheat breeding, but as pigs and wheat are essentially viewed as a commodity in fact there are some remarkably similar principles and problems being faced. Examples from PIC demonstrate that it is possible to add value through breeding and co-operation in commodity chains, although significant marketing effort and cost is required to beat industry inertia. Co-operation across chains can be difficult where players wish to protect their existing relationships and it may be very difficult to convince those further up the chain to participate. PIC have also demonstrated that it is possible, but very difficult, to develop royalty systems that relate better to the value added to each stage of the chain. Adaptations of current royalty systems might allow greater transparency of benefit delivered and greater incentive for breeders to focus on targets to benefit markets.

Specialist soya beans grown in Australia for Japanese niche markets are also very different to wheat in the UK. I uncovered some general principles that might be transferable. Firstly, to know and supply niche markets takes effort and a pragmatic approach. The niche must be supplied with what is wanted and the supplier must be flexible about how this is achieved. In addition, there is no point in messing around, it is necessary to act now not tomorrow. Secondly, farmers must be able to manage financial risk to operate in new or developing niche markets. Thirdly, the customer must be willing to pay for the innovation needed to deliver a product. If they are not, market failure exists and the innovation is not economically viable. Finally, plant species and varieties may not travel well, but when the focus is on the market, it may be more cost effective to select for agronomic characters from existing overseas varieties than starting from scratch. This has especially been the view of wheat varieties for growing in the UK. These traditional views may become less valid when developing and growing varieties primarily for market traits, rather than purely for yields.

I set out to question the scope to add value in wheat chains through plant breeding in the UK. At the close of my study I concluded:

1. It is possible.
2. Success is likely to be hard to achieve.
3. Co-operation is required.
4. Others are trying harder.

I recommend that:

1. UK players consider the possibilities across chains.
2. UK industries drive a change in attitude from the bottom up.
3. UK players must improve co-operation across chains.
4. The UK must promote market-orientated research and technology transfer mechanisms.

2.0 Introduction and Objectives

I began my career as a plant scientist at Newcastle University working on breeding systems in natural plant populations, where I gained a PhD. I have since worked in various roles for NIAB (formerly the National Institute of Agricultural Botany) that have combined research, technology transfer and commercial development activities relating to plant genetic resources. I gained an Open University MBA (Master of Business Administration) in 2002 and currently head NIAB's Laboratory Services. NIAB does not breed mainstream plant varieties, but we do have a fundamental interest in the future development and utilisation of plant genetic resources for mainstream UK crops.

Plant variety is a key component in many food chains. In the last 50 or so years UK plant breeders have added significant value in terms of improved yields and quality. Industry consolidation and changes to the UK systems of variety evaluation have further improved the efficiency of UK cereal food chains in recent years. However, the balance in breeding and variety testing programmes in the cereal sector remain weighted towards agronomic traits such as yield and disease resistance.

The reality for future UK wheat production is likely to be the removal of production subsidy, more competitive world prices and increased competition for instance from the enlarged EU. With the focus for agricultural support moving towards economic sustainability balanced against environmental sustainability, the long-term capability of many UK producers to continue to succeed using existing strategies and given current industry structures and attitudes may be limited. Future food production will be market driven rather than subsidy based. Such fundamental change creates new imperatives to change the balance of effort within breeding programmes as well as structures and attitudes across the UK cereal sector.

Given the inevitable shift to being exposed to market forces it seems logical to assume that breeders and producers involved with cereals must find more scope to exploit consumer trends. One obvious target might be that consumers are increasingly being shown to be associating value with food that is 'natural'. In fact the realities of finding new ways to exploit such opportunities, in an economically viable manner through plant breeding, are far from obvious for a crop like wheat.

Advances in biotechnology are widely acknowledged as offering exciting new potential in the exploitation of plant genetics for human benefit. The range, efficiency and cost of potentially useful molecular tools are constantly improving. The quality and quantity of genetic information being gathered relevant to mainstream crops is increasing. However, even where researchers and industry do utilise the opportunities offered by biotechnology, the focus continues to be mainly on traditional agronomic and end-use quality targets; examples of the latter might be Hagberg Falling Number and protein quality.

On this basis, my interest was to examine the scope for plant breeding to add value relevant to consumers in wheat food chains. I focused on gathering views from across specific chains that seemed to offer innovative or informative principles or lessons. For this reason, my study was not entirely confined to wheat based businesses.

During my study I wanted to focus on:

1. Investigating the role and attitude of stakeholders in the UK wheat food chain and the impact on plant breeding.
2. Defining barriers to exploiting new opportunities to add value, especially those of potential relevance to consumers, in wheat food chains through breeding in the UK.

I aimed to meet these objectives by comparing and contrasting approaches and attitudes in the UK with those being adopted overseas.

From a personal point of view I was also interested in broadening my understanding of businesses beyond my usual sphere of reference. The premise that there are significant benefits to be had by better understanding the needs of businesses beyond immediate customers in ones chain of operation seems entirely logical to me. During one particular discussion on my travels, a former university Professor of Food Technology in Australia told me that only since moving to head a national food trade association does he now feel he understands the needs of the industry properly. If he had appreciated those needs in the same way when he was an active scientist he now believes he would have delivered many times more benefit to the industry by his scientific endeavours than he actually did!

3.0 The Study

I set out to question the status quo and examine the possibilities and barriers to progress at a practical rather than technical level. My report therefore does not include a list of traits for wheat whose development might have commercial potential or define the research needs that will be needed to facilitate delivery of such traits in new wheat varieties.

I travelled in the UK and Australia with additional visits to France and Germany.

3.1 The UK

The UK leg of my study was conducted early on in my study and aimed to define key issues facing UK wheat food chains by meeting with a variety of individuals from across the industry.

3.1.1 Breeding wheat in the UK

The average UK wheat crop yield is about 14.8 million tonnes. Imports stand at about 745,000 tonnes from the EU and 495,000 tonnes from elsewhere. The 2002 wheat crop was worth £1.5 billion and supplied the following markets (Home Grown Cereals Authority (HGCA) figures):

	%
Animal feed	38
Flour milling	31
Export	24
Distilling and industrial use	4
Seed and other	3

Twenty nine percent of UK varieties grown are NABIM (National Association of British & Irish Millers) Group 1 and 2 hard wheats for UK and export bread making, export blending and feed markets. The majority (47 percent) are soft milling types for biscuit and cake making, starch and distilling markets, export blending and some feed markets (Group 3 wheats). Hard and soft Group 4 feed wheats make up the remaining percentage of UK wheat varieties typically grown.

UK yields average eight tonnes per hectare and are still improving. Plant breeding has been shown to have contributed about half of a three-fold increase in wheat yields between 1947 and 1992. Improvements were publicly funded until 1987 at the Plant Breeding Institute (PBI) in Cambridge. Breeders have also influenced market supply. For example, from the 1960s there was enough improvement in the bread-making quality of UK varieties to shift domestic supply from 65 percent Canadian imports to 90 percent UK grown.

The UK is unique in trading grain by named variety. Wheat varieties are said not to 'travel' well and at about 98 percent for winter wheat, UK varieties predominate in UK seed markets. The process of breeding a new wheat variety can take up to 12 years and a typical breeding programme costs up to £1.5 million per year. Breeders must try and manage their risk and focus on targets that will allow them to gain market share ten plus years into the future. Developing new wheat varieties can be risky and expensive for breeders. Most breeders for UK markets are multinationals and consolidation across the players in the UK industry is likely to continue. Companies with an active interest in UK wheat include CPB Twyford, Nickersons, Cebeco, Elsoms, RAGT, Semundo, Syngenta, and Saaten Union.

Wheat remains the most important crop to UK breeders earning around £12 million per annum in seed royalties of a total across all crops of about £20 million. An increase in the use of farm-saved seed (FSS) to around 50 percent and lower seed sowing rates have reduced overall royalties to the breeders (see section 6.1, figure 1). Royalties for FSS are negotiated between the British Society of Plant Breeders (BSPB) and the farming unions and are currently set at 50 percent of the certified seed rate (not for any technical reason).

Persuading growers and end-users to adopt new varieties is not easy. This can be for a number of reasons including transfer costs for users, uncertainty of performance, conservative attitudes towards change or the availability of 'old' varieties like for example, Riband, that do not attract breeder royalties. Targets for development for breeders tend to be those that represent low risk to growers and to end-users, especially if for a premium use.

The development of new varieties is strongly influenced by variety testing systems. A new variety is required by statute to achieve National Listing (NL) at UK or EU level. The variety must be Distinct, Uniform and Stable (DUS) as well as demonstrate Value for Cultivation and Use (VCU) significantly better than existing varieties. The characters tested by the NL system relate to agronomic performance. Although not necessary from a statutory point of view, to gain market share in reality, a variety must also gain Recommended Listing (RL). Farmers and end-users depend on the RL to independently test new varieties and underpin variety choice.

Farmers are used to making variety choices on the basis of agronomic factors because of the influence of yield on return, which has been fuelled by a production based subsidy system. If the agronomic traits of a new variety are not good, not only will it struggle with the testing systems, it will not gain market share. Overall, current wisdom dictates that it is less risky to develop new varieties around agronomic traits than an end-use trait of interest to an end-user.

3.1.2 Views across a UK wheat food chain

A common view is that wheat is a commodity (full stop!). Niche market opportunities are too small and risky to pursue, and seeking progress through plant breeding to add value in wheat outside mainstream quality traits and those of agronomic relevance is unlikely to occur.

i) Farmers and the HGCA

Farmers recognise the value that plant breeding delivers over the long term, but UK royalties are perceived as relatively high. Farmers bear the risk of growing a new variety and breeders must address the balance between benefit to the farmer and the level of royalty charged. It is interesting to note that low returns from the chain to farmers is a situation faced also by breeders, distributors and processors (see Section 6.1, Figure 2).

Agronomic factors still influence cropping decisions more than markets in many circumstances. Many farmers still cite soil type as the most important factor in deciding whether to grow a premium crop. Yield penalties for growing premium milling varieties can be between 10 and 30 percent. Premiums paid vary between years and depend on the quality and quantity of each harvest as well as available contracts. There is a risk each year of over-supply, which keeps the premium acreage down. Farmers may in fact get the biggest premiums on low value feed wheat when prices and demand are high. Planning cropping according to market factors must become as important as agronomic factors. Decision-making criteria will evolve with CAP reform.

The HGCA and the UK Recommended List (RL) have a unique influence on the approach taken to variety choice. The biggest future risk to growers is being disconnected with what the market wants. The HGCA see their role as providing a consensus view of the potential of a variety to remove risk by performing well and delivering a profitable product.

The HGCA intend to continue to improve the RL system to rank varieties according to end-use quality traits. Aside from the RL and initiatives relating to export markets, the HGCA deliver a role in seeking innovation in, and development of, domestic cereal markets. As part of this there is a stronger role for HGCA in driving market focused technology transfer. The recent trend towards freezing HGCA levies may form a barrier to future progress.

Defra has diverse stakeholders and there is concern among farmers and the HGCA that they may be unable to meet the needs of all levels of food production chains. In implementing policy there is a perception of an emphasis on environmental sustainability and a ‘single issue’ approach to policy implementation. In the context of plant varieties, if a plant variety trait deemed to be a ‘sustainable character’ is inversely related to a key market trait, will statutory testing systems of the future penalise the market trait before the sustainable character?

ii) Breeders

Breeders operate in and are driven and influenced by the environment described in section 3.1.1. Market share is critical to breeders and it is less risky to develop new varieties around agronomic traits. Current systems encourage a paradox as follows:

‘…Growers can only grow cultivars that are made available from breeding programmes but breeders only produce cultivars that growers will accept - yes breeders could/should concentrate on end-use

quality for markets but the growers need to accept that this is as important as yield in choosing cultivars to grow, etc…' (UK plant breeding expert).

The more varieties marketed the greater the likelihood of success in capturing overall market share. The drive for market share is increasing the pressure from breeders for the UK Recommended List to increase in size. Breeders are also increasingly looking to act to protect their legal right to royalty income.

I found plenty of evidence that breeders can breed for new types of traits of potential benefit to end-users across food chains, including consumers. Interest from some farmers or from further up the food chain does register, but tends to be weak and is not backed by real commitment. Breeders are increasingly unwilling to shoulder all of what can amount to substantial increases in risk given weak guarantees of return. Some examples of the sort of barriers to progress that breeders perceive are listed below:

- In response to industry demand a new variety was developed that reduced health problems in battery hens and increase growth rates. When the variety was released it was unsuccessful because the feed industry had by then added enzymes to deliver a similar benefit.
- A global search for varieties with nutritional benefit highlighted a Chinese black grained wheat with anti-oxidant properties. It is widely consumed in China. To develop a variety adapted to grow in the UK was estimated at needing an investment of several million pounds. The risk of development to the breeder was too high as financial support could not be established from food manufacturers, retailers or growers.
- There is interest in reducing prostrate cancer and some medical evidence that increasing zinc in the diet helps to reduce the risk of this disease. A variety with a greater propensity to accumulate zinc could be produced. Bread and other foods with naturally increased zinc could be manufactured. This development remains unlikely because it is cost-effective for manufacturers to add zinc chemically. Consumers are unlikely to perceive any difference, although marketing could influence this perception.
- UK wheat varieties are 'red types' and have a 'bitter' taste. Some global breakfast cereal manufacturers add sugar during processing their standard brands in the UK to overcome this. White wheat varieties grown in drier regions of the world do not require the same amount of added sugar. But, to import white wheat for this end-use would add expense for standard UK manufacturing operations. It should be possible to breed white wheat for UK use, but fundamental research is needed to deal with technical complexities like the propensity of white wheat grain to sprout in the UK climate.

  The Wheat Genetic Improvement Network (WIGN) involves scientists and breeders and is a Defra supported initiative that may recognise and broach this type of research need. However, addressing the scientific issues is only one half of the equation. It may remain cheaper for food manufacturers to add sugar during UK processing than to pay a premium for UK produced white wheat grain. Market demand from niches like this may remain insufficiently attractive for breeders to invest in the technology transfer needed to develop a UK white wheat variety. However, providing a variety of UK white wheat could be produced that could compete with foreign imports a larger market would exist.

UK breeders see their links with end-users in the industry and with science as being very good, but are increasingly less willing to take risks. There is not enough volume in niche markets for breeders to justify the cost of developing a variety for that niche compared to developing varieties for larger established markets that are clearly less risky. The hypothesis supplied in section 6.1, figure 3 demonstrates this.

The increasingly risk adverse stance being taken by breeders relates also to the decline in returns over recent years from the seed royalty system. The system places the farmer as the primary customer paying for the benefit of a plant variety. The increased use of farm saved seed, paid at 50 percent of the certified seed rate, led to growers paying significantly less overall to plant breeders in seed royalties. Royalties reward breeders for their intellectual property, but also form the basis for future research and improvement. So the knock on effect of the recent decline in royalty revenue is that comparatively less will be delivered in the future once inefficiencies in supply have been removed through consolidation of the breeding industry.

As discussed in section 3.1.2 i), Defra policies influence farmers' strategies. In doing so they also influence breeder strategies. In line with Defra policy, there could develop focus on delivering value to growers from improved environmental sustainability such as varieties for low input / organic regimes, enhanced proteins and energy for forage or on novel markets for the UK, for instance willow and oilseeds for industrial use. Obviously no bad thing *per se*, unless to the detriment of a focus on the needs of the end-users in food markets.

iii) Millers

The UK milling industry consists of 33 companies operating 68 mills. The two largest companies account for approximately 50 percent of production. The industry is an important UK market, using 5.5 million tonnes of wheat a year to produce 4.5 million tonnes of flour. The representative industry body is NABIM (National Association of British & Irish Millers) who interact strongly with the UK RL system to establish recommendations on the suitability of wheat varieties for bread making. Markets for premium wheat varieties form a small proportion.

Millers would like fewer varieties with better and more consistent bread-making characteristics. Structural capacity designed for bulk handling and seasonal variation in quality restricts the number of varieties that a typical mill is able to process. The sort of innovation that the milling industry might benefit from is a 'super Hereward', or varieties whose end-use traits are more resistant to seasonal variation. Barriers to progress are described as follows from a UK miller:

'…The state of the industry over the last few years is a major worry. Millers are not willing to fund new varieties, but we do have good communication with the breeders and growers via the National List and Recommended List systems through NABIM. Breeders should be very clear about what the industry needs are, but there have been no major steps forward since Hereward over 15 years ago. Malacca was useful but not a massive development…'

UK millers are unlikely to invest in new varieties, commit to use new varieties or commit in advance of variety development to pay more for the new variety. They see breeders and growers as responsible for taking the risks needed to bring new innovations to them. There remains evidence of a lack of trust between millers and their suppliers. Also, the purchase of grain is dissociated from its end-use quality because gain traders are judged by the price on which they purchase grain. Combined, these factors exert barriers to change. One UK miller summarised the danger of continued disconnection between the lower levels of the chain and the consumer as follows:

'…The loss of UK plant breeding and UK production would be unlikely to be a big loss to the UK consumer – excellent quality wheats are available via European import…'

iv) Manufacturers (bread)

Sixty percent of the bread sold in the UK is white and sliced, although speciality breads are growing in popularity. Convenience, enjoyment and health are key consumer trends, and are often demanded in combination. In representing the manufacturing level of the UK wheat food chain my study focused on an in-store bakery (ISB) of a major retailer contrasted with the Warburton supply chain. Baking operations are complex so the raw materials must be as consistent as possible. Four key attributes of bread are:

- Price (critical)
- Volume – this can be manipulated and improved using artificial concentrates.
- Texture – this can also be manipulated and improved using artificial concentrates.
- Flavour and aroma – the crust of the bread is important to these attributes but they are more difficult to manipulate using artificial concentrates.

Only three basic types of flour are purchased by the ISB and flour markets are very price sensitive. The imperative for suppliers is to balance price against quality. The colour, protein quality, protein quantity, starch damage, and enzyme activity of flour must meet tight specifications. The ISB relies on the technical expertise of the miller to deliver to specification. Relationships with consumers as well as millers are strong, but relationships with growers and breeders are weak. R&D at the ISB level is very unlikely to focus on plant breeding. The cost of the raw material is a small proportion of total costs and chemical manipulation can adequately address key problems. The ISB regularly tests UK and overseas flours to monitor the price / quality balance. In poor quality UK seasons imports are easily utilised. ISBs would be interested in traits to reduce the cost of achieving consistent products or traits that are transparent and of interest to the consumer such as flavour and aroma, that cannot be manipulated with concentrates or gluten free flour. But, the ISB would expect suppliers to deliver these types of innovation.

Different attitudes dominate the Warburton – Centaur Grain chain. Warburton are a family owned company that has successfully moved from supplying markets in the north-west of the UK in the 1980s, to full UK coverage. Warburton have achieved a high market share selling in the premium branded marketplace. The Warburton brand is characterised by a long shelf life and high ‘butterability’ after toasting. Centaur Grain is a farmer-controlled business (FCB) that leverages the commitment of members through annual contracts to ensure continuity of supply of a given variety. Without contracts it is not possible to guarantee supply. Centaur now supplies 100 percent of the UK wheat used by Warburton (which is 20 percent of the company’s total requirement). The grain supplied is Hereward and Warburton pay a premium to Centaur growers worth about £17 per tonne above the market price for the qualities of the variety and consistency of supply. Both parties are committed to the relationship. Other bakers have tried to copy the premium niche success of Warburton, but have not been successful in achieving the same brand strength related to quality.

v) Retailers and consumers

Retailers’ indirectly influence breeders’ approach to improving the quality of the grain used in bread. A high percentage of the bread sold through UK supermarkets is low cost, sliced white bread produced by the Chorleywood process. The bread is cheap to produce and is of relatively low quality, which suits the retail, volume driven business model. Price is critical for this category in retail markets. It is difficult for suppliers to make good margins and pay premiums further down the chain. This ensures that signals to wheat growers and breeders to improve quality are weak. There may be a price benefit

to consumers in this situation, but whether their best interests in terms of the health and taste of products are represented is questionable. This demonstrates the dangers inherent in assuming that the needs of the manufacturer or retailer are a direct proxy for those of the consumer (as I have done in this study!).

Consumers and retailers will pay more for added value, but only that which can be marketed to and perceived by the consumer. In some crops, signals from consumers to the grower and the breeder are clear, because the value added from specific traits is transparent to the consumer. For example, consumers may pay more for sweeter and tastier vegetables or fruits. The relationship between adding value relevant to consumers and plant variety is clear and retailers will express an interest in being involved and in marketing new varieties.

In wheat the relationship with the consumer is more complicated. Cereal products are usually processed and the consumer cannot as easily perceive value added to the raw plant material through breeding. Having said that, there are various consumer trends that plant breeding in wheat could hope to help address. Tastier and more 'natural' foods are strong consumer trends. Healthy cereal-based food offerings with no chemical additives should be of interest. But, retailers expect their suppliers to fund their own product innovations and in general food processors and manufacturers tend to overcome issues such as the sweetness of a breakfast cereal or the shelf-life of a loaf of bread using cost-effective additives or other innovations under their own control. This creates a barrier to there being a role for plant breeding to successfully deliver similar benefits to consumers via improvements to the raw material.

I came across some appreciation that there may be opportunities in wheat relating to taste or human health, but given current industry structures there would need to be government incentive before retailer involvement would occur for a crop such as wheat. The consumer trend towards 'natural food' as defined by 'environmentally sound food' is strong. One approach for growers and breeders might lie in the development of more sustainable varieties. The grower would get paid the same price but the 'sustainable variety' would require fewer inputs, so production costs would be lower. The chain would be more efficient and deliver environment benefit.

Supermarkets often work to very short time frames. For example, if Jamie Oliver cooks a madras curry, the sales of madras curry ready meals will increase the next day! Supermarkets are unlikely to support strategic investments in technologies such as plant breeding where much longer horizons are required. It is also viewed as extremely difficult to predict consumer trends with much accuracy beyond five years. Attempting to align a 10-year or longer wheat breeding investment with future consumer trends may be considered very risky.

Overall, I came across a range of views in the retail sector, but did not encounter much enthusiasm for actual involvement in any new initiatives in wheat rooted in plant breeding.

vi) Research

Research is key to continuous improvement in the delivery of benefit from plant varieties. Many UK breeders, as multinationals, have access to excellent in-house R&D facilities. Breeders fund research through universities either as contract research or through programmes like LINK. Ensuring appropriate management of intellectual property (IP) is key for subsequent commercial success. Breeders also contribute to the UK germplasm collection held by the John Innes Centre in Norwich supported by government funding.

Government investment is largest in basic research. Of relevance to plant breeding is that funded through research councils, BBSRC being the most relevant. Much is directed to the advancement of knowledge in the molecular sciences. New scientific developments in understanding how genes function (Genomics) combined with mapping technologies will be used to provide breeders with a genetic 'map' that helps increase the efficiency and speed with which desirable traits can be selected. UK breeders are collaborating with end users and research institutes particularly for molecular selection approaches to improving grain quality and disease resistance.

UK Genetic Improvement Networks (GIN) are a relatively new initiative designed by Defra to support the generation and exploitation new research knowledge in plant genetic resources for UK main crops. They focus on molecular research to identify traits and markers that will have a value, particularly in relation to economic and environmental sustainability. These centres consist mainly of scientists, Defra, Levy Boards and breeders. End-users are not directly involved, highlighting a tendency for a lack of focus of needs across chains. There is concern about a potential lack of support for the industry to transfer the outcome of basic research into commercial practice.

Many breeders are using new molecular technologies in commercial programmes. This is limited in wheat. Improvement in the rate of uptake of molecular technologies from basic research to plant breeders and others in food chains is needed to assist the competitiveness of the UK industry. Cost and IP are potential barriers to viable technology transfer to industry. Research needs also to be planned and co-ordinated across the total length of food chains for maximum impact.

Grower investment in research via HGCA R&D spend was £1,270,000 in 2001/02. The majority of this was spent on variety trials and recommended lists.

3.1.3 Summary of issues

The outcome of my preliminary UK study set the scope for my overseas trips. I found consensus that demand exists for improved agronomics such as sustainable varieties to produce more from less, traits for novel markets and processing quality, for instance more stable protein and HFN across seasons and improved processing efficiency. Some interest may exist further up chains in delivering attributes relating to consumer health and taste in wheat food products. On the supply side, breeders assured that delivery to all these types of demand should be technically feasible. But, the reality in the UK is that wheat is a viewed as a commodity (full stop!). Commercial plant breeders who remain active in the UK will restrict investment to targets most likely to deliver the greatest market share for their varieties. This will exclude small, unproven markets.

Key issues are summarised below.

- *A common attitude is that wheat is a commodity and this status will not change, making investment in market-driven innovations through plant breeding non-viable.*
- *Growers are the primary customers of breeders, not end-users. The National List (NL) and Recommended List (RL) variety evaluation systems influence breeding targets. Other factors such as Defra policy will also influence grower behaviour and therefore breeder strategies.*
- *Trust across chains remains a problem.*
- *Growers, breeders and processors have a low share of the overall value of wheat chains.*

- *Breeders will exert increasing pressure for: changes to the royalty system, a larger RL, steps to recoup 'missing' Farm Saved Seed (FSS) royalties and strengthened intellectual property protection. There may be conflicts with growers and millers.*
- *Current breeding targets must make commercial sense (large, stable) and gaining market share is key. In complex wheat food chains market signals from consumers are weak. Breeders are unlikely to invest in niche end-use markets.*
- *Few examples of innovation in the exploitation of plant variety exist in UK wheat food chains.*
- *There are consumer needs that plant breeding could hope to address for example, higher quality and more nutritious bread. Key barriers are cheaper alternative approaches, such as additives and a lack of transparency of traits to consumers. The chain is unwilling to pay a premium for naturally derived alternatives.*
- *Interest from retailers and manufacturers to collaborate with primary suppliers in wheat chains, especially in terms of investment is low.*
- *The industry often uses the needs of those in the chain closest to the consumer as a proxy for the needs of the consumer.*
- *Improving mechanisms of technology transfer relating to plant genetic resources across wheat food chains is needed.*

3.2 France

My visit to France concentrated on visiting the Limagrain group at a number of locations. The group provides some interesting examples of a different philosophy to breeding and marketing.

3.2.1 Breeding wheat in France

France grows five million hectares of winter wheat. Fifty percent of the wheat produced is exported and 80 percent of domestic produce is of baking quality. The majority of French bread consumed is baguettes, made by a different process to the UK. There is a climatic advantage for growing premium quality wheats in France over the UK. Premium wheat production is concentrated in the Paris basin and south of Bordeaux. Varieties are categorised and traded on end-use quality. 'A' is the top quality class followed by, 'BPS', 'BPC', 'BAU', and 'BB' (biscuit). A high quality (BPS) variety can yield around 8.5 to 9 tonnes per hectare. High yielding feed varieties are favoured in northern France, where yields can be 10-12 tonnes per ha.

About 52 percent of seed sown is certified seed. French varieties must pass through a national list system called the CTPS, which conforms to EU regulations. Royalties to breeders are paid on seed and there is a standard certified seed system, conforming to EU regulations. There is also a system for collecting royalties on FSS called the CVO system. Farmers declare the variety and amounts of FSS and pay a royalty on it. The CVO royalties are lower than on certified seed. Breeders sell their varieties to co-ops that deal with seed production and distribution. Growers choose which varieties to grow based on a system of publicly funded regional trials called the Arvalis.

Breeders target the largest markets, which are semi-early (75 percent) or semi-late types with good bread-making criteria (BPS), good yield and low susceptibility to key diseases such as fusarium, septoria and brown rust. Around 20 breeding companies are active. The key players are Desprez, Benoir, Syngenta, Monsanto-PBI, RAGT and Limagrain-Nickerson that holds 28 percent of the winter wheat market.

French consumers are often seen as more discerning than UK consumers, but there are signs that the French are moving towards more convenience style consumption, just more slowly than in the UK. One growing market that French breeders target are Bio (organic) food markets. However, like the UK, the majority of niche markets are too small to be attractive to breeders in general and wheat is widely viewed as a commodity.

3.2.2 The Limagrain group

The Limagrain group is a farmer owned co-operative from the Auvergne region in central France. The structure and diversity of the group operations are shown in Section 6.1, figure 4. The group operates mainly in Europe, has 600 farmer shareholders, 5000 employees and a €1 billion annual turnover. The group holds a unique position in that they are farmer owned, but also understand the food chain from breeding to baking or snacks in wheat and maize via ownership up the chain. Vertical integration does not add value *per se* but provides control and understanding across the chain.

My experience of Limagrain was that they represent a 'different' ethos and have a strong commitment to add value. As part of this, Limagrain are committed to R&D, spending €74 million per year. This includes a strong interest in innovation through plant genomics. They own Biogemma, a biotechnology firm and have a stake in the French public/private genetics based research collaboration called Genoplante.

i) Selection of French wheat varieties for UK use

Limagrain-Nickerson wheat breeders are working across a chain, on a European basis. Breeders in France are working with UK breeders and a UK baker to find a French variety with better quality attributes and stability of quality across seasons, suitable to be grown on contract in France and the UK. A three-year trial series is near to completion. The trials were integrated with testing by the miller and baker. A particular variety has been selected that is suitable for UK and French production, although better quality was delivered from the French trials, possibly due to better varietal adaptation for the French climate or climate differences *per se*. Fewer, better varieties are attractive to the baker in terms of assuring the consistency of supply. Blending can be used to achieve the right overall quality. The stability of the quality of the variety across seasons was an important target for the research as changing variety is costly for the baker.

ii) Limagrain Céréales Ingrédients

Limagrain Céréales Ingrédients has a turnover of €43.8 million, 142 employees and is a 100 percent Limagrain owned subsidiary operating in international markets (30 percent export). The stated vision is to take an integrated approach to ingredient functionality from plant breeding to the supermarket shelf. The main interest of Limagrain Céréales Ingrédients is in the functionality of their products as defined by usefulness to processors. There is no direct relationship with consumers. Key markets are as follows.

Milling and baking. This includes owning a bakery (Pain Jacquet). The bakery is a separate business and does not necessarily operate preferential business terms with other parts of the Limagrain group. Having said that, the bakery does have an exclusive arrangement for access to FCI® products for improved shelf-life (described below in detail).

Snacks and breakfast cereals. This includes ownership of the chain from breeding to a maize mill and a state-of-the-art snack pelleting factory. The traceability and control Limagrain command is critical for some markets such as baby foods, where a completely closed chain is used to assure full traceability for this market.

A process called extrusion is key to the production of many snacks and cereals. Plant variety has a key influence on the process. The Limagrain group breed for this end-use and use Limagrain Céréales Ingrédients pilot scale extrusion facilities to test the varieties. They also sell snack pellets made of potato or maize in regular or 3D shapes for expansion by hot air or oil. These pellets also utilise unique maize textures derived from the breeding programme, which is described in more detail in the next section. They sell low fat, low salt options and enhanced nutrition fibres, phosphorous, magnesium, vegetable proteins.

Soups, sauces and ready meals. FCI® (Functional Cereal Ingredients) is the key brand for these markets. There are 11 FCI® products that are wheat and maize based food additives that add texture to processed foods. The markets into which the FCI® products are sold are highly competitive. The product competes with 'E number' modified starches which are chemically modified versus the 'natural' heat modification process used in FCI® products. Other 'natural' products such as guar gum also compete for a share of the same markets.

FCI® is an award winning innovation, with high functionality and a wide range of applications. The plant varieties used to form the products are Limagrain 'reserved' for use only by the Limagrain chain. The variety name and details of the specific traits are top secret. The FCI® products either have high amylopectin to confer thaw resistance on processed foodstuffs or have high amylose for longer shelf life in baked products.

Commercial success for FCI® products in European markets has been limited mainly to France, with some success in the UK. Consumers do not look at labels and notice the difference between natural additives and chemical additives and so it is difficult to charge any more for these products despite higher development costs. Retailers label products as, 'carefully selected natural raw materials' and consumers will pay more for this because they trust the retailer. The consumer does not want to know the details, they simply want to trust the brand and will pay more based on marketing and a brand without detailed explanation.

Diet and nutrition. A range of wheat, maize, oat and buckwheat varieties are used to make high fibre food additive products.

Research. The company also markets a research brand that is 90 percent owned by Limagrain and delivers R&D for food industry businesses. The research brand was set up to use advanced industrial methods to select and develop crop varieties specifically adapted to end-user needs.

iii) An integrated approach to adding value in maize

In maize the group ownership ends with a mill that delivers maize flours to Limagrain Céréales Ingrédients. The maize industry is smaller than the wheat sector and it is easier to have closer relationships between players. In the EU 80 percent of maize is used for animal nutrition, 15 percent for wet milling processes and 7 percent for dry milling processes. The Limagrain maize breeding programme differentiates variety development for three key markets:

Adding value for maize based products for human consumption. As maize grain enters a mill, various parts of the grain are removed to leave the 'maize grit'. The maize grit is then rolled into 'hominies', which are flakes used in products like cornflakes. Grains with hard, vitreous endosperm are needed to make good hominies and high starch particle size is needed to facilitate high hominie yield. This defines the return to the miller and so is a critical performance criteria at the processing level.

Limagrain-Nickerson breeders have developed four 'reserved' varieties for hominie production at their mill. Many high quality markets are currently supplied by hard endosperm 'Plata' type varieties bred and grown in South America. The 'Plata' varieties are too late maturing to be grown in France, so the programme is working to develop a variety adapted for France. Problems to overcome are complex and include developing a variety with appropriate organoleptics ('taste' attributes), texture (crunchiness and resistance to milk sogginess), colour (orange not yellow), high hominie yield and agronomics and crop yield.

Adding value for feed markets. Limagrain Nickerson target feed markets for monogastrics (pigs and poultry). These are very large commodity markets. Limagrain aim to use breeding to differentiate their products by producing a variety that increases energy levels per gram of maize feed by 8-10 percent. The variety will be 'reserved' for a fully traceable closed loop chain. One French feed processor has expressed interest, but not commitment.

The feed industry often varies the use of wheat or maize depending on the spot price of raw materials. Limagrain envisage their variety will be the delivery of 8-10 percent more energy from the same amount of raw material. The processor will either chose to pay the same amount for the same amount of feed from less grain, or will derive more feed from the same amount of grain. A key risk to the breeder is if the industry finds a cheaper source of raw material.

Adding value for growers through improved agronomic characteristics. Limagrain growers grow 10,000 ha of maize in the Limain valley. The Limagrain group has two brands of generally available maize variety, the LG brand and the Anjou brand. The two brands derive from two of the groups companies (Force Limagrain and Mais Angevin Nickerson, see Section 6.1, figure 4). The Group also markets varieties in Italy and Germany under different brand names.

3.2.3 Lessons from France

Is it possible to replicate the Limagrain group approach to adding value in commodity crops such as maize and wheat in the UK? Broadly speaking lessons for the UK might be that:

- *It is possible to select for niche markets from what already exists in breeding programmes.*
- *Efficient co-operation and innovation can operate across international borders.*
- *An FCB can lead the way and capture added value through breeding in wheat food chains. Vertical integration is one way to achieve these benefits, there may be others. Growers outside the Limagrain closed loop gain no benefit.*
- *Limagrain-Nickerson profit from breeding maize varieties for chains serving commodity and niche markets.*
- *The challenges in adding value in commodity cereals through plant breeding are likely to be complex and difficult.*

- *Key to the Limagrain group business model is the use of R&D to deliver added value to meet the needs of their customers in the food industry. The vertically integrated structure allows control over the whole of any given chain, which can in itself be used to add value in some markets.*

3.3 Germany

My visit to Germany provided an interesting contrast on the impact that variety testing systems can have on the drivers and barriers to adding value for markets through wheat breeding.

3.3.1 Breeding wheat in Germany

Three million hectares of winter wheat is grown in Germany. Grain is traded on quality parameters defined by a national system. Varieties are grouped according to minimum quality classifications for five quality classes Elite (E), Quality (A), Bread (B), Biscuit (K), and Others (C). The quality class of wheat grown varies across the country and is mainly dependent on climate, but is also influenced by markets. Variety is relatively unimportant and wheat is strongly viewed as a commodity.

The German Federal Office of Plant Varieties publishes a descriptive list each year. These lists describe, characterise and report the performance of newly listed varieties according to EU regulations. The breeders pay for the variety release system, although there seemed to be a system of indirect public funding. The German descriptive lists are large, carrying 130-140 varieties of wheat. All breeding is private and gaining market share is key to breeders profits. Farmers pay royalties to breeders on basic (certified) seed and on farm saved seed. Yield, yield stability and disease resistance are key breeding targets. End-use quality is essentially being maintained but not improved.

Fusarium is a major problem in Germany. Regulations for mycotoxins have been introduced ahead of EU legislation. The responsibility to ensure mycotoxins are controlled has fallen to the millers and this has heavily influenced breeder targets. Fusarium resistant varieties now dominate the market pull from millers.

German mycotoxin legislation has also led to a reduction of the number of varieties in agronomic variety testing systems. Variety decisions taken by farmers are informed by the results of 1-2 year field trials conducted at Federal State level. Eighty new wheat varieties were released last year in Germany. It is costly and probably unnecessary to trial this many varieties, especially as 50 percent of the market is shared between 10-15 varieties. Large variety testing systems are expensive to run and discriminate less well between varieties. Farmers have supported the removal of any variety that is highly susceptible to fusarium from the testing system.

German consumers traditionally value bread. However in terms of improvement, I was given the impression that German millers tend to ignore variety characteristics related to baking quality. One breeder claimed that: '…the baker claims he takes what the miller gives and the miller claims he delivers what the baker wants. In fact neither take any responsibility for the quality or variety...'. The German milling industry is smaller and more diverse than in the UK, but will consolidate.

One of the largest German milling companies confirmed that while there are some specific markets for which the mill requires special varieties of grain and will pay a premium, these represent a very small proportion of the total. Most of the grain purchased by mills is used in blending. Larger mills can manipulate the protein contents of the flours by blending to a fine degree, and have their own research laboratories to underpin innovation. There are some small markets that require specific varieties.

Some markets require contract grown 'clean' crops that guarantee to have been grown without the use of growth regulators for which a premium is paid.

Class A and B varieties are the most commonly grown varieties. Where a mill requires an Elite variety they either have to contract growers or be prepared to pay a premium because of the inverse relationship with yield. In general, millers expect grain to be traceable.

In terms of searching for new markets for value added flour there was interest in developing markets for 'Selenium wheat'. High Selenium flour though, is produced through agronomic manipulation, rather than variety. Chemical additives are currently widely utilised to produce products for niche markets for human health. For example, a bread mix with omega-3 fatty acids for heart health and one fortified with calcium for healthy bones and teeth. Waxy wheats with more amylopectin for longer shelf life were of potential interest to meet some market interest in additive free flour. Processing efficiency was of interest. The 'Macdonalds approach' seemed of particular interest, whereby a much tighter quality specification is applied to the raw ingredients. Higher quality specifications for raw ingredients reduces the cost of subsequent quality control and helps to deliver a cheaper end product.

3.3.2 Lessons from Germany

The German attitude towards wheat as a commodity seemed to be even more marked than in the UK. Broad lessons for the UK can be summarised as follows:

- *A variety testing system with an emphasis on quality classes does not drive improvements in end-use quality if market demand remains weak.*
- *Regulation can act to distort the drivers for breeding programmes.*
- *Larger variety lists do not tend to benefit farmers or the industry.*
- *The development of niche markets via innovations in plant breeding is likely to be particularly difficult when industry attitudes are strongly Luddite towards the concept.*

3.4 Australia

Looking to a country such as Australia for examples that might have validity in the UK requires some degree of understanding of the key differences between the business environments. There are some strong forces in Australia that have, and continue to, encourage proactive seeking out of new markets in agriculture.

Australian domestic markets are small, supplying a population of only 20 million. This has led to a reliance on export markets, particularly in Asia and these export markets change. In rice for example, countries like Indonesia used to be important markets for Australian produce, but rapidly developed the ability to supply themselves and the entire export market disappeared. Export markets can be volatile and require a constant focus on customer needs, especially as competition is increasingly global. Adaptability to changing market forces has thus been an important attribute of successful Australian agricultural businesses for some time.

There is also no direct government subsidy of agriculture in Australia. Public funding in support of primary arable agriculture is through matching funding for the Grains Research and Development Corporation (GRDC). The GRDC is funded by a compulsory levy of 1% of what farmers earn from grain. This is matched dollar for dollar by taxpayers up to 0.5% of GDP. This usually works out to something like farmers funding 60 percent, and taxpayers funding 40 percent of an overall budget of

AU$ 130 million per year. AU$110-115 million of this is invested in various types of research and development.

Some important comparisons between Australia and the UK specific to cereal breeding are:

- In the UK wheat variety is important to trading in many markets, alongside key quality parameters. Variety *per se* is not as important in the trading of Australian wheat, which is driven by the Australian Wheat Board (AWB) quality classifications.
- Wheat breeding was privatised in 1987 in the UK. In Australia, it is only in the last couple of years that breeding programmes have begun to be privatised.
- Royalty is applied on seed in the UK and is high. Royalty systems in Australia vary between states and can be applied at various levels but tend to be relatively low. Farmers invest in privatised plant breeding via investments by the GRDC.
- As long as Plant Variety Rights (PVR) are attained it is theoretically possible in Australia to side step statutory or national based variety testing systems. This is usually only utilised successfully for domestic niche closed loop systems.
- Apart from the Australian Wheat Board (AWB) system and Federal research organisations like CSIRO, much influence on breeding strategy occurs at state level in Australia. Climatic differences across the country are massive and state based organisations variably influence the strategies adopted by breeders. In the UK political and technological issues get organised more at a national level and are influenced by Europe.
- The reliance of Australian growers on export markets and the AWB system has demanded a focus on end-use quality in plant breeding programmes.
- In Australia breeding and research has always been strongly linked. In the UK there are some degrees of separation. The relevance of research output to plant breeding remains high in Australia and mechanims of technology transfer are strong.
- Farmers and industry in both countries tend towards being risk averse when it comes to adopting new varieties or developing new markets, but Australian farmers and industry appear more used to managing risk and adapting to accommodate changing market needs.

3.4.1 Breeding wheat in Australia

Twenty million tonnes of wheat grain is produced each year in Australia. More than half of this is supplied by Western Australia (WA). The Australian grain industry has two distinct advantages: it is close to large Asian markets and it is in the southern hemisphere so can time supply differently to northern hemisphere competitors.

Bulk grain (>40 tonnes) for export is marketed by the farmer controlled AWB single desk. The AWB has an annual turnover of $AU 8 billion per year. Grain is graded and traded by quality via the system introduced some 20 years ago to ensure a regular and constant supply of high quality bulks of wheat to export markets. AWB engages in hedging to offset risk and is able to offer growers various financing options. Farmers contribute their grain to the AWB pool and are quoted a spot price or they can wait and take the pool price based on a pool estimate. Each pool is sold over 1-2 years to get the best price.

Figure 5 (Section 6.1, figure 5) shows the AWB classes. The AWB quality classifications cater for some specific end-uses such as for noodles, but the system is not designed to handle small quantities of grain. Niche overseas markets, requiring 40 tonnes or more of grain, are unlikely to be catered for. The domestic wheat market was deregulated in the early 1990s but the AWB system remains the

basis for much of the domestic trading. However, as long as a variety has Plant Breeder Rights (PVR) nothing, in theory, prevents closed loop systems operating for specific niches in domestic markets.

The economics of breeding depend on the economics of production. Australia has a lot of land, but relatively poor soils. Average wheat yields are around seven tonnes per hectare. The focus for Australian farmers has been to produce high quality bulks of grain in high volumes. Wheat varieties in Australia are primarily 'white skinned' because these can be grown in dry climates with few inputs. The AWB quality classification system acts as a real incentive to breed for and grow varieties with good end-use quality. Because of the highly variable climate in Australia, AWB classifications are awarded on a state by state basis. This can make it difficult and costly for breeders to achieve national coverage.

Breeding in Australia was until recently orgainsed with public funding on a state by state basis. Breeding targets evolved to match the needs of a particular state. In eastern Australia it is possible to produce the best quality wheat with high protein. Breeding to improve yield has been slower due to a higher priority being attached to improving quality. Western Australia (WA) produces very large volumes of lower quality wheat. Breeders here have focusd more on yield than anywhere else. Australian farmers operate to tight production margins and fungicide, herbicide and fertiliser use is limited. Demand for disease resistant varieties has thus been strong in most programmes.

In the last two years there have been changes in the structure of the Australian wheat breeding industry. All programmes previously funded with public money are in the process of being privatised. State based breeding programmes have developed into partnerships as follows:

- WA, Queensland and NSW formed Enterprise Grains Australia (EGA) with investment from GRDC.
- SA formed Australian Grain Technologies (AGT), which is a semi-private company with 50:50 GRDC funding.
- Sydney University breeding programme markets 'Sunprime' varieties.
- There are also now some non-state, fully privatised breeders, including Longreach, Grain*gene*, Grain Biotech Australia. AWB has breeding interests in Longreach and also an investment in Grain*gene*.

Royalty systems are the source of breeders' returns and so have an important influence on breeder strategies. In Australia, royalty to the breeder may be charged at the point of seed sale (Seed Sale Royalty, SSR) and/or as an end-point royalty (EPR). The concept of end-point royalties was introduced about four years ago to facilitate the privatisation of breeding. For the farmer the end-point royalty system is theoretically better because payment to the breeder is based only on what is produced from the seed supplied. As the privatised breeding companies bed down, many Australian growers question why they have to pay any royalty on varieties that they have in fact funded to develop via GRDC.

It is essentially seed commercialisers, licensed by breeders, that decide on the most appropriate royalty system to apply. The level of EPR levied is not related to the price of grain, only the tonnage, so that growers are not disuaded from growing for higher priced, quality markets. A typical EPR might be $AU1.10 per tonne, with 40 cents going to the seed commercialiser and 70 cents to the breeder. The end-point royalty system often has to work on honesty. Growers state how much they sold as grain and how much they used as FSS.

3.4.2 Research and technology transfer models for adding value in cereal food chains

Australian breeding and research have historically been strongly linked. Ensuring the continuation of this linkage between research, plant breeding and technology transfer activities is seen as important for future innovation in wheat food chains. For this reason, Australia provides ideas relevant to the delivery and uptake of research.

According to the Australian Food and Grocery Council (AFGC), consumer trends and preferences form key drivers for what food manufacturers and their suppliers will need to deliver in the future. Taste is top, followed closely by price, brand loyalty and health benefits. Health benefit for consumers is about 'removing guilt'. A consumer will choose a packet of fishfingers with a 'heart foundation tick' as long as the product tastes nice, is a trusted brand and is a reasonable price. The consumer will not chose healthy product over others if the taste is inferior.

A potential barrier to a healthy level of technology transfer from research to industry may be that scientists do not often understand the whole picture. A true story told to illustrate the point, was that of a group of dairy researchers who developed a cream with new anti-microbial properties. The new cream for confectionaries lasted three weeks with no microbial activity. However, the cream could not actually be used because it dried out and looked very unappealing. There was no way consumers would actually buy products using the new cream!

As well as the needs of consumers, food labelling and safety legislation influence what Australian processors and maufacturers need and how they operate. The timeframes in which supermarkets operate also exerts an influence. Supermarkets allow 12 weeks for a new product to achieve the category average. Supermarkets profit via volume sales so will only allocate shelf-space to products that sell. For a manufacturer developing a new product the large investment required demands a high likelihood of success very quickly. This reality influences the level of risk manufacturers are likely take in terms of developing and marketing new products. This is not unlike the situation in the UK. It is useful if scientisits contributing basic research to industry fully appreciate the commercial realities within which end-users must operate.

The National Food Industry Strategy (NFIS) is a joined up government approach that includes a technology transfer mechanism for pre-commercial research called Food Innovation Grants (FIG). These projects are designed to be led by the commercial partner not researchers. Several innovative projects with a focus on wheat food products are in progress. Until completion the commercial success of these projects remains unknown. The system may be analagous to the UK FoodLink system. Some projects from the FIG prgramme relevant to cereals based innovations are described in detail in Section 6.1, figure 6.

Of particular further interest to my study are the Co-operative Research Centres (CRC) and the commercial outcomes from the Food Futures Flagship program of research driven by the Commonwealth Scientific & Industrial Research Organisation for Plant Industries (CSIRO PI).

i) Co-operative Research Centres (CRC)

The Australian Federal government funds the Co-operative Research Centre (CRC) programme. It aims to foster relationships between government, higher education and private industry. The system is designed to require projects to aim to move towards a self-funding status based on marketable output. A medical based CRC on cochlea implants has been the fastest to become self-funded through the commercialisation of research output. The government view is that this kind of focused pre-

commercial research will not get up and running without public support. Three Co-operative Research Centres (CRC) I visited relate to exploiting genetic resources in very focused ways, not seen in the UK.

The Molecular Plant Breeding Co-operative Research Centre (MPBCRC) in Adelaide employs about 100 staff and received a further seven years of funding in July 2003. The programme has a number of core participants including the International Maize and Wheat Improvement Centre (CIMMYT), Mexico. The Australian government matches commercial and state funding, dollar for dollar. Links with industry and the GRDC come from specific projects. Focusing on cereal and pasture species, the aim of the MPBCRC is to develop gene systems and deliver transgenic technologies, develop new generation breeding strategies, tools and molecular marker technologies and deliver molecular marker technologies and genetic solutions.

Plant breeders are the main customers for the research. The technologies developed will be commercialised via a proprietary company and will involve breeding organisations and seed companies. Various programmes for wheat are in progress. One focuses on the development of germplasm using new molecular techniques to deliver a product that can be used directly by breeders. The MPBCRC expect to be self-funding after the current seven-year cycle of funding.

The GrainFoods CRC, based in Sydney, has recently acquired seven years of government funding to the tune of AU$24 million matched by AU$17 million from industry. The GFCRC aims to deliver functional foods based on grains through:

- Producing grains and grain products with higher value.
- Developing new processing and manufacturing technologies.
- Promoting strategic research and business partnerships.
- Securing significant investment in the future of the grains industry.

The CRC will not deal with breeding *per se* but will focus on gene functionality to improve processing and products from raw materials. IP of relevance to global food retailing is expected within two years. The core partners are: Danisco Pty Ltd, Western Technologies (GWF Ltd), BRI, GRDC, Southern Cross University, ECG (Export Grains Centre Ltd), COGGO (Council of Grain Grower Organisations Ltd) and Puragrain Pty Ltd.

A CRC called the Quality Wheat CRC was established in 1995, based in Sydney. The Value Added Wheat CRC (VAWCRC) is a follow-on CRC to this and received seven years of funding from August 2001. The VAWCRC operates as an incorporated joint venture across the food chain. The key partners are: Arnott's Biscuits Ltd., C-Qentec Diagnostics Pty Ltd., Allied Millls Australia Pty Ltd., Goodman Fielder Baking Australia, GrainCorp Operations Ltd., Grains Research & Development Corporation, The University of Sydney, Department of Agriculture (WA), and the NSW Department of Agriculture.

The VAWCRC aims to move wheat from a commodity to a higher value added industry. Wheat genomics and proteomics will be used to develop methods, such as Marker Assisted Selection (MAS) techniques, to underpin the development of new germplasm. New wheat germplasm will be developed with specific high added value uses and improved quality performance when grown in adverse environments. A 'waxy wheat' to confer longer shelf life in baked products will be available soon. The market for waxy wheats is forecast to develop into several 100,000 tonnes per annum. Other targets include markers for selecting for high milling yield, flavonoid content, sprouting tolerance, late maturity amylase and wheat for noodles with improved organoleptics (taste).

As well as meeting researchers, it was also useful to meet with industry participants. Arnott's is Australia's number one biscuit company. Soft wheats suitable for biscuit making are niche varieties in Australia. For a variety of reasons, the domestic supply of suitable grain became threatened and Australian quarantine laws make imports unattractive. To protect their supply Arnott's had to become more involved in the quality and traceability of soft wheat varieties.

Arnott's have moved from an in-house research programme, to using an external contracting model for research to allow direct investment in the improvement of soft wheat varieties. They have found that this works well as it focuses the research effort and it is not as constrained by the short-term goals and bottom line of the company. Arnott's have invested in three soft wheat breeding programmes. They found they did not have to invest an excessive amount, just enough to signal to breeders that the market demand for these varieties remains intact. The agronomics of Australian biscuit wheats are also poor, they tend to yield only six tonnes per hectare.

In a bid to ensure supply and encourage improvement, Arnott's have thus invested in the VAWCRC. Arnott's accept collaborating with their competitors in the VAWCRC to underpin continued overall improvement to the domestic supply of soft wheat grain. Arnott's ability to compete on making biscuits is key to their business success, not their collaborative involvement in breeding wheat. They also felt that as manufacturer they needed to provide clear signals and get involved in breeding, to protect an appropriate supply of raw material into the future.

ii) CSIRO

Half of CSIRO Plant Industries (CSIRO PI) annual budget comes from competitively won private funding (e.g. GRDC and corporates) and half is core government funding. CSIRO PI is an active player in basic research relevant to adding value in wheat through plant breeding.

CSIRO PI has an investment in an initiative called Grain*gene* with Syngenta, AWB and GRDC. The Grain*gene* project aims to identify genetic factors underpinning important quality traits with a view to improving selection efficiency for wheat breeders. Molecular markers are like flags in the genome that are easily detectable and are used to assist in the selection process of plant breeding. Grain*gene* uses a fast-track biotechnology tool with the contribution by Syngenta of over 36,000 pieces of sequenced wheat DNA. Each piece represents a unique gene and can be used on a microarray. Microarrays or 'DNA chips' are arrays of DNA attached to specially treated microscope slides that allow high through-put comparison of genes under particular conditions.

CSIRO National Research Flagships are part of an Australian Government programme. The Food Futures Flagship at CSIRO PI aims to: '…transform the international competitiveness of the Australian agrifood sector and add $3 billion in annual value through the application of frontier technologies to high-potential industries…'.

Ascentia Pty Ltd. is the company set up to market to output from CSIRO Food Futures Flagship research. The first product to market is a new non-GM cultivar of barley called Barleyplus™ that has unique nutritional characteristics. Key consumer benefit is listed as, low glycemic index (GI), high β-glucan, high resistant starch and amylose starch and high insoluble fibre. The GI index rates foods based on the extent to which blood glucose levels rise after eating a given food. Low GI foods may benefit people with diabetes. β-glucan is a soluble fibre that delivers cholesterol lowering properties to food. High insoluble fibre is known to be important in maintaining a healthy bowel. High levels of amylose and resistant starch may also play a role in bowel health.

The first elite Barleyplus™ variety will be ready for market in 2005. Trials in animals are complete and a large human trial has just been completed. Other cereals are in the pipeline. The company is currently grappling with how to market the product to the food industry while maintaining its high value compared to commodity grains.

A second company HRZ Wheat Pty Ltd. is an incorporated alliance of the Western Australia based Export Grains Centre, CSIRO and New Zealand Crop and Food Research. The company was formed to market wheat varieties from research programmes for high rainfall zones. HRZ Wheat hopes to release its first milling quality HRZ wheat by 2008. This is to meet demand from farmers in higher rainfall zones seeking higher value varieties to access human food markets.

1.4.3 Lessons from Australia

I did not come across examples in Australia that to date had gained commercial benefit from adding value in wheat through plant breeding. However, I found examples close to market more apparent than in the UK. Lessons for the UK may be that:

- *The overall sense of optimisim in Australia is higher than in the UK. Attitudes to risk and long term, integrated strategies across the industry are more broad minded than in the UK.*
- *More awareness of the market and meeting the needs of customers across chains in Australia leads to a greater ability and willingness to respond to change.*
- *A firm linkage between research and plant breeding and technology transfer across chains is important for future innovation in wheat food chains. Mechanisms to promote commercial awareness among researchers are critical to ensure delivery of what the market needs.*
- *If processors and manufacturers do not give clear signals and get involved in breeding, an adequate supply of an appropriate raw material into the future can not be guaranteed. Co-operation between industry players, researchers and breeders is desirable and possible.*
- *Rather than subsidy to support agricultural businesses today, farmers in Australia will benefit 'tomorrow' from a large and varied portfolio of investment in research and development through the GRDC. This investment extends to plant breeding programmes.*

3.5 Non-cereal food chains

During the course of my study I came across a number of examples of interesting approaches and attitudes in non-cereal food chains. Two are now described in more detail.

3.5.1 PIC (pig breeding)

Pig breeding has traditionally been driven by demand for traits to increase farm production. PIC, a global pig breeding company, found themselves part of a breeding industry targeting the same traits and marketing similar products. PIC set out to differentiate products from the other breeders by adding value. There is a difference in breeding for fresh pork and processed pork. The latter is particularly comparable to wheat breeding but a number of examples are described.

A closed loop chain with traceability for fresh pork. Waitrose has a simple, joined up chain for fresh pork. All fresh pork is supplied through a chain with full traceability. The chain uses one breeding stock supplied by PIC, one producer with one agronomy system and one processor. This closed loop chain was established about five years ago and was developed in the first instance by the processor who

approached Waitrose. In general, other retailers continue to buy pork as cheaply as possible. Pork is not a growing category, so adding value is not of interest.

Delivering tastier and healthier fresh pork? Fresh pork markets demand differentiation of the end product in terms of its succulence, tenderness, juiciness, flavour, fattiness etc. Healthy eating brands or premium brands market these attributes to the consumer. PIC developed a 'tastier' product and approached several retailers with evidence from independent taste panels of the superior taste attributes of the product. No retailer adopted the offer given current markets.

An efficient chain for commodity pork. PIC also considered the possibility of adding value to pork destined for large processing markets in the UK. It is hard to differentiate pork for these markets. The target for PIC was a pig with more meat to deliver processing efficiency and maximise returns per pig to the processor and the producer. PIC has developed a closed loop chain where they work with a specific abattoir and producer group. PIC bears the breeding cost. The processor pays a premium to the producer because the pig has more meat on the legs and loin. The producer then pays a royalty to PIC. The chain is more efficient and all involved benefit by having a better understanding of how to meet the needs of each stage of the chain.

Adding value for processing. Royalty systems to reward breeders vary in the pig industry. In the UK the majority of royalty is paid on production, typically the number of pigs produced per sow. Alternatively, the royalty is sometimes paid on the number of slaughtered pigs derived from each sow. This delivers a stronger relationship with the return to the producer.

In Germany PIC have developed a system that goes one step further. A pig has been bred that delivers production benefit to the producer and a royalty is paid for this benefit. On the same pig, PIC has demonstrated a measurable processing benefit to the abattoir and they pay a separate royalty for this. A significant increase in marketing effort and research spend was required. PIC has been unable to inspire interest in the UK.

Like wheat, pigs are viewed as a commodity. It may become increasingly difficult to add value through breeding but parallel attempts to add value through breeding in wheat may remain possible. Lessons for the UK wheat sector might be that:

- *It is possible to add value through breeding and co-operation in commodity chains.*
- *Significant marketing effort and cost is required to beat industry inertia. Co-operation across chains can be difficult where players wish to protect their existing relationships.*
- *It may be very difficult to convince those further up the chain to participate.*
- *It is possible, but very difficult, to develop royalty systems that relate better to the value added for each player of the chain. Adaptation of current royalty systems might allow greater transparency of benefit delivered and greater incentive for breeders to focus on targets to benefit end-users.*

3.5.2 Specialist beans for Japanese markets

Agsell is part of NSW Agriculture and works to develop non-cereal markets overseas. I came across some interesting examples demonstrating a strong link between a market need being met by the selection of the right plant variety.

There are a small number of soya breeders in Australia and all focus on varieties for human consumption markets. Genetically modified (GM) crop production is not permitted in Australia and so to compete in world markets for soya feed and oil is not as profitable. There is a premium for GM free soya for human consumption in Japanese markets. Collaboration began between various players to supply a Japanese tofu maker with a non-GM white hilum bean. Dark hilum beans colour tofu in an undesirable manner.

A white hilum Australian variety called Curringa that had the right protein profile was selected. However, the husk split on processing and the quantity of protein normally required could not be achieved in the Australian climate. The Japanese customer accepted these flaws, in return for the white hilum, the right type of protein that gels well and guaranteed supply. The breeder was involved in advising on agronomic protocols to maximise the output of the variety. A profitable niche market was developed and supplied through detailed communication across a chain from the breeders and farmers to the buyers and end-users, across international boundaries.

The Azuki bean is used to produce a specialist product in Asian markets that is used in confectionery products where western societies would use jam. Japanese customers for Azuki beans value fresh lots rather than those stored from the previous years domestic supply. Imports are allowed according to a quota based on estimated domestic production in the autumn. The timing suits the Australian planning period and allows Australian supply to be planned to match the Japanese quota. The Japanese in general are discerning about the quality and freshness of their foods and this generates opportunities for Australia.

A 12-month scholarship by an Australian breeder highlighted a company who wanted a white Azuki bean. An Australian breeder with a white off-type line was identified. This was developed into a white variety. Some research was required to lift the yield of the variety from three tonnes per hectare by improving agronomic practices. A viable niche market has been established.

Tebo and Kintoki beans are also used in Japanese markets and the potential for Australian production using Japanese varieties is being examined. The climate on Hokkaido is very different to that in NSW, long summer days are a particular contrast. Hokkaido varieties of Tebo and Kintoki beans have been selected in NSW. Australian farmers and breeders have had to work hard on the agronomics to produce top quality beans of these types. But progress is being made. A similar approach is being taken to developing Australian production of a small soya bean called Nato. It is fermented until it is almost rotten and eaten in Japan as a breakfast food. NSW agriculture are evaluating Japanese varieties and Australian varieties in NSW and south Queensland. Japanese customers are paying for this selection work.

Supplying niche markets is about risk management. There is an inherent risk of instability for Australian supply of beans onto world and Japanese markets. Australian growers for these markets are astute fiscal mangers who regularly deal in futures to manage their risk. To make niche market supply work, the right links with the right scientists and breeders are needed in order to be able to quickly adapt what is available to meet the specific needs of a market.

HGCA in the UK are active in developing overseas markets for UK grain. Activities involve the production of variety lists for export markets by HGCA Grain Export. Specific projects related to particular markets have been activated. For example, HGCA have sponsored workshops looking at the use of UK grain in imaginative new ways such as for pitta-bread. HGCA also sponsor missions to other countries, including breeders discussing the needs of foreign processors.

While wheat and beans are clearly different, some general lessons that might be used in parallel with HGCA activities when looking to exploit plant genetic resources for niche markets might be:

- *To know and supply niche markets takes effort and a pragmatic approach. The niche must be supplied with what is wanted and the supplier must be flexible about how this is achieved.*
- *It is necessary to act now not tomorrow.*
- *Farmers must be able to manage financial risk to operate in niche markets.*
- *The customer must be willing to pay for the innovation needed to deliver a product. If they are not, market failure exists and the innovation is not economically viable.*
- *Plant species and varieties may not travel well, but when the focus is on the market, it may be more cost effective to select for agronomic characters from existing overseas varieties than starting from scratch.*

4.0 Conclusions and Recommendations

I set out to question the scope to add value in wheat chains through plant breeding. At the close of my study I think:

1. It is possible.

- Plant breeding can deliver a range of benefits for a variety of niche markets, including human health.
- Opportunities to add value in some UK wheat food chains should exist, but will be hard to find.

UK players should consider the possibilities across chains.

- *The development of a market focused UK Recommended List and other HGCA initiatives may form one avenue for general progress.*
- *Individual businesses in wheat chains must seek out their own opportunities.*
- *Industry must champion debate across chains.*

2. Success is likely to be hard to achieve.

- Adding value in wheat via plant breeding will not be suitable for many chains.
- Examples of successful delivery of added value via plant breeding in wheat chains are few.
- There is inertia in the chain in seeking market-orientated developments in wheat breeding.
- Cheaper alternative approaches (additives) and distance from consumers and other end-users across complex chains form barriers.
- It is expensive for a breeder to develop a new variety of wheat. Variety testing systems and delivering benefit to farmers drives rewards.

UK industry should drive a change in attitude from the bottom up.

- *A proactive attitude is needed to drive co-operation among players at the primary end of wheat food chains in order to add value through plant breeding. The effort required to breakdown inertia and long standing attitudes should not be underestimated.*
- *Longer-term, collaborative attitudes towards investment in marketing and R&D are needed.*

- *Closeness to the consumer in the chain is not necessarily a direct proxy for what consumers want. FCB's and other players at the primary end of the wheat food chain must find appropriate mechanisms for their own dialogue with consumers.*

3. <u>Co-operation is required.</u>

- Systems of variety testing must not form a barrier to market-driven innovation in the future.
- Developing insight into priorities at other levels of the chain is necessary for value added chains to operate, which is not easy to achieve. A lack of trust across chains creates barriers to co-operation.
- UK industry will need encouragement to employ innovation derived from research in this area. UK research needs to develop stronger links across chains.

<u>UK players should work to improve co-operation across chains.</u>

- *Players at the primary end of wheat food chains all capture relatively low levels of value. Interest from retailers and manufacturers in wheat breeding is low. Opportunity therefore exists for FCB's and others to collaborate for mutual benefit and to lead progress.*
- *Industry mechanisms to encourage individuals and organ isations to develop insight across the chain within which they operate need to be available to support innovation.*
- *Where appropriate co-operation and innovation should operate across international borders.*

<u>4. Others are trying harder.</u>

- There may be a threat of losing future markets to 'switched on' overseas competitors, especially where markets are initially small and commercially unattractive.
- Research in Australia is closely linked to plant breeding and efforts to promote efficient technology transfer across chains are visible.
- Attitudes to risk and innovation need to be more broad minded.

<u>The UK must promote market-orientated research and technology transfer mechanisms.</u>

- *Australian models of research may provide new ideas to promote the delivery and uptake of research to complex UK wheat food chains. These include NFIS (National Food Industry Strategy), pre-commercial technology transfer funding (FIG), and CRCs (Co-operative Research Centres) relating to the exploitation of plant genetic resources.*

5.0 Appendices

5.1 Appendix 1 Facts and figures

Figure 1: Breeder royalties in the UK from 1996 to 2003 (source: BSPB, UK)

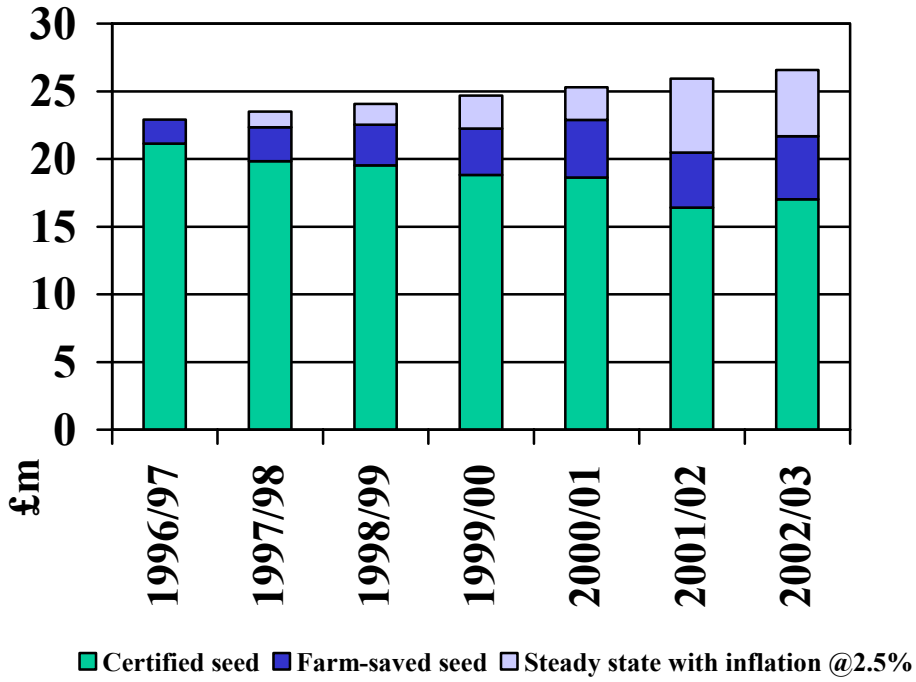

Figure 2: Typical returns in a grain chain – an illustration (Source: Stark, Functional food ingredients: opportunities and challenges, Monsanto)

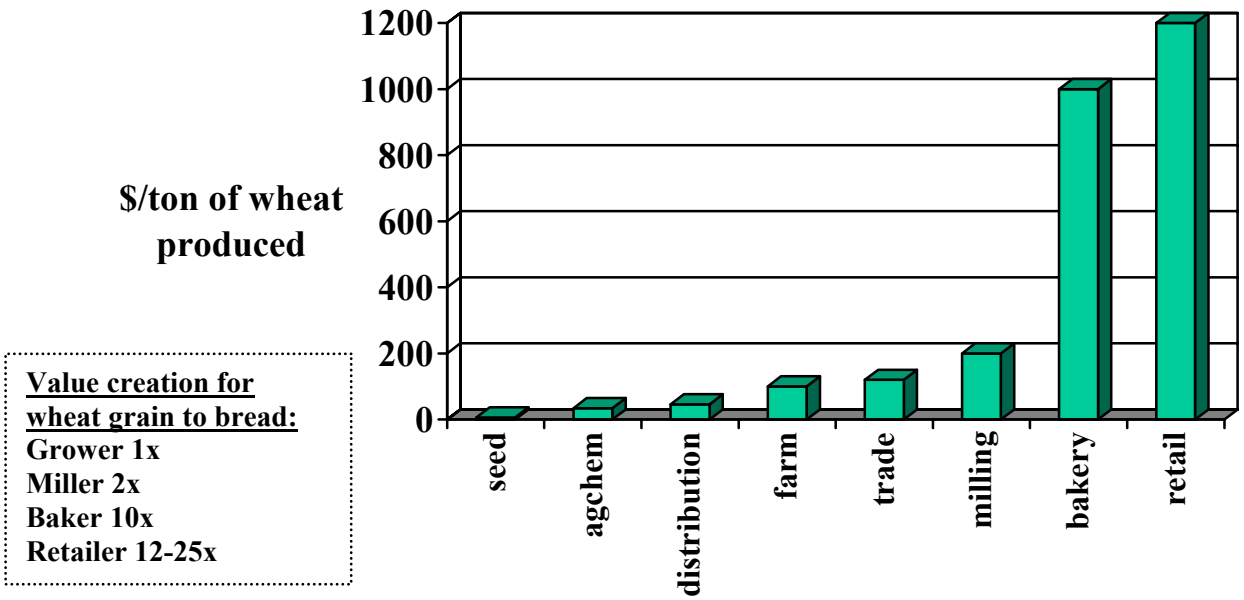

Figure 3: Returns from niche markets and mainstream wheat markets

Returns to a breeder from a niche market:

A grower gets £80 for 1 tonne of quality wheat grain. This makes 2000 boxes of a whole wheat breakfast cereal product (assuming the product uses 0.5kg of grain per box). If the whole grain product is sold by the manufacturer for £1.60 per box then the return at the retail level for the 1 tonne of wheat is £3200. The breeder gets paid a royalty from the grower on the seed at £60 per tonne. Assume the overall volume of grain needed for the niche whole grain product is 6400 tonnes.

Assume a grower needs 1 tonne of seed per 8 ha and can produce a yield of 8 tonnes per ha. The grower gets 64 tonnes of grain from 8ha land. Assume the niche market above requires 6400 tonnes of grain. The return to growers @£80 per tonne is £512,000. The amount of seed needed for the niche market will be 100 (tonnes) x £60 = £6,000 of this in royalty to the breeder.

Returns from a mainstream market:

Breeders pay about £8,000 in official trial fees to get a new variety nationally listed, plus the development costs for the variety. In terms of return on this investment, the breeder will go for a variety that will take market share of commodity markets. For instance, Claire with 20 percent of the UK market will return about £2.4 million per year in seed royalties.

The question for the breeder is: invest £8,000 for the official trials (plus cost of developing the variety) in a niche market to get £6K return or invest in a variety that will gain/retain 20 percent market share and get a potential return of £2.4 million.

Figure 4: The Limagrain group

Figure 5: Australian AWB wheat classification (Source: Bread Research Institute, Sydney NSW)

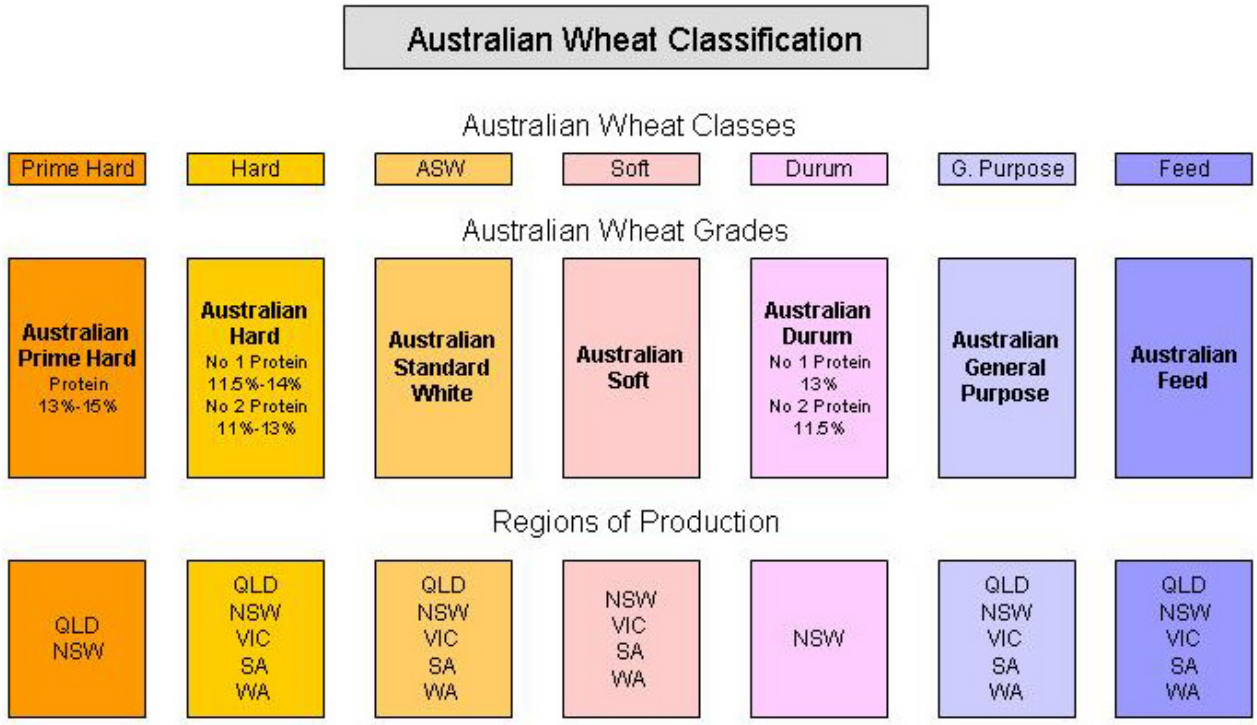

Figure 6: Examples of Australian FIG projects (Source: NFIS, Canberra ACT)

FIG projects related to the grains industry:

- $AU 3.4 million. Western Technologies. Development of non-GM waxy flour and other products. The starch in waxy wheat differs from normal wheat, and gives distinct textural and functional properties to products. The project aims to develop the products and technologies to develop markets for waxy wheats.
- $AU 885,000. The Manildra Group. Development of wheat protein based food ingredients with improved flavour. The aim is to remove the 'cereal' taste of wheat proteins to facilitate their use more generally in food instead of more expensive milk proteins (sodium caseinate).
- $AU 1.97 million. The Uncle Toby's Company. To investigate the effects caused by the addition of novel ingredients on processing conditions and final consumer acceptance of cereal based foods. The aim is to commercialise a range of food products that have high consumer acceptance and nutritional composition to benefit consumer well being. This is an example of a project where the use of specific ingredients may not be acceptable (in terms of organoleptics- taste) to the consumer even though there are health benefits. This is about grain foods and how they taste. The end product will be marketed on health.
- $AU 3.3 million. Western Technologies. Development of new applications using premium plant products for use in high value food markets. Alternative protein sources to dairy proteins.

5.2 Appendix 2 Further reading

During the course of my study I came across a number of recent reports published in the UK made relevant and interesting reading:

- 'The role of future public research investment in the genetic improvement of UK grown crops'. BioHybrids International Ltd and ADAS consulting Ltd. 2002. Funded by Defra.
- 'Investigation of Varietal Characteristics Required for Sustainable Agriculture'. Defra project code VS0128. NIAB, 2003.
- 'Evaluating the potential markets for UK cereal varieties with specific end-user traits'. Bidwells, Crop Management Information and Imperial College, 2004. Funded by The Farmers Fund.