# Agri-Food Biotechnology –
# The Way Forward

**Research Priorities : A Joint Teagasc/Universities report**

## Executive Summary

Biotechnology will be one of the core technologies of the 21st Century, and agri-food has been identified as one of the sectors that will benefit significantly from biotechnology's tremendous potential. Agri-food is of major national importance in Ireland, accounting for 30% of our GNP and employing over 175,000 people. The industry is operating in a rapidly changing global environment, however, with increasing competitiveness, globalisation of prices, and consumer demands for food that is safe, nutritious and produced in a sustainable way.

Biotechnology is arguably the only technology that can seriously address these challenges. The molecular techniques of modern biotechnology will enable us to develop, for example, new and improved vaccines, better diagnostic tests for diseases, novel enzymes for use in food processing, more precise ways of identifying the best individuals to use when breeding the next generation, and ultimately provide the consumer with food that is safer, healthier and produced in an environmentally friendly way.

Biotechnology is a high-tech research based technology, and a well developed research infrastructure is essential if we are to create a vibrant agri-food biotech sector. The existing University-Teagasc capability is a sound foundation for a world-class biotechnology establishment, but growing this establishment will require:

- Significant long-term investment in developing our R&D facilities
- A nationally co-ordinated strategic approach
- Strengthening the existing R&D infrastructure

This will help foster a modern competitive agri-food sector and an indigenous biotechnology industry, as well as attracting and anchoring significant inward investment.

The main research priorities identified by the Agriculture and Food Biotechnology Group are:

***Food***

- Develop fast, accurate tests to detect pathogens in food
- Use molecular techniques to identify new ways to prevent food poisoning
- Investigate ways of improving the nutritional value of Irish food   for example by identifying cattle which naturally produce leaner meat
- Develop novel functional foods, including pro-biotics, for this rapidly growing niche market
- Build on our existing expertise in food starter cultures and bio-processes (used in cheese making, etc.) to yield improved cultures producing industrially useful enzymes, flavours, etc.

***Consumer attitudes***

- Transparent risk assessment processes, an open national dialogue and public involvement in the debate will be essential in communicating to the public the principles, many benefits, safe application and potential risks of biotechnology
- Surveys of consumer attitudes will be useful in addressing mis-conceptions about the technology and in predicting future consumer acceptance of biotech foods and products

***Protecting the environment***

Biotechnology promises to dramatically improve our ability to farm in a sustainable way, and using fewer chemical inputs. Research priorities include:

- Develop ways to reduce the risk of pollution to environment; rehabilitate air, soil and water resources that are already polluted
- Reduce methane emissions from ruminants, and thus help meet our obligations under the Kyoto Agreement
- Develop new ways of treating and recycling manure and other agricultural and agri-food wastes
- Assess the safety and environmental impacts of using a GM crops and GM products

***Sustainable animal production***

Biotechnology will enable us to dramatically improve our ability to detect, treat and prevent diseases and improve the efficiency and genetic merit of our national herds. Research targets include:

- New vaccines for the major diseases affecting Irish agriculture will help both to prevent disease and reduce our dependence on antibiotics and drugs
- Improved diagnostic kits to test for these diseases, especially ones capable of detecting sub-clinical conditions
- Using the latest genome mapping information to improve the speed and efficiency of conventional breeding programmes (ie 'marker assisted breeding'), with a view to improving the disease resistance and genetic merit of the national herds
- Improving the fertility of the high-yielding dairy cow; other targets include a sperm sexing technique and an automated heat detection device for use with suckler herds

***Sustainable crop production***

The first genome map for a plant species will be finished this year and the information will revolutionise our ability to produce new and improve plant varieties. Irish research priorities must include:

- Improved grass varieties, and new crop varieties adapted for the Irish conditions
- Reducing the use of pesticides and herbicides, by designing improved biological pest control systems, and breeding crop varieties with greater disease resistance

This report was prepared by the major Irish R&D performers, and is itself a major first step in establishing the co-operation and critical mass needed if Ireland is to realise the benefits of biotechnology.

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# 1 Introduction

Biotechnology: a set of powerful tools that use living organisms, or components from those organisms, to make new products and processes, or modify existing ones; improve plant and animal productivity; and develop new and useful strains of micro-organisms.

## 1.1 A new agricultural revolution

The 21st Century, it is now widely acknowledged, will be the Biotech-IT Age. The recent *Technology Foresight* reports rightly identified biotechnology as one of the core technologies which Ireland and Irish industry must now embrace. Moreover, the *Foresight* reports also identified agri-food in particular as a sector that can benefit significantly from the tremendous potential offered by modern molecular technologies. This current report, jointly prepared by the major players in Irish biotech agri-food research, identifies the priorities that must be addressed if our agri-food sector is to partake of this new Agricultural Revolution.

Biotechnology is not new. For thousands of years people have been using and manipulating living organisms: yeast to make bread and beer, for example; bacteria to make yogurt and cheese; fungi to produce antibiotics; and domesticating animals and breeding crops for farming, forestry and fisheries. Modern biotechnology, however, which developed over the past 25 years, includes new molecular techniques which greatly increase the power, complexity and precision of what biotechnology can achieve. Most importantly, these molecular techniques have enabled us to begin compiling precise genetic information about gene location and function, and even whole genome maps, information that is fuelling the current rapid explosion in biotechnology.

The agri-food sector forms a major part of our economy. It employs over 175,000 people and accounts for 30% of GNP, 10% of exports, and 32% of the net inflow of funds from international trade. The agri-food industry, however, is operating in a rapidly changing world environment with increased competitiveness, globalisation of prices, and consumer demands for quality, safe, nutritious and convenient food, produced in an environmentally friendly way. Biotechnology is a powerful means to meet these challenges.

Diagnostic techniques that greatly improve our ability to detect diseases; fermentation and enzyme techniques for processing and manufacturing industries; microbial selection and manipulation, used in everything from drug production and cheese-making to bio-remediation of polluted sites; and marker-assisted selection, which is revolutionising the speed and accuracy of conventional plant and animal breeding (see Chapters 6&7). These are just some of the many and varied techniques available to modern biotechnology. Recent public debate focused almost solely on one technique, namely GM crops, but there are many other techniques and they hold out the promise of tremendous benefits to consumers, the environment and the agri-food industry as a whole.

The medical/healthcare sector was the first to reap the benefits of biotechnology and already 20% of the world's pharmaceutical products are biotechnology based. Like the medical sector, agri-food is a biological industry and therefore ideally placed to exploit the potential of biotechnology, as well as capitalise on biotech advances already developed for the medical sector (diagnostic techniques, for example). In agri-food, biotechnology will enable us to:

- Meet consumer demands and produce food that is fresher, healthier, safer and more nutritious but, significantly, no more expensive

- Meet growing legislative constraints and produce food in a sustainable and environmentally friendly way and with fewer chemical inputs
- Treat, reduce and eliminate wastes produced on the farm and at food processing plants
- Address animal welfare concerns with better disease management and prevention
- Increase agri-food production and efficiency, but without increasing costs (thus coping with the trend toward fewer but larger farms and processing plants)
- Develop innovative and niche value-added food products, and so diversify away from price-supported commodities, especially as these supports will not continue indefinitely in the growing free-trade environment

Biotechnology is arguably the only technology that can seriously address all the above challenges and concerns. Already, the benefits are being felt: 80% of the world's cheese is produced using the enzyme chymosin. Identical to the rennet traditionally harvested from calf stomachs, chymosin is produced by modified bacteria; but being purer than rennet it is more effective, easier to handle and cheaper to produce. New biotech vaccines and diagnostic kits are starting to be used in animal disease management programmes; novel functional foods are being marketed to treat a range of conditions; and crops with added vitamins and minerals are being developed to counter nutrient deficiencies (a new rice variety with added vitamin A was introduced in recent months).

## 1.2 A national strategy

Biotechnology is a high-tech, research-based technology. A well-developed research infrastructure is therefore essential if we are to: monitor, evaluate and exploit key international developments; produce and attract skilled biotechnologists; establish and foster a vibrant biotechnology sector; and act as a magnet and anchor for biotechnology inward investment. This requires:

- Significant investment in, and long-term commitment to developing our R&D competency and facilities
- A nationally co-ordinated approach to expanding our skills base
- Strengthening the national infrastructure that supports R&D and technology exploitation

The existing University-Teagasc research capability is a sound strategic base on which to build a world-class biotechnology R&D establishment. Moreover, our food industry, with its clean green image and large capacity, is well placed to exploit this new technology to expand its product range and quality.

Biotechnology is also a powerful horizontal technology. While this report identifies priorities for the agri-food sector, there may be knock-on benefits elsewhere, since many agri-food advances could also be used in the marine, environmental and pharmaceutical/health care sectors, as well as industry in general. Moreover, products and processes developed for our agri-food industry could lead to new Irish biotech companies selling these products and processes on the international market.

## 1.3 Consumer concerns and public dialogue

With biotechnology we can address consumer demands for fresh, nutritious and safe food, public concerns about animal welfare, and societal requirements for sustainable and environmentally friendly production and processing. Consumer acceptance and approval of these technologies, however, will be crucial to their success. The recent and much publicised objections to certain GM crops affect just one aspect of biotechnology, but other biotech procedures and products could by association, and because of a lack of understanding of the benefits, become the subject of similar concerns.

An open national dialogue exploring and explaining the principles, many benefits, safe application and potential risks of biotechnology, is therefore essential. Transparent risk assessment, and public involvement in the debate about strategic development of this technology, must form part of this dialogue. The potential benefits of GM crops must be highlighted so that the public can make informed decisions. Information about consumer and market attitudes to biotechnology and consumer behaviour, both at home and abroad, as well as the factors that shape these attitudes, will also be crucial to the success of this programme.

## 1.4 The priorities

This report identifies the priorities for Irish agri-food biotech R&D for the coming five to 10 years, based on anticipated needs and opportunities. It also outlines the strategic development programme needed to make these targets a reality. As well as introducing new technological advances, biotechnology will fundamentally alter the structure of Ireland's agri-food chain: new liaisons will be needed among crop growers, animal producers and their respective processing industries; and between clinicians and the food industry. In short, we need a new co-operative approach to performing R&D. This will ensure:

- Cost-effective investment
- Balanced strengthening of the national R&D base
- Efficient transfer of R&D results both to existing Irish industry, and to help establish new ventures
- Stronger alliances among critical players in the food industry
- A stronger agri-food business more deeply rooted in Ireland

This report was prepared by the major Irish R&D performers, and is itself a major first step in establishing the co-operation and critical mass needed if Ireland is to realise the benefits of biotechnology.

# 2 Consumer Health and Food Safety

The modern consumer demands food that is fresher, more nutritious, healthier and safer. Changing lifestyles, however, mean that people are also eating more convenience and restaurant meals. These trends have major implications for the food industry and pose challenges with respect to food safety, food processing and food quality. Biotechnology offers us a range of techniques to meet these needs and tackle these problems, as well as providing new opportunities for the Irish food industry. Food traceability and authenticity tests, diagnostic tests to detect and prevent food poisoning, and novel functional foods are just some of the potential applications for food biotechnology.

## 2.1 Food safety

Food safety is the absolute priority. It must be assured to protect the consumer, and to maintain and expand food markets. Priority research themes are:

- To develop rapid and sensitive diagnostic kits to detect pathogens in food (DNA-based approaches offer the best potential)
- Genetic analysis of food-borne pathogens (eg *E coli* 0157 and *Salmonella*) to understand how they survive and grow in food, especially at chill temperatures and during processing and cooking
- Study pathogen-host interactions to identify new ways to treat, and ideally prevent, food-borne illnesses
- Develop proactive approaches to food safety using protection cultures (probiotics) and bacteriocins
- Develop improved processing technologies that minimise the need for chemical preservatives (see also Chapter 3)
- Study the prevalence of antibiotic resistance in food bacteria, and how this is acquired

In addition, genetic technologies mean we can now trace problem organisms to their source. Combined with HACCP (hazard analysis of critical control points), these procedures should significantly improve food safety.

## 2.2 Food for health

Diet and health are intimately connected. Increasingly we know that certain foods and food components can help prevent some diseases, while others can trigger their onset and development. Thus saturated fats are associated with cardiovascular disease, while green vegetables contain useful anti-oxidants which can reduce the risk of cancer. More research is needed if we are to improve the nutritional and health status of our food. Priority research strands are:

- Investigate the beneficial constituents of Irish foods and establish their health consequences. Components of interest here include: conjugated linoleic acid (a heath-promoting fatty acid found in milk and meat and which is thought to help fight cancer, obesity and diabetes); anti-oxidants (which also help prevent cancer); flavonoids, etc.

- Food enrichment with health-promoting ingredients such as vitamins (eg folic acid) and bio-active peptides
- Investigate the undesirable food constituents and their negative effect on human health (such as trans-fatty acids and coronary heart disease)

## 2.3 Functional foods and probiotics

Functional foods, which incorporate either health-promoting active ingredients and/or pro-biotic bacterial cultures, are a new and important food market. These are value-added niche products and marketing studies predict that they will be a key growth area in the next 10 years, possibly even surpassing the low-calorie food market. Functional foods already on sale here include cheeses and yogurts containing probiotic cultures said to improve digestion and the immune function; and spreads and cheeses containing plant stanols and said to reduce cholesterol levels. Other products have been designed to alleviate conditions that include food intolerance, nutritional disorders and osteoporosis. Further research is needed however, to:

- Elucidate how probiotic bacteria actually improve human health (such information would also be essential to support any health claims made for a probiotic product)
- Improve the ability of probiotic strains to withstand food processing
- Increase the range of functional and probiotic products available

# 3 Food quality and processing

Biotechnology can play a major role in enhancing food quality, and in improving food processing techniques, whether by enabling us to improve the quality of the raw materials, or to reduce the use of farm chemicals, or to improve food safety, or to develop new and more efficient processes. Biotech-based enzymes, for example, are already used in the food industry to produce cheese and brew beer, to keep bread fresh, and to produce sweeteners, flavours and vitamins.

## 3.1 Fermentation and flavour

Quality rather than price is increasingly the dominant feature of competitiveness in the food products and ingredients markets. Biotechnology can be employed to improve food quality in various ways, such as providing novel starter cultures and adjuncts to improve the flavour of fermented foods. Over the last 10 years Ireland has established an internationally recognised research programme focused on the starter and flavour bacteria used in the food industry and especially their genetic analysis and improvement. This programme has produced efficient systems to genetically manipulate starter cultures, and identified the genes that control many of the bacteria's commercially important traits.

To exploit these valuable food bacteria, and especially to manipulate them as 'cell factories', we need yet more detailed analysis of their genetic make-up. The long-term aim is to produce bacterial strains that can manufacture valuable metabolites such as organic acids, flavour compounds and substances that can promote human health. Simultaneously, we need new genetic tools to facilitate this work using a process called 'self cloning', as this does not entail the use of foreign DNA, a procedure which may not find favour with some consumers. Finally, the availability of novel enzymes would provide the food processing industry with greater choice and the ability to innovate, leading to more diverse product ranges, with more intense and interesting flavour ingredients, and the use of less severe processing technologies and fewer chemicals. Priorities in this area are:

- Genome analysis of starter cultures, including the development of DNA micro-arrays to study genome diversity, structure and function
- Metabolic engineering of starter bacteria aimed towards valuable end-products such as flavour compounds, amino acids, commercial enzymes and nutrients
- Detailed studies of the metabolic pathways in food bacteria with a view to improved fermentation and flavour development
- Developing novel enzymes for food processing

## 3.2 Bio-processes

A key area in developing new food products and ingredients involves 'bio-processes', notably fermentation technology and the use of molecular separation processes to convert indigenous raw materials into value-added, innovative products. Commercial opportunities in Ireland include the separation and fractionation of milk and whey components, and using micro-organisms to convert milk and beet sugars into natural ingredients for the food and animal feed industries. Establishing a significant capability in bio-processing and fermentation technology will open the way to developing a national culture supply, based on our research into dairy cultures and probiotics. Priorities in bio-process development are:

- Develop innovative protein separation technologies (eg molecular sieving and ion-exchange) for isolating unique protein ingredients from indigenous raw materials
- Strengthen our national capabilities in fermentation technology, with a view to producing a range of products, including enzymes for industrial uses, probiotics for incorporation into food products, and metabolites such as flavour compounds for use as food ingredients

# 4 Consumer perceptions

Used effectively, molecular technology has enormous potential to improve the quality of our life and our environment. Communicating the principles, potential benefits, safe application and potential risks of this new technology, however, will be crucial in allowing the public to make informed decisions about the technology.

## 4.1 Transparency and dialogue

An open national dialogue is needed involving various groups in society to address their concerns about the long-term social and ethical aspects of these new developments, and the long-term effects on human health and the environment. The potential benefits to the consumer must be stressed in terms of biotechnology's ability to provide us with food that is safer, healthier, more nutritious and easier to produce.

Worryingly, there is a tendency in some quarters to equate the terms 'biotechnology' and 'genetically modified / GM', and to use them as meaning one and the same thing. It is crucial that the public understand that GM organisms are just one of the approaches used in biotechnology, and that there are numerous other techniques, differing significantly from GM techniques. Furthermore, many of these other biotech techniques are already tried and tested, and well established and widely (the use of biotech-produced chymosin in cheese-making, for example).

Building relationships with the media and securing balanced media coverage are vital aspects of consumer and public education to ensure that this technology will be understood, appreciated and accepted. The real concerns of the public must be addressed, however, through:

- Increased transparency of the risk assessment process
- Public involvement in the debate on the strategic development of this area

## 4.2 Consumer surveys

Recent consumer concern about biotechnology and genetic engineering was fuelled by the arrival of the first genetically-modified plant products on the Irish market. These products were rigorously tested and are safe, but they have little or no consumer benefit. Understanding consumer reactions will be helpful in addressing any mis-conceptions about the technology, and in predicting the future consumer acceptance of particular GM foods

- Given the current apprehensions about GM foods, part of this R&D programme should be devoted to assessing consumer and market attitudes to biotechnology

# 5 Protecting the Environment

The relationship between agriculture and the environment is complex, with many beneficial and benign effects, but also detrimental ones. Intensive animal and crop production systems are known to affect water, air and soil quality, and biodiversity. Biotechnology promises to dramatically improve our agricultural production systems (see: Chapters 6-7), but it will be important to ensure that these developments do not cause any environmental damage. Biotechnology could also help solve some of agriculture's existing environmental problems. This is the context for the priorities outlined below.

## 5.1 Water quality

A major problem is to control water pollution from agricultural sources, particularly the use of phosphorus and nitrogen. This is both an accepted international goal and of major national concern, witness the recent EPA reports on the quality of Irish lakes and rivers. Phosphorus and nitrogen are essential nutrients, but a fine balance must be achieved between providing enough to maximise production, and protecting the environment. Biotechnology can play a significant role in achieving this balance, by enhancing the nutrient efficiencies of plants and animals. Specific research targets are:

- Develop forage crops that are more efficient at absorbing phosphorus from the soil; this would reduce the need to add phosphorus, and in turn reduce phosphorus levels in the soil and the possibility that phosphorous will pollute the water courses
- Develop improved nitrogen-fixing bacteria so that the inputs of inorganic nitrogen can also be reduced

## 5.2 Air quality

This research will be important in helping Ireland to meets its obligations under the Kyoto Agreement for control of gas emissions.

Agriculture is a significant source of greenhouse and acidifying gases. Ruminants are the major agricultural source of methane, the primary greenhouse gas. Recent international agreements commit us to reducing our emissions, and initial targets can probably be met through improved management or other relatively simple approaches. Further reductions will likely be required, however, and for these the use of biotechnology should be investigated, specifically:

- Modifying rumen fermentation to reduce methane emissions from livestock
- Using micro-organisms to reduce ammonia emissions from the storage and land spreading of manure

## 5.3 Manure and waste management

Agriculture and the agri-food industry generate significant quantities of manure and organic wastes, with manure accounting for over 90% of these. Managing these wastes to ensure the nutrients they contain are recycled and do not pollute the surrounding environment is a significant challenge. Land spreading remains the primary management option, but public tolerance of the associated odour is declining. Moreover, there is growing concern about the possibility that manure and waste could spread disease. Biotechnology has an important role to play in addressing some of these issues, and there is scope for Irish firms to establish an expertise in niche areas, such as tackling the waste from dairy processing plants. Priorities include:

- Diet manipulation to improve nutrient absorption by the animal from the feed, would reduce the quantities excreted. For example, plants with improved phosphorus availability would be beneficial in intensive pig and poultry rearing, as their use would lower the nutrient content of the manure and therefore the build up of nutrients in the soil
- Optimising energy recovery from manure and organic wastes
- Reducing odour emissions using diet manipulation and biological treatments
- Improving nutrient availability for crop production
- Reducing harmful pathogen levels in wastes
- Developing biosensors to rapidly determine nutrient levels in manure and wastes (this will help ensure the best subsequent use of these for plant growth)
- Develop sensors to establish pathogen levels in manure and organic wastes

## 5.4 Soil quality

Soil, the basic medium for food and fibre production, is also a multi-functional system that detoxifies many of the wastes we produce (organic waste is processed by degradation and inorganic by chemical fixation). Soils can become polluted through aerial contamination, land spreading or other disposal, or industrial accident. Pollution endangers the soil's potential for clean food production and represents the loss of a natural resource and amenity. Biotechnology offers significant potential to detect, monitor and rehabilitate polluted soils using plants and microbial agents. Priorities are:

- Develop bio-remediation techniques to rehabilitate polluted soils
- Study the relevant soil microbes and microbial processes

## 5.5 Biodiversity

It is essential that any biotechnology application used in Irish agriculture be environmentally safe. This concern relates in particular to the potential for gene transfer from genetically modified organisms (GMOs) to natural ecosystems (plants, animals and microbes). To prevent this we need effective procedures for testing and monitoring the impact of biocides and GMOs. Research priorities include:

- Assess the environmental impact of GM crops
- Investigate the safety and implications of feeding GM products to farm animals
- Develop fast and cheap biosensors to monitor, analyse and evaluate water, air, waste and soil systems

# 6 Animal health and sustainable production

Animal production underpins much of Ireland's agri-food sector, in particular our sizeable dairy and beef industries. Consequently animal welfare, health and production efficiency are nationally important concerns. New biotech procedures and techniques will enable us to dramatically improve our ability to detect, treat and prevent diseases, and also improve the efficiency and genetic merit of our national herds.

## 6.1 Disease management

Infectious diseases have major implications for animal welfare and production efficiency, human health, and food safety and quality. The increasing incidence of diseases such as BSE, TB and brucellosis in cattle has raised considerable concern, both for animal welfare and because of the possibility of infected foods. Mastitis, the most persistent disease in cows, deserves particular attention as it directly impinges on milk quality. Currently, diseases are controlled mainly with vaccines or drugs, but the emergence of antibiotic- and drug-resistant pathogens means disease will continue to be a problem. Moreover, the use of antibiotics will become ever more severely restricted in the future, posing a major challenge for disease management.

Biotechnology should enable us to develop new and improved vaccines for disease prevention. Vaccines have many advantages over drug-based approaches: they are preventive; are cheap and effective; reduce the need to use chemicals and antibiotics (and so avoid the problem of residues); and minimise the risk of resistance developing. Moreover, it is believed that the risks associated with DNA-based vaccines are far less than those associated with conventional vaccines, which use part or all of the pathogenic organism. Not surprisingly, the world market for veterinary vaccines is growing and in Europe is expected to top ? 3 billion by 2007, with biotech vaccines accounting for 50% of the total. There is therefore tremendous commercial potential for effective biotech vaccines. Irish vaccine research is well underway, and BioResearch Ireland for example, has already developed some six biotech animal vaccines. Research priorities are to develop:

- New vaccines to control the major animal diseases affecting Irish agriculture
- Rapid and sensitive diagnostic tests (DNA- and antibody-based)for new and existing infectious diseases in farm animals, and capable of early detection of sub-clinical disease
- Molecular-based typing of pathogens (akin to 'genetic fingerprinting') to monitor the spread of disease within and between herds and trace the disease source
- Genetic analysis of animal pathogens, particularly those causing mastitis and those harbouring multiple antibiotic resistance; this will improve our understanding of the factors which cause disease and how best to control it (including the use of anti-microbial peptides as an alternative to antibiotics)
- The use of probiotic bacteria in disease prevention, including the use of unusual fermentable substrates which promote the growth of beneficial organisms in the animal's intestine (prebiotics)

## 6.2 Disease resistance genes

An individual's genetic make-up is important in determining their susceptibility to disease. Thus, one long-term approach to disease management is to select animals with the best gene mix for disease resistance. New gene mapping techniques are greatly improving our knowledge of which genes are important in disease resistance and susceptibility, and this information can now be used to assist breeders to identify the animals from which to breed the next generation. Genetically pin-pointing or finger-printing the desired type of individual means selective breeding can now become faster and more precise. (This new approach to conventional breeding is known as *marker-assisted* breeding, and is radically different to, and should not be confused with, the creation of genetically modified organisms.) If this approach is incorporated in national breeding programmes it should greatly improve the disease resistance in our national herds. Priorities are:

- Identify the genetic and cellular basis of disease susceptibility and resistance in farm animals for the major diseases affecting Irish agriculture
- Investigate the immunological, molecular and cellular events involved in animal response to disease, in order to identify targets for new diagnostic tests and vaccines
- Identify the key genes that confer a high degree of disease resistance on animals so as to reduce the use of antibiotics in animal production (for example, the lysozyme gene appears to be associated with resistance to mastitis)

## 6.3 Reproductive biotechnology

Animal reproductive biotechnology underpins the 'new genetics', and improving fertility rates will be central to solving the major production and efficiency bottlenecks in the national dairy and beef herds. Genetic improvement in the national dairy herd has already significantly increased the volume of milk produced per cow, but unfortunately this comes with reduced fertility, notably it seems by affecting embryo survival rate. Biotechnology offers a powerful new approach to improve our understanding of the many mechanisms (endocrine, physiological and genetic) involved in embryo loss. This information will be essential in developing strategies to counter embryo loss and enhance cow fertility.

There is tremendous variation in the quality and genetic status of the national beef herd. This could be overcome by more widespread use of superior genetics, notably artificial insemination (AI) with semen from high merit bulls. This is hard to implement, however, because of the difficulty observing oestrus (or 'heat detection'), crucial to timing an insemination, in suckler cows which are less closely watched than dairy cows. Biotechnology offers new approaches to developing effective automated heat detection methods for use in suckler herds.

Finally, sexing of sperm is a long-standing goal of the dairy and beef industries. Separating sperm into X (female) and Y (male) fractions would dramatically improve the efficiency of milk and meat production. Current separation procedures are slow, however, and require expensive equipment and skilled operators. A successful technique would have a world-wide market. Farm animal reproductive research must therefore focus on:

- Qualitative and quantitative determination of the genetic and biochemical aspects of embryo formation, development and viability, and how these are affected by nutrition, production and genetic make-up
- Adapting industrial advances in micro-chip, biosensor and telecommunication applications, together with endocrine and behavioural measurements, to develop an efficient oestrous detection system for Irish beef suckler herds

- Using new biotech approaches to develop a more practical and cost-effective approach to sperm sexing in cattle

## 6.4 Genome analysis for animal improvement

Genome mapping of farm animal species is proceeding apace, and at the current rate complete sequences for the major species should be available within 5-10 years. The focus will then be on identifying the key genes and the other genetic and molecular 'markers' associated with economically important traits such as growth, meat tenderness and flavour in beef; fat and protein synthesis in the mammary gland, and milk composition in dairy cows; ovulation rate in sheep and pigs; and disease resistance and susceptibility. (Functional genomics using miniaturised technologies such as hybridisation micro-assays or DNA chips should prove particularly useful in this regard.)

A major challenge will be to incorporate this new molecular information into conventional animal breeding programmes. Marker-assisted selection, which uses biotech tests to identify the individuals with the desired genetic make-up so that they can be used to breed the next generation, will greatly improve the speed, accuracy and efficiency of breeding programmes, and should for example result in cattle capable of producing more and better quality milk, and leaner, more nutritious meat. Already, scientists have identified specific genes for enzymes which, for example, reduce the levels of undesirable saturated fatty acids in milk and meat. Genome research for animal improvement will therefore focus on:

- Understanding the genetics and biochemistry underlying important production traits, such as meat and milk composition and quality, so as to enhance production efficiency and provide a safe, wholesome product for the consumer
- Identifying which genes are important in animal performance

# 7 Crop diseases and sustainable production

The future for plant biotechnology is bright. The first complete genetic map of a plant species will be available later this year for Arabidopsis, a member of the mustard family that is widely used in plant research. The genome map of its 20,000 genes will be followed in 2003 by the complete DNA sequence of rice, the most important cereal crop on the planet. The DNA sequences of other commercially important plant species (wheat, oil seed rape, potato, grasses, etc) are also being mapped. These developments have spawned several new techniques (collectively referred to as genomics) aimed at understanding the complex function of genes and their role in development, growth and productivity.

The genomics revolution is at an early phase, and to date most of the international research effort focused on the medical and pharmaceutical applications. The greatest global impact of genomics, however, will result from manipulating the DNA of plants, and ultimately genetically improved vegetation and trees will provide the world with most of its food, fuel, fibre, chemical feedstocks, and even drugs. Conventional breeding methods have made slow but steady progress in genetically improving plants. Now, universities, research institutions and companies throughout the country are starting major biotechnological initiatives to identify the specific genes that code for desirable production and disease resistance characters. This should lead to significant advances and enable us to create low-input systems and to produce varieties breed for specific purposes and for the Irish conditions.

These advances should prove useful across a wide range of areas, but perhaps most important in the Irish context is grass growing, as this accounts for over 90% of Irish agricultural land, and supports over 7 million cattle and 5 million sheep. Other areas that can expect to benefit from biotechnology include cereals, forage crops, fruit and vegetable production, forestry and horticulture.

## 7.1 Low-input production

Techniques that lower our use of agricultural chemicals will help minimise the environmental risks, and enable us to produce food that is safer, more nutritious, longer lasting and hopefully, less costly. The primary target species are: grass (which is of general national importance), the main cereal and forage crops, and important commercial species including potatoes and sugar beet. Priorities for research are:

- Use biotechnology to maximise grass growth rate, length of growing season and digestibility; as cereals and grasses share many genes, comparative mapping should be possible to elucidate such traits
- To lower or eliminate the use of chemicals to treat plant pests and diseases, by using a combination of conventional breeding for resistance factors, and by developing GM crops with traits that reduce / eliminate the need for pesticides
- Develop new varieties, especially potatoes, cereals and sugar beet, adapted to the Irish production environment (soils, climate, conditions)
- Develop new and improved biological pest control systems (such as the nematode worms currently used to control weevil infestation in mushrooms)
- Design integrated pest and disease management systems to reduce the use of chemicals

## 7.2 Genetic markers for plant improvement

Thanks to the various genome mapping projects, many key agronomic plant genes can now be identified, as can the genetic 'markers' associated with important traits. This information makes it possible to use marker-assisted selection as a powerful new adjunct to traditional breeding methods. Long-term aims include producing new and improved plant varieties with better nutritional content (added vitamins and minerals, for example), or higher yield, improved pest or disease resistance, or lower levels of toxins (such as the glycoalkaloids found in potatoes). The following areas using marker-assisted selection and related techniques, have been identified as priorities:

- Improve the disease resistance of our most important crop species (eg by identifying markers associated with resistance to *Septoria*)
- Develop superior animal feed crops (eg forage species with improved nutritional content and digestibility); this should significantly benefit animal health, welfare and productivity
- Select for better adapted beneficial organisms, such as those used in integrated pest and disease management systems for the main crops grown in Ireland.

# Appendix

***Members of the Agriculture and Food Biotechnology Group***

This report was compiled by the Agriculture and Food Biotechnology Group

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The views of other colleagues in various organisations were also sought when compiling this report.