Future foods, future needs: The challenges for science

Mike Boland
Riddet Institute, Massey University, Palmerston North

Food production, processing and distribution today are not meeting the world's needs and must do better. Science today has some of the answers and at least understands most of the questions. There are a lot of new opportunities, but much needs to be done.

Not enough food

How are we going to feed the world? The Food and Agriculture Organization (FAO 2010) estimates that 1.02 billion people were undernourished worldwide in 2009:

> *There are more hungry people than at any time since 1970, the earliest year for which comparable statistics are available. Hunger has increased not as a result of poor harvests but because of high domestic food prices, lower incomes and increasing unemployment due to the global economic crisis. Many poor people cannot afford to buy the food they need.*

This figure from FAO only takes into account energy (i.e. calories). There is a further problem concerning protein nutrition that is not well understood: while some people have enough calories, they do not have enough protein, or enough quality of protein. Others consume protein to excess. At the Riddet Institute we have begun some work together with the FAO in Rome to try to understand the size and scope of this problem.

The nutrition problem is getting worse, rather than improving (Figure 1). World production today could meet all needs today, but distribution of wealth and resources, and political interference are preventing it.

There is a trade-off between land use, energy, water and food, and intensive food production is needed to feed the world (Figure 2).

> ***Energy***: Intensive food production requires use of fertilisers and irrigation as well as mechanisation of farming processes. All these require a lot of energy, usually from fossil fuels. The recent attempt to solve the sustainable energy problem with biofuels resulted in a reduction in food production and

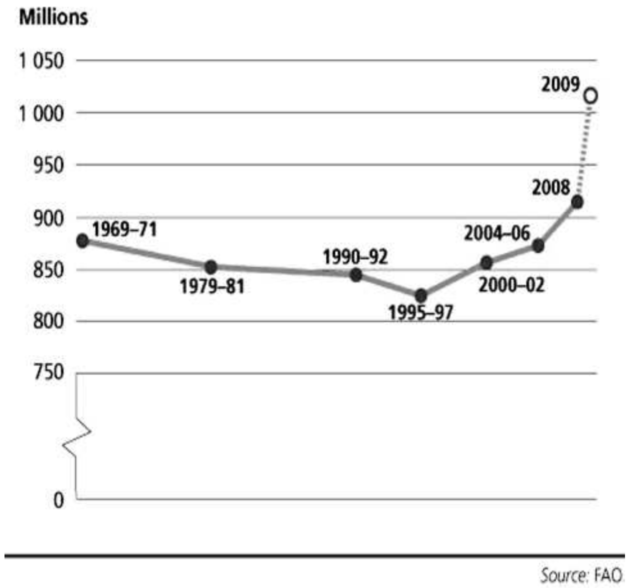

Figure 1. Number of undernourished in the world, 1969–71 to 2009 (FAO 2010).

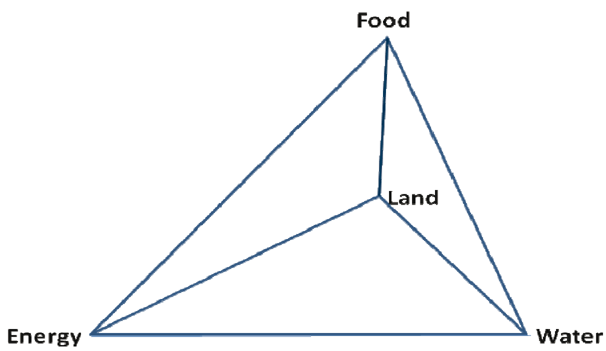

Figure 2. Tensions between water, energy, land, and food.

Mike Boland is a Principal Scientist and Associate Investigator at the Riddet Institute, Palmerston North. Dr Boland has 40 years' experience in scientific research, research management, research outsourcing and technology planning. Before joining the Riddet Institute, he worked in Fonterra R&D for many years in senior positions. He may be contacted at mikeb@xtra.co.nz

exacerbated the food supply problem. Fertiliser production, particularly of nitrogenous fertilisers, needs a lot of energy.

Water: Irrigation requires energy for distribution (and for desalination in some cases). Conversely, use of water for hydro-power generation can make water unavailable for irrigation. New Zealand is relatively unsophisticated in the management of water because we are blessed with adequate water in most areas.

Land: Loss of land due to population growth (urbanisation), desertification and salination are reducing available area. Retention of rainforest for ecological reasons means new land is not being brought in.

Some key facts

World population is expected to be 9.2 billion by 2050. Estimates of about 9 billion are fairly firm and generally accepted. This will require a doubling of present food production (FAO 2010).

It requires about 0.5 (± 0.3) ha cropland to feed a person. This land estimate is based on an East Coast US diet. Variation is due to animal content and fat content, with convergence of all diets at higher fat (Peters *et al*. 2007). The current world agricultural area is of the order of 4 billion ha (FAO 2010) – enough to feed 8 billion if intensively farmed.

Water is required for all food production; 1 kg of grain requires about 1000 L water, and 1 kg beef requires 43 000 L water (water values based on US figures, Pimentel *et al*. 2004).

New Zealand is a major global exporter of water and exports more water equivalence in livestock products than any other country except Australia (Table 1). Trade in water-intensive food products is very important in the developed world and a major source of competitive advantage for New Zealand. What will be the effect of climate change on the water supply for New Zealand and for other food-producing countries?

Challenges to science

Grow more food sustainably

Growing more food and doing so sustainably will require some or all of:

- More land/better use of land.
- More fertiliser/better use of fertiliser.
- Precision agriculture to minimise waste.
- Control of losses: denitrification in soils; methane production in soil and in ruminants.
- Irrigation – better management of water. Manage the weather? Samuel Clemens (Mark Twain) is reputed to have said more than 100 years ago, ‘Everybody talks about the weather, but nobody does anything about it’. Nothing has changed. The vagaries of the weather cause major losses through droughts and floods. We still don’t understand enough to alter the weather. Chaos theory provided some important insights, but not enough to be effective.
- More efficient plants, including drought-resistant plants – use of existing species and development of new cultivars.
- More efficient animals.
- Crop-based replacements for animal products.

Table 1. Livestock virtual water exports and imports (Gm³) (1995–99 – all countries) (data from Chapagain & Hoekstra 2003).

Country	Export	Place	Country	Import	Place
Australia	146	1	Japan	112	1
New Zealand	71	2	Italy	93	2
USA	62	3	Hong Kong	46	3
Canada	48	4	Russian Fed	39	4
Argentina	33	5	Korea Rep.	35	5
Ireland	31	6	Taiwan	29	6
Denmark	28	7	UK	20	7
Netherlands	24	8	Indonesia	15	8
Uruguay	23	9	Mexico	14	9
France	22	10	Philippines	14	10

Grow food that does more

We need to produce food with a better nutritional balance:

- plant protein more like animal protein (balance of essential amino acids);
- protein/energy balance;
- micronutrient accumulators.

We need food with better keeping properties (less waste), with resistance to spoilage and pathogens, and retention of nutritional values during storage and processing.

Many staple crops have antinutritional factors and toxins that can affect nutrition and require processing to remove or destroy them. Removal of phytotoxins and antinutritional factors (i.e. develop cultivars that don’t make them) would increase food value.

Better bioavailability will increase nutritional value. Work done at the Riddet Institute on the rate of digestion of starch from navy beans (used in baked beans) as autoclaved beans (as a paste), bean flour and bean starch (Figure 3) shows rapid starch hydrolysis for pure starch and bean flour, but slower hydrolysis to a lower maximum value for autoclaved bean paste. The natural structure in beans causes slow release of energy (available glucose), which is good, but only about two-thirds of available

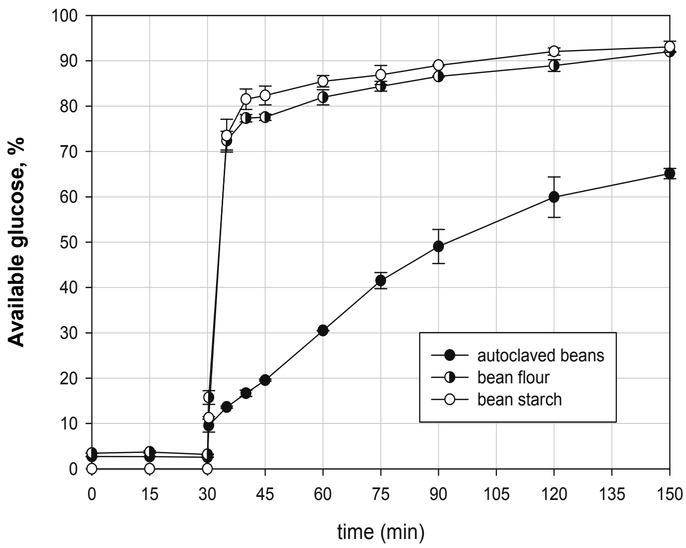

Figure 3. Bioavailability of starch from navy beans (Berg 2010).

energy becomes bioavailable. Different processing could have the same nutritional effect as a 50% increase in intake.

Challenges for science and society

Acceptance of genetically modified crops

Genetic modification offers the potential to improve crop attributes such as salt tolerance, drought tolerance, pest resistance, keeping qualities, nutritional balance (e.g. 'golden rice', genetically modified to biosynthesise provitamin A in the endosperm), and absence of toxic phytochemicals.

Nitrogen fixation

Biological nitrogen fixation can go a long way to offsetting the high energy cost of fertiliser. However, only legumes and a few commensal systems can fix nitrogen. In the New Zealand pasture model, nitrogen is fixed by clover. It is only by animal intervention – the animal eats the clover and then urinates – that nitrogen is transferred to other plants. The dream of getting nitrogen-fixing cereals and grasses has been around for more than 50 years – but we are no closer today than ever to achieving it.

Not the right food

There is a major malnutrition problem with populations where the availability of food is not an issue. However, the wrong sort and amount of food is being consumed.

Metabolic syndrome

The metabolic syndrome is a combination of overweight, cardiovascular disease, hypertension, and diabetes. It is a global problem, not just in western societies, e.g. it is becoming prevalent in China. It is a result of not only too much food, but also the wrong food. Substituting carbohydrate for fat has promoted obesity. High-fructose corn syrup has been implicated, but the mechanism and extent of effect is unclear. Rapid release of sugars, e.g. from processed foods, causes undesirable metabolic responses and lack of satiety response, whereas slow release of sugar is more natural and satisfying.

What is needed is a better understanding of food–energy balance in the body, and new understanding of the mechanisms of satiety.

Micronutrient malnutrititon

More than 2 billion people in the world today may be affected by micronutrient malnutrition of various kinds, the most prominent being (FAO 1997): iodine – 600 million affected, 1.6 billion at risk; iron – 2.1 billion affected; vitamin A – 2.8 million affected, 250 million at risk.

In the case of iodine nutrition, 14 countries in the world suffer from moderate (20–49 μg/L) to severe (<20 μg/L) iodine deficiency, and New Zealand is among 40 countries suffering from mild (50–99 μg/L) iodine deficiency (de Benoist *et al*. 2004).

Goitre has been a traditional problem in New Zealand. Iodised salt was introduced in 1939 and by the 1950s iodine deficiency was almost nonexistent in New Zealand. In a study reported by Skeaff *et al*. (2002), the iodine status of three hundred 8- to10-year-old schoolchildren in Dunedin and Wellington was measured in 1996 and 1997. It was found that 3.6% had urinary iodine levels less than 20 μg/L (severe), 31% less than 50 μg/L (moderate), and 80% less than 100 μg/L (mild iodine deficiency), respectively. An incidence of goitre greater than 5% is considered endemic, and 11.3% of the children had thyroid volumes greater than the upper limit of normal. Likely reasons for this decline in health are: a move from home-made to commercially manufactured foods; a move away from iodised salt in the home; and removal of iodophors (which left traces of iodine in dairy products) in the dairy industry.

Not the best food

Food for health and wellness

A report outlining the expected future of functional foods in the USA was developed for Coca-Cola, but has been publicly released by both Coca-Cola and the Institute for the Future (Distler *et al.* 2008). The leading prediction, based on extensive survey and analysis was:

> *Wellness goes mainstream: Consumers are recognising wellness as a dimension beyond 'not sick' to include overall physical, mental and spiritual wellbeing. The concept of healthy food is moving beyond niche.*

Functional food

> *A food can be regarded as functional if it has beneficial effects on target functions in the body* ***beyond nutritional effects*** *in a way that is relevant to health and well-being and/or the reduction of disease* (Diplock *et al.* 1999).

The global functional foods business is estimated to be worth US$50 billion and growing by 8–10% per annum. There is an opportunity for New Zealand to develop, prove and sell high-value specialised functional ingredients. However, there are new claims of functional foods every week, and there are legislative issues around them. An important future development will be more stringency around functional claims. This will lead to greater consumer confidence, but will also place a greater burden on food manufacturers.

As an example, the omega-3 long-chain polyunsaturated fatty acids are an important class of functional food ingredients. In particular, eicosapentaenoic acid, commonly known as EPA, and docosahexaenoic acid, commonly known as DHA, are important for good health. Both EPA and DHA come mainly from marine foods, typically fish oils. These fatty acids have been implicated in cardiovascular and brain health, although some results are still controversial.

Personalised nutrition – Nutrition information gets customised

With the expansion of knowledge about individual genetics and epigenetics, increased information about specific benefits of particular foods and an increasing awareness of personalised health, consumers will require a more personalised nutritional message and balance in their food (i.e. personalised nutrition).

Mass customisation will be an important approach towards personalised nutrition. The POSIFoods project (Point Of Sale Individualised Foods), a joint project of Riddet with Fonterra and BASF, was an early attempt at this (Boland *et al*. 2005, Boland 2008), and may point the way to future developments. Personal preferences and circumstances, and 'i-power' will also drive the demand for personalised nutrition.

Some emerging science

Designing structured foods for health

Bioavailability

Bioavailability is about two things:

(1) Getting all of the nutritional benefit from the food (e.g. navy bean starch mentioned earlier).

(2) Rate of release – important for managing satiety and obesity.

Foods produced by Nature are organised hierarchically from molecules and assemblies into cells and tissues. Fibrous structures, fleshy materials, encapsulated embryos and complex fluids provide textures, sensory qualities and nutrients, and they regulate the rate of nutrient delivery and metabolic responses. A spike of nutrient in the digestive system is usually not good: steady release over a period is better and more reflects the effect of natural foods.

> *All foods pass through a common unit operation, the GI [gastro-intestinal] tract, yet it is the least studied and least understood of all of the food processes.* (Norton *et al.* 2006)

Understanding the mechanisms and kinetics of the digestive system in response to the foods we eat is the most important aspect of food science today. In particular an understanding of kinetics of nutrient release will be important.

Nanostructures

Nanotechnology is an important emerging area of technology. Natural foods have naturally occurring nanostructures. These can be mimicked to manage nutrition, controlled delivery of nutrients, and protection of vulnerable components.

The casein micelle (Figure 4) is a naturally occurring nanostructure that allows 'packaging' of dense nutritional protein and calcium at a level far higher than its natural solubility. Nanostructures are often deconstructed during processing. Smart food manufacture of the future will be able to make new structures at all scales to create new nutritional and functional value.

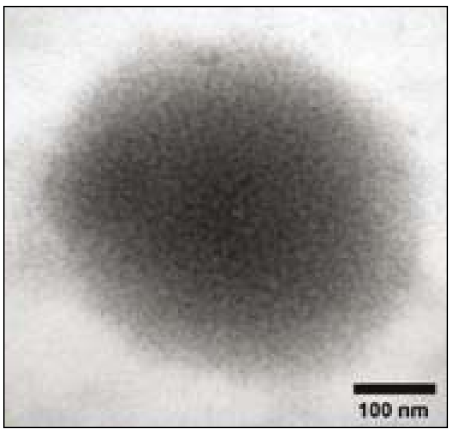

Figure 4. Casein micelle (McMahon 2010).

An example of use of nanostructures to deliver high-quality omega-3 oils is a patented process involving emulsification of fish oil, using a complex protein mixture as a surfactant. The protein mixture forms a thick, complex mixed protein interfacial layer that stabilises the oil droplets. The protein layer also has anti-oxidant properties, thus protecting the polyunsaturated fat from oxidation. Additional unadsorbed protein binds iron, giving additional protection from oxidation (Singh *et al*. 2005).

Food synergy

Nutrition has until recently been considered as the sum of nutrients ingested. It is now clear that relationships between nutrients (and other food components) are just as important. Food synergy looks at the interactions between food components: within a food or food ingredient; in a meal; and even between meals that are close together. We don't eat foods singly or even by single sector. Despite this, much food research is carried out and funded by sector. We eat meals that typically contain a range of manufactured and whole foods, and from a range of production sectors. The interactions between these components in the digestive system are important and just beginning to be understood.

For example, eating kiwifruit with other food changes digestion. Kiwifruit contain an enzyme called actinidin that aids in digestion. When food proteins are consumed together with kiwifruit, digestion in the stomach is enhanced (Figure 5). These proteins will eventually be totally digested in the small intestine, but digestion in the stomach changes the stage and rate of delivery of nutrients during the complete process. It may also affect the generation of peptides with functional food properties.

Conclusion

New initiatives will be needed to feed the world by 2050. These will include novel crops, less waste in the food chain, replacements for animal-based foods, precision planning and cropping to give balanced production for balanced global nutrition.

Better food offers better quality of life for the developed world. This will be achieved through:

- functional foods improving health, wellness and beauty
- protection and delivery of nutrition through nanotechnology
- food synergy achieved by managing the meals we eat, and
- personalised nutrition for better health.

There are important new opportunities for food, based on new knowledge. New Zealand is an important net producer of

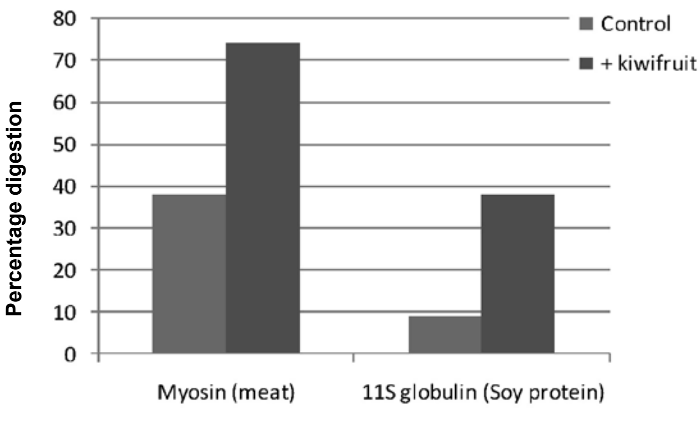

Figure 5. Effect of consumption of kiwifruit on % digestion of food proteins in the stomach.

food, particularly of protein. To address future food production needs, we must engage vigorously in the development of new knowledge. This will require a strong base of agri-food research, development and education to position ourselves as a world leader in knowledge-based food production. This will require collaboration locally and globally. The Riddet Institute is an important linkage between the main food research groups in New Zealand, and offers the breadth of disciplines and critical mass to take advantage of these opportunities. It has important global networks in food science, in particular with the University of Wageningen and Wageningen UR through a recent bilateral agreement, and through the International Food Research Collaboration – a collaboration between New Zealand, Australia, the AFMNet in Canada, and the EU.

References

Boland, M. 2008. Innovation in the food industry: Personalised nutrition and mass customisation. *Food Related Innovation: Technology, Genetics and Consumer Impacts 10*: 53–60.

Boland, M.J.; Munro, P.A.; Haylock, S.J.; James, A.D.L.; Thompson, A.K.; Archer, R.H. 2005. POSIFoods: dairy products and process. Patent PCT/NZ2005/000099.

Benoist, B. de; Andersson, M.; Egli, I.; Takkouche, B.; Allen, H. 2004. *Iodine status worldwide. WHO Global Database on Iodine Deficiency.* World Health Organization, Geneva. ISBN 92 4 159200 1

Berg, T. MSc Thesis, Technical University of Berlin.

Chapagain, A.K.; Hoekstra, A.Y. 2003. Virtual water trade: A quantification of virtual water flows between nations in relation to international trade of livestock and livestock products. Pp 49–76 in Hoekstra, A.Y. (Ed.) *Virtual Water Trade. Proceedings of the International Expert Meeting on Virtual Water Trade*. Unesco-IHE, Delft.

Diplock, A.T.; Aggett, P.J.; Ashwell, M.; Bornet, F.; Fern, E.B.; Roberfroid, M.B. 1999. Scientific concepts of functional foods in Europe: Consensus document. *British Journal of Nutrition 81*: S1–S27.

Distler, V.; Falcon, R.; Keeler, C.L.; Kiernan, P.; Lueck, M. 2008. The Future of Health and Wellness in Food Retailing. Institute for the Future, Stanford.

FAO 1997. Preventing Micronutrient Malnutrition: A guide to food-based approaches. Why policy makers should give priority to food-based strategies. FAO, Rome. http://www.fao.org/documents/pub_dett.asp?pub_id=18770&lang=en

FAO 2010. Hunger: Hunger statistics. http://www.fao.org/hunger/en/

McMahon, D. 2010. Donald McMahon Research interests. College of Agriculture, Nutrition, Dietetics and Food Sciences, Utah State University. http://ndfs.usu.edu/htm/research/donald-mcmahon

Norton, I.; Fryer, P.; Moore, S. 2006. Product/Process integration in food manufacture: Engineering sustained health. *AIChE Journal 52*: 1632–1640.

Peters, C.J.; Wilkins, J.L.; Fick, G.W. 2007. Testing a complete-diet model for estimating the land resource requirements of food consumption and agricultural carrying capacity: The New York State example. *Renewable Agriculture & Food Systems 22*: 145–153.

Pimentel, D.; Berger, B.; Filberto, D.; Newton, M.; Wolfe, B.; Karabinakis, E.; Clark, S.; Poon, E.; Abbett, E.; Nandagopal, S. 2004. Water resources: Agricultural and environmental issues. *BioScience 54*: 909–918.

Singh, H.; Zhu, X.; Ye, M. 2005. Lipid Encapsulation. Patents WO2006 115420, EP1876905.

Skeaff, S.A.; Thomson, C.D.; Gibson, R.S. 2002. Milk iodine deficiency in a sample of New Zealand schoolchildren. *European Journal of Clinical nutrition 56*: 1169–1175