THE IMPORTANCE OF TECHNOLOGY

Professor Colin Dennis CBE DL
Director-General, Campden BRI

We live in a time of great social, economic and technological change. While close to one billion people suffer from hunger or undernutrition and another 2 billion exist on the borderline of barely acceptable nutrition, the potential for dramatically improving the economic status and food situation of developing countries has never been greater. Our track record of agricultural output has weaned us away from the Malthusian view of limits to growth but, given the finite nature of a planet, has also cautioned us on the necessity to pursue technologies and systems that are sustainable.

Global phenomena such as climate change must be continually monitored as it may benefit some countries while dramatically damaging others with respect to agricultural production and sustainable existence.

The ability of the agricultural and food industries to respond to the substantial increase in demand for food over the coming years will be highly dependent on the increased application of existing technologies as well as exploitation of new and innovative technologies. The increased demand for food will emanate both from the predicted population growth but perhaps even more importantly from the broad based economic development in low income countries and the associated dietary changes which will result. Food demand could be as much as double the current requirement by 2050. The need for technological development and exploitation is further emphasised by the fact that the world's arable land and fresh water are not distributed around the world in the same proportions as is the population and in any case both land and water will be a constraint on future food production.

The drivers for technological development are many and varied, including social, economic, political and environmental aspects as well as the push which will come from the advances in scientific research and development. The nature and intensity of these drivers vary, depending on the country and region.

Consumer attitudes and beliefs are essentially influenced by the degree of availability, accessibility and affordability of foods. These differ markedly between developed economies and that situation which exists in many developing countries. Countries whose economies allow consumers to think beyond the cost of food often incorporate social, ethical and environmental dimensions in their choices.

With the increased demand for food and the competing demands for raw materials (eg fuel versus food) it is estimated that the cost of agricultural commodities in the next decades will be 20-50% above the last 10 year average. This will provide a challenge for economies where food represents a significant share of their import payments.

Feeding the expanding number of urban populations will increasingly rely on the development of organised processed food industries and associated supply chains. This view has been reinforced by Dr Yumkella, the Director-General of United Nations Industrial Development Organization who commented earlier this year *"At UNIDO we are convinced that long term poverty reduction can only be achieved through private wealth creation based on industrial development, particularly manufacturing and agro-industrial processing propelled by vibrant entrepreneurship. This implies diversification into higher value products leading to successful domestic and foreign trade. This is why capacity building is one of our priorities".*

Reduced trading barriers in some countries tend to open the way to much longer

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distribution chains, requiring products that will maintain safe hygienic quality for longer periods and will meet all the sanitary and phytosanitary (SPS) needs of importing countries. The traditional technologies of heat treatment will be supplemented by cold processing methods such as ultra high pressure processing and ionizing radiation both of which are capable of producing products of the highest quality.

The international movement of goods will require significantly greater attention to food safety. Non-invasive technologies and sensors to monitor the quality of foods in- or at-line will increasingly replace current time consuming off-line laboratory techniques. While the SPS and Technical Barriers to Trade Agreements are predicated upon science-based international standards, individual countries may opt for differing levels of protection depending on their parochial requirements. However, because so many goods will be entering the flows of international trade, harmonisation of science based safety standards is likely to take place. This will have a profound impact upon food production and processing policies and practices as well as on the technical and managerial training required to carry them out.

Public policies relating to diet, health and nutrition will also drive the need for technological development.

An understanding of the bioavailability of functional components such as vitamins, antioxidants as influenced by diet, food structure and processing is also fundamental. Our concept of nutrition and the impact of technologies may change as we learn more about the fate of food components after ingestion. Nano- and microtechnologies have the potential for protecting and delivering nutrients with greater efficiency.

The acceptance of the need to preserve natural resources and optimise the use of all kinds of inputs will increasingly focus attention towards sustainability and technologies which can assist in preserving the environment as well as delivering social and economic sustainability.

Issues of sustainability apply along the whole food supply chain from agricultural production through ingredients, product and packaging manufacture to storage and distribution via wholesale, retail or food service outlets. More objective data from relevant life cycle analyses are required to evaluate properly the contribution which different components make to the carbon footprint of food supply chains.

The exciting developments in many scientific disciplines particularly molecular biology, genomics, nutrition and human physiology and psychology, bioinformatics, nanoscience, plant, animal, environmental, material and computer sciences, will continue to provide enabling technologies for the agri-food sector.

There is little doubt that biotechnology will become a major contributor to future production and processing technologies. The technology will not only be focused upon improving quantitative outputs but will also produce crops which are adapted to a wider range of climatic conditions (drought, salinity, acidity and temperature). In addition crops with higher levels of beneficial nutrients such as antioxidants will also be produced.

The range of technologies will span from those that increase the total quantity of food by diminishing losses and avoiding contamination, to those that make food look and taste natural and fresh, reduce some components such as fat, sugar and salt, and minimise the use of additives. The wealth of existing and developing technologies available, for example for separation and transformation of raw materials, and the processing, preservation and packaging of finished product, must be used to deliver ingredients and final products to customers and consumers which are safe, contribute to health and wellbeing and sustainability, while enabling companies and entrepreneurs to operate competitively within agreed national and international regulatory frameworks. The opportunities available will be enhanced by enabling technologies such as biotechnology and nanotechnology while information technologies will continue to be pivotal for business and the public sector in an increasingly interdependent and interconnected world.

Technologies are not applied in isolation. In general it is required that policies provide an enabling environment for entrepreneurs, create fiscal incentives for innovation, supply the necessary infrastructure for entrepreneurship (including the availability of appropriate training and development) and promote the adequate backward (eg financial support to small and medium enterprises, risk capital, and information about future markets) and forward linkages (eg international promotion, 'national' brand).

Developing countries interested in establishing or strengthening a food export business will have to face institutional changes to oversee all activities in the food production chain and not just agricultural production. Public policies also need to ensure a science and technology system that provides support to the local industry and promotes the entrance of new small and medium entrepreneurs into the business. The formation of interconnected technology clusters where suppliers, food processors, Government Agencies, research providers and trade associations come together to facilitate the innovation process must be encouraged.

All of the above have to be supported by regulatory frameworks and enforcement strategies that protect consumers' interests locally and abroad and assure the highest standards of food safety and hygiene.

With regard to the movement of food, technologies and systems with the ability to support extended distribution chains will become increasingly important. Together with the movement of goods and people, there is a distinct possibility of creating pandemics through the parallel movement of infectious diseases. This makes implementation of internationally harmonised high quality standards imperative.

The rapid expansion of information and communication technologies (ICT) has provided the direct access and connections to promote and sell raw materials, ingredients and food products. For the first time, entrepreneurs in developing countries have a very strong potential to access international markets with an unprecedented degree of independence. However, the potential to capitalise on this will largely be contingent upon the economic policies that are in place. Such policies must provide strong support to the country's entrepreneurial base. When properly implemented, these policies will have the consequent benefit of generating employment, and general economic development from which all will benefit.

Agro-industrial development policy should not add to the risk of entrepreneurs, but encourage the application of sound, proven methods for the production of products. It is important to consider sustainability in context and carefully adjust its significance within the hierarchy of imperatives weighted to achieve rational and successful industrial development. The globalization of the economy has provided entrepreneurs vastly greater markets. In light of these new developments, policies must support entrepreneurial competitiveness in rapidly changing markets.

It is critical that governments send their most qualified people as negotiators to international fora such as the Codex Alimentarius Commission. Although these meetings generally revolve around technical matters such as standards and analysis, consideration must be given to representation by highly trained negotiators and well briefed legal people who understand the long-term significance of standards in trade. The subject of these meetings may be technical, but the consequences are definitely economic.

Thus future food security will be dependent on the more effective adoption of a wide range of existing and new technologies for agricultural production, food processing and storage and distribution supported by developments in ICT. In addition public policies which promote free trade and capacity building in developing economies will be essential.

FOOD SECURITY – IS IT ATTAINABLE?

Professor Chris Lamb FRS, Director, John Innes Centre

The greatest challenges to agriculture over the next 40 years will be to feed the 9.5 billion people that are expected to occupy our planet by 2050. And to find a way to do so that reduces the strain agriculture exerts on the planet.

These challenges seem daunting, but scientists at the John Innes Centre and elsewhere are already addressing them. The UK's plant science institutes are committed to a concerted research effort akin to a wartime effort, co-opting the brightest and the best scientists for a virtual plant breeding institute to drive forward new strategies and technologies to solve major problems.

While the world population is expected to increase by at least 50%, it will require a doubling of grain production to feed, as more people join the middle classes. People in China and other rapidly developing countries are already eating more meat and dairy products and the demand for animal feed is soaring.

Purple tomatoes genetically modified to contain high levels of anthocyanin

WHERE IS THE BREAD BASKET THAT WILL MEET THIS DEMAND?

Prime agricultural land is being lost to erosion, desertification, salinisation and urbanisation. A survey by the Chinese government predicted in November 2008 that harvests could fall by 40 per cent in half a century if soil erosion continues at its current rate.

There is little prospect of any major new cereal producers emerging. Ukraine and Kazakhstan, with their rich dark soil and vast fields of wheat have been the only two to emerge recently onto the world stage.

North West Europe is one of the few politically stable world bread baskets, with some of the highest yielding and best quality crops in the world. Cereals and grasses flourish with cool summers, mild winters and ample rainfall.

Our stability also allows scientific discovery to flourish. The UK could be the global beacon that catalyses how the rest of the world addresses the grand challenge of agriculture's future.

As the director of the John Innes Centre, an international pioneer in understanding plants and microbes, I can see how scientific research might extend the range of what is currently possible and open up possibilities that we have not even yet imagined.

In the 1970s, JIC's work on semi-dwarfing genes contributed to the 'Green Revolution' that saw world wheat yields double. JIC research also led to the first registered 'semi-leafless' pea varieties. Today the entire £38 million annual UK dried pea market consists of these varieties.

There is still much to learn. JIC science now concentrates on three main areas: how plants develop and grow, how they interact with their environment, and how they produce useful products.

HOW PLANTS DEVELOP AND GROW

Stem cells are the source of all growth in both plants and animals. The ultimate source of cells in the root is the 'quiescent centre' – four stem cells that divide infrequently and can produce any type of cell.

From this starting point, plants can make cellulose fibres stronger than steel that enable them to develop their complex architecture. The appealing aesthetic of plants is partly derived from the remarkable uniformity of leaf and flower size that sets each species apart. This uniformity is achieved using a mobile growth signal secreted from cells to reach their allotted size.

Understanding at this kind of atomic level how plants develop and grow will be essential for improving productivity. For example, plants may be rooted to the spot, but we recently discovered that they use long range communication to control flowering. If we could use this knowledge to help breeders develop crops that flower twice, we could immediately halve all the energy use involved in tilling for just one harvest.

Today, wheat provides more nourishment for more people worldwide than any other crop. British farmers grow roughly 16 million tons of wheat every year and export 5-6 million tons making it our biggest crop export. The high fertility of wheat is derived from the stability of its genome and our scientists discovered the stretch of DNA, the *Ph1* locus, that affords this stability.

The stability of the wheat genome has a downside, as it is a barrier to introducing new traits from wild relatives. There are many traits that would be useful for enhancing yields and reducing carbon use, such as tolerances to drought, salinity and disease resistance. Our ultimate goal in studying the *Ph1* locus is to switch off its activity to allow related chromosomes to pair in wheat hybrids, then switch it back on to restore fertility.

Our work should also further enhance the breeding process through breakthroughs on perenniality and hybrid wheat.

HOW PLANTS INTERACT WITH THEIR ENVIRONMENT

The cue that stimulates cell division in the quiescent centre is ethylene. The hormone perceives when environmental conditions are favourable for growth and communicates a signal to stem cells to start dividing.

Many plants are dependent on subtle cues from the environment to survive. For example, we discovered that in order to flower at the right time, many plants must experience a period of cold to trigger a process called vernalisation. If it doesn't get cold enough, flowering is delayed or may not happen at all. Some of the plants that need to be vernalised are important food species such as sugar beet and wheat.

Since 1818, the arrival of spring in Geneva has been marked by the first bud that appears on the official chesnut tree in the city's Old Town. In 2005 it burst into unexpected bloom in late October following a balmy autumn. Similar unprecedented events are the manifestation of climate change. By understanding processes such as vernalisation and by using advanced breeding techniques to increase plants' resistance to stress, we can help them adapt to longer growing seasons, changes in temperature and water availability, and the arrival of new pests and diseases.

The cellulose fibres of plants provide a major sink for carbon dioxide, but agriculture is also a major contributor to greenhouse gas emissions. The Haber-Bosch process used to produce nitrogen fertilizers is responsible for about half the fossil fuel usage of modern agriculture.

Nearly 80% of the air around us is nitrogen, but only legumes such as clover and beans can use it. Bacteria living in 'nodules' in their roots take nitrogen from the air and 'fix' it into a form the plants can use.

JIC scientists are currently exploring how to engineer rice

Wheat provides nourishment for more people worldwide than any other crop to host these helpful bacteria, which might be achievable using genetic modification. Extending the range of crops able to fix nitrogen would revolutionise the potential for global sustainability by massively reducing the carbon footprint of agriculture.

HOW PLANTS PRODUCE USEFUL PRODUCTS

To help reduce our reliance on petrochemicals, plants can be used as green factories, producing starches, oils and lubricants, drugs, plastics and pharmaceuticals. Improvements could also help to enhance the nutrition they provide.

One aspect of food security is ensuring that food provides all the nutrition we need. In the West where food is abundant, many of us are still not eating the recommended five portions of fruit and vegetables a day to help prevent chronic diseases. The annual cost to the NHS of diet-related disease is estimated to be £20 billion and rising.

Plant pigments called anthocyanins, found at high levels in berries such as blackberry, cranberry and chokeberry, offer protection against certain cancers, cardiovascular disease and age-related degenerative diseases. However, berries are a seasonal fruit, can be expensive to buy and are not adequately represented in the diets of many. We conducted experiments to see whether a more common fruit could be engineered to be high in anythocyanins and have the same health benefits.

Two genes that induce the production of anthocyanins were turned on in tomatoes. This produced our now famous purple tomatoes, with levels of anthocyanins higher than anything previously reported for metabolic engineering. To test the benefits of the purple tomatoes, we fed them to cancer susceptible mice. Their lifespan was significantly expanded compared to mice fed a diet supplemented with normal red tomatoes.

This is an early example of a GMO with a trait that offers a potential benefit for all consumers.

To share our excitement and knowledge of what is possible with leading-edge science, we are training the next generation of scientists both in the UK and abroad, and collaborating with breeders and other research organisations globally.

For example, through the Kirkhouse Trust, two of our scientists designed a course in marker assisted selection for plant breeders in Bangalore. Working with farmers who bring their knowledge of crop production and useful traits, the newly trained plant breeders can help make improvements to the local legume crop. In China we are training scientists in reverse genetics to help them identify the functions of rice genes.

The proposed virtual plant breeding institute would move these efforts up a few gears. One of our former incarnations, the Plant Breeding Institute, was the major vehicle for training wheat breeders in the UK. The last generation of PBI trained breeders are due to retire in the next 10 years with no successors emerging. Breeding companies are no longer taking riskier approaches with long term pay-offs.

Wheat, for example, is close to becoming an orphan crop. Major new genetic variation could be brought in by making wide crosses. A UK effort to improve the germplasm of UK crops would be transferable to other settings and to related developing country crops.

This is just a snapshot of the ways in which we are addressing the global threats to food security. The reality is that given the resources we can help plant breeders and farmers feed and fuel the world with a reduced carbon footprint.

DURING DISCUSSION THE FOLLOWING POINTS WERE RAISED

The reason for creating purple tomatoes containing the antioxidant pigment anthocyanin, which is thought to have anti-cancer properties, was to help by inserting it into a vegetable such as tomatoes that are eaten on a regular basis. It is likely to be much more readily accepted in this form than as a powder used as a food additive.

If we are going to be able to provide for a greatly increasing human population it is transparently obvious to some that there will also be a need to reconsider the animal versus vegetable and grain content of the human diet, especially in view of the competition between human beings on the one hand and farm animals on the other for access to basic feedstocks such as soya and grain.

Converting vegetable and grain feedstocks into expensive meat and dairy produce for human consumption is extremely wasteful of both primary food and increasingly scarce water resources. These can better be used directly and much more efficiently as basic primary resources to feed humankind without passing them through another animal species first, which also involves generating unnecessary greenhouse gas emissions in the process. However there is apparently very great reluctance, for what appear to be short-sighted and possibly commercial market-driven reasons, to go down this road. The currently fashionable and actively promoted high cost animal based protein-rich western diet is gaining an increasing hold in Asia, especially in China. It is ironic that the infinitely sustainable and healthy Chinese diet that is now being replaced is based on 5000 years of agricultural refinement incorporating local recycling of waste products without resort to a dairy industry.

The pressure is on therefore to try to make better use in the future of these increasingly scarce and expensive resources that will be essential for the survival of humanity in the longer term. This will result, for example, in a revolution in Indian agriculture with small family farms disappearing and being replaced by large commercial farming ventures using advanced technology. African farmers are also keen to import new technologies, helped by innovative farmers who act as ambassadors.

Organic agriculture may not be receiving the attention it deserves, possibly as there is currently insufficient organic nitrogen available to feed 9 billion people. Nitrogen fixation by plants would need to be made much more generally available through genetic modification. This will need a new generation of plant breeders to increase global food security using front rank science. However, good applicants are very scarce. A teaching opportunity has been missed to incorporate food and agriculture together with waste management in general education.

The Green Revolution produced crops in Africa that are lower in mineral nutrients resulting in a more restrictive diet which is unrelated to soil condition, and maintaining a healthy diet is very important.