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Novel Food Production

Food production systems worldwide may have to adapt radically to meet the rising global demand for food. Emerging approaches in the food sector include controlled-environment farming, alternative animal feeds, edible insects, and lab-cultured meat. This POSTnote considers these new technologies and summarises their respective advantages and limitations.

Overview

- Agricultural innovation could contribute to a more sustainable food system.
- Controlled-environment farming can increase the yield of some crops and decrease resource use, but is not suited to staple crops like maize and wheat.
- Sustainable sources of animal feed such as insects and algae could reduce the dependence on feed derived from wild fish or soy from tropical rain forest areas.
- For humans, edible insects are a nutritious and resource efficient food source, but cultural aversion to insects as food may be a significant barrier.
- Lab-cultured meat could provide a resource-efficient alternative protein source, but must overcome multiple technical challenges.
- If novel food products are to be accepted by the public, their development should consider societal preferences and behaviours.

Background

Food security – where all people at all times have access to safe, sufficient and nutritious food – is a global priority.[1] Food security is multifaceted, incorporating issues of production, distribution, stability, dietary preference and economic access.[2,3] Daily food intake for a healthy adult should include approximately 260g of carbohydrate, 50g of protein, and 70g of fat[4] (of which 250mg should be omega-3 fatty acids),[5] alongside essential vitamins and minerals.

Alongside any increase in production, the transition to a secure and sustainable food system will require reducing food waste[6] and influencing consumer behaviour.[7] However, projections estimate that global food production will need to increase by 60% between 2007 and 2050 to meet the demand of a growing population.[8] This will be challenging as agricultural productivity is being restricted by the increase in water scarcity (POSTnote 385), the availability and cost of mineral phosphate for fertilisers (POSTnote 477), the widespread decline in soil fertility,[9] the limited land remaining for cultivation,[10] and the impacts of climate change.[11] To increase UK food production, the Government supports a strategy of sustainable intensification, where farmland output is increased while reducing environmental harm.[12] The development and implementation of innovative food production technologies is one aspect this.[13]

This POSTnote summarises three key areas of current food production innovation: controlled-environment farming, alternative animal feeds and novel protein sources. It considers the stage of development and commercial viability of each technology. The note also identifies where policy or regulatory changes may be needed to facilitate adoption of these novel approaches.

Public Acceptance of Novel Food Technologies

Public perception of new food technologies is a key consideration. For example, the rejection of genetically modified (GM) products by some European consumers in the 1990s – the reasons for which are still debated – led to product withdrawal,[14] and has influenced the EU's approach to GM regulation undertaken since.[15] In developing countries, public concerns about GM relate to regulation and perceived threats to traditional farming practices.[16]

In the UK, negative responses to food are associated with: a feeling of lack of personal control over health risks; how ‘unnatural’ the food is perceived to be; and a lack of trust in regulatory bodies, businesses and government.[17] For GM food, emphasising benefits (such as retail price) has been shown to promote acceptance.[18] Gaining consumer insights early in the development of a novel food technology can be important in ensuring commercial success.[19] For example, public acceptance of the novel fungal protein product Quorn is thought to have arisen from its similarity to existing products (e.g. Tofu), the ethical and health benefits it offers, and a lack of moral contentiousness.[20]

Controlled-Environment Farming (CEF)

Technological advances in lighting and climate control are enabling farming to move into controlled indoor environments. CEF is an extension of greenhouse-based horticulture, and theoretically enables maximal yield and quality by giving the farmer total control of the growth environment. Food can be grown all-year-round and close to or within cities, supplementing current city-grown food (Box 1). The crop is also protected from extreme weather events, such as storms, and from pest attacks.[21]

CEF has become economically viable following advances in LED technology: lights produce little heat, and only emit the wavelengths of light needed by plants. Most indoor farms grow plants in a nutrient solution in a system known as hydroponics,[22] although aeroponic systems (using mist) can also be used.[23] Hydroponic systems can be designed as a recirculating loop, optimising water and nutrient-use efficiency and minimising pollution from agricultural waste.[22] Several strategies in CEF are being applied:

- **Vertical Farming**: Stacking growth platforms vertically with LED lights between layers maximises land use. Several industrial-scale vertical farms have been established around the world, including in the USA,[24] Netherlands,[25] Singapore[26] and Japan.[27] Green Sense farm in the USA has 14 levels and 9,290 m^2 of growth area available on a floor space of 2,787 m^2.[24]
- **Aquaponics**: This is the joining of *aqua*culture (fish farming) and hydro*ponics* (plant growth) in a recirculating system, with the nutrient waste from fish used as an input to plant growth.[28] The system is highly efficient because plants and fish are grown together, but is more expensive than growing them separately. It can be economically viable in regions where water is scarce and demand for the products is high. Research is needed on how supplements and treatments (e.g. antibiotics) might pass between the plants and fish, and the potential consequences for human health.[29]
- **Re-use of waste energy**: Cornerways nursery in Norfolk redirects the waste heat and CO_2 produced in the nearby Wissington sugar factory into its greenhouses, enabling tomatoes to be grown from February to November.[30] Similarly, Thanet Earth in Kent directs the waste heat and CO_2 produced by on-site electricity generation into its greenhouses, to grow tomatoes and peppers.[31]
- **Farming in enclosed spaces**: CEF technology has been applied in an underground air raid shelter in Clapham, London, by the start-up Growing Underground.[32] Another example is Freight Farms based in Boston, USA, which sells self-contained farms in shipping containers, with automated climate control, LED lighting and hydroponics.[40]

Box 1. Urban Farming

Recent years have seen increasing interest in urban farming in the UK, in gardens, allotments, community plots and rooftops.[33] Urban farming can supplement local food supplies with negligible transport emissions, but the contribution that it can make to food security is a matter of ongoing debate. In the UK, its contribution is tiny: London urban farming produced 21 metric tonnes (MT) of food in 2013,[33] compared to 12,101,000 MT of wheat produced in the UK in total.[34] Land analysis suggests that there is very little space available in world cities for farming,[35] and there is a lack of empirical evidence linking urban agriculture to improved household food security in low to middle-income countries.[36] However, the contribution that urban production makes varies between regions: for example, 60% of vegetables consumed in Dakar, Senegal, are produced within the city.[37]

Urban farming can be multifunctional, providing well-established social and health-related benefits. Those involved in gardening have increased levels of exercise and tend to eat more vegetables.[38] Where the whole community is involved, urban farming can improve community cohesion and provide employment opportunities.[39] In addition, improved mental wellbeing and increased biodiversity are both associated with areas of green space (POSTnote 448).

Limitations of CEF

CEF requires energy for lighting and climate control, and life cycle assessments (LCAs) are needed in order to evaluate sustainability. A large amount of capital is needed initially which acts as a barrier to small farmers, particularly those in developing countries.[41] CEF may also not be suitable for the most nutritionally important crops: while it works well for lettuce and tomato, larger crops such as wheat and maize require soil anchorage and are too tall to make stacked growth cost-effective.[42]

Alternative Animal Feeds

Finding alternative feed for the livestock and aquaculture industries is a key challenge in the transition to sustainable food production. Selective breeding and improved husbandry over recent decades resulted in significant gains in the feed conversion efficiencies of many species.[43] However, livestock production remains heavily dependent on fishmeal and soymeal, both of which are associated with negative environmental impacts.[44] Demand for soymeal has contributed to the expansion of feedcrop production globally, at the expense of large areas of tropical forests.[45] Fishmeal is produced primarily from wild caught fish: in 2011, 18% of global fishery catch was used to produce feed.[46,47] Fish stocks have been depleted in recent years, which has raised the price of fishmeal.[28]

Insects as Feed for Fish and Poultry

Worms, flies and larvae are natural foods of poultry and some fish species in the wild. The Food and Environment Research Agency (FERA) is co-ordinating an international research project – ProteINSECT – investigating how insects can be reared safely and economically for feed production.[48] Insect meal is rich in protein and nutrients, and industrial rearing in factories could theoretically produce far higher yields of protein per hectare of land compared to soy.[48] Some species can be raised on manure and organic food waste, enabling nutrient recycling; although manure cannot legally be used as feed under current EU regulations.[49] Large-scale production of insect meal reared on organic by-products is being commercialised by several companies: examples include AgriProtein in South Africa and Entomotech in Spain.[50,51]

Limitations of Insects as Animal Feed
Insect meal cannot compete with the price of soya at present, but could undercut the price of fishmeal and take pressure off wild fisheries.[52] However, insects do not naturally contain EPA and DHA omega-3 oils, which are essential dietary components for many fish species (e.g. salmon)[53] and offer well-established health benefits for humans.[54] Various strategies could be used to overcome this problem (Box 2). Questions remain over the water and energy efficiency of insect rearing, given the need for heat treatment and washing of larvae. A life cycle assessment of the rearing process is expected to be published in 2015.[48] There are safety concerns relating to pathogens, and the possibility of heavy metal contamination in food waste used as feed.[55] Acceptance by farmers and consumers could also be an issue. Exploratory survey data suggests that public attitudes are mostly favourable,[56] although intention – measured using surveys and focus groups – may not necessarily translate into behaviour.[20]

Alternative Protein Sources

Demand for animal protein is increasing worldwide (Box 3).[57] The world price of meat and dairy products steadily declined in real terms between 1961 and 2000,[58] but prices are now projected to rise by 32-63% by 2050 compared to 2000.[59] Current approaches to livestock farming are unsustainable in the long-term: the livestock industry accounts for 18% of global green-house gas emissions (POSTnote 453), produces 64% of ammonia emissions (POSTnote 458), pollutes watercourses (POSTnote 478), accounts for 8% of global human water use (POSTnote 385) and occupies 70% of global agricultural land.[60] Vegetable protein from nuts, soy, pea, chickpea and lupin could provide an alternative to livestock protein,[61] but more novel protein sources may also be needed.

Edible Insects

At least 1,900 insect species are known to be safe to eat for humans,[62] and mainstream consumption of insect foods could offer significant benefits in terms of food security and sustainability.[44] Although the nutritional content varies between species, the protein and nutrient profile of insects broadly resembles that of meat.[62] Insects are far more efficient at turning feed into biomass compared to conventional livestock.[62] In addition, insect rearing produces less greenhouse gas and ammonia emissions per kg of protein when compared to pig and cattle production. However, separate life-cycle analyses are required for different species and production environments if rigorous comparisons are to be made.[67] As with conventional meat products, insect foods should be free of viral, parasite and fungal pathogens. Heating and drying treatments during processing can reduce the risk of microbial contamination.[68]

Potential Barriers to Insects as Human Food
Insect-eating is part of traditional eating habits in South-east Asia and many Tropical regions.[62] In Europe, a small number of insect foods have been marketed. Notable UK examples include cubes of ground-up insect produced by the London start-up Ento[69] and bags of whole mealworms, crickets and grasshoppers marketed by Planet Organic.[70] The Dutch supermarket chain Jumbo has been selling insect burgers and nuggets since autumn 2014.[71] However, several constraints may need to be addressed before insects and insect-based foods are mainstream products:

- Current production lines for edible insect protein in Europe are labour-intensive.[72] Development and upscaling of automation technologies in rearing, harvesting and processing is required to reduce costs.
- Another food safety consideration is the potential carryover of heavy metals from contaminated feed into the insects during rearing.[55]
- Allergenicity must also be considered: those who suffer from prawn or dust mite allergies may also be allergic to insects that have shared allergenic proteins,[73] and specific allergies to sole insects also exist.[74]
- The view that insects are disgusting is deep-rooted in Western society, and achieving cultural acceptance of insect-based foods will be a significant challenge.[75] Masking the insect shape can reduce initial disgust;[76] a strategy being implemented in the use of insect powder in protein bars.[77] The use of insect ingredients in trial dishes for popular restaurants (e.g. Wahaca) may also promote

Box 2. Omega-3 Oils for Aquaculture

- Plant-derived omega-3: Genetic modification of a land plant to produce omega-3 has been demonstrated in *Camelina sativa* (false flax), which had no detrimental effects on farmed fish when used as a dietary replacement for fishfeed.[63]
- Omega-3 from single-celled organisms: Some marine algae naturally produce omega-3, and are effective as a substitute for fishmeal in fish and shrimp farming.[64,65] The high costs of microorganism production in large-scale fermenters is currently constraining their use in feed for aquaculture.[53]
- Omega-3 in insect diets: The fatty acid composition of larvae depends on their diet. Black soldier fly larvae become enriched in omega-3 when they are fed fish offal.[66] However, this strategy does not remove the need for fish in the feed production chain

Box 3. Changing Global Diets: Past, Present and Future.
Major dietary shifts observed in the last 50 years are expected to continue – most significantly in countries undergoing rapid urbanisation and economic growth:

- Meat consumption increased by 154% and 27% in developing and developed countries respectively between 1969 and 2007.[9] In the UK, purchases of fish and meat products have remained relatively stable since 1974.[78]
- World per-capita fish consumption increased from an average of 9.9 kg in the 1960s to 19.2 kg in 2012.[47]
- Dietary calories coming from vegetables has declined globally since the 1960s, with a steep reduction for pulses – one of the main sources of vegetable protein.[79]
- Meat consumption is expected to increase by 26% from 2007 to 2050, with developing countries accounting for 80% of this growth.[80] Fish production may need to increase by 50% by 2050 above 2006 levels, in order to meet projected demand.[47]

Box 4. How do you Grow a Hamburger in a Lab?
In 2013, a research group from Maastricht University in the Netherlands succeeded in producing the first lab-grown hamburger at the cost of €250,000.[81] Muscle stem cells from a cow were isolated and allowed to proliferate over a period of 7-8 weeks. The cells were then allowed to self-organise over a number of days into individual muscle fibres; 10,000 of these muscle strips were used in the production of one hamburger.[84] However, technical challenges remain in the production process. Bovine serum, derived from calf blood, is currently needed as a cell culturing medium.[84] A large amount of antibiotics is also currently needed, and mimicking the texture, taste, and nutritional value of conventional meat will be challenging.[81]

acceptance by providing role models for adventurous chefs.[82] Consumer profiling has shown that the most likely early adopters of insect foods will be young males interested in the environmental impact of their food.[83]

Cultured Meat
Another way to increase protein supply is to grow meat.[84] Preliminary life cycle analysis has suggested that lab-grown meat could substantially reduce energy, land and water expenditure, although this is based on a number of assumptions.[85] While the technology required to cultivate meat has been demonstrated in principle (Box 4), the industry is in its infancy. Research groups in the United States, the Netherlands, Canada and Sweden have so far only produced small quantities of tissue.[86]

There are a number of challenges on the path to commercialisation. Upscaling could theoretically be achieved using large cell cultivation vats, but would require substantial investment from industrial partners.[81] It is also not yet clear whether consumers would buy cultured meat. A 2013 survey in the Netherlands found that 52% of respondents would be willing to try it.[87] However, focus groups have revealed initial reactions of disgust, perceived unnaturalness, and scepticism about the benefits offered.[88]

Policy for Sustainable Food Systems
In the UK, government funding for the development and uptake of new technologies is awarded through the Agri-tech catalyst, the Sustainable Agriculture and Food Innovation Platform, and the Rural Development Program.[89] These build on research funded through government recently emphasised the need for investment in a variety of different technologies, and funding allocation based on the consideration of multiple costs and benefits, not just economic growth.[15]

Box 5. Novel Ingredients and Nanotechnology
Growing understanding of foods at the nano-scale could create the capability to control the flavour, texture and nutritional value of food, and may become significant in future food processing. Applications of this technology include reducing fat or sugar content, coating ingredients to prevent microbial attachment, and coating vitamins for easier absorption by the body. Nanotechnology could also be applied in 'smart' food packaging which changes colour when a food is no longer safe to consume.[90] Novel ingredients have recently become controversial because of the widespread practice of using complex chemicals as processing agents or preservatives in processed foods, the use of which consumers are often unaware.[91]

Box 6. Processed Animal Protein (PAP) Regulations
The use of PAP from carcasses infected with BSE (mad cow disease) in livestock feed led to cases of the degenerative brain disease vCJD in humans during the 1980s and 90s.[92] In 2001, the EU banned the use of PAP in feed for farmed animals, with the exception of fishmeal. Insect meal is defined as PAP.[93] However, regulation has not kept pace with the emergence of insect meal as a viable feed in recent years and the legislation needs to be re-worked. Industry is lobbying for a change in policy to exclude insects from PAP legislation, and EFSA is drafting a report on the topic due for release in September 2015.[48]

Regulation of Novel Protein in Food and Feed
Cultured meat and edible insects would both need to gain approval through the Novel Foods Regulation, coordinated in the UK by the Food Standards Agency (FSA). Novel ingredients are also regulated through this pathway (Box 5).[93] A food or ingredient is defined as 'novel' if it does not have a significant history of consumption within the EU before 15 May 1997.[94] Most insects would be classed as novel foods, even if they have been consumed outside of the EU for centuries. EU Regulatory approval requires the submission of a dossier of evidence to demonstrate the safety of the new food. Assessment of the safety dossier is conducted in the UK by the Advisory Committee on Novel Foods and Processes (ACNFP), an independent panel of scientific experts.[95] Regulatory approval for a novel food product can be a long and costly process, which may act as a deterrent to investors – particularly where consumer acceptance is not guaranteed.[96]

Revision currently underway of the EU Novel Foods Regulation will allow foods with a history of safe consumption overseas to be fast-tracked. The European Food Safety Authority (EFSA) is developing allergenicity risk assessment tools, to assess the potential of fast-tracked foods to be allergens. New EU legislation will also close the current loophole that regulates processed insect, but omits from regulation the sale of whole or ground insects.[93] While insects can be used as a feed in aquaculture, they cannot be used as food for other livestock in the EU under Processed Animal Protein legislation (Box 6).

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