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Delivering Food Security with Supply Chain Led Innovations:
Understanding supply chains, providing food security, delivering choice

Food Supply Chain Innovations

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Summary

This overview complements Dr Gail Smith's introductory paper presented in this Volume of *Aspects of Applied Biology*. I include research carried out at the Centre for Food Innovation (CFI) at Sheffield Hallam University to support the statements and caveats I present for continued application of innovation for sustainable outcomes. The ideas presented are those that I hope we can develop during this conference with many others. Our findings will be reported as a series of review papers that will be submitted to *Annals of Applied Biology*. We aim to make clear conclusions for the development of sustainable food supply chains.

Data Capture and Sustainable Supply

Firstly, it is becoming evident that datasets now used for food production Life Cycle Analyses (LCAs) are robust enough to make forecasts to define sustainability with greater confidence than ever before. However, two themes are presented throughout the papers at this conference that suggest they are also significant barriers to sustainable outcomes. They are the capture of data and the distribution of fairness in food supply chains. Assertions based on experimental evidence of what is sustainable are likely to be perturbed by a continued miss-matching of pleasure and quality of life with the requirements of sustainable development. This is beginning to create sensational outcomes in a world where for the first time, urban populations outnumber rural populations and the impact of the 'Brazil, Russia, China, India- or BRIC' nations is being felt on the food system like never before. There are also interesting developments that tend to suggest a universal agreement that intensification of agriculture is required for delivering sustainable food supply. Definitions of intensification range from the more cautious 'sustainable intensification' of the UK Royal Society (2009) to a full commitment to industrialised intensive agriculture (Burney *et al.*, 2010). The later is significant because research supporting this world-view suggests that intensification results in abatement of GHG emissions of the order of 13 Gt CO_2e per year. This is often contentious with many views of what sustainability should be, and, I hope our debates at this conference should consider how intensive both agriculture and food manufacturing should become to support supply.

Clearly, food production capacities are not limitless but significant yield gaps and waste minimisation opportunities exist. What has become clearer in debates across the spectrum of these views of intensification is low yielding agricultural systems are not the answer for 9 billion people (Godfrey *et al.*, 2010). However, limits are a clear certainty for energy supply where all current oil production estimates suggest supply in 2050 will be 90–100 M Barrels per day, falling short of the 120 M Barrels demanded even when we include extraction from shales and tar-sands. It is clear that agricultural energy balances can be improved if we consider those of optimised agricultural systems (Woods *et al*., 2010). Limitations across the food supply chain with regard to water (Strzepek & Boehlert, 2010) and land use (Smith *et al*., 2010) are further acute policy issues. The proceedings papers presented to this conference suggest these limits can incite intense innovation, technological application and regulatory change.

A particular note is made in these proceedings of the health impacts of diet that will continue to drive much innovation because they are clearly associated with enhanced quality of life. Emergent technologies are providing nutritional solutions to obesity, malnutrition and calorific deficiency (Hawkesworth *et al*., 2010). For example, there is intense interest in providing ready-made ingredients from the field with biofortified crops and livestock that provide enhanced mineral, vitamin and fatty acid nutrition. Relating measurements of environmental impact of products such as Global Warming Potential (GWP) to technological and health based interventions will be an important aspect of developing sustainability in supply chains. For example, if new technologies improve the efficiency of drying or dehydration or the healthiness of a product, the environmental benefit of these technologies and/or dietary application should be communicated to stakeholders so that the costs and benefits are visible. Training and efficient data capture are highlighted in these proceedings as limiting these processes within the supply chain even though such communications have a crucial role to play in developing fair and just supply chains.

Ethical considerations of consumers have been a strong trend in market innovations for food and beverage products. Ethical values associated with food products are closely related to issues of health for the consumer and Corporate Social Responsibility (CSR) for food companies. There is no doubt poor nutrition is a major cause of ill health and premature death in many developing and developed countries. Although the figures are avidly debated, it is reported obesity is responsible for an estimated 9,000 premature deaths each year in the UK alone with an estimated treatment cost for ill health due to poor diet of at least £4 billion each year (UK Cabinet Office Strategy Unit 2008). Communicating the importance of balanced diets is clearly a cornerstone of robust public health communication and sustainable supply.

The Food Industry Responses to Sustainability and Social Responsibility

Sustainability is a ‘now’ issue the food and beverage industry has responded to. For example, ‘waste’ is not a word used lightly in the manufacturing sector but there is intense activity to reduce waste across the whole supply chain and divert ‘waste’ streams to valuable co-products (Parfitt *et al*., 2010). However, how waste is minimised globally is extremely variable and a waste minimisation system for all supply chains will require a system of joint responsibility and fairness. If that can be achieved studies presented in this proceedings suggest they will generate new ideas and increase wealth. There are now three specific areas of our industry I would like to specifically cover that are highlighted in the proceedings papers as critical for future success.

The first is water use efficiency. Globally, irrigation of agricultural systems is highest where water- scarcity is most intense. The UK itself will experience a more Mediterranean climate in the future representing a challenge for food manufacturers where assurance and safety protocols will potentially increase water use intensity. The requirement for increased water use efficiency is likely to become more apparent in the food supply chain and water saving technologies, crop breeding and new assurance protocols will all have a role to play. For example, CFI at Sheffield Hallam University have completed trials with fresh vegetable processing using controlled atmospheres in the manufacturing cutting and washing environments to inhibit the activity of Phenyl Alanine Lyase (PAL), an enzyme that causes browning of tissues in the presence of oxygen. Traditionally, sulphites were use as a preservative for inhibiting PAL, this entailed using large volumes of water to dissolve sulphur dioxide and wash produce. The use of controlled atmosphere processing and packaging has not only removed the potential allergenic sulphites form the processing of vegetables but also reduced water use in factories. This represents a clear application of technologies that have an environmental outcome that has been primarily driven by a regulatory requirement to remove an allergen (sulphite). How such solutions are communicated environmentally across their supply chains is a new area of required expertise for many manufacturers.

The second is energy production where we have already identified a clear shortfall in supply. Biofuel and biomass are important co-products of the food supply chain and fermentation is clearly in our folio of industrial expertise. This may offer opportunities for food supply chains to provide energy. There are currently many concerns regarding the sourcing of ethical biomass and biofuel feedstocks on international markets and the potential conflicts that may develop for food or biofuel production. These issues have become very apparent in the UK with the development of three large bioethanol refineries utilising 3 million tonnes of wheat. It is clear that conflicts can be ameliorated using alternative feedstocks and increasing wheat yield but data capture and a thorough understanding of the supply chains is needed. Research at CFI has shown the Vivergo fuels refinery near Kingston upon Hull will require 1.1 million tonnes of wheat each year. If we were to consider a conservative wheat yield for the Region (average for the UK) at 8.5 tonnes of grain per hectare, this will equate to a land-use requirement for almost 130 000 hectares of wheat within Yorkshire and Humber region. This is nearly 60% of the current Region's cultivated area of wheat (Defra Agricultural and Horticultural Survey (AHS) statistics, 2007). An estimate of local grain demand by 37 regional bakeries has suggested a land requirement of 0.023 million hectares to produce 0.195 million tonnes of wheat. Thus, the conflict and concerns are very real and data capture within supply chains could solve many potential problems.

The third and final area I want to highlight is supply chain efficiency, which relates to carbon footprint research. Supply chain efficiency can be defined by the 'carbon footprint'. A typical 200 g mixed sandwich will have 150–220 g of CO_2e emissions associated with growing and processing its ingredients. Transport and packaging can add 20–50 g CO_2e emissions, and greenhouse gas emissions such as methane (from livestock production) and nitrous oxide (from organic and mineral nitrogenous fertiliser use) can significantly increase these emissions. Furthermore, they can be reduced by fit-for-purpose agronomic management.

However, knowledge of supply chain volumes and product choice from farm to shopper by food industry sector (e.g. meat, dairy, vegetables) is limiting our understanding of energy inputs and LCA for food products. Initial studies carried out by CFI at Sheffield Hallam University have used primary data collected for refrigerated transport, diesel consumption and food mileage from regional Yorkshire and Humber food and beverage companies. These data have been converted to GHG emission and social cost secondary data using environmental impact and LCA methods. These data have been extended to a spatial context with the development of GIS (Geographic Information System) methodologies for groups of supply chains. An example is shown in Fig. 1 for the CO_2 emission and social impact of distributing products within 70 km of Leeds for 10 meat manufacturing companies based in the Yorkshire and Humber region. This type of GIS analysis can be extended to livestock agricultural production and health trends spatially. The spatial information for beef production is shown in Fig. 1, it is unlikely that the relationship between centres of farm production and food manufacturing will always be closely related. GIS investigation does offer the potential to build scenarios of how agricultural production and food manufacturing can be planned.

The delivery points for 10 and their associated impacts within 70 km radius of Leeds in a typical week for 10 meat product manufacturing companies in the Yorkshire and Humber region. The delivery points are shown in Fig. 1. Fuel consumed has been calculated using conversion constants for product freight described in research presented by Martindale and others (2008). The fuel consumed for whole freighting operations (products and vehicles) have been obtained using the Department of Transport Freight Best Practice KPI publications. This was typically 3.6 km per litre of diesel for HGV and LGV vehicles. Conversion of fuel consumption to CO_2 amounts has been carried out using the method presented by Martindale and others (2008).

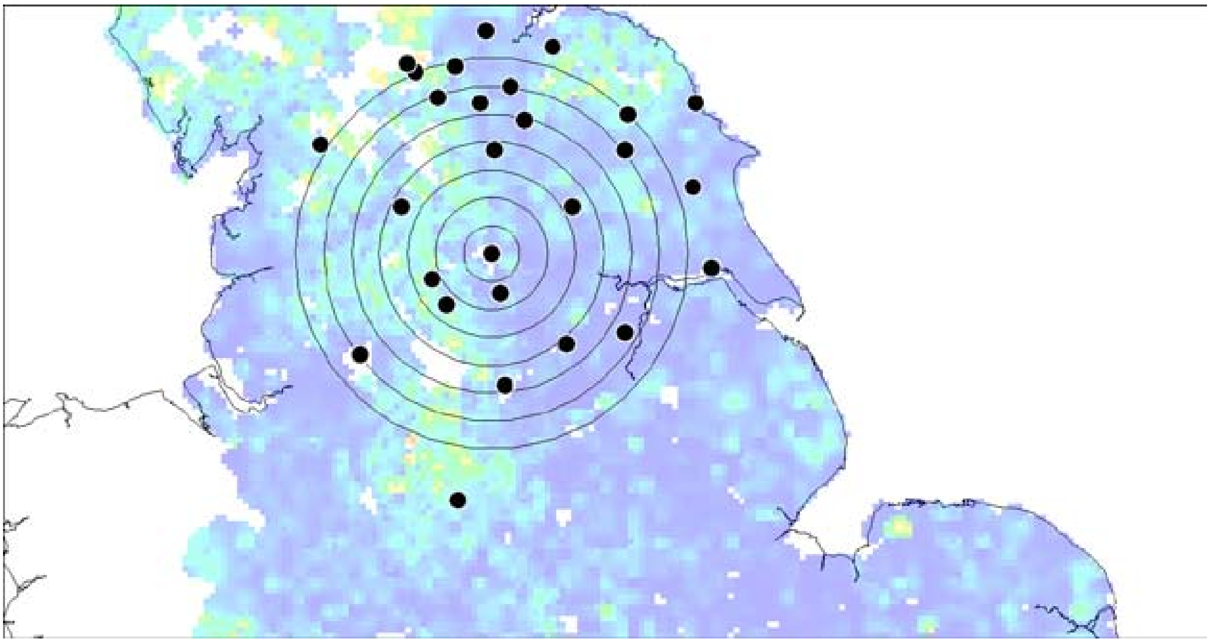

Fig. 1. The destinations of food product deliveries within 70 km of Leeds city centre in a typical week for 10 meat product manufacturing companies in the Yorkshire and Humber region. The concentric circles show 10 km radii from the centre of Leeds, the black circles show destinations of product and the colour grid shows the intensity of beef production (lightest colouring – up to 600 head of cattle per 5 km radius, to 50 head of cattle per 5 km radius for darkest areas). The impact of distribution for these companies within the concentric circles is shown in Table 1.

Table 1. *The delivery points for 10 and their associated impacts within 70 km radius of Leeds in a typical week for 10 meat product manufacturing companies in the Yorkshire and Humber region. The delivery points are shown in Fig. 1*

Radius (km)	Number of destinations	Km travelled	Diesel consumed (L)	CO_2 emitted (kg)	CO_2 cost (£)	Total social cost (£)
10	5	374	196	526	1.66	102.95
20	2	90	147	393	0.40	24.82
30	2	157	47	125	0.70	43.23
40	6	270	86	231	1.19	74.17
50	3	129	40	107	0.57	35.55
60	4	265	94	251	1.17	72.88
70	4	114	101	271	0.50	31.22

The conversion factors for the economic cost of food transport including CO_2 (£0.0044 km^{-1}), and total social cost that includes accidents (£0.0312 km^{-1}), congestion (£0.2226 km^{-1}), transport infrastructure (£0.0008 km^{-1}), noise (£0.0057 km^{-1}) and air quality (£0.0101 km^{-1}) have utilised conversions derived from the Defra (2006) report on the validity of utilising food miles and an indicator of sustainability. The conversion factors were obtained by utilising the costs of CO_2, accidents, congestion, transport infrastructure, noise and air quality reported in the Defra (2006) report and dividing them by the reported food miles by HGV (5.8 Bn km) and LGV (4.7 Bn km) vehicles to obtain the typical cost per km for a particular impact. The sum of accidents, congestion, transport infrastructure, noise and air quality cost is presented as the sum of social cost.

Intensifying the Food Supply Chain

The limits in regional agricultural product supply have been traditionally ameliorated by efficient food logistical infrastructure, preservation and packaging. We are now beginning to account for these limits. Supply chain resource efficiency, managing natural resources, accounting for energy, water and waste will become more critical to the success of the sustainable business model. Global food production statistics suggest a dramatic change in the requirement for products that improve flavour and taste (Table 2). Food staples have remained relatively constant in these terms with palm oil production providing an exception where production area and yield per hectare has increased globally 279% and 193% respectively between 1980 and 2004.

Table 2. *Trends in production for selected agricultural products obtained from FAOSTAT (2008) data that provide key ingredients in the food production system*

Crop	Production (Mt)		Increase (%)
	1990	2005	
Spinach	4.087	13.778	337
Garlic	6.600	15.184	230
Chillies	12.845	28.693	223
Sugar crops	1363.207	1649.669	21
Wheat	592.372	605.946	2

How supply chains respond to taste and quality of life trends is crucial and the global food system must operate in a robust regulatory system that ensures safety of products. This should not stifle innovation and the application of new technologies that enhance nutritional quality of food using novel ingredients, nano-encapsulation of nutrients, biofortification and individual (genomic or metabolomic) nutrient profiling. Crop breeding and agronomic management have a central role in closing yield gaps and increasing nutritive quality. The changing global food trade dynamic must not overlook consumer influences, precautionary attitudes and new regulations. Indeed, technologies and innovations are being deployed in a new bias that does not reflect how things happened in the 19th and 20th Centuries.

Conclusion

The attainment of sustainability and innovation will follow three caveats:

1. The ability to deploy new and established technologies in the agri-food arena
2. Sensing regulatory environments that enable and stimulate innovation
3. Delivery of innovative multidisciplinary approaches to product development that provide consumers with high impact health and ethical information.

Data capture and assessing fairness in food supply chains will be critical to these three caveats.

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