Institution: University of Nottingham

Unit of Assessment: 6; Agriculture, Veterinary and Food Science

Title of case study: Transferring biopolymer technology to the food industry

1. Summary of the impact

Research at the University of Nottingham (UoN) has generated a deep understanding of how semi-crystalline biopolymers, particularly starches and cellulosics, can be controlled through processing to create products with predictable behaviour and with enhanced functionality, especially for texture creation. This knowledge has been transferred to the food industry and to other manufacturers who use natural materials. Concepts developed by UoN have become the bedrock of understanding for large and small manufacturers, enabling them to reduce waste, adapt recipes allowing for cleaner labels and additive reduction, expand the range and quality of materials they can utilise and attempt novel manufacturing procedures.

2. Underpinning research

Key researchers:

Professor John Mitchell, 1974-2008; Professor Sandra Hill, 1999-Present; Associate Professor and Reader Tim Foster, 2007- Present; Associate Professor Bettina Wolf, 2006 – Present; Professor Steven Harding, 1984 – Present; Professor Greg Tucker, 1977 – Present.

A materials science approach to food biopolymers pioneered in the 1980s at UoN and developed through the next 3 decades has made significant inroads into the scientific principles used by manufacturing industries when they consider the materials and the processes they employ. Cooperative research, led by UoN through a serious of LINK schemes **[a-e]**, underpins the scientific basis that many companies now use when seeking new methods or materials for processing.

A key research challenge was the development of methods that could monitor changes in foods and ingredients during processing. These methods were required to be robust enough for commercial use as well as being validated by fundamental techniques. These included a range of rheological, spectroscopy (NMR, FTIR, WAX) and thermal analysis techniques. For example an understanding of protein thermoextrusion problems was solved using a combination of capillary rheometry and charge analysis **[1]**. A battery of tests was constructed to monitor changes in carbohydrate structures across the microscopic, mesoscopic and molecular scales and determine how hydration influenced the behaviour of materials **[2,4]**.

Having established a framework that could be used to consider hydration, thermal and mechanical impact on biopolymers the UoN group extended the programme of research into novel areas. Understanding of phase separation and the creation of networks, gained through an understanding of edible food materials, were applied to packaging **[d, 4]** and cellulosic materials **[5]**. Concepts describing the loss of crystalline order in complex carbohydrates have been applied to lignocellulose. This has extended knowledge of breakage of the materials for the growing biofuels industry and for the application of cellulosics as renewable resources that can be used in a range of applications **[5]**.

One of the major challenges for the food industry has been the reduction expected in the levels of sodium in many foods. This causes technical issues during processing, such as changes in colour and expansion, as well as flavour implications. UoN has tackled this multifaceted problem using a generic materials science approach. This work established that starch structures, at all length scales, are disrupted by sodium in certain processes **[6]** and it is this that influences the colour of many food products. In addition, understanding the rheology of the matrix has led to a greater understanding of salt release, and hence taste **[f]**. This holistic approach to studying foods, based on a materials science approach, allowed UoN to support the Food Standards agency and companies **[e, f]** to reduce salt levels across foods of varying water content (soups to crackers) **[1-6, a-f]**.

3. References to the research

Our work in this area generated more than 100 papers from 1992-2012 and over 80% of the work is encapsulated by the concepts of understanding structures of biopolymers and how these may be altered to create the required functionality. Evidence of the international quality of the research is indicated by the publication of the papers in international, peer-reviewed high impact journals.

1. BENGOECHEA, C., ARRACHID, A., GUERRERO, A., HILL, S. E. and MITCHELL, J.R. (2007). Relationship between the glass transition temperature and the melt flow behaviour for gluten,

casein and soya Journal of Cereal Science. 45(3), 275-284. DOI: 10.1016/j.jcs.2006.08.011
2. BECKER, A., HILL, S. E. and MITCHELL, J. R., 2001. Milling-A Further Parameter Affecting the Rapid Visco Analyser (RVA) Profile Cereal Chemistry. VOL 78(PART 2), 166-172. DOI: 10.1002/1521-379X(200104)53:3/4<121::AID-STAR121>3.0.CO;2-Q
3. DESSE, M, ANG, S, MORRIS, G. A, ABU-HARDAN, M, WOLF, B, HILL, S. E, HARDING, S. E, BUDTOVA, T and AND MITCHELL, J. R. (2009) Analysis of the continuous phase of the modified waxy maize starch suspension. Carbohydrate Polymers. 77, 320-325. DOI: 10.1016/j.carbpol.2009.01.012
4. PAES, S.S., YAKIMETS, I., WELLNER, N., HILL, S.E., WILSON, R.H. and MITCHELL, J.R. (2010) Fracture mechanisms in biopolymer films using coupling of mechanical analysis and high speed visualization technique. European Polymer Journal. 46(12), 2300-2309. DOI: 10.1016/j.eurpolymj.2010.10.003
5. IBBETT, R., GADDIPATI, S., DAVIES, S., HILL, S. and TUCKER, G. (2011) The mechanisms of hydrothermal deconstruction of lignocellulose: New insights from thermal-analytical and complementary studies. Bioresource Technology. 102(19), 9272-9278. DOI: 10.1016/j.biortech.2011.06.044
6. MOREAU, L, LAGRANGE, J, BINDZUS, W and HILL, S. (2009) Influence of sodium chloride on colour, residual volatiles and acrylamide formation in model systems and breakfast cereals. International Journal of Food Science and Technology. 44(12), 2407-2416. DOI: 10.1111/j.1365-2621.2009.01922.x

Underpinning research programmes carried out in co-operation with sponsoring companies:

a. 1988-1996: *Amorphous crystalline transitions in foods (Actif 1 and 2)*. BBSRC, £1.8M, UoN.
b. 1991-1994: *Hydration of hydrophilic materials in foods and drug delivery applications (Hydra)*. BBSRC and DEFRA funding. £1.1M, UoN.
c. 2001-2004: *Stability of foods and food ingredients in the glassy state (Drystore).* BBSRC and DEFRA funding. £400,000. UoN
d. 2001-2004: *Filmstarch: To identify the optimum properties of starches for their utilisation in film formation*. John Innes Institute and UoN, £400,000.
e. 2007 FSA contract N09026 *Salt reduction in premium bread: understanding the influence of physical and chemical properties on stickiness, collapse and open texture.* £60,000 UoN.
f. 2012-2014: *Development of physically modified hydrocolloids and starches for enhanced salt perception (Mixlink*). BBSRC and DEFRA funding. £36,000. UoN.

4 Details of the impact

Food production is the largest manufacturing sector within the UK. The annual turnover is £76.2bn turnover with a gross value added of £20.9bn and this accounts for 16% of total UK manufacturing industry. Around 13% of the people employed in manufacturing in the UK work in the food and drink industry and it is of particular significance in our local East Midlands region where 21% of manufacturing jobs are in the food sector. Large multinational corporations lead the industry, but hundreds of small and medium enterprises make a significant contribution to the market, again the proportion is particularly high within the East Midlands. Innovation, sustainability and efficiency in the industry are often dependent upon relationships between manufacturers, processors and academic researchers. The long-term commitment of Food Sciences at the University of Nottingham (UoN) to understanding the interactions between materials and processing and the implications of phase change (the transitions of biopolymers from crystalline to amorphous forms) has brought about a range of benefits to the industry at international, national and local levels. UoN researchers took a fundamental approach to understanding these processes and transferred the knowledge to industry. Engagement with companies has enabled the commercial utilization of the growing knowledge base. It has been the wisdom accumulated through many UoN research projects, that has impacted on the thinking and activities of food and biomaterials companies large and small.

As described below, UoN engagement with companies has been extensive and the dissemination and knowledge transfer in relation to biopolymers impacts on the sustainability and competiveness of those using biomaterials, within the food and other industries.

***Small company activity*:** The knowledge base generated by UoN research has been effectively disseminated to smaller businesses, particularly to those in the East Midlands. Food and Drink enterprises are a key economic driver in the East Midlands, worth £1.6 billion. Along with Yorkshire and Humber regions, the East Midlands is the country's biggest food manufacturing centre.

Working closely with the Food and Drink iNet (The Food and Drink innovation Network was established in 2008 to co-ordinate specialist support to stimulate innovation in the food and drink industry), UoN has played a key role in increasing the effectiveness of local industry, through knowledge and technology transfer (**Source 1**). Two major EU grants have provided impetus for this knowledge exchange and support for the smaller companies within the East Midlands. UoN expertise on biopolymers has been transferred to SMEs through the UoN Starch Processing Centre (2008-2011). Since inception, 66 separate business support activities occurred with 55 different companies. From this activity 621 people were assisted in their skills development, drawing on the expertise of the UoN researchers. This activity was extended through the addition of lipids to the Centre (award 2013-2015) and the concomitant addition of new interactions with the small companies. This makes UoN a key partner in achieving business goals for many food companies (**Source 1**).

National relevance: Supporting commercial operation within the UK food industry by increasing the knowledge base on crystalline-amorphous behaviour of biopolymers is of major strategic importance. There are many examples where UoN expertise has helped companies establish their unique selling points, by allowing them to use scientific knowledge and measurements based upon UoN expertise to create innovative products. An example of this would be GA Pet Foods a manufacturer of own-label innovative petfood. The Managing Director of the company stated (2013), "*GA Pet Foods has invested in excess of £18 million in the last three years for the innovative manufacture of dry pet foods. We are particularly interested in using sources of animal protein that shorten the supply chain and do not impact upon the resources being used for human foods. To do this novel manufacturing technologies are required, as well as an understanding of the nutritional benefits that could be gained* (**Source 2**)." These technologies have been derived from the research work led by UoN. "*To limit risks and provide a credible background for the work, an academic partner with a history of processing and an understanding of the nutritional requirements of animals was necessary. The group at Biosciences at Nottingham are leaders in this field and have a proven record of industrial collaboration*" (2013, **Source 2**). The retention of a critical mass of technological/research expertise within the UK is essential for a vibrant food industry. McCain Foods, the world's largest producer of French fries and other oven-ready frozen food products state that "*no small part of the decision*" to base their global batter group in the UK came from their knowledge exchange collaboration with UoN (**Source 3**).

International Engagement: Many international companies use expertise from UoN in support of their manufacturing developments. Pepsico is an American multinational food and beverage corporation with interests in the manufacturing, marketing and distribution of grain-based snack foods, beverages, and other products. A statement from the Head of Breakthrough Foods R&D at Pepsico confirms, "*The Nottingham group have proven themselves to be a key partner for Pepsico in Europe and globally in support of our Foods business, predominately though a combination of their scientific leadership in the area of starch and other complex carbohydrates, and their partnership orientated approach to working with industry*" **(Source 4**, 2013**)**. UoN have acted as first port of call to aid in translation of upcoming technologies for many other companies.

Key areas of knowledge transfer have been particularly in the field of alternative raw materials and novel processing (**Source 2**,) and much of this work has been based around enabling companies to understand and monitor factors allowing fat and salt reduction in their products (**2-3,6 and e**). Pepsico confirm that, "*Knowhow created within Biosciences at Nottingham has been used to understand expansion and quality of such products. Providing a mechanistic understanding of the starch – biopolymer matrix that enabled the PepsiCo researchers to devise a new approach to product formulation ultimately led to a successful product re-launch of our Oven baked chips from Lays into the Netherlands and Belgium. We first launched Baked Lays in the Netherlands in 2008 and relaunched in 2010 with the dramatically improved product design which as a strong contributor to the very strong sales uplift we saw post re-launch - the product is held to be one of the best Baked Lays product designs in PepsiCo today.*" (**Source 4**, 2013). Similarly the Director of Fundamental and Applied Research at McCain Foods states, "*McCain's Fundamental Applied Research team has maintained a collaborative relationship with Nottingham University for the past 5 years. In this time the project has produced multiple positive developments*". "*The information and knowledge gained has allowed McCain to complete a long term project in the highly relevant area of fat reduction after many years of work leading to a quantifiable increase in sales and volume. A second project which has real process innovation at its core, again based on starches in*

our applications, will help us significantly reduce our wastage on a global scale." (**Source 3**).

Due to the fundamental approach taken by UoN researchers (**a-d, 1-6**), links with industry and raw material processing have extended from food materials to other biomaterials. UoN is a founding member of the European Polysaccharide Network of Excellence (EPNOE) and within this organisation has helped establish the links between crystalline-amorphous behaviour cellulose and starch which can be applied to non-food materials (**Source 5**). The commercial significance of this is confirmed by a 2013 statement from the Head of Global Development and Innovation Textiles at Lenzing Aktiengesellschaft (**Source 6**), "*Lenzing AG is an Austrian based company specializing in man- made cellulose fibres including the non-woven modal and lyocell (TENCEL®) fibers. The tonnage of fibre produced is ~900,000 per annum and annual sales are in the region of €2,000 million… The Lenzing Group prides itself in leading this industrial field through innovation and technology. The concepts put forward within the European Network of Excellence in Polysaccharides and the comparative understandings between starch and cellulose, led by the team based in Food Sciences at the University of Nottingham, have been of considerable interest to Lenzing AG. This has contributed to our understanding of the properties of semi crystalline materials and how mixtures of polymers may be of use in developing new materials with a commercial application. New processes from these findings are being considered for commercialisation*".

Dissemination of knowledge: The knowledge generated by food scientists at UoN across three decades has generated a body expertise that has been made accessible to small and large businesses. Between 2008 and 2013, the transfer of this knowledge has been a driver for product reformulation (**Source 4**), innovation (**Sources 3 and 6**), waste reduction (**Source 3**) and the promotion of a critical mass of expertise in the industry (**Sources 1 and 3**). A key element of this knowledge transfer from UoN to the local and global food industry has been effective participation and engagement with opportunities for dissemination. For example, the Food Standards Agency, as part of the European Salt Action Network (ESAN), which was set up under the auspices of the World Health Organisation, asked UoN to supply an expert talk at a meeting hosted in Malta for the EU on salt perception and flavour (**Source 7**). Similarly UoN research to improve understanding of the commercial implications of sodium reduction was disseminated to industry through invitations, requested by Pepsico (**Source 4**) to give knowledge transfer presentations on the relevance of Salt Reduction and Processing at the American Cereal Chemist Association (**Source 8**). UoN also participates in knowledge transfer activity through direct engagement with companies. For example, Mars established a multidisciplinary research collaboration with Prof. Hill, which informed strategy for their petfood business.

5. Sources to corroborate the impact

1. Managing Director, Food and Drink iNet. *Will confirm strategic importance of UoN interaction with local companies for East Midlands industry.*
2. Statement from Joint Managing Director, GA Petfoods. *Confirms that the company uses UoN expertise as a basis for developing products.* 2013
3. Statement by Director of Fundamental and Applied Research, McCain Foods. *Corroborates that UoN work has impacted upon sales and volume.* 2013
4. Statement from Senior R&D Director PepsiCo Europe. *Corroborates partnership between company and UoN that led to relaunch of product in Netherlands and Belgium.*2013
5. EPNOE website http://www.epnoe.eu/Members/Academic-members/Univ.-Nottingham *Confirms Nottingham involvement in EPNOE.* 2012.
6. Statement from the Head of Global Development and Innovation Textiles, Lenzing AG, Austria. *Confirms the contribution of UoN through EPNOE to development of new materials with a commercial application, by a leading company in global manufacture of cellulose fibres.*2013
7. (http://www.euro.who.int/en/what-we-do/health-topics/disease-prevention/nutrition/policy/member-states-action-networks/reducing-salt-intake-in-the-population) http://www.aaccnet.org/meetings/archive/2011/Documents/2011AACCIntlProgramBook.pdf : *Corroborates UoN involvement in the Malta meeting on salt reduction*, 2011.
8. http://www.aaccnet.org/meetings/archive/2011/Documents/2011AACCIntlProgramBook.pdf http://www.aaccnet.org/meetings/Documents/2012Abstracts/s12ma09.htm *Confirm UoN involvement in the American Association of Cereal Chemists meetings.* 2011, 2012.