Institution: University of Reading

Unit of Assessment: 6 – Agriculture, Veterinary & Food Science

Title of case study: Mitigation of acrylamide formation in cooked cereal and potato products

1. Summary of the impact

Research at the University of Reading into the origin of acrylamide, a neurotoxin and probable human carcinogen, in cooked cereal and potato products has provided crucial information for the food industry and government agencies. This has enabled important mitigation strategies to be developed. When acrylamide was unexpectedly discovered in food in 2002, there was no explanation for its origin. Pioneering research at Reading showed that it was formed during heating from naturally-occurring sugars and the amino acid asparagine. Because of this knowledge it was then possible to investigate factors affecting acrylamide formation and develop methods of mitigation. Subsequently investigations were undertaken worldwide, including work at Reading, to minimise the problem.

2. Underpinning research

Acrylamide is an industrial chemical known to be neurotoxic and carcinogenic in laboratory animals; therefore, its unexpected discovery in fried and baked potato products, biscuits, bread, crispbread, and coffee, created huge concern worldwide and acrylamide rapidly became one of the biggest scientific issues ever to hit the food processing industry.

Soon after the discovery of acrylamide in food products in 2002, Donald Mottram, Professor of Food Chemistry at Reading and Professor Bronek Wedzicha (University of Leeds) met to discuss the possible origins of acrylamide in heated food and they hypothesised that acrylamide was derived from the amino acid asparagine. They then instigated research at Reading to confirm this hypothesis and established that the Maillard reaction involving asparagine and reducing sugars was the route [1]. Their resulting publication in *Nature* was the first to establish the origin of acrylamide in cooked foods and it has now received well over 1000 citations in the scientific literature.

This research provided crucial direction for food scientists worldwide – academic, government and industry – as they sought to alleviate the acrylamide problem. Our research showed that acrylamide was formed by chemical reactions between natural food components under normal processing conditions. As such, the paper established that complete elimination of acrylamide from all baked and fried potato and cereal products would be impractical to achieve. However, it did demonstrate that mitigation strategies were possible through reduction of essential acrylamide precursors (i.e. asparagine and sugars) in the raw ingredients and through control of the kinetics of the reaction during processing. The chemical pathways leading to acrylamide in food are part of the Maillard reaction, a complex series of reactions between amino acids and sugars that also produces desirable flavours and colours associated with cooked foods. Heating of foods also provides structural changes, which influence digestibility and texture, and creates low moisture products that are shelf-stable. A major challenge, therefore, has been to prepare potato- and cereal-based foods with lower acrylamide levels while maintaining essential colour, flavour and other desirable attributes.

Further research involving Reading addressed these issues by providing more detailed understanding of the chemical pathways involved [2], through investigations of the kinetics of acrylamide formation [3], and examining the relationship with flavour generation. Kinetic models have been generated for cereal and potato products, including French fries, that were used to predict acrylamide formation in relation to sugar and amino acid precursors for different time-temperature regimes [3]. Other work examined potential mitigation strategies, such as modifying pH, and adding components that compete with asparagine in the Maillard reaction. However, strategies that are showing the best long-term potential involve the use of plant genetics and agronomy to reduce acrylamide formation in foods. We have been partners in BBSRC-funded projects with Rothamsted Research that have studied the genetics of asparagine, amino acid and sugar formation in potato, wheat and rye [4, 5] and the role of agronomy in the accumulation of acrylamide precursors during plant growth [6]. One particularly important finding has been that wheat grown under conditions of severe sulphate depletion contained greatly increased concentrations of free asparagine – up to 30 times more compared with wheat receiving normal levels of sulphate – which led to increased levels of acrylamide when heated [6].

Key researchers: Professor Donald Mottram (from 2002 to date), Dr Stephen Elmore (Senior Research Fellow; 2002 to date), Dr Jane Parker (Senior Research Fellow; 2011 to date).

3. References to the research

[1] Mottram, D.S., Wedzicha, B.L. and Dodson, A.T. (2002) Acrylamide is formed in the Maillard

reaction. *Nature*, 419: 448-449. DOI: 10.1038/419448a. Citations: 708 (Web of Science)

[2] Elmore, J.S., Koutsidis, G., Dodson, A.T., Mottram, D.S. and Wedzicha, B.L. (2005) Measurement of acrylamide and its precursors in potato, wheat, and rye model systems. *Journal of Agricultural and Food Chemistry*, 53: 1286-1293. DOI: 10.1021/jf048557b. Citations: 82 (Web of Science)

[3] Parker, J.K., Balagiannis, D.P., Higley, J., Smith, G., Wedzicha, B.L. and Mottram, D.S. (2012) Kinetic model for the formation of acrylamide during the finish-frying of commercial French fries. *Journal of Agricultural and Food Chemistry*, 60: 9321-9331. DOI: 10.1021/jf302415n.

[4] Curtis, T.Y., Muttucumaru, N., Shewry, P.R., Parry, M.A.J., Powers, S.J., Elmore, J.S., Mottram, D.S., Hook, S. and Halford, N.G. (2009) Effects of genotype and environment on free amino acid levels in wheat grain: implications for acrylamide formation during processing. *Journal of Agricultural and Food Chemistry*, 57: 1013-1021. DOI: 10.1021/jf8031292. Citations: 18 (Web of Science)

[5] Halford, N.G., Muttucumaru, N., Powers, S.J., Gillatt, P.N., Hartley, L., Elmore, J.S. and Mottram, D.S. (2012) Concentrations of free amino acids and sugars in nine potato varieties: effects of storage and relationship with acrylamide formation. *Journal of Agricultural and Food Chemistry*, 60: 12044-12055. DOI: 10.1021/jf3037566.

[6] Muttucumaru, N., Halford, N.G., Elmore, J.S., Dodson, A.T., Parry, M., Shewry, P.R. and Mottram, D.S. (2006) Formation of high levels of acrylamide during the processing of flour derived from sulfate-deprived wheat. *Journal of Agricultural and Food Chemistry*, 54: 8951-8955. DOI: 10.1021/jf0623081.

All papers are published in quality, peer-reviewed journals. All are of at least 2* quality.

Grants for research on acrylamide in food (all awarded to Prof Donald Mottram)

Formation of Acrylamide in Potato and Cereal Products
Consortium of Food Companies
Mar 2003 – Feb 2005 £310,000

HEATOX: Health risks from heat treated foods and food products
European Commission
Nov 2003 – Oct 2006 £78,500

Mechanism of the Formation of Acrylamide in Cooked Foods
Food Standards Agency
Jun 2005 – Oct 2007 £38,000

Genetic and Agronomic Approaches to Reducing Acrylamide Formation in Foods
BBSRC with Food Standards Agency
Oct 2004 – Sep 2007 £179,800

Producing Low Acrylamide Risk Potatoes
BBSRC LINK
Jun 2009 – May 2012 £198,914

4. Details of the impact

Industry invests in research

Pioneering research findings from Reading [1] generated enormous worldwide interest from industry and from government departments concerned with food safety and health. Recognition of the impact of this research resulted in significant funding for further research. Initially a consortium of major food companies (Cadbury, Cereal Partners, Danone, McCain, Ryvita, United Biscuits) funded a collaborative research programme, led by Reading, in conjunction with the Universities of Leeds and Nottingham. A 3-year BBSRC LINK project on minimising acrylamide in potato products also received significant funding from food and agriculture companies (ConAgra, Higgins Agriculture, Kettle Foods, PepsiCo, Tesco, United Biscuits). Individual companies have also sponsored shorter-term research at Reading, while other major grants have been provided by BBSRC, Food Standards Agency and the EU.

Reading has, therefore, played a pivotal role in bringing together researchers in the UK, initially the Universities of Reading, Leeds and Nottingham and, later, Rothamsted Research and James Hutton Institute. The outcomes of this collaborative research have had significant impact on the

approaches taken by the food industry all across the world for acrylamide reduction.

Manufacturers adopt mitigation strategies

All large food companies preparing snack foods, biscuits, bread, coffee and similar carbohydrate-rich foods have undertaken studies of their own products. These approaches, taken towards mitigation, were based on our initial finding that acrylamide is formed though the Maillard reaction involving asparagine and reducing sugars in the food. European food manufacturers have freely shared their findings and have produced a "Toolbox", hosted on the FoodDrinkEurope website, which recommends strategies for reducing acrylamide formation in different foods [a]. This collaboration reflects the seriousness of the concern amongst food manufacturers to mitigate acrylamide and the acceptance of our research by the International community.

The Food and Drink Federation report that there has been a significant impact of these mitigation strategies on acrylamide in food products with reductions of 30-40% in potato crisps, 15% in potato fries, and 75% in crispbread [b]. An analysis of over 40,000 acrylamide determinations in commercial potato crisps from European countries showed a 50% reduction in acrylamide levels from 2002 to 2011 [c].

Whilst the food industry has adopted strategies for lowering acrylamide through modifying food processing, many manufacturers remain vulnerable to fluctuations in the acrylamide-forming potential of the crops. Developing best practice for cultivation of particular crops, alongside variety selection and improvement, has an important part to play in acrylamide reduction strategies. In this context, Reading's collaboration with Rothamsted Research, has investigated the lowering of acrylamide precursors in cereals and potatoes This has impacted on the understanding of agronomic and genetic factors affecting asparagine and sugar levels in cereals and potatoes and their influence on acrylamide. The impact also extends to crop producers, where research is leading to increased awareness of how plant varieties and agronomy methods relate to acrylamide formation [d].

Evidence in USA legal actions

In 2005 the State of California initiated action against major manufacturers of potato crisps (chips) and French fries alleging they "violated a State requirement that companies post warning labels on products with carcinogens". In 2008, Mottram acted as an expert witness in the court proceedings, providing evidence that helped the court to reach an appropriate and realistic judgement in which the companies agreed to pay a combined US$3 million in fines and reduce the levels of acrylamide in their products over three years rather than having all potato products known to contain acrylamide carrying a health warning [e].

Public Awareness

Governments and the food industry need to provide consumers with information about acrylamide and associated mitigation measures. Our pioneering research at Reading has been used in the provision of such information to the public by highly respected and influential organisations, such as the National Cancer Institute in the USA [f] and the Food and Agriculture Organisation of the United Nations FAO [g]. Acrylamide formation is one of the biggest scientific issues ever to hit the food industry and it continues to attract huge media interest. Articles describing the Reading research have appeared in popular science media outlets, for example:

Frying and baking explain potential carcinogen in crisps and bread. Nature News. Published online 1 Oct 2002. DOI: 10.1038/news021001-1.

Food 'cancer chemical' reaction identified. New Scientist. Published online 1 Oct 2002. <http://www.newscientist.com/article/dn2860-food-cancer-chemical-reaction-identified.html>

Taking the acrylamide out of wheat. Nature News. Published online 23 November 2006. DOI: 10.1038/news061120-11

Davies, E. (2007). Fries to go? Chemistry World, 4, 46-50. <http://www.rsc.org/chemistryworld/restricted/2007/February/FriesToGo.asp>

Reducing acrylamide levels in French fries. ScienceDaily. Published online 26 Sept 2012. <http://www.sciencedaily.com/releases/2012/09/120926123804.htm>

5. Sources to corroborate the impact

[a] FoodDrinkEurope [website]. Acrylamide Toolbox 2011. http://www.fooddrinkeurope.eu/uploads/publications_documents/Toolboxfinal260911.pdf accessed 16 Oct 2013.

[b] Food and Drink Federation [website]. Acrylamide. <http://www.fdf.org.uk/keyissues.aspx?issue=646> accessed 16 Oct 2013.

[c] Powers, S.J., Mottram, D.S., Curtis, A., Halford, N.G. (2013) Acrylamide concentrations in potato crisps in Europe from 2002 to 2011. Food Additives & Contaminants, 30:1493-1500. DOI: 10.1080/19440049.2013.805439

[d] BBSRC Business Magazine [website]. Under the bar: acrylamide and food safety. 6 Feb 2013. <http://www.bbsrc.ac.uk/news/food-security/2013/130206-f-acrylamide-and-food-safety.aspx> accessed 16 Oct 2013.

[e] State of California Department of Justice [website]. Press release: Atty. Gen. Brown settles potato chip lawsuit. 1 Aug 2008. <http://oag.ca.gov/news/press-releases/atty-gen-brown-settles-potato-chip-lawsuit-heinz-frito-lay-kettle-foods> accessed 16 Oct 2013.

[f] National Cancer Institute [website]. Acrylamide in Food and Cancer Risk. <http://www.cancer.gov/cancertopics/factsheet/Risk/acrylamide-in-food> accessed 16 Oct 2013.

[g] Lutzow, M. Acrylamide in Food. Food and Agriculture Organisation of the United Nations [website] <http://www.fao.org/docrep/005/y4267m/y4267m10.htm> accessed 16 Oct 2013.

Users/beneficiaries who could corroborate claims:

- Principle Investigator, Rothamsted Research; able to corroborate impact of the early research at Reading on the investigations worldwide of mitigation strategies for acrylamide and the impact of subsequent research involving Reading and collaborators.
- Vice President, ConAgra Foods Inc; be able to corroborate the impact in the USA of the research at Reading on the understanding and mitigation of acrylamide in foods.
- Secretary General, European Snacks Association; able to provide corroboration of the impact of the acrylamide research at Reading on the food industry.
- Senior Director Foods Innovation & Science, PepsiCo International Ltd; able to corroborate the international impact of the research at Reading on the understanding and mitigation of acrylamide in foods.