

Institution: De Montfort University		
Unit of Assessment: 3		
Title of case study: Increasing Understanding of the Potential Health Risks from Foods Fried in Polyunsaturate-Rich Oils and Informing Industry's Development of Alternative Cooking Oils		
Period when the underpinning research was undertaken: 2013–2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): Martin Grootveld	Role(s) (e.g. job title): Professor in Bioanalytical Chemistry and Chemical Pathology	Period(s) employed by submitting HEI: September 2012–present
Period when the claimed impact occurred: June 2014–December 2020		
Is this case study continued from a case study submitted in 2014? N		
1. Summary of the impact <p>Research at DMU's Leicester School of Pharmacy has provided new insights into the nature and scale of aldehydic toxins in foods fried in oils rich in polyunsaturated fatty acids, demonstrating that human intake often far exceeds World Health Organization recommended limits. The studies have provided the evidence base for the development and marketing of alternative cooking oils by the food industry. They have supported the export preparedness of virgin sunflower oil producers in East Africa and marketing strategies for popular algae-based and cod liver oils produced by food companies worldwide. Through sustained engagement with the international media, the food industry, public-facing chefs and business owners, the findings have increased public awareness and understanding of the potential health risks involved.</p>		
2. Underpinning research <p>A significant proportion of lipids consumed in the Western diet arises from fried foods, and rising consumption of these food sources has been linked to higher rates of non-communicable diseases such as cardiovascular disease and cancer. When polyunsaturated fatty acids (PUFAs) in cooking oils are heated to high temperatures, as they are during frying, a complex chemical deterioration process known as lipid peroxidation occurs, and high concentrations of toxic agents, particularly aldehydes, are generated.</p> <p>Grootveld, among the first researchers to identify the generation of these toxins in polyunsaturated frying oils in 1994, has continued, at DMU, to lead investigations into the deleterious health effects caused by the degradation of fatty acids in frying oils, and explore the peroxidative resistivity of alternative monounsaturated fatty acid (MUFA)-rich oils. From 2013, Grootveld's group has used high-resolution ¹H NMR analysis to explore the extent to which peroxidation by-products of frying oil lipids accumulate in foods. The group analysed deep-fried potato chip samples from food service businesses as part of these studies. They established that the total concentrations of toxic aldehydes present in both fried chips and packaged potato crisps were, on a ppm scale, at least 50 times greater than those of the potential carcinogens acrylamide and 3-MCPD [R1]. More importantly, the accumulation of the products detected (predominantly <i>trans</i>-2-alkenals, <i>trans,trans</i>-alka-2,4-dienals and <i>n</i>-alkanals) demonstrated a clear route through which these harmful toxic by-products from PUFAs can become available for human consumption. Since acrylamide and 3-MCPD are subject to exacting regulatory limits, the research argued that similar limits should be applied to foods fried in oils with high aldehyde contents [R1]. From 2015, major developments made with the analytical identification of differing aldehydic lipid oxidation products, and the concentrations and patterns of these agents present in fried foods, have facilitated changes in viewpoints on potential toxicological and adverse health hazards posed by their dietary ingestion [R1, R2].</p> <p>Grootveld extended his research by exploring the peroxidative resistance of a novel MUFA-rich algae frying oil (MRAFO) during frying, comparing it with commonly used sunflower, corn, canola</p>		

and extra-virgin olive oils. The novel MRAFO tested in these studies is marketed as Thrive™, a high-stability culinary algae oil that was the first such algal product to be made available to consumers in the United States. The findings, published in *Nature Scientific Reports* [R2], showed that the MRAFO product generated markedly lower levels of food-penetrative, toxic aldehydes than PUFA-rich ones during repeated shallow-frying, and thus appeared to alleviate health risks relative to the other oils tested.

Having established the presence of high aldehyde concentrations in fried sunflower oils, Grootveld analysed the molecular composition and authenticity of East African virgin (unrefined) sunflower oil products produced by manufacturers in Uganda and Tanzania. Results were statistically compared to those obtained on commercially available, refined sunflower oil products purchased from EU retail outlets. This analysis found that East African virgin sunflower oils contained higher levels of MUFAs and lower levels of PUFAs compared with the refined EU oils, rendering them safer for deep-frying purposes [R3]. It also found that these products potentially offer health benefits through their high natural sterol and stanol contents. In a concurrent study, Grootveld's group found that a multivariate ¹H-NMR chemometrics analysis served as a valuable strategy for: (1) modelling the time-dependent generation of aldehydic lipid oxidation products through shallow-frying practices; and (2) the identification of their parent fatty acid sources [R4]. This approach could be used in future predictions of the risk status of ingested fried foods from the fatty acid compositions of oils.

The ¹H-NMR methods were also applied to an analysis of the molecular composition and antioxidant status of four unrefined cod liver oil products, three of which were non-fermented, and one of which was isolated from pre-fermented cod livers. Results confirmed the enhanced peroxidative resistivity of the pre-fermented, antioxidant-rich 'product 4' over the non-fermented products [R5]. 'Product 4' is marketed as Green Pasture Blue Ice™ fermented cod liver oil.

As a combined body of work, the research by Grootveld's group at DMU has demonstrated that toxic aldehydic lipid oxidation products can be detected, quantified and thus monitored in fried foods, meaning that it is now possible to estimate the human intake of such toxins in fried foods prepared domestically or purchased from fast-food restaurants [R6].

3. References to the research

Since 2018, Prof. Grootveld's group has published eleven peer-reviewed journal articles in this area. The *Nature Scientific Reports* paper [R2] has an Altmetric online attention score that puts it in the top 5% of all research outputs scored by the bibliometric service, with the paper reaching an upper bound of 260,000 followers on Twitter.

- [R1] Grootveld, M., Percival, B.C. and Grootveld, K.L. (2018) 'Chronic non-communicable disease risks presented by lipid oxidation products in fried foods', *Hepatobiliary Surgery and Nutrition*, 7(4): 305–312; doi: 10.21037/hbsn.2018.04.01
- [R2] Moumtaz, S., Percival, B., Parmar, D., Grootveld, K.L., Jansson, P. and Grootveld, M. (2019) 'Toxic aldehyde generation in and food uptake from culinary oils during frying practices: peroxidative resistance of a monounsaturate-rich algae oil', *Nature Scientific Reports*, 9: art. 4125; <https://doi.org/10.1038/s41598-019-39767-1>
- [R3] Percival, B.C., Savel, E., Ampem, G., Gibson, M., Edgar, M., Jafari, F., Woodason, K., Frederick, K., Wilson, P. and Grootveld, M. (2019) 'Molecular composition of and potential health benefits offered by natural East African virgin sunflower oil products: A 400 MHz ¹H NMR analysis study', *International Journal of Nutrition*, 3(3): 22–43; doi: 10.14302/issn.2379-7835.ijn-19-2677
- [R4] Grootveld, M., Percival, B.C., Moumtaz, S. and Grootveld, K.L. (2019) 'A ¹H NMR-linked PCR modelling strategy for tracking the fatty acid sources of aldehydic lipid oxidation products in culinary oils exposed to simulated shallow-frying episodes', *International Journal of Chemical and Molecular Engineering*, 13(6): 251–263; doi:10.5281/zenodo.3299355

Best Publication Award received by M. Grootveld.

- [R5] Percival, B.C., Zbasnik, R., Schlegel, V., Edgar, M., Zhang, J. and Grootveld, M. (2020) 'Determinations of the peroxidative susceptibilities of cod liver oils by a newly-developed ¹H NMR-based method: resistance of an antioxidant-fortified product isolated from pre-fermented sources', *BMC Research Notes*, 13(1): art. 73; <https://doi.org/10.1186/s13104-020-4932-6>
- [R6] Grootveld, M., Percival, B.C., Leenders, J. and Wilson, P.B. (2020) 'Commentary – potential adverse public health effects afforded by the ingestion of dietary lipid oxidation product toxins: significance of fried food sources', *Nutrients*, 12(4): art. 974; <https://doi.org/10.3390/nu12040974>

4. Details of the impact

Studies at DMU highlighting the generation of potentially harmful toxins through the exposure of PUFA-rich cooking oils to high-temperature frying have informed the food industry's development of alternative oils that do not readily oxidise to ingestible toxic aldehydes under thermal stress, and an increased public awareness and understanding of this health risk.

(1) PROVIDING THE EVIDENCE BASE FOR THE FOOD INDUSTRY'S DEVELOPMENT AND MARKETING OF ALTERNATIVE COOKING OILS

The UK's Department for International Development funds the Supporting Indian Trade and Investment for Africa (SITA) project, an Indo-Africa trade partnership that aims to build the export capabilities of industries in five East African countries. As part of its efforts to support the development of the sunflower oil sector, SITA commissioned the East African virgin sunflower oil study that led to the publication of R3. The results benefited sunflower oil processors, industry associations and regulatory authorities in Tanzania and Uganda, who found themselves 'in a better position to improve services to their stakeholders' through the verification of the quality of their products' [C1]. According to SITA, several sunflower oil producers from these countries, i.e. millers from farming regions, said the research findings support 'export readiness for EU markets'. It commented: 'Export preparedness and exposure to international markets is vital to ensure sustainability of the sector' [C1].

Thrive Algae Oil ® is a MUFA-rich culinary oil produced from algae – the first of its kind on the market – that was originally developed and manufactured by American company Solazyme. It is available in US-based retailers such as Whole Foods, Walmart and Amazon. The product was acquired by large Dutch food and biochemical company Corbion in 2018, who made a strategic decision to extend the sale of Thrive Algae Oil to the business-to-business environment. Grootveld's *Nature Scientific Reports* paper [R2] 'formed the basis for marketing material for Thrive Algae Oil's push into the B2B space', as confirmed by the former Head of R&D for Solazyme and consultant for Corbion, who also stated that 'Professor Grootveld's seminal paper on toxic aldehydes in frying oils was a pivotal contributor to our decision to engineer an oil high in MUFA (≥94%) and low in PUFA to minimize the generation of toxic aldehydes during frying events' [C2].

Similarly, the research in *BMC Research Notes* [R5] reported the favourable peroxidative resistivity of naturally-fermented cod liver oil products marketed by US company Green Pastures Products. The company's General Manager of Production and Quality Assurance stated:

The finding of this project reveals the unique properties of our products and provides the scientific evidence of the benefits of fermented cod liver oil. The results have been used to improve our production processing, including extending the fermenting period to increase the yield and adjusting the storage condition to help save cost ... A professionally-prepared Health and Medicine Research Outreach article ... and podcast based on these findings, which was sent to dozens of our wholesalers, facilitated the dissemination of beneficial product information to thousands of customers. We anticipate at least a 5% increase in sales will be achieved after the results are broadcasted to our wholesalers and retail customers in this quarter [C3].

(2) INCREASING PUBLIC AWARENESS AND UNDERSTANDING OF HEALTH RISKS ATTACHED TO FOODS FRIED IN PUFA-RICH COOKING OILS

Since June 2014, Grootveld has proactively engaged with the media, food organisations and high-profile chefs to increase public awareness and understanding of the potential health risks of frying foods in PUFA-rich cooking oils. In 2015, Grootveld ran a series of experiments for the popular BBC documentary series *Trust Me I'm A Doctor*, which were designed to determine which oils are best to cook with. The analyses found that the PUFA-rich oils, like corn oil and sunflower oil, generated very high levels of aldehydes in contrast to the oils and fats rich in saturated fats or MUFAs (like butter and olive oil). Grootveld identified two previously unknown aldehydes that had not been seen in other oil-heating studies. Based on the study's conclusions, later published in R1 and R2, the programme's presenter, Dr Michael Mosley, communicated three main recommendations to an estimated 3,000,000 viewers in the 29 July 2015 episode [C4]:

- To reduce aldehyde production when cooking by choosing an oil or fat high in monounsaturated or saturated lipids and low in polyunsaturates, with olive oil representing a good compromise.
- Minimise the amount of oil use when cooking.
- Keep oils tightly sealed in a cool, dry cupboard to prevent oxidation during storage.

During the programme, Mosley conveyed this message to viewers [C4]: 'Some of the oils we've been told are good for us (most notably sunflower oil and vegetable oil), actually turned out to be potentially dangerous when used for cooking.' He also emphasised that saturated fats like lard and butter, which are 'usually demonised', were least likely to produce high concentrations of toxins when fried at high temperatures, although they should be used 'sparingly'. The findings broadcast in the documentary were widely covered in traditional and online media [C5]. This included articles authored by Mosley in the BBC's online news magazine [C4] and the *Daily Mail* [C4]. As an indication of the impact of the media coverage on public understanding, the *Mail* article, which was shared 9,000 times on social media, received 1,130 comments from readers, of which nearly 70% responded positively [C5]. A large percentage (64%) confirmed that they would maintain their cooking practice by continuing with monounsaturated and saturated frying oils [C4]. Another, albeit smaller group, said that they would modify their domestic frying/cooking strategies to exclude polyunsaturated cooking oils as much as possible and replace them with monounsaturated oils (e.g. olive oil), a move that was in line with the article's key message [C5]. The experiments performed for the documentary were cited in a 'Fact Check' article [C6] in *The Conversation*, which concluded that olive oil is one of the better options for frying foods.

Findings from the studies carried out for the BBC documentary, coupled with similar conclusions drawn in an article by Grootveld and colleagues in the American Oil Chemists' Society magazine *INFORM* [C7], have had a sustained influence since June 2014. For example, *The Telegraph* covered the findings in two articles in November 2015, *Women's Health* magazine (UK) published a related feature in 2016 and *The Times* ran similar articles in 2017, 2018 and 2019 [C5]. The *Telegraph* articles led to the New Zealand Heart Foundation reiterating this key message: 'Avoid deep frying foods but if you must do so, avoid oils that are rich in polyunsaturated fats because these are unstable at high temperatures' [C5]. The Australian Oilseeds Federation said Grootveld's studies 'vindicated the longstanding recommendations of the Australian oilseed industry that oils high in polyunsaturated fats, such as traditional sunflower and corn oil, should not be used for deep frying' [C5].

Grootveld's findings on thermal stressing of different fats during deep-frying informed a report compiled for the Healthier Catering Commitment (HCC) group. HCC is a London scheme and award, running across 22 boroughs in London and backed by the Greater London Authority, that supports fast-food businesses to make their food 'healthier'. The Greenwich representative on the HCC, writing in 2018, said Grootveld's input had been 'very useful to our area of work' and confirmed that some of the HCC criteria took into account frying method and the fat/oil used to fry foods [C8]. The Head of Nutrition for Jamie Oliver Group consulted Grootveld in 2017 'to make sure that the public health message that comes across [in Jamie Oliver's books and TV shows] ties in with research such as yours [Grootveld's] and that we aren't recommending

anything wildly inaccurate'. She said that as a result of Grootveld's findings she would be asking the food development team 'to check the temperature of the frying oil and the frying time for the recipes where this is relevant' [C8]. Grootveld was acknowledged in the popular 2016 cook book *River Cottage A to Z: Our Favourite Ingredients, and How to Cook Them* for his research-based advice on cooking fats and oils. Co-author Hugh Fearnley-Whittingstall [C8] wrote: 'His [Grootveld's] research and guidance have been crucial in allowing us to navigate this complex and confusing subject and present the most up-to-date information, in layperson's terms, to readers.' Noting that Grootveld's work continues to inform his recipe writing, including 'invaluable input' for his upcoming book *Eat Better Forever*, due to be published December 2020, Fearnley-Whittingstall said the research 'has been very instrumental in increasing my own knowledge in this area, and by extension the knowledge of my readers'.

5. Sources to corroborate the impact

- [C1] Reaction to the SITA-funded study on East African virgin sunflower oils (via SITA website), July 2019: <http://www.voicesofsita.com/2019/07/22/sita-study-reveals-health-benefits-of-east-african-sunflower-oils/>
- [C2] Corroborating statement from former Head of R&D at Solazyme Inc. and consultant for Corbion
- [C3] Corroborating statement from the General Manager of Production and Quality Assurance at Green Pastures Products LLC.
- [C4] Links to coverage of research in BBC documentary series *Trust Me I'm A Doctor*: <https://www.bbc.co.uk/programmes/articles/3t902pqt3C7nGN99hVRFc1y/which-oils-are-best-to-cook-with>; <https://www.bbc.co.uk/programmes/p02ybfrf>; <https://www.bbc.co.uk/news/magazine-33675975>
- [C5] Summary PDF report of media coverage of the research over the impact period, including a *Daily Mail* article by Dr Michael Mosley (including reader comments): <https://www.dailymail.co.uk/health/article-3176558/It-s-healthier-cook-LARD-sunflower-oil-Extraordinary-experiment-shows-ve-told-cooking-oils-wrong.html>
- [C6] Fact Check article in *The Conversation* on health risks attached to frying oils: <https://theconversation.com/amp/fact-check-is-it-bad-for-your-health-to-eat-food-fried-in-olive-oil-79680>
- [C7] Feature article in *INFORM* magazine, American Oil Chemists' Society. <https://www.aocs.org/stay-informed/inform-magazine/featured-articles/detection-monitoring-and-deleterious-health-effects-of-lipid-oxidation-november/december-2014?SSO=True>
- [C8] Compilation of corroborating statements from food and nutrition advisers, publishers and chefs.