FHIS Food & Health Innovation Service

Food Processing Technologies for Reduction of Fat in Products

Quotec Ltd, January 2012

Prepared by Dr John Stanford, Senior Consultant
Checked by Ian Blakemore, Head of Food Division

CONTENTS

1 Introduction

Concern over levels of obesity and excess weight in the UK population has in recent years led to an increasing focus on efforts to reduce the quantities of fat eaten by consumers. Many initiatives are centred around social issues such as better education on the risks associated with high fat foods and on better diet choices such as reduced consumption of high fat foodstuffs and increased consumption of fruit and vegetables. Consumers however have a deeply entrenched expectation of the organoleptic properties of food and the experience that eating gives, and the satisfying nature of, for example, fried foods means that their consumption remains high. It thus seems apparent that strategies complementary to that of improved diet will be necessary. One such strategy is in the replacement of fatty ingredients with alternatives which can duplicate the functionality of traditional ingredients without loss of other properties. These replacement ingredients, which include materials such as starches, proteins and celluloses, are now widely available and are incorporated into many commercial recipes. Dissatisfaction remains however amongst consumers on the organoleptic qualities of some such products.

Fats have always been physically removed through traditional techniques such as skimming and cutting. Modern manufacturing process methods aim to physically remove fats using advanced technologies, or prevent their incorporation into the food matrix. This report provides an overview on recent innovations in this area, highlighting emerging technologies and current research.

A number of discrete areas have been identified and the report is arranged correspondingly. A brief overview of the broad areas covered is given below.

- **Advanced technologies** being developed by major food corporations are bringing low fat versions of common food ingredients to the market. The technologies include cryogenic crystallisation and super critical fluid extraction.

- **Solvent extraction** has been explored for the extraction of fats from finished products such as cheese.

- **Frying** is the cause of much fat absorption into food. There has been much activity to control fat uptake in food processing, based upon pre and post frying treatments, modifications of the frying method, and edible barrier techniques.

- The structure of foods can be manipulated so that parts of the food matrix not contributing to **sensory perception** can be replaced with fat free areas, in the form of complex air or water emulsions.

The following section 2 comprises of a table which summarises the technologies investigated, with an indication of their potential for reducing fat levels in the product, where known. Sections 3-6 provided more detailed discussion with some hypotheses on the mechanism of fat reduction.

2 Table Summarising Technologies and Fat Reduction Potential

Technology	Application	Indicative fat reduction vs. conventional product	Sensory observations/ claims	Reference
Advanced Technologies				
Cryogenic Crystallisation	Powdered Fats	20% in laminated pastry	No loss of quality	BOC Group Ltd (2003)
Solvent Extraction	Cocoa Mass	90-95% in cocoa powders	Desirable textural qualities	Cargill Inc. (2010)
Supercritical Fluid Extraction (CO_2)	Cheese	24% in parmesan cheese	SFE treated parmesan preferred by panellists	Yee et al (2007)
Pre-Frying				
Sweet Pre-treatment	Crisps	30% in potato crisps	Increased sweetness and excellent crispness	Mai Tran et al (2006)
Air Drying	Potato Frying	14.5% in potato cylinder	None	Moreno and Bouchon (2008)
Warm Oil Blanching	Crisps	Approx. 50% in potato crisps	Preservation of taste components compared with water or steam blanching	Frito-Lay Trading Company (2011)
SuperHeated Steam	Battered Snacks	23% in battered sausage	Good match on colour and crispiness better than conventional product	Primo-Martin and Deventer (2010)
Modified Frying				
Vacuum Frying	Crisps	51 % in carrot crisps	Lighter coloured product	Duiek et al (2010)
Radiant Heating	Frozen Foods	37-38% in chicken patties and potato cakes	Favourable flavour compared with conventional product	Nelson et al (2010)
Pulsed Electric Field	Crisps	39% in potato crisps	None	Janositz et al (2011)

Table continued:

Technology	Application	Indicative fat reduction vs. conventional product	Sensory observations/ claims	Reference
Barrier Layers				
Whey/soy Protein	Deep-fried Vegetables	29% in cassava products	None	De Grandi Castro Freitas et al (2009)
Whey Proteins	Battered Meat	27% in battered chicken	None	Dragich and Krochta (2009)
Methylcellulose	Deep-fried Dough Products	80% in potato dough model system	None	Quasem et al (2009)
Dry Particle Coating	Deep fried Dough Products	36% in doughnuts	No significant difference except appearance	Lee et al (2008)
Sensory Perception Approaches				
Air Emulsions	Emulsified Products	None reported	None	None
Water in Oil in Water (WOW) Emulsions	Cheese	26% in White Fresh cheese	Good results after 3 days, declining after 15 days.	Lobato-Calleros et al (2008)

3 Advanced Technologies in Ingredients Manufacture

3.1 Cryogenic Crystallisation

Powdered fats have characteristics which are different from the conventional amorphous structures. The BOC Group Limited (2003) patented a technique to prepare powdered fats by the use of cryogenic spray crystallisation. In conventional spray crystallisation a liquid stream is sprayed through a nozzle and rapidly cooled with air to form powders, a process which can be highly controlled to give consistent particle size distributions. In the cryogenic technique products normally molten at low temperatures, such as fats, are subject to cooling using a medium such as carbon dioxide or nitrogen gas. The result of this is that fats can be crystallised into powdered form with the opportunity to utilise various nozzle designs to engineer particle size and shape. The fat crystals are smaller than can be achieved using other commercially employed technologies such as scraped surface technology. Such crystals have enhanced functionality in foods such as baked products such that they can be used in smaller amounts than conventionally produced fats without loss of "mouthfeel" or appearance. Thus using a shortening produced from cryogenically re-crystallised hard fat it was found possible to prepare laminated pastry with at least 20% by volume less fat than in conventional products and without loss of quality criteria. For example, three commercial shortenings were compared with reduced fat versions. Simply reducing the amount of fat in the conventional recipe to 70% resulted in approximately 50% loss of baked pastry height. When the same level of re-crystallised fat produced by cryogenic crystallisation was used however there was no loss of pastry lift and other characteristics such as palate cling were favourable.

3.2 Solvent Extraction

Cocoa powder used in the production of food products such as cake mixes, frostings, cookies and chocolate drinks can have a fat content of 10-20%. This fat level can be reduced by extracting it using either supercritical fluid extraction (SFE) or more conventionally using solvents such as food grade propane and butane. At elevated pressures carbon dioxide can exist as a supercritical fluid, a phase of matter where distinct gas and liquid phases do not exist. The use of supercritical carbon dioxide as an extraction solvent in food processing is well known.

Cargill Inc. (2010) described the processing of cocoa mass to produce low fat cocoa powder containing 0.5 to 2% fats. Solvent extraction was favoured over SFE, reasoning that SFE requires expensive plant and the fluid of choice, supercritical carbon dioxide is not a good solvent for typical cocoa fats. Extraction using solvents such as propane, butane or pentane was said to produce a cocoa powder with desirable taste, mouth feel and related characteristics and to be effective as a food additive. The solvents furthermore have good solubility for fats, without extracting flavour components desirable in the product. The cocoa powders were lighter in appearance than full fat versions, but this was said to not be significant when blended into product recipes with other ingredients. A range of products were explored including milk chocolate, ice cream, frosting, syrup, cakes and brownies. A trained sensory panel reported the flavour differences between the fat-free powders and standard counterparts as "negligible". Residual solvent levels were no more than about 3 ppm.

4 Extraction of Fat from Finished Products

4.1 Supercritical Fluid Extraction

Advanced technologies have also been applied to finished food products. Yee et al (2007) investigated the effect of fat reduction in cheese using carbon dioxide in a supercritical fluid extraction. Grated cheddar cheese and parmesan cheese were subjected to a range of conditions with the maximum fat reduction being 51% for cheddar and 56% for parmesan. Analysis of the profile of the fats removed showed that only non-polar lipids (triacylglycerides and free fatty acids) were extracted. More polar lipids such as phospholipids were retained in the cheese matrix. This is significant from a health viewpoint because phospholipids have many health related benefits. Thus the retention of these fats in cheese may provide added benefit to consumers in addition to lowering the overall fat content.

Profiling of the flavour components present in the cheeses showed that in the case of the SFE versions more components were actually detected, suggesting that in the full fat versions several components are masked. This could have an impact on flavour perception by a consumer. Sensory tests provided information on whether consumers could perceive the change in SFE cheeses, and how acceptable the final product was to the panellists compared to other products. The conclusion of the tests was that the panellists could identify the difference between the full-fat and SFE cheddar cheese samples, but could not differentiate between the parmesan samples, and actually preferred the SFE parmesan sample (24% fat reduced version).

5 Frying

5.1 Frying Overview

In order to obtain products with low fat content it is helpful to understand the mechanism by which fat is incorporated into products during the frying process. This can be up to 40% of the total food weight product

Bouchon (2009) described the essential features of oil absorption during deep fat frying. Frying is essentially a dehydration/absorption process. When the food is immersed in hot oil the high temperature of the frying oil causes the evaporation of water at the surface of the food. As water from the external layers escapes and moves into the surrounding oil a dehydrated crust is formed, the temperature of which then increases above the boiling point of water. The loss of water from the external crust layer leaves empty spaces into which oil can migrate. It has been shown however that during frying the vigorous escape of water vapour generates a barrier to oil migrating into the porous crust, limiting oil uptake during most of the immersion period. Consequently, oil uptake mostly occurs when the food is removed from the oil and cools down. The largest amount of oil absorption is caused by a vacuum effect as steam condenses in the crust, with further oil remaining as surface oil. Studies by Moreira et al (1997) on tortilla chips for example showed that only 20% of the total oil content was absorbed while they were immersed in oil, and that almost 64% of the total oil was absorbed during post-frying cooling.

Oil reduction methods then attempt to intervene in the processes described above. They can in general be divided into pre and post frying treatments, and modified frying methods i.e. a variation from the normal process of frying in hot oil at atmospheric pressure in the 170-190^{O}C range.

5.2 Pre-Frying Treatment Techniques

Pre-frying treatments aim to reduce oil absorption by reduction of surface permeability. Mai Tran et al (2006) reviewed a range of treatment options. A number could be rejected for obvious reasons, amongst them immersing in difluorodichloromethane to remove excess oil (ozone destructant), silica in frying oil (gritty product) and soaking in salt (over salty product). A 'sweet' pre-treatment technique however was investigated in which potato slices were dried and then dipped into sugar solutions before frying as normal. The research showed that an oil reduction in the product of 30% was possible. The paper does not speculate on the mechanism but it can be speculated that the sugar interacts with the surface of the potato to reduce the permeability of oil into the slice.

Moreno and Bouchon (2008) evaluated the effect of freeze-, air- and osmotic- drying pre-treatments on oil absorption during potato frying. They concluded that freeze drying increased oil suction compared to the control, mainly because sublimation of water from the potato surface creates an external porous structure that reduces the resistance to oil absorption, whereas air drying diminished it, probably due to the lower permeability of the external tissue which could be due to shrinkage of the external pores. Interestingly, osmotic dehydration previously reported as being effective in oil absorption reduction turned out to be ineffective, even increasing the oil taken up compared to the control. The difference between results found in this study and those reported in earlier literature was due to the way results were reported. Normally, oil uptake results are expressed on a dry basis, a basis that, as revealed in this study, can be noticeably increased during osmotic dehydration due to solid impregnation, hiding the real effect. Therefore to carry out adequate comparisons between treatments in absolute terms, it is necessary to calculate the net amount of oil taken up by each sample. The increase in oil uptake of osmotically dehydrated samples was, similarly to freeze drying, mainly attributed to the greater external pore space available due to the considerable water lost during the pre-treatment process.

Battered frozen snack products are subject to two frying steps. Products are coated in batter and then fried for a short time to set the batter so that the product can be frozen and stored. Then, prior to serving, the frozen item is fried again.

Primo-Martin and Deventer (2010) investigated super-heated steam (SHS) as an alternative to the pre frying step in the preparation of deep fried battered snacks. Previous work in this area has shown that low fat products can have poor crispiness characteristics, hence this was a key feature of this research. The study showed that battered sausage snacks prepared with a 3 minute SHS pre-treatment step at 180^{O}C were a good match for those subject to a conventional frying pre-treatment of 180^{O}C for one minute. After allowing 20 minutes post frying storage, the SHS pre-treatment gave a product with 12.7% oil content, compared with 16.4% for conventional frying. There was also a good match on colour parameters, and crispiness (assessed by the mean intensity of the sound emitted during fracture of the crusts) was higher for the SHS treated product.

5.3 Modifications of Frying Method

Warm Oil Blanching

In the above section 5.2, Morena and Bouchon demonstrated that an air drying pre-treatment has potential for producing reduced fat products. This was explored further by Frito-Lay Trading Company (2011) in patenting a pre-treatment technique claimed to be a process for making a healthy snack food. In this patent a range of pre-baking techniques were reviewed. As discussed above, the purpose of pre-baking appears to be to shrink the surface of the food, making it less permeable to oil in the subsequent frying process. The review however suggests that nearly all the prior art processes resulted in a low fat product which had organoleptic properties far less desirable than the fried potato crisp counterpart. Some oil absorption is clearly necessary to get a good flavour. Accordingly, Frito-Lay patent a process whereby a snack food is subject to an oil blanching stage as a warm oil dip at an oil temperature of 85–90 ^{O}C for about 80 to 100 seconds, followed by 'explosive dehydration[1]' in a non-oil medium such as microwave, radio frequency radiation or superheated steam. This is said to simulate the frying process but avoiding the immersion process implicated in high oil content in the product. An advantage of oil blanching with a warm oil dip is the preservation of minor constituents of the food slice that make important

---

[1] Explosive dehydration simulates a dehydration profile corresponding to a fried food product but in a non-oil medium.

contributions to flavour and colour that may be solubilised or otherwise impaired if using a classical water or steam blanching. Although no frying is involved, the technique of oil blanching as disclosed here brings the flavour of the finished chip much closer to its fried counterpart when compared to other blanching methods.

One advantage of adding oil before the explosive dehydration is that it will be heated up for a short period toward the end of the explosive drying and this develops fried-flavour characteristics.

Vacuum Frying

Dueik and Bouchon (2010) investigated vacuum frying of novel snacks. In a vacuum frying process, the frying vessel is enclosed and pressure reduced so that the boiling point of water is reduced to well below 100^{O}C . This means that the dehydration process can be driven by lower oil temperature, in these experiments either 98 or 118^{O}C. At these lower temperatures degradation of surface structural characteristics which might permit oil penetration are postulated to be much less. The experiments did indeed show that for vacuum fried carrot, potato and apple chips oil uptake was up to 51, 57 and 27% respectively less than for non-vacuum fried controls. An additional benefit is that there was less degradation of nutritional components such as carotenoids and ascorbic acid. As would be expected, cooking at lower temperatures leads to preservation of natural colours and a lighter coloured product from vacuum frying, and consideration would need to be given to consumer acceptance of such products.

In an additional study by Dueik et al (2010) on vacuum frying of carrot crisps, further postulation on the mechanism of lower oil absorption is made. At the end of the vacuum frying process, a basket containing the crisps is lifted from the hot oil and then the vessel is pressurised by opening a valve to the atmosphere. It is suggested that this causes vapour inside the surface pores to rapidly condense, obstructing the absorption of oil. This is somewhat at odds with the argument presented by Bouchon in section 5.1 above that rapid condensation within the pores causes a vacuum effect which draws in oil. The two situations are not exactly comparable however and other mechanistic subtleties might be occurring.

Radiant Frying

Radiant frying avoids immersion in oil altogether. A characteristic of frying is the high heat flux generated compared with other processes such as conventional baking. In radiant frying systems, powerful halogen emitters are positioned so as to generate a heat flux which is comparable to the frying process. Nelson et al (2010) compared a proprietary radiant system, the FryLess 100K, with oil immersion frying. Food is transported through this system in baskets via a variable speed chain conveyor.

In the study, frozen chicken patties and potato cakes were obtained from a grocer. Control samples were cooked according to manufacturer's instructions and the conditions served as models for the radiant frying process. The patties and cakes were then cooked in the FryLess system. The results showed that oil content in the radiant fried product was 37-38% less than in the immersion cooked product. This is to be expected hence the key question is with regard to how good the organoleptic properties are. Accordingly, a preliminary sensory evaluation was carried out. Panellists noted differences between the radiant and immersion fried products, particularly that the radiant products were less oily and less crispy. Flavour characteristics were however preferable in the radiant fried product, suggesting that the increased oil content in the conventionally fried product masked some flavour components.

Overall, panellists preferred the radiant fried products over the immersion fried products.

Pulsed Electric Field (PEF)

PEF is a newly emerging processing application in which a liquid food or other product that can be pumped is passed through a chamber where it is subject to a short (10 nano seconds to 20 microseconds) pulse of very high voltage. Interest has initially been from a food safety perspective as the high voltage field created in the liquid kills microorganisms by disrupting their cell membranes. The technique however also has the potential to influence mass transfer processes through the disruption of plant based cell structures. PEF is for instance being investigated in how it can facilitate the process of extraction of juices from fruit.

Janositz et al (2011) investigated the effect of PEF on the diffusion characteristics of potato slices, including the uptake of oil in frying processes. They found that PEF treated samples had a fat reduction in the order of 39% compared to untreated or blanched samples. In consideration of this, the authors speculate that the PEF process causes permeabilisation of cell membranes within the potato, which allows for greater diffusion of water from the core to the surface, resulting in a thicker water vapour layer at the surface which prevents oil penetration. This however is in conflict somewhat with the argument presented in section 5.1 which states that the majority of oil is absorbed after removing from the heating medium. PEF treatment could be having an effect on the microstructure of the crust layer which reduces oil adsorption. Further research is needed to elucidate this mechanism.

5.4 Barrier Layers

There are a range of edible materials available which can be coated onto food products to form layers which constitute a barrier to ingress of other materials. De Grandi Castro Freitas et al (2009) looked at the potential for three barrier layers to reduce the fat uptake in cassava product during deep-fat frying. Edible coatings from three hydrocolloids were explored – whey protein, soy protein and pectin. The coatings were applied to preformed cassava products by immersion in aqueous solutions of the biopolymers. The products were then tray dried, pre fried in vegetable oil and then frozen and stored for 30 days before the final frying at 180^{O}C for 1.5 minutes. The results showed that an oil reduction of up to 29% compared with a control was possible, with whey proteins and soy protein giving the best results. No sensory evaluations were carried out.

Dragich and Krochta (2009) looked at the use of whey protein as a coating for fat-uptake reduction in fried chicken. Reviewing earlier work, the authors suggested that certain steps were necessary to give a good result:

- Protein coatings appeared to have better promise than polysaccharides such as methyl cellulose.
- To encourage film formation, a sufficiently strong solution is required.
- The film should be formed as an external layer on the product, not incorporated into the product itself.
- As most fat uptake in fried chicken products is in the coating, not the meat, the barrier layer is best applied to the coating.

Consequently the experiments showed that coating chicken with a wheat flour/batter/wheat flour/10% Denatured whey protein isolate (DWPI) film combination gave good fat reduction in the fried product, with fat uptake in the coating reduced from 37% to 27%. The authors hypothesise that the DWPI film modifies the surface structure of the product by filling pores in the surface which would otherwise provide a route for oil ingress. Alternatively, the larger moisture content of the DWPI film increases the surface tension with the oil, contributing to less fat uptake. No sensory evaluations were carried out.

Quasem et al (2009) looked at the effect of methyl cellulose (MC) coating on oil uptake in deep-fat fried starchy dough systems. The study used potato dough cylinders as a model food, and observed a dramatic reduction of 80% in oil uptake for a 0.5% MC coating compared with a control. They concluded that MC had the potential to significantly reduce oil uptake during frying of potato dough. Unusually, increasing the frying temperature decreased oil uptake; this is thought to be due to the gelatinisation of MC at higher temperature, making it an even more resistant barrier. The efficacy of MC stated here is somewhat surprising given that Dragich and Krochta suggested the superiority of whey proteins.

Lee et al (2008) showed lower fat uptake in food composites prepared by dry particle coating techniques, using doughnuts as the model substrate.

Soybean hulls are inexpensive by products of soybean processing and are high in fibre contents. The hulls were microparticulated by a jet milling process. These were further impacted with wheat flour in a hybridisation process to form wheat flour/soybean hull composites. These were then made into doughnuts, fried and fat uptake and other characteristics compared with controls made with conventional wheat flour. The results showed that composites with up to 10% soybean hull reduced fat content from 40.5% to 26%. The authors hypothesise that the soybean hulls form a protective layer around the flour particles, reducing oil penetration into the doughnut. Penetration can also be reduced by simply working with soybean hull/wheat flour mixtures, but these were not quite so effective. Sensory evaluation showed no significant difference in appearance, flavour, crispiness, taste and general preference, except that the composite with 10% soybean hull had a somewhat low score for appearance.

6 Sensory Perception Approaches

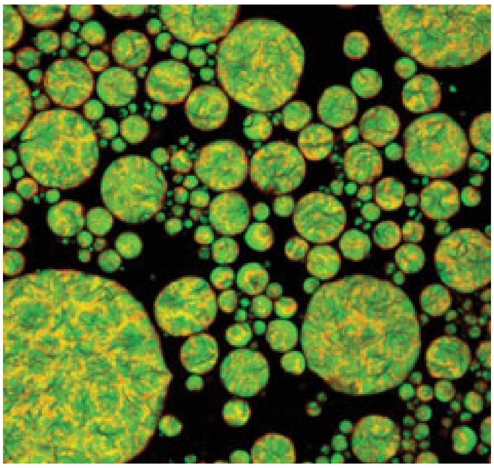
This approach has great promise, but is still mainly at the research and development stage.

6.1 Air Emulsions

A major challenge in creating low fat food products is in providing an acceptable organoleptic experience for the consumer. One approach to this is in creating low fat products that accurately resemble the full fat version in terms of their sensory behaviour and perceived indulgence. Many food stuffs are emulsions of oil droplets in water. It is possible that small, stable air bubbles designed to resemble oil droplets in terms of their size and physical properties could be used to produce a new generation of low fat foods. The consumer senses the properties of the food stuff on the outside of the bubble but, because part of the interior of the bubble is replaced with air, actually consumes less fat. Ongoing research shows the potential of this approach, but there is a major challenge in stabilising suitable emulsions to give a product with acceptable shelf life. It is well known that aerated systems are destabilised by a range of physical processes including coalescence. It has been shown that by selecting the correct surface stabilising molecule that stability can be increased; this is particularly true for proteins and specifically hydrophobin proteins.

Hydrophobins are filamentous proteins that are produced in certain edible fungi and so have potential as food grade materials. Tchuenbou-Magaia et al (2009) described air-filled model emulsions for the food industry stabilised with hydrophobins. In their study the hydrophobins were extracted from *Trichoderma reesei.* Reagents such as trifluoroacetic acid and sodium dodecylsulphate (SDS) were part of this process, so work remains to demonstrate food grade hydrophobins.

Creating an air filled emulsion had three essential steps. Firstly, air cells with hydrophobin coats were created by ultrasonic irradiation of an aqueous hydrophobin solution. Secondly, an oil in water emulsion was created by high shear mixing of sunflower oil into a stabilised aqueous phase. The two phases were then blended together to create a tri-phasic emulsion of air-in-oil-in-water, with the air/water interface stabilised by hydrophobins. The image below[2] shows a micrograph of a tri-phasic emulsion.



Water phase – black background
Oil phase – large yellow bubbles
Air phase – small green bubbles

The triphasic emulsions were studied to assess their rheological and stability properties against a comparable conventional biphasic oil-in-water emulsion. The study found a good match in terms of flow properties, and that the triphasic emulsion had excellent stability over a period of 45 days. The authors concluded that the model studies demonstrated a real opportunity to create low fat food products base on air filled emulsions.

6.2 Water in Oil in Water (WOW) emulsions

WOW emulsions are of similar interest to the AOW emulsions described above. While there has been some investigation on real food stuffs, a better understanding of structure and stability of WOW model emulsions is necessary before they can be successfully incorporated into food.

Surh et al (2007) explored the preparation and characterisation of WOW emulsions containing biopolymer gelled water droplets. There have been many difficulties associated with preparing these types of multiple emulsions for utilisation within the food industry due to problems with internal water

[2] Image taken from Chemistry World article "Clever Comestibles" August 2011

droplet coalescence and expulsion and diffusion of water molecules from the internal aqueous phase to the bulk aqueous phase. The study attempts to prevent some of these problems by creating an internal water phase containing whey protein isolate, which can be gelled by heating the OW phase. The authors postulated that the gelled structure should be more stable against disruption when homogenising the OW phase into water. The paper describes many detailed studies on the structure and stability of triphasic WOW emulsions but concludes that gelling the internal phase did not facilitate the formation of WOW emulsions, compared with non-gelled. It does however appear to improve the prospects for stabilisation of the WOW emulsions once formed.

Lobato-Calleros et al (2008) prepared reduced fat cheese like products from WOW emulsions and looked at structural and textural characteristics. The study compared standard white fresh cheese made from skim milk, with cheese prepared from blends of skim milk with WOW emulsions based on canola oil and various edible biopolymers such as gum Arabic, carboxymethylcellulose and amidated low-methoxy pectin (LMP). The WOW cheeses had fat levels ranging between 11.3 and 13.0 g/100g cheese, compared with 15.3g in the conventional cheese. Sensory testing with a panel of 80 consumers gave very promising results. After 3 days, mean overall preference of the WOW cheeses compared well with conventional cheese (score 3.7 out of 5), with LMP cheese at 3.9 scored slightly better. After storage at 15 days however preference for the WOW cheeses declined somewhat, with the CMC version rated as giving a "teeth grinding sensation". The paper shows that there is still work to do to bring WOW based products up to the required standard for consumers.

7 Conclusion

The studies presented above show clear potential for using manufacturing technology to produce reduced fat products. One approach is to formulate recipes with ingredients that have been subjected to advanced technologies to either reduce their fat content or structurally alter them to enhance their functionality. Alternatively there are a range of techniques already available which could be implemented by many food processors, particularly for deep fried products. Studies on these techniques have been published in the literature, some on model systems, and the processor would have to consider whether they were appropriate for their own products.

Authors have hypothesised on the mechanisms of some of the fat reduction methods, but ambiguities remain and it is clear that more research needs to be done, particularly in understanding surface phenomena.

Where sensory studies have been done, the results reported often suggest that the products obtained have characteristics comparable to those of conventionally produced products. In some cases additional benefits are revealed, such as unmasking of flavour components in the presence of less oil.

Sophisticated approaches to manipulating consumer sensory perception through approaches such as triple emulsions are being researched but it is clear that much more needs to be done before affordable, stable, fit for purpose products can be routinely produced.

8 Bibliography

BOUCHON, P. (2009). Understanding Oil Absorption During Deep-Fat Frying. *Advances in Food and Nutrition Research,*57, pp. 209-2031

CARGILL INCORPORATED(2010), *Low-Fat Cocoa Powder,* Patent Number US 7709041.

DE GRANDI CASTRO FREITAS, D., APARECIDA GARCIA BERBARI, S., PRATI, P., MATTA FAKHOURI, F., COLLARES QUIEROZ, F.P. and VICENTE, E. (2009).Reducing of fat uptake in cassava product during deep-fat frying. *Journal of Food Engineering,* 94, pp. 390-394.

DRAGICH, A.M. and KROCHTA, J.M. (2009). Whey Protein Solution Coating for Fat-Uptake Reduction in Deep-Fried Chicken Breast Strips. *Journal of Food Science,* 75, (1), pp. S43-S47.

DUEIK, V. and BOUCHON, P. (2011). Vacuum Frying as a Route to Produce Novel Snacks with Desired Quality Attributes According to New Health Trends. *Journal of Food Science,* 76, (2), pp. E188-E195

DUEIK, V., ROBERT, P. and BOUCHON, P. (2010). Vacuum frying reduces oil uptake and improves the quality parameters of carrot crisps. *Food Chemistry,* 119, pp. 1143-1149

FRITO-LAY TRADING COMPANY, GMBH (2011), *Process For Making A Healthy Snack Food,* Patent Number US2011/0064854.

LEE, J.S., KIM, B.K., KIM, K.H. and PARK, D.J. (2008). Preparation of Low-Fat Uptake Doughnut by Dry Particle Coating Technique. *Journal of Food Science,* 73 (3), pp. E137-E142

LOBATO-CALLEROSA, C., SOSA-PEREZA, A., RODRIGUEZ-TAFOYAA, J., SANDOVAL-CASTILLAB, O., PEREZ-ALONSOC, C. and VERNON-CARTER, E.J. (2008). Structural and Textural Characteristics of reduced-fat cheese like products made from W-1/0/W-2 emulsions and skim milk. *LWT Food Science and Technology,* 41, pp. 1847-1856

JANOSITZ, A., NOACK, A.K and KNORR, D. (2011). Pulsed electric fields and their impact on the diffusion characteristics of potato slices. *LWT- Food Science and Technology,* 44, pp. 1939-1945

MAI TRAN, T.T., DONG CHEN, X. and SOUTHERN, C. (2007) Reducing oil content of fired potato crisps considerably using a ‘sweet’ pre-treatment technique. *Journal of Food Engineering,* 80, pp. 719-726

MOREIRA, G.R., SUN, X. and CHEN, Y. (1997) Factors affectin g oil uptake in tortilla chips in deep-fat frying. *Journal of Food Engineering,* 47, pp. 97-107

MORENO, M.C. and BOUCHON, P. (2008) A Different Perspective to Study the Effect of Freeze, Air and Osmotic Drying on Oil Absorption during Potato Frying*. Journal of Food Science*, 73, (3), pp. E122-E128

NELSON III, L.V., JENSEN, JEAN.L and KEENER, K.M. (2010). Evaluation of Potato Cakes and Breaded Chicken Patties Fried by the FryLess 100K Radiant System Compared to Oil Immersion Frying. *American Society of Agricultural and Biological Engineers Annual International Meeting,* 3, pp 2496-2504

PRIMO-MARTIN, C. and DEVENTER, H. van (2010) Super Heated Steam As An Alternative To The Pre-Frying Step In The Preparation Of Deep-Fried Battered Snacks : High Crispness And Low Oil Content. *International Conference on Food Innovation ; Food Innova 2010,* pp. 1-4

SURH, J., VLADISAVLJEVIC, G.T., MUN, S. and McCLEMENTS, D.J. (2007) Preparation and Characterization of Water/Oil and Water/Oil/Water Emulsions Containing Biopolymer-Gelled Water Droplets. *Journal of Agricultural and Food Chemistry,* 55, pp. 175-184

TCHUENBOU-MAGAIA, F.L., NORTON, I.T. and COX, P.W. (2009). Hydrophobins stabilised air-filled emulsions for the food industry. *Food Hydrocolloids,* 23, pp.1877-1885

QUASEM, J.M., MAZAHREH, A.S., ABU-ALRUZ, K., AFANEH, I.A., AL-MUHTASEB, A.H. and MAGEE, T.R.A. (2009) Effect of Methyl Cellulose Coating and Pre-Treatment on Oil Uptake, Moisture Retention and Physical Properties of Deep-Fat Fried Starchy Dough System. *American Journal of Agricultural and Biological Sciences* 4, (2), pp. 156-166.

THE BOC GROUP LIMITED, *Cryogenic Crystallisation of Fats,* Patent Number EP 1285584B1, 2003

YEE, J.L., KHALIL, H. and JIMINEZ-FLORES, R. (2007). Flavor partition and fat reduction in cheese by supercritical fluid extraction : processing variables. *Le Lait,* 2007, pp. 269-285