Rising to the challenges: Solution-based case studies highlighting innovation and evolution in reformulation

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An era of innovation - Six solution-based case studies highlight evolution in reformulation

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Abstract

Over the last few years food research and development have increasingly focussed on reformulation, balancing desired dietary changes with environmental considerations and consumer acceptability. This article includes a selection of case studies, from across food industry sectors, that have responded to health and sustainability trends and challenges with creative solutions. These include innovative ingredients that may facilitate sugars and saturated fat reduction and increase the amount of fibre and healthy fats in products. The case studies, written by company personnel, illustrate the breadth of food and nutrition-related initiatives that are currently being undertaken to help develop potentially healthier, more nutritious or more environmentally responsible foods for the future, whilst at the same time helping to satisfy consumer demands for cleaner labels. They were selected by the British Nutrition Foundation (BNF) as useful examples of ongoing innovation in this field. BNF also invited Jon Poole from the Institute of Food Science and Technology to describe some of the key challenges for reformulation and new product development.

Foreword

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The interface between human health and nutrition and food science and technology is a fascinating one. Scientists who not only understand the complex human nutritional challenges relating to healthy eating, reducing malnutrition and obesity but who can then turn their attention to the development of workable and desirable ingredients are critical in the development or reformulation of products. The following case studies provide a wide and vibrant cross-section of examples where this linkage is clearly understood and applied very effectively.

Over the last few years the emphasis in terms of food research and development has been gradually changing from new product formulation, to reformulation and now, as we are seeing in these case studies, to a more intelligent form of reformulation which attempts to balance desired dietary changes with consumer acceptability and other factors such as environmental considerations and supply constraints. Rarely these days is it a mere binary choice between using or reducing an ingredient such as sugar or salt; whether or not to increase the levels of fibre in a product; or whether to replace saturated or trans fats with other 'healthier' fats.

Whilst it should not be the primary goal when it comes to reformulation, it is clear that more and more consumers are seeking what are referred to as 'clean labelled' products – that is, products containing fewer ingredients or fewer or no ingredients that are seen as 'non-natural'. The whole debate over what is deemed 'natural' is not one for discussion here, but this often irrational aversion to what are seen as 'non-natural' ingredients can, frustratingly, lead to consumers sometimes making less-healthy food choices. This desire to avoid non-natural ingredients is also now further compounded by the increasing desire to seek out sustainable or environmentally friendly options.

Interestingly, in a bid to develop alternative, healthier ingredients, many of the case studies featured here have been inspired by, or have derived their solutions from, nature. This can result in the double benefit of developing potentially healthier or more nutritious solutions whilst at the same time helping to satisfy consumer demands for cleaner labelling or products with greener credentials.

Ultimately, consumer acceptance is fundamental in the development of any food product. The list of ingredients on a product's label may persuade consumers to initially purchase it but, unless the taste, and texture of the product satisfies our incredibly discerning palates, then the product will ultimately fail to sell. As many big brand owners will testify, even the slightest change in taste or mouth-feel to an existing top-selling food product can completely disenfranchise its previously loyal consumer base.

So, this becomes a key challenge when developing any new ingredient – how to develop or introduce nutritionally beneficial ingredient options whilst still keeping within the parameters of what will be acceptable to, or even preferred by, the consumer.

Paradoxically, developing ingredients and products that are more likely to satisfy consumer demand for simplicity and wholesomeness, can often originate from the most complex and scientifically-driven research projects. Ultimately all ingredients need to be compliant within a rigorous regulatory framework, especially when relating to novel foods. So, built into these projects, there will have been considerable time and effort invested in ensuring regulatory compliance, as well as sensory research into user acceptability and consideration over how to scale up production from concept through to a mass market production.

Turning to the main theme of these case studies, the future of ingredients will be largely driven by demands to provide healthier food options – either driven by consumer demand or by governmental interventions designed to deliver against public health agendas and targets. All of this, of course, sits against a backdrop of the challenges of climate change and the need to be able to feed a still-growing global population from an ever-depleting availability of viable land and resources.

None of the above challenges are expected to be short-term or transitory issues – and, of course, they are also challenges that are being faced globally. This is reflected through the scale of the resources invested in the featured case studies. These are generally complex projects, many involving multinational collaborations. Some have also involved multidisciplinary research teams calling on more 'traditional' disciplines such as food science and technology and food chemistry, through to mechanical engineering, nano technology, computer sciences and even astro-physics. These case studies are therefore already the future of ingredients.

Cocoa Pulp: a sugar replacer for chocolate

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Background

The two biggest cocoa growing regions in the world are Latin America and West Africa. It had been observed that Macaque monkeys in South America were attracted to cocoa pulp. They would pluck the cacao fruit off the trees and break them open to eat the white, fleshy, sweet pulp surrounding the cocoa beans. The pulp has a tangy, sugary, floral taste, which has been compared to a lychee or guava and contains naturally occurring sugars (see Table 1). The beans are bitter however, so these were discarded by the monkeys.

The pulp is eaten by people in West Africa, Latin America and other cacao growing countries as a juice or a fruit on its own, or as an ingredient for ice cream making, smoothies and alcohol production, but it is more often treated as a waste product of the bean.

The aims behind the cocoa pulp project were threefold:

- To meet the consumer demand for natural sugars that can replace refined sugars in products such as chocolate. Cocoa pulp is a plant source of sugar that has not been used before.
- To pursue a vision to create a chocolate made entirely from one natural ingredient source.
- To prevent less waste in the food chain and create a new industry and source of income for the cocoa farmers, as there is currently no commercialization for industrial production of cocoa pulp.

Composition of cocoa pulp

The product composition of cocoa pulp is shown in Table 1.

Table 1: The composition of cocoa pulp

Nutrient	Per 100g
Energy	308kcal
Fat	1.0g
Of which saturates	0.0g
Carbohydrates	59.0g
Of which sugars	59.0g
Fibre	21.5g
Protein	5.0g
Sodium	95mg

'Cacao sugar' is a naturally occurring sugar, and is a combination of sucrose, fructose and glucose, which are common in other fruits (see Table 2). The variation of sugars in the cacao sugar is due to a number of factors including cocoa cultivation, agricultural practises and conditions, weather conditions, fruit (pod) ripeness and post-harvest practices.

Table 2: The sugars content of cacao sugar

Sugar	g/100g	Type of sugar
Glucose/Fructose	9.0 – 13.5	Monosaccharides
Sucrose	0.5 – 6.0	Dissaccharides

The cocoa pulp is pasteurised, frozen and dried to create a workable ingredient for chocolate manufacturing. Chocolate made with cocoa pulp has approximately 35% less total sugar when compared to a typical 70% dark chocolate and is higher in fibre (Nestle 2020). A sugar reduction claim cannot be made to consumers as chocolate made with cocoa pulp is slightly higher in calories than standard 70% chocolate. This is because there is a higher percentage of cocoa liquor and cocoa butter, which has a high fat content, in the product. Therefore a chocolate product does not meet the EU requirements to make a sugar reduction claim.

Novel Food: Regulatory Approval in the EU

Cocoa pulp has not been commonly consumed in the EU prior to 15th May 1997 when the first Regulation for novel foods came into force. Nestlé applied to the European Commission for the use of cocoa pulp as a 'Traditional Food' and were the first company to successfully have the application approved in 2019 (EFSA 2019). The Commission Implementing Regulation, permitting the use of cocoa pulp within the EU, was published on the 14th February 2020 (EU 2020).

The Future

It is important to Nestlé to source pulp ethically and sustainably and the pulp is sourced from farms that are part of the Nestlé Cocoa Plan's sustainability programme (Nestle 2019). Whilst the cocoa pulp has been specifically created for use in chocolate, it has many other potential applications. The new chocolate, with its rich fruity taste, was launched in Japan (November 2019) and Australia (February 2020) with great success and will be launched in other countries in 2020 and beyond. Cocoa pulp is a good example of how scientific knowledge and technological expertise can combine to reimagine familiar foods.

A sweet culture: sugar reduction in fermented dairy products

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Health organisations, governments and retailers are setting objectives to reduce sugar in foods while consumers are increasingly focussed on sugar content and looking for healthy, natural products that still have a favourable taste profile. In the dairy category, yogurt has come under some scrutiny for its added sugar content.

Yogurt has largely been considered a healthy food recommended in many food based dietary guidelines, being a good source of protein and calcium. More recently, some research has suggested that microorganisms naturally present in yogurt may also contribute health benefit. However, the sugar content of yogurt has perhaps altered consumer perception of yogurt as a healthy food choice.

Dairy producers are therefore faced with the challenge of reducing sugar, yet keeping the familiar sweet acceptable taste that consumers have become accustomed to. Chr. Hansen's Sweety® culture is an innovative solution that is seeking to achieve this. The modified culture differs from standard as these bacteria can use galactose rather than glucose from the breakdown of lactose, the naturally occurring disaccharide sugar in milk, allowing greater glucose content in the product matrix. As glucose provides more sweetness than lactose (gram for gram), the Sweety® culture enables manufacturers to add less sugar (up to 20% less) for the same sweetness intensity. This sugar reduction may help food manufacturers in their attempts to reach government sugar targets, comply with retailer guardrails and specifications or support a more favourable composition for a nutrient profiling system (e.g. a healthy food logo or in front-of-pack traffic light labelling).

Moreover, sweetness perception in yogurt is quite complex, and the balance of sweet and sour taste to facilitate consumer sensory acceptance is important. The stable pH of Sweety® culture can help minimise post-acidification, the process whereby the pH of yogurt gradually drops over its shelf life, shifting the balance of taste to favour sour over sweet. The pH stability enables a more consistent sweet taste over the shelf life of the yogurt and further reduces the level of added sugars required to counter post acidification.

Interest in healthier eating is encouraging many consumers to reduce their sugar intake. Yet the consumer trend to seek 'clean label' products and avoid artificial ingredients has been notable, and maintaining acceptance of existing solutions such as the use of no- and low-calorie sweeteners is proving challenging. Through this innovative approach Sweety® may have found a solution that targets both aspects.

Current regulations mean that the Sweety® culture requires no special labelling. Rather, it is shown in the ingredients list as 'culture', or by mention of the specific strains *Streptococcus thermophilus* and *Lactobacillus bulgaricus*. The Sweety® culture then not only facilitates the use of less added sugars, but can do so with a clean label.

SWEETY® cultures for sugar reduction in fermented dairy products received the Reformulation Innovation Award at Food Ingredients Europe 2019

Amai Proteins - An Innovation in Sweetness

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The high prevalence of obesity globally is a major public health concern, and the contribution of excess sugar consumption to the obesity crisis has been widely recognised (as described by Stanner and Spiro 2020 in this issue). However, whilst the need for sugar reduction is understood, it is highly challenging: Issues around taste/ aftertaste, product fitness including texture and mouthfeel, cost and consumer acceptance are hampering progress. In addition, although consumers may perceive sugar reduction as an important consideration for health, their perception of other sweetening agents *e.g.* conventional artificial sweeteners, may not always be favourable (see Erikson and Carr, 2020 and Bingley, 2020 in this issue). On top of health concerns, sugar production poses a sustainability challenge of protecting environmental resources as land, energy, and water are under increasing pressure.

An ideal solution then would be a healthier alternative to sugar with a lower calorie and lower glycaemic impact that is better for the environment, and technologically and economically viable for wide use in the food industry. Nature may hold the key for such a solution in the form of 'sweet proteins' – proteins that can be found in some dense jungle shrubs that are 700-3,000 times sweeter than sugars gaining them the evolutionary advantage of attracting animals for seed dispersal. But if sweet proteins are so good, why are we not well-acquainted with them? One sweet protein, (thaumatin E957), is globally approved for use in foods but it is primarily used as an enhancer and a masker rather than as a mainstream sweetener.

Three main challenges prevent sweet proteins from entering the mass market. Firstly, sweet proteins are costly, with limited supply. For example, thaumatin is extracted from the katemfe fruit, which is hand-picked in West Africa and shipped to Europe for extraction. Secondly, as proteins, they exhibit compromised stability and are denatured in high temperature, high acidity and high fat conditions. Thirdly, they have a suboptimal sweetness profile, mainly due to a lingering aftertaste. The innovative approach of Amai proteins is to address these barriers using Computational Protein Design, effectively redesigning the amino acid sequence of sweet proteins – allowing changes in the taste profile and greater stability in more extreme conditions. Thus the 'natural' sweet proteins can be redesigned, for example, to more resemble the proteins found in microorganisms in the Dead Sea (halophiles) or hot springs (thermophiles), allowing use within food production *e.g.* to withstand pasteurisation in dairy products. The resulting 'designer proteins' have a novel sequence made out of the natural amino-acids, i.e. they are just like any other protein.

Using precision fermentation, the designer proteins are expressed in genetically modified yeast or other host microorganisms and are then harvested from the fermenter. Thus, they can be grown efficiently and at any scale needed in any of the numerous food-grade fermentation plants. While the host organism is a genetically-modified microorganism, as the product itself is a pure protein with no remains of DNA or the host organisms, it is regarded by the regulatory authorities (EU-EFSA or US-FDA/USDA) as GMO-free (genetically modified organism free). This is important for consumer acceptance. Still, there may be a need for consumer education so that technological advances with potential significant public health benefit are not hampered by the failure to address public fears about such techniques.

The Amai sweet protein is 10,000 times sweeter than sucrose, with very small amounts needed to impart the same sweetness, making it 90% cheaper than sugar and with a significantly smaller environmental footprint. In the prototype formulations, some 35-70% sugar reduction has been enabled.

The Amai sweeteners were tested by thousands of consumers in a wide-range of applications such as ketchup, sauces, yogurt, cranberry juice, carbonated soft drinks and sweetened-beer (also known as shandy). The protein still needs to undergo regulatory approval but has already been approved for R&D use with fee-bearing collaborations from leading food and beverage multinationals (PepsiCo, Danone, Ocean Spray and others), and its use in foods is expected within two years.

Amai sweet proteins, if used widely, may well contribute to sugar reduction in the population. Moreover there is also potential for the use of Amai's advanced computational techniques for adapting other alternative proteins for more sustainable meat, plant and milk alternative designer proteins. Computational Protein Design may well be part of our food future.

Amai Proteins won the 2018 TechTour competition, the EU's top startup competition; the 2019 Most Innovative Pre-Series A Supply Tech AgFunder Innovation Award; the 2019 Food Ingredients Europe 'Most Innovative Food or Beverage Ingredient' award; the 2019 top Israeli startup competition, The Journey, award, and is now competing at the Extreme Tech Challenge finalist impact competition after winning the regional competition in Berlin.

Exploiting Oleogelation for the replacement of saturated and *trans* fat in foods

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As discussed in the paper by Brouwer in this Special Issue (Brouwer 2020), dietary saturated fat has been shown to raise blood cholesterol concentration, which is an established risk factor in cardiovascular disease. As well as being naturally present in many foods, in particular fatty meat and whole milk/milk products, saturated fat is present to some extent in all fat-containing foods, from vegetable oils to manufactured cakes and biscuits. Fats that predominantly comprise saturated fatty acids are characterised by being solid at room temperature (see Bruce, 2020 in this Special Issue) and this solid fat is an integral structural component in many formulated foods, as well as modifying texture and contributing flavour. In chocolate, for example, cocoa butter (which has a relatively high saturated fat content) provides a solid texture, but also the melt-in-the mouth properties characteristic of chocolate (Talbot, 2014). Ice-cream and whipped cream are stabilised by partially coalesced solid fat droplets that adsorb to and form a network between the air bubbles in the foam (Euston & Goff, 2019). When incorporated in meat products such as sausages, as well as providing texture and lubrication in the mouth, fats are also a reservoir for flavours (Orthoefer & Kim, 2019). Solid fat is added to baked goods such as bread to shorten or plasticize/lubricate the texture, a process dependent on crystallization of the fat (Smith & Metin, 2013). Given the important role of solid, saturated fat in many foods, direct replacement with polyunsaturated oils or carbohydrate/protein based fat replacers and mimetics is either difficult or not possible.

In this case study we report on an alternative means of fat replacement involving the solidification of polyunsaturated liquid oils using a self-associating plant phytosterol oleogel technology (Matheson *et al.*, 2017b, Matheson *et al.*, 2017a, Matheson *et al.*, 2018b, Matheson *et al.*, 2018a, Dalkas *et al.*, 2018). A mixture of the sterol ester γ-oryzanol (ORY, from rice bran) and a sterol (typically β-sitosterol, SIT) will form a network of nm diameter tubules when dispersed in a triglyceride oil (Figure 1). This solidifies the oil and offers the possibility that it can be used to replace saturated fat in foods, whilst maintaining texture and flavour.

However, there are a number of technical challenges that have held back application of phytosterol oleogels in foods. Firstly, whilst there are many sterols that can be combined with ORY to form a gel, ORY is the only readily available sterol ester. Since the acid group attached to the ORY (ferulic acid) seems to play a key part in tubule interactions, thus probably playing a role in gel texture (Figure 2), finding alternative sterol esters could allow enhanced or controlled gel properties. We have synthesized alternative sterol esters to understand how the acid group controls tubule association and gel properties. Secondly, the gel is very sensitive to the presence of water (Matheson *et al.*, 2017a, Matheson *et al.*, 2018b), and finding sterol gelators that are water stable is a priority if the technology is to be used in medium to high water activity foods. Finally, the gelation process is prone to supercooling, but can be promoted by shear forces that will be generated by stirring in mixers, or during flow down a pipe. The mechanism by which shear initiates gelation has to be understood so that the oleogel structure can be controlled and manipulated during food processing (which can involve significant shearing).

In 2008 EFSA approved the cholesterol lowering health claim for plant sterols (Bressonet al., 2008) but to date their mixtures have not been exploited as olegelators in foods. If these technical challenges highlighted here can be surmounted, phytosterol oleogels will offer a dual impact on blood cholesterol levels (plant phytosterols are also reported to have a lowering effect on blood cholesterol in their own right (Katan *et al.*, 2003)), with a concomitant effect on an important risk factor for cardiovascular disease.

To fully understand the mechanisms of oleogelation will require further study of both the detailed tubule structure and how they interlink in a gel. Recently we have been awarded beam time at the Institute Laue Langevin in Grenoble to study the tubule structure using small angle neutron scattering (SANS). This will allow us to probe tubule structure at nanometre length scales, adding unprecedented detail to our understanding of the phytosterol oleogels.

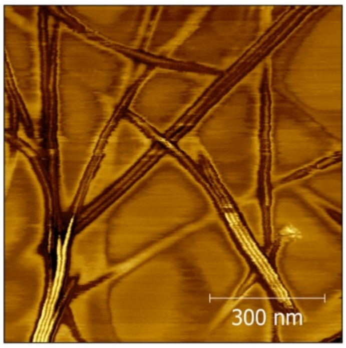

Figure 1 – Atomic force microscopy shows the fine structure of self-associated ORY+SIT self-associated tubules, and the interacting network gel structure Source: Matheson et al. (2017b) reprinted with permission from the American Chemical Society.

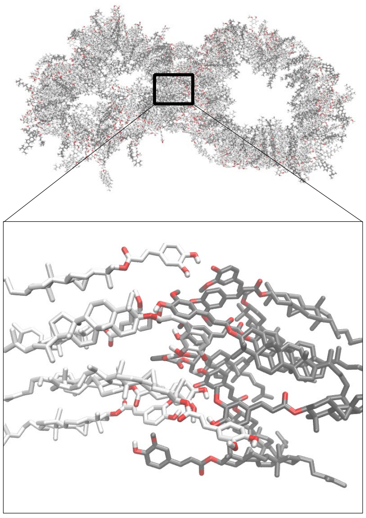

Figure 2 – Interactions between tubules can be probed *in*-silico using molecular dynamics simulations, and show hydrogen bonds, vdW interactions and π-π contacts between the ferulic acid groups of oryzanol in the interface of two tubules. Source: Dalkas *et al*. (2018) reprinted with permission from the American Chemical Society.

Algae-fed Salmon - Innovation in Health and Sustainability

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As UK consumers seek healthier lifestyles, they are moving towards eating less red meat, more vegetables and more seafood. According to the FAO, global consumption of farmed seafood has surpassed wild seafood and is an important contributor to food security and healthier populations (FAO, 2018). In fact, aquaculture is one of the fastest growing food producing sectors in the world (FAO 2018).

In the UK, salmon is a very popular seafood choice and one of the best sources of important long chain omega-3s (EPA and DHA fatty acids) and the UK government recommends eating oily fish, like salmon, at least once a week (SACN/COT 2004). Long chain omega-3s are found in the fish fillet because salmon eat forage fish and accumulate high levels of omega-3s. Thus, when salmon are farmed, fish oil is a critical nutrient in the feed as it is the primary source of long-chain omega 3s. As fish farming continues to grow, fish oil supplies are not expected to keep up with this growth.

Opportunity for innovation

Recognizing this looming resource constraint, scientists turned to the original source of long chain omega-3s – marine microalgae. In the wild, marine microalgae are at the base of the food chain for fish. By growing the marine microalgae via fermentation, Corbion, a Netherlands-based ingredients company, are producing an abundant, clean and sustainable source of long chain omega-3s called AlgaPrime™ DHA that can help towards reducing the dependency on fish oil in aquaculture feed.

Adoption of algae omega 3s in fish feed is growing

One of the biggest challenges in introducing a new ingredient is whether feed companies and farmers will make the investment to test and adopt the new product. It takes commitment to innovation by all those along the salmon farming supply chain, and it requires resources to test and verify that algae omega- 3s work well. Corbion worked with leading aquaculture feed producer, BioMar, and many fish farmers to lead the way in introducing algae omega-3s to farmers and retailers. By late 2019, more than 25% of all Norwegian salmon feed contained algae (Gibson 2019).

Tesco supports algae-fed salmon

As part of Tesco's effort to create a sustainable shopping basket, it announced its work to revise Tesco's farmed salmon standards with recommended targets to lower the levels of wild-caught fish used in aquaculture feeds (Tesco 2019). Part of the process includes working with their salmon suppliers and feed developers to support the scale-up and use of more sustainable feed ingredients, such as algae omega-3s. As Tesco takes the lead, numerous other retailers are also considering revising their salmon specifications to include algae omega-3s in their feed.

Call out box – Tesco's statement

> "To build on this development, we are in the process of updating our own brand farmed salmon standards with targets to reduce the amount of wild-caught fish that is fed to the salmon we source. While this is a positive step, transitioning the entire aquaculture industry to more sustainable feeds such as algal oil will require the commitment from many businesses and organisations."

In 2020, AlgaPrime™ DHA was recognized by *Fast Company* as a World Changing Idea in the Food Category.

Utilisation of butternut squash peels to improve the fibre content of tortillas

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Summary

With the ever-growing health issues of obesity, diabetes and cancer, and concern over food waste, as part of its research into calorie reduction and fibre enhancement, Campden BRI has successfully used food waste to double the fibre content of a tortilla, helping it achieve a 'high fibre' claim.

The rationale for the innovation

The majority of UK adults do not reach the 30 g daily recommended fibre intake (Roberts et al, 2018), increasing the risk of cardiovascular disease, type 2 diabetes mellitus, and colorectal cancers (Fatma et al, 2020). Therefore, manufacturers are increasingly trying to reformulate products to enhance fibre levels. Commonly, purified fibres such as inulin are used as they offer great functionality and do not impact on the colour and odour of the product. Alternatively, the incorporation of highly fibrous foods – including by-products such as butternut squash skin – into existing products opens opportunities for the development of innovative new products while valorising currently underutilised foods. As part of the member-funded research project "Calorie reduction and fibre enhancement", this project aimed to develop a powder ingredient from butternut squash peels and assess its impact on a tortilla wrap by replacing 20% of the wheat flour.

The specific aim of the innovation

We wanted to demonstrate with this project that it is possible to improve the fibre level of an existing product through the valorisation of an underutilised vegetable by-product up to a level that may allow a 'high fibre' claim to be made on this product under the conditions laid down in the Annex to Regulation (EC) No 1924/2006 on nutrition and health claims made on foods, and the General Conditions laid down under Article 5 of this Regulation (EC 2008). At the same time, we used a range of instrumental methods to identify any changes of product characteristics that this approach may have caused.

The outcome of the innovation

There are many factors to consider when incorporating dietary fibre into a product. An ingredient's functionality can modify both the finished product's appearance, texture and taste, and the behaviour of the product during manufacture. Incorporating the butternut powder changed the colour of the tortilla. Colour plays a critical role in determining the consumer's acceptance of a product, and our reformulation created a golden yellow tortilla, a food colour that's generally accepted as appealing (see Figure 3).

The future impact of our innovation

The research is part of a three-year project which aims to provide the food industry with an understanding of the functionality of dietary fibres, their performance and potential new sources. The insights gained from this project may be of assistance to anyone who aims to develop innovative new products and improve the nutritional value of their products while at the same time repurposing a food by-product. The approach taken in this project may be translateable to other by-products and suitable for other product applications.

Figure 3: Normal tortillas and the golden yellow tortillas made with butternut fibre

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Conflict of Interest

None of the authors received a financial contribution for this article. Jon Poole is employed by the Institute of Food Science and Technology. He is also a self-employed organisational development consultant. The work that the case study by Lucas Westphal, Leandra Molina Beato and Michael Adams was based on was funded by the Campden BRI Member Funded Research programme. Lucy Barraud is employed by Nestle. Jessica Bentley is employed by Chr. Hansen. Jill Kauffman Johnson and Chris Haacke are employed by Corbion. Ilan Samish is employed by Amai Proteins.

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