

The British Frozen Food Industry

— A Food Vision



2 November 2010

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1. Foreword

Austin Mitchell MP
Great Grimsby

Our country needs to work towards a sustainable, secure and healthy food supply. To achieve this we need to ensure fair prices, choice and access to food, along with a continuous improvement in food safety, changes to deliver healthier diets and a more environmentally sustainable food chain.

As a Grimsby MP and as a consumer, frozen food is dear to my heart and so I welcome The British Frozen Food Industry – A Food Vision report. Alongside chilled and ambient foods, it is clear from the evidence presented that frozen has a key role to play in our future food choice.

Frozen can deliver high quality, good value, safe foods with an extended storage life. It can offer a nutritional profile comparable to fresh foods and help to provide dietary portion control. It can also offer emerging environmental benefits including a contribution to reducing food waste and the ability to preserve and use seasonal foods all year round.

I hope that this report will help consumers, retailers and the foodservice industry to recognise the important role that frozen food can play in UK food provision over future decades.

2. Executive summary

The food industry is aware that food supply chains should be made more resilient, profitable and competitive- whilst delivering wholesome, healthy, safe and ethical food products. A resource efficient and technologically advanced agri-food industry depends on harnessing innovative ideas and processes within its working practices. It therefore relies on the appropriate underpinning skills base and research.

In recent years there has been a need to reduce impacts, increase energy efficiencies and 'get more from less' - in order to keep food businesses competitive and profitable. The Food 2030 vision promotes reducing carbon footprint, whilst enhancing quality and wealth throughout the food system. Supply chain operations are crucial in delivering this vision and the delivery of safe and nutritious food is a key driver. Preservation and freezing are a key provider of these sustainable outcomes.

This report evaluates the impact of the frozen food supply chain with regard to market trends, sustainability, health and innovative technologies. The British frozen food industry has been a source of much innovation in delivering healthy wholesome food that can provide longer-term preservation and resilience in fast moving supply chains.

The British frozen food industry has responded to market trends with the implementation of novel engineering solutions and new product development. It is now apparent that the continued development of frozen food supply has significant environmental benefits - especially with regard to the all year round availability of seasonal food and the minimisation of waste. These benefits can be realised by 60 million UK food consumers and the frozen food industry has identified areas where it can further improve this food experience.

Our vision is dependent on the maintenance of profitable companies and satisfied customers in highly competitive environments with very complex behaviours. This in turn depends on product innovations, further environmental improvements and continued development of wholesome and healthier products.

In conclusion, the British frozen food industry has never been more relevant than it is today. It is a source of many skills, expertise and innovative approaches to food production. The frozen food supply chain provides resilience to an otherwise insecure supply chain. It delivers safety and high quality nutrition preserved by freezing. Furthermore, it can deliver significant environmental benefits - especially through minimising waste and providing all year round availability of seasonal foods.

Key report findings

The UK frozen food market

i. Retail

- In 2008 the total UK retail food market was valued at £62.3 billion. Consumers spent £5.1 billion on frozen foods, equating to 8% of this total.
- During the later 2000s, an economic downturn and new marketing campaigns focusing on the 'freshly frozen' quality of raw ingredients and their nutritional benefits, has prompted a slow resurgence for frozen. Sales of frozen foods grew by 5% between June 2007 to June 2008.
- 38.2% of consumers consider frozen food as being as good for you as fresh, though this figure has increased from 28.7% in 2005. In general, consumers recognise frozen's benefits of freshness being locked in, no use of preservatives, good taste, less waste, longer shelf life and better value.

ii. Foodservice

- In 2009 the UK foodservice frozen market was worth £2,261 million.
- Frozen food sales have increased in the UK foodservice sector between 2006 and 2009 – despite fewer outlets and falling overall sales. The total value of frozen food purchases increased by 2.4% over the period.
- Market data forecasts predict that by 2014, the value of frozen food purchases will have grown 8% to £10.9 billion.
- In a difficult economic period, many caterers are searching for better value. Independent research, reviewing the cost effectiveness of buying in frozen ready made alternatives (rather than manufacturing duplicate dishes from scratch), found that scratch dishes cost over 24% more than frozen.
- Three quarters of caterers recognise frozen offers all year round availability, minimises wastage, is less likely to deteriorate in transit, has longer storage life - permitting a wider menu range, and is easier to use – demanding less kitchen expertise.

Frozen technology & quality

- Freezing is a widely used method to maintain quality and extend storage life of high water content foods.
- Freezing forms ice crystals that remove water from the food matrix thereby increasing concentration of solutes and reducing water

activity. This increases the stability of food and enables storage over extended periods of time.

- By freezing food, the quality, safety and nutritional content of the food can be preserved close to its initial values. It is therefore extremely important to freeze the highest quality products to ensure quality once food is thawed.
- In some cases the freezing rate can have an effect on food quality and this is related to the size and distribution of the ice crystals.
- The freezing process can be carried out using a range of equipment. Freezing systems may be either continuous or batch. Current freezing systems can be divided into air, contact, immersion or cryogenic.
- A number of new and innovative freezing technologies are currently undergoing development.

The sustainability and social responsibility opportunity

- The frozen food supply chain has made significant gains in conserving energy, reducing greenhouse gas emissions and improving manufacturing efficiency. However, high variability in practice exists and current work programmes will reduce this to improve best practice across the frozen food sector.
- Highly significant areas of greenhouse gas emissions and energy use are from transport and retail display of frozen foods.
- Utilisation of frozen food is likely to create a more sustainable use of seasonal foods that are consumed out of season.
- Reduction of food waste and improved dietary portion control is likely to be realised with the effective use of frozen food in domestic and food service sectors.

Nutrition

- There is no significant evidence that the nutritional quality of food is compromised by freezing.
- Research into nutrients from specific frozen food groups show no evidence of a reduction in food quality.
- The nutritional quality of chilled foods can be compromised in general treatments by the consumer in tested post-purchase scenarios.
- The use of frozen food can improve menu planning and aid the provision of a healthy balanced diet.
- The use of frozen food can reduce waste





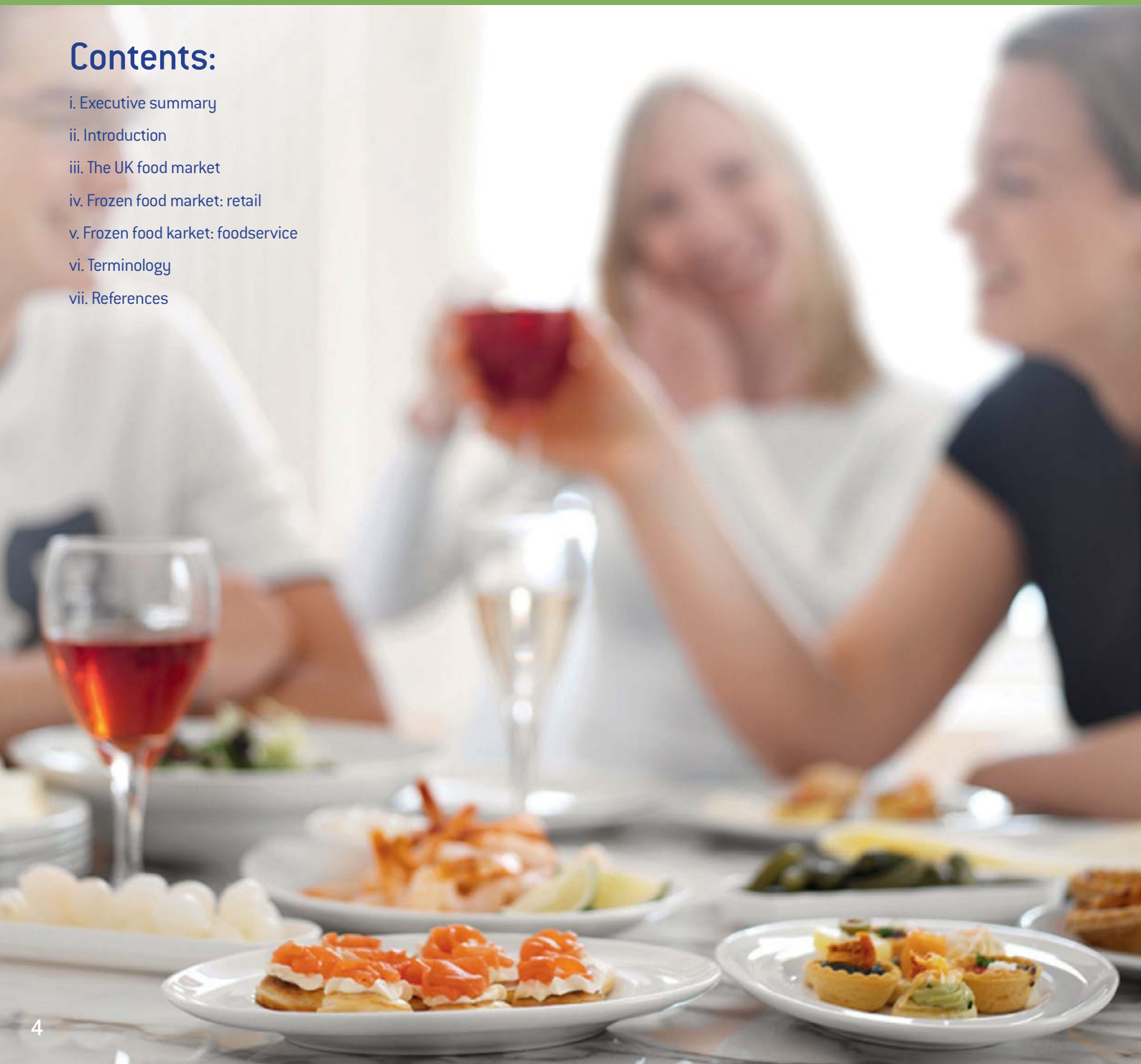
3. The UK Frozen Food Market

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i. Executive summary

Retail

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Foodservice

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- Market data forecasts predict that by 2014, the value of frozen food purchases will have grown 8% to £10.9 billion.
- In a difficult economic period, many caterers are searching for better value. Independent research, reviewing the cost effectiveness of buying in frozen ready made alternatives (rather than manufacturing duplicate dishes from scratch), found that scratch dishes cost over 24% more than frozen.
- Three quarters of caterers recognise frozen offers all year round availability, minimises wastage, is less likely to deteriorate in transit, has longer storage life - permitting a wider menu range and is easier to use – demanding less kitchen expertise.

ii. Introduction

Frozen food became commercially available in the UK during the 1940s and 1953 saw the introduction of the first frozen ready meal. The increasing emphasis on leisure time and the greater ownership of domestic freezers meant that by the middle of the 1970s frozen food had become a staple of everyday life. The frozen food market remained buoyant throughout the 80's and 90's as, while convenience continued to be key, consumers also wanted year-round availability of seasonal and healthy foods.

Yet, during the early 2000s intense media coverage of the link between diet, health and obesity swayed public opinion as to what type of food is healthy and good quality. This has led to a distorted consumer view of 'fresh' food as wholesome and nutrient rich, and processed food being of reduced quality and nutrient value (see

Nutrition p.22). This was reflected in frozen sales: in 2005, profound shifts in consumer eating habits resulted in the market value of frozen ready meals falling by 13% (Mintel, May 2010).

However, during the latter half of this decade, a downturn in the economy and new marketing campaigns focusing on the 'freshly frozen' quality of raw ingredients and citing their nutritional benefits, has prompted a slow resurgence for frozen. Sales of frozen have risen as it is considered to offer quality, value for money and to minimise food waste.

iii. The UK food market

In 2008 the total UK retail food market was valued at £62.3 billion (Mintel, April 2009).

Consumers spent £5.1 billion on frozen foods (Kantar Worldpanel, September 2010), equating to 8% of the total. Given that there were estimated to be 26.5m households (Mintel, April 2009) the average weekly grocery bill was £45, of which £3.60 was spent on frozen food.

In 2009, the foodservice sector (which covers restaurants, pubs, hotels, leisure, contract catering and institutions) spent £10.1 billion on food (Horizons, April 2010), of this 22% was frozen food (£2.3 billion), 43% (£4.4 billion) chilled/fresh and 35% (£3.5 billion) ambient.

iv. Frozen food market: retail

a. Retail frozen food market value

According to Kantar Worldpanel, over the three years 2007-2010, the UK retail frozen market has increased by 11.3% from £4,585 million to £5,102 million. This increase is mainly due to the average unit price, which for this market has increased by 9.0% from £2.33 to £2.54. The number of units sold has increased by 2.1% from 1,969 million to 2,011 million. However, the annual rates of increase have slowed down from +6.2% to 0% in value, +2.3% to +0.2% in units and +3.8% to -0.2% in average unit price (Figure 1).

Retail Frozen Market								
	10/09/2007	07/09/2008	YoY %	06/09/2009	YoY %	05/09/2010	YoY %	3yrs growth
£ - m	4585	4870	6.2%	5103	4.8%	5102	0.0%	11.3%
Units - m	1969	2015	2.3%	2007	-0.4%	2011	0.2%	2.1%
Av unit price	2.33	2.42	3.8%	2.54	5.2%	2.54	-0.2%	9.0%

Figure 1: Retail Frozen Market (Source: Kantar Worldpanel, September 2010).

b. Retail frozen food categories

Within the retail frozen market, savoury foods perform best, with 17.2% of the market, fish is second with 14.2% followed by ice-cream with 13.6%. Potato products sell the greatest number of units, but their average unit price is the lowest at £1.14 putting them sixth place in terms of value (Figure 2).

Between 2007 and 2010 Kantar Worldpanel data highlights:

- **Frozen pizzas:** have seen growth, up 12.7% in value and +9.9% in number of units sold, though their average unit price has only risen by 2.5%.
- **Ice cream:** sales grew above the average at 16.4% in value, 3.3% in units and 12.7% average unit price.
- **Confectionery and desserts:** sales grew below the average at 5.7% in value, 0.5% in units and 5.1% average unit price.
- **Fish:** sales grew above the average at 15.9% in value and 8.9% in units but below the average at 6.4% average unit price. According to Mintel, nearly nine in 10 adults eat fish at home. Consumers look for freshness and quality rather than price (Mintel, September 2010). Although chilled fish is considered to be tastier than frozen by two in five seafood eaters, nearly half of them neither agree nor disagree, signalling a sizeable group of potential converts to the frozen segment (Mintel, September 2010).
- **Meat and poultry:** sales grew below the average at 6.8% in value, -14.5% in units whilst this category saw the greatest price rise, up 24.9% from £2.74 to £3.43.
- **Vegetables:** sales grew above the average at 14.8% in value, 3.1% in units and 11.4% average unit price. Frozen fruit and vegetables represent approximately 5% of the total fruit and vegetable market (Mintel, January 2009). In January 2009 Mintel predicted real growth of 10% for the frozen fruit and vegetable sector between 2008 and 2013. While below that of 14% for the total market, it compares favourably with the 7% achieved for the previous five years. Frozen vegetables are seen to represent good value for money without compromising on convenience.
- **Potato products:** sales grew below the average at 10.8% in value and 2.0% average unit price but above the average at 8.6% in units.
- **Ready meals:** sales grew below the average at 3.7% in value, -7.4% in units but over the average at 12.0% average unit price. It would appear that the growth in home cooking has put pressure on ready meals as one in four users has cut back in favour of cooking. However, one in six has adopted them as a substitute to eating out or takeaways (Mintel, May 2010). This is reflected in the rise in the average unit price. However Mintel forecasts that the ready meal market will grow by 16% between 2010 and 2015, but as food inflation is not expected to ease in the short run, this will translate into 12% decline in real terms. Frozen ready meals are forecast to grow at 4%, below that of chilled at 18%.
- **Savoury foods:** sales grew above the average at 12.6% in value, 2.5% in units and 9.8% average unit price.

Retail Frozen Market					
	£ - m	% of total	Units - m	% of total	Av unit price
Ice Cream	695	13.6%	342	17.0%	2.03
Confect. & desserts	276	5.4%	81	4.0%	3.42
Fish	726	14.2%	125	6.2%	5.78
Meat & poultry	552	10.8%	161	8.0%	3.43
Vegetables	413	8.1%	290	14.4%	1.42
Potato products	534	10.3%	470	23.4%	1.14
Ready meals	646	12.7%	179	8.9%	3.6
Pizzas	384	7.5%	105	5.2%	3.65
Savoury foods	878	17.2%	257	12.8%	3.42
Total	5102		2011		2.54

Figure 2: Retail Frozen Market 52 weeks to 05/09/10
(Source: Kantar Worldpanel, September 2010)

c. Retail frozen food costs

Food prices declined in real terms by about 12% between 1998 and mid-2007, but then rose rapidly to a peak in February 2009 which was higher in real terms than prices in January 1998 (Figure 3). Since this peak in February 2009 food prices have been relatively stable and not rising with general inflation (Retail Price Indices, ONS 2010).

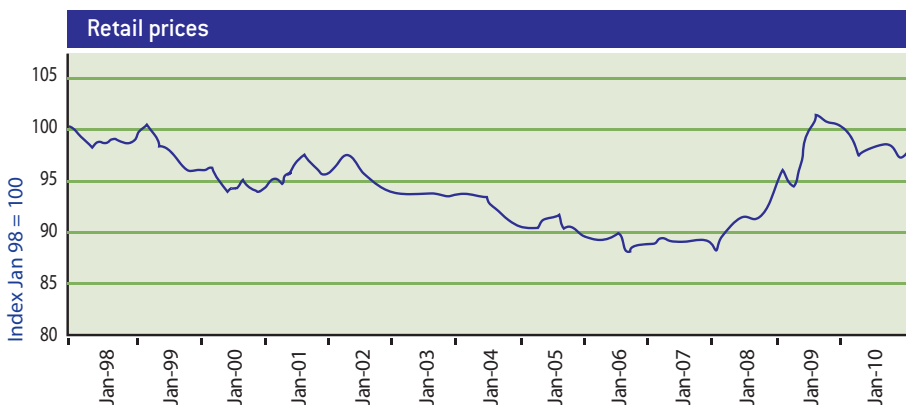


Figure 3: Retail Prices Indices (Source: National Statistics).

Between 2006 to 2010 food price inflation indices from Kantar Worldpanel confirm that frozen food (22.8%) has shown much lower price inflation than fresh (44.4%) or ambient (30%). Based on at least 75,000 products tracked over time this data offers the truest measure of what has happened to pricing within these categories.

Mintel's Impact of Rising Food Prices report in November 2008, highlighted that 14% of shoppers said they had switched from fresh/chilled products to dried/tinned/frozen products in the last year in order to save money. Such behaviour had resulted in sales of frozen foods growing by around 5% between June 2007 and 2008. The report considered that frozen food was appealing to shoppers saving money as they are invariably better value than equivalent fresh products and minimise food waste and consumers can use as little or as much as they want at a time.

BFFF commissioned independent research entitled Cost, Waste and Taste Comparison of Frozen Food versus Fresh Food in a Consumer Market (BFFF, 2010). In this investigation, nine families were asked to document the purchase and waste of fresh food over a one week period and then repeat this process using frozen equivalents. The mean results of this investigation showed purchase of frozen main meals was 33% less expensive than fresh; savings ranging from 13% to 57% were achieved. In addition to these monetary savings, the use of frozen food resulted in over a third less wastage, and contrary to expectation, some frozen meals were rated 'better than' or 'as good as' the fresh versions.

In October 2009, 9% of adults had switched from buying fresh/chilled groceries to dried, tinned or frozen variants (Mintel, December, 2009), mirroring a downturn in the economy.

d. Retail frozen food shopper profiles

According to the Kantar Worldpanel figures for the 52 weeks to 28 December 2008, families

buy proportionately more frozen foods (47.2% of the frozen food market) compared to their total grocery shop (41.4% of the total grocery market). This peaks for those with children in the 5-10+ years group.

Consumers in the less affluent C2, D and E social class groups buy more, with Class D buying proportionately most (16.5% cf. 13.5%).

In October 2009, 9% of adults had switched from buying fresh/chilled groceries to dried, tinned or frozen variants (Mintel, December, 2009), mirroring a downturn in the economy.

e. Retail frozen food shopper attitudes

In July 2007 a study by Leatherhead Food International found that consumer perceptions of frozen food were clearly more positive prior to any direct comparison with chilled. They recognised the benefits of freshness being locked in, no use of preservatives, good taste, less waste, longer shelf life and more economical. However, stigma, snobbery and not being able to see the actual frozen food product were highlighted as key barriers to purchase.

Fewer than half of adults (38.2%) consider frozen foods as being as good for you as fresh food, although this figure has increased from 28.7% in 2005 (Mintel, September 2010). This is demonstrative of a gradual change in perception, as a result of recent marketing campaigns (Bird's Eye 2004 'We don't play with your food', McCains 2010 'It's all good') promoting the 'freshly frozen' quality of raw ingredients and citing their nutritional benefits (Leatherhead, July, 2007).

More recently the effect of top chefs like Delia Smith - who have highlighted their use of frozen fruit and vegetables - appears to be having a wider effect, with consultation proposed on the Government's Healthy Start scheme for voucher use to be widened to include frozen fruit and vegetables. Consumers also suggested that more education, credible endorsements, organic and local produce, variety and making the frozen aisle in the supermarket more inspiring could help turn the tide of opinion (Leatherhead, July, 2007).

People are increasingly wanting to cook at home. In 2009, 52% of people stated that they 'really enjoy cooking' (up 4.2% since 2005) and 54.4% 'prefer to prepare meals from scratch' (up 1.2% since 2007). This poses an opportunity for frozen

food component producers. However there is still a minority (13.6%) who 'don't have time to spend preparing and cooking food' (Mintel, September, 2010), which offers future prospects for ready meal manufacturers.

f. Retail frozen food shopper projections

The AB population is projected to grow faster than any other socio-economic group between 2010 and 2015 (Mintel, May, 2010). This will benefit chilled foods, but less so the frozen food sector as this group is least likely to buy frozen foods.

However, the 25-34s and the over 55s are the largest growing age groups. With less disposable income, the 25-34s group are more likely than average to have changed their grocery shopping habits by switching from fresh/chilled products to dried/tinned/frozen variants (Mintel, December, 2009). In addition, the over 55s eat fish at home more frequently and are more likely than average to think that 'frozen foods are as good for you as fresh foods' (Mintel, September, 2010). Added to this, one-person households are expected to rise faster than any other group. Consumers in this group buy more ready meals and are more likely than average to think that 'frozen foods are as good for you as fresh foods' (Mintel, May, 2010).

v. Frozen food market: foodservice

a. UK trends in eating out

Despite difficult economic times, eating out continues to be a growth market for UK consumers, with a spend of £32 billion on this activity during 2008. This is an increase of 26% since 2003 (Mintel, July 2009). It is the most popular out-of-house activity (Peach Factory, July 2008). It has now become a universal and regular activity and is seen as 'affordable luxury'; 'an antithesis to the doom and gloom about the recession' (Mintel, July, 2009).

Consumers are moving away from eating out at traditional times so food outlets are having to provide increasingly flexible menus, both in terms of the food on offer and the price points (Mintel, July, 2009). This is seen to benefit the low cost outlets, which in turn should benefit the frozen food market. In 2009, 41% of food purchased by QSRs was frozen, as opposed to 9% bought by full service restaurants.

b. Foodservice frozen food market value

In 2009, the UK foodservice frozen market was worth £2,261 million (Horizons, April, 2010). Frozen food sales have increased in the UK foodservice sector between 2006 and 2009 – despite fewer outlets and falling overall sales. Data shows that the total value of frozen food purchases increased by 2.4% over the period - whilst at the same time the number of outlets in the sector fell by 1.8% and the number of meals provided by the sector also fell by 4.4%.

Chilled and frozen food sectors are key sectors in the foodservice industry and account for 65% of all the food purchased by foodservice operators (Figure 4).

c. Foodservice frozen food market usage

The Foodservice sector can be broken down into the following key sub sectors: restaurants and QSRs, pubs hotels and leisure, plus contract catering and institutions. The largest of these sub sectors for the frozen foodservice market is the restaurant and QSR category that accounts for 48% of the market by value.

The pubs/hotels/leisure market sector and the contract catering and institutions sector have declined year on year by -3.6% and -3.4% respectively while the restaurant sector had a marginal drop of -0.1% year on year as the recession reduces the number of consumers visiting pubs and hotels.

The restaurant/QSR sector is especially dependent on the frozen food sector, which accounts for 28% of its total food purchases and is the only sector to have delivered long term growth for frozen food 2004 compared with 2009. As the total frozen foodservice market has declined by £44 million since 2004 at constant prices, the restaurant/QSR sector is a key player to minimise further losses.

It is worth noting that comparing 2009 with 2004 figures showed that the frozen foodservice market had grown by £34 million during that time period with 73% of this growth accounted

for by the restaurant/QSR sector. Therefore the importance to the frozen foodservice market, of the restaurant/QSR sector, particularly the quick service restaurants, cannot be underestimated, as consumers continue to purchase food products in fast food restaurants and coffee shops that the frozen food industry supplies.

d. Foodservice frozen food costs

The BFFF commissioned independent research entitled Cost Comparison of Frozen Food and Fresh Food in A Small Pub or Restaurant (BFFF, 2009). This pilot studied the overall cost of using frozen foods compared to fresh foods. It compared six dishes; two starters - canapés and breaded camembert, two main courses - lamb shank and salmon en croute, and two desserts - strawberry cheesecake and profiteroles. Each frozen and 'fresh' dish was made to exactly the same recipe and specification. Cost implications were then calculated taking into consideration; the cost of raw materials (i.e. food ingredients); the cost of the energy used to prepare the dishes; any waste costs associated with the preparation of the dishes; the costs associated with washing and cleaning; and the cost of the manpower used to create dishes out of individual ingredients. In nearly all cases during the research, dishes made to a duplicate recipe from scratch cost at least 24% more than their frozen counterparts. This rose to 66% with more labour intensive dishes which involved a high skill level.

On the whole the study considered it was more cost effective to buy ready made frozen alternatives than manufacturing the food from 'scratch', particularly the more labour intensive operations which involve a high skill level at a considerable cost. It was also felt that the 'bulk buying' power of a large organisation during the purchase of ingredients would significantly reduce the unit raw material costs based on a small foodservice business manufacturing its own meals.

It was found that the large time factor involved in the preparation, cooking and finishing times would be significantly reduced using the frozen alternative and this would have a positive saving on energy costs. In terms of wastage at the point of serve, a saving would be made due to little or even no preparation of ingredients when using a frozen alternative. Staff costs could also be kept to a minimum as the skill levels of the staff required running the kitchen would be low.

e. Foodservice frozen food attitudes

Research conducted by Horizons FS Limited in 2005 identified the reasons why caterers purchased frozen foods within all foodservice sectors and business types. Interviewing 230 food purchasing decision makers from seven categories - from restaurants and pubs to health and education catering - 16% of caterers stated that they were buying frozen more frequently than one year previously. Figure 8 highlights their prompted perceptions on the primary benefits of frozen.

Though the research clearly showed caterer's knowledge of the industry agreed benefits – such as all year round availability, minimised wastage and longer storage life, it did also highlight some myths and misperceptions about the taste and

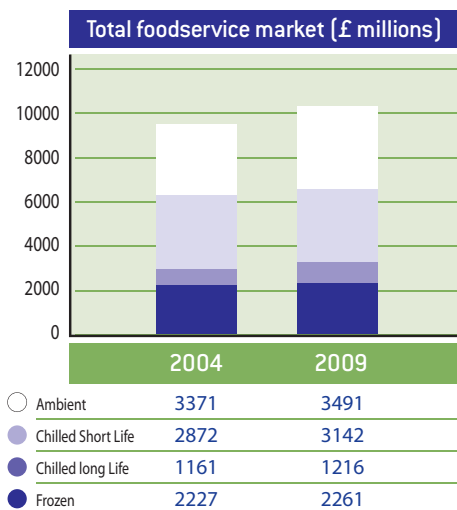


Figure 4: Total foodservice market (Source: Horizons data). Note: "Chilled – short life" is the same as "fresh" and the figures are at constant prices i.e. the figures for 2004 are at 2004 prices and 2009 are at 2009 prices.

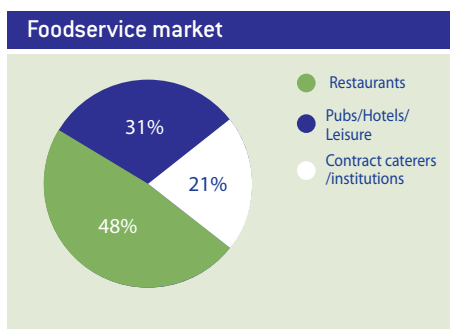


Figure 5: Total Frozen Foodservice Market 2009 (Source: Horizons data).

Foodservice market			
	2004	2009	% change
Restaurant/QSR	1078	1133	+5.1%
Pubs/Hotels/Leisure	684	676	-1.2%
Contract catering and Institutions	465	453	-2.6%
Total	2227	2261	+1.5%

Figure 6: Total Frozen Foodservice market: £ millions (Source: Horizon data).

Frozen Versus Fresh				
Product	Frozen £	Fresh £	Cost £ Difference	Buying Frozen %Saving
Canapes	0.41	0.68	0.27	66%
Camembert	0.48	0.45	-0.03	-7%
Lamb	3.05	4.16	1.11	27%
Salmon	1.77	1.89	0.12	6%
Strawberry	0.78	1.03	0.25	24%
Profiteroles	0.24	0.68	0.44	65%

Figure 7: Cost comparison of frozen vs. fresh including the cost difference and % difference. The cost comparisons were calculated per portion and the cost difference was expressed as a figure and a percentage.

quality of frozen in comparison to fresh. Twenty-two per cent of purchasing decision makers felt that frozen quality was less good and 14% considered that frozen had less flavour. Reviewing both scientific evidence and sensory taste studies (see Frozen Technology & Quality p.10) it is clear that the industry has ammunition to refute both of these arguments moving forward.

For consumers eating out, new Peach Factory research has recently established what they would most like restaurants and pubs to provide (see Figure 9).

f. Foodservice frozen food projections

Market data forecasts from Horizons, prepared in March 2010, predict that by 2014, the value of food purchases by the total foodservice market will have grown by 8% to £10.9 billion, an increase of £815 million on 2009 figures.

In line with the current climate, it anticipated that restaurants/QSRs will be responsible for the continued growth and success of the foodservice market overall with an increase in value of this sector of 13.4% over the next five years.

The picture for the frozen foodservice sector also predicts positive growth of 4.2% to £2.4 billion by 2014, again with the increase being driven by expansion in the restaurant/QSR sector. For the frozen foodservice sector, the QSRs are particularly important given that in 2009 they accounted for 86% of the frozen food purchased in the total restaurant/QSR sector. The quick service sector includes fast food restaurants, cafes and takeaways and foodservice stakeholders will be keen to develop products for this potential growth market.

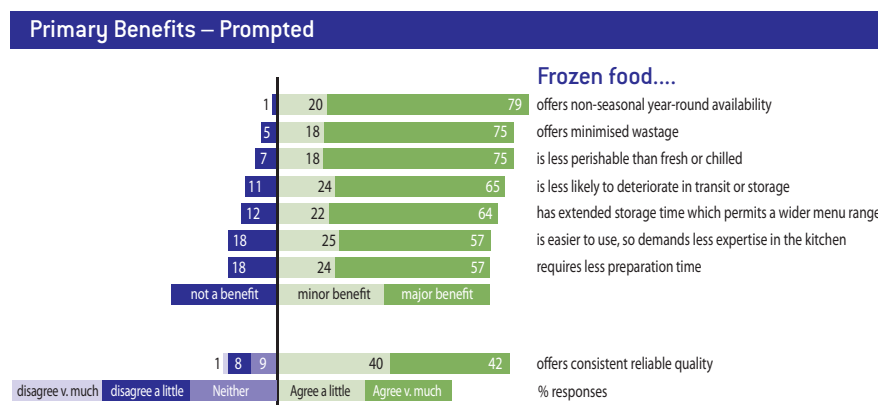


Figure 8: Primary Benefits [Prompted], Caterers' Perspective of Frozen Foods, Horizons, September 2005.

Eating out	
Better value	54%
More healthy food/drink options	37%
Local sourcing	35%
More varied menus	34%
Cleaner restaurants	27%
More exciting menus	26%
Better service	26%
Organic ingredients	13%

Figure 9: Eating out and the consumer 2008, Peach Factory/Harris Interactive (survey February 2008).

vi. Terminology

- Ambient food is that stored at ambient temperatures such as in glass, cans and dehydrated products
- Chilled long life includes food stored at chilled temperatures with a shelf life of at least 8 days
- Frozen food is that stored below 0°C
- Restaurants include full service restaurants, fast food restaurants, cafes and takeaways
- Hotels include bed and breakfasts, holiday camps, youth hostels and caravan parks
- Leisure includes visitor attractions entertainment, clubs, events and mobile caterers, on board travel
- Contract catering includes staff catering, health care (state care, independent care, care homes), education and services (government services, welfare services).

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4. Freezing Technology & Quality

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i. Executive summary

- Freezing is a widely used method to maintain quality and extend storage life of high water content foods.
- Freezing forms ice crystals that remove water from the food matrix thereby increasing concentration of solutes and reducing water activity. This increases the stability of food and enables storage over extended periods of time.
- By freezing food, the quality, safety and nutritional content of the food can be preserved close to its initial values. It is therefore extremely important to freeze the highest quality products to ensure quality once food is thawed.
- In some cases freezing rate can have an effect on food quality and this is related to the size and distribution of the ice crystals.
- The freezing process can be carried out using a range of equipment. Freezing systems may be either continuous or batch systems. Current freezing systems can be divided into air, contact, immersion or cryogenic systems.
- A number of new and innovative freezing technologies are currently undergoing development.

ii. A brief history of frozen food and the key developments to date

The use of low temperatures to preserve foods has been known for many years. 'Natural cooling' using snow and ice was used by Paleolithic and Neolithic peoples and inhabitants of caves in Santander, Spain circa 100,000 BC for food preservation. The means to create a cooling effect by mixing salts and ice was also widely known in many countries in the 1500s and was reported by Robert Boyle in 1662. The Victorians also created ice using shallow lakes of water that were cooled by radiant cooling during the night. They also gathered snow and ice which was kept in ice houses and used to create iced desserts (Beamon, 2001). Active or 'artificial' cooling to generate ice using machinery was first developed in 1755 by William Cullen who made ice by vaporising water at low pressure. This was followed in 1834 by Jacob Perkins who invented the first ice making machine (using ethyl ether as the refrigerant). Technological developments followed rapidly with the first patents on freezing foods and the first cold storage warehouse being opened in 1865 in New York. From 1868 onwards there were massive developments in frozen foods. In 1868 the Anchor Lines ships *Circassian* and *Strathleven* first brought meat from New York to Glasgow. The trade was later extended to the US, southern hemisphere and then South America, for the first time enabling abundant meat supplies available abroad to be transported to the UK. By 1900 London was the centre of the meat import trade and in World War One meat was exported from London to France for the troops. During this period there were rapid developments in technology and refrigerants which became gradually more reliable and efficient (Dunsdon, 2005).

The main development of frozen food as a convenience product occurred after 1922. This was partially due to the development of Freon (CFC) refrigerants which enabled freezers to be more widely available. In addition the quality of frozen food improved partially due to the knowledge of people such as Clarence Birdseye who understood the need for fast freezing to maintain the quality of many foods (Birdseye, 1933). Further technological developments during the 20th century allowed frozen foods to become more widely available and the range of products to increase.

iii. Why freeze food

The cold chain is essential in ensuring the safety, organoleptic quality, nutritional content and market value of perishable foodstuffs from harvest or slaughter to the consumer. Most food products require various types of refrigeration in order to maintain quality and to extend shelf life throughout the cold chain.

Most foods have a high water content and the water aids biochemical deterioration. Due to their low aw (water activity) 'dry' foods are far more stable than 'wet' foods. Freezing forms ice crystals that remove water from the food matrix thereby increasing concentration of solutes and reducing aw. Freezing is therefore a widely used method to maintain quality and extend storage life of high water content foods (Nesvadba, 2008). Unlike chilled foods, frozen food is maintained at temperatures below -12°C where there is little chance of growth of bacteria, yeasts or moulds. Therefore frozen storage mainly influences food quality and food safety is rarely an issue.

Microorganisms can survive the freezing process and frozen storage and retain their ability to multiply after thawing when conditions become favourable. However, their susceptibility varies considerably. Organisms such as protozoan parasites are destroyed by freezing and storage. Gram-negative bacteria are less sensitive to freezing than protozoa but tend to be more susceptible than Gram-positive bacteria to freezing. Viruses and bacteria spores are relatively resistant to freezing. Freezing has been shown to reduce levels of the pathogen *Campylobacter* spp. in naturally contaminated chicken skin and minced chicken meat by approximately one log₁₀ cfu/g one day after freezing (Sampers et al, 2010). The UK Food Standards Agency (FSA) has recently highlighted the fact that 65% of raw shop-bought chickens are contaminated with *Campylobacter* and that there are an estimated 300,000 cases of food poisoning attributed to *Campylobacter* per year in England and Wales. Freezing can be used to reduce *Campylobacter* in poultry and therefore is an intervention strategy that can contribute to reduction in levels of *Campylobacter*.

All food deteriorates in quality over time. Freezing reduces the rate of deterioration and therefore foods can be stored for considerably longer periods than fresh foods. Apart from the case of products that fundamentally require freezing for their structure such as ice cream, the quality of food cannot be improved by freezing and therefore it is important that only food of good quality is frozen. This was appreciated for fish as early as 1898 by

workers in America (Stevenson, 1898).

It is therefore extremely important to freeze the highest quality products to ensure quality once food is thawed. Vegetables and fruit are highly perishable products with extremely rapid deterioration in quality at ambient temperatures after harvesting. A number of works have studied the problems of deterioration of flavour, texture, colour and vitamins in vegetables. Favell (1998) stated that the deterioration in vitamin C in peas, green beans, broccoli, carrots and spinach that occurs after harvest is accelerated by temperature and will continue until the product is blanched or frozen. As with ambient foods, frozen food quality will not improve over time.

A number of studies have shown that freezing and frozen storage has minimal effects on vitamin C levels in vegetables. Tosun and Yücecan (2008) found that initial vitamin C levels in okra, potatoes, green beans, broccoli, spinach and peas decreased by 19.1-51.5% during pre freezing operations. After a commercial freezing process of 6 months total losses in vitamin C were between 27.6 and 57.9%. The authors concluded that pre-freezing operations had a major effect on vitamin C retention but that the freezing process and storage had minimal effects. Other work that reviewed available literature on the vitamins C and B and phenolic compounds in fresh, frozen and canned fruits and vegetables concluded that often the nutrient benefits of canned and frozen products over fresh produce are ignored (Rickman et al, 2007).

Recent work has shown that in practice few differences can be found between frozen commercial products and fresh products (BFFF, 2009). Food quality changes can however occur as in most instances frozen food is stored above its glass transition temperature (the temperature at which no further water can be frozen). For most food the glass transition temperature is below -30°C and most frozen storage facilities will operate at between -18 and -22°C. However, it should be noted that storage lives of foods vary considerably and are often more dependent on factors that occur prior to freezing than those post freezing (Evans and James, 1993).

iv. The freezing process

In the freezing process the temperature of a food is reduced to a level close to the temperature of the medium used for the freezing process. Initially there is a period of pre-cooling where the surface of the product will often drop below the freezing point of the food (subcooling) before the temperature jumps back to the freezing point (point where water is converted to ice). The surface temperature then drops towards the freezing medium temperature and the freezing front begins to move from the surface into the product. In the centre of the food the freezing plateau can be observed as water is frozen to ice (latent heat) before the temperature is reduced towards that of the freezing medium (Figure 1).

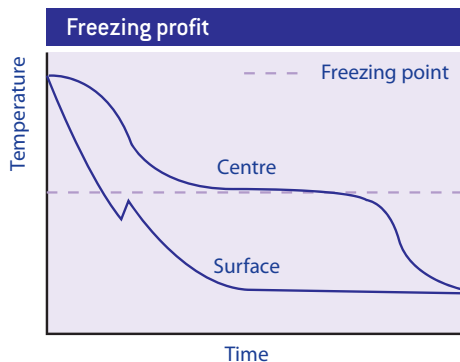


Figure 1: Typical freezing profile for a food.

The freezing rate determines the type, size and distribution of ice formation. Slow freezing induces the formation of large ice crystals that have the potential to degrade food texture. Rapid freezing enhances nucleation and formation of smaller ice crystals. It is possible to avoid ice formation completely at very high rates of cooling (up to 10,000°C/min) and achieve vitrification leading to a glassy state. Slow freezing of cellular tissues (especially from meat, fruits and vegetables) leads to large extracellular ice crystals that damage cells. Upon thawing, extracellular ice does not re-enter the cells and may cause extensive drip loss.

Whether the size of ice crystals is of extreme importance depends on the product. In ice cream ice crystal size must be small to ensure customers cannot detect ice (consumers can detect ice crystals of greater than 40-50 μm) (LeBail and Goff, 2008). However, in other products such as concentration of liquid foods or freeze drying large ice crystals are preferable.

Freezing rate will have an effect on mass transfer from products. Fast freezing minimises weight loss as water at the surface of a product is rapidly converted to ice. Therefore a rapid reduction in the surface temperature of food being frozen is usually beneficial. Once a product is frozen sublimation of ice from the product surface can occur and if excessive can lead to the surface of products such as meat becoming dry and spongy (often referred to as 'freezer burn'). For this reason most frozen product is packaged to minimise weight loss and maintain product quality.

v. Freezing technologies and their benefits

Food may be frozen in either batch operations or in continuous freezing systems where food is automatically fed through the freezer. The type of system depends on the product, level of throughput of product and flexibility in the freezing process required.

Unless products are thin, freezing in the centre of foods is controlled by conduction. Increasing the heat transfer coefficient at the surface therefore has minimal benefits above low heat transfer coefficients. The food cooling load varies during the cooling period with the maximum heat load at the beginning of the process. Although active cooling using refrigeration systems is the primary means of freezing food in the food industry it is

possible in many instances to obtain some free cooling from ambient air. Cooked foods can be cooled by 20-30°C by blowing ambient air over the product whilst maintaining a relatively large temperature difference between the food and air. Typically short ambient cooling of hot product can reduce overall heat loads by 40-50% whilst also reducing ice build up on freezer evaporators from water evaporated from unwrapped product (Evans, 2008).

The following sections detail the types of freezing systems available and their relative benefits.

a. Air based systems

Blast freezing rooms

The most common air freezing systems use a fan to blow refrigerated air around an insulated room. Food products are either manually loaded or pass through the room/tunnel on conveyors. Batch systems are the simplest freezing systems but are often characterised by poor air flow and uneven cooling times. Continuous systems overcome the problems of uneven air distribution since each item is subjected to the same velocity/time profile.

Most air based freezing systems are based around an insulated room where air is distributed from an evaporator or evaporators. On occasions this room may be a store room where the air flow is often uneven and slow (chamber freezing). Although not recommended, chamber freezing is often carried out due to availability of space to freeze product. When chamber freezing, care needs to be taken that the temperatures of food at the centre of large pallets does not remain at a level where microbial growth can occur. For example Wanous et al. (1989) found that sausages at the centre of a pallet required six to seven days to achieve -15°C from a starting temperature of 7°C.

The main advantage of air blast freezers is the flexibility to be able to freeze a range of products. In practice, air distribution is a major problem, often overlooked by the system designer and the operator. As the freezing time of the product is reduced as the air speed is increased, an optimum value exists between the decrease in freezing time and the increasing power required to drive the fans to produce higher air speeds (n.b. power of the fan is proportional to the cube of velocity). This optimum value can be as low as 1.0m s⁻¹ air speed when freezing beef quarters, to 15m s⁻¹ plus for thin products.

It is essential in all refrigerated rooms that food is loaded correctly and does not impede air movement around the room and that air does not bypass the food. By correct loading and ensuring that air did not by-pass product in the room Odey (2006) found that for the same air temperature and freezing times that the fan power to blow the air around the room could be reduced by half. In another example from New Zealand, Edwards and Fleming (1978) showed that by optimising air flow and using two stage fans that the energy consumed during carton freezing of lamb could be reduced to a quarter of that used in conventional air blast freezing.

Carton/box freezer

Carton freezers are used for freezing small cartons such as those containing ice cream. Box freezers are used for freezing boxed product such as meat, fish and poultry. The cartons or boxes are loaded automatically onto an upper track and are hydraulically pushed through a freezer. Tracks are placed at many levels and the product is lowered between each level to the exit. Freezing is usually accomplished in three to 24 hours.

Tunnel/belt

Product is conveyed through a tunnel usually by an overhead conveyor or on a belt. Most commonly air is directed across the product but may be directed at the product from above when a belt is used to convey product. The product is evenly spaced and so uniform air flow around the product can be achieved. Generally most freezers are restricted to one product size and shape so that product loading can be optimised. However, often racks or trolleys are used to enable a range of products to be processed.

Fluidised bed

Fluidised beds are usually used to freeze small IQF (Individually Quick Frozen) products such as small fruits or vegetables, meat mince or prawns. The product travels through a tunnel on a mesh belt and air is blown from underneath the belt onto the product. Air velocities are sufficient to partially fluidise the product and therefore product does not clump together and each item is frozen individually. Product is fed in at one end of the freezer and overflows from the exit. Often the bed is angled or shaken to assist product flow. High heat transfer coefficients are achieved due to localised high air velocities over the surface and therefore freezing times are short. Due to the small product and the short freezing time these systems can be compact.

Spiral freezer

Spiral freezers generally require a smaller footprint than tunnel freezers but tend to be taller. They are constructed around a belt that is stacked in a spiral of up to 50 layers. Therefore they allow a long belt to be used in a small area of the production plant. Air flow can be either horizontally through the stacks or vertically through the belt.

Impingement

Impingement technology increases the surface heat transfer in air and other freezing systems (Newman, 2001; Sundsten et al., 2001; Everington, 2001). Impingement is the process of directing a jet or jets of fluid at a solid surface to effect a change. The very high velocity (20–30 m s⁻¹) impingement gas jets 'break up' the static surface boundary layer of gas that surrounds a food product. The resulting medium around the product is more turbulent and the heat exchange through this zone becomes much more effective. Impingement freezing is best suited for products with high surface area to weight ratios (e.g. burgers) or for product requiring crust freezing. Testing has shown that products with a thickness less than 20 mm freeze most effectively in an impingement heat transfer environment. When freezing products thicker than 20 mm, the benefits of impingement freezing can still be achieved; however, the surface heat transfer coefficients

later in the freezing process should be reduced to balance the overall process efficiency.

Impingement freezing has substantial advantages in terms of freezing times. In trials carried out by Sundsten et al. (2001), the time required to freeze a 10 mm thick 80 g hamburger from +4°C to -18°C in a spiral freezer was 22 minutes whereas in an impingement freezer the time was two minutes 40 seconds. In addition dehydration was significantly higher for hamburgers frozen in the spiral freezer (1.2%) compared to the impingement freezer (0.4%).

b. Contact based freezing systems

Plate freezer

Plate freezers are contact freezers where a refrigerant is passed through metal plates that are clamped either side of the food being frozen. The plates may be horizontal or vertical depending on the type of product being frozen. During the freezing process pressure is maintained on the plates and this prevents packs 'bulging' and helps maintain the shape of the products. Plate freezers can operate as batch freezers where the freezer is manually loaded at the start of each cycle and unloaded at the end or can be configured to automatically pass food through. The maximum benefits of plate freezers are gained when there is good contact between the food and the plates as this provides good heat transfer. Therefore well packed boxed goods such as meat, fish or spinach are good candidates for plate freezing. The depth of product is usually less than 50–60 mm as the major benefits of high heat transfer are reduced with increasing thickness of product. At the end of each freezing cycle a short hot gas defrost period is usually used to release the product from the plates.

Work by De Jong (1994) comparing air blast and plate freezing of beef cartons in New Zealand showed that the power consumed per carton of beef for plate freezing was lower than two alternative air blast freezing processes. This was corroborated by Visser (1996) who demonstrated that freezing times could be reduced from 47 to 18 hours and energy costs reduced by 24% when plate freezing rather than air blast freezing meat.

Band freezer

These are relatively rare and are designed to freeze very thin layers of product (generally 40 mm or less). Most usually band freezers are used for liquids or pastes and the product is either placed on a single band or between two bands that are refrigerated.

Drum freezer

A drum freezer is somewhat similar to a band freezer but is more compact. The liquid or paste is frozen on a rotating drum that is refrigerated. Often the product is flaked or cut into pellets at the exit to the freezer.

Scraped surface heat exchanger (SSHE)

Scraped surface heat exchangers are used for liquid or semi-liquid products such as ice cream. The SSHE consists of a refrigerated drum which the liquid is fed into. Scraper blades are used to scrape the product from the walls of the drum, a process that simultaneously aerates and freezes the product. The resultant product is usually

extruded at about -5°C and in the case of ice cream the freezing process is completed in a 'hardening tunnel' (a blast freezer) before storage at typically around -25°C. SSHEs usually achieve fast freezing rates to below the initial freezing point of the product and this is an important feature for products such as ice cream where small ice crystals are vital for customer satisfaction.

c. Immersion systems

Immersion freezers utilise a solution of salt, sugar or alcohol to freeze products such as fish or meat. The product is immersed either wrapped or unwrapped in the solution or sprayed with the solution whilst conveyed through a tank. Generally heat transfer coefficients are high in immersion freezing and so freezing rates are high.

d. Cryogenic systems

In air based cryogenic systems a cryogen (usually liquid nitrogen) is either sprayed directly onto product in a tunnel or is expanded in a heat exchanger which is used to cool air blown around a tunnel. In these systems the cryogen is generally 'lost' to atmosphere after the freezing process and so a large store of the cryogen that is regularly refilled is required for operation. Cryogenic systems generally achieve very fast freezing rates but the high operational costs restrict their use to high value products.

Cooper (1980) collated and compared the costs for a number of freezing operations. When freezing beef burgers the overall operating costs (investment, fixed costs and variable costs) to freeze using a spiral freezer was just over half that required for liquid nitrogen or carbon dioxide freezing. It is relatively difficult to directly compare the energy costs for the three systems as the energy costs for production of the cryogen should be taken into account and these vary considerably (a new cryogen production plant may consume half the energy of an older less efficient one). Although operational costs for the liquid nitrogen and carbon dioxide plants were more than the spiral freezer, if the costs of evaporative weight loss were taken into account the overall differences between operating costs between the three systems were considerably less.

e. Freeze drying

In freeze drying a product is frozen before the ice is sublimated at low pressure. To enable sublimation (as it is an endothermic process) some heat is required. However, care must be taken to prevent 'collapse' of the food though melting of the ice and loss of rigidity of the food being dried. Although freeze dried product has advantages such as low weight, it generally does not have as high a product quality after rehydration as a fresh product.

vi. Refrigeration systems and refrigerants

A large variety of systems are used to freeze and store frozen food throughout the cold chain. A large proportion of freezing and cold storage refrigeration plant in the UK is operated using either ammonia (R717) or a fluorinated refrigerant. The exception is in consumers' homes where increasingly new freezers will be operated using a hydrocarbon. Ammonia and hydrocarbons have a zero GWP (Global Warming Potential) and will have a low environmental impact if the refrigerant should leak.

Fluorinated refrigerants are increasingly coming under legislation to prevent leakage as they have high GWPs. From the 1st January 2010 the EC (ODS) Regulation 2037/2000 specified that no virgin HCFC (hydro fluorocarbon) could be supplied or used for servicing existing equipment. From the 1st January 2015 the same regulation states that no recycled or recovered HCFC can be supplied or used to service existing equipment. This covers R22 which is still a relatively common refrigerant throughout the food cold chain. A survey carried out for the Carbon Trust (2005) found that 70% of food processing had refrigeration plant containing R22.

A number of initiatives are tackling moving to more environmentally sound refrigerants. CO₂ with a GWP of one is becoming a more commonly used refrigerant and has been used in freezing facilities, cold stores and supermarkets. Alternative technologies using hydrocarbons are also being trialled in supermarkets in applications where the flammability risks can be minimised. Some new low GWP refrigerants such as HFO (Hydro-Fluoro-Olefins) are coming onto the market but as yet are not fully tested in a wide range of applications. Ammonia is already a sound option for larger refrigerant plant and there are considerable opportunities to reduce the refrigerant charge through using compact heat exchangers and to reclaim heat for space or hot water heating. Heat reclaim or reuse is also an opportunity to utilise absorption or adsorption technologies, although to date these have had limited use in food freezing. Due to greater interest in reducing direct and indirect emissions from refrigeration plant many of these technologies are now being evaluated and are becoming more feasible propositions.

vii. Frozen food quality, storage life, assessment of quality

Storage life for frozen foods can be extremely variable, ranging up to several years for packaged frozen foods. The definition of storage life and the methods of measurement are often quite variable (e.g. sensory assessment, chemical or instrumental tests or a combination). This results in often quite large variations in quoted storage lives.

The definition of storage life varies considerably and depends on the level of change in quality used to detect end of storage life. The IIR (International Institute of Refrigeration) classify the practical storage life (PSL) of a food product as 'the period of storage at that temperature during which the product retains its characteristic

properties and remains both suitable and acceptable for consumption or the intended purpose'. The term 'high quality life' (HQL) is also sometimes used to define storage life. HQL is defined as 'the time elapsed between freezing of an initially high quality product and the moment when, by sensory assessment, a statistically significant difference ($P < 0.01$) from the initial high quality (immediately after freezing) can be established' (IIR, 1986).

Generally lower temperatures will achieve longer storage life. For frozen foods experimental data from many different publications showing storage life of beef, pork and lamb meat demonstrate a clear effect of temperature on storage life, with lower temperatures resulting in extended storage (Evans and James, 1993). There is however considerable scatter between results at any one temperature and this is likely to be due to a variety of product processing and packaging (PPP) factors.

a. Product processing and packaging (PPP) factors

The main product, processing and packaging factors affecting frozen food are presented (Table: 1). To have maximum shelf life the food should have good initial microbiological, physical and organoleptic qualities and undergo as few higher temperature processes as possible (apart from some decontamination procedures). The variations in PPP factors have often led to variable and contradictory conclusions and recommendations and therefore care needs to be taken when applying published data. In many cases trials on individual products are required to obtain the level of security required to ensure consumer satisfaction.

viii. Novel approaches to freezing

A number of novel freezing technologies are currently being developed for static and continuous based systems that may be the food freezing systems of the future.

Air cycle

Air cycle is one of the oldest refrigeration technologies. Air cycle machinery was used on board ships in the 1800s to maintain food temperature. However, the large reciprocating machinery was rapidly replaced at the beginning of the 1900s by smaller lighter systems using other refrigerants as new technology developed. Today high-speed turbo machinery is available that is compact and lightweight and therefore the use of air as a refrigerant is a commercial possibility.

The principle of the air cycle is that when air is compressed its temperature and pressure increases. Heat is removed from the compressed air at constant pressure and its temperature is reduced, ideally while providing useful heat to high temperature processes. The air is then expanded and its temperature reduces as work is taken from it. The air then absorbs heat (gaining temperature) from low temperature processes at constant pressure, where it starts the cycle again.

The application of air cycle to food processing has many advantages. Air is safe and any leakage from the system is not a risk to the workers, the

	Factor	Effect
Product	Variations in the raw material	Breed of animal, different cultivars of fruit or vegetables all can have a positive or negative effect on affect quality
	Time between harvest or slaughter and freezing	Initial good quality of samples, optimum ripeness, cleanliness and little damage extremely important for optimal storage life
	Handling during harvest/slaughter,transport and processing	Good handling essential for long storage life
	Seasonality of the product	Variable effects
Processing	Cutting, slicing and dicing	Can increase enzymatic activity by cutting cells, can distribute and accelerate growth of microorganisms
	Heating prior to freezing	Can result in longer storage life but meat cooked to higher temperatures more susceptible to oxidative changes in storage
	Frying	Tends to produce short storage lives, due to high fat content of the product (increases rancidity)
	Breading	Breading can have a protective effect but as many breaded products are fried the addition of oil may be counterproductive
	Mincing	Mincing induces heat and the increased surface area lowers enables more contact between product and oxygen which reduces storage life (rancidity, dehydration)
	Addition of fat	Lowers storage life unless a high grade wrapping material, which has the ability to exclude air is used
	Smoking	Generally advantageous due to the antioxidant properties of the smoke
	Additives	Addition of salt, spices, seasoning, antioxidants and protein concentrate shown to have variable effects
	Mechanically recovered meat	Storage problems due to its high fat content and increased rancidity
Packaging	No packaging	Results in more rapid rancidity in meat and fatty products than wrapped product. Dehydration resulting in freezer burn and extreme toughening
	Wrapping low water and oxygen permeability pack	e.g. vacuum pack can more than double the storage life of a meat product
	Waterproof packing	Helps prevent freezer burn and tight packing helps to prevent an ice build up in the pack
	Low conductivity packaging	Can extend freezing times and consequently reduce storage life
	Dark or opaque packaging	Longer colour retention than products exposed to the light

Table 1: Main PPP factors affecting frozen foods.

food or the environment. It is not flammable, neither does it suffocate and it is food safe. The primary reason for using an air cycle for food processing is that the range of operating conditions available is greatly increased. A number of theoretical studies have indicated the potential for air cycle in food processing operations [Russell, Gigiel and James, 2000]. Fast freezing of small products using the low temperatures available from air cycle systems can compete economically with cryogenics.

Acoustic/Stirling

Acoustic/Stirling refrigerators have been developed which harness sound waves. The technology is reported to be less efficient than vapour compression technologies but with scope for improvement. In addition the system allows proportional control and this may enable equipment to be developed to meet varying loads that might make the technology more efficient than conventional refrigerators. Thermoacoustic refrigeration uses high-intensity sound waves in a pressurised gas to pump heat. The principle of the system is that an acoustic standing wave creates regions of alternating compression (high pressure) and low pressure in the gas. Provided the gas is thermally insulated from the surroundings the changes in pressure also result in changes in temperature. Usually metal plates are arranged with some in the high and others in the low pressure areas. The heat from the hot plates is conducted outside whilst the cold plates absorb heat from the refrigerator. Work at Penn State University has developed a demonstrator acoustic refrigerator for storage of ice cream which is currently undergoing

further development with the view to future commercialisation [Poese et al, 2004].

Dehydrofreezing

Dehydrofreezing has mainly been used for fruits and vegetables. A large part of the water (50-60%) in the product is removed prior to freezing using an osmotic solution and this results in a freezing process that is faster and causes less ice crystal damage than a conventional process. Due to less water being contained in the product the refrigeration heat load is also reduced. Texture and flavour are claimed to be superior to those of a conventionally frozen product.

Electrocaloric

Electrocaloric cooling is the electrical analogue of magnetocaloric cooling. Electrocaloric cooling is based on the ability of a material to change temperature by applying an electric field under adiabatic conditions. An electrocaloric device has two thin films separated by a vacuum layer. If a voltage is passed across the gap, the most energetic electrons on the negative side 'jump' across to the positive side. As the electrons leave the negative side it gets colder. Potentially such devices can be thermodynamically very efficient and could outperform classic direct expansion refrigeration systems. In 2006 researchers from Cambridge University reported in 'Science' that thin films of perovskite PZT showed a giant electrocaloric effect with the materials cooling down by up 7°C in a field of just 25 volts [Mischenko et al, 2006].

Hydrofluidisation

Hydrofluidisation utilises a pump that circulates

refrigerant through orifices or nozzles to create agitating jets in a refrigeration vessel. This forms a fluidised bed of highly turbulent liquid that agitates product and generates extremely high heat transfer coefficients at the surface of the products. Suitable refrigerant media include brines, soluble carbohydrates (such as sucrose, invert sugar, glucose (dextrose), fructose and other mono- and disaccharides) with additions of ethanol, salts and glycerol. Freezing rates for fish and vegetables have been shown to exceed those for IQF products with heat transfer coefficients exceeding 900 Wm⁻²K⁻¹ [Fikiin, 1992, Fikiin and Pham, 1985]. This leads to low weight loss as the surface of the product is frozen extremely rapidly.

Magnetic

Technologies such as magnetic cooling have potential advantages such as no harmful refrigerants and potentially higher efficiencies than those of vapour compression technologies. Magnetic refrigeration takes advantage of the magnetocaloric effect; the ability of some metals to heat up when they are magnetized and cool when demagnetized. Much of the original work and most prototypes developed were based on the use of gadolinium magnets that are rather expensive. More recent work has looked for new materials that are cheap, have suitable transition temperatures and exhibit a large magnetocaloric effect.

Work to develop small (domestic) magnetic refrigerators has been ongoing at Ames Laboratory in America and Camfridge in Cambridge (UK) [Wilson et al, 2007].

Magnetic resonance

Magnetic resonance freezing (MRF) utilises continuous magnetic wave vibrations which impede ice crystallisation. When cooling is applied this allows water to be supercooled below its freezing point. When the magnetic field is removed the product can freeze rapidly. This has claimed benefits of small ice crystals, little cellular damage and low water loss during the freezing process. Published information on MRF technologies is rather limited with much retained within commercial companies.

Power ultrasound assisted freezing

Power ultrasound uses sound energy to accelerate freezing. Ultrasound can create cavitation in cells which promotes ice nucleation and accelerates heat and mass transfer. Ultrasound can potentially fracture ice crystals leading to small crystal sizes and in some cases better product quality. Although the technology has considerable promise for high value product considerable research is still required for industrial application (Zheng and Sun, 2006).

Pressure shift freezing

Two main processes exist; High-Pressure Assisted Freezing and High-Pressure Shift Freezing (HPSF).

High-Pressure Assisted Freezing occurs under constant high pressure whilst temperature is lowered to the corresponding freezing point. Freezing occurs from the outside of the product with ice nucleation in the outer area of the food which grows radially into the centre. There is little evidence that structure or texture are any different from product frozen at atmospheric pressure. Potentially freezing times can be less than at atmospheric pressure.

HPSF is potentially a method to produce frozen food with small ice crystals and consequently little tissue damage and high quality. At atmospheric pressure ice has a freezing point of 0°C. With increasing pressure the freezing point of water is lowered until at 207,500kPa the freezing point is -22°C. HPSF involves increasing the pressure of a sample and reducing the temperature to create super-cooled water. At this point the pressure is released to create ice instantaneously. The pressure can be released slowly over several minutes or rapidly over a few seconds. This produces small ice crystals of granular shape almost instantaneously throughout the sample. When the pressure is released there is a large release of heat of fusion and a consequent rise in sample temperature. Improvements in texture and histological damage of samples have been reported but deteriorations in colour, water holding capacity, and texture of meat products have also been reported and appear to be related to applied pressure (Fernandez-Martin et al, 2000, Massaux et al, 1998). HPSF has the advantage of deactivating some vegetative microbes, with the level of inactivation ranging from about three to eight log cycles.

Although HPSF has many advantages sample sizes are relatively small and the vessels required for the process are expensive and the freezing process is a relatively slow batch operation with small throughputs. Although ice crystals are small and uniform the maintenance of such structures needs uniform temperature control in frozen storage and this may be difficult to practically achieve.

ix. Conclusions

Freezing enables food to be stored for extended periods of time and the initial quality of the product to be maintained. In terms of food quality pre-freezing treatment of food is equally, if not more, important than the actual freezing process.

A range of freezing technologies are currently available and selecting the ideal process for a particular food is an important factor in ensuring quality. Several novel technologies have potential as freezing technologies of the future. However, these are still only small scale and are only likely to be suitable for commercial freezing in the long term. In the shorter term, the food industry is becoming more aware of environmental issues. Due to consumer pressure and rising energy costs energy is becoming increasingly important and companies are seeking ways to reduce energy consumption by improving the efficiency of the process and optimising efficiency of equipment used for freezing. Environmental pressures are also encouraging the use of new low GWP refrigerants and there is renewed interest in older refrigerants such as ammonia, CO₂ and air. The increasing need to produce new and novel products is fuelling the need for flexible equipment that can future-proof manufacturers against unexpected changes in the market.

X. References

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5. The Sustainability & Social Responsibility Opportunity

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i. Executive summary

- The frozen food supply chain has made significant gains in conserving energy, reducing greenhouse gas emissions and improving manufacturing efficiency. However, high variability in practice exists and current work programmes will reduce this to improve best practice across the frozen food sector.
- Highly significant areas of greenhouse gas emissions and energy use are transport and retail display of frozen foods.
- Utilisation of frozen food is likely to create a more sustainable use of seasonal foods that are consumed out of season.
- Reduction of food waste and improved dietary portion control is likely to be realised with the effective use of frozen food in domestic and food service sectors.

ii. Introduction

Those of us who work in food businesses are increasingly aware that we must take action to make our food supply chains more sustainable, as many governments, agencies and businesses also recognise in detailed research and published reporting (such as the UK Government's Food 2030 report). Now or soon food production must increase by 50%, climate change will make food supply more unpredictable. The big messages emerging are focussed on the ways in which we manage food supply chains particularly with regard to their associated greenhouse gas (GHG) emissions, resource use and waste production.

Global events have demonstrated food supply and consumer demand are finely tuned and not as flexible as many consumers in Europe have come to expect. The indicators of global food supply and price show primary food commodities including small grains, oils and dairy products are volatile. The debate on the sustainability of the food system and secure supply was established in the 2008 Defra discussion paper 'Ensuring the UK's Food Security in a Changing World'. How we manage, store and preserve food is a vital aspect of food security and sustainability.

Frozen food will have an important role to play in this world view. The 2009 Food and Agriculture Organisation's State of the Food and Agriculture report makes clear that the demand for processed and livestock products will increase as emerging economies experience nutritional transitions that reflect growing affluence. Preservation and freezing of food offers a number of sustainable outcomes that can deliver transitions and maintain sustainable nutrition which are described in the research reported here. The British frozen food industry has aligned many of its resource efficiency actions with the sustainability indicators reported by Defra through the Food 2030 vision and we can achieve even greater resource efficiency through knowledge transfer.

The British frozen food industry has led innovations that enable the delivery of the large diversity of food and drink recipes that are intimately associated with cultural and economic activities. These are delivered in a sustainable way that is

constantly improving in light of market trends, nutritional research, technical innovations and the emerging need to 'get more from less' to reduce environmental impact. Our goal is that these relationships are manifested as a sustainable food system in the UK that delivers health and wealth without compromising future generations. The research presented here determines frozen preservation of food as a key driver in delivering sustainability.

iii. An overview of the frozen food sustainability opportunity

Our analysis demonstrates frozen food supply chains are required for the maintenance of a safe and secure food supply. There are a number of sustainability criteria the frozen food industry is currently using to achieve efficiency targets. Current analysis of supply chains using Life Cycle Analysis (LCA) shows that the embodied energy and GHG emissions as global warming potentials (GWP) for frozen food can equal or be lower than chilled or unprocessed foods. The frozen food industry has improved the efficiency of energy use and identified large variability of energy use in manufacture, storage and transport operations suggesting further sector improvements are achievable. This has been achieved by identifying changes in design of freezing infrastructure and operational practices that improve energy efficiency.

In this analysis of sustainability it is identified that the frozen food sector can go further in achieving sustainability targets in line with government indicators if innovation within the sector is continued to be stimulated and supported using initiatives that support resource efficiency measures for small and large companies in the UK food supply chain. A significant benefit of using frozen food identified here is the potential reductions in domestic food waste. Future improvements in the domestic management of frozen foods will be a source of future reductions in greenhouse gas (GHG) emissions and domestic waste arisings.

iv. The sustainable opportunity

The principles for the development of a sustainable food system have been determined by a number of cross-government reports including Food Matters and Food 2030 (UK Cabinet Office Strategy Unit, 2008, Defra, 2010). These reports are a response to the Food Industry Sustainability Strategy published by Defra in 2006 that resulted in the implementation of measures by the frozen food industry to conserve energy used by GHG emissions. These are industry wide target criteria that will integrate with the sustainability indicators of reducing diet related disease, food miles and waste.

Maintaining an appropriate quality of life depends on efficient food supply chains and these require effective food preservation that is largely provided by assured low temperature storage and delivery. The need for a fit for purpose cold supply chain has been the source of intense innovation that has alleviated the scourge of food insecurity and food poisoning for billions of people worldwide.



In Europe, nearly 400 million people are served safe food everyday because the cold chain enables the storage and delivery of chilled and frozen products (Raspor, McKenna, Lelieveld, and de Vries, 2007). This is most visible to consumers as refrigeration in retail environments and the operation of cold supply chains is a mainstay of modern lifestyle. However, a fit for purpose cold food supply chain reduces the risk and variability in production and manufacturing outputs so that post-harvest loss and food waste due to variability in price or demand are minimised. Furthermore, the development of effective longer-term frozen storage provides a buffer effect for the supply of food during crises and provides the crucial property of resilience in times of insecurity (Martindale and Swainson, 2008). Understanding the impact of the frozen food supply chain with respect to the Government food system sustainability indicators of energy use, GHG emissions, food miles and waste is critical.

v. GHG emission reduction

There is an established requirement for an efficient frozen food supply chain providing choice and safe food which has been complemented with an emergent need for sustainability. At present only top line GHG emission statistics exist for the food and beverage industry and the frozen food industry sector has determined specific GHG emissions for the frozen supply chain (Audsley et al. 2009; James et al. 2009). Reported GHG emissions for the cold food chain suggest significant gains can be made. GHG emissions are certainly significant for the sector and a typical picture of the cold supply chain in the UK based on energy consumption is shown in Figure 1. The scenario is based on direct CO₂ emissions and the extrapolations use published statistical data. However, it is important to distinguish the impacts of frozen and chilled food supply chains. This is because published LCAs for food products suggest frozen food supply chains can have the same or reduced embodied energy and global warming potentials (GHG emissions) (Wallén, Brandt and Wennersten, 2004).

Combined with a consideration of frozen preservation and the important purchasing behaviours associated with seasonality and locality in modern food retail environments these factors are the focus of intense current research across the frozen food supply chain.

Figure 1 shows up to 20 million tonnes of CO₂ emissions are associated with the cold food supply chain from manufacturer to retail and service sectors. This research has identified retail (5.5 million tonnes of CO₂ emissions), transport (8.2 million tonnes of CO₂ emissions) and manufacturing (at present unknown CO₂ emissions) sectors as the most intensive energy users and GHG emitters for cold food supply. Storage and service sectors are relatively low intensity points of CO₂ emissions and energy use. Figure 1 is our best current understanding of the frozen food supply chain. Two areas we require greater data are freezing in the manufacturing environment and the impact of both freezing and chilling in the domestic environment. An estimate for manufacturing can be made of 2 million tonnes of CO₂ emissions from the manufacturing sector if potato products are considered to make up 10% of the frozen product

and ready meal market by volume (James et al. 2009).

The scenario developed in Figure 1 considers the UK frozen food supply chain and the imported cold chain impacts are currently untested. If we consider Kenyan green beans for example, around 20,000 tonnes are imported into the UK each year by air freight for the chilled market (Legge, Orchard, Graffham, Greenhalgh and Kleih (2006). This represents a CO₂ impact of 1.5 kg CO₂ per kg of beans if we use food mile figures reported by Defra and AEAT (2006). An estimate of the CO₂ emissions associated with blast freezing for UK grown produce is 0.5-1 kg CO₂ per kg of vegetable product. This initial study suggests potential GHG savings are made if UK grown produce is frozen. However, the issues of smallholder livelihoods and consumer preference are complex and need to be better understood for definitive actions to be made at present.

vi. The knowledge transfer opportunity

Established research from the frozen food sector suggests large amounts of variability in the performance of cold chain operations. This is apparent for frozen storage where 76% of cold storage in the UK is controlled by third party logistics companies, 14% by retailers and 10% by manufacturers. A survey of cold store efficiencies has shown cold store efficiencies can vary sixteen-fold with the lowest energy consumption being 25 kWh m⁻³ yr⁻¹ for frozen and mixed (chilled and frozen) stores (Evans 2009). This high variance in performance can be minimised by improvements in design and working practices in stores. However, variances in freezing energy efficiency in the manufacturing, transport and retail sectors reported by James et al. 2009 show improvements in energy consumption of at least 20% are possible across the frozen food supply chain.

A future sustainability target for the frozen food sector is a continued alignment of commercial practices towards the best energy efficiencies in the industry because such initiatives will improve the energy costs and environmental credentials of British frozen food businesses.

There are many challenges the frozen food industry currently faces with regard to improving freezing performances and the foremost challenge of efficient data collection and recording primary data on energy use from all enterprises. We now know where likely action points for environmental improvement are transport, retail, manufacture and domestic management of frozen food.

vii. Waste reduction

Whereas the frozen food sector can implement performance improvements with knowledge transfer and new technologies, the domestic environment and consumer behavioural change remain a significant future challenge. For example, if the catering outlet scenario shown in Figure 1 is scaled to 25 million homes using 8 kWh per day for chilling and freezing it will account for 31.5 Mt CO₂ emissions. These are significant emissions and it is likely that home food freezing is not made full use of because

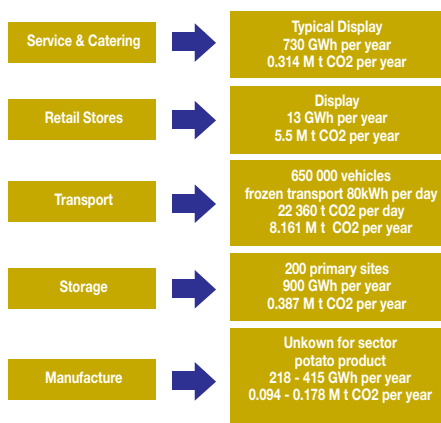


Figure 1: Estimated energy use and associated CO₂ emissions for refrigeration of food in the UK supply chain. The conversion factor used for GWh of electricity to tonnes of CO₂ in this scenario is used from a Yorkshire and Humber Regional business tool, ENWORKS. The conversion factor is 430 tonnes CO₂/GWh. The scenario presented does not represent a full life cycle analysis and extrapolates current data reported by Defra (2009) for energy use in the cold food chain.

at least 15% of food and drink purchases are currently disposed of without consumption (WRAP, 2009).

These products add to the national GHG emission inventory for food and a way to reduce them could be frozen preservation and portion control.

A further challenge for the frozen food sector is to understand how manufacturing decisions for portion control and domestic freezing management can reduce domestic waste arising. Food related behavioural change in the domestic environment remains a significant target for improving sustainability using frozen foods. There is no significant evidence that shows the sensory characteristics of specific frozen food groups is different to chilled or ambient produce even though preference for many fresh vegetables by consumers is often observed (Gormley, 2008). Understanding this preference and why other food groups including bread and prepared foods are 'thrown and not frozen' is a challenge for the frozen food sector. The shelf life for frozen foods is at least three months to 15 months at -12°C (ice cream is an exception at one month) and frozen choices could significantly improve diet planning, portion management and waste reduction (Zaritzky, 2008).

The advantage of freezing to inventory and stock planning is well known in industry and it is an opportunity to extend these practices to the domestic kitchen by improved consumer communication.

viii. Conclusions

The research reported here identifies opportunities the frozen food sector is responding to through research and knowledge transfer programmes. If they are not to be stifled by communications that incorrectly suggest to consumers that fresh food is best then the impact of poor diet and food waste can be minimised using frozen food preservation. A greater understanding of the impacts associated with the imported chilled food supply chain and consumer preference for chilled foods are required for future food sustainability policy. Our current understanding is that utilising frozen food options in a balanced diet can minimise GHG emissions, waste and poor dietary choices in our food system. Frozen foods have an important role to play in the future sustainable vision of the UK food system.

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6. Nutrition

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i. Executive summary

- There is no significant evidence that the nutritional quality of food is compromised by freezing.
- Research into nutrients from specific frozen food groups show no evidence of a reduction in food quality.
- The nutritional quality of chilled foods can be compromised in general treatments by the consumer in tested post-purchase scenarios.
- The use of frozen food can improve menu planning and aid the provision of a healthy balanced diet.
- The use of frozen food can reduce waste

ii. A place for frozen food

The obesity epidemic and intense media coverage of the link between diet, health and obesity, has swayed public opinion as to what type of food is healthy and good quality. Whilst consumers may view fresh food as wholesome and nutrient rich, processed food is considered to be of reduced quality and nutrient value. In the past, this opinion has been reflected in frozen food sales; in 2005, profound shifts in consumer eating habits resulted in the market value of frozen ready meals falling by 13% (Mintel, 2010).

Some suppliers have attempted to change consumer perceptions by promoting the many benefits of frozen food. The McCain's 2010, 'It's all good' campaign focused on the quality of raw ingredients and cited the health benefits of some of their lower fat, higher fibre range of chips. The rolling Birds Eye 'we don't play with your food' programme, promotes the freshly frozen message; their 'field fresh' vegetable range and 'just caught taste' omega three-rich fish range have been well received. These positive marketing strategies are not however consistent with in-store messages; consumers are still predominantly faced with a multitude of brightly packaged, cheap and multi-buy offers.

A recent report by Mintel (2010) suggests that while British, Indian and Chinese meals are the most popular frozen food choices, sales of premium, diet and healthy ranges are steadily increasing. As these foods are predominantly bought by younger males from single households, UK demographic trends could favour growth in sales: smaller households are accounting for a bigger share of the population. This generation of consumers are likely to be persuaded by contemporary food trends such as health and wellbeing, provenance and quality.

iii. Nutrient deterioration

The quality and deterioration of food is influenced by growing conditions and varieties of plants, feeding of animals, conditions of harvest and slaughter, sanitation, damage to tissues, storage temperatures and many other variables. Produce intended for commercial freezing retains a high vitamin and mineral content because it is frozen at source within hours of harvest or slaughter. Typically, the freezing process will preserve food without causing major disruption to its size, shape,

texture, colour and flavour. Changes which do occur, particularly during the blanching process, are necessary to inactivate natural spoilage enzymes, but little further alterations are expected during deep frozen storage (Leino, 1992; Kmjecik and Lisiewska, 1999).

In contrast, by the time consumers receive fresh food, extensive oxidative degradation during handling, transport and storage may have occurred (Rickman et al., 2007; Lund, 2000). A study by Bushway et al. (1989) suggests fresh produce is typically available to the consumer after a period of three to seven days in retail distribution and storage. Adding to that the duration of home storage, it is postulated that the nutrient content of fresh produce can fall below that of frozen. Increasingly, fresh food such as fruit and vegetables are stored at refrigeration as oppose to ambient temperatures, thus fresh produce can be exposed to a variety of environments which potentiate changes in quality characteristics, before they reach the consumer (Shewfelt, 1990).

iv. Food waste and cost

It is increasingly apparent that freezing is an important, yet underutilised technology in terms of helping to preserve and maximise the nutrient content of food (Archer, 2004).

The use of frozen food in the home and on a catering scale can be specifically beneficial in terms of its contribution towards reduction in food waste and cost. In a commercial setting, unpredictable levels of customer demand for a varied menu and quick service, mean frozen food plays a unique and necessary role. Foodservice establishments benefit from the cost and time advantages of using ready-made frozen products that would otherwise be labour intensive and/or require a high level of skill to produce.

As previously mentioned, the BFFF commissioned independent research entitled 'Cost, Waste and Taste Comparison of Frozen Food versus Fresh Food in a Consumer Market' (BFFF, 2010). In this investigation, nine families were asked to document the purchase and waste of fresh food over a one week period and then repeat this process using frozen equivalents. The mean results of this investigation showed purchase of frozen main meals was 33% less expensive than fresh; savings ranging from 13% to 57% were achieved. In addition to these monetary savings, the use of frozen food resulted in over a third less wastage, and contrary to expectation, some frozen meals were rated 'better than' or 'as good as' the fresh versions.

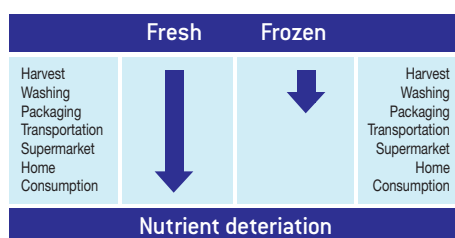


Figure 2: Nutrient Deterioration. While nutrient deterioration ceases for frozen food post blanching, for fresh food nutrient deterioration continues until it is consumed.

v. Contribution of frozen food to dietary intakes

UK survey data on the nutritional contribution of frozen foods to dietary intakes is insubstantial. The rolling National Diet and Nutrition Survey programme provides a continuous cross-sectional survey of food consumption, nutrient intakes and the nutritional status of those living in private households in the UK. This survey has the potential to provide unique insights into the consumption and provision of nutrients from frozen sources, yet fresh and frozen data are jointly analysed [Bates et al., 2010]. US nutrition surveys have shown that although most individuals eat an inadequate quantity of fruit and vegetables, they are more likely to consume them in a processed, rather than fresh form [USDA-ARS, 2005].

These important findings may be useful to health professionals attempting to facilitate 5-A-DAY targets; incorporating frozen foods into the diet could help some individuals increase their fruit and vegetable intakes. Since freezing is an effective preservation technique, there is also great potential for food intended for freezing to be free of chemical preservatives and lower in salt. Such strategies for improving the profile of frozen food fit well with Government targets and current consumer demands. Rather than diminishing our diets, frozen foods could facilitate the selection of a balanced diet, as they enable individuals to shop less frequently and stock a wide range of foods on which to base varied and nutritious meals.

The potential contribution to nutrition by using frozen food on a catering scale was recently examined in two cases. In the first instance, menus were collected from primary schools in Derbyshire and Warwickshire. NetWISP V3.0 dietary analysis software was used to analyse the food, firstly as fresh and then as frozen; these values were converted into energy, macronutrients and micronutrients. Subsequent statistical analysis showed no significant difference between fresh and frozen food classification for the 37 nutrients tested. This trend remained when the menus were analysed by school area, vegetables only and meat and fish only [Harden et al., 2009].

The result of this investigation correlates with a subsequent pilot study where menus were obtained from a hospital in northern England: nutritional and statistical analysis showed no significant difference between fresh and frozen food classification for the 37 nutrients tested [Harden et al., 2010]. These outcomes suggest frozen food can be effective in providing adequate nutrition for primary school children and those under hospital care. Other advantages of using frozen food on a catering scale such as its contribution towards reduction in food waste, availability, convenience and improved price stability were also evident.

vi. Recent research

A search for peer-reviewed, English language studies published between January 2000 and July 2010 using MEDLINE (the National Library of Medicine's bibliographic data base) reveals 12 studies which have examined the effect of freezing on nutrient and sensory parameters

[Table 1]. Of these studies, only three compared nutritional values of fresh compared to frozen food samples [Lisiewska et al., 2009; Scott and Eldridge, 2005; Hunter and Fletcher, 2002], nine investigated the impact of freezing on the nutrient content of fruit and vegetables [Phillips et al., 2010; Cruz et al., 2009; Lisiewska et al., 2009; Phillips et al., 2005; Scott and Eldridge et al., 2005; Martins et al., 2004; Mohammed et al., 2004; Giannakourou and Taoukis, 2003; Hunter and Fletcher, 2002], one examined the folate content of ready meals [Johansson et al., 2008] and one examined lipid and protein oxidation in meat [Soyer et al., 2010].

vii. Vitamin C

As vitamin C is highly water soluble and vulnerable to chemical and enzymatic oxidation it is frequently used as a proxy indicator for plant nutrient deterioration [Favell, 1998]. Half the studies cited in the MEDLINE search examined vitamin C retention in fruit and vegetable samples; two studies found vitamin C was not affected by freezing [Cruz et al., 2009; Mohammad et al., 2004], two studies documented plant species and tissue specific vitamin C deterioration [Phillips et al., 2010; Giannakourou and Taoukis, 2003] and one study noted nutritional and sensory parameters were affected at only very low freezing temperatures [Martins et al., 2004]. The vitamin C content of plants varies considerably due to the nature of food as a biological material; citrus fruit and brassicas contain high levels, whilst root crops tend to contain relatively little. In addition, within plants inherent vitamin variability occurs, for example peas contain between 20-40mg per 100g at harvest depending on factors such as variety and agronomy. These nutrient variations within and between species can have an effect on the integrity of investigative studies.

viii. Fruit and vegetables

One of the most informative studies to date was conducted by Favell [1998] who investigated the vitamin C content of fresh and frozen vegetables at various stages of storage and processing. The results of his study showed the nutrient status of frozen peas and broccoli was similar to that of fresh three day old samples. In addition, frozen peas were superior in nutrient content to fresh samples that had been stored at ambient temperatures for several days. The nutrient status of frozen carrots and green beans was similar to vegetables at the point of harvest (zero days old). Frozen spinach was nutritionally comparable to freshly harvested vegetables and superior to all stored ambient and chilled samples. These findings are particularly useful because comparisons which reflect the potential product lifecycle are made.

The food industry has however evolved in the 12 years since this study was conducted; an up to date study which reflects modern processing and storage procedures and examines a wider range of produce is warranted. The quality of frozen food is affected by freezing and thawing rates; when products are frozen slowly large ice crystals can form within the food causing cell wall damage [Boonsumrej et al., 2007]. The formation

of smaller ice crystals minimise tissue damage and drip loss during thawing. Quick freezing methods, which accelerate and optimise the process, can prevent large ice crystal formation [Martino et al., 1998]. The evaluation of novel techniques such as cryogenics and air blast freezing, warrant investigation.

Rickman et al. [2007] conducted an extensive review of 56 contemporary and classical studies that had examined the nutritional differences between fresh and frozen fruit and vegetables. They concluded that the loss of nutrients in fresh products during storage and cooking were more substantial than is commonly perceived and that frozen fruit and vegetable consumption should continue to be promoted as part of national and international food based guidelines.

Fruit and vegetables play a critical role in the diet; they are characteristically low in fat, salt and energy, high in carbohydrates and fibre and provide significant levels of micronutrients. Thus incorporating fruit and vegetables into meals fits in well with UK government guidelines to eat a healthy balanced diet. Scientific evidence which suggests high intakes of fruit and vegetables could reduce the risk of developing certain chronic diseases has led to the implementation of public health initiatives such as the 5-A-DAY campaign. The 5-A-DAY message extends to frozen fruit and vegetables because regardless of any nutrient degradation during processing, storage and cooking, they are all typically good sources of certain vitamins, minerals and fibre.

Farmers are under increasing pressure to provide year round crops and are often forced to grow certain varieties for their breadth of yield rather than quality. It has been suggested that a number of pre- and post-harvest factors are responsible for the wide variation in vitamin C content of fruits and vegetables at harvest [Mozafar et al., 1993]. Lee and Kader [2000] conducted an in depth investigation of these factors and suggested that low light intensity, overuse of nitrogen fertilizers and intensive irrigation decrease the vitamin C content of many fruits and vegetables. Freezing technology allows farmers to optimise growing conditions and harvest crops at their peak; in return the consumer receives high quality produce all year round.

ix. Carotenoids

One of the studies cited in the MEDLINE search examined the effect of freezing on the carotenoid content of corn samples. The carotenoid content of fresh, commercially canned and frozen samples of two cultivars, from the same production field was studied. Corn samples were harvested daily over a five-day-period and randomly selected for analysis. The results of this experiment showed that post-freezing, detectable levels of total carotenoids in both corn cultivars significantly increased. The authors of this work suggest increasing the carotenoid of corn by freezing may have effects on its bioavailability. Carotenoids are responsible for the yellow, orange, and red pigmentations in fruit and vegetables. The health benefits of dietary carotenoids are reasonably well documented and carotenoids such as lycopene are of particular interest due to their antioxidant abilities and

possible links with reduced chronic disease risk [Basu et al., 2001].

x. Folate

Two of the studies cited in the MEDLINE search examined the effect of freezing on the folate content of thawed vegetarian ready meals and fruit and vegetables. Johansson et al. [2008] showed that the folate content of ready meals was predominantly influenced by the folate content of the initial ingredients and meals with higher levels were less likely to lose folate during freezing and cooking processes. Phillips et al. [2005] homogenized fruit and vegetable samples before freezing. The frozen samples were measured for their folate concentrations at zero, two, seven, 30 days and then at three month intervals for a total of 12 months; no changes in folate content were detected in any of the samples at any of the measured time points.

xi. Meat and fish

Just one of the studies cited in the MEDLINE search examined the effect of freezing on meat. In this study, the effects of freezing temperature [−7 °C, −12 °C and −18 °C] and duration of frozen storage [−18 °C up to six months] on lipid and protein oxidation in chicken leg and breast meat was evaluated [Soyer et al., 2010]. The results of this study suggest that while frozen storage duration had a significant effect on lipid oxidation, freezing temperature had no significant effect. Oxidative reactions in meat are the most important contributors to quality loss, including flavour, texture, nutritive value and colour [Morrissey et al., 1998] and may also induce a number of unfavourable changes in proteins [Levine et al., 1990; Xiong, 2000].

An early observation by Bennion [1980] was that prolonged frozen storage increased the toughness and disruption of fish muscle proteins; there are no studies to affirm this trend when modern freezing techniques are employed. In general, people living in the UK currently consume less than the recommended two portions of fish a week [FSA, 2010]. One reason for this may be that fresh fish deteriorates rapidly resulting in off odours and flavours. Providing quality fresh fish is logistically problematic in cases where fish has to be transported from harvesting to the geographically remote customer.

xii. Food safety

The safety of food can be enhanced by processing methods which are designed to eliminate harmful bacteria. Some treatments, such as pasteurization, are well understood and accepted. Freezing contributes to food safety by slowing the movement of molecules, causing microbes [bacteria, yeasts and moulds] to enter a dormant stage. Although it successfully prolongs the shelf life of many food products [Proudlove, 2001; Sun, 2006] and destroys, for example, the trichinosis parasite in pork [Potter and Hotchkiss, 1998] the process by which this occurs apparently remains elusive to the consumer. A recent report suggests 85% of households significantly underestimate the length of time frozen food can be stored safely and 39% throw away safe food

because they couldn't remember when it was frozen [Birds Eye Foods, 2010].

Despite a general increase in microbiological outbreaks in processed food, frozen food, with few associated outbreaks of food borne illness, has earned a very good safety reputation. In most cases where outbreaks have occurred, contaminated raw materials or post process contamination, as opposed to freezing, have been implicated [Mayes and Telling, 1993]. Freezing is considered to be one the best processes for preventing the growth of spoilage and pathogenic micro-organisms present on and within meat and fish products [Potter and Hotchkiss, 1998]. Archer et al. [1995] suggests the potential of freezing, in terms of food safety technology, is underutilised and research into the identification of variables which could maximise the potential of freezing for safety is warranted.

xiii. Food quality

The initial quality of raw materials substantially affects the quality of a final product. Ensuring that food intended for freezing is 'on the day fresh' and of the highest nutritional and sensory quality is essential, because with few exceptions frozen storage will not improve the quality of the food, only maintain it (Gaman and Sherrington, 1996). Organoleptic alterations caused by the freezing process, frozen storage and thawing are largely due to the changes produced in chemical compounds. As the flavour of frozen food is well preserved, the sensory quality of frozen food is most commonly determined by its visual and orosensory texture.

Historically, the freezing process has been shown to have some unfavourable effects on the texture of food. Bennion (1980) for example, suggested prolonged frozen storage increases the toughness and disruption of fish muscle proteins. Contemporary research, coupled with innovative freezing methods, has however revealed more positive outcomes. Muela et al. (2010) investigated the effect of various frozen storage conditions on the sensory quality of beef and Vieira et al. (2009) examined the effect of freezing method and duration on the instrumental quality of lamb. Overall, only small sensory differences were documented and these alterations were attributed more to factors such as the post-mortem ageing of the meats rather than the freezing process. The effect of storage time on the functional attributes of meat was assessed by Farouk et al. (2004). Storage times of zero, three, six, nine and 12 months were examined and increases in pH, emulsion activity and stability were recorded. They found that

whilst total protein stability decreased with storage time, tenderisation increased. Sousa et al. (2007) optimised the pre-treatment, freezing method and thawing mode of soft fruits to the extent that these products scored highly in subsequent objective texture and sensory attribute tests.

A recent, independent, commercial sensory comparison study used a panel of 32 chefs to examine the sensory characteristics of foods commonly served in UK pubs, restaurants and hotels (BFFF, 2009). Each food was presented in its fresh and frozen form and panellists were asked to rate the products in terms of their acceptability. The results of this investigation showed there was no statistically significant difference in overall ratings in seven out of the eight products tested. Panellist found all products acceptable, and in some cases, frozen products achieved a higher overall rating score than the fresh.

xiv. Conclusions

The common assumption that fresh food has greater nutritional value than its frozen counterpart is misconceived. Rapid and highly organised methods of harvest/slaughter to freeze have evolved with the express purpose of minimising nutrient losses. In contrast, the time taken to pack, transport and deliver fresh food may translate into days or weeks before they are consumed resulting in a gradual loss of nutrients over time. The benefits of using frozen food in the home and on a catering scale are numerous, specifically in terms of contribution towards reduction in food waste, all year-round availability, safety, convenience, improved price stability and extended shelf life.

Reference	Nutrients under investigation	Study details	Findings
Phillips et al. (2010)	Vitamin C	Vitamin C content of homogenised raw fruits and vegetables (collard greens, Clementine's and potatoes) were analysed at time points up to 49 weeks.	Vitamin C levels were stable for the Clementine samples but decreased in collards and potatoes. No comparison to fresh in an acute setting was made.
Soyer et al. (2010)	Lipids and protein	Meat was frozen at three different temperatures over 6 months and levels of lipid and protein oxidation was determined.	Lipid and protein oxidation occurred simultaneously in frozen chicken meat. Oxidation was higher in leg than breast meat.
Cruz et al. (2009)	Vitamin C	Vitamin C content of watercress measured after a 4 month storage period.	Vitamin C content of frozen watercress was not generally affected by freezing.
Lisiewska et al. (2009)	P, K, Ca, Mg, Na, Fe, Zn, Mn, Cu, Cr and Ni	Mineral content of spinach and kale was measured after blanching, cooking in brine and 12 months of freezing.	Frozen spinach and kale contained significantly less potassium and magnesium. Decreases in other elements were specific to vegetable type. Modified freezing methods resulted in greater levels of the analysed constituents in almost every case, compared to the traditional freezing method.
Johansson et al. (2008)	Folate	Folate content of 10 vegetarian ready meals.	Folate content of thawed ready meals provided 23-81µg per portion (400g). Meals with higher levels of antioxidants were less likely to lose folate through freezing or cooking processes.
Phillips et al. (2005)	Folate1	5MTHF content of homogenised frozen fresh fruits and vegetables were determined.	No significant change in 5MTHF levels observed after 12 months of freezing.
Scott and Eldridge, (2005)	Carotenoids	Corn samples were harvested over a 5-day period and carotenoid2 content was measured in the fresh, frozen and canned samples.	Freezing increased the carotenoid content of some corn samples.
Martins et al. (2004)	Vitamin C	Vitamin C content of frozen green beans measured after storage (1, 4, 14 and 60 days) at temperatures ranging from 5 oC to -18oC.	The nutritional and sensory parameters of green beans were retained at storage temperatures of 5 oC, -6 oC and -12 °C. At -18 °C sensory parameters were well retained, but ascorbic acid and starch degraded.
Mohammad et al. (2004)	Vitamin C	The ascorbic acid content of strawberries exposed to slow (-20oC) and fast (-50-100oC) freezing was determined.	The different freezing methods had no effect on the ascorbic acid content of strawberries.
Giannakourou and Taoukis (2003)	Vitamin C	Vitamin C losses in green vegetables stored at temperatures between -3oC and -20oC were measured.	The type of plant tissue significantly affected the rate of vitamin C loss – spinach was most susceptible to degradation followed by peas, green beans and okra.
Hunter and Fletcher (2002)	Antioxidants	Total antioxidant activity of water and lipid-soluble extracts from fresh, stored and frozen vegetables was determined.	Antioxidant activity declined in stored samples. Samples of frozen peas and spinach had a substantially higher antioxidant activity than canned or jarred samples.

Table 1: Medline search results; the effect of freezing food on nutrient and sensory parameters

Xv. References

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