

# Upgrading the Cold Chain for Consumer Food Products



**The National  
Food Centre**

RESEARCH & TRAINING FOR THE FOOD INDUSTRY

RESEARCH REPORT NO 32



# UPGRADING THE COLD CHAIN

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## FOR CONSUMER FOOD PRODUCTS

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### Authors:

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Ronan Gormley B.Sc. Ph.D.

Martine Brennan B.Sc. Ph.D.

**The National Food Centre**

**Dunsinea, Castleknock, Dublin 15**

Francis Butler B.E. Ph.D. M.B.A.

**Department of Agricultural & Food Engineering**

**University College Dublin, Earlsfort Terrace, Dublin 2**

ISBN 1 84170 191 2

December 2000





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## SUMMARY

The prepared consumer foods sector in Ireland is undergoing sustained dynamic growth. Products that are distributed chilled or frozen require a cold chain and there is potential to increase product quality by optimising the cold chain. This potential prompted the current study.

Part 1 dealt with the potential adverse effects of mild temperature abuse (fluctuating storage temperatures below the freezing point), and the potential benefits of superfreezing (storage at  $-60\text{ }^{\circ}\text{C}$ ) on the quality attributes of raw salmon, smoked mackerel, strawberries, blanched broccoli, ice cream, hollandaise sauce, cheese-topped pizza and pork pieces in gravy. The fluctuating and superfreezing regimes had a large effect on product rancidity as shown by free fatty acids (FFA) and peroxide values (PV). The pattern in the FFA and PV data was the same for each fat-containing product in that superfreezing gave the lowest values and the fluctuating regime the highest. However, the FFA and PV values were generally low and did not adversely affect taste panel response. The fluctuating and superfreezing regimes had a minimal effect on the texture/consistency, colour, flavour (taste panel response), and vitamin C content of the product range. The conclusion is that superfreezing is beneficial for the long-term storage of 'sensitive' products, especially those containing significant amounts of fat. Fluctuating temperatures below the freezing point should be eliminated from the cold chain as they have an adverse effect on the quality of 'sensitive' products and promote rancidity.

Part 2 investigated the use of freeze-chill technology for instant mashed potato, steamed salmon and steamed broccoli. Freeze-chilling consists of freezing and frozen storage followed by thawing and chilled storage. The technology may have logistic benefits for food processors in that it enables 'chilled' products to reach more distant markets and facilitates bulk-production of these foods. The tests indicated that instant mashed potatoes, steamed salmon and steamed broccoli are good candidate foods for freeze-chilling.

Part 3 consisted of performance testing of disposable temperature, and time-temperature indicators under isothermal and non-isothermal conditions.



Temperature indicators give a visible colour change if a predetermined threshold temperature has been exceeded and have potential use for monitoring of storage temperatures in the cold chain. The results of the tests showed that the Chillcheck™ temperature indicators performed reliably under isothermal conditions. In varying temperature conditions, they responded more to surface/ambient temperatures rather than to product core temperatures. In practical use, no colour change would indicate that the temperature control had been satisfactory. However, if the colour changed, caution must be exercised in interpreting the result as relatively minor temperature fluctuations may have caused the staining with little adverse impact on product quality. The work on time-temperature indicators suggests that the 3M Monitormark™ 5I may not be sufficiently responsive to accurately integrate the time-temperature history for high risk perishable food products.

## INTRODUCTION

The reports of the Food Industry Development Group (Anon, 1998), the Agri Food 2010 Committee (Anon, 2000a), and the Bord Bia Annual Review (Anon, 2000b) all predict continued rapid growth in the prepared consumer foods area in Ireland. A high proportion of these products require a cold chain, either frozen or chilled. It is imperative, that the cold chain, both domestic and export is designed to provide optimum product quality. This requirement prompted the current study, which embraced four components:

- (i) Mild temperature abuse: The potential adverse effects of mild temperature abuse below the freezing point on the quality of eight frozen food products was investigated. This research was necessary in view of the shortage of practical information on the effects of mild temperature abuse on the quality of frozen food products (Bøgh-Sørensen, 1999). Three temperature fluctuation cycles of -30 °C to -10 °C to -30 °C on consecutive weeks followed by storage at a steady -30 °C for 8 months were examined.
- (ii) Superfreezing: The potential beneficial effects on product quality of storing frozen foods at -60 °C (superfreezing) was investigated using the



same range of products as employed for the temperature abuse studies. Findings from Scandinavia (Magnussen and Johansen, 1995) indicate that it is beneficial to store certain seafoods at -60 °C and hence the current study on fat-containing products, and on foods such as strawberries and broccoli which contain vitamin C.

- (iii) Freeze-chill technology: This was evaluated in view of its emerging importance for the food industry and also because of the shortage of information on the topic (Boknaes *et al.*, 2000). Freeze-chilling consists of freezing and frozen storage followed by thawing and then retailing at chill storage temperatures. It offers logistic and other advantages. For example: (a) foods can be prepared in bulk, then frozen and stored at deep freeze temperatures until required. Some or all of the batch can then be thawed as necessary; (b) freeze-chilling enables “chilled” foods to reach distant markets in that product can be shipped deep frozen and then thawed when it reaches its destination prior to retail display; (c) freeze-chilling can reduce the number of product recalls as it enables routine microbiological tests to be completed before the product is released from the factory. Freeze-chill tests were conducted on instant mashed potato, steamed salmon and steamed broccoli, and will be extended to a wider product range in follow-up studies.
- (iv) Temperature indicators: Temperature control is critical in the storage, handling and distribution of perishable foods and hence there is a requirement for efficient monitoring of storage temperatures. Disposable temperature indicators, and/or time-temperature indicators, are an alternative to using conventional electronic temperature monitoring. Temperature indicators undergo an irreversible colour change if a predetermined temperature is exceeded. The goal of this work was to test the performance of temperature indicators, and time-temperature indicators when stored under isothermal and non-isothermal conditions.

The results of the tests are presented in three parts in this report. Part I deals with mild temperature abuse and with superfreezing, Part II with freeze-chill technology; and Part III with temperature indicators.



## PART I: EFFECT OF (I) MILD TEMPERATURE ABUSE AND (II) SUPERFREEZING ON THE QUALITY OF FROZEN FOODS

Many frozen foods are multi-component, for example, ready-meals. Factors such as mild temperature abuse, or storing foods at very low temperatures (superfreezing) may have varying effects on the quality of particular components. This prompted a study on the potential adverse effects of mild temperature abuse, and on the potential benefits of superfreezing, on a range of products. The results were compared with control products held at a constant  $-30\text{ }^{\circ}\text{C}$  over an 8 month storage period.

### MATERIALS AND METHODS

The frozen products tested were: raw salmon, smoked mackerel, strawberries, blanched broccoli, ice cream, hollandaise sauce, cheese-topped pizza, and pork pieces in gravy. The ice cream and cheese-topped pizza were commercially frozen; all the other products were prepared and frozen in a laboratory blast freezer at  $-35\text{ }^{\circ}\text{C}$  for 2 hours. A number of the products had a significant fat content and these were chosen to see if the development of rancidity was affected by the fluctuating temperature regime or the superfreezing treatment.

The eight frozen products were temperature abused by subjecting them to temperature fluctuations below the freezing point. This comprised three temperature fluctuation cycles of  $-30\text{ }^{\circ}\text{C}$  to  $-10\text{ }^{\circ}\text{C}$  to  $-30\text{ }^{\circ}\text{C}$  on consecutive weeks followed by storage at a steady  $-30\text{ }^{\circ}\text{C}$  for 8 months. Each fluctuation was achieved by transferring product from a chest freezer at  $-30\text{ }^{\circ}\text{C}$  to one at  $-10\text{ }^{\circ}\text{C}$  and back again after 48 hours. The temperature abuse regime is referred to as the fluctuating regime.

A sample set of the frozen product range was transferred to a Sanyo ultra-low temperature freezer and was held at  $-60\text{ }^{\circ}\text{C}$  for 8 months. This is referred to as the superfreezing regime.

Physical, chemical, sensory and microbiological tests were conducted on the product range after 0, 1, 2, 4 and 8 months in frozen storage. The type of tests varied from product to product depending on requirements (Table 1). For



**Table 1:** Range of tests carried out on frozen ready-meal components that were stored at fluctuating temperatures, or superfrozen at -60 °C for 8 months.

Product								
	SALMON	MACKEREL (smoked)	STRAWBERRIES	BROCCOLI	ICE CREAM	PIZZA	PORK PIECES	HOLLANDAISE SAUCE
<b>Test Procedure</b>	↓	↓	↓	↓	↓	↓	↓	↓
Penetrometer (mm/10)	-	-	-	-	-	+	-	-
Viscosity (cp)	-	-	-	-	-	-	-	+
Shear [Newtons (N)]	+	+	+	+	-	-	+	-
Total viable count (TVC)	+	+	+	+	+	+	+	+
Moisture (%)	+	+	+	+	-	+	+	+
Drip (%)	-	-	+	+	-	-	-	-
Water-holding capacity (WHC)	+	+	-	-	-	-	+	-
Free fatty acids (FFA)	+	+	-	-	+	+	+	+
Peroxide value (PV)	+	+	-	-	+	+	+	+
Total volatile bases N (TVBN)	+	+	-	-	-	-	-	-
Colour (Hunter L, a, b)	+	+	+	+	-	-	-	+
Hue angle (θ)	+	+	+	+	-	-	-	+
Colour difference (ΔE)	+	+	+	+	-	-	-	+
Vitamin C (mg/100g)	-	-	+	+	-	-	-	-
Soluble solids (%)	-	-	+	-	-	-	-	-
Titrateable acidity <sup>1</sup>	-	-	+	-	-	-	-	-
Sensory evaluation	+	+	+	+	+	+	+	+

<sup>1</sup>ml 0.1M NaOH for 10g pureed strawberry to pH 8

Test conducted = (+)

Test not conducted = (-)



*Storing food products at  
-60°C (superfreezing).* ▶



example, a rancidity test is not appropriate for strawberries whereas it is for the cheese topping on a pizza. Details of sample preparation and of the test procedures have been published (Gormley *et al.*, 2001; O’Leary *et al.*, 2000).

## RESULTS AND DISCUSSION

The effects of the fluctuating, superfreezing and control regimes on the quality of the eight products are listed below under a number of headings:

### *Effect of frozen storage on product rancidity*

The temperature regimes had a larger effect on product rancidity than on any of the other quality measurements over the product range. The pattern in the data for free fatty acids (FFAs) and peroxide values (PVs) was the same for each product type in that superfreezing gave the lowest values, the control was intermediate, and the fluctuating regime the highest (Table 2 and Figure 1); the magnitude of the differences between treatments were generally largest at the 8-month test date. Smoked mackerel had by far the highest PV and FFA values (Table 2).



**Table 2:** Effect of temperature during frozen storage on rancidity: Peroxide (meq/kg fat) and free fatty acid (% oleic acid) values<sup>1</sup> for frozen food products stored under three temperature regimes

	Temperature regime			F-test	LSD <sup>6</sup>
	Superfreezing	Control	Fluctuating		
<b>Peroxide values</b>					
Salmon <sup>2</sup>	3.86	5.62	6.97	***	0.81
Smoked mackerel	11.95	16.71	20.53	***	2.04
Ice cream	1.51	1.98	2.82	***	0.14
Cheese (pizza) <sup>3</sup>	3.21	3.66	7.16	***	0.06
Hollandaise sauce <sup>4</sup>	1.08	1.38	1.70	***	0.16
Pork pieces <sup>5</sup>	1.93	2.56	2.95	***	0.24
<b>Free fatty acids</b>					
Salmon <sup>2</sup>	0.67	0.89	1.27	***	0.09
Smoked mackerel	2.41	3.29	4.61	***	0.35
Ice cream	0.10	0.11	0.17	***	0.01
Cheese (pizza) <sup>3</sup>	0.61	0.64	0.77	***	0.01
Hollandaise sauce <sup>4</sup>	0.16	0.19	0.24	***	0.07
Pork pieces <sup>5</sup>	0.46	0.69	1.22	***	0.20

<sup>1</sup> Data are averaged over 5 test dates

<sup>2</sup> Raw salmon

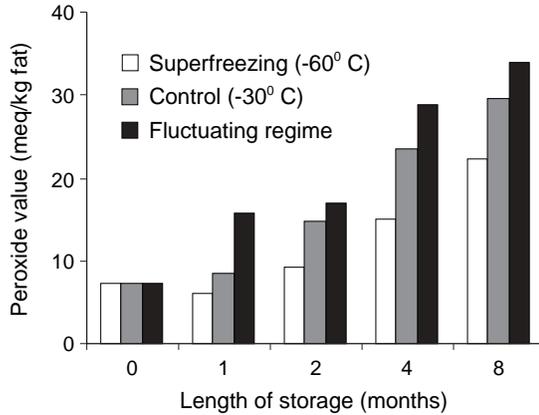
<sup>3</sup> Cheese topping on a pizza

<sup>4</sup> Prepared from dry mix (300g) with milk (4L) and butter (1.6 kg)

<sup>5</sup> Steamed in gravy

<sup>6</sup> Least significant difference

The PV and FFA values generally increased with length of time in frozen storage (Table 3). The PV values for salmon, smoked mackerel, and ice cream rose considerably between the 2 and 4-month test dates, while those for cheese topping, hollandaise sauce and pork pieces rose more uniformly over the storage period (Table 3). The pattern of increase for the FFAs was fairly similar to that of the PVs, except in the case of ice cream where there was no increase until the last test date (Table 3). The PV values of smoked mackerel (Figure 1) are fairly typical of the PV and FFA patterns for the other products tested.



**Figure 1:** Peroxide values for smoked mackerel stored for 8 months under different deep-freeze temperature regimes. Significant increases in peroxide values were caused by storage temperature ( $P < 0.001$ ), storage time ( $P < 0.01$ ) and the interaction of storage temperature and time ( $P < 0.05$ ).

Ideally, PV values for fish should be below 10 meq/kg. In this regard 17% of 180 taste panel responses (9 panels x 20 tasters) detected rancidity in smoked mackerel samples, 8% in salmon and 4% in pork from the fluctuating temperature regime. Rancidity is noticeable in most oils at FFA values of 0.5 to 1.5%, while in butter oil an FFA value of less than 0.3% is desirable. Eight per cent of taste panel responses indicated rancidity in hollandaise sauce from the fluctuating regime and 0% in ice cream and cheese pizza topping.

#### *Effect of frozen storage on product texture/consistency, colour and vitamin C content*

The superfreezing and fluctuating regimes had a minimal effect on texture/consistency of the product range, and on parameters related to texture such as water-holding capacity or drip on thawing; details for the individual products are given below. However, taste panellists commented that the fluctuating regime gave an inferior texture in steamed salmon, broccoli and stewed pork. In the case of ice cream, 37% of panellists found that



**Table 3:** The effect of length of time in frozen storage on rancidity of products. Peroxide (meq/kg fat) and free fatty acid (% oleic acid) values<sup>1,2</sup> for frozen food products stored<sup>1</sup> for 8 months

	Length of time (months) in deep freeze					F-test	LSD
	0	1	2	4	8		
<b>Peroxide values</b>							
Salmon	2.80	2.36	1.41	7.50	13.34	***	3.21
Smoked mackerel	7.27	10.10	13.68	22.42	28.51	**	7.90
Ice cream	1.20	1.30	1.18	3.28	3.56	***	0.24
Cheese (pizza)	3.38	5.80	5.73	6.13	6.18	***	0.15
Hollandaise sauce	0.58	1.22	1.24	1.53	2.29	*	0.86
Pork pieces	1.52	1.85	2.29	3.53	3.21	***	0.53
<b>Free fatty acids</b>							
Salmon	0.32	0.51	0.49	1.26	2.12	***	0.09
Smoked mackerel	1.51	3.04	2.09	2.91	7.62	***	1.35
Ice cream	0.10	0.10	0.10	0.10	0.22	***	0.01
Cheese (pizza)	0.46	0.53	0.59	0.90	0.97	***	0.02
Hollandaise sauce	0.11	0.14	0.16	0.27	0.28	***	0.13
Pork pieces	0.33	0.60	0.91	1.02	1.08	***	0.05

<sup>1</sup> Data are averaged over the superfreezing, control and fluctuating regimes

<sup>2</sup> See footnotes in Table 2

superfreezing gave the creamiest product in comparison with percentages of 14 and 18 for the control and fluctuating regimes respectively.

The fluctuating regime gave a pale salmon colour after 8 months frozen storage as indicated both by Hunter colour meter values and sensory panel response. The temperature regimes had a minimal effect on the colour of the other products and did not influence the vitamin C content of broccoli; however, superfreezing resulted in a better retention of vitamin C in strawberries. The lack of treatment effects in strawberries and broccoli could be due to the over-riding negative effects of blast freezing, i.e. cell damage due to a slow freezing rate.



### *Effect of frozen storage on taste panel preference*

Taste panels were conducted on the three replicates for each product type after 1, 2, 4 and 8 months storage resulting in 96 panels in all. Each had 20 tasters who were asked to rank the samples from the superfreezing, control and fluctuating regimes from 1 (most preferred) to 3 (least preferred). The best rank sum a sample could achieve was 20 (i.e. all 20 tasters preferring it most) and the worst 60 (all tasters giving it the 3rd preference). This converts to corresponding mean scores of 1.0 and 3.0 respectively, with low values best. Relatively few of the 96 panels showed significant preferences between the samples from the three treatments. There was no instance where panels for each of the three replicates, for a given product, on a given test date each showed a statistically significant effect. However, there was an underlying non-significant trend in favour of the samples from the superfreezing regime (all samples received mean panel scores of  $<2$ ) in comparison with those from the fluctuating regime (all samples, with exception of ice cream, had mean scores  $>2$ ).

### *Summary of results of frozen storage on a product basis*

Only statistically significant treatment effects are given below and the data cited are always in the order superfreezing, control, fluctuating. Many of the results have been published (see list of publications from this project).

**Salmon:** The effects of the treatments on PVs and FFAs are given in Tables 2 and 3. The control treatment gave the highest shear value on cooked product using the Kramer shear cell (1760, 1904, 1795N) and highest water-holding capacity (96.5, 97.4, 96.6%). The fluctuating regime gave the largest change in colour (Hunter meter) and superfreezing the least as indicated by colour difference values ( $\Delta E = 5.04, 6.69, 8.83$ ). All tests, with the exception of shear value and sensory evaluation, were conducted on raw salmon. The treatments had no effect on TVC, moisture content or TVBN status.

**Smoked mackerel:** The effects of the treatments on PVs and FFAs are given in Tables 2 and 3. The treatments had no effect on TVC, moisture content, water-holding capacity, TVBN, or colour.

**Ice cream:** The effects of the treatments on PVs and FFAs are given in Tables 2 and 3. Taste panel comments suggested that superfreezing gave the creamiest product.



**Pizza:** The effects of the treatments on PVs and FFAs for the cheese topping are given in Tables 2 and 3. Measurements were made in the top half of each base; the pizza bases from the fluctuating regime had the highest moisture content (38.6, 38.0, 40.0%) and suggests moisture migration from the topping. The treatments had no effect on moisture content in the bottom half of the base (mean 38.6%), or in the topping (mean 53.6%), on TVC, or on penetrometer readings (hemispherical probe) on the base.

**Hollandaise sauce:** The effect of the treatments on PVs and FFAs are given in Tables 2 and 3. The superfreezing regime gave the least white sauce on the basis of Hunter meter L/b (white/yellow ratio) values (2.8, 3.0, 2.9). The treatments had no effect on sauce consistency, moisture content (mean 64.4%), or TVC.

**Stewed pork pieces:** The effect of the treatments on PVs and FFAs are given in Tables 2 and 3. The fluctuating regime gave a lower water-holding capacity than the other two treatments (96.1, 96.8, 90.4%). The treatments had no effect on moisture content (mean 72.2%), shear value (Kramer shear cell), or TVC.

**Strawberries:** Those from the fluctuating regime had the highest shear value measured in the Kramer shear cell (329, 330, 388N) while superfreezing had a better conserving effect on vitamin C (26.0, 22.8, 20.9 mg/100g). Samples from the superfreezing regime showed the largest change in colour ( $\Delta E = 6.05, 4.86, 4.63$ ). Frozen storage had no effect on titratable acidity, soluble solids content, drip loss, or moisture content. The lack of treatment effects in strawberries could be due to the negative over-riding effects of blast freezing. Tests on procedures for assessing freezing damage in strawberries indicated that (i) a shear test, (ii) the rate and extent of rehydration of freeze-dried samples, and (iii) the level of centrifugal drip from rehydrated freeze-dried samples were suitable methods (Moro and Gormley, 1998/99).

**Blanched broccoli:** Broccoli from the control treatment had a lower drip loss on thawing than samples from the other regimes (20.0, 18.2, 20.5%). The treatments had no effect on shear value (Kramer shear cell), moisture and vitamin C contents, or colour (Hunter meter). The absence of treatment effects could be due to the negative over-riding effects of blast freezing.



## CONCLUSIONS

- Superfreezing ( $-60\text{ }^{\circ}\text{C}$ ) is beneficial for the long-term storage of 'sensitive' products, especially those containing significant amounts of fat. However, the quality benefits must be balanced against the increased cost of storing products at  $-60\text{ }^{\circ}\text{C}$ .
- Fluctuating temperatures below the freezing point had an adverse effect on the quality of 'sensitive' products and promoted rancidity. This indicates the need to store such products at a steady  $-30\text{ }^{\circ}\text{C}$  or colder.



## PART II: EFFECT OF FREEZE-CHILLING ON THE QUALITY OF READY-MEAL COMPONENTS

Freeze-chilling consists of freezing and frozen storage followed by thawing and chilled storage. It may have logistic benefits for food processors in that it enables 'chilled' products to reach more distant markets and facilitates bulk production of these foods. There is relatively little information on the quality and safety of freeze-chilled foods, although tests have been carried out on fish (Boknaes *et al.*, 2000). However, the effect of freezing on food is well documented (Anon, 1986), as is that of chilling (Gormley, 1990). There is also extensive information on cook-chill and cook-freeze (Church and Parsons, 1993) systems for ready-meals in the catering sector. The objective of the current study was to evaluate the effect of freeze-chilling on the quality of instant mashed potato, steamed salmon and steamed broccoli; many of the results have been published at a wide range of fora (see list of publications from this project).

### MATERIALS AND METHODS

The full details are contained in O'Leary *et al.* (2000) and only an outline is given here. Instant mashed potato was reconstituted according to the manufacturer's instructions; fresh salmon fillets were steamed (12 min) and cooled (30 min); fresh broccoli was steamed for 2 min, cooled (10 min in iced-water). Once prepared, the samples were assigned to the freezing and chilling regimes (process treatments), and the short-term and long-term trials were performed as follows:

*Short-term trials.* The three products were subjected to four process treatments.

**Freeze-chill:** Blast frozen at -35 °C (2.5 hours); stored at -25 °C for 1 week; thawed overnight at 4 °C; held in chilled storage at 4 °C for 5 days.

**Freeze:** Blast frozen at -35 °C (2.5 hours); stored at -25 °C for 1 week; thawed overnight at 4 °C.

**Chill:** Chill storage at 4 °C for 5 days.



**Fresh:** Cooked and tested on the same day.

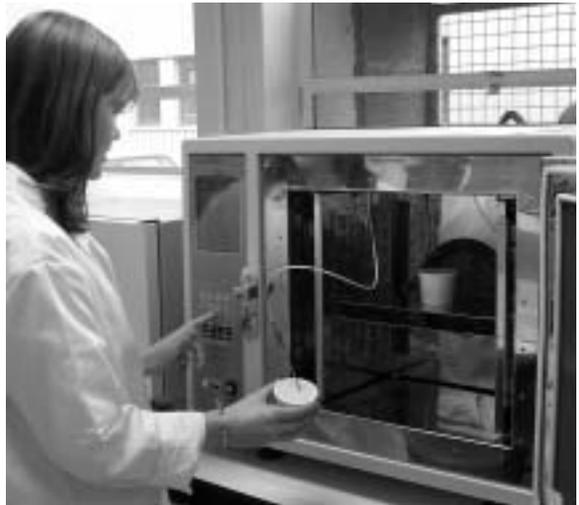
*Long-term trials.* The three products were subjected to three process treatments and were tested on five occasions over time. The chill treatment was omitted from the long-term trials.

**Freeze-chill:** Blast frozen at  $-35\text{ }^{\circ}\text{C}$  for 2.5 hours; stored at  $-25\text{ }^{\circ}\text{C}$  for 1, 4, 8, 16 and 32 weeks; thawed overnight at  $4\text{ }^{\circ}\text{C}$ ; held in chilled storage at  $4\text{ }^{\circ}\text{C}$  for 5 days.

**Freeze:** Blast frozen at  $-35\text{ }^{\circ}\text{C}$  for 2.5 hours; stored at  $-25\text{ }^{\circ}\text{C}$  for 1, 4, 8, 16 and 32 weeks; then thawed overnight at  $4\text{ }^{\circ}\text{C}$ .

**Fresh:** Cooked and tested the same day.

Softness and adhesiveness of the potato mash were measured using a cylindrical probe (12.5 mm in diameter), and the shear values of the salmon and broccoli with a Kramer shear press fitted with a standard test cell (100 g samples). Product colour was measured with a Hunter colour meter (5 cm aperture) and drip loss on thawing by a centrifugal procedure. Sensory analyses, moisture content, total viable count (TVC), vitamin C content (potato and broccoli), free fatty acids (FFA) and peroxide values (PV) (salmon) were performed by standard procedures.



*Liquid nitrogen freezing of  
mashed potato.* ▶



## RESULTS AND DISCUSSION

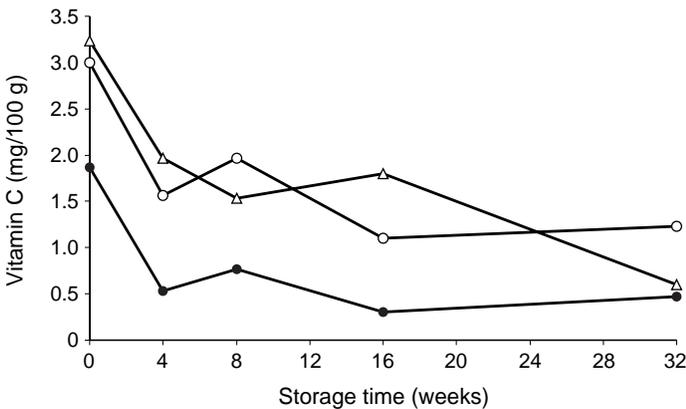
### *Mashed potato and steamed broccoli*

The results for instant mashed potato are summarised in Table 4 (short-term test) and Figure 2 (long-term test), and those for steamed broccoli in Table 5

**Table 4:** The effect of the freeze-chill process, and freezing or chilling alone, on the texture, colour, and drip loss of instant mashed potato (short-term test)

Test	Treatment				F-test	LSD
	Freeze-chill	Freeze	Chill	Fresh		
Penetrometer value (N) <sup>1</sup>	7.27	6.33	6.05	4.68	**	0.976
Adhesiveness (N)	0.87	1.08	2.75	2.60	***	0.732
Colour (L/b)	3.80	3.92	4.28	4.10	***	0.090
Centrifugal drip (g/100 g)	22.6	23.1	0.8	0.6	***	3.38

<sup>1</sup> Low values indicate softness

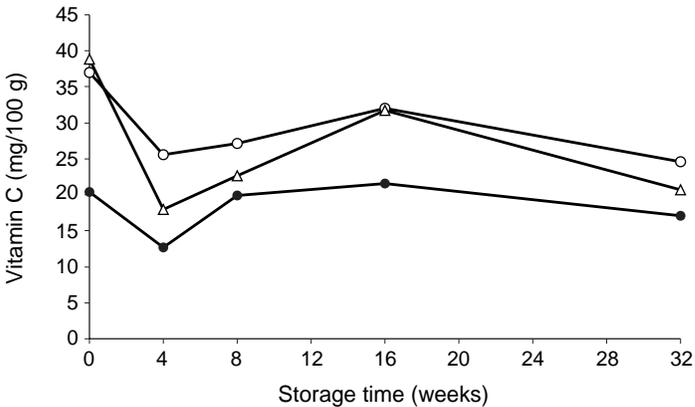


**Figure 2:** Change in vitamin C content of mashed potato over a period of 32 weeks: freeze-chill (●), freeze (○) and freshly prepared (Δ). Process treatment ( $P < 0.001$ ), SED = 0.20; storage time ( $P < 0.05$ ), SED = 0.44



**Table 5:** The effect of the freeze-chill process, and freezing or chilling alone, on the drip and vitamin C content of steamed broccoli (short-term test)

Test	Treatment				F-test	LSD
	Freeze-chill	Freeze	Chill	Fresh		
Centrifugal drip (g/100 g)	30.7	30.8	22.0	22.7	**	4.80
Vitamin C (mg/100 g blanched)	21.2	35.5	24.6	34.8	**	8.68
Vitamin C (mg/100 g cooked)	18.9	29.6	19.2	28.2	***	5.44



**Figure 3:** Change in vitamin C content of steamed broccoli over a period of 32 weeks: freeze-chill (●), freeze (○) and freshly prepared (Δ). Process treatment ( $P < 0.001$ ), SED = 1.25; storage time ( $P < 0.01$ ), SED = 3.01

(short-term test) and Figure 3 (long-term test). There were no significant differences in the moisture (mean value 75.7%) or vitamin C contents (mean 1.60 mg/100 g), or in the TVC (mean 2.84 cfu/g), of mashed potato from the process treatments. Freeze-chilling had a negative effect on the textural properties and vitamin C status of the instant mashed potato and broccoli. However, the textural changes did not influence taste panel response as none of the panels on the two products showed significant differences between the



*Measuring softness and adhesiveness of mashed potato.* ▶



four process treatments. The negative effect of freeze-chilling on textural properties was due to the freezing component of the freeze-chill process as the effects also manifested themselves in the freeze-only, but were absent in the chill-only and freshly-prepared treatments. In the case of instant mashed potato, freeze-chilling caused a loss of adhesiveness and a large increase in centrifugal drip (Table 4). This was probably due to the effects of freezing on starch properties and can be largely overcome by using a hydrocolloid such as xanthan gum. Further freezing tests were conducted on instant mashed potato in a special freezer at temperatures of -30, -60 and -90 °C. Corresponding drip losses were 21, 18 and 12% respectively, indicating that freezing at -90 °C gave the least damage (Redmond *et al.*, 2000 and 2001).

The freeze-chilling and chill-only process treatments gave a reduction in the vitamin C content in instant mashed potato and steamed broccoli. This was due to the chill component of the freeze-chill process, and similar results have been obtained by other authors for a range of chilled vegetable products. Tests were conducted in the current study to boost the vitamin C content of freeze-chilled



*Using fluidised bed technology to encapsulate vitamin C. ▶*

instant mashed potato by adding encapsulated vitamin C after cooking but before freeze-chilling. This resulted in vitamin C contents of 21 (fresh instant mash), 18 (frozen and thawed) and 13 mg/100 g (freeze-chilled) compared to values of 19, 16 and 8 mg/100 g when an equivalent amount of non-encapsulated vitamin C was added. These data indicate that encapsulation, using a fat coating melting at 50 °C, protected the vitamin C content of freeze-chilled instant mashed potato (Brennan *et al.*, 2000; Aguilar *et al.*, 2000).

### *Steamed salmon*

The development of rancidity in fatty fish such as salmon can be responsible for off-flavours, and low taste acceptability. Freeze-chilling raised peroxide values in steamed salmon compared with the other three process treatments (Table 6). This was expected as the freeze-chilled steamed salmon was the 'oldest' (13 days in the short-term test) of the four treatments at time of testing. Both the peroxide and free fatty acid values were low, overall, and did not result in a low taste panel rating. Moisture content (mean 64.2%), centrifugal drip (mean 6.1%), free fatty acid content (mean 0.3 g/100 g), and

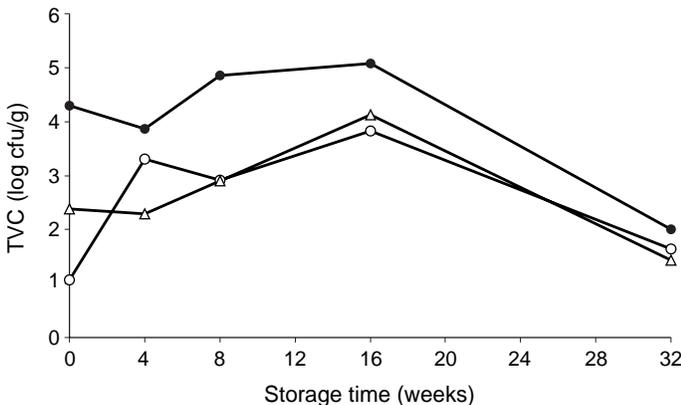


**Table 6:** The effect of the freeze-chill process, and freezing or chilling alone, on the texture, rancidity and bacterial count of steamed salmon (short-term test)

Test	Treatment				F-test	LSD
	Freeze-chill	Freeze	Chill	Fresh		
Shear (N)	1147	1300	922	1236	*	254.8
Peroxide value (meq/kg fat)	1.50	1.12	1.01	0.80	*	0.44
Total viable count (log cfu/g)	3.62	1.50	2.68	1.91	*	1.444

hue angle ( $\theta$ ) (mean 56 °) of the salmon did not vary significantly between the different treatments.

Freeze-chilled salmon may have a more open structure (due to freezing damage) and more free water (containing cell nutrients) which could be conducive to microbial growth during the follow-on chilling phase. The highest total viable count found in the short term tests was log 3.62 cfu/g



**Figure 4:** Change in total viable bacterial count of steamed salmon over a period of 32 weeks: Samples were stored frozen (-25 °C) followed by 5 days chilled storage (●); frozen (○); or freshly prepared, (Δ). Process treatment ( $P < 0.001$ ),  $SED = 0.27$ ; storage time ( $P < 0.05$ ),  $SED = 0.65$



(Table 6) in freeze-chilled salmon, which was within acceptable limits for such a product. Values of log 5.07 cfu/g were found at week 16 for the freeze-chilled salmon in the long-term tests; however, after 32 weeks the count was log 2.01 cfu/g. This was an unexpected result and may be due to different counts on different portions of salmon.

#### *Safety and labelling of freeze-chilled foods*

The use of good manufacturing practice (GMP) and hazard analysis of critical control point (HACCP) is mandatory in the production, storage, distribution and retailing of freeze-chilled foods; national and EU Regulations must also be adhered to [S.I No. 165 of 2000; European Communities (Hygiene of Foodstuffs) Regulations 2000]. Particular attention should be focused on the thawing step and careful temperature control should be exercised; thawing in the current tests was overnight at 4 °C. Information on the cold chain is available from The National Food Centre in a technical manual entitled “*Managing the Cold Chain for Quality and Safety*” (F-FE 378A/00). Normal safety “rules” for frozen foods prevail in the frozen component of the process, and those for chilled foods in the chill part. The labelling requirements are those of conventionally chilled foods. However, it is desirable for reasons of consumer information and product liability to label the product as “previously frozen”. A use-by-date must also be employed and this label should be attached at the start of the thawing process.

## CONCLUSIONS

- Instant mashed potatoes, steamed salmon and steamed broccoli are good candidate foods for freeze-chilling.
- The implementation of GMP and HACCP is mandatory in the production, storage, distribution and retailing of freeze-chilled foods. The labelling requirements are those of conventionally chilled foods.
- R&D on freeze-chilling is continuing at The National Food Centre and at University College Dublin on an extended product range. This includes mashed potato from different cultivars, carrots, green beans, pasta-based dishes such as lasagne, and multi-component ready-meals.



## PART III: DISPOSABLE TEMPERATURE INDICATORS

Temperature control is critical in the storage, handling and distribution of perishable foods and there is a requirement for more efficient monitoring of ambient storage temperatures. Temperature indicators are small (postage stamp-sized) disposable labels that give a visible response if a pre-determined threshold temperature has been exceeded. This occurs as an irreversible colour change or colour migration on the indicator. Temperature indicators give no indication of the scale of temperature abuse that has occurred. However, in time-temperature indicators the extent of the colour migration is dependent on the extent of the temperature abuse of the product. The objective of this work was to test the performance of selected commercially-available temperature indicators and time-temperature indicators when stored under isothermal and non-isothermal conditions. The results have been published/presented at a range of fora (see list of publications from this project).

## MATERIALS AND METHODS

The temperature indicator (Chillchecker™, Temperature Indicators Ltd., Cumbria, UK) used consists of an absorbent paper above a reservoir of a blue-dyed compound, with a specific melting point. To activate the temperature indicator, the outer casing is depressed, thus pushing the absorbent paper onto the reservoir. The compound in the reservoir has a specific melting point, which is the response point of the temperature indicator. In the case of the two indicators examined, Type 5 and Type 6 Chillchecker™, this was 5°C and 9°C respectively. Once the response point of the temperature indicator has been exceeded, the compound melts, irreversibly staining the absorbent paper.

The time-temperature indicator used was the 3M Monitormark™ (St. Paul, Minn., USA). Diffusion of a dye occurs if the ambient temperature is greater than the melting point of the dye. The advancement of the dye can be seen through five viewholes along the length of the indicator. A nomogram indicates the relationship between the duration of time the temperature was above the indicator response point, and the distance stained, at a number of temperatures.



### *Isothermal testing*

This set of tests was designed to determine the reproducibility of the times taken to stain (response times) for the Type 5 and Type 6 Chillchecker™ temperature indicator and the 3M Monitormark™ 5I time-temperature indicator over a range of set temperatures (see Tables 7-9). The indicators were left in an environmental chamber for 45 minutes to equilibrate prior to activation and the test was repeated six times for each temperature, for two different manufacturing batches.

### *Non-isothermal testing*

The objective of non-isothermal testing was to determine the performance of temperature indicators in varying temperature conditions. Temperature indicators were attached to 1 litre cartons of milk and orange juice which were placed, respectively, in an environmental chamber at 4°C (Type 5) or 8°C (Type 6), for 72 hours to equilibrate. Product temperature was measured by a single platinum resistance probe and a second probe was attached to the surface of each carton. The environmental chamber temperature was ramped up to 15°C (Type 5) or 18°C (Type 6) in a linear fashion (1°C/minute) and the temperature indicators were activated 60 seconds after the ramp



*Temperature and time-temperature indicators.* ▶



commenced. The time to full staining of each of the indicators was recorded. The test was repeated five times for each of four manufacturing batches.

## RESULTS AND DISCUSSION

### *Isothermal testing*

Staining never occurred at ambient temperatures of 4.5°C or below for the Type 5 (set point 5°C) or at 9.0°C or below for the Type 6 (set point 9°C) (Tables 7 and 8). Above these temperatures, staining occurred rapidly and full staining was completed in seven minutes. The results showed that the temperature indicators were quite dependable with staining occurring once the set temperature was exceeded by 0.5°C. Conversely, if ambient temperatures were held below the set point, staining never occurred. In

**Table 7:** Average time taken to stain for the Type 5 Chillchecker™ temperature indicator under isothermal conditions. This temperature indicator has a set point of 5 °C.

Ambient temperature (°C)	Time taken to stain (seconds)
10	247
8	302
6	362
5.5	388
5	427
4.5	No staining
4	No staining

**Table 8:** Average time taken to stain for the Type 6 Chillchecker™ temperature indicator under isothermal conditions. This temperature indicator has a set point of 9 °C.

Ambient temperature (°C)	Time taken to stain (seconds)
12.0	156
10.0	192
9.5	419
9.0	No staining
8.5	No staining
8.0	No staining



contrast, the time required for the time-temperature indicator to fully stain was very long (37 – 48 hours). However, the difference in the time required to fully stain at 7°C and 15°C was comparatively small (Table 9). Full staining of the time-temperature indicator could equally be obtained by subjecting a product to a temperature of 15°C for 42 hours or 7°C for 48 hours. However, these two temperature conditions could have different quality and safety implications for a perishable product. This indicates that the 3M Monitormark™ 5I time-temperature indicator is not sufficiently responsive to accurately integrate the time-temperature history for high risk perishable food products.

*Non-isothermal testing*

Staining occurred at an ambient temperature of 9°C (430 seconds after activation) for the Type 5 indicator with a set point of 5 °C, and 13°C (530 seconds after activation) for the Type 6 indicator with a set point of 9 °C (Figures 5 and 6). Carton surface temperatures were within 0.5°C of ambient temperatures. However, in both cases, product core temperatures increased by less than 0.5 °C. This indicates that the temperature indicators responded more to surface/ambient temperatures than to product core temperatures.

**Table 9:** Time required for staining to reach the different viewholes of the 3M Monitormark™ 5I time-temperature indicator under isothermal conditions

Ambient temperature (°C)	Time taken to reach viewhole number (hours)				
	1	2	3	4	5
7	7.1	18.2	25.9	37.5	47.6
10	6.4	16.8	24.3	36.0	45.7
15	6	15.1	21.9	32.2	42.0
20	5.9	13.8	19.8	29.1	39.3
25	5.3	12.0	18.7	27.4	37.0

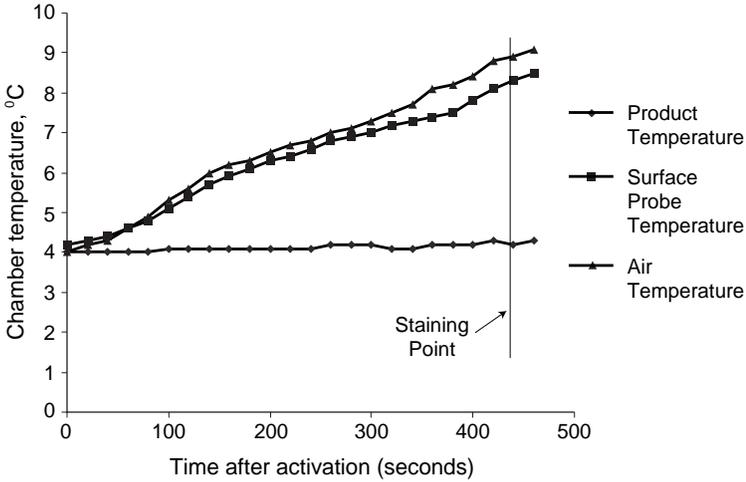


Figure 5: Change in product, surface and ambient temperature for the Type 5 Chillchecker™ temperature indicator

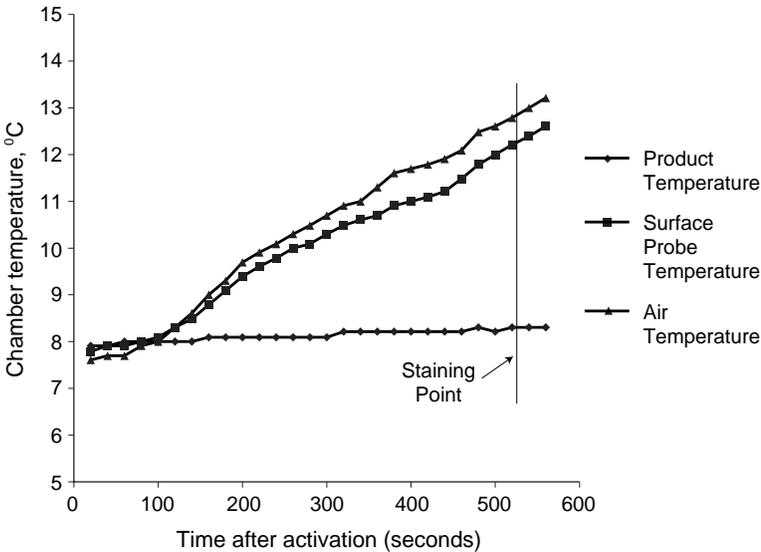


Figure 6: Change in product, surface and ambient temperature for the Type 6 Chillchecker™ temperature indicator



This would indicate to a user that temperature abuse had occurred, though product core temperatures rose by less than 0.5 °C.

## CONCLUSIONS

- The Chillchecker™ temperature indicators performed reliably under isothermal conditions. They responded more to surface/ambient temperatures than to product core temperatures under varying temperature conditions.
- The 3M Monitormark™ 5I time-temperature indicator may not be sufficiently responsive to accurately integrate the time-temperature history for high risk perishable food products.



## RECOMMENDATIONS TO INDUSTRY

- Storing frozen foods at  $-60\text{ }^{\circ}\text{C}$  (superfreezing) minimises the development of rancidity in fat-containing food products. However, the quality benefits must be matched against the higher cost of superfreezing.
- Temperature fluctuations below the freezing point, e.g. three cycles of  $-30$  to  $-10$  to  $-30\text{ }^{\circ}\text{C}$ , have the potential to promote rancidity in fat-containing foods and it is important, therefore, to eliminate such fluctuations in the cold chain.
- Freeze-chill technology offers logistic advantages in the preparation of ‘chilled’ products (e.g. mashed potato, steamed salmon, steamed broccoli); it enables ‘chilled’ products to reach more distant markets; it can reduce the number of product recalls.
- Disposable temperature indicators may have application as part of a cold chain monitoring programme for food companies. In the short to medium term their use is more likely on boxes/outers/pallets than on individual retail packs.
- The use of Good Manufacturing Practice and Hazard Analysis of Critical Control Point is imperative in the production, storage, distribution and retailing of freeze-chilled foods.
- The labelling requirements are those of conventionally chilled foods, and products should be marked as ‘previously frozen’ for reasons of consumer information and product liability.
- Industry facts sheets on superfreezing, freeze-chill technology, and disposable temperature indicators are available from The National Food Centre, as is Technical Manual (F-FE 378A/00) on *Managing the Cold Chain for Quality and Safety*.



## ACKNOWLEDGEMENTS

The skilled assistance of T. Walshe, K. Hussey and G. Redmond is gratefully acknowledged. Thanks are also extended to food companies who supplied test samples for the project.



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# The National Food Centre

RESEARCH & TRAINING FOR THE FOOD INDUSTRY

Dunsinea, Castleknock, Dublin 15, Ireland.

Telephone: (+353 1) 805 9500

Fax: (+353 1) 805 9550