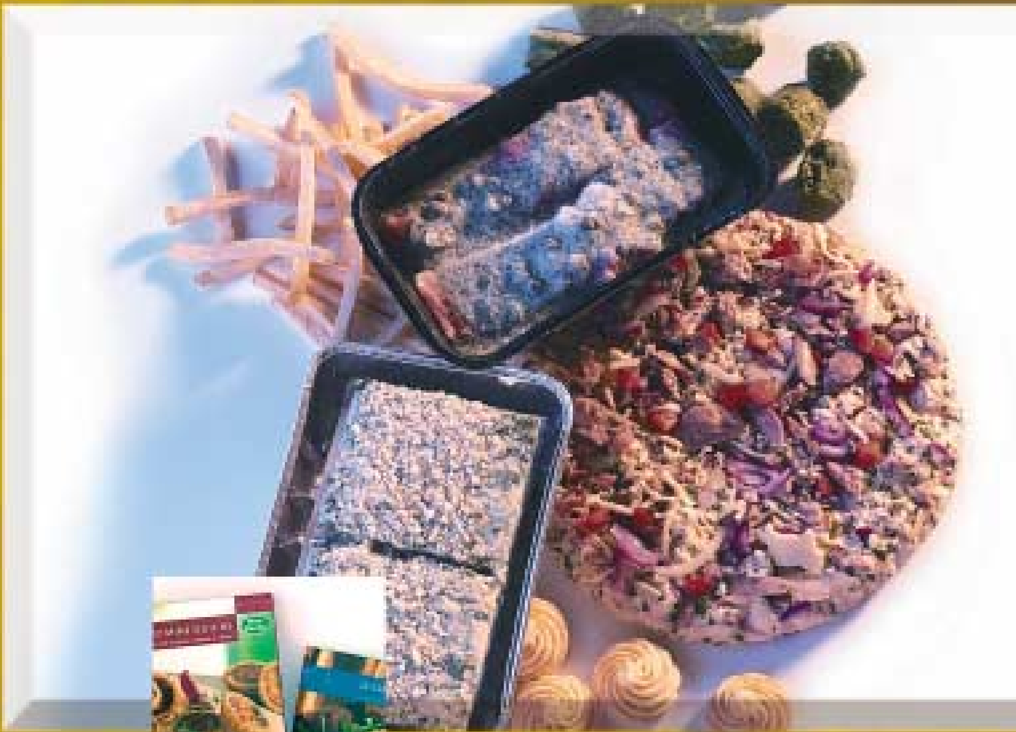
Teagasc

Agriculture and Food Development Authority

FINAL REPORT

Project RMIS No. 4885

Freeze-Chilling of Ready-to-eat Meal Components



The National Food Centre

RESEARCH & TRAINING FOR THE FOOD INDUSTRY

RESEARCH REPORT NO 66

FREEZE-CHILLING OF READY-TO-EAT MEAL COMPONENTS

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CONTENTS

SUMMARY

Freeze-chilling of food consists of freezing and frozen storage followed by thawing and then retailing at chill storage temperatures. It offers logistic, transportation and storage advantages to food manufacturers.

Freeze-chilling has particular application to ready-meals and their components. Mashed potato (three cultivars), steamed carrots, steamed green beans and beef lasagne were found suitable for freeze-chilling and their quality and sensory properties compared favourably with their frozen, chilled and fresh counterparts. Long-term storage was conducted on these products with the frozen storage element of the freeze-chill process extended up to one year. This had no negative impact on the final chilled products provided the normal protocols for frozen storage were adhered to. Modified atmosphere packaging was combined with freeze-chilling but it had little impact on shelf-life extension for the product range with the outcome similar to that for samples packed in air. Tests on the freeze-chilling of white sauces showed the importance of using freeze-thaw stable starches.

Tempering (thawing) trials for freeze-chilled products in laboratory incubators and in a commercial tempering unit were conducted on mashed potato, steamed carrots and lasagne. Best-practice thawing procedures were established and the importance of stacking configurations for outer boxes (each with a number of lasagne ready-meals) was highlighted in the case of the commercial tempering unit. Trials on the re-freezing of freeze-chilled products indicated that re-freezing is an option provided the normal storage protocols for frozen and chilled foods are observed.

Industry participated in the project; eight food companies including a multinational (two subsidiaries), two ready-meal companies, four SMEs and a start-up company used the research findings.

INTRODUCTION

The ready-meals market has grown significantly in Europe over the past decade with the chilled sector experiencing the most dynamic growth (Mintel, 1997). It is expected to grow by 20% from current values to exceed €6.8 billion by 2005; the growth potential is particularly strong in southern European countries (Sands, 2002). The strong demand for products that are fresh, healthy, safe to eat and of good quality has particularly contributed to the growth in this sector (Mahon *et al.*, 2000; Anon., 1994). Chilled ready-meals are perceived to be of better quality than frozen. However, the former have a relatively short shelf-life while the latter offer better manufacturing and distribution flexibility, food safety and extended storage time (Kobs, 1997).

Freeze-chilling is a dual process, which consists of freezing and frozen storage followed by thawing and chilled retail display (O'Leary *et al.*, 2000). It has logistic advantages over chilling as it (i) allows bulk preparation of frozen products followed by controlled batch release of thawed product into the chill chain, (ii) enables 'chilled' products to reach foreign markets more easily, and (iii) reduces the level of product recalls as it enables routine microbiological tests to be completed before the product is released from the factory. The main reason for conducting the current tests arose from the concern that freeze-chilling might predispose products to more rapid quality deterioration in the final chill phase of the process compared with chilled foods that had not been previously frozen. For example, the thawed food could be more susceptible to microbial growth due to nutrients in the drip, and because freezing may open up the cell structure of vegetables and meats thereby adversely affecting colour, texture, vitamin retention and sensory acceptability. The research addressed the freeze-chilling of mashed potatoes (three cultivars), carrots, green beans, lasagne, white sauces and commercial ready-meals supplied by manufacturers. The elements of temperature abuse, tempering (thawing), re-freezing and modified atmosphere packaging were investigated. The results were disseminated through publications, workshops, fact sheets and person-to-person contacts with food companies (see page 26 for list of publications). The technology has been transferred to eight food companies to date.

MATERIALS AND METHODS

The process treatments, testing schedules and gas flushing details for the different products are given (as appropriate) as footnotes to the text in the Results and Discussion section. Additional information is contained in the research publications (see list on page 26).

Texture measurement

The texture (penetration force) of mashed potato was measured using a cylindrical probe (12.5 mm diameter) attached to a Kramer shear press (Allo Precision Metals Engineering Inc., Maryland, USA). The probe was lowered (probe entry speed 4.5 mm/s; exit speed 5.5 mm/s; penetration depth 30 mm) into pots containing 130 g ± 1 g of potato and the maximum penetration force (N) was recorded. Shear values for the cooked carrots, green beans and lasagne were measured with a Texture Gauge (TG4-E, Food Technology Corp, Virginia, USA) fitted with a standard Kramer shear cell (entry speed 4.3 mm/s) and using 100g of product.

Colour

The colour of the mashed potato (in pots) and lasagne was measured using a HunterLab model D25 Colour Difference Meter (Hunter Associates Laboratory Inc., Virginia, USA) fitted with a 5 cm diameter aperture. The instrument was standardised against a white tile before each session. The colour was expressed as L/b (white/yellow ratio). For the cooked carrots, the colour of 10 individual discs was measured against a black tile using a 2.5 cm diameter aperture and expressed as hue angle ($\cot^{-1} a/b$). Cooked green beans, were tested in a Hunter cylindrical cup (d 56mm, h 38 mm) (5 cm diameter colour meter aperture).

Centrifugal drip loss

Drip loss (%) from the processed foods was assessed (in duplicate) by measuring the water loss from weighed aliquots after centrifugation (Anese and Gormley, 1996) at 223 x g for 10 min at 10°C using a MSE Mistral 3000I (MSE Ltd., Leicester, UK).

Vitamin C

The vitamin C content of mashed potato was measured by titration (2, 6 dichloroindophenol titrimetric method) (FWTG, 1997).

Taste panel acceptability

Fifteen panellists (20 for lasagne), experienced in sensory analysis, were presented with heated samples and asked to score on a 5 cm line (with no divisions) with end-points of 'unacceptable' (0) and 'very acceptable' (5). The point marked on the line by each panellist was measured and the mean score for each treatment calculated.

Statistical analyses

A one way analysis of variance was used (Version 6.12, SAS Institute Inc., Cary, NC, USA). Where significant differences were present, individual treatments were compared using the least significant difference test.

Microscopy tests

Light and scanning microscopy were used to examine the structure of carrots and mashed potato after freezing and chilling. (Oxley, 2003).

Total viable count and psychrotrophic count

Total viable count and psychrotrophic count analyses were carried out in accordance with BS 5763 part 1 and ISO 6887 part 1 (Anon., 1999).

RESULTS AND DISCUSSION

[1]Freeze-chilling of mashed potato: different cultivars

The objective was to examine the effect of freeze-chilling on the quality of mash from Rooster, Golden Wonder and Maris Piper with a view to their use in ready-meals.

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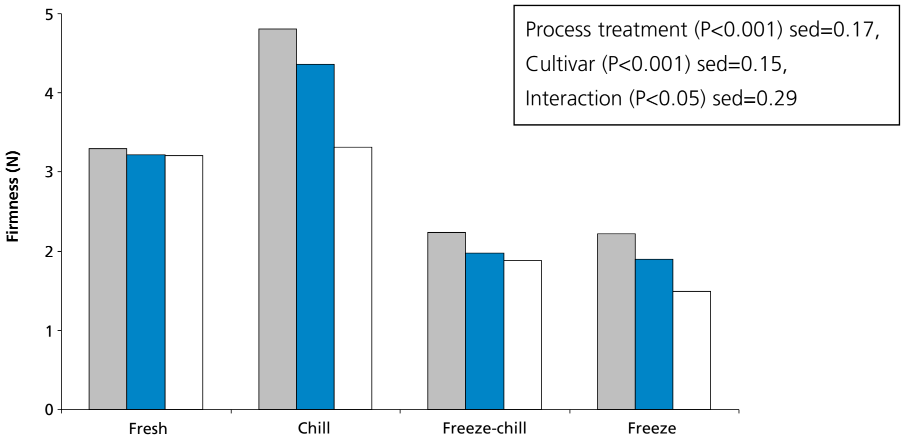
[1] The mashed potato (in plastic cups) was subjected to one of the following treatments: (i) Freeze - chill: blast freeze at -30°C for 2.5h; store at -25°C for 4d; thaw overnight at 4°C; store at 4°C for 4d; test; (ii) Freeze: blast freeze at -30°C for 2.5h; store at -25°C for 4d; thaw overnight at 4°C; test; (iii) Chill: store at 4°C for 4d; test; (iv) Fresh: cook and then test.

The texture of mashed potato is critically important for its acceptability and a soft mealy texture is preferred to one that is sticky, cohesive or gluey (Longree, 1950). In the current study, freeze-chilling and freezing led to less firm, less adhesive potato mash compared to chilling and preparing fresh (Figure 1). This was most likely due to cell wall damage (IIR, 1986) caused by ice crystal formation during the freezing process (Fennema, 1993). Of the cultivars, Rooster produced a firmer, more adhesive mash than Golden Wonder or Maris Piper.

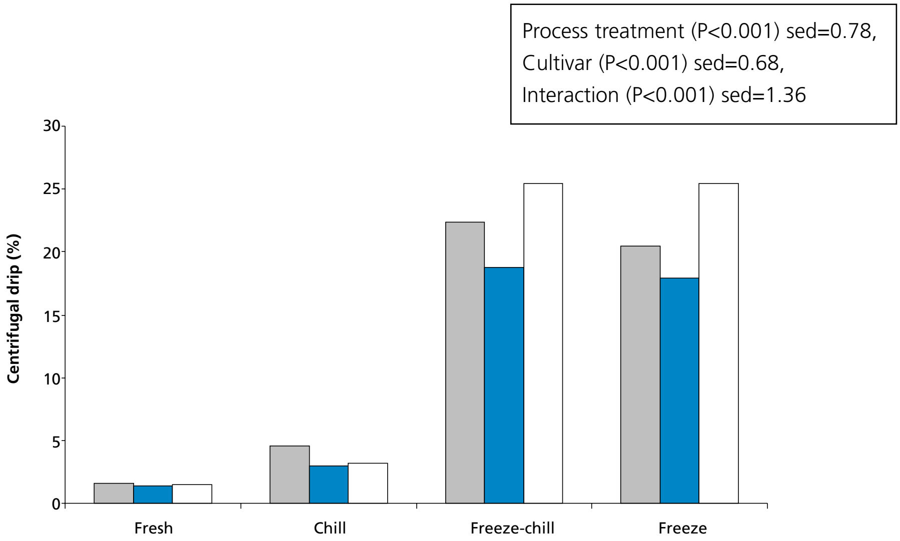
Colour is often the first characteristic by which a consumer judges a food product before purchase (Gormley, 1978). In general, chilling led to a brighter coloured mash (higher L/b value) than any of the other treatments. This finding was similar to that of O'Leary *et al.* (2000) for reconstituted potato flakes. Rooster mash had a lower L/b ($P<0.001$) value than mash from Golden Wonder or Maris Piper. This was similar to the findings of Chassery and Gormley (1994) for these cultivars both raw and cooked. Freezing and freeze-chilling led to a higher centrifugal drip than chilling or preparing fresh (Figure 2). This may be due to the breakdown in cell structure as a result of freezing with a consequent loss of fluids (IIR, 1986) on thawing.

New season potatoes are a rich source of vitamin C. However, values fall considerably during potato storage followed by further losses during cooking and warm-holding (Gormley, 1999). Mash from Rooster cultivar had a higher vitamin C content than that from Golden Wonder or Maris Piper although all values were low. As expected, fresh potato mash had a higher vitamin C content than the other three treatments and chilled and freeze-chilled potatoes had the lowest content (Redmond *et al.*, 2003). Tests were also conducted on the use of encapsulated vitamin C for maintaining vitamin status in freeze-chilled mashed potato (see below).



Process treatment (P<0.001) sed=0.17,
Cultivar (P<0.001) sed=0.15,
Interaction (P<0.05) sed=0.29

Figure 1 The firmness (penetration force) of fresh or processed mashed potato of cultivars Rooster (▨), Golden Wonder (■) and Maris Piper (□)



Process treatment (P<0.001) sed=0.78,
Cultivar (P<0.001) sed=0.68,
Interaction (P<0.001) sed=1.36

Figure 2 The centrifugal drip (%) from fresh or processed mashed potato of cultivars Rooster (▨), Golden Wonder (■) and Maris Piper (□).

[2]Freeze-chilling of mashed potato: effect of freezing rate

Freezing can lead to changes in texture, colour, drip loss, nutritive value and microbial load (IIR, 1986; Fennema, 1993). There is also a gradual and irreversible reduction in product quality during frozen storage, even at –60°C (Gormley *et al.*, 2002). The objective of this study was to examine the effect of different freezing conditions during the freezing stage of the freeze-chilling process on the quality of mashed potato. Tests were conducted on mash made from reconstituted potato flakes (termed reconstituted) (Chivers Ireland Ltd., Dublin) and on mash made from freshly-boiled potatoes (termed fresh).

Figure 3 shows the core potato temperature profiles for reconstituted mashed potato for the three different freezing regimes. As expected, the lowest freezing temperature (-90°C) led to the fastest reduction in product temperature ($P<0.001$). The pots of potato chilled at -90°C reached an internal temperature of -25°C within 24 min compared to 78 min for samples frozen at -30°C. Similar results were obtained for fresh mashed potato.

A major textural problem with reconstituted mashed potato is stickiness/firmness, presumably due to excessive extracellular 'free starch' produced by diffusion of starch through the cell walls during cooking, and by rupture of the cooked cell walls during mashing and mixing (Faulks and Griffiths, 1983). Ice crystal formation during freezing leads to further destruction of cell walls and therefore more 'free starch'. This may explain why the frozen reconstituted mashed potato was firmer in the current study than the chilled. Lowering the temperature of freezing resulted in a softer mash for rehydrated potato but not for fresh mashed potato. Lowering the freezing temperature had no effect on the vitamin C content, colour or sensory acceptability of mashed potato (fresh and reconstituted), but drip loss decreased linearly ($P<0.001$) with temperature of freezing.

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[2] The freezing stage of the freeze-chill process was carried out using a liquid nitrogen cryogenic environmental chamber (CM-2000, Carburos Metalicos, Madrid, Spain). The mashed potato was frozen at -30, -60 or -90°C to an internal temperature of -25°C; stored at -25°C for 1 week; thawed at 4°C; stored at 4°C for 1 week; then tested.

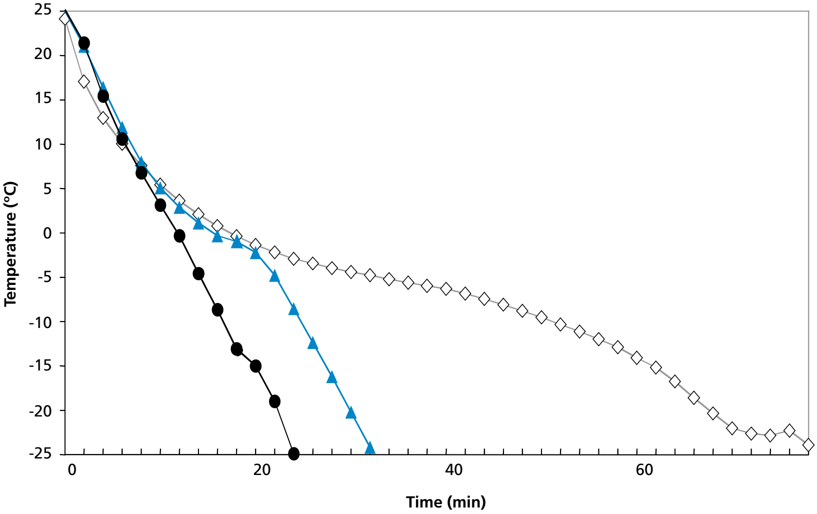

Figure 3 Average core temperatures for reconstituted mashed potato during freezing at -30°C (◇), -60°C (▲) and -90°C (●)

[3]Vitamin C retention in freeze-chilled mashed potato

Vitamin C is a labile nutrient and losses occur in cooked and then chilled vegetables (Williams *et al.*, 1995) and also in freeze-chilled mashed potato (Decazes *et al.*, 2001; O'Leary *et al.*, 2000). To overcome this, the addition of encapsulated vitamin C to freeze-chilled mashed potato was investigated. Encapsulation is a process by which liquid droplets or solid particles (in this case vitamin C) are packed in continuous shells, usually made of partially hydrogenated vegetable oil. The shells, or microcapsules, are added to the cooled mashed potato and protect the vitamin C during chill storage of the

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[3] Cooled mashed potato sample sets (20g/pot; cultivar Rooster) were prepared containing (a) ordinary vitamin C (OVC) (33 mg/100g), (b) encapsulated vitamin C (EVC) (50 mg/100g), and (c) no vitamin C (NVC). All samples underwent one of the following process treatments: (i) *Fresh*: cook and test, (ii) *Chill*: store at 4°C for 8d; (iii) *Freeze-chill*: blast freeze at -30°C for 2.5h; store at -25°C for 7d; thaw overnight at 4°C; store at 4°C for 8d; (iv) *Freeze*: blast freeze at -30°C for 2.5h; store at -25°C for 15d; thaw overnight at 4°C.

mash. The fat cocoon melts during microwaving of the chilled potato thus releasing the vitamin C which is then ingested by the consumer.

Preliminary tests were conducted on the rate of release of vitamin C from encapsulated vitamin C over the temperature range 20-90°C (Decazes *et al.*, 2001). This was followed by tests on the effect of freeze-chilling on the retention of encapsulated vitamin C in mashed potato. The mash was reheated in a microwave oven at 700 W for 30s to a centre temperature of 78 to 83°C prior to vitamin C analysis.

The vitamin C content of the unsupplemented mashed potato (NVC) was low (circa 2mg/100g) in the fresh and in the processed products (Figure 4). This may have been due to the cooking and mashing of the potato. The chill and freeze-chilling treatments had a dramatic reducing effect on the vitamin C content ($P<0.001$) of the potato with added OVC. In contrast, the chilled and freeze-chilled samples with added EVC had circa 15mg/100g (Figure 4) indicating that encapsulation was exerting a protective effect during chilled storage. The freeze-only treatment resulted in a good retention of both the OVC and EVC (Figure 4). This result was expected as vitamin C is normally well retained in frozen foods (Favell, 1998).

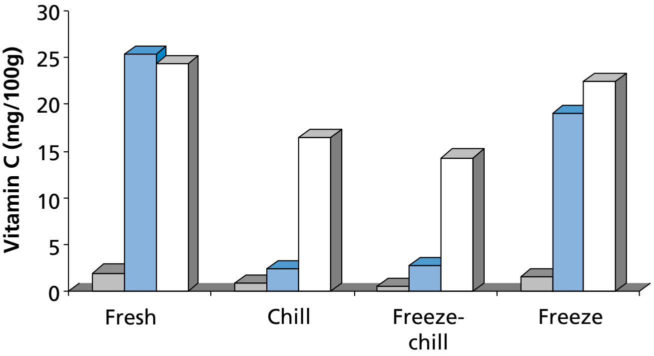

Figure 4 Effect of process treatments (and fresh) on the vitamin C content of fresh and processed mashed potato without added vitamin C (▨), with added vitamin C (🟦) and with added encapsulated vitamin C (☐)

[4]Freeze-chilling of steamed carrots and green beans

The effect of freeze-chilling on the quality of steamed carrots and green beans with a view to their use as components in ready-meals was examined. The keeping quality of thawed fruit and vegetables may be adversely affected by the expansion and growth of ice crystals, which cause collapse and rupture of cell walls (Khan and Vincent, 1996). In the current study, freeze-chilling and freezing led to less firm (lower shear values) carrots than chilling or preparing fresh but this was not the case for green beans. Freeze-chilling and freezing led to a higher drip loss than the fresh or chill treatments for both carrots and green beans. For carrots, drip loss from the fresh and chill treatments was low (average = 2.1%) compared to the freeze-chill and freeze treatments (average = 19.2%), whereas drip loss from the fresh and chilled green beans was much higher (average = 22.1%), although significantly lower than the freeze-chilled or frozen green beans (average = 31.4%). No difference was found in cooked carrot colour between the four treatments but differences were found in cooked green bean colour, in that freeze-chilling and chilling led to lower hue angles (less green) than freezing or preparing fresh (Figure 5) (Redmond *et al.*, 2004a)

Adams and Moss (1999) suggested that freezing and then thawing might make some foods more susceptible to microbiological attack due to the destruction of antimicrobial barriers in the product and also due to increased moisture and condensation on the product. The freezing step should not cause an increase in the microbial load, but may have an influence on subsequent growth in chilled storage of freeze-chilled products. However, this was not found in the current study as no difference was found in TVC values between the treatments for either carrots (average = 2.2 $\log_{10}$ cfu/g) or green beans (average = 3.2 $\log_{10}$ cfu/g). No difference in sensory acceptability was found between the process treatments for steamed carrots. However, sensory

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[4] Steamed carrots (Nairobi variety) and green beans (Kenya or Gambia) were subjected to one of the following freezing/chilling treatments: (i) *Freeze-chill:* blast freeze at -30°C for 2.5h; store at -25°C for 7d;thaw overnight at 4°C; store at 4°C for 7d; test; (ii) *Freeze*: blast freeze at -30°C for 2.5h; store at -25°C for 14d; thaw overnight at 4°C; test; (iii) *Chill*: store at 4°C for 7d; test; or (iv) *Fresh*: cook and test.

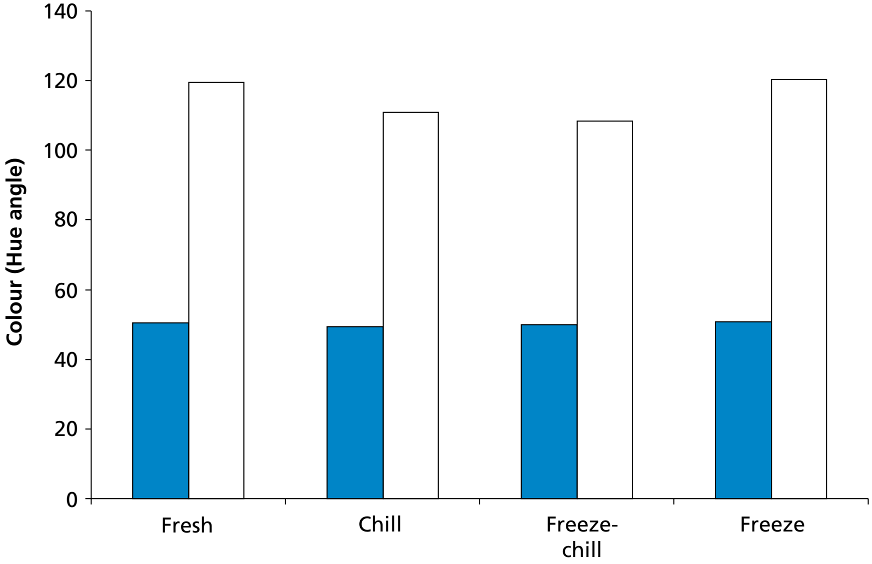

Figure 5 The colour (hue angle) of fresh or processed steamed carrots (🟦) and green beans (☐)

acceptability was lower for the fresh green beans than for processed beans. No explanation can be given for this other than that flavour changes may have taken place during freezing, frozen storage or chilled storage. These data suggest that freeze-chilling is a suitable technology for steamed carrots and green beans (Redmond *et al.*, 2004a).

Freeze-chilling of white sauces

Starch-based white sauces are a frequent constituent of ready-meals and serve several purposes. The sauce assists in imparting a flavour sensation to the protein food, which is complementary to the intended eating experience. It also creates an appearance and colour that satisfies eye appeal. It covers the meat or vegetables and prevents dehydration and freezer-burn during storage. However, freezing traditional white sauce releases water from the sauce (syneresis) after thawing, which decreases acceptability. The suitability of different starch types for use in freeze-chilled white sauce and the effect of different freezing rates on the quality of freeze-chilled white sauce was examined.

Three modified starches, Purity W and Thermflo (modified waxy maize starches), and National Frigex CL (modified tapioca starch) were used (trial 1) to produce three white sauces. Each sauce was subjected to both freeze-chilling and chilling. The amount of liquid separation (syneresis) in the freeze-chilled and chilled sauces throughout the chilled display period was low (less than 4%). The syneresis level did not change with time, indicating that the sauces remained stable post-thawing during chilled display for up to eight days. There was no difference in viscosity between the chilled and freeze-chilled sauces on any day of the chilled display period. Freeze-chilling of the white sauce did not affect colour (Hunter L/b; white/yellow ratio) when compared to chilling.

Two modified starches (Thermoflo and National Frigex CL) were used to investigate the effect of freezing rates on syneresis, colour and rheology of freeze-chilled white sauces. The starches were used to make white sauces which were frozen at -30°C, -60°C or -90°C to an internal temperature of -25°C, and then stored at -25°C for 2 days followed by holding at 4°C for 8 d. The level of syneresis in freeze-chilled sauces frozen at different rates was less than 2%, regardless of the freezing rate used. Freezing rate had no effect on the viscosity of the freeze-chilled white sauce and did not appreciably affect the colour. It was concluded that the starches were freeze-thaw stable and were suitable for use in freeze-chill applications in ready-meals. (Dempsey, 2003).

Freeze-chilling of lasagne

Lasagne is an increasingly popular ready-meal with average consumption per capita in Ireland at 0.32 kg annually, compared to 0.2 kg in the UK and 1.0 kg in Belgium (Anon, 2001a). The objective was to examine the effect of freeze-chilling on the quality of beef lasagnes (unit size 300g) from a ready-meal company. They were received (at 4°C) in the laboratory approximately 36 hours after production and were subjected to three process treatments (freeze-chilling, chilling and freezing). A fresh sample was used as control.

Freeze-chilled lasagnes had a brighter colour (L/b) than chilled lasagnes before heating, but this was not evident after heating (Table 1). No difference was found in shear values or sensory acceptability between the treatments but a significant difference was found in TVCs in that freeze-chilled and frozen lasagne had higher TV counts than chilled or fresh. This result was unexpected as freezing usually gives a reduction in TVC values (Redmond *et al.*, 2004b).

Table 1: Effect of short-term frozen storage on the quality of freeze-chilled lasagne

	Fresh	Chill	Freeze	Freeze-chill	F test	LSD[a]
Unheated lasagne						
Centrifugal drip (%)	0.84	1.56	10.07	3.41	$P<0.001$	1.99
Colour (L/b)	5.59	5.17	5.37	5.55	$P<0.05$	0.29
Shear value (N)	274	258	289	256	NS	48
TVC ($\log_{10}$ cfu/g)	1.76	1.95	3.62	4.03	$P<0.001$	0.64
Heated lasagne						
Centrifugal drip (%)	-	2.15	2.77	2.29	NS	1.57
Colour (L/b)	-	2.49	4.01	3.17	$P<0.01$	0.7
Shear value (N)	-	216	229	232	NS	30
Sensory acceptability	3.75	3.64	3.38	3.60	NS	0.54

[a] LSD = Least significant difference

Frozen and freeze-chilled lasagne had significantly higher drip loss values than fresh or chilled before heating but this was not evident after heating (Table 1). This could be due to structural damage to components as a result of freezing (Khan and Vincent, 1996). However, it is likely that moisture redistribution took place during re-heating thereby offsetting the adverse effects of freezing. This increase in drip loss for the unheated lasagne is not of major concern for manufacturers as the lasagnes are re-heated before consumption (Redmond *et al.*, 2004b).

The texture of pasta products is critical for consumer acceptability. The pasta component can either harden or soften depending on interactions with the other components of the meal. Gonzalez et al. (2000) suggested that redistribution of moisture (moisture migration) after cooking was one of the main mechanisms by which al dente pasta loses its mechanical properties. Texture tests on a macaroni and cheese product (Anon, 2002) showed that the pasta component softened during chilled storage. However, these changes were minimised on cooking. Similar results were found for a cheese and tomato pasta-based product. In the present study, no difference was found in texture between freeze-chilled, frozen, chilled or fresh lasagne, either before or after re-heating suggesting that storage conditions had little effect on the texture of the final heated product. (Redmond et al., 2004b). All microbial counts were below the upper limit of 100,000 cfu/g set out by the Food Safety Authority of Ireland for ready-to-eat meals at point of sale (Anon, 2001b).

[5]Long-term freeze-chilling of products

One of the advantages of freeze-chilling is that products can be stored frozen prior to chilled retail. The objective was to examine the effect of long-term frozen storage (up to 12 months) prior to thawing and chilling, on the quality of mashed potato, steamed carrots, steamed green beans and lasagne. Frozen storage for up to 12 months followed by chilling led to a firmer product than freezing alone for mashed potato and green beans. Length of time in frozen

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[5] The products were subjected to one of the following treatments: (i) *Freeze - chill:* blast freeze at -30°C for 2.5h; store at -25°C for 0, 3, 6, 9 or 12 months; thaw overnight at 4°C; store at 4°C for 6 or 7d; (ii) *Freeze*: blast freeze at -30°C for 2.5h; store at -25°C for 0, 3, 6, 9 or 12 months; thaw overnight at 4°C; test.

storage had no effect on drip loss values of freeze-chilled or frozen mashed potato (average 21%), cooked carrots (average = 26%) or green beans (average = 31%).

Time in frozen storage reduced (P<0.001) the brightness (i.e. lower Hunter L/b values) of freeze-chilled and frozen mashed potato. Process treatments were also different (P<0.001) with freeze-chilled mash having a brighter colour (L/b value of 3.20) than frozen mash (2.98). Frozen storage time had no effect on the colour (hue angle) of carrots (average = 45°) or green beans (average = 118°), and no difference was found between freeze-chilling and freezing (Redmond *et al.*, 2004a). Length of time in frozen storage had no effect on the vitamin C content of mashed potato but freeze-chilling led to a reduction in vitamin C content compared to freezing (0.64 *vs* 1.68 mg/100g respectively). Time in frozen storage had no effect on the sensory acceptability of the three products nor were differences found in sensory acceptability between freeze-chilled and frozen carrots (average = 1.97) or green beans (average = 2.34). However, freeze-chilling led to a lower (P<0.01) sensory score (2.52) than freezing (2.75) for mashed potato.

Length of time in frozen storage had no effect on the TVC values of freeze-chilled and frozen mashed potato but did have an effect on values for both green beans and carrots (Figure 6). For green beans, TVC values before frozen storage were higher than at any other storage time, while carrots stored for 9 months had the lowest TVC values. Freeze-chilling also led to significantly higher TVC values than freezing for all three products which agrees with the findings of O'Leary *et al.* (2000) for a range of products. However, all values were below the limit (log 5 cfu/g) set by the Food Safety Authority of Ireland for cooked vegetable products at point of sale (Anon. 2001b). The overall findings suggest that long term frozen storage does not result in an increased microbial load in the follow-on chill phase of the freeze-chill process for mashed potato, steamed carrots or green beans.

Freeze-chilled lasagne (commercially-produced) was stored frozen at –30°C for up to 12 months followed by thawing and chilling at 4°C for 7d. Frozen lasagnes were used for comparison. Quality and sensory tests were conducted on both unheated and heated samples (Redmond *et al.*, 2004b); however, only

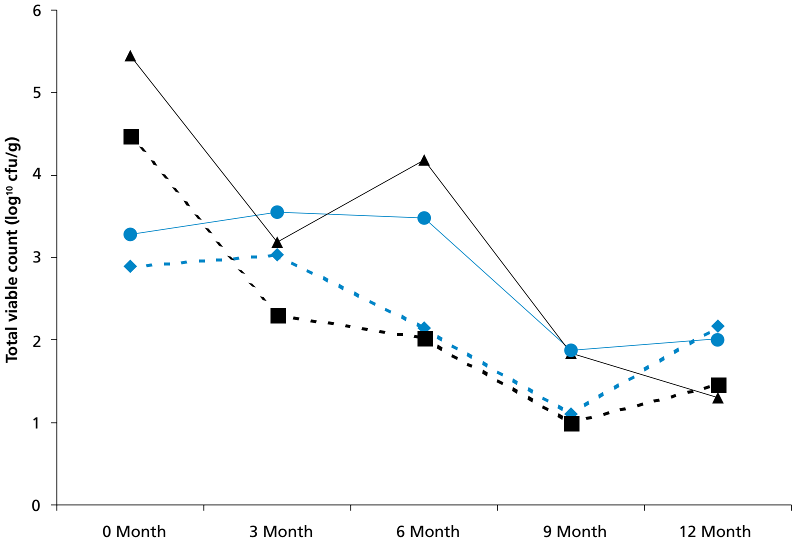

Figure 6 Effect of long-term frozen storage on the total viable count (TVC) values of frozen and freeze-chilled cooked carrots and green beans: frozen carrots (◆); frozen green beans (■), freeze-chilled carrots (●); freeze-chilled green beans (▲).

results for the latter are presented. The term 'heated' refers to samples microwaved at 700 W in accordance with the manufacturer's instructions followed by cooling to 4°C before testing. Drip losses tended to decrease with length of frozen storage time especially for the freeze-chilled samples (Table 2). This may reflect increased water binding by the meat or pasta components of the lasagne. However, this was not reflected in product softness as lasagne stored frozen for 12 months had the highest shear values (Table 2).

Sensory tests indicated a non-significant deteriorative trend in sensory acceptability with increasing length of time in frozen storage as indicated by sensory scores of 3.9 (6 month), 3.6 (9 month) and 3.4 (12 month). Several panellists commented on the pasta component of the meal being tough or leathery. However, even after 12 months frozen storage lasagnes were still acceptable [3.4 on a scale of 0 (unacceptable) to 5 (very acceptable)].

Table 2: The effect of long-term frozen storage on the firmness, drip loss and colour of heated[a] lasagne: product frozen for up to 12 months was compared with freeze-chilled product (frozen for up to 12 months followed by chilled storage for seven days).

Treatment	Time (months)[b]	Shear value (Newtons)	Centrifugal drip (%)	Colour (L/b)[c]
Frozen	3	229	4.09	3.60
	6	227	2.15	3.49
	9	227	4.52	3.17
	12	277	1.73	3.25
Freeze-chilled	3	211	4.66	3.34
	6	212	4.68	3.66
	9	236	2.06	2.90
	12	244	0.64	2.77
ANOVA (F test)	Treatment	$P<0.05$, LSD=13	NS	$P<0.01$, LSD=0.14
	Month	$P<0.001$, LSD=13	$P<0.05$, LSD=1.92	$P<0.001$, LSD=0.24
	Interaction	$P<0.05$, LSD=18	NS	NS

[a] Microwaved at 700W followed by cooling to 4°C and testing

[b] Time in storage at –30°C

[c] White/yellow colour ratio

[6] Modified atmosphere packaging (MAP) with freeze-chilling

The effect of packaging in modified atmospheres or air on the shelf-life of mashed potato, steamed carrots, steamed green beans and lasagne was established.

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6 The products were packed in: (i) air; (ii) CO_2/N_2 (40:60%); (iii) $CO_2/O_2/N_2$ (40:30:30%); (iv) CO_2 (100%); (v) N_2 (100%); then blast frozen at -30°C for 2.5h; stored at -25°C for 3 weeks; chilled at 4°C for 9d; tested.

No difference was found in quality between freeze-chilled carrots stored in MAP or in air. For mashed potato, packing in air led to a less firm and less bright potato mash than storing in MAP. No difference was found in TVC between any of the packing atmospheres indicating that MAP had no added benefit to the keeping quality of freeze-chilled mashed potato.

MAP and storage time (in chill) had no effect on the texture, centrifugal drip loss, TVC values or moisture content of freeze-chilled steamed green-beans, but storing in air gave greener beans (high hue angle) than storing in $CO_2/O_2/N_2$(40:30:30%). This suggests that storing in air benefited the colour of freeze-chilled green beans.

Packing in $CO_2/O_2/N_2$ (40:30:30%) led to a less bright lasagne than packing in CO_2/N_2 (40:60%) or air, but atmosphere had no effect on lasagne colour once heated. Pack atmosphere had no effect on drip loss but lasagnes in CO_2/N_2 (40:60%) were firmer than in air for frozen lasagnes; however this was not the case for the freeze-chilled lasagnes. Atmosphere had no effect on TVC values but an interaction ($P<0.05$) was found between process treatment and atmosphere *i.e.* TVCs increased in the order air, CO_2/N_2 (40:60%), $CO_2/O_2/N_2$ (40:30:30%) for the frozen lasagnes while the order was the opposite for the freeze-chilled samples (Redmond *et al.*, 2004b).

In general, MAP had little or no effect on the firmness, drip loss or TVC values of freeze-chilled mashed potato, steamed carrots or steamed green beans.

Temperature abuse of freeze-chilled products

Chilled and freeze-chilled foods may be more at risk of temperature abuse than frozen products. (O'Leary *et al.*, 2000; Adams and Moss, 1999). The effects of different temperatures (4, 7, 10°C) in the final chill phase of the freeze-chill process on the TVC (mashed potato) and psychrotrophic counts (mashed potato and steamed carrots) was studied over an 8d period (Oxley, 2003).

No significant difference was found in TVCs (potato) or in psychrotrophic counts (potato or cooked carrot) between freeze-chilling and chilling on any of the test days. This indicates that the freezing and thawing of the mashed potato and cooked carrot did not make the products more conducive to microbial growth over the chill storage period. However, increasing chilled storage temperatures in the chill phase of the freeze-chill process gave an increase in microbial growth for both carrots and potatoes. No difference in TVCs or in psychrotrophic counts was evident after 1d at any of the storage temperatures. However, differences were found after 4 and 8d between each of the storage temperatures. For example, mashed potato stored at 10°C had an average TVC of 6.5 compared to 3.1 and 1.3 $\log_{10}$ cfu/g for potato at 7°C and 4°C respectively on d8. Similar results were found for the psychrotrophic counts. Psychrotrophic counts for cooked carrots after 8d at 10°C averaged 8.6 compared to counts of 5.7 and 3.4 $\log_{10}$ cfu/g at 7°C and 4°C respectively. These data show that the products stored at 10°C for 8d post-thawing had unacceptable microbial counts and indicate the need for careful temperature control in the final chill phase of the freeze-chill process (Oxley, 2003). While these TVCs and psychrotrophic counts do not necessarily signify a safe or unsafe product, they can give a good indication of the potential for growth of pathogens if contamination was to occur.

Tempering of freeze-chilled products

The tempering (thawing) of freeze-chilled foods is of paramount importance to food companies. Tempering is a method used to speed up the thawing of frozen foods. Warm/hot air was used to temper frozen ready-meals/meal components on a laboratory scale (trial 1) and using a commercial tempering unit (trial 2) (Gerety, 2004).

Trial 1 studied the effects of different thawing rates on the quality of reconstituted mashed potato, fresh mashed potato and cooked carrots. The cooked samples were placed in plastic trays (110 x 150 x 55 mm), heat sealed and thermocouples inserted in the core and outer parts of samples prior to blast freezing. Thawing was carried out at air temperatures of 4°C, 10°C and 20°C (incubators were used to deliver the 10°C and 20°C thawing regimes) and the temperature of the samples was recorded at 5 min intervals using a datalogger. When the outer thermocouples of the potato and carrot samples in the 10°C and 20°C incubators reached 4°C the samples were placed in chill storage at 4°C. Quality tests and TVCs were carried out on d1 and 8 of chilled storage for reconstituted mashed potato while fresh potato mash and carrot samples were tested on d1, 5, 7 and 9 of chilled storage.

Time-temperature profiles comparing thawing rates in air at 4, 10 and 20°C showed that reconstituted mashed potato thawed at the higher temperatures reached 4°C in the fastest time. The thawing curves (Figure 7) are based on readings from the thermocouples inserted in the outer part of the sample. The samples placed in the 20°C incubator reached 4°C in 2 h, those thawed at 10°C took 7 h while it took over 24 h for the frozen mash placed in chilled storage at 4°C to reach 4°C. The thawing rates and patterns of real mashed potato and of cooked carrots were similar to the reconstituted mashed potato.

Increasing the thawing rate had no effect on the colour of reconstituted mashed potato (L/b units) or cooked carrot (hue angle) on any of the test days when compared to thawing at 4°C. The colour of real mashed potato was effected by thawing rates ($P < 0.001$) and chilled storage time ($P < 0.05$) with the 4°C samples giving the darker product on each test day.

The different thawing temperatures had no effect on the centrifugal drip loss of reconstituted or real mashed potato but cooked carrots thawed at 20°C had the lowest ($P < 0.05$) content (average 29.9 g /100 g) while the 4°C samples had the highest (average 32.2 g /100 g). The higher thawing temperatures resulted in a softer reconstituted mashed potato (average range 3.59 N at 4°C to 2.75 N at 20°C) but the firmness of real mashed potato was not affected. Increasing thawing rates led to an increase ($P < 0.001$) in firmness in cooked carrots on all test days.

Increasing the thawing temperature and chilled storage time had no effect on TVC values in reconstituted or real mashed potato. However, higher thawing temperatures led to an increase ($P < 0.05$) in microbial growth in carrots on d9 ranging from less than 10 cfu/g at 4°C to 1,000 cfu/g at 20°C.

Sensory panellists indicated no preference for any of the potato mashes from the thawing treatments or chilled storage days. All sensory data were in the moderate to very acceptable range.

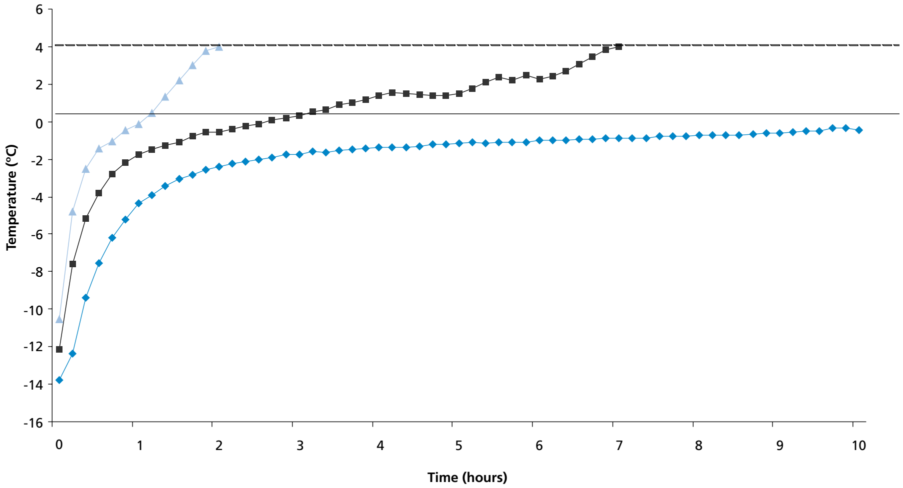

Figure 7. Thawing rates of reconstituted mashed potato at air temperatures of 4°C (◆), 10°C (■) and 20°C (▲). Potato mash temperature was measured at the outer part of the sample.

Trial 2 used a commercial tempering unit (SB10, 6-pallet unit; cubic capacity 20m^3) supplied by Dawson Rentals and located at The National Food Centre. In the tests, 216 commercially-produced lasagne ready-meals were placed in 27 boxes (outers) (2 rows of 4 in each box). T-type wire thermocouples were inserted in the geometric centre (core) and between the meal and plastic seal (surface) of 12 meals at random before freezing. The frozen meals in the boxes were placed in the tempering unit in one of three box configurations: (a) separated, (air space between every box), (b) 3 together, (air space between groups of 3 boxes), and (c) stacked (no air spaces).

During thawing the unit blows warm air (set at 28°C) over the frozen product (via heaters and fans) until the product surface temperature reaches 3°C. Heaters and coolers alternate until this sensor is satisfied. The product core sensor then takes control of the heaters and coolers until its setpoint of 3°C is reached. The unit then switches to holding mode. Lasagne surface temperatures were higher than the core values at time intervals 0, 4 and 8 hours of the thawing cycle but were similar thereafter (Figures 8 and 9) with values equilibrating at about 3°C after 12 h. When the boxes were stacked in threes, the temperatures in the centremost box were circa 10°C lower at each testing time than the temperature in the more exposed boxes, and the product surface and core temperatures were still circa - 4°C after 24 h. This shows that tight stacking is not an option and the best practice for efficient tempering is a separated box configuration.

Re-freezing of freeze-chilled products

Many prepared food products have "suitable for freezing" stamped on the pack and consumers may freeze food products for convenience and to extend

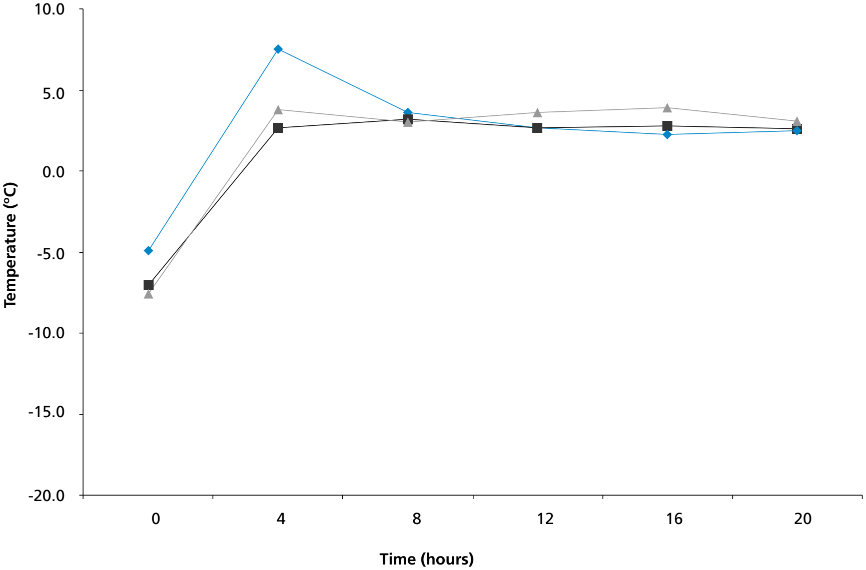

Figure 8. Surface temperature (°C) in lasagne ready-meals during tempering in a commercial tempering unit using three stacking configurations. Boxes containing 8 meals were tempered separately (◆), in groups of 3 boxes together (■), or stacked without circulating air space (▲).

shelf-life. However, with freeze-chilled foods home freezing or re-freezing means a second freezing which may raise issues of product quality and safety. Therefore, the effect of a re-freezing/ thawing step on the quality attributes of freeze-chilled mashed potato, sliced steamed carrots and commercially-produced lasagne ready-meals was examined. Frozen samples of the three products were prepared/obtained as described previously, held at -25°C for 7d, thawed overnight at 4°C, stored at 4°C for 7d followed by testing (to determine baseline values, *i.e.* thaw 1 tests). The freeze-chilled samples were then refrozen by fast (blast freezing at -30°C for 2.5 h) or slow (cabinet) procedures and held at -25°C for 7d. They were thawed at 4°C overnight and tested again (*i.e.* thaw 2 tests). The colour, shear values, centrifugal drip loss and vitamin C content (potatoes only) of the freeze-chilled mashed potato, steamed sliced carrot and heated lasagne were unaffected by re-freezing (both methods) or thawing. However re-freezing/thawing did reduce the

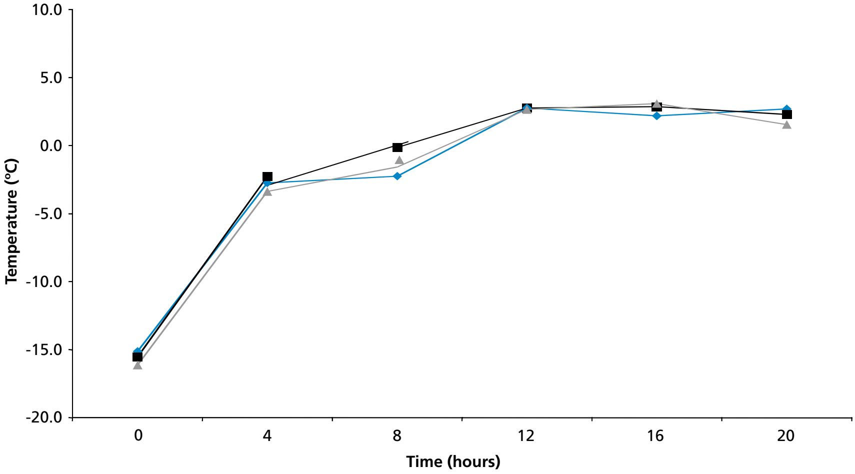

Figure 9. Core temperature (°C) in lasagne ready-meals during tempering in a commercial tempering unit using three stacking configurations. Boxes containing 8 meals were tempered separately (◆), in groups of 3 boxes together (■), or stacked without circulating air space (▲).

adhesiveness of the freeze-chilled mashed potato but the effect was small in practical terms. The microbial status of the freeze-chilled (unheated) lasagne was not affected by re-freezing/thawing. All samples had TVC values below the upper limit of $\log_{10}5$ cfu/g specified by the Food Safety Authority of Ireland for ready-to-eat meals at point of sale (Anon., 2001b). These overall data suggest that freeze-chilled mashed potato, steamed sliced carrot or lasagne can be re-frozen/thawed without impairing quality and safety. However, it is imperative that no temperature abuse occurs during the chill phase of the freeze-chill process.

Industry trials

Freeze-chilling trials were conducted at The National Food Centre and in-factory on a range of commercial products. To date, eight food companies including a multinational (two subsidiaries), two ready-meal companies, four SMEs and a start-up company have used the research findings.

CONCLUSIONS

- Freeze-chilling is a suitable technology for many ready-meals and ready-meal components, including sauces, and offers logistic and shelf-life benefits during distribution and retailing.
- Extended frozen storage (up to 1 year) prior to chilling has little adverse effect on the quality of a range of freeze-chilled products.
- Modified atmosphere packaging (MAP) did not benefit the quality and shelf-life of freeze-chilled mashed potato, steamed carrots or lasagne.
- Results from a commercial tempering unit showed that boxed ready meals should not be stacked as air circulation is prevented.
- Freeze-chilled mashed potato, steamed sliced carrots and lasagne can be successfully re-frozen provided temperature abuse does not occur during the final chill phase of the freeze-chill process.

RECOMMENDATIONS TO INDUSTRY

Freeze-chilling of ready-meals and ready-meal components can offer logistic and distribution advantages over chilling.

Foods intended for freeze-chilling must be suitable for freezing and thawing, *i.e.* they must not suffer significant structural damage and should give zero or minimal drip on thawing.

Good manufacturing practice (GMP) and HACCP are imperative throughout the overall process. Particular attention must be given to the thawing/tempering phase of the freeze-chill process, especially when re-freezing is being considered as an option.

Freeze-chilled products should be labelled as ‘previously frozen’ for reasons of consumer information. A use-by date must also be employed and this label should be attached at the start of the thawing process.

An industry fact sheet on freeze-chilling is available from the authors.

OTHER FREEZE-CHILLING RESEARCH AT THE NATIONAL FOOD CENTRE

Tests on the freeze-chilling of steamed salmon and broccoli (O'Leary *et al.*, 2000), and on raw fish fillets/portions (whiting, mackerel, farmed salmon) (Fagan *et al.*, 2003, 2004) have been completed. Research on the sous vide cooking of ready-meals/components (carrots, broccoli, salmon, cod, beef, lamb, chicken, sliced potato, rice, pasta shells, sauces) followed by freezing or chilling is nearing completion (Tansey *et al.*, 2003). Research has also been completed on the effect of fluctuating *vs* constant frozen storage temperature regimes on selected quality characteristics of a range of foods/food products (Gormley *et al.*, 2002).

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LIST OF PUBLICATIONS FROM THIS PROJECT

This project has generated 43 publications. A selection of these follows:

Dempsey, A. 2003. The effect of starch type and freezing rates on freeze-chilled starch-based sauces. MSc Thesis, University College, Dublin.

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