Agriculture and Food Development Authority

FINAL REPORT

Project Armis No. 4555

Rapid Cooling of Cooked Meat Joints

The National Food Centre

RESEARCH & TRAINING FOR THE FOOD INDUSTRY

RESEARCH REPORT NO 49

Contents ▶

RAPID COOLING OF COOKED MEAT JOINTS

Authors:

Tony Kenny M.Sc. Ph.D.
Eoin Desmond B.Sc. Ph.D
Patrick Ward
The National Food Centre, Dunsinea,
Castleknock, Dublin 15

and

Da-Wen Sun M.Sc. Ph.D. C.Eng.
Department of Agricultural & Food Engineering,
University College Dublin,
Earlsfort Terrace, Dublin, 2

ISBN 1 84170 277 3
February 2002

Agriculture and Food Development Authority

Teagasc 19 Sandymount Avenue Ballsbridge Dublin 4

CONTENTS

Summary 1

Introduction 2

Procedure and Results 4

- (i) Effects of method of cooling on quality of hams at 20% brine injection level 5
- (ii) Effect of brine injection level on yield, quality and rate of cooling of vacuum-cooled hams 7
- (iii) Rapid chilling of flash-roasted joints 11
  - (a) Rate of chilling and effect on quality 11
  - (b) Uniformity of chilling 14
  - (c) Effect of rate of cooling on retention of nutrients 16
- (iv) Prediction of temperature and weight changes by mathematical modelling 17

Conclusions 18

Recommendations to Industry 20

Acknowledgements 22

Publications from this project 22

References 24

SUMMARY

Conventional cooling by air-blast or even by immersion in liquid is unlikely to achieve recommended cooling rates when dealing with joints weighing 5kg or more because meat has a low thermal conductivity. The objective was to investigate vacuum cooling as a technique for rapid chilling of cooked meat joints. In vacuum cooling, the food is enclosed in a chamber and reduction of the pressure to about 7 mbar causes evaporation of water from the surface of the food and from cavities in the food. The energy required to evaporate the water is extracted from the food, resulting in rapid chilling

Vacuum cooling (VC) gave significant ($P<0.05$) reduction in cooling time e.g. from core temperature 70° to 4° in 1.9 hours for netted 5 – 6 kg hams, compared to 11.7 hours for blast chilling (BC) and 14.3 hours for slow air chilling (SC). However, VC gave an increased weight loss of about 11% compared to about 4% for the other methods. Sensory panels rated VC hams as tougher but did not downgrade them in overall acceptability. Increased weight loss due to VC was corrected by increasing the level of brine injection in pork legs from 20% to 30% and getting a yield after VC similar to that for SC hams injected at 20% without reduction in eating quality. The higher the brine level in hams, the faster was the rate of vacuum cooling but weight loss was similar for different brine levels.

VC was the only one of the three methods under these test conditions that conformed to recent microbiological safety recommendations for cooked meat joints of a reduction in core temperature through the critical 40° → 15°C zone inside 4 hours.

VC of cooked meat joints was not satisfactory when the joints were enclosed in moulds or in cooking bags. Therefore, the technique may be more suitable for final cooling of joints after *flash roasting*, when the joints in commercial practice are normally without wrapping, than for cooling after initial cooking. Much of the cooked meat joints processed in industry are given a coating followed by a finishing flash-roasting so as to gain a more desirable appearance and flavour. During the simulation of factory practice of roasting, the temperature of the meat rose to about 80°C near the surface and the core

temperature rose to over 40°C. VC of hams after flash-roasting gave a reduction of core temperature through the critical 40° → 15°C zone in 1 hour as against 5 hours for blast-chilling. The difference could be significant in terms of microbiological safety. A greater weight loss (9.8% versus 2.4%) and slight toughening of texture with the VC flash-roasted hams would have to be set against increased safety in such a handled and re-heated product. Nutritional value of flash-roasted ham was not affected by rate of cooling.

INTRODUCTION

An overview of the cooked meat sector on the island of Ireland (Enterprise Ireland, December 2000) stated that the whole cooked meats sector has a retail value of about €120 m in the Republic of Ireland and €30m in Northern Ireland. Cured products, mainly ham, account for over 70% of the market. Annual growth rate was given as 7.8% in overall cooked meats and 20% in premium quality products in RoI with growth being lower in NI. In addition, there is a growing market for cooked meats as ingredients e.g. diced ham for pizza toppings or sliced cooked meats for sandwich manufacture. These figures illustrate the economic importance of the sector and it is expected that consumer demand for such ready-to-eat convenience products will continue to increase.

Efficiency of processing can be assessed in terms of safety of product, yield, eating quality, appearance and storage life. Slow cooling of pasteurised cooked meats could allow growth of surviving spore-forming bacteria, reduction of yield and impairment of eating quality and nutritional value. There is no EU Regulation on cooling of cooked meats though there are several national guidelines. In the U.S., cooling conditions are specified in a Federal regulation, and the up-dated 1999 Guidelines complying with the Regulation require that during cooling of either partially or fully cooked meats, the product's maximum internal temperature should not remain between 54° and 27°C for more than 1.5 hours, nor between 27°and 4° for more than 5 hours. In the U.K., a 1998 Report (Gaze, Shaw and Archer, 1998) on microbiological aspects of cooling of large joints of meat states that the most critical phase is between 40° and 15° and that the meat should be through that in not more than 4 hours. It recommends that total cooling time to 5° should be not more than 10 to 12 hours and preferably 8 to 10 hours.

Conventional cooling by air-blast or even by immersion in liquid is unlikely to be able to achieve the above recommended cooling rates when dealing with joints weighing 5kg or more. This is because these methods rely on heat conduction to cool the inside of the joints and meat has a relatively low thermal conductivity. In addition, the temperature of the cooling medium must be above -2°C to avoid surface freezing of the meat. James (1990) reported that in commercial operations, process cooling times can be long, up to 21h, and final temperatures high, 15 to 20°C. Burfoot *et al.* (1990) showed that cooling of large (about 7kg) hams from 70 to 10°C took over 5 h using immersion in water at 0°C and over 10 h using air cooling.

One method that does allow for rapid chilling is vacuum cooling. The technique is well established commercially for cooling of lettuce and mushrooms. Some research was done on its application to cooked meats but effects on quality and yield were not covered (McDonald & Sun, 2000). In vacuum cooling, the food is enclosed in a chamber and reduction of the pressure to about 7 mbar causes evaporation of water from the surface of the food and from cavities in the food. The energy required to evaporate the water i.e. the latent heat of evaporation (about 2,500 kJ/kg for water) is extracted from the food, resulting in rapid chilling. A diagram of a laboratory-scale demonstration vacuum cooler assembled at UCD for this project is shown in Figure 1.

The aim of this project was to determine the performance of vacuum cooling for cooked meat joints compared with slow-air and air-blast chilling.

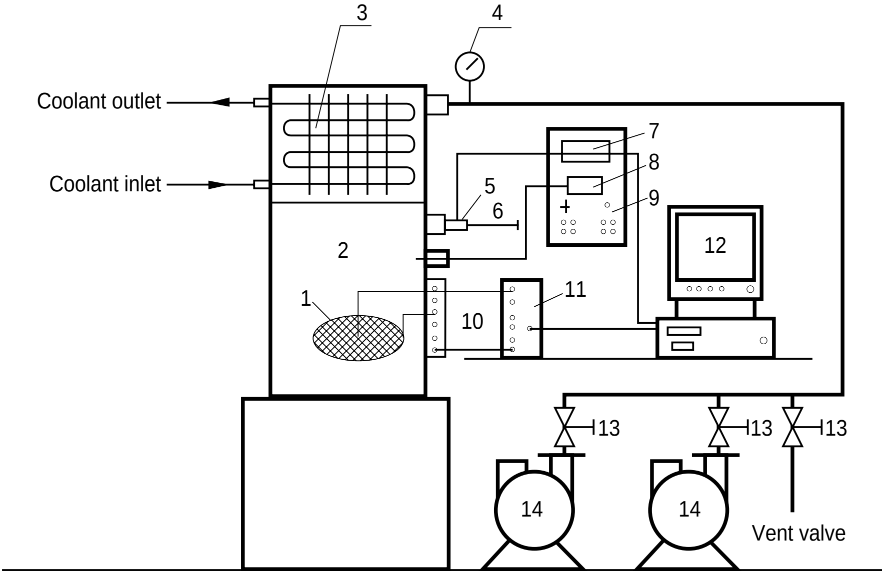


Figure 1: Schematic diagram of the vacuum cooler demonstration unit. 1 product; 2 vacuum chamber; 3 condenser; 4 pressure gauge; 5 pressure transducer; 6 bleeding valve; 7 pressure indicator & controller; 8 temperature indicator & controller; 9 control panel; 10 thermocouples; 11 data acquisition system; 12 computer; 13 vacuum valve; 14 vacuum pump.

PROCEDURE AND RESULTS

The work was divided in four parts:

(i) the effect of cooling method on weight loss and quality in cooked ham joints which had been prepared at a 20% level of brine injection;

(ii) the feasibility of increasing brine injection level to compensate for increased moisture loss in vacuum cooling;

(iii) the efficiency of vacuum cooling for joints flash-roasted after initial cooking and cooling;

(iv) the prediction of temperature and weight changes by mathematical modelling.

(i) Effects of method of cooling on quality of hams at 20% brine injection level

Six replicate trials were carried out in each of which whole-muscle cooked hams, weighing 5-6 kg and prepared from boned-out pork legs, were subjected to three cooling methods;

(a) Vacuum Cooling (VC, @ 7-10mbar residual pressure)

(b) Blast-Air Chilling (BC, air @ 1°C and 2 m/sec adjacent to the meat)

(c) Slow-Air Chilling (SC, air @ 2°C and 1m/sec)

The hams were wrapped only in elastic netting because wrapping of the joints in plastic film, even perforated or in film in moulds, restricted vacuum cooling. Details of materials and methods employed in the six trials are given in Desmond *et al.*, 2000.

Chemical analysis (Table 1) showed that cooling method did not significantly affect fat or salt content. However, the VC ham had the lowest moisture content, 70.7%, which is expected due to the evaporation under vacuum. The lower moisture and corresponding higher protein content of the VC ham could be expected to affect its texture.

Cooling time from 70° to 10°C (core temperature) was reduced by VC by up to 8 h and from 70° to 4°C by 10 h compared to the other methods (Table 2 and Fig. 2). There was no difference in cooling rate to 10° between BC and

Table 1: Effect of method of cooling on chemical composition of cooked ham.

Treatment	Moisture %	Fat %	Protein %	Salt %
Vacuum cooled	70.7^{c}	4.2^{a}	22.3^{a}	2.1^{a}
Blast chilled	72.8^{ab}	3.7^{a}	19.8^{b}	2.1^{a}
Slow chilled	72.2^{b}	3.4^{a}	20.9^{ab}	1.9^{a}

[a-c] Means in the same column with different letters are significantly different ($p<0.05$)

Table 2: Rate of cooling, yield and WHC* of cooked hams cooled by three methods.

Parameter	Vac-cooled	Blast chill	Slow chill
Cooling rate: 70°C to 10°C (hr)	1.3[b]	8.6[a]	9.6[a]
Cooling rate: 70°C to 4°C (hr)	1.9[c]	1.7[b]	14.3[a]
Chill loss (%)	11.3[a]	4.7[b]	4.4[b]
Total yield (%)	96.6[b]	107.4[a]	106.5[a]
WHC (%)	75.3[a]	73.4[a]	74.0[ab]

* WHC: Water-holding capacity

[a-c] Means in the same column with different letters are different ($p<0.05$)

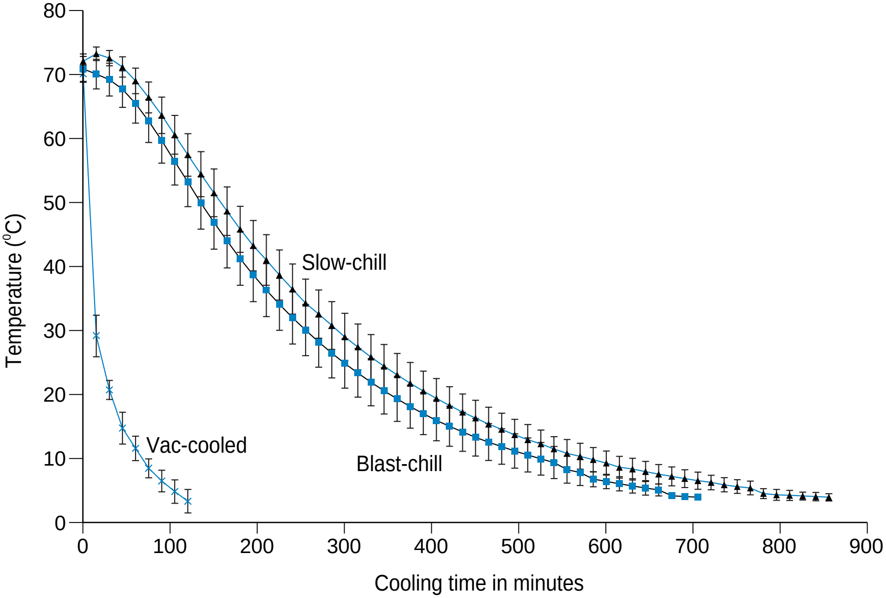


Figure 2: Core temperatures for cooked hams cooled by three methods; six hams were used in each method.

SC while cooling to 4°C was faster for BC (11.7h) than SC (14.3h). Campden & Chorleywood Food RA (Gaze *et al.*, 1998) recommended 10 h as good practice and 12.5 h as maximum time for the cooling of cured meat products to 5°C. The VC hams easily bettered the good practice time while the BC ham achieved the recommended maximum time and the SC ham failed to meet the standard.

Weight loss (Table 2) was 11.3% after VC compared with 4.7% after BC and 4.4% after SC. Other workers (Burfoot *et al.*, 1990) reported weight losses of 8.2% after VC and 2.5% after convection cooling. Due to the higher weight loss during chilling, the VC hams had a significantly lower total yield (96.6%) than BC (107.4%) and SC (106.5%).

(ii) Effect of brine injection level on yield, quality and rate of cooling of vacuum-cooled hams

To counteract the lower yield in vacuum cooled hams, a higher level of brine injection was examined. Two injection levels, 20% and 30%, and two cooling methods, vacuum (VC) and slow (SC), were compared using a 2x2 factorial design in six replicate trials on hams of about 5 kg in weight. Details of materials and methods used are given in Desmond, Kenny and Ward, 2001. The results (Tables 3-4 and Fig 3) support the following conclusions:

Injection level did not affect rate of cooling significantly and there was no interactive effect between cooling method and injection level (see block B in Table 3 and cooling curves in Fig. 3).

Injection level did not affect taste panel ratings for tenderness, juiciness and overall acceptability (see block B in Table 4). Vacuum cooled hams were less tender and juicy than slow cooled hams (see block A in Table 4) but were equal to them in saltiness, overall flavour and overall acceptability.

The 30% injection level in vacuum cooled hams gave yields (106.5%) similar to that of the 20% injected slow cooled 'control' hams (105.0%) without reduction in quality.

Table 3: Effect of cooling method (vacuum and slow cooling) and injection level (20% and 30%) on chill loss, yield and rate of chilling of cooked hams of about 5 kg weight.

	Chill loss (%)	Total yield (%)	Cooling time 70°C to 10°C (h)	 70°C to 4°C (h)
A: Cooling method				
Vacuum cooling	11.1	103.4	1.7	2.5
Slow cooling	6.4	109.3	7.9	12.5
Significance[1]	***	***	***	***
B: Injection level				
20 %	8.6	102.7	4.8	7.8
30 %	8.9	110.0	4.9	7.3
Significance[1]	ns	***	ns	ns
Interactions A x B				
Significance[1]	ns	ns	ns	ns
Samples				
Vac cooling x 20 %	10.7	100.3	1.6	2.4
Vac cooling x 30%	11.4	106.5	1.8	2.6
Slow cooling x 20 %	6.4	105.0	8.1	12.1
Slow cooling x 30 %	6.5	113.6	7.8	12.9

[1] Significance level: *,**,***: $p<0.05$, $p<0.01$, $p<0.001$ respectively; ns = not significant

Vacuum cooling, but not slow-air cooling, conformed to recent recommendations for cooked meat joints of a reduction in core temperature to 5°C inside 10 hours, or a transition through the critical 40°C to 15°C zone inside 4 hours. This confirmed the previous results in part (i).

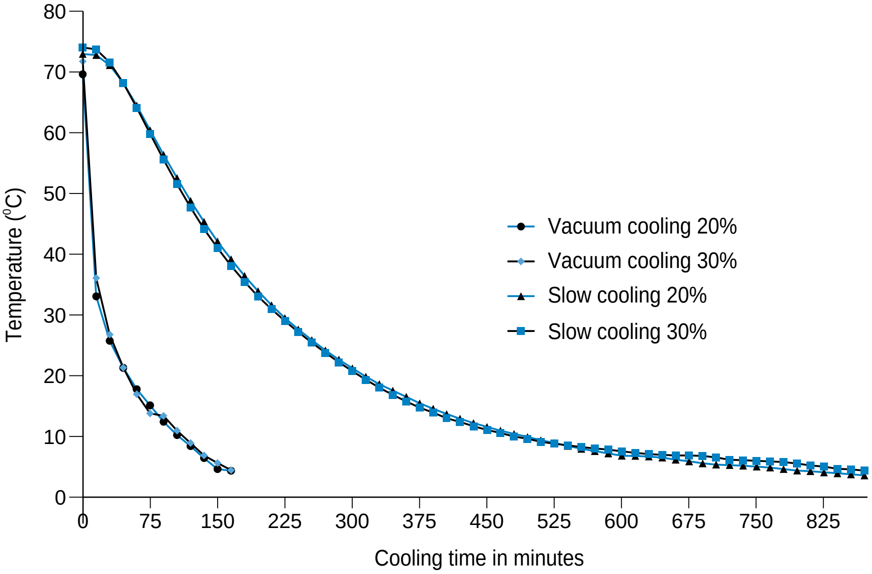


Figure 3: Core temperature for cooked hams using two levels of brine injection (20% and 30%) and two cooling methods (vacuum cooling and slow cooling). Each treatment used six hams of about 5kg.

Table 4: Effect of cooling method and injection level on sensory quality and on instrumentally-measured texture and colour of cooked hams of about 5 kg weight.

	Sensory Panel				Instrumental texture and colour	
	Tenderness	Juiciness	Overall acceptability	Cured colour	Kramer shear force	L-value (lightness)
A: Cooling method						
Vacuum cooling	4.1	3.7	4.2	3.4	30.1	55.0
Slow cooling	4.6	4.2	4.3	3.7	29.1	57.4
Significance[1]	*	**	ns	ns	ns	*
B: Injection level						
20 %	4.4	3.9	4.3	3.3	29.7	55.1
30 %	4.2	4.0	4.2	3.7	29.5	57.3
Significance[1]	ns	ns	ns	ns	ns	*
Interactions A x B						
Significance[1]	ns	ns	ns	ns	ns	ns
Samples						
Vacuum cooling x 20 %	4.1	3.5	4.1	3.2	31.2	53.7
Vacuum cooling x 30 %	4.0	3.8	4.3	3.6	29.0	56.2
Slow cooling x 20 %	4.8	4.2	4.5	3.5	28.2	56.4
Slow cooling x 30 %	4.4	4.1	4.1	3.8	29.9	58.4

[1] Significance level: *, **, ***: $p<0.05$, $p<0.01$, $p<0.001$ respectively; ns = not significant

Contents

(iii) Rapid chilling of flash-roasted joints

(a) Rate of chilling and effect on quality

Much of the cooked meat joints processed in industry are given a coating followed by a finishing roasting in order to give a more desirable appearance and flavour. Rapid chilling of these re-heated joints is even more desirable than after the initial cooking, for assurance of safety. A preliminary monitoring of post-cook roasting and final chilling of cooked hams was carried out in an export-licensed factory. This showed that during the roasting cycle the core temperature of the cooked hams rose to approximately 30°C. After roasting, the hams are placed in a chill at 0°C and the core temperature took about 3.5 and 5.5 hours to reach 10°C and 4°C respectively.

In a further trial, 5 pairs of cooked hams from five batches produced at the factory were transported to the laboratory, coated with caramel solution and roasted in a dry-air oven at 130°C for 90 minutes to simulate factory practice, after which one of each pair was vacuum–cooled (Fig. 4) and the other blast-chilled. During the roasting the temperature of the meat rose to about 80°C near the surface and about 35°C in the core. The core temperature rose further, to over 40°C, after termination of roasting.

The rates of cooling of product roasted by the two methods were 1 hour for core temperature to fall from 40° to 15° by VC (Fig. 5) compared to 5 hours by BC (Fig. 6 and Table 5). This difference could be significant in terms of microbiological safety in a product that is initially pasteurised, not sterilised, and that has to be subjected to handling after initial cooking and then re-heated.

The greater weight loss with VC (mean value 9.8% versus 2.4% for BC) would have to be set against the possible gain in safety. The VC hams were also tougher as indicated by the higher hardness and chewiness figures from instrumental Texture Profile Analysis (Table 5). However, experience suggests that the size of the differences would not indicate a reduction in overall acceptability by a taste panel.

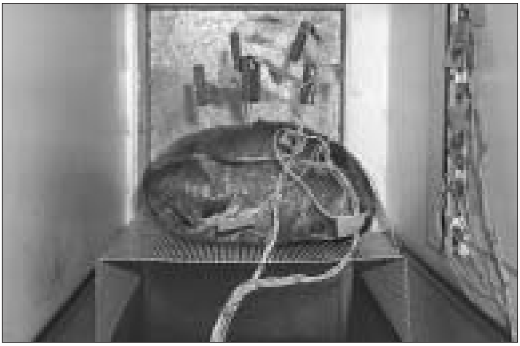


Figure 4: Flash roasted ham in vacuum cooler chamber with thermocouples inserted at various points of the ham.

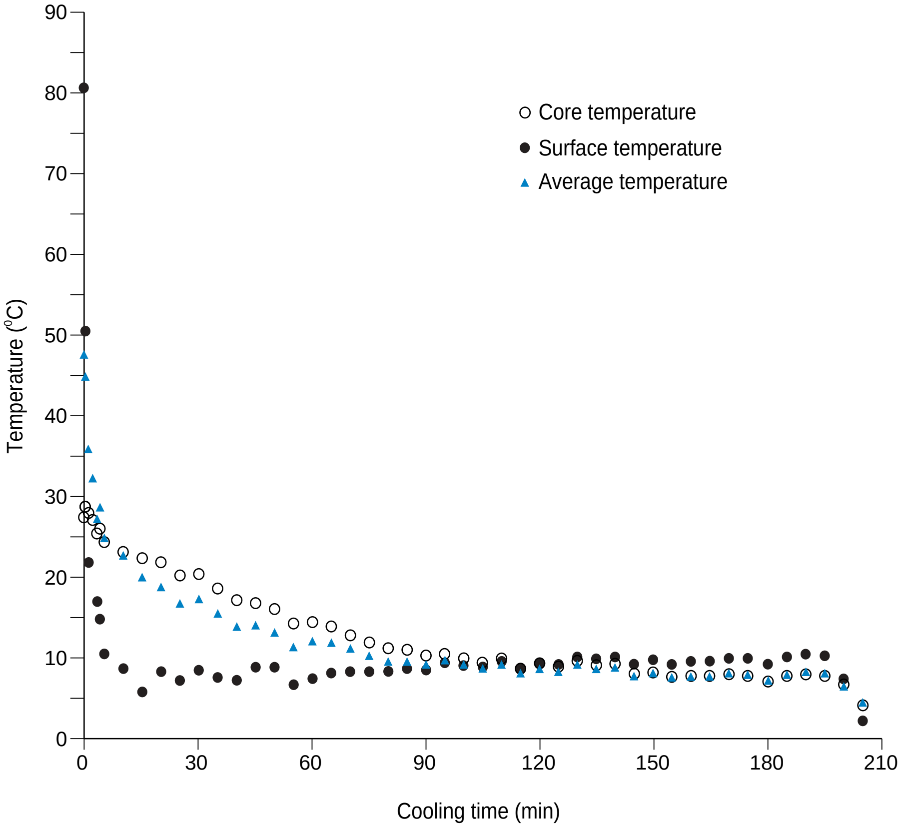


Figure 5: Core, average and surface temperatures during vacuum cooling of flash-roasted hams.

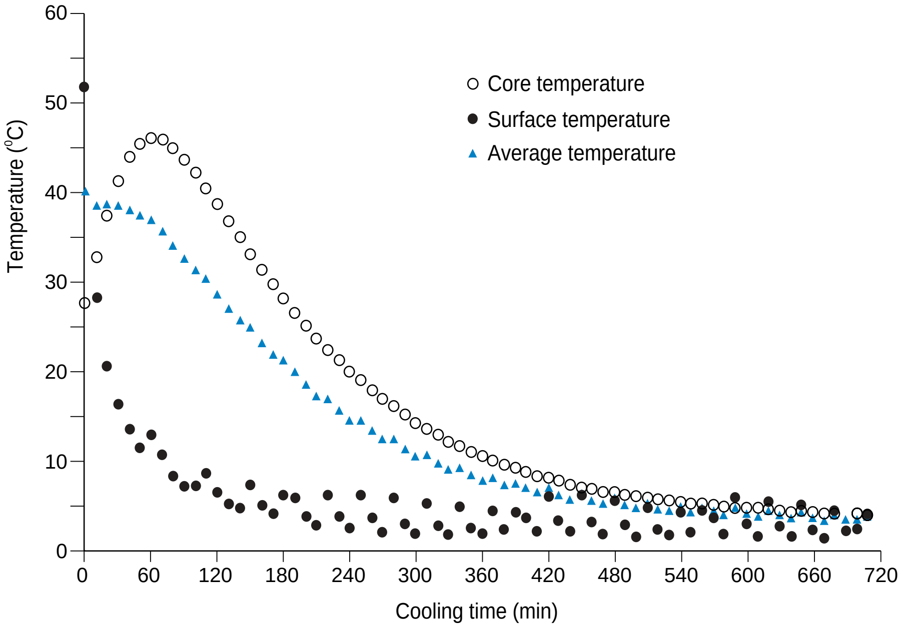


Figure 6: Core, average and surface temperatures during air blast cooling of flash-roasted hams.

Table 5: Effect of cooling method on rate of chilling, yield and texture of flash-roasted cooked ham (mean values from 5 tests).

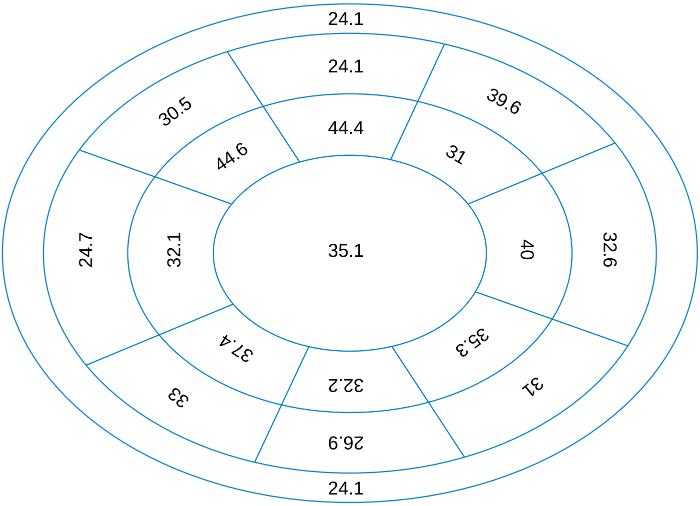
Parameter	Vacuum-cooled	Blast-chilled
Core cooling time (min) to reach 10°C	67	319
Core cooling time (min) to reach 4°C	153	500
Weight loss in chilling (%)	9.8	2.4
Texture Profile Analysis		
Hardness (N)	118	104
Chewiness	314	243
Springiness (mm)	6.1	5.7

(b) Uniformity of chilling

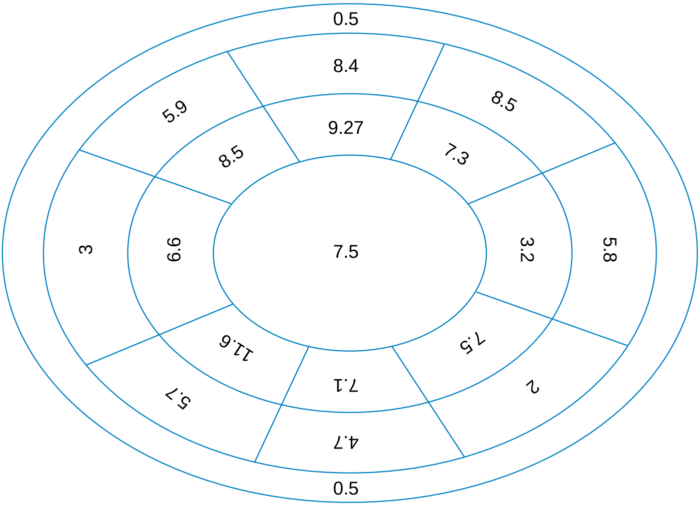
In addition to more rapid cooling, VC gives much more uniform cooling, as shown for flash-roasted joints by Figures 5-7.

In Figs. 5 and 6, the core and surface temperatures are mean values of two thermocouple readings and the average temperature is the mean of the readings of 16 thermocouples inserted uniformly within the joint. The curves in Fig. 5 show that the difference between the average temperature and the core temperature is small (less than 3.5°C after 5 min) indicating that the temperature distribution inside the joints is very uniform during vacuum cooling. For air blast cooling, there is a significant difference between the average temperature and the core temperature (Fig. 6). With vacuum cooling, the maximum temperature is not always in the core of the joint. When maximum temperature within a VC joint was 10°C, the difference between the maximum temperature and the average value was 0.8°C and the temperature difference between the core and the surface was 1°, compared with 2.4° and 5.7°C respectively for BC joints. The greater uniformity of temperature distribution in VC joints is a further advantage in terms of microbiological safety. It could also be beneficial in preventing surface freezing during cooling of meat joints.

Figure 7 shows a typical mapping of temperature distribution within a flash-roasted joint during vacuum cooling, showing that the temperature distribution became rapidly more uniform as cooling continued. For air blast cooling (not shown) the temperature difference between core and surface remains larger and temperature distribution much less uniform.



Temperature distribution 1 min after start of vacuum cooling.



Temperature distribution 30min after start of vacuum cooling.

Figure 7: Temperature distribution (°C) during vacuum cooling of flash-roasted ham joints of about 5kg weight.

(c) Effect of rate of cooling on retention of nutrients

Vitamin B_1 (thiamin) was chosen as test nutrient as it is relatively sensitive to heat and oxidation at pH between 6 and 7 and meat, particularly pork, is an important dietary source of it. Vitamin B_1 is essential for normal functioning of nerve tissue.

Chemical analysis for thiamin in 5 vacuum-cooled (VC) and 5 blast-chilled (BC) flash roasted hams showed (Table 6) similar residual levels of the nutrient in the samples from both cooling treatments, indicating that there was no nutritional benefit from the more rapid VC method. Moreover the level found was approximately 1 mg per 100 g of ham, which is similar to that usually quoted for raw pork. This indicates that, allowing for dilution by addition of brine and leaching out of water-soluble constituents during cooking, the nett loss of thiamin in original factory cooking, factory chilling, flash roasting and re-cooling is insignificant.

Table 6: Effect of cooling method after flash-roasting on thiamin content (mg/100g) of cooked ham.

Sample No.	Vacuum-cooled	Blast chilled
1	1.16	1.09
2	1.11	1.10
3	0.99	0.87
4	0.84	0.82
5	0.78	1.03
Mean value	0.98	0.98

(iv) Prediction of temperature and weight changes by mathematical modelling

Computational fluid dynamic (CFD) simulations on vacuum cooling of a cylindrical ham (150 mm x 380 mm) were conducted, based on a mathematical model to represent one vacuum pump running for the first 40 minutes and then two pumps until cooling finished. Comparison of the experimental temperature with the predicted results (Fig. 8) shows the temperature profiles obtained from thermocouples inserted at the core (75 mm depth) and near the surface (3 mm). The core was cooled from 74°C to 11.9°C in 73 minutes. The predicted temperature was 11.2°C, which showed satisfactory agreement between simulation (Fig 8-CFX) and experimental (Fig 8-EXP) results. The effect of the second vacuum pump starting after 40

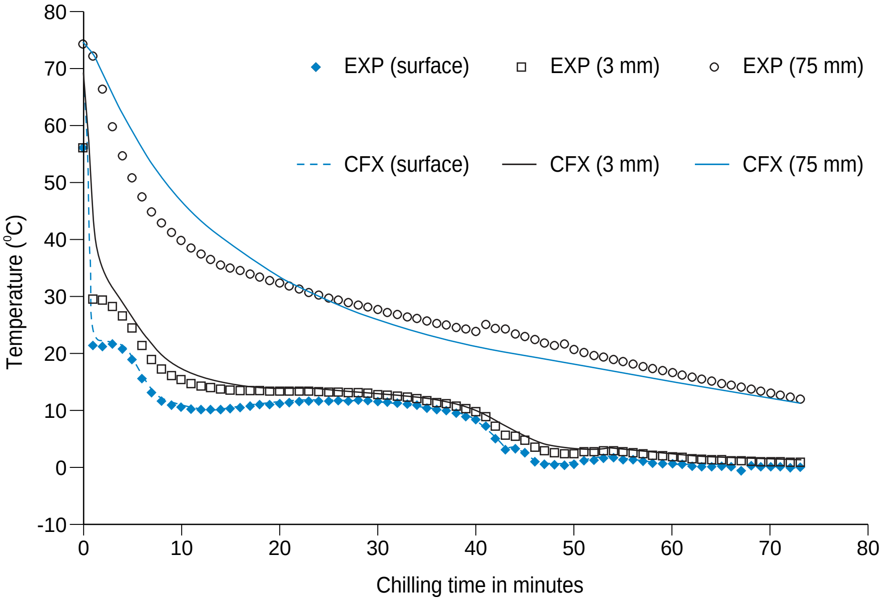


Figure 8: Comparison of predicted (CFX) and observed (EXP) temperature profiles in hams of about 5kg being vacuum cooled after cooking. Curves represent readings from thermocouples placed at the surface, at a depth of 3mm and at the core (75mm) of the hams.

minutes chilling time is clearly visible in the curves for both measured and predicted temperature profiles.

For weight loss, a predicted average of 10.3% was also in good agreement with the experimental cumulative figure of 11.1% after 73 minutes of vacuum cooling. The model also afforded a profile of the weight loss, confirming that it occurred mainly within a thin layer near the surface and end of the ham; the weight loss for a large part of the joint was under 5%.

CONCLUSIONS

- Vacuum cooling gives significant reduction in cooling time e.g. from core temperature 70° to 4° in 1.9 hours for netted 5–6 kg hams, compared to 11.7 hours for blast chilling and 14.3 hours for slow air chilling. However vacuum cooling gave an increased weight loss of about 11% compared to about 4% for the other methods. Sensory panels rated vacuum cooled hams as tougher but overall acceptability was not downgraded.
- Increased weight loss due to vacuum cooling was off-set by increasing the level of brine injection in pork legs from 20% to 30% and getting a yield after vacuum cooling similar to that for slow cooled hams injected at 20%, without reduction in eating quality.
- The higher the brine level in hams the faster is the rate of vacuum cooling but weight loss is similar for different brine levels.
- Vacuum cooling was the only one of the three methods under these test conditions that conformed to recent microbiological safety recommendations for cooked meat joints of a reduction in core temperature to 5°C inside 10 hours and a transition through the critical 40°→15°C zone inside 4 hours. Mapping of temperatures showed that vacuum cooling also gave much more uniform temperature distribution in the meat than did blast chilling. This is of added potential benefit in microbiological safety.

- Vacuum cooling of cooked meat joints was not satisfactory when the joints were enclosed in moulds or in cooking bags. Most of the trials in the project were carried out with the joints enclosed only in netting which in commercial cooking applies only to some premium quality hams and premium turkey breast crowns i.e. most joints are wrapped during cooking. For this reason the technique may be more feasible for final cooling of joints after flash roasting, when the joints in commercial practice are normally without wrapping, than for cooling after initial cooking.

- Vacuum cooling of hams after flash-roasting gave a reduction of core temperature through the critical 40°→15°C zone in about 1 hour as against 5 hours for blast-chilling. The difference could be significant in terms of microbiological safety in such a handled and reheated product. The greater weight loss (9.8% versus 2.4%) and the slight toughening of texture with the vacuum cooled flash-roasted hams would have to be offset against the possible gain in safety.

- Nutritional value of flash-roasted ham was not affected by rate of cooling, as indicated by comparison of thiamin (vitamin B1) content after vacuum cooling and blast chilling.

- Mathematical modelling using computational fluid dynamic (CFD) procedures gave predicted temperature and weight loss profiles agreeing closely with experimentally determined figures, indicating the potential value of CFD simulation for assessing safety implications of alterations in cooling parameters for cooked meats.

RECOMMENDATIONS TO INDUSTRY

Surveillance on food safety by regulatory authorities such as the Food Safety Authority of Ireland requires cooked meat processors to pay increased attention not only to thoroughness of cooking but also to the rate of cooling. Some bacteria could be present on the meat after cooking, due to under-cooking or to spores which survive the normal cooking or to contamination after cooking. Slow cooling could be a safety hazard if some of these bacteria are pathogens and if it allows them time to multiply.

What cooling rate is adequate? As yet, there are no statutory regulations in the EU governing cooling of cooked meats but there are guidelines. Irish guidelines drafted for the Dept. of Health in 1991 (Food Advisory Committee, 1991) on cook-chill systems in hospitals and catering premises recommend that joints should be cooled from 74°C to 10°C or below within 2.5h of removal from the cooker. These guidelines apply only to hospital and catering operations and joints not exceeding 2.5kg in weight. Commercial producers of cooked meat joints weighing 5kg and more can not achieve this standard in blast chill rooms.

The US has Federal Regulations regarding the cooking and cooling of meat and meat products which require that all product shall be chilled from 48.8°C to 12.7°C in no more than 6 hours and chilling shall continue and the product shall not be packed for shipment until it has reached 4.4°C. A comprehensive report in 1998 based on trials by Campden & Chorleywood Food Research Association in the UK recommends the following cooling times for cooked hams and other similar-sized cured and uncured joints:

	Cooling time (hr)			
	Uncured meat products		Cured meat products	
	Good practice	Maximum	Good practice	Maximum
to 50°C	1	2.5	1.25	3.25
from 50°C to 12°C	6	6.0	7.50	7.50
from 12°C to 5°C	1	1.5	1.25	1.75
Total time to 5°C	8	10	10	12.5

The results correspond with the above-noted US regulations, especially in regard to the most critical phase, between 50° and 12°. The report also recommends that if products are re-heated after initial cooking and cooling (in order to create a surface-roasted or hot-smoked product) the cooling time should be regarded as the total accumulation of time the product spends at or above 5°C after the initial cook.

This project assessed the capability of vacuum cooling for large cooked meat joints. Vacuum cooling gave a large reduction in cooling times (1.9 hr for vacuum versus 11.7 hr for blast chilling) and was the only one of the three methods tested that conformed to the above microbiological safety recommendations for large cooked meat joints. However, it was not suitable for cooked meat joints that were enclosed in moulds or in cooking bags; with joints enclosed only in netting, it increased cooling weight loss by about 7 percentage units. The technique performed well in final cooling of joints after flash roasting and may be more suitable for this purpose, when the joints are normally without wrapping, than for cooling after initial cooking.

ACKNOWLEDGEMENTS

We thank Messrs. J. McGrath and E. Vesey for butchery assistance; Dr K McDonald, UCD, for assistance in the vacuum-cooling trials and staff of Dairygold Foods Ltd., Dawn Farm Foods, Glanbia plc and Kerry Foods (Wicklow) for comment and advice.

PUBLICATIONS FROM THIS PROJECT

Desmond, E.M., Kenny, T.A., Ward, P. 2001. The effect of injection level and cooling method on the quality of cooked ham joints. *Meat Science* (In Press).

McDonald, K., Sun, Da-Wen and Kenny, T.A. 2001. The effect of injection level on the quality of a rapid vacuum cooled cooked beef product. *Journal of Food Engineering*, **47** (2), 139-147.

McDonald, K. and Sun, Da-Wen 2001. The formation of pores and their effects in a cooked beef product on the efficiency of vacuum cooling. *Journal of Food Engineering*, **47** (2), 175-183.

Desmond, E.M., Kenny, T.A., Ward, P. and Sun, Da-Wen. 2000. Effect of rapid and conventional cooling methods on the quality of cooked ham joints. *Meat Science* **56** (3), 271-279

McDonald, K. and Sun, Da-Wen 2000. Vacuum cooling technology for the food processing industry: A review. *Journal of Food Engineering*, **45,** 55-65.

McDonald, K., Sun, Da-Wen, and Kenny, T.A. 2000. Comparison of the quality of cooked beef products cooled by vacuum cooling and by conventional cooling. *Lebensmittel Wissenschaft und Technologie*, **33,** 21-29.

Hu, Z. and Sun, Da-Wen. 2000**.** CFD simulation of heat and moisture transfer for predicting cooling rate and weight loss of cooked ham during air-blast chilling process. *Journal of Food Engineering*, **46** (3), 189 -197.

Wang, L., Sun Da-Wen and Kenny, T.A. 2000. Effect of cooling environments on cooling rate of cooked meats. *Irish Journal of Agricultural and Food Research*, **39** (1), 138-139 (abstract).

Hu, Z. and Sun, Da-Wen. 2000. Computational fluid dynamics simulation of heat and moisture transfer for predicting cooling rate and weight loss of cooked meats. *Irish Journal of Agricultural and Food Research*, **39** (1), 148 (abstract).

Kenny, T.A., Desmond, E.M. and Ward, P. 1999. The efficient preparation of cooked meat joints for the chill chain. Proceedings: *Workshop on optimising the cold chain for food quality and safety*, The National Food Centre, Dublin 15.

Sun, Da-Wen, Kenny, T.A., McDonald, K. and Desmond, E.M. 1999. Vacuum cooling of cooked hams. *Irish Journal of Agricultural and Food Research*, **38** (1), 149-150 (abstract).

McDonald, K., Sun, Da-Wen, Desmond, E.M. and Kenny, T.A. 1999. Application of vacuum cooling to enhance the safety and quality of cooked meats. *Irish Journal of Agricultural and Food Research*, **38** (1), 150 (abstract).

Hu, Z., Sun, Da-Wen and Bryan, J. 1999. Simulation of cooling process of cooked ham in an air-blast freezer using computational fluid dynamics code. *Irish Journal of Agricultural and Food Research*, **38** (1), 150 (abstract).

REFERENCES

Burfoot, D., Self, K.P., Hudson, W.R., Wilkins, T.J., and James, S.J. 1990. Effect of cooking and cooling method on the processing times, mass losses and bacterial condition of large meat joints. *International Journal of Food Science and Technology* **25**, 657-667.

Desmond, E.M., Kenny, T.A., Ward, P. and Sun, Da-Wen. 2000. Effect of rapid and conventional cooling methods on the quality of cooked ham joints. *Meat Science* **56** (3), 271-279.

Desmond, E.M., Kenny, T.A. and Ward, P. 2001. The effect of injection level and cooling method on the quality of cooked ham joints. *Meat Science* (In Press).

Enterprise Ireland. December 2000. The Pig Industry in Ireland-A Strategic Study. Wilton Terrace, Dublin 2.

Food Safety Advisory Committee. 1991. Guidelines on cook-chill systems in hospitals and catering premises. *Report to the Minister for Health and the Minister for Agriculture and Food*. Stationary Office, Dublin.

Gaze, J.E., Shaw, R. and Archer, J. 1998. Identification and prevention of hazards associated with slow cooling of hams and other large cooked meats and meat products. *Review No. 8. Campden & Chorleywood Food Research Association.*

James, S.J. 1990. Cooling systems for ready meals and cooked products. In: *Process Engineering in the Food Industry-2: Convenience Foods and Quality Assurance.* 88-97. Elsevier Applied Science, London.

Contents

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