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The Ultra Rapid Chilling of Pork

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SUMMARY

Pork carcasses and sides were ultra rapidly chilled in air at −30°C and 1 m/s for 4 h and compared with controls chilled in air at 0°C and 0·5 m/s for 24 h. All the required heat was removed during the 4-h process, there was a 1% saving in evaporative weight loss, the pork could be cut and packed immediately and there were no important differences in appearance and bacteriological quality. The loin from sides, but not carcasses, froze during chilling and showed a fourfold increase in drip loss. Loins from both sides and carcasses were tougher than the controls.

INTRODUCTION

The majority of abattoirs in the United Kingdom produce pork during a 24-h cycle. After slaughter the pigs are chilled in air, nominally at 4°C and 0·5 m/s, which requires 14 to 16 h (Cooper, 1972) and, unless a night shift is operated, the pigs cannot be cut or transported until the following morning. Such a long batch chilling operation leads to a number of major problems. Large chill rooms are required, because the whole day's production has to be held overnight, and any increase in production must be accompanied by a corresponding increase in chill room capacity. New chill rooms are expensive in terms of capital investment, and many existing abattoirs also lack the required space to extend their chilling facilities. Hence, chill rooms are often grossly overloaded, which accentuates a

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problem common to all batch refrigeration systems—that of peak product loads.

James & Bailey (1982) described the effect of peak loads in a number of refrigeration processes, whilst Cox & Bailey (1977) investigated its importance during the chilling of beef carcasses. Pork carcasses behave similarly to beef sides, in that the large quantity of heat released in the initial hours of chilling is far above the average extraction rate required during the total process. Very few chill rooms are designed with sufficient refrigeration capacity to overcome the initial heat load; consequently, air temperature rises, leading to an extended cooling cycle.

An important economic consequence of the extended chilling process, or holding the carcass after chilling is complete, is increased weight loss. This is due to the high rate of evaporation from the slowly cooling surface and a reduced, but still substantial, loss from the cooled carcass. Batch cooling systems for pigs show an average weight loss, measured over 24 h, of between 1·9 and 2·8 % (Cutting, 1973). Any reduction in this weight loss has a considerable effect on the operating profits of a pig meat producer.

A number of chilling regimes have been developed to overcome some, if not all, of these problems. Chilling in two stages with the first stage consisting of a conveyerised pre-chilling tunnel operating at sub-zero temperatures is the most common solution. The pre-chiller serves two requirements in that it rapidly lowers the surface temperature, consequently reducing the rate of evaporative weight loss, and has the capacity to absorb the initial peak heat load. Such systems can reduce the average weight loss during chilling to between 1·0 and 1·5 % (Cooper, 1972; Wernburg, 1972). In Denmark a three-stage system has been developed and it is reported (Hermansen, 1982) that the overall weight loss has been decreased to 0·7 %. The first two stages are conveyerised tunnels, running at −18 °C and −5 °C, respectively, which remove the majority of the heat before the temperatures are allowed to equalise in the final room. Even though these systems have overcome many of the deficiencies of the traditional chill room, they still retain the problems of being based on a 24-h operating cycle.

An obvious way of overcoming all the problems is to bone or joint the carcass while hot. Work has been carried out in America on accelerated processing of pork loins (Moore *et al.*, 1966; Weiner *et al.*, 1966; Hinnergardt *et al.*, 1973) and investigations are being carried out in Denmark (Danish Meat Research Institute Annual Report, 1981) on hot jointing of pork. However, in both cases further chilling is required after

jointing and since more cut surface area is then available for evaporation, weight losses can be very high unless the pieces are individually wrapped or crust-frozen.

A possible solution that does not seem to have been investigated in depth is to use a very rapid chilling regime that will remove all the heat from the carcass in 3 to 4 h. The carcasses could then be cut into primal joints, packaged and despatched or frozen. If such an operation were conveyerised it would continuously overcome any peak load problems. The surface temperature of the carcass would fall very rapidly, minimising evaporative weight loss. By replacing an overnight chill by one of 4 h or less, the throughput capacity of an abattoir could be increased by a factor of 3 to 4 without extra space being required. Apart from these main advantages, other investigations (Penny, 1969; Taylor & Dant, 1971) have shown that rapid chilling reduces the amount of drip released when pork is cut into joints. A further possible advantage of such a process is increased shelf life of the pork. The majority of the bacterial load on a carcass is found on the surface and a rapid reduction of the surface temperature will retard bacterial growth.

There are a number of possible disadvantages or unknowns in such a system. After the required chilling period, there will be steep temperature gradients through the carcass which may have an adverse effect on subsequent cutting operations. Even if the required amount of heat is extracted, the temperature deep inside the pig will still be high and when the carcass is cut any contamination of the warm exposed surface could increase microbiological growth. The warm exposed surface would also increase the weight loss unless suitably wrapped.

The toughening effect of rapid chilling on the texture of both lamb and beef is well documented (Locker & Haggard, 1963; Marsh & Leet, 1966; Taylor & Dant, 1971; Bendall, 1972) and its underlying cause, cold-shortening, has been investigated in detail. Cold-shortening is not thought to be a problem in pigs due to their very rapid rate of post-mortem glycolysis and the protection afforded to the muscles by the insulating layer of subcutaneous fat. A study by Moore *et al.* (1966) using very rapid chilling rates on pork loins did not show any significant amount of toughening, but Bendall (1975) showed that pork muscles can shorten in experimental situations.

The aim of the work described in this paper was to investigate the practicalities of removing all the heat from a pork carcass in 4 h, to measure the evaporative weight loss, to determine if the carcass could be cut

into primal joints and to show any detrimental effect of microbiological load, water-holding capacity, texture and appearance.

EXPERIMENTAL

Method

Twenty-four Large White × Landrace pigs of mean hot carcass weight 72·2 kg (range 65 to 81 kg) and mean backfat thickness 12·3 mm (range 9 to 19 mm) measured at MLC P2 (MLC, 1975), obtained from the same source were used. The pigs were delivered to the abattoir in batches of four, laired overnight, electrically stunned, stuck and dressed in the normal manner. One pig in each batch was split hot after dressing and a second pig was split hot in three of the six batches. The sides and carcasses were held in air at 16 °C ± 1·0 °C until 50 min post mortem, then one carcass and one side were transferred to the experimental tunnel previously described by Bailey & Cox (1976) and cooled at −30 °C ± 0·5 °C, 1 ± 0·1 m/s for 4 h. A second carcass and side were placed in a conventional chill room operating at 0 to 4 °C, average velocity 0·5 m/s, for 24 h as controls. On three occasions the remaining carcass—and on the other three occasions one of the remaining sides—were rapidly chilled at −30 °C ± 0·1 °C, 1 ± 0·2 m/s for 4 h in the calorimeter room described by James & Bailey (1982). The remaining three sides were not used.

After chilling, the sides and carcasses from the tunnel and the conventional chill were band-sawn into five primal joints (head, shoulder, loin, belly and leg) and vacuum-packed. The primals from the rapidly chilled pigs were packed individually in insulated boxes and held in a chill room at 0° ± 0·5 °C for 24 h to allow temperatures to equalise. They were then removed from the insulated boxes and packed in solid fibreboard cartons for a further 24 h. All the vacuum packed primals from the conventionally chilled pigs and those from the calorimeter room were placed directly in fibreboard cartons and held for 48 h at 0 °C.

After 48 hours' storage a sample, containing the four ribs measured from the kidney knob forward, was removed from each loin. Two single chops from each sample were then used in four different methods of measuring drip or drip potential, and the remaining double chop provided material for texture, sarcomere length, colour and fibre optic probe determinations.

Measurements

During chilling, equalisation and storage of primal joints

The temperatures of the rapidly chilled sides and carcasses were measured in the leg, loin and shoulder using multi-point copper–constantan probes similar to those described by Bailey *et al.* (1974). Meat temperatures in the conventionally chilled sides and carcasses were measured using single point thermistor sensors placed in the deep and on the surface of the leg, shoulder and loin. Ambient temperatures in both cases were recorded using single point sensors positioned in the air stream directly above the carcasses. During the temperature equalisation process the temperature at the centre of each primal joint was recorded using two single point copper–constantan hypodermic probes.

The air speed in the chilling tunnel was monitored continuously at a point 0·5 m above the carcass using a Phoenix Instruments Ltd 'Envivent' anemometer. An average value for the air speed in the conventional chiller was obtained by taking a series of readings around the carcasses using an Airflow Developments Ltd Edra Five anemometer.

The temperatures and air speed during rapid chilling and the temperatures during equilisation were recorded to $\pm 0{\cdot}25\,^{\circ}C$ and $\pm 0{\cdot}2$ m/s using a Solartron computer controlled data logging system. Temperatures in the conventional chill were recorded on a Grant Microprocessor controlled data logging system to $\pm 0{\cdot}5\,^{\circ}C$.

Both sides and carcasses were weighed to ± 100 g at 50 min post mortem and on completion of chilling (either 4 h 50 min or 24 h post mortem) on a calibrated electronic balance. Primal joints were weighed to ± 1 g before vacuum packing and after the 48-h storage period on a Sauter electronic balance. The joints were removed from the packs and allowed to drain for 10 min before the second weighing.

Samples for microbiological analysis were taken at 50 min post morten from carcasses to be rapidly chilled, and sides and carcasses to be conventionally chilled. Sides to be rapidly chilled could not be used in this evaluation because the subsequent vacuum packaging would be broken when the thermocouples were introduced to measure the equalised temperature. The required alternative data was obtained by sampling sides cooled under the same conditions in the calorimeter room. Areas of 50 cm^2 on the head, shoulder, loin, belly and leg of each carcass or side were swabbed using the method described by Kitchell *et al.* (1973), the swabs being placed in 10 ml of maintenance medium (0·85 % NaCl + 0·1 % bacteriological peptone). A second set of microbiological samples

was taken after the vacuum packed primals had been stored for 48 h. Two 50 cm^2 areas were swabbed on each joint, one from a cut surface and the second from a site adjacent to that sampled at 50 min post mortem. Both swabbings were bulked in 10 ml of maintenance medium. All the samples were transported to the laboratory in an insulated container maintained at 0 °C, and processed within 1 h of collection. Swabs and maintenance media were thoroughly mixed by hand using a sterile aluminium rod. Bacterial counts were then made using the loop-tile technique (Hudson & Roberts, 1982) on standard plate count agar (Oxoid CM 463) and incubated for 2 days at 37 °C or 3 days at 25 °C. Counts were calculated using the method of Farmiloe *et al.* (1954).

At the end of the 48-h storage period all joints were marked on an acceptable/not acceptable basis for fat–lean separation, sagging of cut surface and bandsaw damage, by three experienced butchers.

Loin samples

One chop from each loin sample was used to simulate the amount of drip that would be released on retail display. The chop was weighed and placed in a polystyrene tray, overwrapped in cling film and stored at 0 °C ± 0·1 °C for 4 days. It was then removed, allowed to drain for 1 min and reweighed.

Two core samples, 25 mm in diameter, 25 mm long, were removed from the lean of a second chop, weighed, then hung inside nets and placed in polyethylene bags. The bags were stored at 0 °C ± 0·10 °C for 4 days before the core samples were removed and reweighed. The weighings for both methods of drip production were made to ±0·01 g using a Sartorius 120 g electronic scale.

Two further 0·3 g samples were taken from the second chop and drip potential was measured using the press method of Grau & Hamm (1953). The amount of extra-fibre space in the remainder of the muscle was determined using the method detailed by George *et al.* (1980).

The remaining double chop was boned at 2 days post mortem. The fat was then removed, trimmed and its yellowness index (ASTM Designation E313-67) measured on a Hunterlab D25 Colour Difference Meter. The *M. longissimus dorsi* was split into two equal sections with adjacent fresh faces. These faces were covered with oxygen permeable film (Cannings–Parry Packaging Vitafilm) and exposed to air for 1 h at 5 °C. Their colour was then measured at three positions on each face using the Hunterlab Colour Difference Meter and the results expressed as uniform lightness (L), hue (H) and saturation (S) (Taylor & MacDougall, 1973). The light

scattering properties of the *M. longissimus dorsi* were measured at ten positions in one of the sections using the Meat Research Institute Fibre Optic Probe (MacDougall & Jones, 1975). The other section was vacuum packed, frozen and stored at −20 °C for between 2 and 3 weeks. After storage the section was thawed at 5 °C for 15 h, cooked in a water bath at 80 °C for 35 min, cooled by immersion in running water for 20 min and temperatures equalised for 2 h at 5 °C. Ten or eleven 1-cm cubes were then removed from the section and sheared at 90 °C to the fibre direction using a J. J. texture testing machine fitted with Volodkevitch-style jaws, and the work done in shearing calculated.

Measurements of sarcomere length were made on the second section using the method described by Voyle (1971).

RESULTS

Temperatures

The average equalised temperature in the centre of each of the five primal joints of rapidly chilled sides and carcasses is shown in Table 1. The average temperature in the loin joints was significantly lower ($P < 0{\cdot}01$) in the sides than that in the whole carcasses. The mean temperature of the belly in rapidly chilled whole carcasses, and the loin and belly in rapidly chilled sides, was below the initial freezing point of lean pork (−1·5 °C). The average maximum temperatures, recorded at the end of the 4-h chilling process, in the three most important commercial joints (Table 2)

TABLE 1
Mean and Standard Deviation of the Equalised Temperature (°C) in the Five Primal Joints from the Rapidly Chilled Sides and Carcasses ($n = 6$)

	Side		*Carcass*	
	Mean	*SD*	*Mean*	*SD*
Head	−0·4	2	0	1·4
Shoulder	1·2	2·7	3	1·2
Loin	−1·9	0·2	0·3	1·6
Belly	−1·7	0·8	−2·1	0·5
Leg	0·3	1·3	0·6	1·2

TABLE 2
Maximum Temperature (°C) at the End of the 4-h Chilling Process in the Shoulder, Loin and Leg of Rapidly Chilled Sides and Carcasses ($n = 6$)

	Side		*Carcass*	
	Mean	*SD*	*Mean*	*SD*
Shoulder	10·7	3·3	18·6	6·1
Loin	−1·9	0·7	2·0	1·7
Leg	14·6	1·7	14·6	2·5

were significantly different ($P < 0{\cdot}05$) between sides and carcasses in both the shoulder and loin, but not the leg. It can be seen from the average temperature profile through the loin after 4 hours' blast chilling (Fig. 1), that the whole of the lean was below −1·5 °C in the side and above −1·5 °C in the whole carcass. A detailed analysis of the temperature results, together with the product load data, is to be published at a later date.

Cutting

There was no observable difference between any of the four treatments in respect of fat–lean separation, sagging of cut surfaces and bandsaw damage. The bellies in the rapidly chilled carcasses, and both the bellies and loins in the rapidly chilled sides, were too cold and stiff for defatting or boning, but suitable for cutting and/or direct distribution.

Weight loss during chilling and storage of primal joints

Evaporative weight loss during chilling is shown in Table 3 as a percentage of the hot weight recorded at 50 min post mortem. There was no significant difference in percentage loss between sides and whole carcasses within one chilling treatment, but there was a significant difference ($P < 0{\cdot}001$) between treatments. The overall average loss of the rapidly chilled pigs was 1·1 %, almost 1 % less than the 2·05 % mean loss from the conventionally chilled pigs.

There are no significant differences between the overall mean weight losses during vacuum packed storage (Table 3) for any of the treatments.

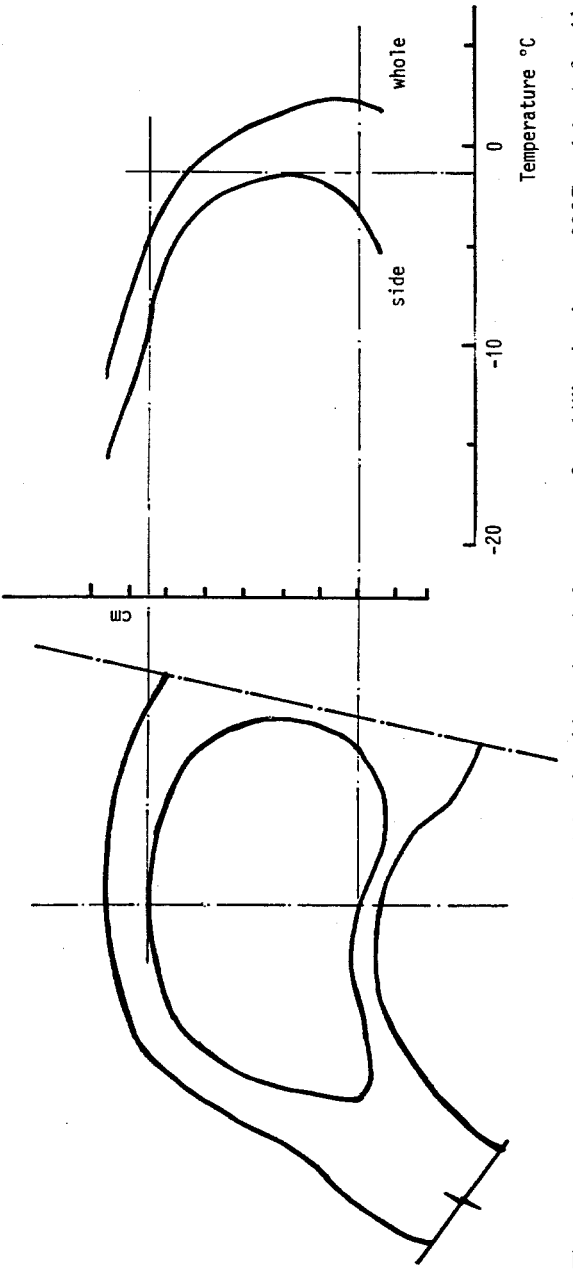

Fig. 1. Temperature profile through the loin of a side and a whole carcass after chilling in air at −30 °C and 1 m/s for 4 h.

TABLE 3

The Effect of Rapid and Conventional Rates of Chilling Using Sides and Whole Carcasses on Evaporative Weight Loss, Drip Loss, Texture and Appearance

($n = 6$ for split carcasses and 12 for whole carcasses unless otherwise shown in parentheses)

	Rapid		*Conventional*		*Residual*
	Side	*Whole*	*Side*	*Whole*	*mean square*
Evaporative loss during chilling (%)	1·13	1·10 (6)	1·98	2·11 (6)	0·024
Drip losses					
Drip in vacuum packs (%)	<0·2	<0·2	<0·2	<0·2	
Drip in retail packs (%)	2·31	0·86	0·99	0·76	0·31
Drip from core samples (%)	10·71 (12)	7·10 (24)	6·31 (12)	5·06 (24)	7·2
Interfibre space (%)	15·40	10·08	10·07	9·74	14·62
Grau–Hamm (fluid area, cm^2)	7·83	8·16	8·02	9·02	1·06
Texture					
Instrumental measurement (J)	0·18 (61)	0·21 (122)	0·16 (63)	0·16 (129)	0·001 28
Sarcomere length (μm)	1·70	1·55	1·56	1·54	0·015
Appearance					
Lightness (L)	45·5	46·0	48·4	47·6	1·06
Hue (H°)	46·85	48·8	50·05	48·6	2·93
Saturation (S)	11·45	10·71	11·58	11·85	0·614
Fibre optic probe	28·7	28·4	33·2	33·0	20·76
Fat yellowness index (Y)	27·7	27·5	26·3	25·7	9·84

Drip losses from loins

Drip loss measured in the retail pack for rapidly chilled sides was significantly higher ($P < 0{\cdot}001$) than for any of the three other treatments (Table 3). Two of the three methods of measuring drip potential produced the same result, with drip from the core samples of rapidly chilled sides being significantly higher ($P < 0{\cdot}001$) than for all other treatments and the amount of interfibre space being significantly higher ($P < 0{\cdot}01$). The results of the Grau–Hamm measurements indicate no significant difference in the means obtained from any of the four treatments.

Texture

Instrumental measurement

There was no significant difference in the work done to shear the samples from sides or whole carcasses of conventionally chilled pork (Table 3), but the value of 0·18 J for rapidly chilled sides was significantly higher ($P < 0{\cdot}05$) than either of the conventionally chilled treatments. The work done to shear rapidly chilled whole carcasses 0·21 J was significantly higher ($P < 0{\cdot}001$) than the value obtained in any of the other treatments.

Sarcomere length

Sarcomeres obtained from rapidly chilled sides (Table 3) were significantly longer ($P < 0{\cdot}05$) than those obtained from any of the other three treatments.

Appearance

The lean of chops from conventionally chilled sides and whole carcasses was significantly lighter ($P < 0{\cdot}01$) (Table 3) than that from rapidly chilled sides and whole carcasses. Hue measurements showed that the lean from rapidly chilled sides was significantly ($P < 0{\cdot}05$) more reddish/pink than that obtained in any of the other treatments. Chops from both rapidly chilled treatments were significantly less saturated ($P < 0{\cdot}05$) than those from conventionally chilled pigs. The mean fibre optic probe measurements in Table 3 showed a significant difference ($P < 0{\cdot}05$) between the mean values obtained for rapidly and conventionally chilled pork, higher values being found in the conventionally chilled *M. longissimus dorsi.*

There was no significant difference between the yellowness indices of the fat.

Microbiology

There was no significant difference between the bacterial counts (Table 4) on the freshly slaughtered pigs consigned as whole carcasses or sides to rapid chilling or conventional chilling. After chilling, cutting and 2 days' storage in vacuum packs there was again no significant difference between counts from rapid or conventionally chilled material.

TABLE 4
Mean Total Viable Counts (TVC) (log/cm^2) Incubated at 37 and 25 °C from Freshly Slaughtered Pigs and Vacuum-packed Pork Stored at 0 °C for 2 Days ($n = 30$ carcasses and 15 for sides)

	Rapid		*Conventional*		*Significance*
	Side	*Carcass*	*Side*	*Carcass*	
Freshly slaughtered pigs					
TVC 37 °C	3·63	3·49	3·40	3·43	NS
TVC 25 °C	4·23	4·16	4·00	4·09	NS
Vacuum-packed joints					
TVC 37 °C	2·99	2·79	3·04	2·99	NS
TVC 25 °C	3·53	3·38	3·62	3·60	NS

NS = Not significant.

DISCUSSION AND CONCLUSIONS

These results show that the total product heat load can be extracted from a 70 kg pig carcass in a single-stage 4-h chilling process, using air at −30 °C and 1 m/s. The average equalised temperatures in the primal joints after 24 h ranged from −2 °C in the belly to +3 °C in the shoulder of whole pigs, and from −2 °C in the belly to +1 °C in the shoulder of a side. A whole or jointed carcass can therefore be packed within 5 h of slaughter and stored or transported, without any further chilling being required or product load imposed on the system. The results indicate that the amount of heat extracted from a whole carcass—and certainly the amount extracted from a side—is more than that removed in most overnight systems operating at

a nominal air temperature of 4 °C. The majority of the belly in the whole carcass and the loin and belly in the side is below the initial freezing point of lean pork. After chilling there are substantial temperature gradients through all sections of the carcass, as shown by the maximum temperatures, but these seem to present no problem to a bandsaw cutting operation. In hot jointing it is difficult to avoid misshaped joints and shrinkage on cooling, but in this system the outer layers of the carcass are completely chilled and the fat solidified, giving substantial rigidity to the meat. The overcooling of the belly and loin would be a problem if further processing such as boning, or defatting, was required on-line, as an extra tempering operation would be needed.

Bacteriological counts on the freshly slaughtered pigs were of the same order as those found in UK commercial abattoirs (Roberts *et al.*, 1980). A comparison of counts taken from freshly slaughtered carcasses and from vacuum-packed joints subsequently derived from them is not strictly valid because the surfaces differ. However, in over 86 % of cases, counts from vacuum-packed joints were less than those from the same anatomical area of the appropriate carcass. Since there was no statistical difference between counts on rapidly, or conventionally chilled, material after storage, it is reasonable to assume that, even if not proved to be better, this system is no worse, from a bacteriological point of view, than commercial chilling operations.

The evaporative weight loss during chilling was approximately 1·0 % less for the rapidly chilled sides and whole carcasses than for the controls and, at 1·13 and 1·10 %, respectively, is lower than published results for other chilling systems (Cooper, 1972; Cutting, 1973). This saving in weight was retained after packing and storage and there is therefore a real economic gain to the meat producer. Overall profits of wholesale meat producers tend to be low, of the order of 2 % of turnover, so a weight saving of this magnitude can increase profits by up to 50 %. This saving would be negated if the system resulted in increased drip loss at a later stage in the distribution chain.

Three of the methods used to measure drip potential in the loin (retail display, core sample and inter fibre space) showed that the potential is increased in rapidly chilled sides, but not in rapidly chilled whole carcasses. The Grau–Hamm values did not show the same pattern as the other methods, perhaps because pressure is applied to the sample. While it may not be a suitable test in this case, it could be applicable to pressed meat products. A comparison between the temperature profiles through

the loin of rapidly chilled sides and whole carcasses (Fig. 1) provides a good indication of the source of the increased drip. The whole of the lean in the side is below the initial freezing point while little, if any, of the lean on the whole carcass has been frozen. An increase in drip due to freezing is a well documented phenomenon (Penny, 1974; Jul, 1982) and is almost certainly the cause in this case.

Although there were small differences in the appearance of loins derived from different treatments, all the values fell within a range normal for pork (MacDougall, 1970). Rapidly chilled loins were slightly darker and slightly less saturated than conventionally chilled controls and these results were confirmed by the fibre optic probe values which showed a decrease in light scattering. This result is to be expected since a rapid reduction in temperature tends to move pork away from a pale, soft and exudative type of material.

The instrumental texture results which show that rapid chilling can have a toughening effect on pork are scientifically interesting, and also indicate a possible commercial problem area. It has been reported in previous work (Bendall, 1975) that the phenomenon of cold shortening, well known in lamb and beef, could be produced experimentally in pork, but it was considered unlikely that rapid chilling could cause toughening under commercial conditions (Bendall, 1972). While no evidence of cold shortening in the form of reduced sarcomere lengths was found in this experiment, sarcomere samples were obtained from a very small area and Marsh & Leet (1966) showed that cold shortening can occur in localised zones which can easily be missed during sampling. The difference of 0·05 J between the rapid and conventionally chilled whole carcasses might be detected by a taste panel but may not be commercially important (Wood *et al.*, 1979).

If a faster rate of chilling leads to toughening in pork then the rapidly chilled side, in which the temperature falls more quickly, should be tougher than the rapidly chilled whole carcass. The reverse is shown in these results and the only hypothesis that we can advance to explain this reversal is that pre-rigor freezing in the case of the rapidly chilled side alleviated some of the toughening effect. If this hypothesis is true, it would explain why experiments on rapidly chilled pork, in which the samples have been frozen pre-rigor, have failed to show toughening (Dransfield, 1982).

This experiment has shown that a rapid chilling system for pork is feasible, can achieve a substantial saving in evaporative weight loss and

produces no problems in cutting, appearance and bacteriological quality. There are a number of possible drawbacks to such a system. Any major freezing of the lean during the process will produce a large increase in the drip from the retail cut, and the meat may also be tougher in parts. The first drawback does not present a major problem in that either whole carcasses could be used, or the process modified slightly to minimise freezing. An increase in toughness is more problematical, since the experiment has only shown its existence in a section of the carcass which has been cooled extremely rapidly. It might affect only thin sections of the carcass or very small carcasses and there is at present insufficient evidence to indicate if the degree of toughening is of any commercial significance.

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