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The Effect of Pre-slaughter Showering and Post-slaughter Rapid Chilling on Meat Quality in Intact Pork Sides

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ABSTRACT

Thirty pairs of Landrace or Large White pigs were used to determine the effects of pre- and post-slaughter cooling treatments on pork quality and yield. One animal from each pair was showered in cold water and after slaughter one side from each carcass was rapidly chilled and the other side was conventionally chilled. Two experiments were carried out in winter: they examined different times of exposure to cooling treatments; a further experiment was carried out in summer time.

Showering caused a reduction in the temperature of the deep loin at 40 min post mortem *($P < 0.01$). Rapid chilling caused a further reduction in carcass temperature and the rate of pH fall was lower ($P < 0.05$) in the rapidly chilled sides. There was a stong indication that showering in the winter time lowered drip loss in slices of* Longissimus dorsi *muscle ($P = 0.077$) whereas showering in the summer time was not effective. Shower water temperature may have been important in this regard. Showering did not lower drip loss in intact pork legs.*

Rapid chilling was not effective in lowering drip loss in either slices of Longissimus dorsi *or intact pork legs. Rapid chilling at $-20°C$ for 3 h without an air blast lowered evaporative chill losses in sides of pork by 27–29% ($P < 0.1$) compared to normal chilling. Reduced treatments gave reduced effects. Neither treatment had any significant effect on cooking loss or toughness in broiled slices of pork* Longissimus dorsi *muscle.*

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INTRODUCTION

Showering of pigs with water before slaughter has long been practised in the pigmeat industry as a means of cleaning pigs and cooling them before slaughter. However, information on the optimum method of showering and the practical benefits is scarce.

Immersion in cold water (0·5°C) for 30 min before slaughter gave a slower rate of pH fall *post mortem* and darker pork but meat water-binding capacity was not consistently improved (Sayre *et al.*, 1961; Kastenschmidt *et al.*, 1964). Showering with cool water (13°C) for 2 h lowered the temperature of the loin (Van Logestijn *et al.*, 1977) and reduced the incidence of both PSE and DFD in the pork carcasses (Sybesma & Van Logtestijn, 1966). Similar findings were reported by Smulders *et al.* (1983).

Showering reduced fighting in groups of pigs possibly due to the disappearance of sty odour (Van Putten *et al.*, 1983). Pigs did not have a preference for luke warm water over cold; however, this was not tested in winter.

Rapid chilling of pig carcasses using very cold air (about −25°C) immediately after carcass dressing is practised in many European slaughter plants. The main stimulus to the commercial practice is the saving in evaporative weight loss accompanying rapid carcass chilling. The effect of rapid chilling on pork quality may benefit pork colour and water-holding capacity but can adversely affect tenderness.

Increased toughness is associated with ultra-rapid chilling systems employing blasts at −30°C or below and may be sufficient to deter the commercial application of the process (James *et al.*, 1983; Brown & James, 1988). Toughening is greater in carcasses with a slow development of rigor mortis (Moller & Vestergaard, 1988); that is, in carcasses with high pH values but with normal final pH values. An investigation at Danish bacon factories using pre-chilling tunnels operating at about −25°C and average air speeds of 3 m/s showed that toughening occurred in certain factories but not in others (Barton-Gade *et al.*, 1987). The most likely explanation was irregular air blasts in some pre-chillers—a blast of 12–15 m/s immediately under the ventilators was the likely cause of cold toughening of the meat at one of the plants. Taylor and Dant (1971) found that drip loss from pork joints was halved by 'quick cooling' sides (in still air at 0°C) compared to conventional batch cooling. However, rapid chilling of pork sides at −30°C for 4 h at 1 m/s almost halved the evaporative weight loss but increased drip loss in meat cuts and toughness in the cooked meat (James *et al.*, (1983).

The aim of the experiment was to examine the effect of pre-slaughter showering and rapid carcass chilling, alone and in combination, on meat quality and yield.

MATERIALS AND METHODS

The design of the experiments was that of a split plot with a factorial arrangement of the treatments. The investigation consisted of three experiments and 30 experimental runs were completed in total, with two pigs used per run. The first experiment (winter experiment) consisted of twelve runs and was carried out in winter. The second (winter: reduced treatments) consisted of six runs and examined the effects of shorter cooling treatments than used in the first experiment. The third (summer experiment) consisted of 12 runs and was carried out in the summer; the treatments used were the same as in the first experiment.

Purebred Landrace were the preferred breed with purebred Large White being used if the former were not available. The animals were reared under uniform conditions at the Department of Agriculture Progeny Testing Station at Thorndale, Co. Dublin. The experimental pigs were taken, in pairs of either full brothers or half brothers, from the population of boars selected for culling each week. The usual reason for culling the boar pigs was failure to achieve the required breeding index score. The average live weight was 92 kg.

Transport group size varied from three to ten and overloading did not occur. The pigs were loaded and transported in a truck for 20 min to the experimental abattoir at Dunsinea. They were held indoors without further mixing until slaughter. The time in lairage averaged 2 h 29 min $\pm$ 19 min (winter experiment) 2 h 48 min $\pm$ 14 min (winter: reduced treatments) and 3 h 3 min $\pm$ 16 min (summer experiment).

Showering

About 1 h 40 min before slaughter one of each pair of pigs, selected at random, was showered using a cold water spray with an average flow rate of 26·7 litres/min/m^2 for two periods of 30 min with a 30 min break between each period. In the 'reduced treatments' experiment, showering was for two periods of 15 min with a 15 min break. The showered pigs often exhibited some initial agitation on commencement of the treatment but usually settled down after a few minutes, and remained standing throughout the shower. At the end of the treatment the showered animal was visibly pinker and much cleaner than the non-showered animal. Five to ten minutes after showering, the control and treated pigs were stunned using a hand-held low voltage (90 V, 50 cycles/s) stunner for 7 s before slaughter.

After bleeding, the core temperature was measured by inserting a clinical thermometer in the rectum for 2 min. The carcasses were scalded and dehaired at 62°C for approximately 4 min followed by singeing and

scraping. The carcasses were evicerated at 27–29 min *post mortem* and were split along the spinal column. The temperature of the *Longissimus dorsi* (LD) muscle was measured at 40 min *post mortem* at the level of the last rib.

Chilling

The hot weight of each side was measured and one side of each carcass was rapidly chilled for 3 h at −20°C and an air speed below 0·5 m/s (2 h at −20°C for the 'reduced treatments' experiment) and was then transferred to a normal chill operating at 3°C and between 85 and 90% relative humidity for a further 15 h (16 h in the 'reduced treatments' experiment). The other side of each carcass was chilled conventionally at 3°C for 18 h.

The temperature of each pork side was monitored at two points, at the centre of the LD muscle between the last thoracic vertebra and first lumbar vertebra at a depth of 3 cm, and in the centre of the gammon (entering adjacent to the aitch bone) at a depth of 6 cm. The air temperatures of the chill and freezer were also monitored. Temperature readings were automatically logged (Hewlett–Packard 85B microprocessor) at 15 min intervals throughout chilling.

The sides were removed from the chill at 19 h *post mortem*, reweighed (cold weight) and evaporative losses calculated. The leg was removed just above the head of the femur, the foot was removed at the knee and the middle was cut across at the point of the last rib. Two slices of LD muscle, each 2·5 cm thick, were taken at the level of the first and second lumbar vertebrae and trimmed while keeping the surrrounding facia of connective tissue on the LD muscle intact. The first slice was used to measure drip loss, the second to measure cooking loss and tenderness.

Probe measurements

pH was measured using an Orion Research Model 221 equipped with an Orion combined glass electrode (Cat. No. 91-03). Fibre optic probe (FOP) value was measured using the TBL Fibres (Leeds, UK) instrument. pH values were measured at the following locations and times *post mortem*: in the LD at the last rib at 45 min, 4 h (3 h in the 'reduced treatments' experiment) and 20 h; in the LD between the 5 and 6 last rib and in *M. semimembranosus* (SM) through the exposed muscle surface at a depth of 3 cm at 4 h (3 h in the 'reduced treatments' experiment) and 20 h *post mortem*. FOP values were measured at the same anatomical locations and time *post mortem* as pH measurements except FOP_1 which was measured at 35 min *post mortem*. Fresh incisions were used for each probe measurement to avoid

disrupted tissue. Subscripts 1, 3, 4 and 20 on FOP and pH refer to probe values measured within the first hour *post mortem* and at 3, 4 and 20 h *post mortem.*

Drip loss was measured by the method recommended by Honikel (1987). A weighed slice was suspended in a pre-weighed plastic bag (polyethylene, 400 gauge) and sealed. The sample was suspended for 48 h at 1°C. Drip was calculated as a percentage of the initial weight of the lean meat. Drip was also estimated on the pork leg. The leg was weighed and suspended on a hook through the rind at the knee hock. A pre-weighed bag was placed over the leg and sealed. After suspension for 48 h at 1°C the drip was expressed as a percentage of the initial weight of the leg.

Cooking loss and tenderness were measured using the method of Boccard *et al.* (1981). Cooking loss was measured in a 2·5 cm slice of LD and toughness was measured on strips of the cooked meat measuring $1 \times 1\,cm^2$ in cross-section (Instron model 1140 fitted with Volodkevich type jaws with a drive speed of 100 mm/min). The maximum shear force required to bite through each sample cross the direction of the meat fibres was recorded. Ten samples were measured per cooked slice and the mean shear value estimated and expressed in Newtons.

RESULTS

Using two cooling treatments in combination gave a 2×2 split plot design: showered, normal chill; showered, rapid chill; non-showered, normal chill; non-showered, rapid chill. The time required for the pork sides to cool to 10°C in these four treatment groups was, respectively, 8, 4, 8 and 4 h in the mid-loin and 13, 10, 13 and 10 h in the deep leg for both the winter and summer experiments. For the 'reduced treatments' experiment the corresponding times were 8, 5, 8 and 6 h in the mid-loin and 13, 11, 13 and 12 h in the deep leg.

Winter experiment

The ambient temperature in the lairage was $11{\cdot}6 \pm 1{\cdot}8$°C (SEM) and the shower water temperature was $8{\cdot}9 \pm 1{\cdot}9$°C. Showering did not lower the rectal temperature (Table 1) but reduced the temperature in the LD muscle by about 3·5°C. Loin muscle pH values were unaffected by showering (Table 2) but rapid chilling reduced the rate of pH fall, most noticeably at 4 h *post mortem.* Both showering and rapid chilling were individually effective in lowering the FOP_{20} values in the loin muscle. The combined treatment (showered and rapidly chilled) was most effective. The treatments used had

TABLE 1

Rectal Temperature at Slaughter (Top) and Temperature of *M. longissimus dorsi* at 40 min Post-slaughter (Below) for Showered and Non-showered Animals. Values are Mean and Pooled SEMs in °C

	Showered	*Non-showered*	*SEM*
Winter experiment ($n = 11$)	39·0	39·3	0·25
Winter (reduced treatments) ($n = 6$)	38·7	39·4	0·45
Summer experiment ($n = 12$)	39·5	39·5	0·35

	Showered (Normal chill)	*Showered (Rapid chill)*	*Non-showered (Normal chill)*	*Non-showered (Rapid chill)*	SEM
Winter experiment ($n = 7$)	$36·9^{a}$	$37·1^{a}$	$40·6^{b}$	$40·4^{b}$	0·28
Winter (reduced treatments) ($n = 6$)	37·8	38·0	40·1	40·2	0·42
Summer experiment ($n = 12$)	$38·1^{ax}$	$37·6^{ay}$	$39·9^{b}$	$40·0^{b}$	0·18

^{ab} Indicates significant difference at $P < 0·001$.
^{xy} Indicates significant difference at $P < 0·05$.

only minimal effect on pH and FOP values in the SM muscle (Table 2).

The chill loss from pork sides was reduced by 26·5% on average by rapid chilling (Table 2). This was shown by combining the data for the four treatment groups in Table 2 and comparing rapid versus normal chilling (1·50 versus 2·04, SEM = 0·12, $P = 0·006$).

The drip loss from slices of LD was reduced by showering (Table 2). This was confirmed by combining the data from the four treatment groups in Table 2 and comparing the showered versus non-showered treatments (2·15 versus 3·70, SEM = 0·56, $P = 0·077$). Rapid chilling caused a non-significant reduction in per cent drip loss in the LD slices, as is shown by comparing rapid versus normal chilling (2·72 versus 3·13, SEM = 0·19, $P = 0·156$). Drip loss from pork legs was lowered by rapid chilling, but only in the non-showered pigs (Table 2).

Neither showering nor rapid chilling had any significant effect on cooking loss or shear value in slices of LD muscle (Table 2).

Winter 'reduced treatments'

The ambient temperature in the lairage was 11·1 ± 2·2°C (SEM) and the shower water temperature was 8·5 ± 2·7°C. The rectal temperature was not reduced by showering (Table 1) but the LD muscle was reduced by about 2°C (37·9 versus 40·1°C, SEM = 0·41, 0·011, for showered versus non-showered pigs).

TABLE 2

Winter Experiment. Results are Shown for the Four Treatment Groups for pH and Fibre Optic Probe (FOP) Values in *M. longissimus dorsi* (LD) and *M. semimembranosus* (SM) and Percentage Mass Loss during Chilling (Chill Loss), Storage (Drip loss) and Cooking of Pork Sides or Cuts

	Showered normal chill	*Showered rapid chill*	*Non-showered normal chill*	*Non-showered rapid chill*	*SEM*
pH Values					
LD (last rib)					
pH_1 ($n = 12$)	6·20	6·28	6·17	6·20	0·08
pH_4 ($n = 12$)	$5·64^{p}$	$5·89^{q}$	5·65	5·73	0·09
pH_{20} ($n = 12$)	$5·49^{a}$	$5·60^{bx}$	$5·48^{ay}$	5·55	0·03
LD (5–6 last rib)					
pH_4 ($n = 12$)	$5·73^{p}$	$5·99^{qx}$	$5·71^{y}$	$5·87^{x}$	0·09
pH_{20} ($n = 12$)	$5·50^{x}$	$5·56^{yz}$	$5·51^{xy}$	$5·57^{z}$	0·02
SM					
pH_4 ($n = 12$)	5·78	5·82	$5·68^{p}$	$5·89^{a}$	0·07
pH_{20} ($n = 12$)	5·61	5·62	5·62	5·61	0·03
FOP values					
LD (last rib)					
FOP_1 ($n = 12$)	7^{x}	7^{x}	9	10^{y}	1·0
FOP_4 ($n = 11$)	16	13	20	20	3·8
FOP_{20} ($n = 12$)	28^{p}	18^{qx}	30^{pz}	25^{y}	2·2
LD (5–6 last rib)					
FOP_4 ($n = 11$)	16^{x}	13^{y}	21	19	3·2
FOP_{20} ($n = 12$)	28^{p}	20^{qx}	33^{p}	28^{y}	2·7
SM					
FOP_4 ($n = 11$)	22	21	25^{p}	18^{q}	2·5
FOP_{20} ($n = 12$)	27	28	29	30	1·7
Chill loss (%)					
Pork sides ($n = 8$)	$2·14^{p}$	$1·43^{qx}$	$1·93^{y}$	$1·56^{q}$	0·12
Drip loss (%)					
LD slices ($n = 12$)	$2·17^{x}$	$2·13^{x}$	$4·09^{y}$	3·32	0·60
Pork legs ($n = 12$)	0·14	0·15	$0·17^{x}$	$0·14^{y}$	0·01
Cooking loss (%)					
LD slices ($n = 7$)	22·4	23·5	25·1	23·1	1·10
Shear value (N)					
LD slices ($n = 7$)	73·0	73·4	72·5	77·9	5·16

^{ab} indicates significant difference at $P < 0·001$.
^{pq} indicates significant difference at $P < 0·01$.
^{xyz} indicates significant difference at $P < 0·05$.

The rate of pH fall in the LD muscle was reduced by showering and also by rapid chilling (Table 3); the sides that were showered and rapidly chilled had the slowest rate of pH fall. A similar effect was not significant in the SM.

FOP_{20} values in the LD muscle at the 5/6 last rib were lowered by showering (Table 3). This was shown by combining the data for the four

TABLE 3

Winter: Reduced Treatments. Measurements of Pork Quality and Yield for the Four Treatment Groups (See Table 2 for Details)

	Showered normal chill	*Showered rapid chill*	*Non-showered normal chill*	*Non-showered rapid chill*	*SEM*
pH Values					
LD (last rib)					
pH_1 ($n = 6$)	6·31	6·28	6·12	6·09	0·07
pH_3 ($n = 6$)	$5·87^{x}$	$6·05^{yp}$	$5·59^{zq}$	$5·76^{xz}$	0·07
pH_{20} ($n = 6$)	$5·60^{p}$	$5·66^{ap}$	$5·50^{q}$	$5·55^{bq}$	0·02
LD (5/6 last rib)					
pH_3 ($n = 6$)	$5·99^{px}$	$6·14^{ay}$	$5·68^{qb}$	$5·93^{p}$	0·07
pH_{20} ($n = 6$)	5·57	$5·62^{p}$	$5·50^{qx}$	$5·57^{y}$	0·02
SM					
pH_3 ($n = 6$)	5·88	5·92	$5·77^{x}$	$5·92^{y}$	0·11
pH_{20} ($n = 6$)	5·69	$5·75^{x}$	$5·64^{y}$	5·68	0·03
FOP values					
LD (last rib)					
FOP_1 ($n = 6$)	6	7	8	9	1·8
FOP_3 ($n = 6$)	11	11	22	19	3·8
FOP_{20} ($n = 6$)	24^{x}	18^{y}	26^{x}	25	2·5
LD (5/6 last rib)					
FOP_3 ($n = 6$)	10	9	21^{x}	17^{y}	5·0
FOP_{20} ($n = 6$)	26	21^{xp}	34^{q}	33^{y}	2·8
SM					
FOP_3 ($n = 6$)	19	18	21	19	2·7
FOP_{20} ($n = 6$)	27	27	29	27	2·4
Chill loss (%)					
Pork sides ($n = 6$)	$2·14^{pa}$	$1·88^{q}$	$2·03^{a}$	$1·60^{rb}$	0·06
Drip loss (%)					
LD slices ($n = 6$)	2·85	3·41	3·93	3·72	0·50
Pork legs ($n = 6$)	0·13	0·13	0·16	0·14	0·01
Cooking loss (%)					
LD slices ($n = 5$)	$22·4^{x}$	$22·4^{x}$	$26·0^{y}$	23·2	0·95
Shear value (N)					
LD slices ($n = 5$)	74·1	73·9	64·7	65·1	3·08

^{ab} As for Table 2.
^{pqr} Indicates significant difference at $P < 0·01$.
^{xyz} As for Table 2.

treatment groups in Table 3 and comparing showered versus non-showered (23·8 versus 33·3, SEM = 2·14, $P = 0{\cdot}016$). Rapid chilling did not consistently lower FOP_{20} values in the LD muscle (Table 3). In the SM muscle there was no significant effect of treatment on FOP values.

Evaporative weight loss from pork sides was reduced by 16·7% on average by rapid chilling (Table 3). This can be seen by combining the four treatment groups in Table 3 and comparing rapid chill versus normal chill (1·74 versus 2·09, SEM 0·04, $P = 0{\cdot}001$). Drip loss from LD slices and pork legs was not significantly reduced by any of the treatments (Table 3). There was no consistent effect of showering and/or rapid chilling on cooking loss or shear value in LD slices.

Summer experiment

The ambient temperature in the lairage was $19{\cdot}5 \pm 2{\cdot}0$°C (SEM) and the shower water temperature was $15{\cdot}8 \pm 1{\cdot}6$°C. The rectal temperature was unaffected by showering (Table 1) but LD muscle temperature was lowered by about 2°C. This can be seen by combining the four treatment groups in Table 1 and comparing showered versus non-showered (37·85 versus 39·96°C, SEM = 0·15, $P < 0{\cdot}001$).

Showering did not slow the rate of pH fall in loin or leg muscles (Table 4) whereas rapid chilling did in both muscles. Similarly, showering did not lower FOP values in the loin or leg muscles but rapid chilling did (Table 4). This effect is shown by combining the four treatment groups in Table 4 and comparing rapid chill versus normal chill. This comparison gave LD (last rib) FOP_4 values of 22·3 versus 26·4 (SEM = 1·24, $P < 0{\cdot}01$) and FOP_{20} values of 24·0 versus 27·5 (SEM = 1·05, $P < 0{\cdot}05$). The same comparison gave LD (5/6 last rib) FOP_{20} values of 27·5 versus 30·1 (SEM = 0·84, $P < 0{\cdot}05$), SM FOP_4 values of 26·0 versus 32·8 (SEM = 1·11, $P < 0{\cdot}001$) and FOP_{20} values of 32·5 versus 36·2 (SEM = 1·13, $P < 0{\cdot}05$).

Chill losses in pork sides were reduced by 29·2% on average by rapid chilling (Table 4). Drip loss in LD slices was not affected by treatment (Table 4) but rapid chilling lowered the percentage drip loss in pork legs. This is shown by combining the four treatments in Table 4 and comparing rapid chill versus normal chill (0·24 versus 0·29, SEM = 0·01, $P < 0{\cdot}01$).

Neither showering nor rapid chilling had a consistent effect on cooking loss or shear values (Table 4). This was confirmed by examining the combined data for these two variables. However, showered normal chilled, were significantly tenderer than non-showered rapid chilled pigs.

The correlations between objective measurements of pork quality (pH and fibre optic prove values) and drip losses in loin slices and intact pork legs are given in Table 5 using data from the winter and the summer experiment

TABLE 4
Summer Experiment. Measurements of Pork Quality and Yield for the Four Treatment Groups (See Table 2 for Details)

	Showered normal chill	*Showered rapid chill*	*Non-showered normal chill*	*Non-showered rapid chill*	*SEM*
pH Values					
LD (last rib)					
pH_1 ($n = 12$)	6·06	6·11	6·18	6·12	0·05
pH_4 ($n = 12$)	$5·43^{apx}$	$5·62^{b}$	$5·65^{y}$	$5·70^{q}$	0·06
pH_{20} ($n = 12$)	$5·46^{x}$	$5·51^{y}$	5·49	5·52	0·03
LD (5/6 last rib)					
pH_4 ($n = 12$)	$5·59^{x}$	$5·76^{y}$	$5·66^{p}$	$5·87^{yq}$	0·07
pH_{20} ($n = 12$)	$5·48^{w}$	$5·54^{x}$	$5·50^{wyx}$	$5·55^{wxz}$	0·03
SM					
pH_4 ($n = 12$)	$5·59^{p}$	5·68	$5·63^{a}$	$5·84^{qb}$	0·06
pH_{20} ($n = 12$)	5·55	5·54	5·57	5·53	0·03
FOP values					
LD (last rib)					
FOP_1 ($n = 11$)	6	7	6	7	1·0
FOP_4 ($n = 11$)	32^{a}	21^{b}	21	23	3·8
FOP_{20} ($n = 12$)	30^{x}	24^{y}	25	24^{y}	1·9
LD (5/6 last rib)					
FOP_4 ($n = 11$)	26^{x}	19^{y}	18	20	2·9
FOP_{20} ($n = 12$)	30	29	30	26	1·9
SM					
FOP_4 ($n = 11$)	33^{x}	30	33^{a}	22^{by}	3·3
FOP_{20} ($n = 12$)	37^{x}	32^{y}	36	33	2·2
Chill loss (%)					
Pork sides ($n = 12$)	$1·88^{a}$	$1·38^{b}$	$1·96^{a}$	$1·33^{b}$	0·06
Drip loss (%)					
LD slices ($n = 12$)	4·71	4·34	4·15	3·92	0·58
Pork legs ($n = 12$)	$0·30^{x}$	0·25	$0·28^{p}$	$0·22^{yq}$	0·02
Cooking loss (%)					
LD slices ($n = 11$)	23·8	23·7	$25·3^{x}$	$23·0^{y}$	0·95
Shear value (N)					
LD slices ($n = 10$)	$59·8^{x}$	62·9	67·7	$70·8^{y}$	3·24

^{ab} As for Table 2.
^{pq} As for Table 2.
^{xyz} As for Table 2.

TABLE 5

Correlation Coefficients (r) between Drip Loss and pH or FOP Values in Pork Carcasses in the winter and summer Experiments (Combined). Probe Measurements were made in *M. longissimus dorsi* at the Levels of the Last Rib and the 5/6 Last Rib, and in *M. semimembranosus*. Drip was Measured in a Slice of *M. longissimus dorsi* Taken at the First Lumbar Vertebra and also in the Intact Leg. The Values of the Correlation Coefficient for the Different Levels of Significance are: $r = 0{\cdot}21$, $P < 0{\cdot}05$; $r = 0{\cdot}28$, $P < 0{\cdot}01$; $r = 0{\cdot}35$, $P < 0{\cdot}001$ ($N = 83$)

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*
(1) FOP_1 LD Last Rib	1·00															
(2) pH_1 LD Last Rib	−0·38	1·00														
(3) pH_4 LD Last Rib	−0·08	0·74	1·00													
(4) pH_4 5/6 Last Rib	−0·07	0·68	0·89	1·00												
(5) pH_4 SM	0·01	0·35	0·50	0·52	1·00											
(6) FOP_4 LD Last Rib	0·36	−0·82	−0·68	−0·63	−0·29	1·00										
(7) FOP_4 5/6 Last Rib	0·43	−0·78	−0·65	−0·70	−0·34	0·82	1·00									
(8) FOP_4 SM	0·03	−0·42	−0·49	−0·47	−0·75	0·38	0·40	1·00								
(9) pH_{20} LD Last Rib	0·06	0·46	0·56	0·53	0·37	−0·42	−0·46	−0·30	1·00							
(10) pH_{20} 5/6 Last Rib	0·09	0·33	0·45	0·45	0·33	−0·34	−0·41	−0·22	0·80	1·00						
(11) pH_{20} SM	0·17	0·14	0·28	0·33	0·42	−0·16	−0·19	−0·21	0·50	0·38	1·00					
(12) FOP_{20} LD Last Rib	0·28	−0·64	−0·60	−0·59	−0·29	0·72	0·69	0·24	−0·63	−0·56	−0·28	1·00				
(13) FOP_{20} 5/6 Last Rib	0·33	−0·59	−0·51	−0·52	−0·24	0·62	0·65	0·26	−0·61	−0·64	−0·29	0·79	1·00			
(14) FOP_{20} SM	0·04	−0·31	−0·30	−0·31	−0·50	0·41	0·38	0·71	−0·37	−0·30	−0·35	0·36	0·38	1·00		
(15) % Drip Loss LD	0·19	−0·65	−0·66	−0·58	−0·42	0·66	0·62	0·43	−0·47	−0·39	−0·25	0·59	0·54	0·33	1·00	
(16) % Drip Loss Ham	−0·07	−0·29	−0·36	−0·31	−0·49	0·32	0·31	0·69	−0·37	−0·34	−0·35	0·27	0·30	0·68	0·43	1·00

combined. The highest correlations with drip loss in LD slices were obtained for measurements made at the level of the last rib, adjacent to the location of the drip measurement; these were, for pH_1 ($r = -0{\cdot}65$, $P < 0{\cdot}001$), pH_4 ($r = -0{\cdot}66$, $P < 0{\cdot}001$), FOP_4 ($r = 0{\cdot}66$, $P < 0{\cdot}001$) and FOP_{20} ($r = -0{\cdot}59$, $P < 0{\cdot}001$).

Measurements of pH and FOP in the loin were only weakly correlated with drip loss in the leg. The best correlations with drip in pork legs were for FOP_4 and FOP_{20} measured in the SM muscle with r values of 0·69 ($P < 0{\cdot}001$) and 0·68 ($P < 0{\cdot}001$), respectively (Table 5).

The temperature of the loin at 40 min *post mortem* was significantly correlated with drip in LD slices ($r = 0{\cdot}28$, $P < 0{\cdot}05$, $n = 55$). Cooking losses and shear values were significantly correlated with drip in LD slices with r values of 0·47 ($P < 0{\cdot}001$, $n = 55$) and $-0{\cdot}44$ ($P < 0{\cdot}001$, $n = 55$), respectively.

DISCUSSION

The experiments confirmed that early exposure to very cold air (−20°C) gave a substantial saving in evaporative weight loss during chilling of pork sides and the savings were proportional to time in rapid chill, increasing from 17% for the 2 h rapid chilling treatment to 27–29% for the 3 h treatment. There was no additional benefit due to pre-slaughter showering. Greater savings in chill loss were reported by James *et al.* (1983) and Gigiel and James (1984) using air at −30 to −40°C and 1 m/s to chill sides in a 4 h cycle. However, the potential weight gain was lost by evaporation during the subsequent overnight holding unless the carcass was jointed and packaged. The present treatment achieved consistent savings in overnight chill loss by holding at −20°C at less than 0·5 m/s for 2 or 3 h before conventional chilling. The benefit in reducing overnight chill loss in the present experiment may be associated with the different temperature and air speed used here compared with James *et al.* (1983) and Gigiel and James (1984). In particular, any benefit that may result from reducing the air speed deserves further investigation. In the present experiment air speed was very low because, with only two sides in the −20° chill at any one time, rapid air circulation was unnecessary to achieve a substantial increase in the rate of cooling.

Increased toughness in the cooked meat (James *et al.*, 1983; Gigiel & James, 1984; Barton-Gade *et al.*, 1987) and higher drip loss (James *et al.*, 1983) may accompany very rapid chilling of pork sides. There was no toughening of the LD muscle as a result of chilling at −20°C without an air blast. The possibility of increased toughening of the exposed muscles in the shoulder and neck region was not examined. In no situation did rapid chilling increase drip in LD slices or intact pork legs.

The main muscle system responsible for water binding, the myofibrils (Hamm, 1960), shows contrasting responses to cooling at different temperatures. There is an early positive effect of cooling to below 30°C on the water-binding capacity of muscle. This is due to reduced muscle protein denaturation (McLoughlin & Goldspink, 1963; Offer & Trinick, 1983). Further rapid cooling of the muscle may have a negative effect on water binding because of cold induced shortening of the sarcomere and the associated movement of cell water. Honikel (1987) found a linear relationship between final sarcomere length and drip loss of pork muscles, with drip loss doubling as sarcomere length shortened to half of its original value. To achieve an overall reduction in drip loss from meat cuts, cooling systems must exploit the early beneficial effect and avoid the later detrimental response.

The cooling treatments used were effective in reducing drip loss in pork cuts in the winter experiment, and in loin slices the benefits were sufficient to be economically worthwhile (a decrease from 4% drip in the controls to 2% in the showered and rapidly chilled group). A similar trend was apparent in the 'reduced treatment' experiment, while in the summer experiment drip loss in loin slices was unaffected by treatment.

In the winter experiment the main factor reducing drip in loin slices was showering. The results indicate that showering was less effective in the summer experiment. A possible explanation may be the lower temperature of the shower water in the winter experiment. Consequently, the LD muscle temperature at 40 min *post mortem* was significantly lower in the winter ($37{\cdot}0 \pm 0{\cdot}32$°C) compared to the summer experiment ($37{\cdot}9 \pm 0{\cdot}24$°C, $P < 0{\cdot}05$).

Although showering was effective in lowering the temperature of the LD muscle in all three experiments, it had no effect on rectal temperature. The normal rectal temperature in the pig is 39·2°C with a range of 38·7 to 39·8°C (Andersson, 1984). The values obtained for showered and non-showered pigs in the three experiments fell within the normal range and on no occasion were significant differences observed between the two groups. This result suggests that the cold treatment was not severe enough to overcome the homeothermic regulatory mechanism of the pig. Observations of pigs during and after showering revealed no obvious signs of stress. Shivering was not apparent and the animals behaved normally while being walked from the shower to the stunning pen. Body temperature may have been maintained during showering by a combination of physical regulation (insulation) and non-shivering thermogenesis. The latter effect is predominantly due to the calorigenic effect of adrenalin and non-adrenalin, which are both released in increased amounts by the cold (Andersson, 1984).

The cooling treatments were successful in slowing down the rate of pH fall

in all three experiments and the main effect was associated with the rapid chilling treatment rather than the pre-slaughter showering. Lactic acid production in post-mortem muscle is a temperature-dependent process (Cassens & Newbold, 1966). Slower acidification associated with faster cooling would be expected to reduce the extent of muscle protein denaturation, as noted above. The lower FOP values associated with the cooling treatments indicate reduced light scattering, confirming reduced protein denaturation. The improvement in FOP values was small, but nonetheless important, in view of the industry's strong aversion to pale pork.

The relationships between drip loss and fibre optic probe or pH values in pork sides were examined by Tarrant and Long (1986) using these data. The usefulness of FOP for predicting drip loss increased with time *post mortem* while the usefulness of pH decreased. FOP at 35 min *post mortem* was not significantly related to drip loss, whereas the pH_1 value was. At 4 h *post mortem* both FOP and pH values were equally useful for predicting drip loss, showing moderately high correlations. At 20 h *post mortem* the FOP value was superior to the pH value. In the loin muscle, predictability of drip loss using probe measurements increased with the proximity of probe and drip measurements to each other.

CONCLUSIONS

(1) Showering of pigs with cold water reduced the temperature of the loin muscle at 40 min *post mortem* and, in certain circumstances, also reduced drip loss in pork cuts.
(2) Holding pork sides in air at $-20°C$ for 2 or 3 h before normal chilling at $+3°C$ significantly lowered evaporative weight loss in sides, reduced the rate of pH fall in loin and leg muscles and lowered drip loss in intact pork legs.
(3) The combination of showering and rapid chilling was more effective than either treatment on its own in the winter experiment in terms of reducing drip in LD slices, slowing the rate of pH fall and lowering FOP values in the LD muscle.

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