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Factors affecting the composition and amount of 'white exudate' from cooked bacon

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Abstract

Bacon sometimes produces a white, unsightly fluid that exudes from the surfaces during cooking —a phenomenon that has resulted in frequent consumer complaints. The quantity of exudate from bacon of known history was assessed subjectively, by ranking photographs following 'dry-frying', and objectively, by collecting exudate in an ice cooled tray after grilling. Trained assessors ranked samples in order of visible exudate as follows: dry cured < Wiltshire cured < rapid cured bacon. Bacon that had been tempered prior to slicing produced more exudate that untempered bacon. Wiltshire cured bacon — made over a wide range of brine injection gains (9, 13 and 18%) and brine NaCl levels (6, 16 and 26%) and assessed 1, 2, 4 or 6 weeks after production — all produced some exudate, the amount of fluid released being positively related to bacon salt content. The highest losses were at 6 weeks. Cooked pork, sliced to 4 mm, also produced exudate, similar in composition and amount to that from bacon. The exudate contained 76–88% water, 80–130 mg/g protein and 2–6% NaCl, depending on the type of bacon and method of cooking. SDS–PAGE patterns of bacon exudate were similar to those of pork drip, suggesting it consists mainly of sarcoplasmic proteins. Traces of actin and myosin were detected but in much smaller quantities than expected.

Keywords: Bacon; Dry cured; Rapid cured; White exudate; Wiltshire cured

1. Introduction

Though bacon remains a popular product, one of the frequent consumer complaints concerns the unsightly, white liquid that sometimes exudes from it during cooking. On further cooking, this browns and darkens and eventually becomes burnt on the base of the pan or grill. There is no evidence that this affects eating quality, nor that it is necessarily indicative of an inferior product. A similar phenomenon occurs during the cooking of pork, but in bacon the quantity of exudate is often considered excessive and is more obvious because of the contrast in colour. Bacon that produces less exudate, or none at all, would have a distinct marketing advantage.

Little is known about the origin or composition of the exudate, though it is usually associated with 'modern' bacon rather than that produced by more traditional methods. Most modern bacons are produced relatively quickly compared with traditional dry curing or Wiltshire-style bacon which requires several weeks to achieve a stable product. Processing time has been reduced by using smaller, boneless pieces rather than whole sides and by the advent of multi-needle injectors which can achieve a more rapid distribution of the curing ingredients (Hughes, 1988). Most modern bacon has a higher moisture content than formerly, a lower nitrite (for legislative and health reasons; Hughes, 1988) and lower salt (for taste reasons), though the salt content can't be reduced below about 1.5% for safety reasons (Varnam & Sutherland, 1995). It is also tempered prior to high-speed slicing, either by freezing and bringing the temperature back up to the required target temperature or by reducing the temperature from above 0°C to that required (James & Bailey, 1987).

Obtaining a fundamental understanding of its origin and composition will facilitate the control and manipulation of the amount of exudate produced during

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cooking. It was the purpose of this paper, therefore, to determine the composition of the exudate using sodium dodecyl sulphate polyacrylamide gel electrophoresis (SDS–PAGE) and compare it with that of the drip from pork. Methodology was also developed to assess the quantity of exudate — subjectively and objectively — from bacon of known history (differing in the curing procedure and method of tempering) and fresh pork.

2. Materials and methods

Four experiments were carried out, investigating the effects of bacon type, injection level, salt concentration, maturation time and tempering on the amount of exudate produced during cooking. The amount of exudate was assessed qualitatively by photographing samples after dry-frying (i.e. frying without oil) and ranking these subjectively. The amount of exudate was also measured quantitatively by collecting the fluid released during grilling over an ice-cooled tray. The protein composition of the exudate was analysed using SDS–PAGE.

Pigs were selected 24 h post-slaughter at a local bacon processing plant, where the Wiltshire-style and rapid cured bacons were produced. Fibre optic probe measurements were made and ultimate pH was measured to ensure none of the pigs used exhibited PSE or DFD characteristics.

In all cases, the *longissimus thoracis et lumborum* (LTL) muscle was used for the assessment and analyses.

2.1. Visual assessment and composition of exudate (Experiment 1)

Pork, Wiltshire cured and rapid cured bacon were produced at a local bacon processing plant, as described later. In addition, four packs of typical dry cured bacon (with no added water) were purchased from a local supermarket. All pork and bacon samples were photographed under standard conditions after dry-frying. Twenty photographs of cooked bacon (four replicates each of Wiltshire and rapid cured bacon, tempered and untempered, plus 4 replicates of dry cured bacon) were ranked (BSI, 1989) by individual assessors in order of visible exudate. All assessments took place in a purpose built sensory suite, illuminated by artificial daylight.

Visible exudate was removed from the pork and bacon samples after cooking for a standard time. Four samples of exudate from cooked pork and cooked bacon were obtained and held chilled on ice before being analysed by SDS–PAGE. Dry cured bacon produced only low amounts of exudate and these were combined to give a single sample for analysis. In order to compare the composition of bacon exudate with that of drip from pork, drip from raw pork (four samples) was also analysed by SDS–PAGE, along with four 'coagulated drip' samples that had been heated in a test tube, for 10 min in a waterbath at 80°C, and then filtered.

2.1.1. Pork loin and Wiltshire cured bacon

Pork loin and Wiltshire cured bacon were obtained from four bacon weight pigs. Each pig was split on the day after slaughter and one side used for bacon and the other for pork loins. After splitting, uncured loins were transported under refrigeration to Langford, for vacuum packed storage at 1°C. Drip was measured on duplicate 25 mm thick slices of LTL removed from the loin at 1 day post-slaughter.

The opposite sides of the four pigs were put through a traditional factory Wiltshire curing process, multi-needle injected to 11% gain, before immersion and maturation. Salt levels in the injection brine and immersion brine were not measured on this occasion but would be similar to those reported in Experiment 2. After 9 days processing, loin samples of bacon corresponding to the pork loin samples were removed and transported to Langford for storage at 1°C.

2.1.2. Rapid cured bacon

Loins from a further four bacon weight pigs (one side only) were boned out and multi-needle injected to 17% gain, before vacuum packing. Salt level in the injection brine was not measured on this occasion but would be similar to that reported in Experiment 2. The bacons were transported to Langford for storage at 1°C.

Half of the pork loins and bacon were tempered to −7°C (blast frozen at −25°C for 4 h and equilibrated overnight at −7°C) and then sliced to 4 mm thickness, whilst the remainder was sliced without tempering.

2.2. Effect of bacon type and tempering method (Experiment 2)

Wiltshire-style and rapid cured bacon were produced from bacon weight pigs (60–70 kg cold weight, P_2 fat depth of 12 mm max.) at a local bacon processor, under controlled conditions. Two pigs were used on each of four occasions. Each pig was split on the day after slaughter and one side Wiltshire cured and the other rapid cured.

After tempering and slicing by one of four treatments (see later), the bacon was dry-fried as previously and photographed. Eight photographs per pig (two bacon types×four tempering treatments) were ranked by individual assessors in order of visible exudate.

Two samples of exudate from each treatment and cure (two pigs from one experimental run only) were stored frozen before analysis by SDS–PAGE.

Bacon was also grilled and the released fluid collected on an ice-cooled tray, as described later.

2.2.1. Wiltshire bacon

Sides were multi-needle injected to a target weight gain of 11% (actual 10.9±1.74) and immersed for 3 days before maturing until 10 days from slaughter. The NaCl concentration in the injection and immersion brines were 19.9 and 24.3%, respectively. The final yield of bacon (% over raw weight) was 106.6% (±1.71).

2.2.2. Rapid cured

Backs were removed, boned out and the short back multi-needle injected to a target weight gain of 18% (actual 18.7±1.2%). The injection brine was the same as that for the Wiltshire bacon but diluted to offset the higher injection level, to achieve a target NaCl in the bacon of 3 to 3.5%, as in the Wiltshire sides. NaCl concentration in the injection brine was 13.5%. After injection the backs were vacuum packed and held at 5°C for 2 days, after which they were removed and drained overnight before being sub-divided for tempering and slicing.

2.2.3. Tempering and slicing

Each back was divided into four sections and subjected to one of four treatments before slicing to 4 mm. Treatment 1 was carried out at Langford using a standard bacon slicer whilst treatments 2, 3 and 4 were carried out at a local factory specialising in high speed slicing of bacon. All sliced bacon was vacuum packed (250-g packs) and stored at 1°C for 4 days before assessment.

Treatment 1	no tempering, no forming (control)
Treatment 2	tempered to −7°C and formed
Treatment 3	blast frozen at −20°C, followed by equilibration to −7°C and formed
Treatment 4	blast frozen at −20°C, followed by equilibration to −7°C, not formed.

2.3. Effect of injection level, salt concentration and maturation time (Experiment 3)

Pigs with three levels of backfat thickness were selected (<8 mm, 11 mm, and >13 mm) and processed as three batches of six pigs giving a total of 18 pigs. The loins from all pig sides were divided in half so that four loin portions were obtained from each pig, with an anterior and posterior portion from both left and right sides.

Bacon was prepared using each combination of three injection levels (9, 13 and 18%) and three NaCl concentrations (6, 16 and 26%), giving a total of nine treatments (T1 to T9), as shown below.

		NaCl concentration in brine (%)		
		26	16	6
Injection level (%)	9	T1	T2	T3
	13	T4	T5	T6
	18	T7	T8	T9

Loin portions were allocated in such a way that each treatment was applied to every loin position at least once during the trial and there were eight replicates per treatment.

After multi-needle injection, the half loins were drained for 5 min before weighing to give the pumping gain, then vacuum packed. The loin sections were held for 1 week at 4°C to simulate a relatively slow curing process, before being put into further storage at 1°C for up to 6 weeks from injection.

At 1, 2, 4 and 6 weeks from injection, the vacuum packs were opened and slices (4-mm thick) cut from each half loin section, before re-vacuum packing the remainder of the loin section for further storage. This progressive sampling was designed to indicate the effect of extended maturation periods. All the bacon was sliced at 1°C at Langford, with no tempering treatment.

At each assessment time, the LTL portions of 10 slices of bacon from each of the four treatments were grilled, as described later, to determine 'exudate' loss.

2.4. Exudate loss from pork and bacon (Experiment 4)

Four bacon weight pigs were selected 1 day after slaughter and split. The left sides were Wiltshire cured by injection, immersion and maturation. The right sides were cut to give a short back section of fresh pork which was vacuum packed and transported to Langford for storage at 1°C.

The pork and bacon backs were sampled at 13 days post-slaughter. A 5 cm portion was removed from each end of the back, before cutting 10 4-mm thick slices from each end, giving anterior and posterior samples. Extra slices were cut to provide samples for analysis of salt and moisture. Trimmed portions of LTL were grilled the following day and the amount of 'exudate' measured.

2.5. General materials and methods

2.5.1. Dry-frying

Slices of trimmed LTL were fried in a Teflon-coated pan placed on a Scholtes T65 cooking hob on heat setting no. 8 (range 1–12) for 4 min without turning. The LTL slices were removed from the pan and all visible exudate collected for analysis. In some cases, the white exudate which formed on the slices during cooking could be totally recovered but, in most cases, the amount of exudate was so great that it overflowed on to the hot surface of the pan where it dried and could not be recovered.

Slices were weighed before and after cooking, exudate having been removed from the surfaces, to give the total weight loss. Slices were photographed in the pan after cooking, under standard conditions. These were ranked using trained assessors whose colour vision had been

assessed using the Ishihara test (Anon, 1967). All assessors had normal colour vision.

2.5.2. Grilling

Slices of LTL, trimmed of all fat, were placed on a mesh grill supported on a metal tray which was set on a bed of ice. The bacon was grilled for 4 min using a Falcon grill (Gwyndd Foundries, Wales) on medium heat at shelf position 5. Fluid which fell from the bacon during cooking was collected in the cooled tray. After cooking, any exudate or liquor on the bacon slices was scraped off and added to that in the cooled tray. The recovered fluid was transferred from the tray to a test tube which was heated in a waterbath at 80°C for 10 min, to ensure that coagulation was complete. The coagulate and free liquid was then cooled for 30 min before filtering through a Whatman filter paper (Grade 54 hardened). The coagulate trapped on the filter paper was weighed. The following measurements were made.

Total weight loss: the difference between the weight of bacon before and after cooking, expressed as a percentage of the initial bacon weight.

Recoverable fluid: the total weight of fluid released during cooking and collected in the pre-cooled tray, expressed as a percentage of the initial weight of bacon.

Evaporative loss: determined as total weight loss less the recoverable fluid, expressed as a percentage of the initial weight of bacon.

Exudate: the weight of coagulate remaining on the filter paper, expressed as a percentage of the initial weight of bacon.

Exudate in cooking loss: the weight of exudate expressed as a percentage of the weight of recoverable fluid.

2.5.3. Identification of proteins by SDS–PAGE

SDS–PAGE was used to analyse the composition of raw drip, coagulated drip, exudate from cooked pork and the exudate from cooked bacon. Raw drip was diluted using 90.8 ml of 1% (w/v) sodium dodecyl sulphate (SDS) to 0.2 ml drip. Aliquots were frozen for subsequent analysis by SDS–PAGE. To 0.2 g (±0.2 g) each of the coagulated drip and exudate samples was added 8.8ml deionised water and the sample homogenised in a laboratory homogeniser (Silverson Machines, Chesham, UK). Then 1 ml of 10% (w/v) SDS was added and the sample heated at 60°C for 30 min. Aliquots of these samples were frozen for subsequent analysis. Duplicate extractions were performed on each sample.

2-Mercaptoethanol was added to frozen samples to bring the concentration to 1% 2-mercaptoethanol. The sample was heated at 60°C for 15 minutes and then an equal volume of a solution of 10% (w/v) Ficoll (Type 400, Sigma Chemical Co. Ltd., Poole, Dorset, UK) and 0.02% (w/v) bromophenol blue was added. Electrophoresis was performed on gels containing 12.25% (w/v) acrylamide, 0.15% (w/v) *N*,*N*′-methylenebisacrylamide (similar to Young & Davey, 1981) using a discontinuous buffer system (Laemmli, 1970) and omitting the stacking gel. Gels were stained overnight in Serva Blue G and destained in the acetic acid and methanol solutions described by Weber and Osborn (1969). The amount of each sample loaded was 30 μg protein calculated from UV protein assays. Protein bands were tentatively identified by comparison with mobilities of myofibrillar and sarcoplasmic proteins run on similar gels.

2.5.4. Fibre optic probe (FOP) measurements

Fibre optic probe (FOP) measurements were made using a FOP Probe (Premier Electronics, Leeds, UK), calibrated daily. A reading above 50 was used to indicate the PSE condition (MacDougall, 1984).

2.5.5. pH

Ultimate pH (pH_u) was measured on homogenates of 1 g of meat in 10-ml distilled water, using a combined glass electrode.

2.5.6. Drip loss

A 25-mm thick slice of pork LTL was weighed, placed in a netting bag, suspended inside an inflated polythene bag at 1°C for 24 h, dried with an absorbent paper towel and then re-weighed. Drip loss was expressed as a percentage of the original weight.

2.5.7. Moisture content

Samples were dried to constant weight by freeze drying for 72 h.

2.5.8. Salt content

Chloride ions were precipitated by the addition of an excess of standard $AgNO_3$ in acid solution and heating. Subsequent addition of potassium permanganate oxidised the organic matter and the excess permangante was reduced by addition of glucose. The excess $AgNO_3$ was titrated with potassium thiocyante.

2.5.9. Total protein

Total protein was determined after hydrolysis of wet exudate with NaOH by the Lowry method, using $CaCO_3$/potassium tartrate, alkaline $CuSO_4$ and Folin Ciocalteu reagent. Absorbencies were read at 600 nm, using bovine serum albumin as standard.

2.6. Statistical analysis

The data were analysed by factorial analysis of variance using the appropriate number of factors. An

unpaired *t*-test was used to analyse the data in Experiment 4. Data derived from ranks were analysed using the Friedman test (Friedman, 1937) for demonstrating recognition by assessors of differences between samples. Two samples were significantly different when their ranking sums were greater than $1.96 \times \{[JxPx(P+1)]/6\}^{0.5}$ where J is the number of panellists and P is the number of products.

3. Results

3.1. Visual assessment and composition of exudate (Experiment 1)

The bacons were produced from pigs with a mean pH_u of 5.3 (range 5.29–5.33) and a mean FOP value of 29 (range 25–36), indicating that none of the pigs exhibited the PSE condition. The mean NaCl content of the LTL was 3.1, 3.8 and 2.7% for the Wiltshire, rapid cure and dry cured bacon, respectively, with mean moisture contents of 72.5, 74.3 and 71.2%, and pHs of 5.55, 5.64 and 5.64, respectively.

Table 1 shows the order of ranking by the 12 assessors, following dry-frying. This clearly demonstrates differences between bacon types. Least exudate was produced by the dry cured bacon and most by the rapid cured bacon, the Wiltshire-style bacon being intermediate. This is what might be expected given the higher injection level (18% compared with 11% for the Wiltshire cured bacon), moisture content (74.3, 72.5 and 71.2% for rapid, Wiltshire and dry cured bacons, respectively) and cooking loss (39.2, 31.1 and 34.5% for rapid, Wiltshire and dry cured bacons, respectively) of the rapid cured bacon.

Table 1
Influence of bacon type (rapid, dry or Wiltshire cure) and tempering on visual assessment of exudate from bacon LTL cooked by dry-frying (Experiment 1)[a]

Panel Code	Rank sum	Banding (no difference)	Meat samples
521	12		raw
488	27		dry cured
774	34		dry cured
198	54		dry cured
856	59		Wiltshire, untempered
637	73		dry cured
223	79		Wiltshire, untempered
755	96		Wiltshire, untempered
817	107		Wiltshire, untempered
381	128		Wiltshire, tempered
331	151		rapid, untempered
519	155		rapid, untempered
454	168		rapid, untempered
274	169		Wiltshire, tempered
676	175		rapid, tempered
299	183		Wiltshire, tempered
964	195		rapid, untempered
818	206		rapid, tempered
142	224		Wiltshire, tempered
393	228		rapid, tempered
346	249		rapid, tempered

[a] Two samples are different at the 0.05 level of significance if the difference in their ranking sums is greater than 59.6.

There was also a clear effect of tempering — samples that had been tempered before slicing losing more exudate than untempered samples.

Moisture, NaCl and protein contents for drip, coagulate and bacon exudate are shown in Table 2. Pork drip had a protein content of 238 mg/g, with a mean drip loss of 5.0%, within the range expected (Savage, Warriss, & Jolley, 1990). The protein content of all other samples was lower, exudate from Wiltshire cured bacon having a protein content only one third that of pork drip. As might be expected, salt contents were high in the three bacon samples. Moisture content was lowest for the dry cured bacon but similar for the other samples.

Fig. 1 shows the SDS–PAGE patterns for pork and bacon samples. Replicates were similar so that only one example is shown for each type of sample. The three pork samples (i.e. raw drip, drip coagulate and cooked pork exudate) had very similar patterns but there were small differences between them (e.g. protein band 3 was more prevalent in the cooked pork exudate). Similarly, the three bacon samples had very similar patterns, with small differences. For example, the dry-cured bacon differed from the other two by not having protein bands 3, 4 and 6 (probably creatine kinase and/or phosphoglycerate) and having band 9.

Compared with the drip and exudate from pork, bacon samples had much lower amounts of band 2 (probably phosphorylase b and/or phosphorylase b kinase) and exhibited a protein band (band 10) which was absent in the pork samples. Otherwise, the electrophoretic patterns were similar.

The two major myofibrillar proteins, myosin and actin, would be expected to appear on the gels at the

Table 2
Composition of pork drip, coagulate from drip and exudate from pork and bacon cooked by dry-frying (means ± S.D.) (Experiment 1)

	Moisture (%)	NaCl(%)	Total protein (mg/g)
Pork drip	83.1 ± 0.6	< 0.3	238 ± 23
Coagulate from drip	82.3 ± 0.3	< 0.3	213 ± 21
Pork exudate	83.1 ± 1.0	< 0.3	168 ± 24
Wiltshire bacon exudate	82.1 ± 0.7	4.9 ± 0.5	83 ± 7
Rapid cure exudate	80.8 ± 0.7	6.3 ± 0.4	131 ± 8
Dry cure exudate[a]	76.4	5.0	84

[a] Dry cure bacon produced only small amounts of exudate, so these were combined to give a single sample for analysis.

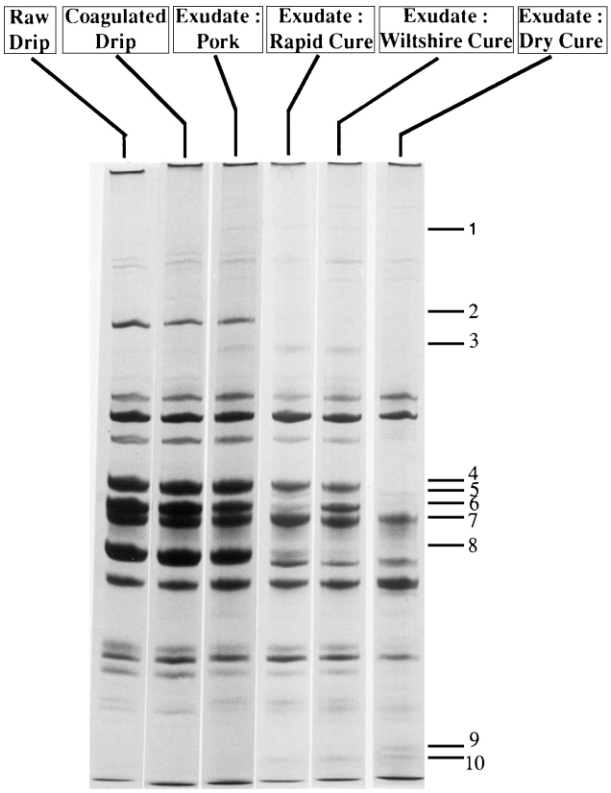

Fig. 1. SDS–PAGE patterns of drip from pork (raw, coagulated and exudate) and exudate from three types of bacon (Experiment 1).

position of bands 1 (myosin heavy chain) and 5, respectively. Band 5 was present in all the bacon exudate samples, although faint. Band 1 was variable, with trace amounts in most of the samples, including pork exudate.

3.2. Effect of bacon type and tempering method (Experiment 2)

The mean ultimate pH in the LTL of the eight pigs used was 5.38±0.06 (range 5.30–5.47). The mean NaCl content of the LTL was 3.2 and 2.8% for the Wiltshire and rapid cured bacon, respectively, with mean moisture contents of 72.4 and 76.5% and pHs of 5.62 and 5.58 respectively.

The weight losses from the bacons cooked by grilling are shown in Table 3. The total weight loss ranged from 27 to 30% for the rapid cured bacon and from 19 to 22% for the Wiltshire cured bacon, rather lower than the weight losses reported in Experiment 1 for bacon of similar composition (in terms of pH, moisture and salt content) which was dry-fried. Weight loss due to evaporation accounted for 65–91% of the total loss. Although less than evaporative loss, the amount of recoverable fluid is the more important component of total weight loss, since it is visible and it contains the coaguable material. Only a small part of the recoverable fluid was coaguable (approximately 0.1–1.7% of the weight of the bacon LTL). The evaporative weight loss during grilling was similar for both types of bacon and all four treatments. However, there were pronounced differences between the two types of bacon for other weight losses, the rapid cure bacon having a higher total weight loss, fluid loss and weight of exudate.

Within the bacons, treatment 1 (no tempering) resulted in the lowest loss of recoverable fluid and coaguable material. Tempering, in general, appeared to increase the amount of recoverable fluid and the weight of coaguable material, but it was difficult to discriminate between the effects of the different tempering procedures.

Though the experiment was not designed to examine the influence of pH, it was noticed that the pigs with the highest losses were those with the lowest ultimate pH (Fig. 2), even though the pH range was small (5.30–5.47). None of the pigs were identified as exhibiting PSE symptoms at the factory.

Table 4 shows the order of ranking by the 12 assessors, following dry-frying. Bacons were ranked within

Table 3
Influence of bacon type and tempering method on weight losses from the trimmed LD muscle of bacons cooked by grilling (means±S.D.) (Experiment 2)[a]

	Total weight loss (%)[b]	Evaporative weight loss (%)	Recoverable fluid (%)	Coaguable material (%)	Coagulate in recoverable fluid (%)
Rapid cure					
Treatment 1	27.2±3.3	20.0±1.2	8.2±3.0	0.89±0.42	11.2±4.2
Treatment 2	28.7±4.7	18.7±2.3	10.0±4.9	1.60±1.00	15.3±4.0
Treatment 3	27.4±4.5	19.0±2.1	8.4±3.1	1.43±0.77	16.4±4.8
Treatment 4	30.3±4.6	18.9±2.6	11.4±2.9	1.66±0.45	14.7±3.1
Wiltshire cure					
Treatment 1	19.9±3.1	18.1±1.8	1.9±1.6	0.14±0.18	4.7±4.5
Treatment 2	20.7±4.4	17.6±2.6	3.0±2.1	0.44±0.43	11.1±6.6
Treatment 3	22.4±6.4	18.5±5.9	3.9±1.3	0.68±0.61	15.3±8.8
Treatment 4	20.6±2.2	17.4±1.9	3.2±1.4	0.48±0.23	15.1±4.2

[a] Values are the means and standard deviations of eight sides (four replicates × two sides).
[b] Weight losses are expressed as a percentage of initial raw weight.

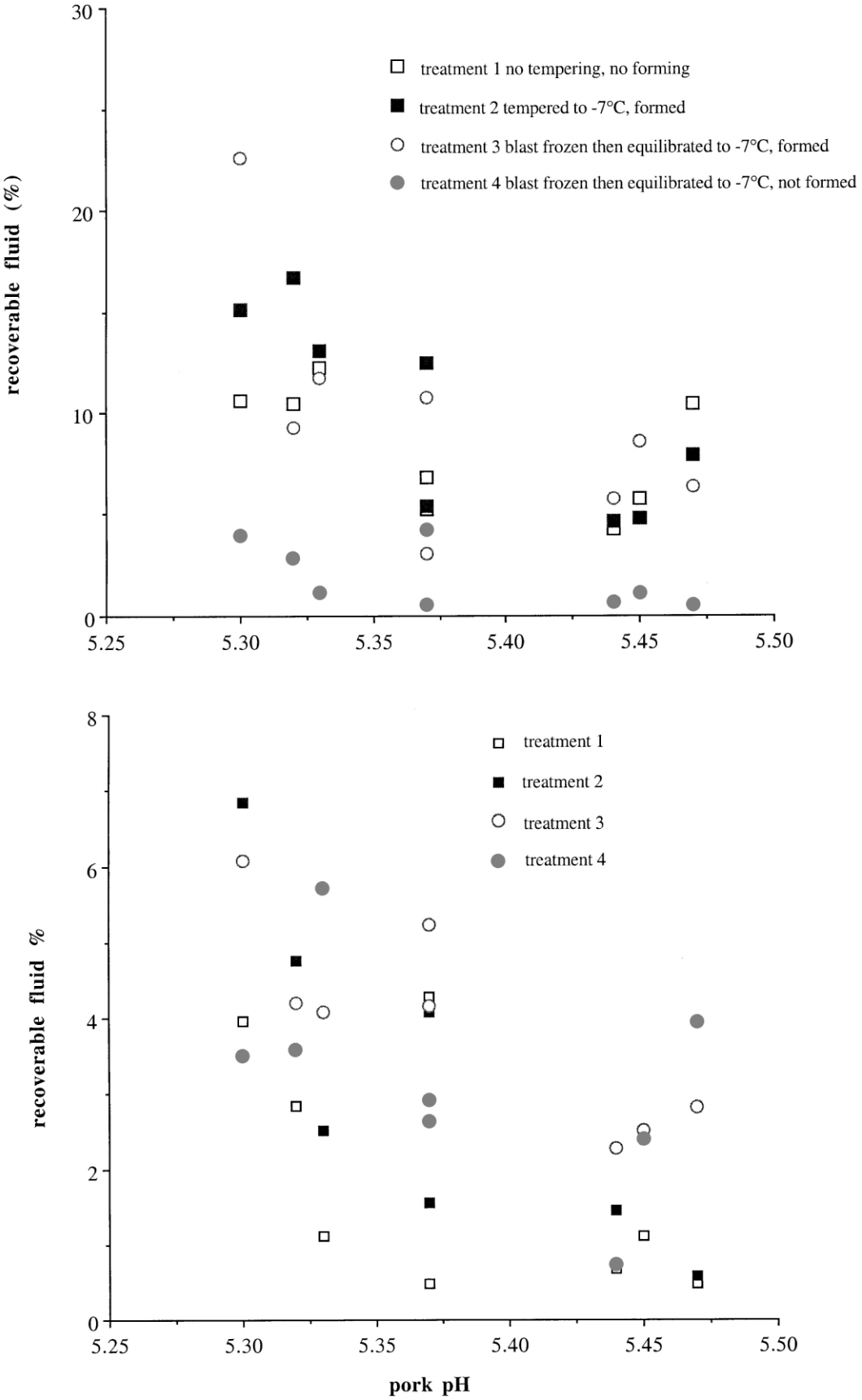

Fig 2. Relationship between pork pH and % cooking loss from Wiltshire (lower) and rapid cured bacon (upper) subject to different tempering regimes before slicing (treatments 1–4) (Experiment 2).

Table 4
Influence of bacon type (rapid, dry or Wiltshire cure) and tempering method on visual assessment of exudate from bacon LTL cooked by dry-frying (Experiment 2)[a]

Pig 1		Pig 2	
Rank Sum	Treatment	Rank sum	Treatment
11	Wiltshire (T1)	10	Wiltshire (T1)
21	Wiltshire (T4)	20	Wiltshire (T2)
36	Wiltshire (T3)	41	Rapid cure (T3)
44	Wiltshire (T2)	42	Wiltshire (T3)
51	Rapid cure (T4)	45	Wiltshire (T4)
55	Rapid cure (T3)	52	Rapid cure (T1)
62	Rapid cure (T2)	73	Rapid cure (T2)
80	Rapid cure (T1)	77	Rapid cure (T4)

[a] Two samples are different at the 0.05 level of significance if the difference in their ranking sums is greater than 21.5.

pig and since the ranking was similar for all eight pigs, data is shown for just two. As in Experiment 1, there were clear differences between the two types of bacon, the Wiltshire cure having less exudate than the rapid cured bacon. With Wiltshire cured bacon, the untempered bacon (treatment 1) was consistently selected for lowest exudate loss, with smaller differences between treatments 2, 3 and 4.

Fig. 3 shows the SDS–PAGE patterns for bacon samples from all four tempering treatments. The protein bands were similar to those in experiment 1 for exudate from Wiltshire and rapid cured bacon and the numbering system is the same up to band 10. For the Rapid cured samples, tempering (treatments 2, 3 and 4) gave similar patterns. Treatment 1 (no tempering) had less of protein bands 11, 4, 6 and 12. For the Wiltshire cured samples, the tempering treatments were all similar but treatment 1 (no tempering) appeared to have slightly less protein band 13 than the others.

The mean NaCl content of the exudate from the rapid cure bacon was 2.26% (2.55, 2.54, 1.58 and 2.36% for treatments 1, 2, 3 and 4, respectively), with a mean moisture content of 86.1% (84.9, 86.2, 87.6 and 85.5% for treatments 1, 2, 3 and 4, respectively). The exudate from the Wiltshire bacon had a similar composition with a mean NaCl content of 1.78% (1.42, 2.32, 1.68, 1.69% for treatments 1, 2, 3 and 4, respectively) and mean moisture content of 86.7% (83.6, 86.2, 88.1 and 88.8% for treatments 1, 2, 3 and 4, respectively). The lower salt content of the exudate compared with that in experiment 1, where it was collected after dry-frying, is probably due to the different methods of cooking and exudate collection, since it would not be concentrated by evaporation of the liquid phase.

3.3. *Effect of injection level, salt concentration and maturation time (Experiment 3)*

The bacon was made from pigs with a mean ultimate pH of 5.37 (range 5.18–5.51) in the *M. longissimus dorsi*.

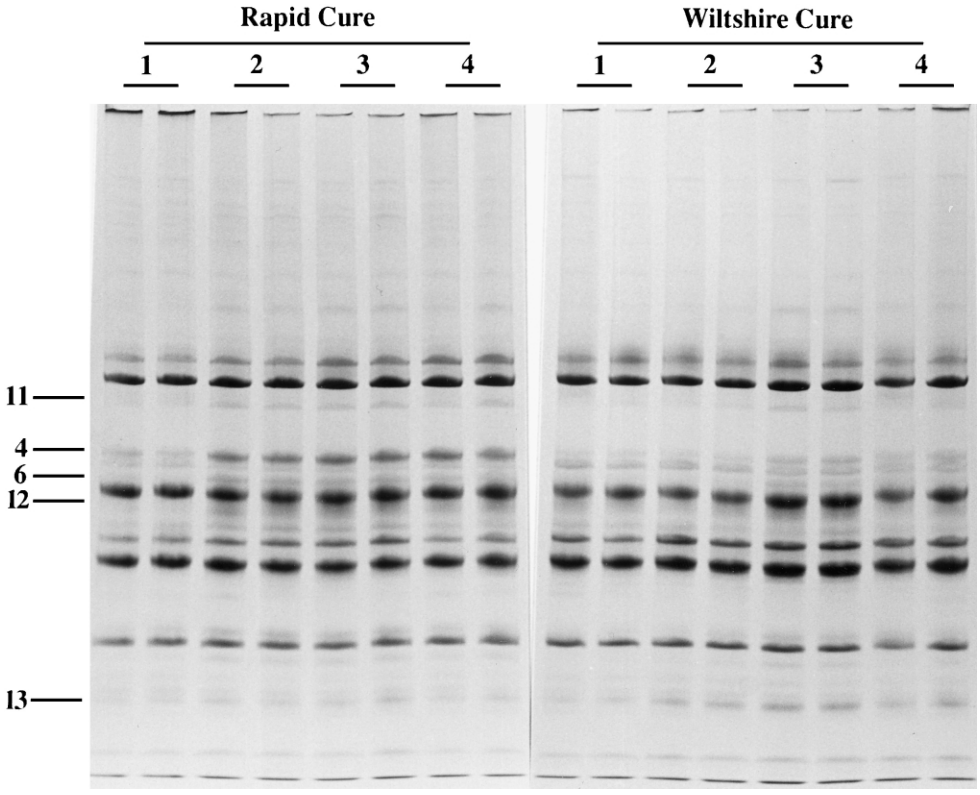

Fig. 3. SDS–PAGE patterns of exudate samples from rapid and Wiltshire cured bacon (Experiment 3).

Table 5
Mean ultimate pH and FOP values for pigs, and salt and moisture contents of bacon made at target injection levels of 9 (treatments 1–3), 13 (treatments 4–6) and 18% (treatments 7–9) and salt concentrations of 6, 16 and 26% (Experiment 3)

	Treatments									s.e.d.[b]	Sig
	1	2	3	4	5	6	7	8	9		
pHu	5.34	5.41	5.34	5.38	5.44	5.33	5.37	5.36	5.35	–	ns[a]
FOP	49	51	52	46	40	53	51	46	52	–	ns
Injection gain (%)	10.6	10.6	9.1	12.3	11.7	11.6	15.9	17.0	16.6	1.0	***
Salt content (% bacon wt)	1.86	1.31	0.62	3.28	1.74	0.80	3.20	2.41	1.09	0.29	***
Moisture content (% bacon wt)	74.0	74.5	74.6	74.1	75.0	74.8	74.4	75.1	75.9	0.55	*

[a] ns, $P > 0.05$.
[b] s.e.d., standard error of differences of means.
*$P < 0.05$.
**$P < 0.01$.
***$P < 0.001$.

There was no significant pH or FOP difference between treatments (Table 5). Six of the pigs had values greater than 50, which indicates a tendency towards PSE characteristics (MacDougall, 1984); these pigs also tended to have low pH_u, another property which can be associated with PSE muscle (Offer, 1991).

Injection levels varied considerably about the target values but there were no significant differences between treatments, for a given target injection level. Overall mean injection levels were 10.1, 11.9 and 16.5% compared with target levels of 9, 13 and 18%. Thus, actual levels were slightly lower than target injection levels at 13 and 18%, but higher at a target of 9%. Mean NaCl contents ranged from 0.62 to 3.28%, broadly in line with predicted NaCl concentrations. Only treatments 4, 7 and possibly 8 gave bacon with commercially acceptable levels of salt; other treatments gave levels of $< 2\%$. Despite significant differences in injection gain, this was not reflected in consistently higher bacon moisture contents at the high injection levels (Table 5). This suggests that bacons with the higher injection levels lost more moisture during maturation than those with lower injection levels, presumably due to their higher water activity. Injected salt appears to have been retained, suggesting that this moisture loss was largely by evaporation rather than salt-containing 'drip'.

Cooking performance was assessed after 1, 2, 4 and 6 weeks storage at 1°C. There was a significant effect of storage time on total weight loss ($P < 0.001$), evaporative loss ($P < 0.001$) and the quantity of coaguable material ($P < 0.05$), and the coagulate in the recoverable fluid ($P < 0.001$; Table 6). The highest total loss was at six weeks, suggesting that prolonged storage may reduce the water holding capacity of the bacon. Evaporative loss was also highest after 6 weeks storage. In contrast to total loss and evaporative loss, the quantity of coaguable fluid was lowest at week 6, especially in treatments 3, 6 and 9 (i.e. those with the lowest NaCl level).

Table 6
Significant effects of treatment and storage time (1, 2, 4 or 6 weeks) on weight losses during cooking of bacon made with target injection levels of 9 (treatments 1–3), 13 (treatments 4 to 6) and 18% (treatments 7–9) and salt concentrations of 6, 16 and 26% (Experiment 3)[a]

Storage time	Weeks				s.e.d.[b]	Significance
	1	2	4	6		
Total weight loss (%)	31.6	30.1	31.0	35.1	0.60	***
Evaporative loss	25.7	24.2	25.3	29.5	0.58	***
Coaguable material	0.57	0.63	0.55	0.39	0.075	*
Coagulate in recoverable fluid	8.5	9.8	8.2	5.8	0.75	***

Treatments	1	2	3	4	5	6	7	8	9	s.e.d.[b]	Significance
Evaporative loss	25.9	26.4	28.2	25.4	25.5	27.4	24.5	25.8	26.4	0.86	**
Recoverable fluid	5.0	4.9	4.1	6.1	6.4	3.6	8.8	7.2	6.0	0.66	***
Coaguable material	0.43	0.43	0.37	0.44	0.50	0.36	1.09	0.77	0.41	0.11	***
Coagulate in recoverable fluid	8.1	7.6	7.1	6.7	7.7	8.0	11.8	10.0	6.0	1.11	***

[a] ns, $P > 0.05$.
[b] s.e.d., standard error of differences of means.
*$P < 0.05$.
**$P < 0.01$.
***$P < 0.001$.

There was a significant effect of treatment on evaporative loss ($P<0.01$), recoverable fluid ($P<0.001$) and the weight of coaguable material ($P<0.001$), but no significant effect on total weight loss ($P>0.05$; Table 6). The evaporative loss was greatest in the three treatments (3, 6 and 9) using the lowest salt level (6%). Generally, the quantity of recoverable fluid increased with increasing injection gain and with increasing NaCl concentration. The weight of coaguable material was significantly higher in treatments 7 and 8, i.e. at the highest injection level and with the highest salt contents. Thus, the combination of high injection level and high brine salt appeared to increase the quantity of recoverable fluid and the weight of coaguable material.

The interaction between storage time and treatment did not significantly affect weight losses during cooking ($P>0.05$).

Fig. 4 shows the relationship of the weight losses during cooking with bacon salt content. Salt content was positively related to the weight of recoverable fluid and coaguable material and negatively related to evaporative loss. Thus, bacons with the highest salt levels had less evaporative loss but more fluid loss (but did not differ in total weight loss from bacons with lower salt levels).

3.4. Exudate loss from pork and bacon (Experiment 4)

The cooking losses from pork and bacon anterior and posterior slices, derived from four animals (with mean pH_u and FOP values of 5.35 and 44, respectively), are shown in Table 7. The total weight loss for the bacon was relatively high, compared with the values reported in Experiments 2 and 3, though the relative proportions of evaporative loss, recoverable fluid and amount of coaguable material were similar.

The pork slices behaved differently to the bacon during cooking, having higher losses (which were significant for all but the recoverable fluid). However, brine injection levels for the bacon were relatively low, ranging from 6.13 to 7.57%, rather than the anticipated 10 to 11%, resulting in a drier bacon than that in Experi-

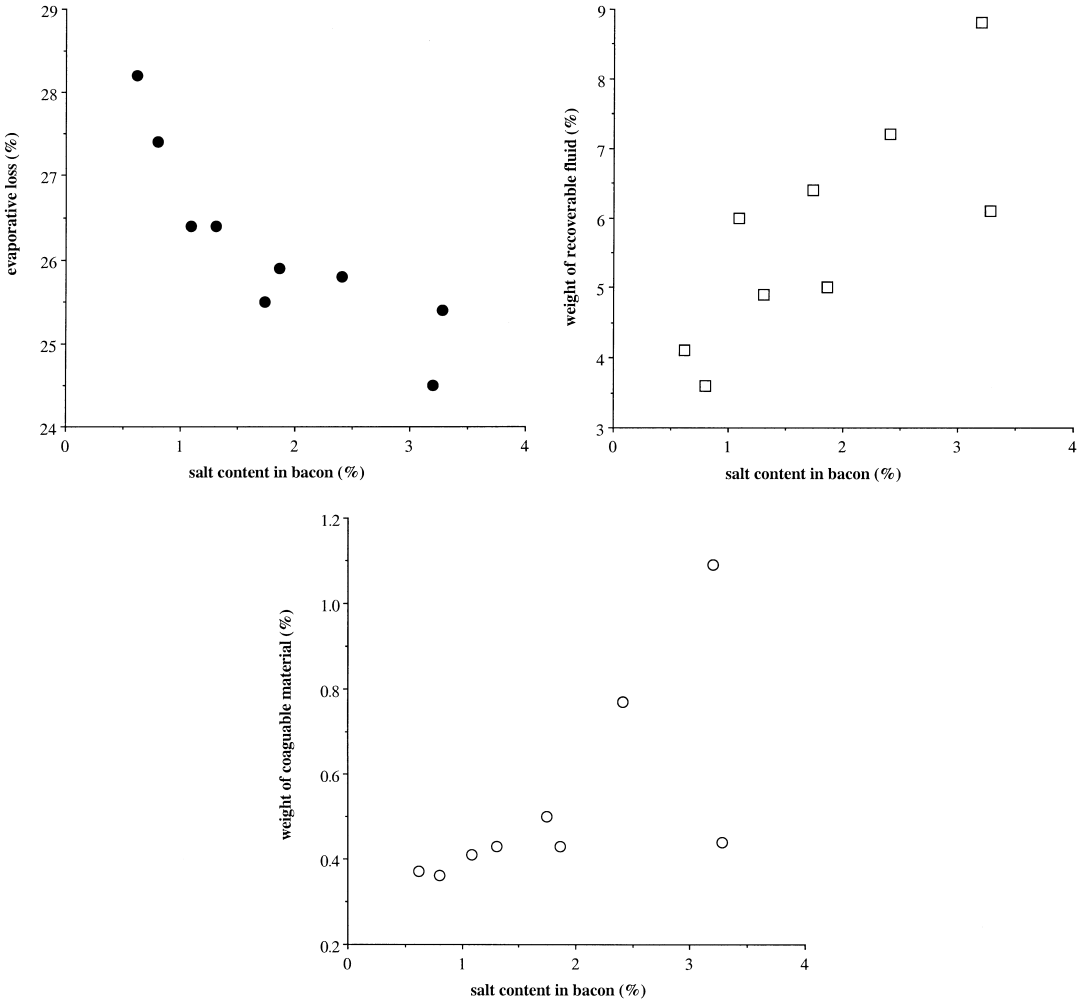

Fig. 4. Relationship between bacon salt content, evaporative losses, weight of recoverable fluid and coaguable material for Wiltshire cured bacon, made at different injection levels and brine salt concentrations, cooked by grilling (Experiment 4).

Table 7
A comparison of weight losses from the trimmed LTL muscle of pork and bacon cooked by grilling (means ± S.D.) (Experiment 4)[a]

	Pork	Bacon	Significance
Total weight loss	34.6 ± 1.6	30.5 ± 3.7	*
Evaporative weight loss	28.3 ± 2.9	25.7 ± 1.2	*
Recoverable fluid	6.3 ± 2.6	4.8 ± 3.5	ns[b]
Coaguable material	2.1 ± 2.1	0.3 ± 0.2	***
Coagulate in recoverable fluid	33.9 ± 7.6	6.8 ± 4.0	***

[a] Means are the average of 8 values, derived from 4 pigs and anterior and posterior slices of LTL.
[b] ns $P > 0.05$.
*$P < 0.05$.
**$P < 0.01$.
***$P < 0.001$.

ments 2 and 3. Thus, for this particular bacon, pork produced more exudate though this may not have been the case had the comparison been made with rapid cured or a Wiltshire bacon with a higher injection level.

4. Discussion and conclusions

4.1. Exudate composition

SDS–PAGE patterns of the exudate from cooked pork and drip were similar (Fig. 1). The bacon samples did differ from exudate from pork (band 2, for example, was absent in bacon but present in pork samples) but not markedly and, the overall similarity to the pork samples, suggests that the exudate from bacon is similar in composition to that of drip. Previous work from this laboratory has shown that drip consists of predominantly sarcoplasmic proteins (Savage et al., 1990). This suggests that the exudate from cooked pork and bacon also consists of mainly sarcoplasmic proteins.

One might anticipate that the exudate from bacon would differ from that of pork since the addition of salt, either dry or as a brine, is often used to solubilise meat proteins (for example Jolley & Purslow, 1988). Actin and myosin are the major protein components of the myofibril, comprising about 70% of the protein in muscle (Jolley & Purslow, 1988). However, only trace amounts of actin and myosin were evident at the positions where one would expect to find these two proteins (bands 5 and 1, respectively). The exudate from cooked bacon, thus, contains less actin and myosin than the 'sticky exudate' that is produced during the manufacture of reformed hams (Jolley & Purslow, 1988).

Previous work has shown that myosin is irreversibly denatured when meat blocks were exposed to high concentrations of sodium chloride (5M or about 29% NaCl) (Dilber-Van Griethuysen & Knight, 1991), resulting in minimal protein extraction (Callow, 1931). Dilber-Van Griethuysen & Knight (1991) argued that such salt concentrations could pertain during curing, immediately following injection, when there would be localised areas of high salt concentration, followed by a slower equilibration. This could account for the alternate light and dark bands (tiger-striping) sometimes seen in sliced bacon (Voyle, Jolley, & Offer, 1986) and provides a reasonable explanation for the virtual absence of myosin and actin in the bacon exudate examined here (Fig. 1).

4.2. Origin of the exudate in cooked bacon

Having identified the composition of the exudate, it is of interest to consider how the exudate is formed during cooking. Elevated temperatures result in the denaturation of myofibrillar and connective tissue proteins (Bendall & Restall, 1983) and shrinkage of the myofibrils, the main water compartment in muscle (Offer & Knight, 1988a). This results in the expulsion of water from the myofibrils, with weight losses of about 20–30% depending on the cooking method and type of bacon, and a consequent shrinkage in the dimensions of the product. In bacon, a large proportion of the water (65–90%) is lost by evaporation because of its large surface area; the rest is manifest as fluid, containing a small quantity of protein together with any liquefied fat. In the case of bacon, the fluid also contains salt. The proteins, derived from the sarcoplasm, are mainly low molecular weight and readily soluble. Heat denaturation of these proteins causes them initially to coagulate, entrapping some water and salt, conferring the typical appearance of the white exudate associated with cooked bacon. Further cooking results in evaporation of water from the exudate and a concentration of the solid material, which eventually darkens and burns on to the surface of the pan or grill.

4.3. Quantity of exudate from bacon

This work has identified a number of factors that influence the quantity of exudate in cooked bacon.

4.3.1. Curing method

Rapid cure bacon consistently produced more exudate than Wiltshire cured bacon, whether assessed subjectively by trained assessors or objectively by quantifying the weight losses during cooking. The data suggest that the water holding capacity of the rapid cured bacon was inadequate to retain the extra water added during processing (injection levels were 18 and 11% for the rapid cure and Wiltshire cured bacon, respectively), resulting in higher cooking losses compared with the Wiltshire cured bacon. Estimates, shown in Table 8, suggest that the moisture contents of the two bacon types after cooking were similar.

Table 8
Calculated weight changes during processing and cooking of Wiltshire and rapid cure bacons[a]

	Dry frying			Grilling		
	Total weight (g)	Weight of water (g)	% Water	Total weight (g)	Weight of water (g)	% Water
Rapid cure						
Initial weight	100.0	70.0	70.0	100.0	70.0	70.0
Weight after injection	118.0	88.0	74.6	118.0	88.0	74.6
Weight after cooking	71.7	41.7	58.6	87.4	57.4	65.7
Wiltshire cure						
Initial weight	100.0	70.0	70.0	100.0	70.0	70.0
Weight after injection	111.0	81.0	73.0	111.0	81.0	73.0
Weight after cooking	76.5	46.5	60.8	87.8	57.8	65.8

[a] The calculations are based on an initial moisture content of 70% and the mean cooking losses in Experiments 1 and 2.

One of the major differences between Wiltshire and rapid cured bacon concerns the period of maturation. The data in Table 5 suggest that the Wiltshire bacons with high injection levels lose more water by evaporation during maturation than those with low injection levels, presumably as a result of their higher water activity, resulting in only minor differences in bacon moisture content. In rapid curing, however, the bacon was held in vacuum packs, rather than an overnight period to allow for drainage of excess fluid, thus giving little opportunity for evaporation. This provides an explanation for the higher moisture content of the rapid cured bacon and the higher weight loss during cooking (Table 3).

4.3.2. Bacon tempering

Our results suggest that the partial freezing of meat, necessary for the high speed slicing of bacon, increases the amount of exudate produced. It is well known that freezing increases the amount of drip in pork — typically double that of unfrozen pork (Offer & Knight, 1988b) — and since approximately 60% of the water would be frozen at −7°C, even in bacon with 2–3% salt (Sheard, Jolley, Katib, Robinson, & Morley, 1990), this result is not surprising. The precise mechanism is unclear but it is known that freezing has marked effects on the structure of muscle. Freezing results in formation of large columns of ice crystals outside the muscle cells and a consequent dehydration and shrinkage of the muscle fibres; these re-swell on thawing in a time-dependent fashion (Offer & Knight, 1988b). Thus, freezing has marked effects on the structure of the main water holding compartment in meat (the myofibrils) and the state and location of the water.

4.3.3. Storage period

Previous work from this laboratory has shown that a white, milky exudate sometimes collects in the corners of vacuum packed bacon, becoming progressively worse with time, especially at low salt levels (Applegate, 1989) and high storage temperatures (Sheard, unpublished results). These observations, and the higher weight losses at 6 weeks reported in Table 6, may have a common mechanism — possibly microbial in origin — resulting in a reduction of water holding capacity.

4.3.4. Injection level and brine salt concentration

Wiltshire cured bacon made over a wide range of injection gains (9, 13 and 18%) and NaCl levels (6, 16 and 26%) and assessed 1, 2, 4 or 6 weeks after production, all produced some exudate. Some important conclusions can be drawn from the weight loss results. There were significant differences between treatments in terms of recoverable fluid and the weight of coaguable material but not total weight loss; this suggests that total weight loss alone is not a good indicator of appearance during cooking, at least for Wiltshire cured bacon.

The weight of recoverable fluid and coaguable material was positively related to bacon salt content (Fig. 4). This, in turn, depends upon the injection level and brine salt concentration. There appears to be no other obvious explanation for the relationships in Fig. 4 other than that mentioned previously, i.e. the influence of high salt concentrations on meat structure, even for transitory periods, leading to irreversible denaturation of myosin (Dilber-Van Griethuysen & Knight, 1991) and the inhibition of swelling (Offer & Knight, 1988a).

4.3.5. Influence of meat pH

Though the experiment was not designed to examine the influence of pH, this conceivably could be one of the most important factors affecting processing and subsequent weight losses during cooking, given the relatively large differences in cooking losses over a narrow range of pHs (Fig. 2). It is well know that PSE meat has a poor water holding capacity. It occurs when a carcass experiences a rapid pH fall whilst the temperature is still high, resulting in a reduced lattice spacing and denaturation of myosin (Offer, 1991). Conversely, the lattice

spacing is increased in the DFD condition which, conceivably could be advantageous in maximising bacon yield and reducing losses during cooking.

5. Summary

This work has elucidated the composition of the white exudate produced during the cooking of bacon, provided a rational basis for understanding how the exudate is produced and identified some of the major factors affecting the quantity of exudate. Appropriate methodology has also been developed that would allow other factors to be investigated in more detail. There appears to be some justification for the view that 'modern bacons', which invariably have high injection levels, are associated with more exudate. However, some loss of exudate during the cooking of bacon seems to be inevitable, regardless of the production method, since its appearance is associated with the sarcoplasmic fluid present in uncured pork. It has been demonstrated that the production of exudate cannot be attributed to any single cause but, rather, depends upon many different factors, some of which may be inter-dependent. The factors of importance include meat pH, the method of manufacture (including brine injection level and brine salt level), tempering conditions for high speed slicing, storage time and the method of cooking; other factors such as slice thickness may also be important.

Acknowledgements

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