A PRACTICAL INVESTIGATION INTO THE HYGIENIC PRODUCTION OF 'SKIN-ON' SHEEP CARCASSES AND CATTLE AND SHEEP FEET

Project code: M01027

Contractor: The University of Bristol

Start date: 1 November 2003
Finish date: 31 March 2006

Alan V. Fisher, Carol-Ann Wilkin
(Division of Farm Animal Science, Department of Clinical Veterinary Science)

and

Graham Purnell
(Food Refrigeration and Process Engineering Research Centre, Faculty of Mechanical Engineering)

A prepared sheep carcass, showing some of the sites where skin has been excised for microbiological analysis

Contents

Page

1. Executive Summary

There is a demand, in the United Kingdom, for sheep meat with the 'skin-on', emanating primarily from consumers of African origin whose native culture embraces, as a desirable food, singed and smoked carcasses of a range of mammalian species. To satisfy this demand, sheep carcasses, whose wool has been burned off as part of the dressing process, are produced illegally in the UK or are imported. Current EU and UK legislation does not allow the production of sheep carcasses with the skin on; this has led to the illegal production of skin-on sheep meat in unlicensed premises that are not subject to official inspections and hence there is concern about the hygienic status of meat originating from such sources. There is also a demand for sheep and cattle feet that have been produced using similar procedures and these are being produced commercially in regulated abattoirs and are traded legally. The aim of this project was to devise a production process for skin-on products and the main focus was on the sheep carcass. A limited microbiological study was made on sheep feet but there was no attempt to devise a production protocol based on HACCP principles, or an evaluation of their appearance and organoleptic properties, as the one used commercially seemed perfectly adequate. Hence the objectives (O3(b), O5 and O6) of producing cattle and sheep feet, and O2 (to optimise a hot water immersion treatment system for skin-on cattle and sheep feet and to develop a system for monitoring their temperature during processing), were removed from this project by the Food Standards Agency.

The first phase of this project was a pragmatic evaluation of different options for removing the wool and the second phase determined the effects, on microbial counts, of specific steps in the selected method. In addition to meeting microbiological targets, it was necessary to ensure the process resulted in a product that was acceptable to accustomed consumers of such products and an assessment of this was another important objective. The shelf-life of skin-on meat was also studied as a logical extension to the microbiological comparison with conventional carcasses.

Three methods to remove the wool from sheep carcasses were explored. Hot water scalding, as used for pig carcasses, did not consistently facilitate the removal of wool by subsequent scraping and there was no clear evidence of improvement by increasing the temperature of the water or duration of submersion. Singeing the wool using hot air was effective but was probably too slow to have practical application. Singeing using a naked gas flame emerged as the best option, the wool burning quickly and the underlying skin also being singed to give a light brown colour. It was also clear from these explorative studies that (a) the fleece needs to be shorn prior to slaughter to give a wool length of about 5 mm in order to effect adequate singeing and (b) the carcass needs to be washed after singeing in order to remove charred wool residues.

A bespoke singeing rig was designed and built to provide a consistent singe operation which, in subsequent project tasks, enabled carcasses to be compared when alternative procedures, at other stages in production, were

used. This took the form of an octagonal ring, carrying eight gas burners that moved vertically over a stationary and suspended carcass, under the power of a microprocessor-controlled electric motor. The degree of singeing required was attained using three down-up cycles of the burners (the parked position was at the top of the cycle). Carcass surface temperatures, measured with an infrared thermometer, showed that during the defleecing singe, the temperature reached 515°C at incandescent glowing sections of fleece, directly under the burners. Immediately following singeing, the carcass surface temperature was reasonably uniform at around 70-85°C.

Following singeing the carcass was washed using a pressure washer with water at 60°C. The quantity of water used was variable but on average was estimated to be approximately 20 litres per carcass.

The optimal sequence of steps based around the gas singeing/washing procedures was established by comparing *Enterobacteriaceae* and Total Viable Counts (TVC) on carcasses produced according to two alternative methods for each step. For practical reasons it is preferable to eviscerate after singeing/washing as the body cavities are intact during these procedures and thus prevent entry of water (plus contaminants) and there is no exposed meat that might partially cook. However, evisceration poses a risk of bacterial contamination of the carcass through increased handling and it was shown that a final single cycle of the burners ('toasting) after evisceration reduced mean counts of *Enterobacteriaceae* by 0.5 log CFU/cm^2 and TVC by 1.7 log CFU/cm^2). Similarly, splitting the carcass (to remove the spinal cord in older sheep) and routine carcass inspection before applying the Health Mark were both shown to increase counts of both groups of organisms if conducted after toasting. Defining the sequence in this way was based on hazard identification but a full HACCP plan was not developed (Objective O5) as the project focused on the process and its microbiological consequences. Only superficial monitoring of potential CCPs (e.g. singe temperature) was carried out. Hazards posed by veterinary medicine residues in the sheep skin/skin-fat lay outside the scope of this project.

Toasting did not obscure the dye-based Health Mark. Comparison of skin-on carcasses produced according to the best protocol with carcasses dressed conventionally (skin-off) in the same abattoir showed a clear microbial reduction on the former. As an example, of the total possible number of counts (10 carcasses x six sites) of *Enterobacteriaceae*, 97% were below the detectable limit on the skin-on carcasses compared with 57% on the conventional ones.

Chilling carcasses generally produced different and opposite results in conventional and skin-on carcasses, decreasing microbial counts on the former but increasing counts on the latter. This was probably due to the very low initial counts on the skin-on carcasses and thus no competitive flora to inhibit introduced contaminants.

The shelf life of meat is determined by changes in muscle colour, lipid oxidation and proliferation of spoilage organisms. There was no significant difference ($P \leq 0.05$) between skin-on and conventional meat in colour or rancidity. The same groups of spoilage organisms were present on both types of carcasses and those monitored were lactic acid bacteria, *Pseudomonas* spp., yeasts and moulds, and TVC. The growth of spoilage organisms was complicated as there were several significant interactions between the factors (carcass type, days on display, carcass joint). Overall, there were indications that counts were higher on the skin-on meat but this was clearly significant only for yeasts and moulds. This was presumed to have arisen from the handling involved in removing and packaging the samples and the low initial microbial loading on the skin-on meat.

Skin-on carcass and meat appearance, and the aroma of skin-on meat during cooking, were assessed by a panel of men of Nigerian and Ghanaian origin, all of whom had prior experience of this type of product. Overall, carcasses and the resultant meat produced according to the evolved protocol were judged to be typical and acceptable. The conclusion from this project is that skin-on sheep carcasses that meet consumer requirements can be produced to an acceptable hygienic status using the described methods.

A year-long survey of predominant lesions that might pose a difficulty to detect in skin-on carcasses was conducted in a commercial abattoir slaughtering substantial numbers of older sheep (primarily cull ewes). The three most frequently occurring conditions noted throughout the year were, in decreasing order, abscesses, bruising and emaciation with observed total numbers of carcasses affected being 726, 42 and 28, respectively, out of a total of 10,245 slaughtered. The number of carcasses exhibiting arthritis was actually greater than those that were emaciated, with a total of 34 but the observations were not as evenly spread across months. There was only one case of *Cysticercus ovis* detected, located in the flank, and two carcasses showing hydatidosis.

Abscesses exceeded 90% of all the conditions recorded in some months and the lowest value was 66%. It is likely that many of these would be detectable in a skin-on carcass but there is no objective basis to qualify this statement. Abscesses are removed by localised trimming unless they are numerous enough to require condemnation of the carcass. They are not of public health concern but are clearly of consumer concern and cannot be allowed to enter the food chain. The two other relatively commonly occurring conditions, arthritis and emaciation, would be readily detectable in skin-on carcasses. It is suggested that the Meat Hygiene Service considers the implications, for the meat inspection procedure, of leaving the skin on and whether there need to be any new measures stipulated for this type of carcass.

2. Glossary

Singeing The burning of the wool and partial browning of the skin occurring during the application of dry heat to the fleece. In the automated process using the singeing rig, it is specifically the application of naked flame during the three down-up cycles of the ring burner.

Smoked The term to describe the skin-on carcass at the end of the production process, it having been through the singeing and toasting processes.

Toasting A final application of naked flame to the previously singed and pressure washed carcass in a single down-up cycle using the automated rig.

3. Aims and Objectives of the Investigation

In several countries, particularly Islamic and west African, it is commonplace to cook and eat the meat of a number of mammalian species, especially goat, with the skin-on. Ethnic communities of like people living in the UK also seek to obtain such meat and there is a demand for sheep meat with the 'skin-on' as a more accessible alternative. Sheep carcasses, whose wool has been burned off as part of the dressing process, thus imparting a smoked flavour to the product, are currently produced illegally in the UK or are imported. Current EU and UK legislation does not allow the production of sheep carcasses with the skin on and it is stipulated that the carcass must be flayed during the dressing process. This has led to illegal production of skin-on sheep meat in unlicensed premises that are not subject to official inspections and therefore may pose a risk to public health (possibility of diseased stock, unhygienic environment and practices, inadequate carcass dressing including SRM control). These illegal carcasses are known colloquially as "Smokies".

There is also a demand by these same consumers for unskinned feet of cattle and sheep, also usually smoked.

If these skin-on meats are produced in suitably licensed premises and with due regard to a product-specific HACCP plan, it may be possible to achieve a microbiological status on a par with conventionally dressed carcasses. However, it is known that the fleece or skin is a primary vector for the importation of contamination to the slaughterhouse[1] and twenty-seven species of bacteria have been identified as colonising the sheep fleece[2]. The fact that pelt removal is regarded as one of the critical control points in a HACCP plan for sheep slaughter[3] is recognition of the potential contamination that the fleece imposes. Additional evidence of the potential contamination posed by the fleece is furnished by reducing its bulk through pre-shearing, which may be done immediately after bleeding out the carcass, which significantly lowers carcass contamination[4]. In the (illegal) production of smokies, the fleece is sheared to leave a wool length of about 1 cm[5]; nevertheless, there must still be a significant risk of pathogens being present on the dressed carcass. The question that needs answering is whether burning off the fleece, an essential process in the production of smokies, reduces bacterial numbers to an acceptable level. Some information of perhaps tenuous relevance does exist for pig carcasses for which singeing or flaming is a commonly practised procedure in carcass dressing. Of course, the pig carcass has already been scalded and largely dehaired by the time it reaches the singeing stage so the two species-specific practices are not directly comparable. However, singeing *per se* has been shown to reduce pathogenic bacteria by two orders of magnitude.[6]

The aim of this project was to devise a HACCP-based production process for skin-on products that resulted in acceptable microbiological levels through a strategy of testing different options or procedures and measuring their microbiological effects. In addition to meeting microbiological targets, another

important objective was to ensure that the process resulted in a product that was acceptable to accustomed consumers of such products.

Leaving the skin on the finished carcass may have implications for meat inspection and, hence, the safety and wholesomeness of meat to the consumer. As an extension to the main project, a survey in a commercial abattoir was conducted to establish the frequency of occurrence of conditions and lesions, on older sheep particularly, that might pose a problem of detection in skin-on carcasses.

4. Experimental Procedures

4.1 Preparation of skin-on sheep feet at a commercial abattoir

The work on skin-on sheep feet was confined to a study visit to an abattoir that had devised a process for their production plus a limited microbiological examination of the product coming out of that abattoir. The rationale was that if that process resulted in a hygienically acceptable product there was little need to devise alternative methods. A commercial procedure for the preparation of skin-on sheep feet is practised at the Birmingham Halal Abattoir and a visit was made to observe the process and to collect specimen examples for microbiological testing.

Feet were removed by knife at the carpal articulation or, for hind feet, by cutting the metatarsal (this seemed generally to be the case from examination of severed feet; we did not witness dressing). Dirty feet were delivered in batches from the slaughterhall to the feet processing room (located one floor above) by a lift. They arrived in batches so correlation with the carcasses was on a batch basis. If a carcass was condemned, the entire batch of feet was also condemned.

The feet were dirty, covered in blood, faecal material, straw, etc. Batches were picked over to remove any unacceptable for processing (basis not explained). They were emptied into a revolving drum with paddles and a hot water sparging system (originally a potato peeler). The feet were tumbled in constantly changing water for about 15-20 minutes until cleaned and dehaired (small amounts of wool that remained were picked off by an operator before the next stage – singeing).The nails were also removed during this process.

The cleaned feet were then singed by being placed in a single layer on a constantly moving chain conveyor that passed between two sets of gas burners. We were told that the singeing process significantly extends shelf life (claimed to be 7 days). The finished product was discharged into plastic trays that were stored on the floor.

The feet were further processed before despatch. The hoof was cut between the claws and the coil (sebaceous) glands of the interdigital pouch were exposed and removed. The proximal ends of the metacarpals were trimmed of burnt blood residue. We were told that the butcher would then cut off the extremities of the prepared feet and discard these. The remainder would be cut into sections (using a bandsaw, presumably) and the consumer would cook the product in a ‘stew’ on a gentle heat for a long time (overnight).

Twelve feet were brought back to Langford for microbial determinations. They were not chilled during transportation back to Langford (approximately 3 hrs) but they were stored under chill conditions (+2^{0}C) overnight before microbiological examination was carried out. Six feet were intact and six had

had the coil gland removed. Within each of these groups of six, three were sampled using wet/dry swabbing (20cm^2 using a 10x2 cm template) and three by the excision method (5cm^2 x 2 = 10cm^2). To the wet/dry swab samples, 25ml of MRD was added and to the excised pieces, 50ml of MRD was added. These were then designated as the 10^0 samples. Samples were further serially diluted in MRD to 10^{-6} and each dilution plated, singly, onto VRBG (for enumeration of *Enterobacteriaceae*) and PCA (for enumeration of TVC), using the 0.1ml spread plate method. Plates were incubated at 37°C for 24h (VRBG) and 30°C for 72h (PCA), respectively.

4.2 Skin-on carcass production; a pragmatic evaluation of alternative methods

All the animals used in the carcass production trials were supplied by the same producer and were females, over 12 months of age and were pure or part Shetland. Unless otherwise stated, all sheep were shorn within a week of slaughter so that the wool length was approximately 5 mm.

The practical goals of this project were twofold:

Remove wool
Impart smoked colour, odour, flavour to skin

At the outset, two methods of wool removal were identified and considered to be feasible options. The first was loosening of the wool in its follicles and softening the superficial layers of the skin by immersing the carcass in hot water, followed by mechanical abrasion to remove the fibres. The second was to burn the wool in its entirety and remove the charred remains by some mechanical means.

4.2.1 Hot water treatment

Three carcasses were processed in a first run to assess the likely feasibility of this approach. The first one was scalded in a pig tank at 60 ^{0}C for approximately six minutes and was then 'de-wooled' by hand scraping using a pig scraper and knife. The carcass was then singed with a hand-held gas torch equipped with a 6cm diameter burner. The second was similarly scalded and then put through the mechanical pig dehairer which employs rubber-mounted scrapers on a revolving barrel. The third was processed as the second but the head and feet were removed prior to placing in the dehairer.

A second trial was conducted to more critically evaluate the factors involved in scalding by assessing the ease of wool removal after different scald water temperature x immersion time combinations. A three (temperature) x two (time) factorial design was used and six ewes were obtained with the specification being that they should be as homogeneous as possible regarding size and age to minimize any possible animal-effect variation. In the event, although the six ewes were quite similar in skeletal size, there were differences in condition

score. The choice of nominal temperatures was 60, 65 and 70 ^{0}C. and the two immersion durations were 5 and 7 minutes. Temperature was measured with a probe immersed in the scald water. After the scald, each carcass was vertically suspended and three areas (rump, belly, neck) were scraped, with a pig scraper, by the same operator (slaughterman) using five vertical strokes (3 down, 2 up). A wool removal score (a combination of apparent ease of separation and area of denuded skin made visible) was arrived at by consensus of four persons (scientists and technicians) involved in the project and ranged from 1 (no wool removed; no skin visible) to 10 (wool easily removed; large areas of skin visible).

4.2.2 Hot air singeing.

An investigation was made of the use of hot air to singe the wool and skin as an alternative to naked flame scorching. Two devices were provided (by Welwyn Tool Co.); one had a low air volume/velocity delivery but could reputedly achieve temperatures around 800 ^{0}C ('gun' A); the other had a greater volume displacement of air but produced a lower temperature, reputedly around 600 ^{0}C ('gun' B).

Both 'guns' were used on a single, non-scalded carcass. Gun A was fitted with a flat, wide nozzle; Gun B was not fitted with a nozzle. Wool singeing was followed by dry scraping to remove the wool using a pig scraper.

A second carcass was scalded in the pig tank, the aim being to determine the efficacy of skin singeing of a de-wooled carcass using hot air. The tank water was heated to about 62 ^{0}C and the carcass immersed for 7 minutes. This proved to be inadequate and a further immersion of approximately 2 minutes was needed to allow wool to be plucked by hand. The carcass was then removed and scraped by pig scraper and knife to remove wool which remained very difficult to remove in some areas. The left side of the ventral surface was singed with Gun A (one area without the nozzle, another with) and the right side with Gun B. Finally, the second carcass was pressure washed.

4.2.3 Naked flame (gas torch) singeing

Five animals were used for the initial trial. One ewe had been shorn approximately four months earlier and had a fleece length of about a approximately 2 cm. The other ewes had been shorn the previous week and had a fleece length 5 – 10 mm. There was one all-black animal. A hand held gas torch was used with a 'fish tail' burner of approximately 5 cm width, coupled to a 4.7 kg propane gas bottle. A large and powerful electric fan was provided to extract smoke and products of combustion from the room where the exercise was conducted. Carcasses were suspended from a tubular frame on wheels.

The exercise was qualitative only and the objectives were to establish how much smoke was produced, what degree of singeing was necessary, and what additional measures (e.g. scraping) were necessary, all these being preliminaries to the construction of a purpose made singeing apparatus. In addition, assessment was made of the advantages/disadvantages of

eviscerating the carcass before singeing. Three carcasses were eviscerated prior to, and two subsequent to, singeing.

4.2.4 Construction of a singeing rig

It was clear at an early stage in the evolution of the production method for smoked, skin-on sheep carcasses that several steps would be involved and the sequential order of these steps, as well as the manner of execution of the steps themselves, would have implications for the hygienic status of the final product. In order to evaluate the implications of a particular step, all other steps needed to be carried out repeatably and consistently and it was clear from the initial trial that using manual singeing, it would be practicably impossible to perform to this standard. It was necessary to produce experimental singeing equipment for this purpose.

Gas burners were selected as the main singeing heat source due to their low-cost, speed of action and current use in the meat industry for singeing pork carcasses. The final system had a ring of eight inward directed gas burners moving up and down around a suspended carcass. The burner ring was chain driven from a DC motor controlled by a small programmable logic controller. Adjustable microswitches on the support structure controlled the stroke end positions. The full report on the rig development and details of its operation and the outcome of trials are given in Appendix A.

Carcass surface temperatures were taken on an ad hoc basis with an infra-red (IR) thermometer. During the defleecing singe, the temperature reached 515°C at the incandescent glowing sections of the fleece, directly under the burners. Immediately after cessation of singeing, the carcass surface temperature was reasonably uniform at around 70-85°C. Temperatures recorded during the toasting singes were lower, being in the range 82-276°C. There was no attempt to control the temperature (which would have been difficult to do as the burner-carcass distance was not constant owing to the irregular carcass shape); rather, the duration of singeing was controlled and a suitable degree of singeing was obtained after three down-up* cycles of the ring burner so this was adopted as a standard procedure.

4.3 Microbiological methods

4.3.1 Preparation and sampling of carcasses

Six sites on the carcass were identified as those most likely to be contaminated (e.g. close to cuts made to open body cavities) and which also were widely distributed over the carcass surface. These were the rump, belly, flank, brisket, shoulder and neck. Sites were randomly allocated to the carcass left/right sides.

* The parked position for the burner ring and hence its starting location at the beginning of a cycle was at the top of the rig, at the ‘up’ position

Each site was sampled using the excision method, as an earlier pilot study had identified a better recovery from these products using this method.

Each sample was defined by cutting a 5 cm^2 circle in the skin using a cork borer that has been pre-disinfected with azowipes, and removal completed using a sterile scalpel and forceps to lift and separate the circle of skin from the carcass. The skin samples were transferred aseptically to a labelled, sterile stomacher bag and stored on ice during transportation to the laboratory, each sampling site being kept separately and not pooled at this stage. When the comparison was with conventionally prepared, skin-off, carcasses, samples from corresponding carcass sites were removed to quantify carcass surface contamination. All samples were kept chilled prior to microbiological testing for *Enterobacteriaceae* (faecal contamination), and total viable counts (TVC, general contamination).

In specific investigations, the effect of chilled storage on the growth of microbial populations on skin-on carcasses was determined. These carcasses were stored in a chiller at 2-4 ^{0}C for a period of 5 days. After this time, sampling was carried out in exactly the same way as described above, and using the same sampling sites (from the complementary carcass sides). In addition to enumeration (see section 4.3.2), a 0.1ml sample from the 10^0 dilution of each after-chilling sample was enriched by adding it to 10ml heart infusion broth (HIB) and 10ml nutrient broth (NB) and incubated at 37°C and 30°C, respectively, for 24h. After 24h, a loopful from each HIB broth was spread onto VRBG agar, and a loopful from each NB agar spread onto PCA to examine for presence/absence of *Enterobacteriaceae* and TVC. VRBG plates were incubated at 37°C for 24h and PCA plates at 30°C for 72h.

4.3.2 Microbiological examination of the carcass samples

25 ml of MRD were added to each stomacher bag and each bag was stomached for two minutes to release bacteria from the surface. This was designated the original sample (10^0). Each sample was serially diluted in MRD to 10^{-3}. All four dilutions were plated (singly) onto plate count agar (PCA) using the 1 ml pour plate method, and 10^0 to 10^{-2} were plated onto violet red bile glucose agar (VRBG) using the 1ml pour plate method, to examine for TVC and *Enterobacteriaceae*, respectively. Once set, plates were incubated at 37ºC for 24h (VRBG) and 30ºC for 72 h (PCA).

All colonies on the PCA plates were counted, and only the dark pink/purple colonies counted on the VRBG. For each sample, the CFU/cm2 for TVC and *Enterobacteriaceae* were calculated using the following formula

$$\frac{N \times D \times V}{S}$$

N = count on the plate
D = dilution from the original sample i.e. count at 10^{-2}, D = 100
V = volume of liquid added to the stomacher bag
S = area of skin sampled (5 cm^2)

4.4 Microbiological validation of the skin-on carcass production: sequence of steps

4.4.1 Effect of including a toasting step after evisceration

The idea of including a toasting step arose as a result of observations on the 'finished' carcasses (often there were areas of insufficient browning after singeing) and from considerations of the properties of such carcasses that might be factors in subsequent microbial growth (toasting would beneficially dry the carcass surface).

Twenty carcasses were processed in three separate batches (8, 6 and 6). Within each batch, half the carcasses were singed, pressure-washed and eviscerated; the other half were similarly processed but a toasting step was included, following evisceration. Microbial counts were made on skin samples removed immediately after carcass production and after refrigeration.

4.4.2 Carcass splitting before and after toasting

If sheep (or goats) have one or more permanent incisors erupted through the gum, either the entire vertebral column has to be removed or the carcass has to be split and the spinal cord removed. This is because the spinal cord of such animals is categorized as one component of SRM (Specified Risk Material), posing a (theoretical) risk of transmission of spongiform encephalopathy disease to consumers. The additional handling of the carcass to perform splitting and the contact between the saw and the carcass may introduce contamination. This trial was conducted to determine whether measurably greater microbial contamination occurred on carcasses toasted before splitting compared to carcass sides toasted after splitting.

Twenty carcasses were processed in three separate batches (6, 10, and 4). All the carcasses were singed, pressure-washed and then eviscerated. Following evisceration, half the carcasses in each batch were split before toasting, and the other half of each batch had the toasting step carried out before splitting.

4.4.3 Carcass hygiene inspection before and after toasting

Current carcass inspection procedures involve manual handling of the carcass to some degree, for example using palpation to detect inoculation abscesses, incision of joints. Although inspectors will observe the rules of personal hygiene, such handling may, nevertheless, introduce contamination. This trial was conducted to determine whether measurably greater microbial contamination occurred on carcasses toasted before inspection compared to those toasted after inspection.

Twenty carcasses were processed in three separate batches (8, 8 and 4). Two meat inspectors were used to perform the carcass inspections in their customary ways. Batch 1 was inspected by Inspector A who confined the inspection to a visual and palpatory examination. Inspector B examined batches 2 and 3 and, as well as performing some palpation, incised the joints of the hind

limbs. Within each batch, half the carcasses were singed, pressure-washed, eviscerated, toasted and then inspected; the other half were similarly processed but inspection preceded the toasting step. Microbial counts were made on skin samples removed immediately after carcass production.

4.4.4 Comparison of microbial status between conventionally produced and smoked, skin-on sheep carcasses produced according to the evolved protocol
The qualitative/semi-quantitative results of the investigations described under Sections 4.2.1 to 4.2.4, together with the quantitative microbiological results of the investigations described under Sections 4.4.1 to 4.4.3, led to a carcass production protocol whose sequence of steps resulted in the lowest levels of microbial contamination. In order to place the hygienic status in context, microbiological comparisons were made between the carcasses produced according to this protocol and conventionally dressed and skinned sheep carcasses processed in the same abattoir.

Twenty carcasses were processed in three separate batches (8, 6 and 6). Within each batch, half the carcasses were produced according to the smoked, skin-on protocol; the other half were conventionally dressed, a procedure that included carcass skinning following slaughter. Microbial counts were made on skin samples removed immediately after carcass production and after refrigeration.

4.5 Shelf life of skin-on sheep meat

4.5.1 Microbiology
The smoked, skin-on sheep carcass is an unusual product in the developed world and is new to meat science. The nature of the smoked skin surface may well determine how it supports or suppresses microbial populations post production. Because the shelf life of a product is of high importance to the meat retailing industry, and because nothing was known of the shelf life of this type of meat, a comparison was made with conventionally produced sheep meat.

4.5.1.1 Preliminary study to identify microflora
The first aim was to determine which spoilage organisms were present on the smoked skin. One carcass was produced using the best practice skin-on protocol (see Figure 7) then stored under chill conditions for 24h. Boneless meat comprising lean, fat and skin, was dissected from the shoulder, breast, loin and leg, cubed, mixed, and 200 g were put into each of four polyfoam meat retail trays. Trays were over-wrapped with oxygen-permeable plastic film and stored at 2-4 ^{0}C. One tray was removed and sampled immediately (Time 0) to give an indication of the starting microflora on the product. The further three trays were removed from the chiller and sampled after each of 3, 6 and 9 days further storage.

All the meat from a tray (200 g) was placed in a sterile bottle, 300 ml MRD added and the contents mixed. A sub-sample was transferred to a stomacher bag and the bag was stomached for two minutes. The resulting diluent was

denoted as the original sample (10^0). Samples were further serially diluted to 10^{-3} in MRD. Each dilution was plated, singly onto the following agars, using the 0.1 ml spread plate method:

Agar	Organism	Growth conditions
PCA	TVC	22ºC & 30ºC for 72h
MRS	Lactobacilli	25ºC, 72h & 30ºC, 48h
Rose-bengal	Yeast/moulds	22ºC for 5 days
CFC agar	*Pseudomonas* spp.	25ºC & 30ºC for 48h
STAA agar	*Brochothrix thermasphacta*	22ºC & 25ºC for 48h

Agars were examined for the relevant bacteria and the number of bacteria per gram of meat were calculated using the formula.

$$\frac{N \times D \times V}{G}$$

N = count on the plate
D = dilution from the original sample i.e. count at 10^{-2}, D = 100
V = volume of liquid added to the stomacher bag
G = amount of meat used in grams

4.5.1.2 Comparison of shelf life between skin-on and conventional sheep meat
These studies compared the shelf life of the smoked, skin-on product with meat from conventionally dressed sheep carcasses. Five carcasses of each category were used (two lots: 6 and 4) and the day following slaughter pieces of boneless meat were removed from the shoulder, breast, leg and loin of each carcass. Each piece of meat was chopped into cubes (approx 1 x 1 x 1 cm) and 50g of this meat added to each of four polyfoam retail meat trays (one for each storage period and meat type). Each of the resulting 160 trays was then over-wrapped with oxygen-permeable plastic film and labelled with the carcass number, sample site and storage period (0, 3, 6, 9 days). Each tray was then placed in a chiller at 4ºC with lighting to simulate storage in retail display cabinets. Trays were removed separately from the chiller at the designated times and bacterial counts (total viable count, *Lactobacillus* spp., *Pseudomonas* spp., yeasts and moulds) were determined as above (4.5.1.1) but with 50 g meat added to 100 ml MRD. and only one temperature for each type of agar, as follows:

Agar	Organism	Growth conditions
PCA	TVC	22ºC for 72h
MRS	Lactobacilli	25ºC, 72h
Rose-bengal	Yeast/moulds	22ºC for 5 days
CFC agar	*Pseudomonas* spp.	25ºC for 48h

4.5.2 Meat colour and rancidity

Meat cubes from each of the ten carcasses in 4.5.1.2 and from each of the four sampling sites (40 samples altogether) were placed in separate trays which were over-wrapped and stored under the same conditions as the samples for microbial testing. Colour of the lean meat in these trays was measured daily for six days using a Minolta Chromameter to record the CIELAB colour space coordinates L* (lightness/darkness), a* (redness/greenness) and b* (yellowness/ blueness). When muscle tissue is exposed to air during retail display in plastic trays overwrapped with plastic film, the desirable bright red colour is first produced, resulting from oxygenation of the muscle pigment myoglobin to oxymyoglobin. After a few days, the oxymyoglobin at the surface of the meat begins to oxidize (the change from the ferrous Fe++ form to the ferric Fe+++ in the haem pigment) and brown metmyoglobin is formed.

The change in the visual appearance of meat that occurs during storage is reflected in the degree of saturation of colour. This is a measure of the colour intensity or 'lack of dullness' [7]. It is dependent on the values of the coordinates a* and b*, being the square root of the sum of the squares of these values.

After six days storage, rancidity development (lipid oxidation) was estimated by measuring the thiobarbituric acid reacting substances (TBARS) [8].The main chemical so measured is malonaldehyde which is a secondary oxidation product of polyunsaturated fatty acids (containing more three or more double bonds).

4.6 Visibility of the Health Mark after toasting

If inspection is to precede toasting, and the Health Mark is applied immediately following inspection, then the mark will need to withstand the toasting process and be clearly visible afterwards.

A stamp used to signify boar taint, taking the form of two parallel lines, was used to represent the Health Mark as it was not permissible to use the Health Mark itself on a carcass that did not meet the legislative requirements for human consumption. The mark was applied to the leg and loin of a singed, washed and eviscerated carcass and the carcass was then toasted. Photographs of the mark before and after singeing were taken.

4.7 Assessment of the organoleptic properties of skin-on carcasses and meat by assessors with previous experience of the product

The aim of this task was to establish if the skin-on products were of acceptable quality to consumers (to determine their 'affective status', using sensory science terminology). Assessment of the quality of the finished products was made by a panel comprising seven African postgraduate students from the University of Bristol with previous experience of these meats. Five of these were Nigerian males and two were Ghanaian males. All were under 30 years of age except

one Ghanaian, who was more than 40 years old. These assessors were recruited from an intra-university trawl and details of their previous handling and eating experiences with skin-on smoked products were obtained using a questionnaire.

The following assessments were made:

(a) Carcass appearance. Three female sheep carcasses prepared according to the standard skin-on protocol were suspended on gambrels from the hind limbs. Two assessments were made of the carcass appearance: was it typical/atypical (two-choice question); and was it acceptable (eight-point category scale ranging from extremely acceptable to extremely unacceptable – Appendix B)

(b) Cubed raw meat cut from one of the carcasses in (a) was assessed for its acceptability using the eight point category scale (Appendix B).

(c) Cooked meat. Cubed meat cut from one of the carcasses in (a) was cooked in water in a lidded pan until the meat aroma was very evident. Each assessor in turn assessed the aroma for its acceptability using the eight point category scale (Appendix B).

4.8 An abattoir survey of lesions in slaughtered sheep

This survey was conducted to provide background information on the type and frequency of lesions which could potentially be obscured if the skin were to be left on the carcass. The survey involved monthly visits, over a period of one year, to a cooperative abattoir, situated in the West Midlands, whose kill comprised a large proportion of cull ewes.

Prior discussion with MHS veterinarians resulted in a list of conditions that were considered to be of most relevance to this exercise. These were set out in the form of a recording sheet that was used to log the observations made by a Bristol University technician who was a qualified meat inspector. This sheet is shown in Appendix N.

The observer was present at the start of kill, at approximately 05:30 am, and stood at a point on the slaughter line immediately post-evisceration where he inspected the outer carcass surface for lesions. Condemnations were made by MHS staff and noted. Any abscesses missed by the technician and noted by the MHS Meat Inspector were pointed out and included in the total. Likewise, the technician informed the Meat Inspector of lesions that he found in advance of the carcass reaching the Inspector. On each observation day, observations were made for approximately 9 hours, less breaks, and terminated around 14:00 – 14:30h. The number of carcasses observed on most visits approached, or slightly exceeded, 1000.

4.9 Statistical analysis

For the trials conducted on skin-on carcass production (described in section 4.4), the detectable threshold for both *Enterobacteriaceae* and TVC was 5 CFU/cm^2 (for 5 cm^2 excision samples) For levels below this threshold, a value of 2.5 CFU/cm^2 was used in the data analysis.

For the preliminary shelf-life study, the detectable limit was 1.18, arrived at as follows: 200 g of meat was added to 300 ml of MRD; this gave the 10^0 sample. Samples were serially diluted in MRD; 0.1ml sample plated out using the spread plate technique. Therefore, 1 colony on the 10^0 plate, comes from 200 g of meat added to 300ml MRD

1 x 1 x 300/200 = 1.5 CFU/g in 0.1 ml which is 15 CFU/g in a 1ml sample. The Log_{10} of 15 is 1.176 = 1.18

For the main shelf life study, the detectable limit was 1.18, arrived at as follows: 50 g of meat was added to 100 ml of MRD; this gave the 10^0 sample. Samples were serially diluted in MRD; 0.1ml sample plated out using the spread plate technique. Therefore, 1 colony on the 10^0 plate, comes from 50 g of meat added to 100 ml MRD

1 x 1 x 100/50 = 2 CFU/g in 0.1 ml which is 20 CFU/g in a 1 ml sample. The Log_{10} of 20 is 1.30

Effects of treatments were obtained from analysis of variance using Minitab. For variables whose F-ratio probabilities were significant ($P \leq 0.05$), the Tukey HSD test was applied to calculate adjusted P-values for all pairwise comparisons of treatments. Means that were thus found to be significantly different are indicated in the Analysis of Variance Results Tables (see Appendices) as those lacking a common superscript.

5. Results and Discussion

5.1 Preparation of skin-on sheep feet at a commercial abattoir

The microbiological results for the twelve sheep feet produced commercially are shown in Table 1. The sheep feet that had had the gland removed and the bone trimmed, were significantly more contaminated (P<0.05 for wet/dry swabbed samples and P<0.001 for excised samples) than those which had no further handling after treatment. Clearly these process steps that took place after the feet were singed introduced microbial contamination. More specifically, *Enterobacteriaceae* counts were below the detectable limit of the sampling for the intact sheep feet, but were detected at low levels from those which had been subject to further handling. For those feet where the gland had been removed, recovery of the total viable count by excision sampling was found to be significantly higher (P<0.05) than the recovery by wet/dry swabbing. No significant difference was found in the recovery of *Enterobacteriaceae* from these feet by the two sampling methods used, although there was a higher recovery of *Enterobacteriaceae* from the excised samples.

Table 1. *Enterobacteriaceae* and TVC counts on the surface of singed, skin-on sheep feet produced commercially at an abattoir

Foot No.	Type	Sampling	*Enterobacteriaceae* (CFU/cm^2)	TVC (CFU/cm^2)
1	Intact	Swab	< 12.5	1.75×10^3
2	Intact	Swab	< 12.5	1.40×10^3
3	Intact	Swab	< 12.5	2.55×10^3
4	Intact	Excision	< 50.0	4.10×10^4
5	Intact	Excision	< 50.0	8.95×10^3
6	Intact	Excision	< 50.0	6.60×10^3
7	Gland removed	Swab	12.5	3.04×10^6
8	Gland removed	Swab	12.5	3.38×10^6
9	Gland removed	Swab	25.0	1.80×10^6
10	Gland removed	Excision	50.0	5.9×10^6
11	Gland removed	Excision	100.0	7.85×10^6
12	Gland removed	Excision	200.0	6.10×10^6

Enterobacteriaceae counts of <12.5 (swabbing) and <50.0 (excision method) for the intact feet were below the detectable levels. The threshold for intact feet sampled by swabbing was lower than for intact feet sampled by excision because of the different areas of skin sampled in the two methods and the resultant dilutions for plating out. For gland-removed feet sampled by swabbing, a value of 12.5 means one bacterium was detected, 25.0 means 2 bacteria detected. For gland-removed feet sampled by excision, a value of 50.0 means 1

bacterium detected, 100.0 means two bacteria and 200.0 means four bacteria detected.

5.2 Skin-on carcass production; a pragmatic evaluation of alternative methods

5.2.1 Hot water treatment

Following immersion in a pig scald tank at 60^0C for six minutes, wool was removed from the carcass by manual scraping. This method of removal was time consuming but eventually quite large areas of the wool could be removed although this was difficult in some places. After singeing with a gas torch a satisfactory finish was achieved, the colour of the skin varying between golden to 'brown toasted', depending on the duration of exposure to the flame.

The second carcass was similarly scalded and was put through a mechanical pig dehairer. The head got stuck and eventually a forelimb broke. There was some evidence that a mechanical de-wooling would work but the design specification for the pig machine was wrong as the sheep carcass was smaller than those of commercial slaughter pigs. The third carcass was also scalded and put through the dehairer after removal of feet and head. Even so, the carcass still got stuck and was incompletely de-wooled at the end.

In the second trial, the efficacy of different time x scald temperature combinations was explored more fully and the ease of wool removal was assessed (Table 2).

Table 2. Consensus scores for wool removal. Score range 1 to 10 where1 = no wool removed; no skin visible; 10 = wool easily removed; large areas of skin visible.

	Scald water temperature		
Immersion duration	60^0C	65^0C	70^0C
5 min.	*Carcass no. 1* Rump:7 Neck: 4 Belly: 1	*Carcass No. 3* Rump:9 Neck: 5 Belly: 9	*Carcass no. 5* Rump:10 Neck: 10 Belly: 10
7 min.	*Carcass no. 2* Rump:4 Neck: 1 Belly: 6	*Carcass no. 4* Rump:9 Neck: 5 Belly: 9	*Carcass no. 6* Rump:7 Neck: 5 Belly: 6

These results must be interpreted as indicative only as there were no replicate observations within any treatment cell. However, it seems that there was no advantage in extending the immersion time from 5 to 7 minutes. Indeed, there may be disadvantages for meat quality as superficial tissues may undergo protein degradation with prolonged heating (there was no direct evidence for this but subdermal temperature, measured in this trial by a temperature probe,

reached 52°C even when water temperature was 60°C, and several protein-related changes occur at temperatures of 30-40°C. There was evidence of better wool removal with increasing temperature, with a bigger difference between 60 and 65°C than between 65 and 70°C.

Overall, scalding to remove wool was not consistently effective and, although there was no objective basis for between animal variation in ease of wool removal, observations from this and the earlier trial suggested that there may indeed be animal factor(s).

5.2.2 Hot air singeing

Gun A was fitted with a flat, wide nozzle and it quickly blackened the wool of the first carcass in an even manner but scraping was necessary to reveal the skin for further singeing. Gun B was not fitted with a nozzle but it worked quite well, 'opening up' the scorched fleece and seemingly removing some charred wool from the surface. Again, some scraping was necessary to remove all the wool.

The second carcass was scalded in the pig tank (62°C for approximately 9 minutes) and scraped by pig scraper and knife to remove wool, the intention being to assess how well the hot air burners could singe the naked skin. The right side of the ventral surface was singed with Gun B and the left side with Gun A (one area without the nozzle, another with). There was not much difference between guns, and although a pale golden (and even) colour could be achieved, it took a lot longer than with the gas torch previously used in pilot trials.

The second carcass was pressure washed following skin singeing and this removed some of the more heavily blackened areas where residual wool had charred.

The conclusions from this trial were (a) hot air blowers were too slow in singeing the wool to be of practical application, and (b) a washing step would likely be necessary to remove charred wool following singeing.

5.2.3 Naked flame (gas torch) singeing

This objective of this trial was to determine the general effects of singeing wool using a hand-held gas torch. The general conclusions from this qualitative assessment were:

- On shorn sheep, the amount of smoke produced was not great but was substantially more for sheep with a longer fleece.
- Non-eviscerated carcasses were preferable for the following reasons:

  The bung end (anus) was not released so there was no exposed meat in the anal area or along the ventral midline which would be cut to remove the abdominal organs. Exposed meat undergoes a degree of cooking under a gas flame and there are unsatisfactory colour changes.

If washing after singeing is necessary then a non-split carcass is under a reduced risk of contamination inside the body cavities.

If wool residues after singeing need to be removed by scraping or brushing, this is easier on the 'full' abdomen than on the slack abdominal wall of an eviscerated carcass. The abdomen became taut after singeing to give a firm surface to clean.

The effects of singeing, and consequent heating of the carcass surface, on subsequent processes in the evisceration operation were not known.

- The best results were obtained by a repeated cycle of singe – scrape, singe –scrape, where 'scrape' means either using a knife or a stiff–bristled brush, finishing with a wash. Burning for longer, without scraping, followed by a wash resulted in very short fibres remaining ('5 o' clock shadow') and the skin was insufficiently singed.
- Post-singe washing was necessary to remove black deposits of burnt skin/lanolin. The power wash was effective at doing this but water under normal pressure was not tried. The quantity of water used was dependent on the time taken to effectively remove charred deposits and this varied between carcasses, due to a number of factors. In the production SOP it is stated "pressure wash until washed region stops changing colour". Water use was not measured directly but was estimated, based on the washer rate of throughput and a wash time of one and a half minutes, to be approximately 20 litres per carcass.
- The black-wooled sheep gave an unappetising carcass as the surface was a dark grey even after extensive singeing.
- The conclusion was that there are two steps in the required process: wool removal followed by singeing of the skin. One way forward would be to achieve a higher, evenly distributed singeing temperature followed by a cleaning step, possibly based on mechanical scraping. Equipment to enable this needed to be designed and constructed.

5.2.4 Construction of a singeing rig

The details of the rig construction and the proving trials are given in Appendix A.

5.3 Microbiological validation of the skin-on carcass production; sequence of steps

The results of these trials are presented as bar charts as these clearly show treatment effects. Full tabulated results and statistical analysis are presented in the Appendices.

5.3.1 Effect of including a toasting step after evisceration

This trial was designed to examine whether a further heat treatment after evisceration would reduce microbial contamination of the carcass. The microbiological results for the comparison between singed, skin-on carcasses

and similar carcasses that were toasted post-evisceration, are shown in Figs. 1 and 2.

The carcasses that did not have the final toasting step applied had higher site mean counts (log_{10} CFU/cm$^{2)}$ of *Enterobacteriaceae* (0.96 vs. 0.43 pre-chill; 0.55 vs. 0.40 post chill) and TVC (2.69 vs. 0.99 pre-chill; 2.20 vs. 0.90 post-chill) than those which had undergone the final toasting step (Appendix C).

There was a significant interaction between the treatments (toast/no toast and before/after chill) for overall carcass levels of *Enterobacteriaceae* but not for TVC (Appendix C; P = 0.005 and 0.412, respectively). There was a tendency for counts to decrease after chilling in each comparison but it was significant only for *Enterobacteriaceae* on the non-toasted carcasses.

There were no significant differences in the mean number of *Enterobacteriaceae* CFU/cm^2 between the non-toasted carcasses after chilling and toasted carcasses both before and after chilling. However, non-toasted carcasses had significantly higher levels of TVC than toasted ones both before and after chilling so the extra heat treatment had a lasting effect on total bacterial numbers. Only one carcass had detectable levels of *Enterobacteriaceae* immediately after toasting, and then in just three of the six carcass sites examined, with a maximum count of 40 CFU/cm^2. This contrasts with the non-toasted carcasses of which every one had detectable levels of *Enterobacteriaceae* on at least one carcass site and just over one half (36) of the total 60 sites had no detectable levels of *Enterobacteriaceae.*

On seven of the ten non-toasted carcasses, the sample sites which had the highest *Enterobacteriaceae* counts were either the belly or the brisket; no site had consistently the highest TVC counts on these carcasses.

Although chilling reduced site bacterial numbers overall, the TVC counts on the belly showed some increases in numbers after chilling, particularly on the toasted carcasses (eight of the ten carcasses), with increases of up to two log units. After chilling, 11 of the 51 non-toasted samples and 0 of the 60 toasted samples that had undetectable levels of *Enterobacteriaceae* gave positive results after enrichment. Corresponding figures for TVC were 5 of 12 (non-toasted) and 10 of 36 (toasted).

Clearly, there is a degree of microbial re-contamination of the carcass during evisceration but the toasting step reduces this by a substantial degree. Toasting is a recommended step in the process.

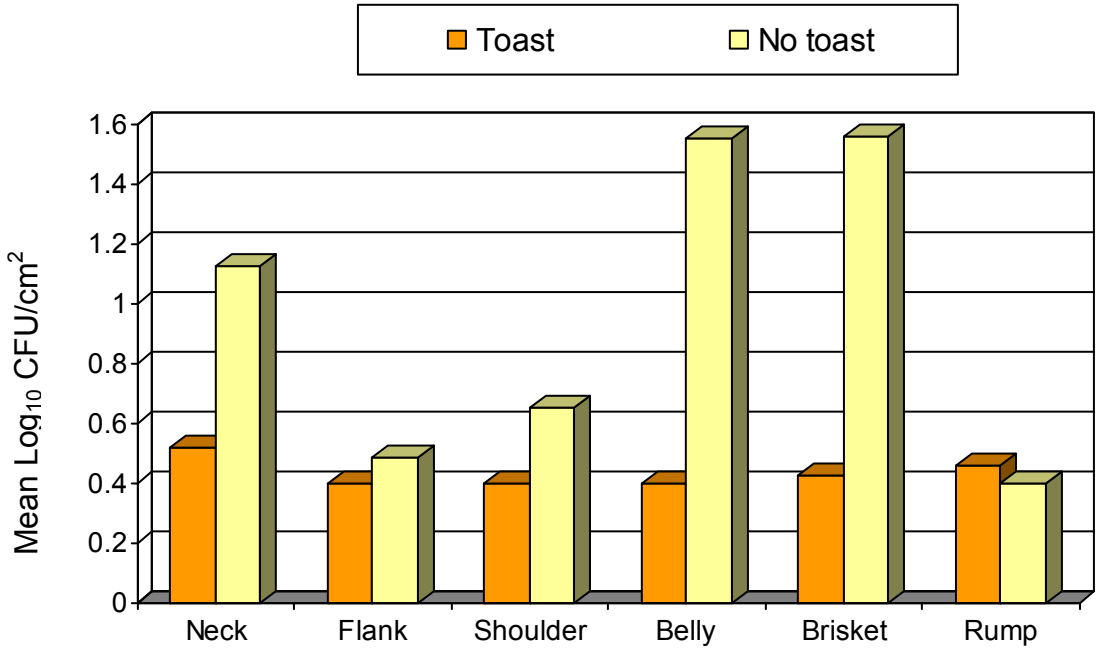


Figure 1. The effect of including toasting as a final dressing step on the number of *Enterobacteriaceae* on six sites on the carcass immediately after preparation

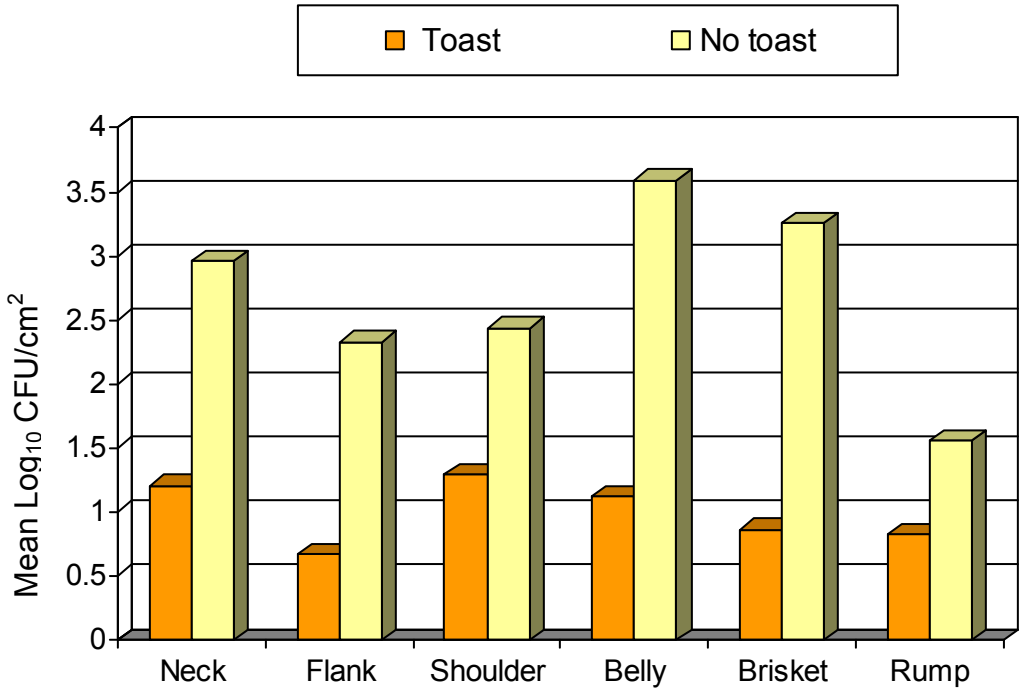


Figure 2. The effect of including toasting as a final dressing step on the number of TVC on six sites on the carcass immediately after preparation

5.3.2 Effect of splitting the carcass before or after toasting on its microbiology
If the carcass has to be split to meet legislative requirements the additional handling and contact with equipment may introduce contamination. This trial was conducted to determine whether measurably greater microbial contamination occurred on carcasses toasted before splitting compared to carcass sides toasted after splitting

Overall, the counts of both *Enterobacteriaceae* and TVC (Log_{10} CFU/cm^2) were low irrespective of whether the carcasses were split before or after toasting (Figs. 3 and 4). The difference between treatments in numbers of *Enterobacteriaceae* was not significant (full tabulated results and statistical analysis are shown in Appendix D). However, differences in TVC were significant (P= 0.003) and counts at some sites on the carcasses that were split after toasting were up to 1 log_{10} CFU/cm^2 more than on those split before toasting, with the brisket area showing the highest bacterial counts on these carcasses (Fig. 4).

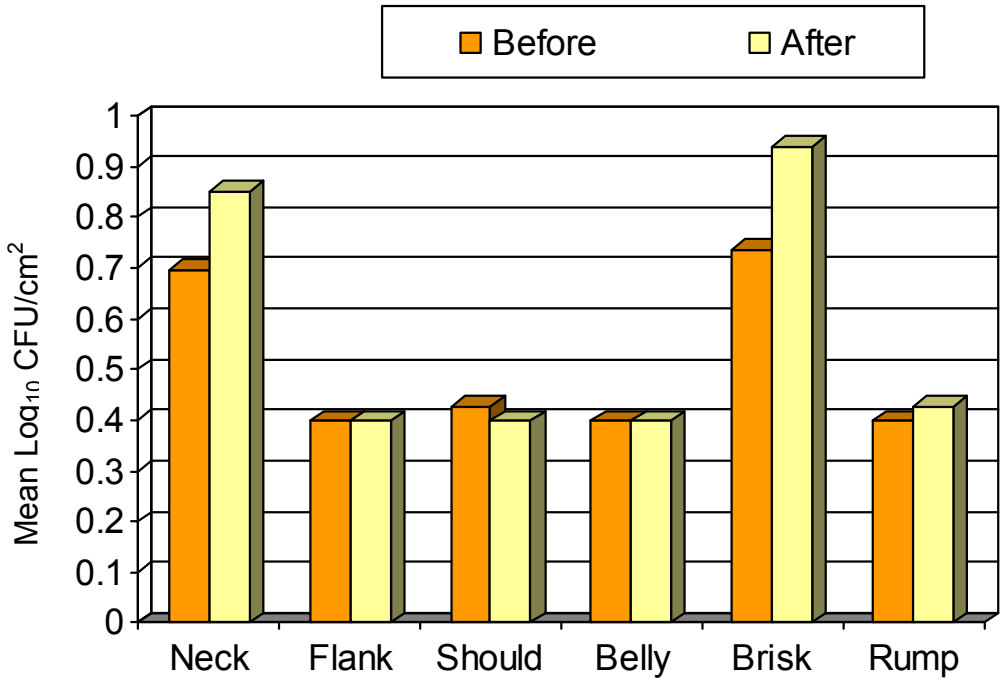


Figure 3 The effect of splitting the carcass before or after toasting on the number of *Enterobacteriaceae* on six sites on the carcass immediately after preparation.

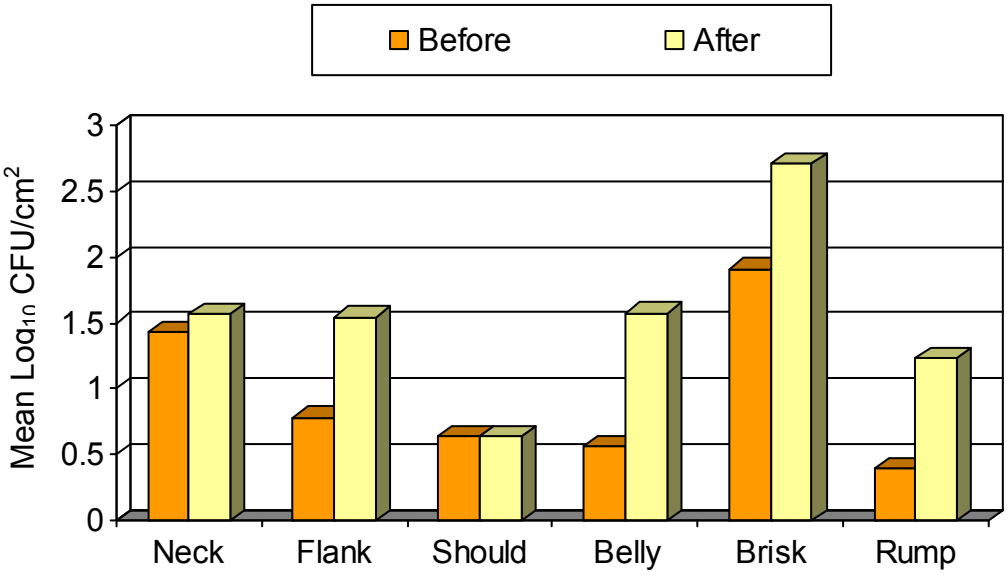


Figure 4. The effect of splitting the carcass before or after toasting on the number of TVC on six sites on the carcass immediately after preparation.

There was little difference between the treatments in the number of undetectable *Enterobacteriaceae,* being 53 out of a possible 60 for those split before toasting and 50 of 60 for those split after toasting. However, for TVC, the difference between treatments was greater, with undetectable returns being 36 and 19 out of a possible 60, for splitting before and after toasting, respectively (Appendix D).

It is concluded that the additional handling required to split the carcass does introduce a small amount of additional contamination to a toasted carcass that has low initial levels of contamination. It is recommended that splitting be performed prior to the toasting step. To avoid partial cooking of the carcass tissues exposed after splitting, it may be preferable to configure the gas burners so that the medial surface of the carcass is not directly flamed (this was not done in the described trials).

5.3.3 Effect of inspecting the carcass before or after toasting on its microbiology
This trial was conducted to determine whether the handling necessary to conduct a carcass inspection using current procedures results in a measurably different level of microbial contamination when performed before or after toasting. The results are shown in Figs. 5 and 6. Full laboratory results and statistical analysis are shown in Appendix E.

As in the time of splitting comparison, the overall levels of microbial contamination were low and there was no difference in numbers of *Enterobacteriaceae* when carcasses were inspected before or after toasting (P= 0.833) (Appendix E). TVC were clearly more prevalent on the carcasses inspected after toasting and the mean difference was highly significant

(P=0.004). There were 20 occurrences of counts of 2–5 Log_{10} CFU/cm^2 compared with 9 occurrences of counts of 2–3 Log_{10} CFU/cm^2 on carcasses inspected before toasting.

The highest levels of contamination were seen on the neck region, for both *Enterobacteriaceae* and TVC and in both treatments. This probably reflects the inclusion of some larger (longer) carcasses whose neck region was not completely singed or toasted because the lower limit of burner travel in the rig was set too high.

There was no significant difference between the treatments in the number of undetectable *Enterobacteriaceae*, being 56 out of a possible 60 for those inspected before toasting and 54 of 60 for those inspected after toasting. For TVC, the difference between treatments was greater, with undetectable returns being 32 and 21 out of a possible 60, for inspection before and after toasting, respectively (Appendix E).

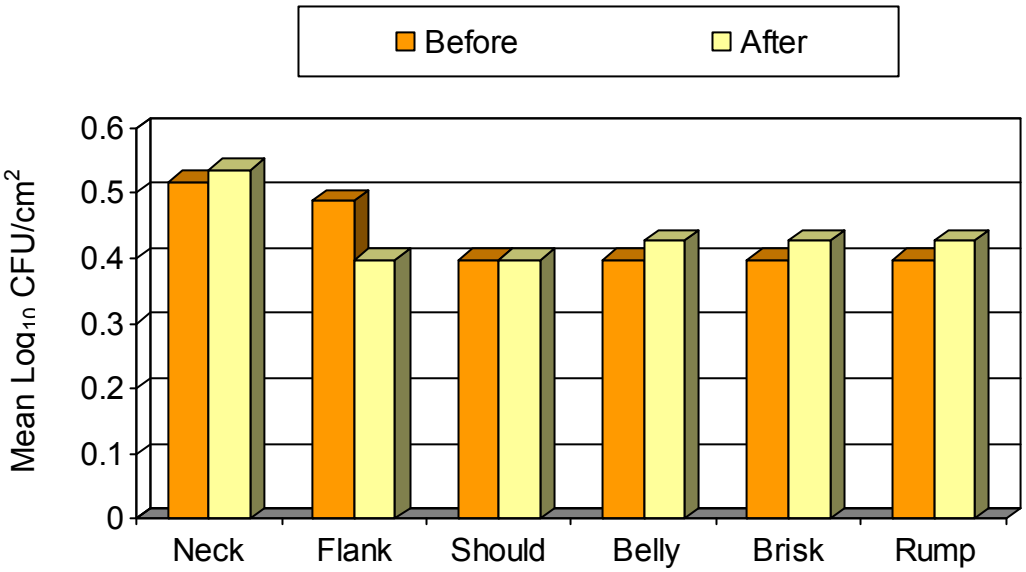


Figure 5. The effect of inspecting the carcass before or after toasting on the number of *Enterobacteriaceae* on six sites on the carcass immediately after preparation.

.

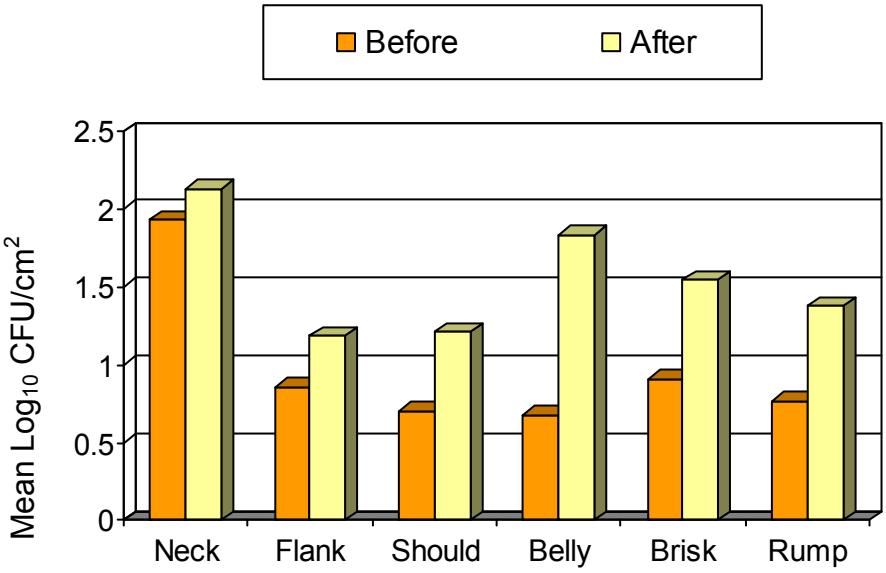


Figure 6. The effect of inspecting the carcass before or after toasting on the number of TVC on six sites on the carcass immediately after preparation..

5.3.4 Comparison of microbial status between conventionally produced and smoked, skin-on sheep carcasses produced according to the evolved protocol
Based on all the previous results in section 5.3, a best practice protocol emerged in which the sequence of individual steps was as shown in Fig. 7.

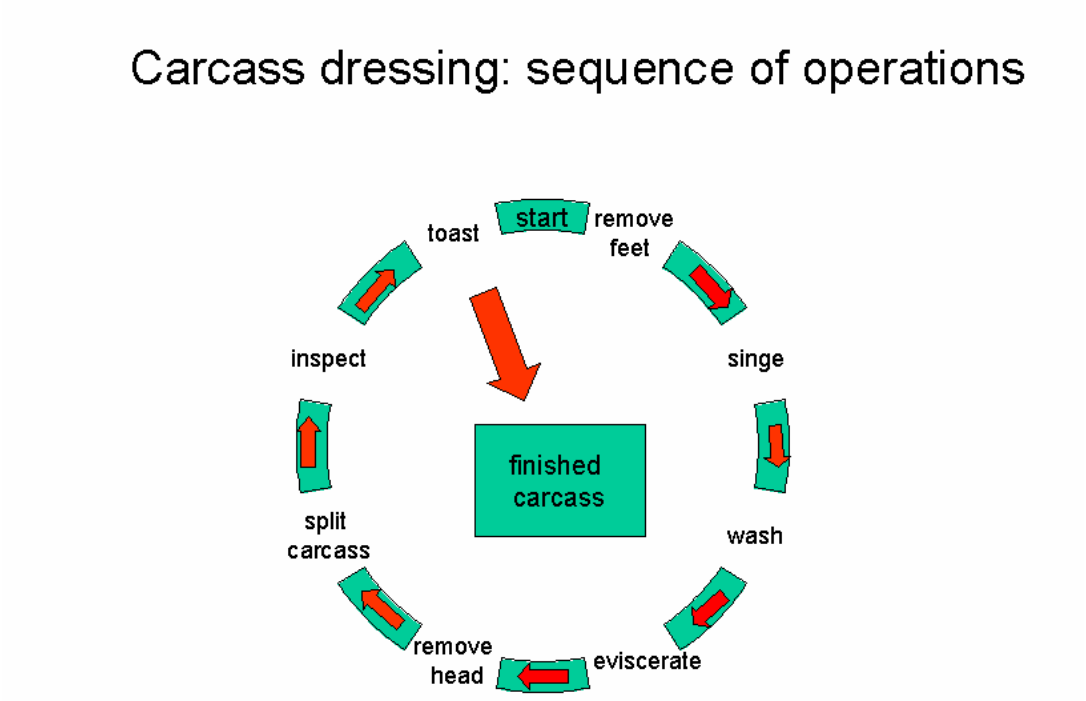


Figure 7. Sequence of steps in the best practice protocol for the production of skin-on sheep carcasses.

In order to demonstrate the microbiological quality of carcasses produced according to this protocol, comparisons were made with carcasses dressed conventionally in the same abattoir. The results are shown in Figs. 8 and 9 for carcasses immediately post preparation (pre-chill). Full laboratory results and statistical analysis are shown in Appendix F.

The conventional carcasses had higher *Enterobacteriaceae* numbers on the sites sampled (Fig. 8), with a minimum mean value of 0.7 Log_{10} CFU/cm^2 (rump site) compared with a maximum of 0.5 Log_{10} CFU/cm^2 for the skin-on carcasses (neck site). The belly and brisket sites were the most heavily contaminated by *Enterobacteriaceae* in the conventionally dressed carcasses, a finding in agreement with Zweifel and Stephan (2003), but corresponding counts on the skin-on carcasses were not at detectable levels (Fig. 8). In total, there were 58 of the possible 60 counts of *Enterobacteriaceae* below the detectable level of 5 CFU/cm^2 in the skin-on carcasses compared with 34 of 60 in the conventionally dressed carcasses. For TVC, 35 of the possible 60 counts were below the detectable level of 5 CFU/cm^2 in the skin-on carcasses compared with 5 of the

possible 60 in the conventionally dressed carcasses. When detected, TVC were consistently above 2 Log_{10} CFU/cm^2 at the different sites on the conventionally dressed carcasses but only just exceeded 1 Log_{10} CFU/cm^2 on the skin-on carcasses (Fig. 9).

There were significant interactions (Appendix F) between the treatments (conventional/skin-on and before/after chill) for both *Enterobacteriaceae* and TVC ($P < 0.001$ and 0.039, respectively). For both groups of bacteria, counts on conventional carcasses were lower after chilling than before but there were no differences for the skin-on carcasses. The *Enterobacteriaceae* and TVC results for the skin-on carcasses, both pre- and post-chill, are very similar in magnitude to the values shown in Appendix C for the toasted carcasses.

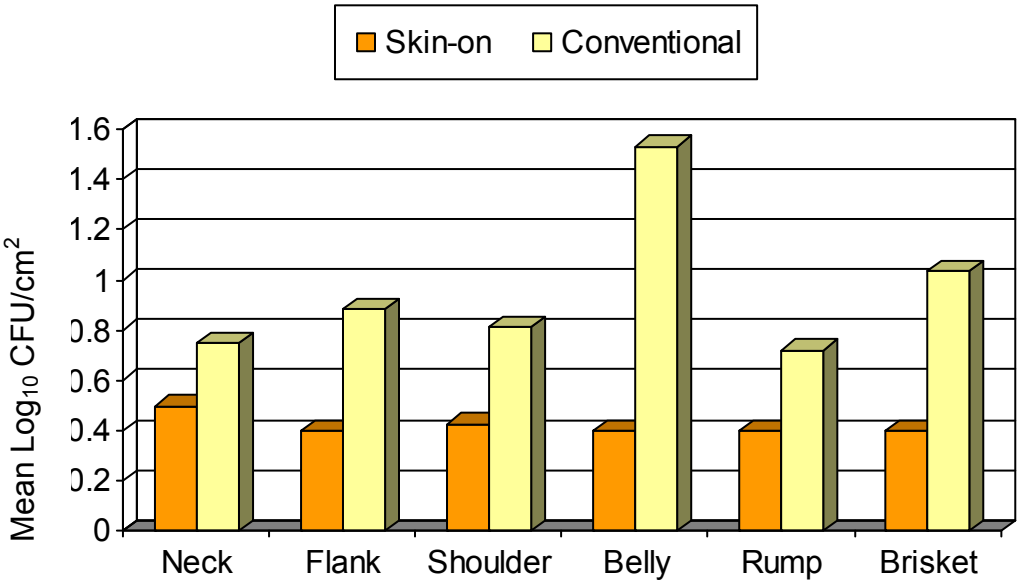


Figure 8. Comparison of *Enterobacteriaceae* counts between conventionally dressed and skin-on carcasses produced according to the standard protocol on six sites on the carcass immediately after preparation

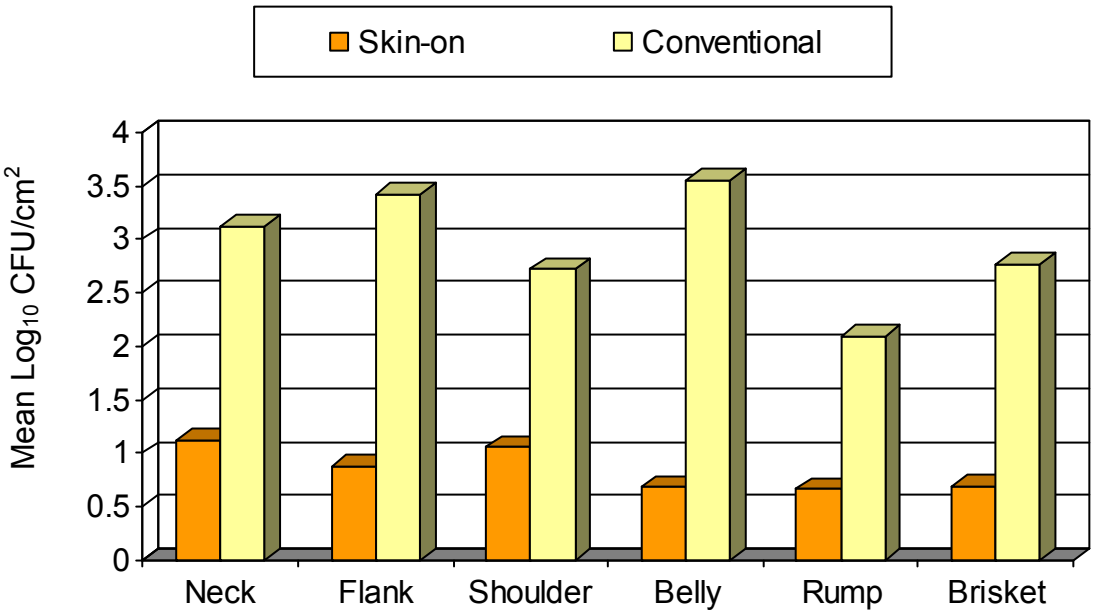


Figure 9. Comparison of TVC counts between conventionally dressed and skin-on carcasses produced according to the standard protocol on six sites on the carcass immediately after preparation

5.4 Shelf life

The shelf life of meat is determined by three factors:

(a) colour of lean
(b) rancidity of lipids
(c) spoilage by microorganisms

In overwrapped, fresh meat the deterioration usually occurs in the order in the listing, above, so the first quality characteristic to decline to unacceptable levels is the colour of the lean. However, there are interactions between the oxidising and oxidative processes affecting colour, rancidity and growth of some bacteria so a more complete understanding of the problem is achieved by measuring all three parameters especially as the progression of spoilage was not known in the skin-on, smoked product.

5.4.1 Microbiology

5.4.1.1 Preliminary study to identify microflora

All groups of presumptive spoilage organisms were present and exhibited growth over nine days storage (Fig. 10). There was no great change in numbers over the first three days and the greatest change was seen between days three and nine. The highest counts were for the *Pseudomonas* species and the TVC after six and nine days. The most rapid growth was seen in the *Pseudomonas* species after day three. The full results are given in Appendix G.

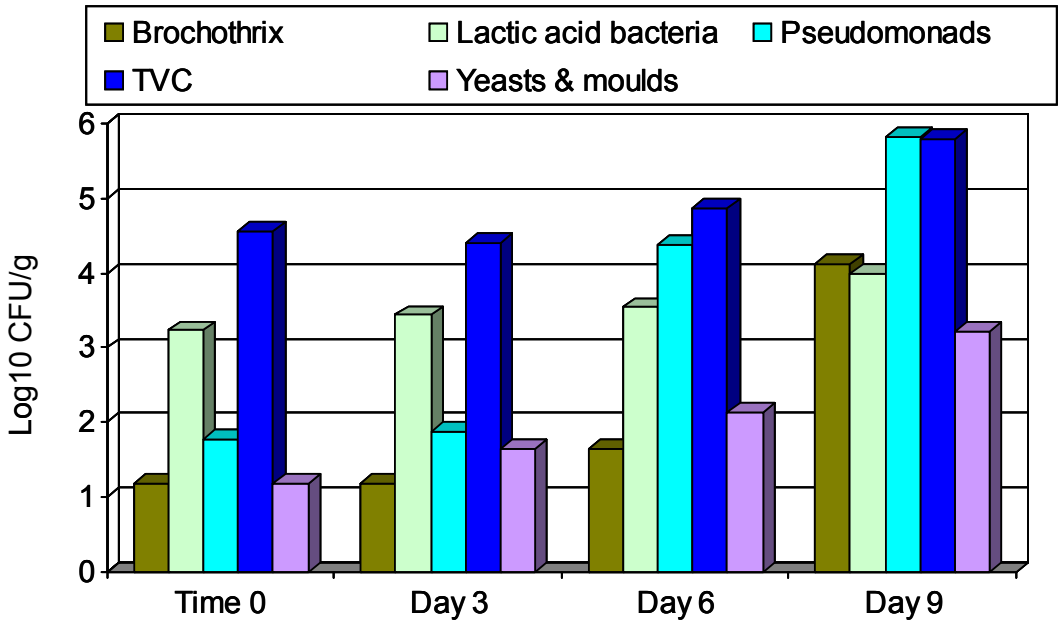


Figure 10. Prevalence of five groups of microorganisms on skin-on sheep meat in overwrapped trays at 2-4^{0}C, stored for 9 days.

5.4.1.2 Growth of microorganisms on skin-on and conventional sheep meat

All spoilage groups present in the preliminary study were represented in the comparative samples, except *Brochothrix* (Figs 11-14). Full laboratory results and statistical analysis are shown in Appendix H. The counts at time zero (immediately after carcass production) tended to be somewhat lower in the comparative study than in the preliminary study with the exception of the yeasts and moulds. However, there was a more marked growth of all groups up to day nine in the comparative study when they exceeded counts in the preliminary study by 2-3 Log_{10} CFU/g (4 Log_{10} CFU/g for yeasts and moulds). More importantly, there were no major differences between the conventional and skin-on meats, presumably because the handling involved in removing, cutting and packing the samples contaminated both products equally and the initial microbial loading was of little consequence. For lactic acid bacteria, counts at the start of the display period (day zero) were higher on the skin-on meat than on conventional meat but the opposite was seen on days three, six and nine, resulting in a significant ($P = 0.034$) interaction between days and meat type (Appendix H).

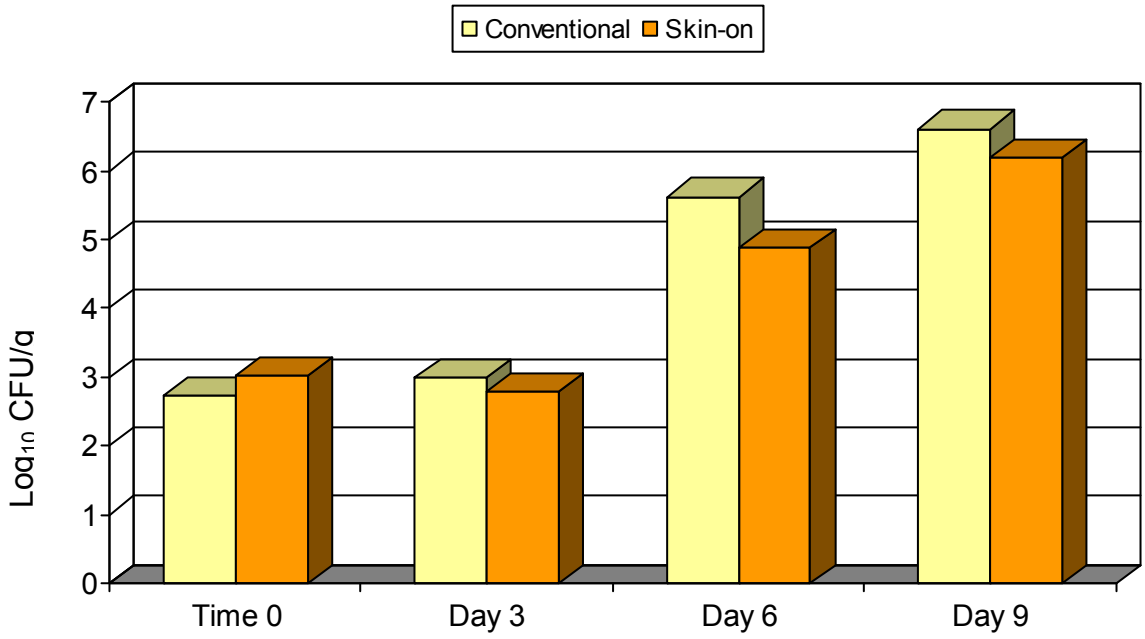


Figure 11. Mean lactic acid bacteria counts on overwrapped meat from four carcass sites on conventional and skin-on sheep meat sampled at four time points during storage at 2 – 4°C

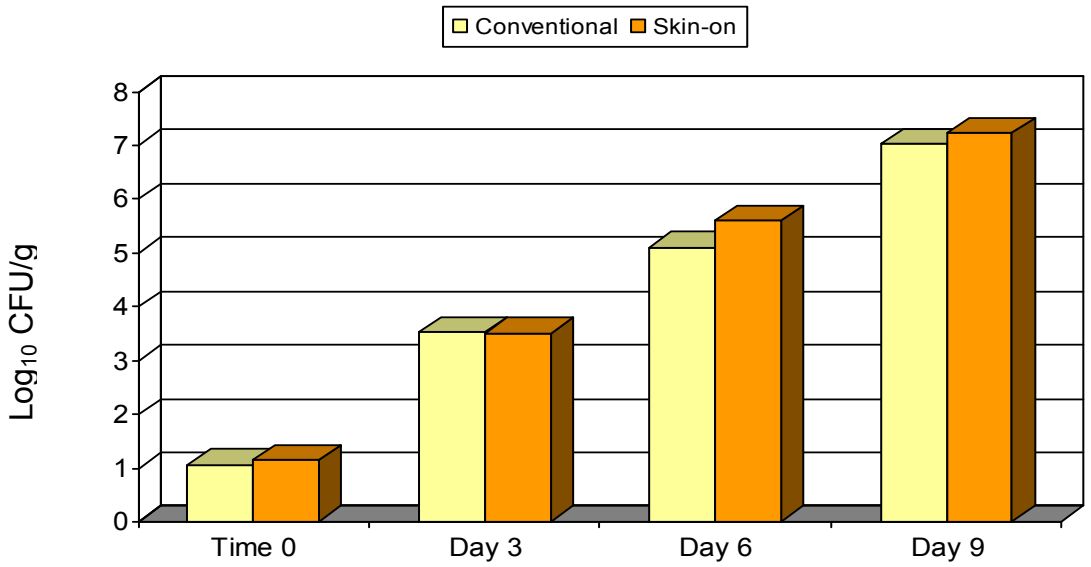


Figure 12. Mean Pseudomonas species counts on overwrapped meat from four carcass sites on conventional and skin-on sheep meat sampled at four time points during storage at 2 – 4°C

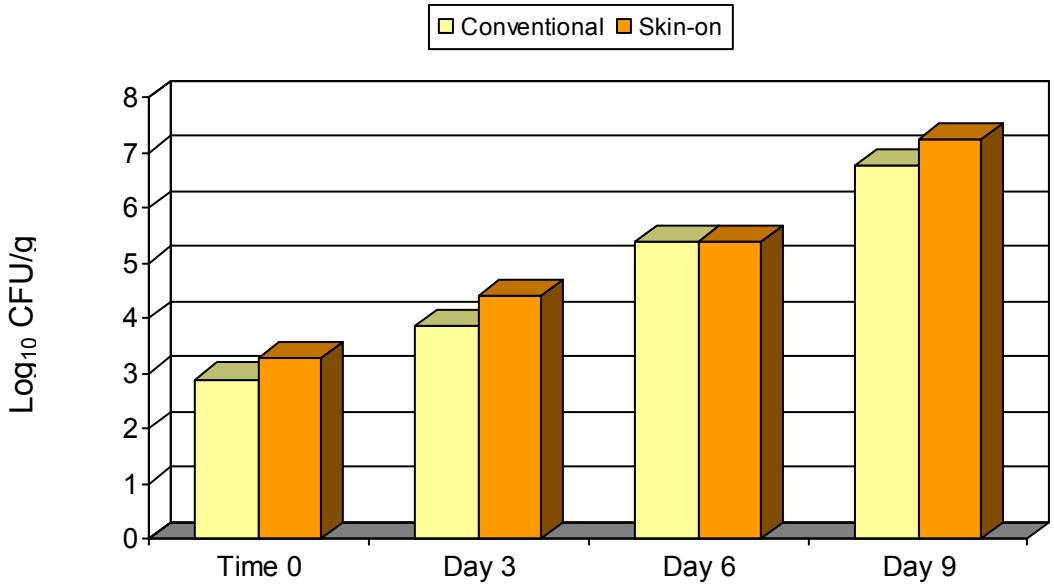


Figure 13. Mean yeast and mould counts on overwrapped meat from four carcass sites on conventional and skin-on sheep meat sampled at four time points during storage at 2 – 4 ^{0}C

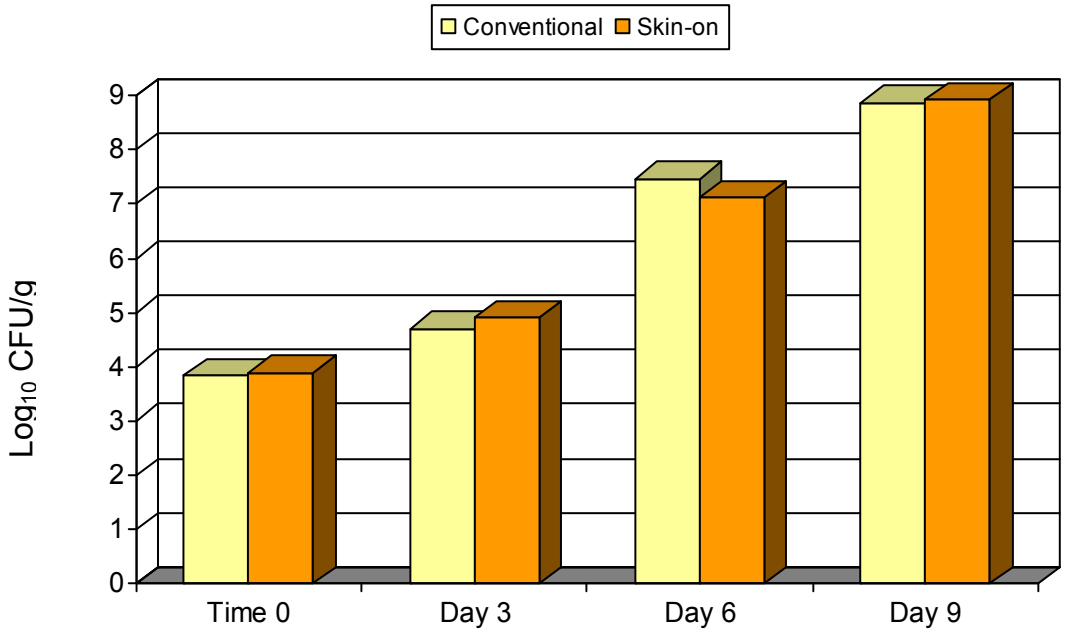


Figure 14. Mean TVC counts on overwrapped meat from four carcass sites on conventional and skin-on sheep meat sampled at four time points during storage at 2 – 4 ^{0}C

Some anatomical region effects on carcass contamination occurred. On days six and nine, and for most groups of micro-organism, counts tended to be lower on the loin and leg cuts than on the breast or shoulder, particularly on meat from the conventionally dressed carcasses. This difference was most evident in the yeast and mould counts where a significant (P = 0.006) meat cut x days displayed interaction occurred, the breast and shoulder counts exceeding those of the loin and leg by 0.5 – 1.3 Log_{10} CFU/g across the range from day zero to nine days storage. There was a significant (P = 0.015) interaction between meat cut and the main treatment (conventional versus skin-on carcass) for the *Pseudomonads*. In the shoulder, *Pseudomonad* counts were higher on the meat from conventional carcasses whereas they were higher on the skin-on meat from the other joints.

For both lactic acid and TVC counts, levels on the breast were significantly higher than on the loin (by about 0.65 Log_{10} CFU/g (P = 0.001) and 0.45 Log_{10} CFU/g (P = 0.007), respectively (full results in Appendix H).

5.4.2. Meat colour and rancidity

As shown in Fig. 15, there was a decrease in saturation during the first six days of display but there was no consistent difference between conventional and skin-on meat: the skin-on *gluteobiceps* had higher saturation levels throughout the display period than the corresponding muscle from the conventional carcasses whereas the opposite trend was seen for the *longissimus*.

In both muscles from both types of carcass, the decline in saturation values over six days was about two units. This is generally regarded as being indicative of an accumulation of metmyoglobin that is sufficient to deter consumers from purchasing the browner meat [9] (Appendix J).

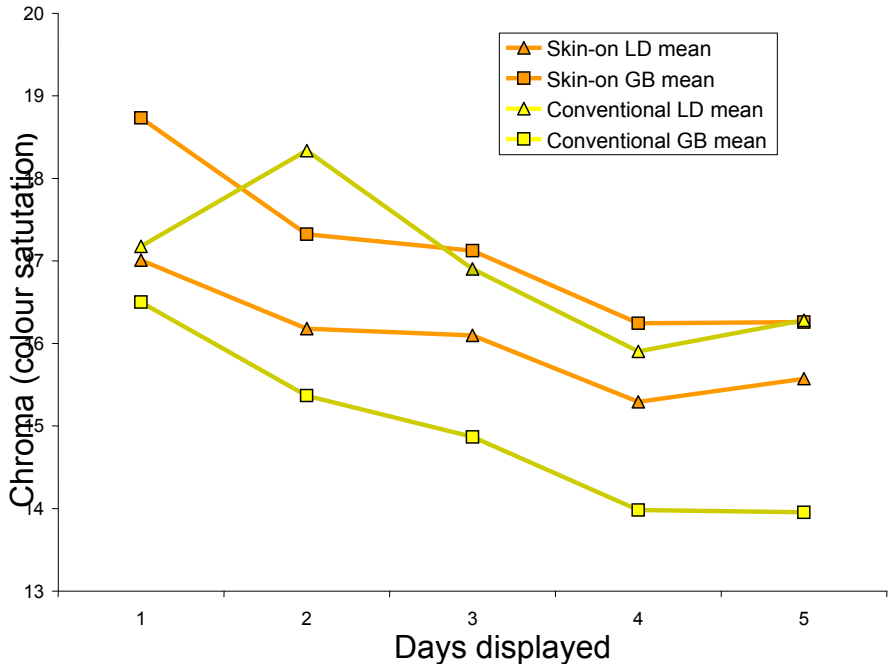


Figure 15. The decline in meat colour saturation with time in two muscles from conventional and skin-on carcasses. GB: gluteobiceps; LD: longissmus.

There were no significant differences between conventional and skin-on meats in rancidity, nor between the two muscles (*gluteobiceps* and *longissimus*), with overall mean values of about 0.55 mg/kg (Appendix K). This value is probably below that which evokes detection of rancidity by consumers.

5.5 Visibility of the Health Mark after toasting

The visibility of the stamp using the food grade dye Chocolate Brown HT, conventionally used for the Health Mark, was assessed subjectively before and after toasting. It was concluded that the mark was quite visible if the desired degree of browning of the skin was achieved. This is supported by the photographic evidence in Appendix L.

5.6 Assessment of the organoleptic properties of skin-on carcasses and meat by assessors with previous experience of the product

Of the three carcasses shown to the assessors (Appendix M), one (carcass number 1) was unanimously considered to represent a typical smoked sheep (Table 3). Carcass number 2 was considered to be the least representative with about half the assessors each claiming typicality and atypicality. The difference in appearance of the three carcasses was not due to the production as this was

identical. Rather, it was a result of the animal's characteristics, notably the skin colour which was rather greyish in carcass 2 and dark and mottled in carcass 3. This emphasizes the need to use only white wooled, white skinned sheep.

Table 3. Assessors' responses to the question on typicality of skin-on carcass appearance

	Typical		Atypical	
	No.	%	No	%
Carcass 1	7	100	0	0
Carcass 2	3	43	4	57
Carcass 3	5	71	2	29

Table 4. Assessors' responses to the question on acceptability of skin-on carcass appearance

	Carcass 1		Carcass 2		Carcass 3	
	No.	%	No.	%	No.	%
Extremely acceptable	3	43			1	14
Very acceptable	4	57	2	29	2	29
Moderately acceptable			2	29	1	14
Slightly acceptable					2	29
Slightly unacceptable			1	14	1	14
Moderately unacceptable			1	14		
Very unacceptable			1	14		
Extremely unacceptable						

The acceptability ratings of the carcasses' appearance is shown in Table 4. These reflect the results in Table 3 to a large extent but qualify those previous responses somewhat. Thus, although 100% of the responses in Table 3 categorize carcass 1 as having a typical appearance, just under half of the responses qualify that carcass as being extremely acceptable and just over half

as very acceptable. For carcass 2, 58% of the responses indicated a carcass in the acceptable half of the range, rather more than considered it to be typical. Likewise, only one response placed carcass 3 in the unacceptable half of the range compared with two indicating it was atypical. Overall, some responses indicated that appearance was acceptable even if atypical and considering all three carcasses together, the production protocol adopted results in a desirable product.

When cut into cubes (as befits meat intended for casseroles and stews), the appearance of meat from carcass 1 was judged to be extremely or very acceptable as was its aroma when boiled in water (Tables 5 and 6, respectively).

Table 5. Assessors' responses to the question on acceptability of skin-on meat cubes appearance

	No.	%
Extremely acceptable	4	57
Very acceptable	3	43
Moderately acceptable	-	-
Slightly acceptable	-	-
Slightly unacceptable	-	-
Moderately unacceptable	-	-
Extremely unacceptable	-	-

Table 6. Assessors' responses to the question on acceptability of the aroma of boiling skin-on meat cubes

	No.	%
Extremely acceptable	3	43
Very acceptable	4	57
Moderately acceptable	-	-
Slightly acceptable	-	-
Slightly unacceptable	-	-
Moderately unacceptable	-	-
Extremely unacceptable	-	-

5.7 An abattoir survey of lesions in slaughtered sheep

The results of observations made during the period May 2005 – March 2006 are shown in Table 7. The three most frequently occurring conditions noted throughout the year are, in decreasing order, abscesses, bruising and emaciation with observed total numbers of carcasses affected being 726, 42 and 28, respectively, out of a total of 10,245 slaughtered. The number of carcasses exhibiting arthritis was actually greater than those that were emaciated , with a total of 34 but the observations were not as evenly spread across months. There was only one case of *Cysticercus ovis* detected, located in the flank, and two carcasses showing hydatidosis.

The overwhelming preponderance of abscesses among the conditions recorded is shown in Figure 16 where the proportion exceeds 90% in some months and whose lowest value is 66%. The seasonal frequency of abscesses, expressed as the percentage of carcasses affected, is shown in Figure 17. There was an apparent seasonal effect with peak occurrences approximately 6 months apart in August and January/February, almost certainly related to husbandry practice (vaccination).

Abscesses can occur in any tissue and at any depth from the surface although many, including those resulting from the immune system reaction to the adjuvant contained within a vaccine, tend to be relatively superficial. It is likely that many of these would be detectable in a skin-on carcass but there is no objective basis to qualify this statement. Abscesses are removed by localised trimming unless they are numerous enough to require condemnation of the carcass. They are not of public health concern but are clearly of consumer concern and cannot be allowed to enter the food chain.

The two other relatively commonly occurring conditions, arthritis and emaciation, would be readily detectable in skin-on carcasses. It is suggested that the Meat Hygiene Service consider what implications leaving the skin on has for the meat inspection procedure and whether there need to be any new measures stipulated for this type of carcass.

Table 7. Monthly totals of specific conditions recorded for slaughtered sheep

JANAN MEATS LTD							
CONDITION	CODE	19/05/2005	08/06/2005	22/07/2005	25/08/2005	29/09/2005	25/10/2005
Abscesses (localised, injection)	SAB	40	43	113*	110	76	69
Anaemia	SAN						3*
Arthritis	SAR				7*	4*	2**
Fever/septicaemia/toxaemia	SFE						
Jaundice	SJU						
Melanosis	SML						
Oedema/emaciation	SOE	8 emaciated*	5 emaciated*	2 emaciated**	4 emaciated	2 emaciated**	1 emaciated***
Pyaemia/generalised abscessation	SPY	1			2		
Trauma (bruising/fractures/ dislocation)	STA	12 bruised**	8 bruised**	10 bruised***	2	2 bruised***	2 bruised****
Tumours	STU						
Other	SOT				1**	1****	
Total kill		929	860	1200	1015	1148	1090
		* 2 condemned ** hind limbs and shoulders	* 1 condemned ** 1 severely bruised hind limb; 7 minor bruised shoulders	* 1 popliteal ** 2 condemned, 1due to enteritis *** 1 severely bruised hind limb & 2 shoulders removed	* fore limb ** C. ovis in flank	* 1 fore & 3 hind limbs ** 2 condemned *** flanks **** liver lipoma	* condemned ** fore limbs *** condemned **** 1 severely bruised back & 1 fore limb

CONDITION	CODE	18/11/2005	13/12/2005	25/01/2006	22/02/2006	28/03/2006
Abscesses (localised, injection)	SAB	52	75*	33	68	47
Anaemia	SAN			2*		
Arthritis	SAR	11*	2**	5**	1*	2*
Fever/septicaemia/toxaemia	SFE				1 fevered**	
Jaundice	SJU					
Melanosis	SML					
Oedema/emaciation	SOE	3 emaciated**		2 emaciated***	1 Oedema***	1 emaciated**
Pyaemia/generalised abscessation	SPY			2 pyaemia****		
Trauma (bruising/fractures/ dislocation)	STA	4 bruised***	1bruised***		2 (1 bruised, 1 fracture)****	1***
Tumours	STU					
Other	SOT		2****		1*****	
Total kill		1010	864	364	762	1003
		* 7 fore & 4 hind limbs ** condemned *** 2 loins & 2 shins	* 1 popliteal, 1 ischiatic (leg condemned) & 1 pre-scapular (shoulder condemned) ** 1 fore & 1 hind limb *** fore limb **** hydatidosis (total condemnation)	* condemned ** 3 fore & 2 hind limbs *** condemned **** condemned NB low kill numbers - shortage of sheep "Waiting for batches to arrive"	* fore limb ** condemned *** condemned **** severely bruised hind limb & broken rib ***** septic pleural pneumonia, condemned	* fore limbs ** condemned *** severely bruised flank

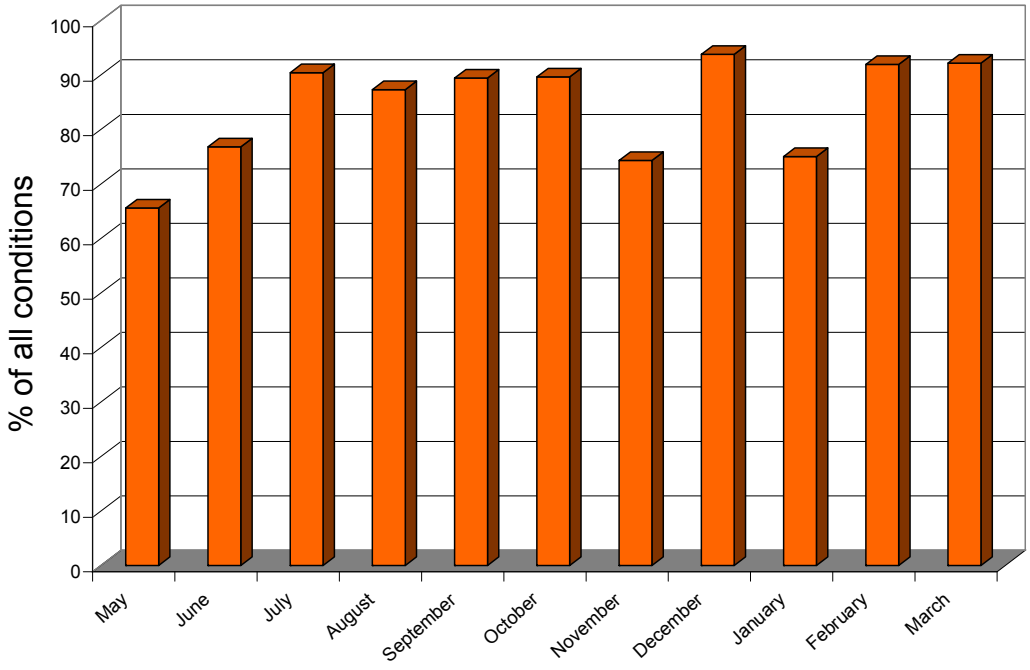


Figure 16. Monthly frequency of abscesses as % total number of conditions

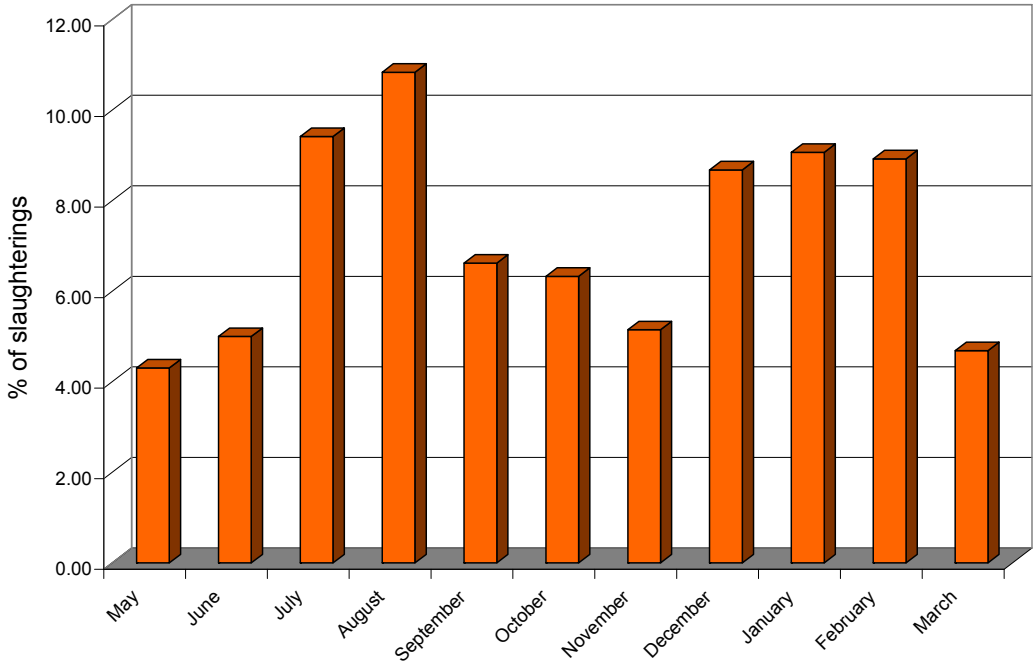


Figure 17. Monthly frequency of abscesses as % animals slaughtered

6. Conclusions

This project has demonstrated that, using a specific series of processing steps, it is possible to produce singed, skin-on sheep carcasses that have lower microbial counts than conventionally dressed sheep carcasses produced in the same abattoir. Key factors in the process are a starting wool length of not more than 5mm, the use of gas burners to singe and remove the wool, a pressure wash to remove charred fleece, and a final 'toasting' pass of the burners after all carcass dressing and handling operations have been completed. Carcasses and meat produced according to this procedure are visually and olfactorily acceptable to consumers accustomed to this product. A survey of lesions occurring in older sheep in a commercial abattoir indicate that abscesses predominate and the implications of this for inspection of skin-on carcasses will need to be considered by the Meat Hygiene Service should legitimate production of these carcasses be undertaken.

7. Acknowledgements

The authors wish to acknowledge the slaughter and dissection staff at the Langford abattoir for their help in processing and sampling the carcasses, Alison Small (Official Veterinary Surgeon) for her sound, sensible advice on regulatory procedures, and Steve and Christian James from the Food Refrigeration and Process Engineering Centre for their input in the early stages of the project. Thanks also go to Richard and Andrew Wear for supplying the animals and preparing them according to our wishes, and for providing facilities and man-hours in the making of a video documenting the production of smoked, skin-on sheep carcasses.; to the staff of the Langford Photographic Unit for recording and editing the video and to Jackie Bayntun for undertaking many of the statistical analyses.

Finally, the authors acknowledge the financial support and project guidance given by the Food Standards Agency without whom this study would not have taken place.

8. References

1. Satin, M. 2002. Use of irradiation for the microbial decontamination of meat: situation and perspectives. Meat Sci., 62, 277-283.

2. Meyer,W., Neurand, K. and Tanyolac, A. 2001. General anti-microbial properties of the integument in fleece producing sheep and goats. Small Ruminant Res., 41, 181-190.

3. Food Standards Agency 2002. Guidelines for meat plant operators on the implementation of Hazard Analysis and Critical Control Point (HACCP) principles & microbiological testing procedures (draft).

4. Schroder, B. and Ring, C. 1998. Minimising the bacterial count on lamb carcases by means of slaughtering methods. Fleischwirtschaft 78, 641

5. B.Davies, personal communication

6. Gill, C.O. and Bryant, J. 1993. The presence of Escherichia coli, Salmonella and Campylobacter in pig carcass dehairing equipment. Food Microbiology 10, 337-344.

7. .Warriss, P.D 2004. Meat Science. An Introductory Text. CABI Publishing, Wallingford. 310 pp.

8. Tarladgis, B.G., Watts, B.G., Younathan, M.T. and Dugan, Jr, L. 1960. A distillation method for the quantitative determination of malonaldehyde in rancid foods. J. American Oil Chem. Soc 37, 44-48.

9. MacDougall, D.B 1982. Changes in the colour and opacity of meat. Food Chem. 9, 75-88.

Development of experimental sheep carcass singeing equipment

In order to evaluate hygienic methods for producing skin-on smoked sheep carcasses, a consistent, repeatable process was required. This appendix describes the iterative design process to produce experimental singeing equipment for this purpose.

Gas burners were selected as the main singeing heat source due to their low-cost, speed of action and current use in industry for singeing pork carcasses. The final system had a ring of 8 inward directed gas burners that moved up and down around a suspended carcass. The burner ring was chain driven from a DC motor controlled by a small programmable logic controller. Adjustable microswitches on the support structure controlled the stroke end positions.

This equipment has demonstrated consistent production of the desired golden-brown final carcass surface colour, and was used to perform the repeatable singeing actions required for microbiological process analyses.

Initial Trials for Heating Method Selection

Various heating methods for singeing were evaluated with manual manipulation of the heat sources. Of particular importance was the selection of the type of heat source to be used. Radiant electric space heaters, balloon gas burners, gas powered weed burners and industrial hot air blowers were all considered. After primary investigations and enquiries, radiant electric space heaters and balloon gas burners were discounted as the costs would be excessive. Gas burners and hot air blowers were both assessed practically. Whilst both gas burners and hot air blowers were efficacious, gas burners were selected for the singeing equipment as they were cheaper, quicker, and have already been accepted into the slaughter industry for singeing pork carcasses.

Construction of Singeing Experimental Equipment Mk1

The initial design concept was to rotate the carcass during singeing to give an even heating effect. However, the asymmetric profile of a hanging sheep carcass resulted in the carcass parts at a greater offset from the rotation axis receiving a considerably greater heating effect than the parts less distant from the rotation axis. Whilst the burner(s) could be moved back and forwards to track the profile of the carcass, this was considered un-necessarily complex for a first experimental prototype.

The revised outline design for singeing with gas burners was to suspend the carcass from a gambrel as in normal butchery practice and then pass a ring of inward facing gas burners vertically over the carcass. The key function of this first prototype was to produce repeatable singeing to enable microbiological analyses of the final singed carcass.

Appendix A

Mk1 Design

For design purposes 6 carcasses were measured to size the experimental singeing equipment. Gas burner nozzles are typically small to focus heat in a specific location. In the singeing application the largest readily available nozzles were selected which would enable the heat to be spread evenly over the carcass. These had a diameter of 70 mm and a flame length of 420 mm. A shorter burner offset was used which would theoretically allow the burning gas to spread around the carcass giving a more even all-over singe. Working outwards from the centreline of the carcass using mean body diameter, a reduced flame length, nozzle length and an allowance for burner supports, a burner support ring diameter of approximately 1 m was calculated. For ease of construction this was transmuted into an octagon 1 m across flats. This octagonal burner ring carried 4 inward pointing gas burners and be moved vertically up and down around a hanging carcass.

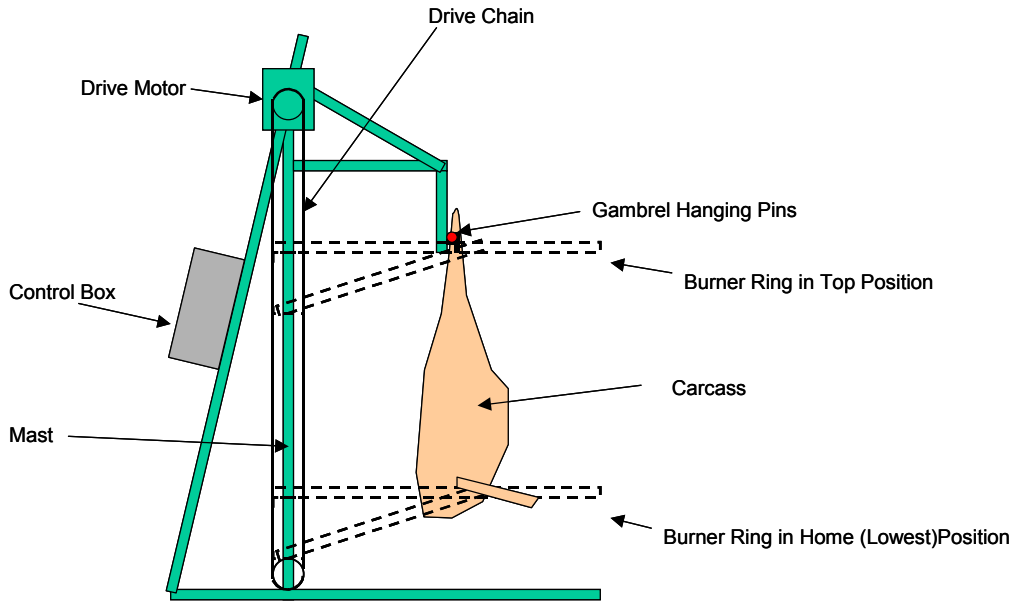


Figure A1. Side view of Mk1experimental singeing equipment

To ease construction and subsequent adjustments the majority of the rig (Figure A1) was built from a proprietary machine building system using slotted aluminium extrusions as the main constructional element. Simple brackets fixed by T-bolts into the slots joined the extruded sections. The burner ring was supported on a chain driven carriage that was able to travel up and down the mast. A 24vDC motor powered the chain. Microswitches were located in the slots in the mast and used to signal end of carriage travel. A small programmable logic controller (PLC) unit controlled the carriage motion. A wiring diagram is shown in Figure A2. The PLC unit was introduced to ensure controlled and consistent motions and allow for later reprogramming of sequences and functionality.

Appendix A

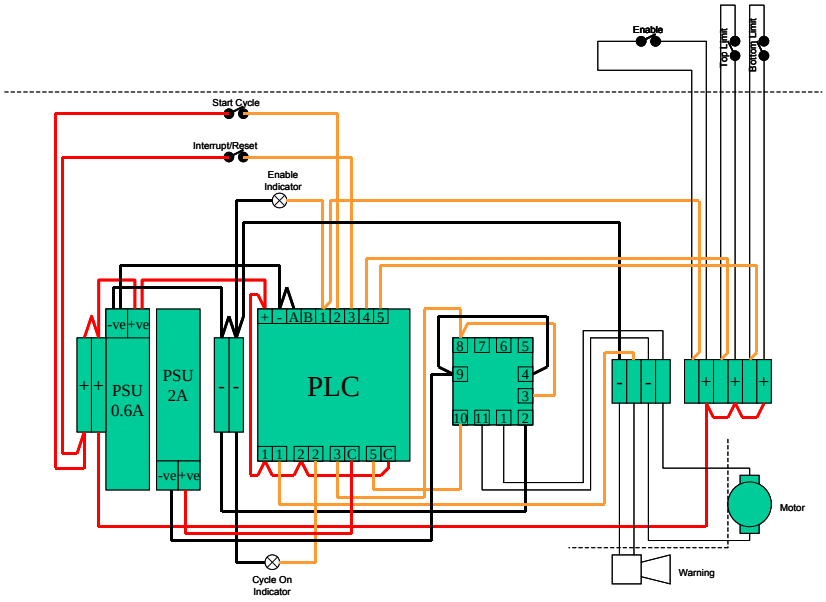


Figure A2. Wiring Diagram for Mk1 experimental singeing equipment

No motion would take place unless the enable contact was made. This could serve as a deadman's handle or barrier interlock on a final system. On pressing the cycle start button, the control program ensured the carriage was at the home position (bottom of travel) and then executed 3 up-down cycles before stopping in the home position. Selecting lower end position as home allowed for easier access for lifting the gambrelled carcass on to the support pegs. A movement warning siren would sound before any motion started. If the interrupt/reset contact were made, all motion would stop. The system would reposition the carriage to the home position upon the next press of the start button, before executing the 3 up-down cycles.

The gas burner system (Figure A3) was controlled manually. This was to reduce the risk associated with auto-ignition systems in the experimental equipment. Each burner had individual control to allow for development adjustments. Each burner valve would be adjusted to, and then remain in, the required position for even singeing. The gas supply valve would then be used to control the entire set of burners. To light the system, the gas supply valve would be opened slightly to admit a small gas flow to the burners, each burner would be lit with a long handled taper or piezo-igniter, and then only when personnel were clear, would the gas supply valve be turned fully open.

Appendix A

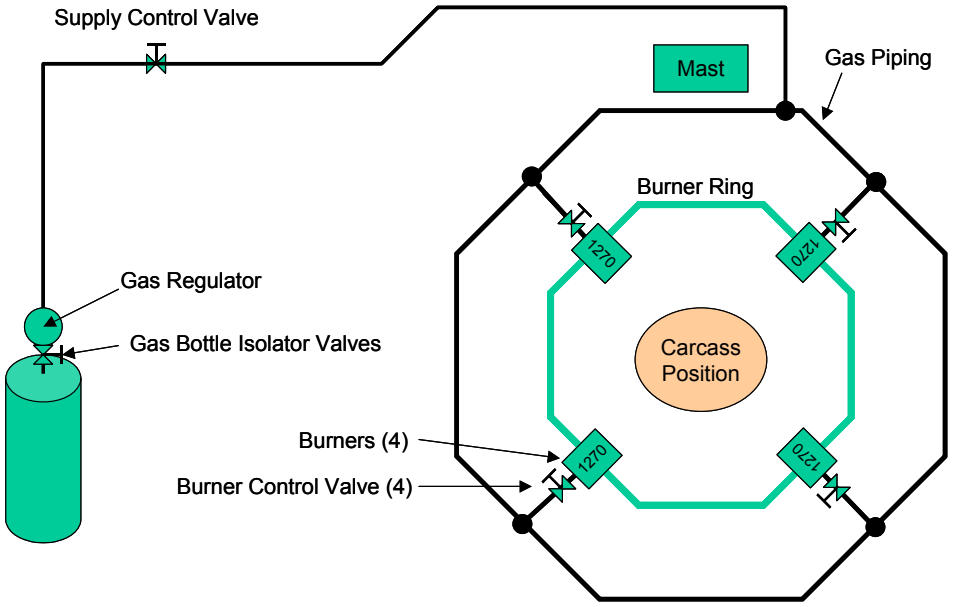


Figure A3. Gas system on Mk1 experimental singeing equipment

Mk1 Experimental Singeing Equipment Trials (June--July 2004))
All sheep used were killed, bled-out and gambrelled in the abattoir before transport to the singeing equipment on an A-frame trolley. The gambrel was then hung onto the rig.

For the first sheep, three up-down singeing passes were made. There was limited success in removing wool with burning alone. Additional scraping or brushing was required. The desired golden skin colour was only apparent where all wool had been removed. The wool was more than 10 mm long and this was thought to contribute to the problem.

The second ewe was nominally black but in fact much of its coat was grey and the wool was again more than 10mm long. Before transit to the singeing equipment, this carcass was scalded in the pig tank at 63°C for 5 min. The scalding did not successfully loosen the wool such that it could be easily scraped or brushed off. The carcass, now with variable fleece cover, some of which was sodden. was subjected to 3 up-down singeing cycles. Again, singeing did not remove the thick wool. However, where the skin was exposed, even though wet, the desired golden colour resulted.

The third ewe was sheared just after slaughter, the fleece was reduced to less than 5 mm in many places. This carcass was singed without scalding and following singeing, it was de-wooled using a rotary brush attached to a power drill and other parts were scraped. Substantial amounts of charred fleece were removed, exposing more skin than had been seen in previous trials. Pressure washing removed even more charred fleece giving a close to fleece-less carcass. Finally a single up-down singeing cycle was performed by interrupting PLC program at the appropriate point. The result was generally good, with complete wool removal in the adequately singed carcass areas, together with a more uniform golden colour over more of the carcass than seen before.

Carcass four was scalded at 80°C for 5 minutes, then scraped. This did not enable any more wool to be removed than the 63°C scald used previously. The carcass then received 3 up-down singeing cycles and pressure washed. Wool was only successfully removed in heavily singed areas. Subsequent singeing was ineffective because the fleece was both relatively long (>10mm) and sodden.

After singeing, all carcases were eviscerated whilst hanging on the experimental equipment. This was made difficult by the carcass being able to swing freely under evisceration forces. Access for both the butcher and the gut bin into which the viscera are deposited was hindered by the low home position of the burning support ring.

The conclusion from these trials was that the singeing rig generally worked well and would provide a sound basis for a standard protocol to be applied during the project.

Based on a review of the work to date, it was decided that for future work we should use only white sheep, shorn so that the wool length did not exceed 5 mm. If the skin could be exposed, the desired golden brown colouration could be produced. The process would include the following steps: 3 cycle singe (dry), pressure wash, 1 cycle drying. Scraping/brushing may or may not be required.

Modifications required to Mk1
To improve uniformity of singe, four additional burners would be added, positioned between the current burners. A back support to hold the carcass during evisceration was required and the base of the unit would be modified to allow access for the gut bin directly below the carcass. The home position would be moved to the top of the stroke to improve access to the carcass.

Construction of Singeing Experimental Equipment Mk2.

Although the existing gas circuit was working well, there was not the capacity to add another 4 burners and have all 8 operating at the required gas flow. A second, parallel gas circuit, identical to the first was added to the equipment (Figure A4). A burner nomenclature was adopted, that when viewed from above, the ‘North’ burner was closest to the mast.

Appendix A

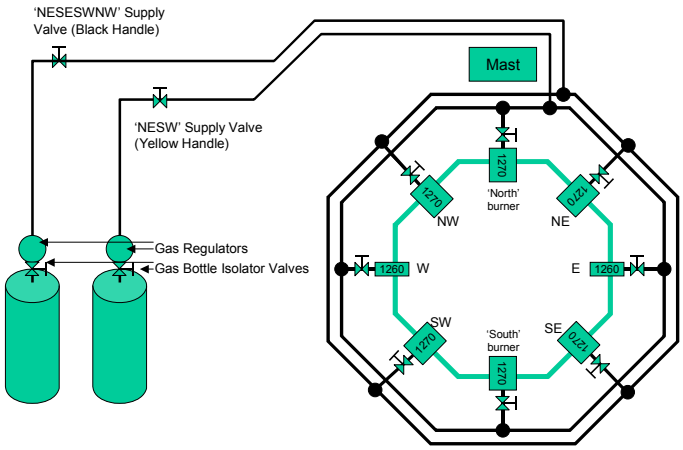


Figure A4. Gas circuit for Mk2 experimental singeing equipment

The main constructional change required in Mk2 (Figure A5) was the addition of a back support to resist carcass evisceration forces. This could not interfere with burner ring motion when not in use. A solution using a pivoting, H-shaped, back support frame mounted on the mast was easily incorporated due to the use of the slotted beam machine construction system. When not in use the back support rests on the base of the rig, outside the zone of burner movement. To eviscerate, the frame was swung up to support the carcass spine and held in position by chains. Other small frame modifications were readily made to

- allow gut bin access to below carcass
- slightly lower and set back the carcass hanging pins
- centralise burners on each side of octagon

A simple PLC program change set the top of stroke to be the home position. The interrupt button would be used to give the single final 'toasting' pass after pressure washing.

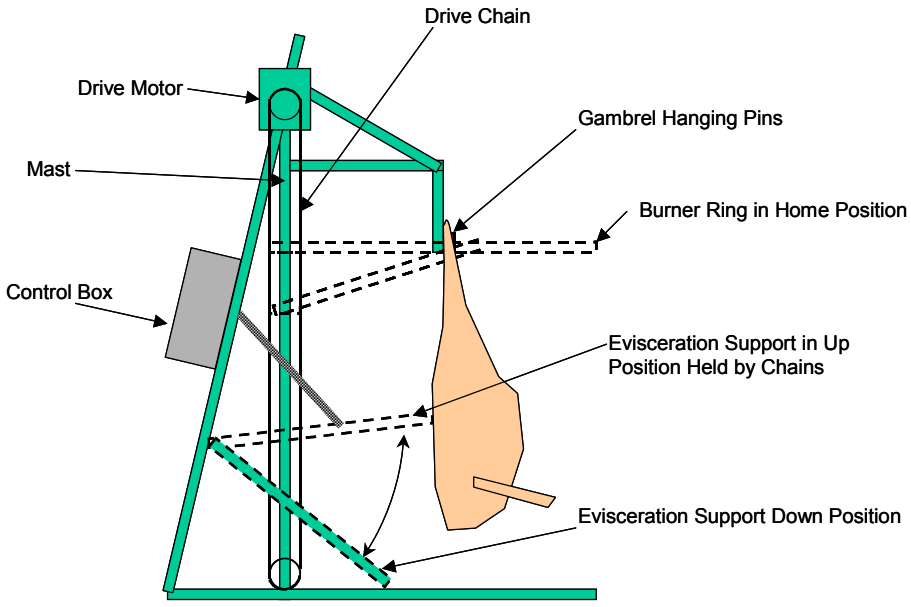


Figure A5. Evisceration support and revised burner home position for Mk2 experimental singeing equipment

Appendix A

Mk2 Experimental Singeing Equipment Trials (July-2004)
These trials processed carcasses with the singeing method suggested by previous work. Sheep were closely sheared on the farm then brought to the abattoir, slaughtered, bled and gambrelled. Carcasses were then manually lifted and hung on the gambrel support pins. This task was eased considerably by the changes to the burner ring home position and re-positioning of the hanging pins. Three down-up hair singeing passes were then made with the 8 burners providing a substantially more uniform singeing effect over the entire carcass. The mast hindered pressure washing of the dorsal sections of the carcass. The back support frame was then swung up and the carcass eviscerated. Although this was now much easier than in Mk1 there were still difficulties caused by the carcass moving under the effects of evisceration forces and the butcher having to stoop under the burner ring in home position. The final single 'toasting' down-up cycle dried the carcasses well and in most cases produced the desired golden-brown colouration.

Although mostly effective, this procedure did not fully remove all the hair from every carcass. Since the location of remaining fleece varied from carcass to carcass, this was put down to animal variation rather than a systematic processing error in the equipment.

The singeing method used was adopted as the basis for the baseline singeing protocol:
1. Close shear sheep on farm.
2. Stun, bleed, gambrel, and hang onto singeing equipment
3. Make 3 down-up 'singeing' passes
4. Pressure wash to remove charred fleece
5. Eviscerate
6. Make 1 down-up 'toasting' pass.

Modifications required to Mk2
The measures made to improve the carcass support during evisceration were insufficient and some alternative method was required. The burner ring home position needed to be raised to improve butcher access during evisceration. Access to the carcass during pressure washing needed to be improved.

The PLC program and control box would be updated to remove the need to use the interrupt button to perform a single down-up 'toasting' cycle.

Construction of Singeing Experimental Equipment Mk3

A third microswitch was added above the existing top of stroke microswitch to form a new home position. The higher home position would prevent the burner ring hindering the carcass loading and evisceration processes. The burner ring would start and finish motion at the high home position, but the top of singeing passes would still be indicated by the existing top of stroke microswitch.

A second button was added to the control panel to initiate a single down-up 'toasting' cycle.
The PLC program and control box wiring (Figure A6) was modified to accommodate the additional microswitch and button.

A potential technique to ease the difficulties of carcass handling and loading, pressure washing, and evisceration was evaluated. The concept (Figure A7) was to hang the carcass on a purpose built A-frame trolley immediately after gambrelling. This activity could take place in the abattoir and thus not be hindered by the frame or burner ring of the singeing equipment. The trolley would then be wheeled to the rig and docked into a location feature at the base to ensure repeatable carcass positioning. The new high home position would make it possible for the carcass and trolley to pass below the burner ring. The three singeing passes would be made, and then the carcass could be trolleyed out from the rig for pressure washing thus removing the access restrictions caused by attempting to pressure wash in-situ. The more direct grounding of forces, as there would be no cantilevered support structure, would ease evisceration. The trolley was then reinserted to the singeing rig station for the final toasting pass. The back support and gambrel hanging pegs were removed and a trolley was specifically designed to pass below the burner ring at the high home position and not obscure burners during the singeing and toasting passes.

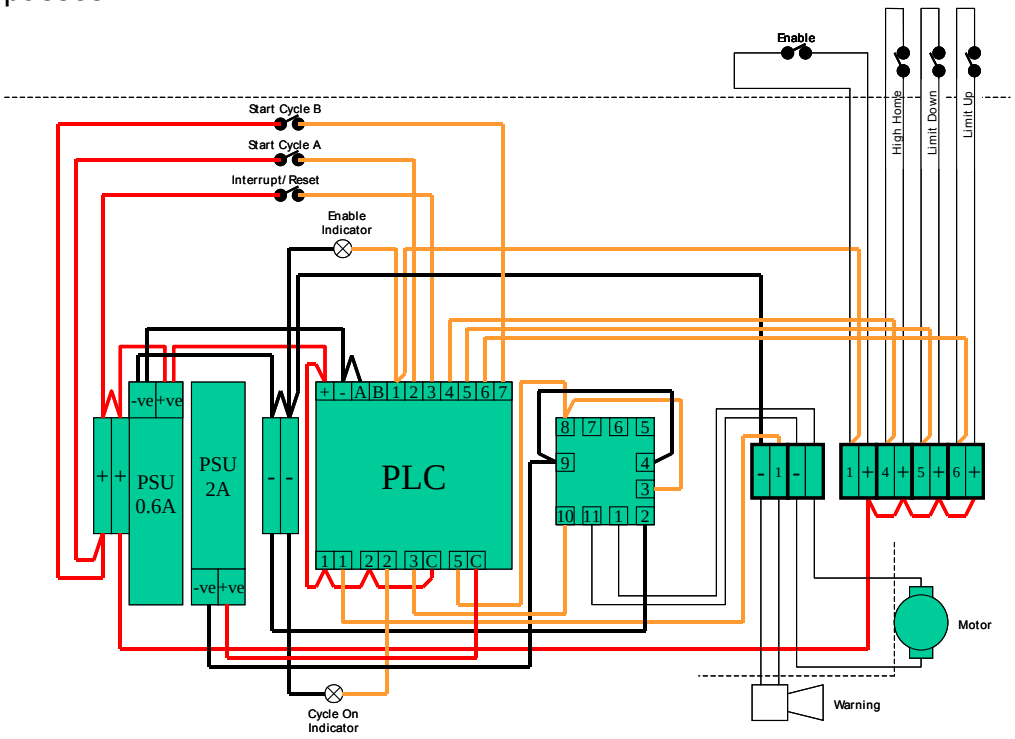


Figure A6. Wiring Diagram for Mk3 Experimental Singeing Equipment

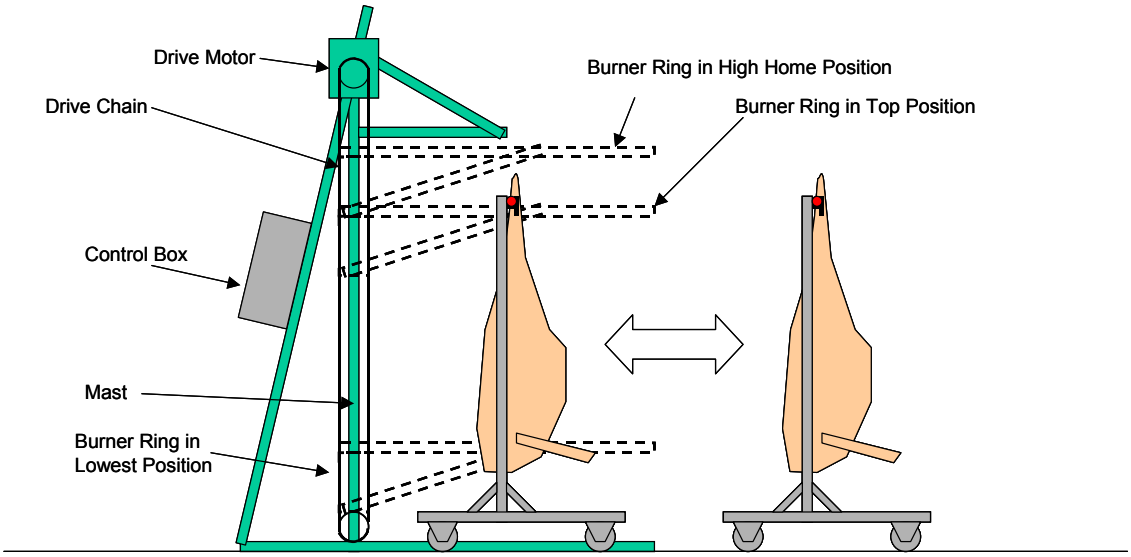


Figure A7. Trolley concept carcass support

Mk3 Experimental Singeing Equipment Trials (Aug-2004)
Two sheep with short (5-10mm) trimmed fleece were processed with the revised equipment. The equipment performed singeing and toasting operations as intended, producing a good appearance smoked carcass. The singeing effect was acceptably uniform over the entire carcass surface. Carcass handling, washing and evisceration tasks were eased by adoption of the trolley support concept.

The equipment was moved to a room adjacent to the abattoir for trials to compare baseline microbiological hygiene of singed skin-on carcasses against conventional dressing methods. Four carcasses were processed in the Mk3 experimental singeing equipment. Whilst the processing of the carcasses proceeded satisfactorily, it was noted that the ceiling immediately above the equipment was becoming extremely hot (>200 °C). This heating was not apparent until the rig was moved to the trials room with a lower roof height. A makeshift baffle plate protected the ceiling for the duration of the first trials but addition heat extraction methods would be required.

Carcass surface temperatures were taken with an IR thermometer. During the 3 pass defleecing singe, temperatures varied greatly from 70 °C (head end of carcass after 1 pass, just before burners reached it again) to 515 °C (incandescent glowing sections of fleece directly under burners). After the defleecing the singed carcass surface temperature was reasonably uniform at around 70-85 °C. Temperatures recorded during the toasting singes were lower, being in the range 82-276 °C.

Modifications required to Mk3
The singeing and carcass handling aspects proved to be effective; however, additional equipment was required for heat extraction.

Appendix A

Singeing Experimental Equipment Mk4

The waste heat from the rig travels upwards due to natural convection. In the equipment development space this was not a problem as it had high ceilings, but in the trials room with only 600 mm between the top of the rig and the ceiling, ceiling temperatures in excess of 200 °C were measured. A vertical flue arrangement to duct heat away driven by the natural convection was not possible because of the restricted clearance. A single skinned hood was built above the rig to collect rising heat and fumes. A large displacement extractor fan (600mm diameter) was connected to the side of the hood with 150mm flexible ducting. Even though the hood would heat up considerably, a sufficient volume of hot air would be drawn away through the duct by the fan to prevent heat damage to the ceiling.

Mk4 Experimental Singeing Equipment Trials (Sept-2004)
The remaining 6 carcasses to complete the initial baseline microbiology trials were processed in the Mk4 equipment. The desired golden-brown surface appearances were seen in all cases. Acceptable ceiling temperatures were seen.

Conclusions

Equipment to reproducibly provide singed skin-on sheep carcases has been designed and constructed. This equipment is sufficiently consistent in processing to allow further process microbiological variation trials to be conducted.

Appendix B

Assessment Categories

Scales used to assess the acceptability of the carcasses and meat by consumers with previous experience of the products.

Extremely acceptable
Very acceptable
Moderately acceptable
Slightly acceptable
Slightly unacceptable
Moderately unacceptable
Very unacceptable
Extremely unacceptable

Appendix C

Toast versus no toast. Individual carcass x site microbial counts

With toasting	Counts before chilling (CFU/cm^2)		Counts after chilling (CFU/cm^2)			
	Enteros	TVC	Enteros	Enrich-ed	TVC	Enrich-ed
Carcass1						
Neck	<5	30	<5	-	<5	-
Flank	<5	10	<5	-	<5	+
Shoulder	<5	<5	<5	-	<5	-
Belly	<5	<5	<5	-	25	+
Rump	<5	<5	<5	-	5	+
Brisket	<5	<5	<5	-	30	+
Carcass 2						
Neck	<5	5	<5	-	<5	+
Flank	<5	<5	<5	-	5	+
Shoulder	<5	10	<5	-	<5	+
Belly	<5	<5	<5	-	1.10×10^2	+
Rump	<5	5	<5	-	<5	-
Brisket	<5	<5	<5	-	<5	+
Carcass 3						
Neck	<5	<5	<5	-	<5	-
Flank	<5	<5	<5	-	<5	+
Shoulder	<5	<5	<5	-	<5	+
Belly	<5	<5	<5	-	2.65×10^2	+
Rump	<5	10	<5	-	<5	-
Brisket	<5	2.00×10^2	<5	-	<5	+
Carcass 4						
Neck	40	5	<5	-	<5	+
Flank	<5	<5	<5	-	35	+
Shoulder	<5	5	<5	-	<5	-
Belly	<5	10	<5	-	1.25×10^2	+
Rump	10	10	<5	-	<5	+
Brisket	5	5	<5	-	<5	+
Carcass 5						
Neck	<5	20	<5	-	5	+
Flank	<5	<5	<5	-	1.10×10^2	-
Shoulder	<5	4.00×10^3	<5	-	5	+
Belly	<5	90	<5	-	90	+
Rump	<5	15	<5	-	<5	-
Brisket	<5	<5	<5	-	30	+

Appendix C

With toasting	Counts before chilling (CFU/cm^2)		Counts after chilling (CFU/cm^2)			
	Enteros	TVC	Enteros	Enrich-ed	TVC	Enrich-ed
Carcass 6						
Neck	<5	7.60×10^3	<5	-	1.05×10^4	+
Flank	<5	1.45×10^2	<5	-	<5	-
Shoulder	<5	2.85×10^3	<5	-	<5	-
Belly	<5	40	<5	-	85	+
Rump	<5	2.45×10^2	<5	-	35	-
Brisket	<5	6.40×10^2	<5	-	<5	-
Carcass 7						
Neck	<5	<5	<5	-	<5	-
Flank	<5	5	<5	-	5	-
Shoulder	<5	<5	<5	-	<5	-
Belly	<5	1.95×10^2	<5	-	<5	-
Rump	<5	<5	<5	-	25	-
Brisket	<5	<5	<5	-	<5	-
Carcass 8						
Neck	<5	<5	<5	-	25	+
Flank	<5	<5	<5	-	5	-
Shoulder	<5	1.50×10^2	<5	-	<5	-
Belly	<5	30	<5	-	35	+
Rump	<5	<5	<5	-	<5	-
Brisket	<5	<5	<5	-	<5	-
Carcass 9						
Neck	<5	15	<5	-	<5	-
Flank	<5	<5	<5	-	<5	-
Shoulder	<5	<5	<5	-	<5	-
Belly	<5	10	<5	-	40	-
Rump	<5	<5	<5	-	<5	-
Brisket	<5	<5	<5	-	<5	-
Carcass 10						
Neck	<5	40	<5	-	<5	-
Flank	<5	<5	<5	-	<5	-
Shoulder	<5	<5	<5	-	<5	-
Belly	<5	5	<5	-	4.15×10^2	-
Rump	<5	<5	<5	-	<5	-
Brisket	<5	<5	<5	-	10	+

Appendix C

Without toasting	Counts before chilling (CFU/cm^2)		Counts after chilling (CFU/cm^2)			
	Enteros	TVC	Enteros	Enrich-ed	TVC	Enrich-ed
Carcass1						
Neck	<5	1.42 x 10^4	<5	-	1.60 x 10^2	+
Flank	<5	1.47 x 10^3	<5	-	1.01 x 10^3	+
Shoulder	<5	10	<5	+	<5	+
Belly	60	1.95 x 10^3	<5	+	1.60 x 10^3	+
Rump	<5	<5	<5	-	25	+
Brisket	<5	25	<5	-	65	+
Carcass 2						
Neck	<5	2.50 x 10^3	<5	-	8.10 x 10^2	+
Flank	<5	45	<5	-	<5	+
Shoulder	<5	4.55 x 10^3	<5	-	5.05 x 10^3	+
Belly	<5	2.60 x 10^3	<5	-	8.10 x 10^2	+
Rump	<5	1.70 x 10^2	<5	-	<5	+
Brisket	25	4.35 x 10^3	<5	+	3.15 x 10^2	+
Carcass 3						
Neck	1.44 x 10^4	2.50 x 10^4	<5	+	4.15 x 10^2	+
Flank	5	5.33 x 10^3	<5	+	6.60 x 10^2	+
Shoulder	30	4.40 x 10^2	<5	-	3.40 x 10^2	+
Belly	3.85 x 10^4	3.45 x 10^4	1.75 x 10^2	+	3.30 x 10^3	+
Rump	<5	5	<5	+	<5	-
Brisket	8.05 x 10^2	1.85 x 10^3	15	+	6.50 x 10^2	+
Carcass 4						
Neck	5	1.45 x 10^3	<5	-	70	+
Flank	10	2.05 x 10^3	<5	+	8.35 x 10^2	+
Shoulder	40	1.05 x 10^3	<5	-	5.10 x 10^2	+
Belly	70	7.90 x 10^2	<5	-	6.75 x 10^2	+
Rump	<5	1.50 x 10^2	<5	-	<5	+
Brisket	2.35 x 10^2	7.70 x 10^2	5	-	3.15 x 10^2	+
Carcass 5						
Neck	5	1.40 x 10^2	<5	-	40	+
Flank	<5	<5	<5	-	15	-
Shoulder	<5	20	<5	-	45	-
Belly	<5	3.45 x 10^3	<5	+	1.90 x 10^4	+
Rump	<5	6.65 x 10^2	<5	-	35	-
Brisket	<5	8.80 x 10^2	<5	-	2.25 x 10^2	+

Appendix C

Without toasting	Counts before chilling (CFU/cm^2)		Counts after chilling (CFU/cm^2)			
	Enteros	TVC	Enteros	Enrich-ed	TVC	Enrich-ed
Carcass 6						
Neck	<5	7.85×10^2	<5	-	7.50×10^2	+
Flank	<5	5.00×10^3	15	+	1.01×10^5	+
Shoulder	<5	6.35×10^2	<5	-	1.52×10^3	+
Belly	5	1.32×10^4	<5	+	1.92×10^5	+
Rump	<5	90	<5	+	4.75×10^2	+
Brisket	45	3.30×10^4	<5	-	1.48×10^3	+
Carcass 7						
Neck	<5	1.44×10^3	<5	-	4.20×10^3	+
Flank	<5	6.60×10^3	<5	+	2.96×10^3	+
Shoulder	<5	5.05×10^2	<5	-	3.55×10^2	+
Belly	1.15×10^2	3.20×10^3	20	+	1.83×10^5	+
Rump	<5	40	<5	-	1.65×10^2	+
Brisket	4.35×10^2	1.60×10^4	5	+	1.03×10^4	+
Carcass 8						
Neck	<5	7.50×10^2	<5	-	1.60×10^3	-
Flank	<5	10	<5	-	<5	-
Shoulder	<5	1.38×10^3	<5	-	4.35×10^2	+
Belly	50	1.41×10^3	2.55×10^2	+	7.10×10^3	+
Rump	<5	20	<5	-	<5	+
Brisket	45	7.10×10^2	<5	-	50	+
Carcass 9						
Neck	80	5	<5	-	45	-
Flank	<5	<5	<5	-	<5	-
Shoulder	<5	80	<5	-	35	-
Belly	<5	5.30×10^3	15	+	5.10×10^3	+
Rump	<5	<5	<5	-	<5	-
Brisket	<5	9.00×10^2	<5	-	1.10×10^2	+
Carcass 10						
Neck	70	5.50×10^2	<5	-	<5	-
Flank	<5	1.20×10^2	<5	-	3.00×10^2	+
Shoulder	5	1.60×10^2	<5	-	<5	-
Belly	45	5.15×10^3	35	+	9.85×10^3	+
Rump	<5	10	<5	-	<5	-
Brisket	60	8.50×10^3	<5	-	7.80×10^3	+

Appendix C

Two-way (toast/no toast and pre-/post-chill) analysis of variance results

Treatment & chill specification / Bacteria group	Least Squares Means				SED	P		
	Toast		No toast					
	Pre-chill	Post-chill	Pre-chill	Post-chill		Treatment	Chill time	Interaction
Enterobacteriaceae	0.433[a]	0.398 [a]	0.964[b]	0.545[a]	0.095	<0.001	0.001	0.005
TVC	0.994 [a]	0.899 [a]	2.689 [b]	2.197 [b]	0.193	<0.001	0.130	0.412

[a, b, c] Within a row, different superscripts indicate significantly different (P<0.05) means…

Appendix D

Carcass splitting before and after toasting. Individual carcass x site microbial counts

	Split before toasting (CFU/cm^2)		Split after toasting (CFU/ cm^2)	
	Enteros.	TVC	Enteros.	TVC
	Carcass 1		Carcass 2	
Neck	2.10 x 10^2	7.75 x 10^2	<5	5
Flank	<5	<5	<5	7.50 x 10^2
Shoulder	<5	<5	<5	5
Belly	<5	<5	<5	<5
Rump	<5	<5	<5	<5
Brisket	15	65	<5	10
	Carcass 3		**Carcass 4**	
Neck	<5	<5	<5	<5
Flank	<5	5.85 x 10^2	<5	<5
Shoulder	<5	<5	<5	<5
Belly	<5	<5	<5	5
Rump	<5	<5	<5	<5
Brisket	<5	5	1.60 x 10^2	4.60 x 10^3
	Carcass 5		**Carcass 6**	
Neck	<5	5	<5	5
Flank	<5	<5	<5	1.70 x 10^2
Shoulder	<5	<5	<5	<5
Belly	<5	15	<5	80
Rump	<5	<5	<5	<5
Brisket	<5	20	<5	4.50 x 10^2
	Carcass 7		**Carcass 8**	
Neck	<5	15	90	9.00 x 10^2
Flank	<5	80	<5	2.00 x 10^2
Shoulder	<5	<5	<5	<5
Belly	<5	5	<5	1.45 x 10^2
Rump	<5	<5	<5	95
Brisket	<5	2.80 x 10^4	<5	4.80 x 10^2
	Carcass 9		**Carcass 10**	
Neck	15	1.20 x 10^3	<5	<5
Flank	<5	<5	<5	15
Shoulder	5	1.55 x 10^2	<5	5
Belly	<5	5	<5	30
Rump	<5	<5	<5	<5
Brisket	<5	20	5	9.10 x 10^2

Appendix D

	Split before toasting (CFU/cm^2)		Split after toasting (CFU/ cm^2)	
	Enteros.	TVC	Enteros.	TVC
	Carcass 11		**Carcass 12**	
Neck	<5	<5	<5	70
Flank	<5	<5	<5	<5
Shoulder	<5	10	<5	10
Belly	<5	<5	<5	<5
Rump	<5	<5	<5	1.44×10^3
Brisket	<5	<5	<5	5
	Carcass 13		**Carcass 14**	
Neck	<5	40	<5	<5
Flank				
Shoulder	<5	<5	<5	20
Belly	<5	5	<5	3.40×10^2
Rump	<5	<5	<5	50
Brisket	<5	80	30	8.00×10^2
	Carcass 15		**Carcass 16**	
Neck	<5	<5	1.15×10^2	7.30×10^2
Flank	<5	<5	<5	7.00×10^2
Shoulder	<5	<5	<5	<5
Belly	<5	<5	<5	<5
Rump	<5	<5	<5	<5
Brisket	50	9.50×10^2	15	6.40×10^3
	Carcass 17		**Carcass 18**	
Neck	5	1.00×10^3	<5	7.10×10^2
Flank	<5	<5	<5	<5
Shoulder	<5	<5	<5	5
Belly	<5	<5	<5	3.50×10^3
Rump	<5	<5	<5	5
Brisket	<5	25	5	8.20×10^2
	Carcass 19		**Carcass 20**	
Neck	<5	5	50	3.70×10^2
Flank	<5	<5	<5	5
Shoulder	<5	<5	<5	<5
Belly	<5	<5	<5	1.70×10^2
Rump	<5	<5	5	6.00×10^2
Brisket	50	7.20×10^2	35	7.40×10^3

Appendix D

Treatment / Bacteria group	Least Squares Means			
	Split before toast	Split after toast	SED	P
Enterobacteriaceae	0.509	0.569	0.074	0.427
TVC	0.955	1.545	0.191	0.003

Appendix E

Carcass inspection before and after toasting. Individual carcass x site microbial counts

	Inspected before toasting (CFU/cm^2)		Inspected after toasting (CFU/ cm^2)	
	Enteros.	TVC	Enteros	TVC
	Carcass 1		Carcass 2	
Neck	<5	<5	<5	<5
Flank	<5	<5	<5	<5
Shoulder	<5	5	<5	<5
Belly	<5	<5	<5	<5
Rump	<5	<5	<5	<5
Brisket	<5	<5	<5	<5
	Carcass 3		**Carcass 4**	
Neck	10	6.40×10^2	<5	<5
Flank	<5	<5	<5	<5
Shoulder	<5	<5	<5	<5
Belly	<5	25	<5	<5
Rump	<5	5	<5	<5
Brisket	<5	<5	<5	<5
	Carcass 5		**Carcass 6**	
Neck	<5	6.65×10^2	<5	NC
Flank	<5	<5	<5	<5
Shoulder	<5	<5	<5	10
Belly	<5	<5	<5	6.85×10^3
Rump	<5	<5	<5	<5
Brisket	<5	5	<5	1.00×10^2
	Carcass 7		**Carcass 8**	
Neck	5	NC	<5	1.50×10^2
Flank	<5	5	<5	<5
Shoulder	<5	<5	<5	<5
Belly	<5	<5	<5	NC
Rump	<5	25	<5	5
Brisket	<5	<5	<5	<5
	Carcass 9		**Carcass 10**	
Neck	<5	<5	<5	2.10×10^2
Flank	<5	5	<5	5
Shoulder	<5	5	<5	<5
Belly	<5	<5	<5	5
Rump	<5	15	<5	20
Brisket	<5	15	<5	20

Appendix E

	Inspected before toasting (CFU/cm^2)		Inspected after toasting (CFU/ cm^2)	
	Enteros.	TVC	Enteros.	TVC
	Carcass 11		**Carcass 12**	
Neck	<5	<5	<5	70
Flank	<5	<5	<5	70
Shoulder	<5	30	<5	5
Belly	<5	<5	<5	20
Rump	<5	<5	<5	<5
Brisket	<5	<5	5	1.00×10^5
	Carcass 13		**Carcass 14**	
Neck	<5	1.24×10^3	5	7.50×10^2
Flank	<5	<5	<5	2.20×10^2
Shoulder	<5	<5	<5	1.06×10^3
Belly	<5	5	<5	1.25×10^3
Rump	<5	<5	5	2.10×10^4
Brisket	<5	<5	<5	85
	Carcass 15		**Carcass 16**	
Neck	<5	3.00×10^2	<5	1.10×10^3
Flank	20	3.10×10^2	<5	1.04×10^3
Shoulder	<5	<5	<5	3.75×10^2
Belly	<5	<5	<5	5.00×10^2
Rump	<5	<5	<5	1.35×10^2
Brisket	<5	NC	<5	<5
	Carcass 17		**Carcass 18**	
Neck	5	2.75×10^2	15	NC
Flank	<5	2.00×10^2	<5	<5
Shoulder	<5	60	<5	1.10×10^2
Belly	<5	80	<5	60
Rump	<5	50	<5	3.85×10^2
Brisket	<5	70	<5	40
	Carcass 19		**Carcass 20**	
Neck	<5	3.50×10^2	5	1.01×10^4
Flank	<5	<5	<5	95
Shoulder	<5	<5	<5	15
Belly	<5	<5	5	2.10×10^2
Rump	<5	5	<5	15
Brisket	<5	3.00×10^2	<5	1.15×10^2

Appendix E

Treatment / Bacteria group	Least Squares Means			
	Inspect before toast	Inspect after toast	SED	P
Enterobacteriaceae	0.429	0.424	0.022	0.833
TVC	0.959	1.524	0.192	0.004

Appendix F

Conventionally dressed versus skin-on carcasses. Individual carcass x site microbial counts

Conventional carcass	Counts before chilling (CFU/cm^2)		Counts after chilling (CFU/cm^2)	
	Enteros.	TVC	Enteros.	TVC
Carcass 1				
Neck	<5	<5	<5	2.30×10^2
Flank	<5	<5	<5	2.20×10^2
Shoulder	<5	<5	<5	<5
Belly	1.40×10^2	1.40×10^2	<5	3.45×10^3
Rump	<5	<5	<5	1.40×10^2
Brisket	55	55	<5	6.45×10^2
Carcass 2				
Neck	20	1.43×10^4	<5	5.15×10^3
Flank	<5	7.20×10^2	<5	5.60×10^2
Shoulder	10	1.50×10^2	<5	5.20×10^2
Belly	1.45×10^2	1.41×10^3	10	9.20×10^2
Rump	50	2.00×10^2	<5	10
Brisket	35	1.01×10^3	<5	15
Carcass 3				
Neck	<5	1.50×10^2	<5	35
Flank	25	7.75×10^3	<5	3.00×10^3
Shoulder	40	1.22×10^3	<5	15
Belly	1.45×10^3	5.80×10^3	<5	1.02×10^3
Rump	<5	45	<5	10
Brisket	1.00×10^2	1.45×10^2	15	10
Carcass 4				
Neck	10	2.75×10^2	<5	5.10×10^2
Flank	1.50×10^3	7.10×10^3	<5	2.80×10^3
Shoulder	<5	6.90×10^2	<5	<5
Belly	1.60×10^3	1.54×10^4	<5	60
Rump	55	5.35×10^3	<5	5
Brisket	30	1.56×10^3	<5	8.60×10^2
Carcass 5				
Neck	1.20×10^2	7.80×10^3	<5	4.10×10^3
Flank	<5	3.00×10^3	<5	7.55×10^3
Shoulder	<5	2.15×10^3	<5	50
Belly	15	2.55×10^3	10	2.25×10^3
Rump	10	3.25×10^2	<5	10
Brisket	10	1.46×10^3	<5	2.75×10^2

Appendix F

Conventional carcass	Counts before chilling (CFU/cm^2)		Counts after chilling (CFU/cm^2)	
	Enteros.	TVC	Enteros.	TVC
Carcass 6				
Neck	<5	2.95×10^3	<5	6.40×10^3
Flank	<5	1.28×10^3	<5	2.25×10^3
Shoulder	<5	3.10×10^2	<5	5
Belly	<5	1.35×10^3	<5	8.90×10^2
Rump	<5	1.60×10^2	<5	5
Brisket	10	1.55×10^2	<5	9.90×10^2
Carcass 7				
Neck	5	4.05×10^3	10	1.70×10^4
Flank	30	4.25×10^3	<5	1.14×10^4
Shoulder	5.70×10^2	2.05×10^4	<5	30
Belly	<5	2.60×10^3	<5	3.35×10^3
Rump	<5	3.85×10^2	<5	7.10×10^2
Brisket	<5	2.30×10^2	<5	7.55×10^2
Carcass 8				
Neck	<5	1.65×10^3	5	7.00×10^2
Flank	<5	2.60×10^3	<5	<5
Shoulder	<5	2.65×10^3	<5	1.25×10^3
Belly	<5	6.70×10^3	10	9.20×10^2
Rump	<5	50	<5	50
Brisket	<5	1.36×10^3	<5	9.60×10^2
Carcass 9				
Neck	<5	7.90×10^2	<5	9.00×10^2
Flank	<5	4.70×10^3	<5	5.80×10^3
Shoulder	<5	75	<5	4.90×10^3
Belly	35	6.40×10^3	5	9.15×10^3
Rump	<5	50	<5	3.75×10^2
Brisket	<5	2.75×10^2	<5	4.05×10^2
Carcass 10				
Neck	<5	2.00×10^2	<5	1.00×10^4
Flank	<5	1.36×10^3	5	2.05×10^3
Shoulder	<5	95	<5	3.25×10^3
Belly	5	8.00×10^2	<5	3.00×10^3
Rump	<5	<5	<5	<5
Brisket	<5	1.12×10^3	<5	1.49×10^3

Appendix F

Skin-on carcass	Counts before chilling (CFU/cm^2)		Counts after chilling (CFU/cm^2)	
	Enteros.	TVC	Enteros	TVC
Carcass1				
Neck	<5	<5	<5	2.00×10^2
Flank	<5	<5	<5	5
Shoulder	<5	<5	<5	<5
Belly	<5	5	<5	50
Rump	<5	<5	<5	<5
Brisket	<5	20	<5	2.20×10^2
Carcass 2				
Neck	<5	<5	<5	<5
Flank	<5	<5	<5	15
Shoulder	<5	<5	<5	<5
Belly	<5	5	<5	<5
Rump	<5	<5	<5	<5
Brisket	<5	<5	<5	<5
Carcass 3				
Neck	25	6.10×10^2	<5	3.35×10^3
Flank	<5	65	<5	<5
Shoulder	<5	<5	<5	15
Belly	<5	<5	<5	<5
Rump	<5	<5	<5	<5
Brisket	<5	<5	<5	<5
Carcass 4				
Neck	<5	10	<5	<5
Flank	<5	<5	<5	<5
Shoulder	<5	1.35×10^2	<5	30
Belly	<5	<5	<5	<5
Rump	<5	50	<5	4.35×10^2
Brisket	<5	5	<5	<5
Carcass 5				
Neck	<5	10	<5	5
Flank	<5	20	<5	<5
Shoulder	5	60	<5	<5
Belly	<5	30	<5	<5
Rump	<5	15	<5	<5
Brisket	<5	35	<5	<5

Appendix F

Skin-on carcass	Counts before chilling (CFU/cm^2)		Counts after chilling (CFU/cm^2)	
	Enteros.	TVC	Enteros	TVC
Carcass 6				
Neck	<5	<5	<5	1.15×10^2
Flank	<5	30	<5	30
Shoulder	<5	<5	<5	5
Belly	<5	<5	<5	5
Rump	<5	10	<5	15
Brisket	<5	<5	<5	<5
Carcass 7				
Neck	<5	5.35×10^3	<5	3.30×10^2
Flank	<5	60	<5	40
Shoulder	<5	30	<5	90
Belly	<5	40	<5	5
Rump	<5	<5	<5	45
Brisket	<5	10	<5	1.65×10^2
Carcass 8				
Neck	<5	<5	<5	<5
Flank	<5	<5	<5	10
Shoulder	<5	1.50×10^2	<5	4.15×10^2
Belly	<5	<5	<5	<5
Rump	<5	<5	<5	10
Brisket	<5	<5	<5	<5
Carcass 9				
Neck	<5	<5	<5	<5
Flank	<5	<5	<5	<5
Shoulder	<5	10	<5	<5
Belly	<5	<5	<5	<5
Rump	<5	<5	<5	<5
Brisket	<5	<5	<5	<5
Carcass 10				
Neck	<5	5	<5	<5
Flank	<5	<5	<5	<5
Shoulder	<5	<5	<5	10
Belly	<5	<5	<5	<5
Rump	<5	<5	<5	<5
Brisket	<5	<5	<5	<5

Appendix F

Two-way (conventional /skin-on and pre-/post-chill) analysis of variance results

Treatment & chill specification / Bacteria group	Least Squares Means				SED	P		
	Conventional		Skin-on					
	Pre-chill	Post-chill	Pre-chill	Post-chill		Treatment	Chill time	Interaction
Enterobacteriaceae	0.955[a]	0.466[b]	0.420[b]	0.398[b]	0.076	<0.001	<0.001	<0.001
TVC	2.944[a]	2.535[b]	0.850[c]	0.901[c]	0.157	<0.001	0.108	0.039

[a, b, c] Within a row, different superscripts indicate significantly different (P<0.05) means…

Shelf life preliminary study to identify microflora present

	Sampling Time			
	Time 0 (Log_{10}CFU/g)	Day 3 (Log_{10}CFU/g)	Day 6 (Log_{10}CFU/g)	Day 9 (Log_{10}CFU/g)
Brochothrix (22ºC)	1.18	1.18	1.65	4.13
Brochothrix (25ºC)	<1.18	<1.18	1.78	4.10
Lactic acid bacteria (25ºC)	3.23	3.44	3.54	4.00
Lactic acid bacteria (30ºC)	4.08	3.19	3.10	3.60
Pseudomonas (25ºC)	1.78	1.88	4.38	5.83
Pseudomonas (30ºC)	1.48	1.78	4.32	5.80
TVC (22ºC)	4.56	4.41	4.88	5.80
TVC (30ºC)	4.78	4.48	4.69	5.68
Yeasts & Moulds (22ºC)	1.18	1.65	2.13	3.22

Calculation of detection limit of 1.18: 200 g of meat was added to 300 ml of MRD; this gave the 10^0 sample; samples serially diluted in MRD; 0.1ml sample plated out using the spread plate technique. Therefore, 1 colony on the 10^0 plate, comes from 200 g of meat added to 300ml MRD

1 x 1 x 300/200 = 1.5 CFU/g in 0.1 ml which is 15 CFU/g in a 1ml sample. The Log_{10} of 15 is 1.176 = 1.18

Shelf life comparison: lactic acid bacteria (Log_{10}CFU/g, MRS agar)

	Conventional				Skin-on			
	Day 0	Day 3	Day 6	Day 9	Day 0	Day 3	Day 6	Day 9
	Carcass1				***Carcass 2***			
Shoulder	2.20	2.94	6.39	7.00	2.66	2.30	4.00	5.89
Breast	2.60	3.08	5.95	7.02	3.15	2.68	6.24	6.97
Leg	3.11	3.90	6.16	7.46	4.11	3.92	4.90	6.69
Loin	3.06	2.74	4.62	6.23	3.94	4.35	5.05	6.56
	Carcass 3				***Carcass 4***			
Shoulder	1.78	2.82	6.54	7.85	2.70	2.75	5.55	6.08
Breast	2.68	2.92	6.28	7.84	2.48	2.50	6.04	7.48
Leg	3.05	2.74	5.64	7.11	3.70	3.84	5.99	7.20
Loin	2.62	2.58	5.66	6.78	3.38	2.86	4.78	6.02
	Carcass 5				***Carcass 6***			
Shoulder	2.78	3.13	6.41	7.78	2.72	2.55	5.90	6.75
Breast	2.83	4.13	6.45	7.43	2.75	2.50	5.68	7.38
Leg	2.34	2.87	5.72	7.37	3.08	3.00	6.38	6.92
Loin	3.05	2.74	5.60	6.64	3.53	3.75	5.91	6.94
	Carcass 7				***Carcass 8***			
Shoulder	2.75	2.84	5.87	6.42	3.25	3.34	4.94	5.72
Breast	3.53	3.66	6.78	6.76	3.45	3.00	4.24	5.55
Leg	2.45	3.00	4.30	5.64	3.38	2.00	4.02	5.66
Loin	1.78	3.20	4.15	5.59	1.78	2.20	3.12	5.82
	Carcass 9				***Carcass 10***			
Shoulder	3.33	2.87	6.10	6.30	2.25	2.38	3.53	4.82
Breast	3.30	3.18	5.60	5.88	3.19	2.50	5.30	6.36
Leg	2.45	2.64	3.94	4.59	3.47	1.78	3.79	4.86
Loin	2.96	2.08	4.24	4.58	1.60	1.60	3.36	4.22

Appendix H

Shelf life comparison: *Pseudomonas* spp. (Log_{10}CFU/g, CFC agar)

	Conventional				Skin-on			
	Day 0	Day 3	Day 6	Day 9	Day 0	Day 3	Day 6	Day 9
	Carcass1				***Carcass 2***			
Shoulder	<1.30	3.60	6.16	6.60	<1.30	2.55	6.75	7.56
Breast	1.78	4.53	6.22	7.30	1.90	4.84	7.27	7.08
Leg	<1.30	3.58	4.78	8.16	<1.30	1.30	6.38	7.00
Loin	1.60	3.78	4.30	8.08	<1.30	1.78	6.07	7.30
	Carcass 3				***Carcass 4***			
Shoulder	1.30	4.15	5.00	7.60	1.30	3.70	5.34	6.30
Breast	1.30	3.95	5.08	6.78	1.30	3.58	6.81	6.90
Leg	<1.30	3.76	5.08	6.30	1.78	4.60	6.45	7.34
Loin	1.30	3.64	5.38	7.62	2.20	4.86	6.73	7.41
	Carcass 5				***Carcass 6***			
Shoulder	<1.30	3.53	4.60	7.25	1.30	4.15	5.30	7.08
Breast	1.30	4.25	5.20	6.30	1.30	4.00	5.25	7.15
Leg	<1.30	3.88	4.60	7.60	1.90	4.38	4.60	7.00
Loin	<1.30	2.88	4.30	7.30	<1.30	3.78	4.30	6.90
	Carcass 7				***Carcass 8***			
Shoulder	2.30	4.45	5.75	6.30	<1.30	2.60	3.60	6.20
Breast	1.30	4.00	6.30	7.08	<1.30	3.20	4.90	7.41
Leg	<1.30	1.60	4.30	6.60	<1.30	4.45	7.09	8.35
Loin	1.30	3.48	5.08	5.60	1.90	3.76	5.73	8.05
	Carcass 9				***Carcass 10***			
Shoulder	2.55	3.34	6.00	7.45	1.60	3.20	5.20	7.50
Breast	1.60	3.68	5.68	7.20	2.58	3.76	4.90	8.07
Leg	1.30	2.25	4.15	6.41	2.30	3.78	5.38	7.38
Loin	2.48	2.30	4.30	7.00	1.60	1.78	4.00	6.60

Calculation of detection limit of 1.30: 50 g of meat was added to 100 ml of MRD; this gave the 10^0 sample; samples serially diluted in MRD; 0.1ml sample plated out using the spread plate technique. Therefore, 1 colony on the 10^0 plate, comes from 50 g of meat added to 100 ml MRD

1 x 1 x 100/50 = 2 CFU/g in 0.1 ml which is 20 CFU/g in a 1 ml sample. The Log_{10} of 20 is 1.30

Appendix H

Shelf life comparison: TVC (Log_{10}CFU/g, PCA agar)

	Conventional				Skin-on			
	Time 0	Day 3	Day 6	Day 9	Time 0	Day 3	Day 6	Day 9
	Carcass1				***Carcass 2***			
Shoulder	4.22	5.00	8.37	9.17	4.19	4.55	6.51	8.60
Breast	4.01	5.45	8.03	9.25	4.13	5.82	7.74	9.06
Leg	4.14	5.36	7.78	9.23	4.50	4.43	6.50	8.72
Loin	3.68	4.02	7.66	9.25	4.72	5.03	7.58	9.17
	Carcass 3				***Carcass 4***			
Shoulder	3.73	5.48	7.92	9.14	3.95	4.78	7.91	9.22
Breast	4.05	4.95	8.20	9.09	4.11	5.48	7.91	9.19
Leg	3.88	4.73	7.70	9.09	4.12	5.32	7.84	9.10
Loin	3.66	4.13	7.48	9.19	4.28	5.62	8.17	9.45
	Carcass 5				***Carcass 6***			
Shoulder	3.83	5.66	7.77	9.19	4.09	5.01	8.07	9.19
Breast	4.22	5.21	8.14	8.96	4.01	5.35	7.84	9.25
Leg	4.36	5.43	7.52	9.14	4.06	4.98	7.78	9.51
Loin	3.84	4.23	7.43	9.06	4.30	6.20	7.72	9.14
	Carcass 7				***Carcass 8***			
Shoulder	4.10	5.06	7.18	9.35	4.47	4.80	6.92	9.04
Breast	4.26	5.09	8.20	9.51	4.34	4.73	5.94	8.98
Leg	2.92	3.67	7.02	8.89	4.13	4.37	7.70	9.09
Loin	2.66	4.44	7.02	7.99	2.96	4.04	5.93	8.44
	Carcass 9				***Carcass 10***			
Shoulder	4.26	4.35	7.19	8.49	4.15	4.61	5.90	8.57
Breast	3.84	4.58	6.64	8.16	4.42	5.03	6.62	8.61
Leg	3.05	3.62	5.93	7.48	4.20	4.46	5.93	8.00
Loin	4.09	3.58	6.05	7.61	3.17	3.70	5.78	7.90

Appendix H

Shelf life comparison: Yeast and moulds (Log_{10}CFU/g, Rose-Bengal agar)

	Conventional				Skin-on			
	Day 0	Day 3	Day 6	Day 9	Day 0	Day 3	Day 6	Day 9
	Carcass1				***Carcass 2***			
Shoulder	3.58	4.55	6.08	7.76	3.78	4.41	5.39	7.08
Breast	3.56	4.84	6.34	7.53	3.82	4.66	5.62	7.43
Leg	2.38	3.50	5.13	7.23	1.90	3.05	5.02	6.39
Loin	2.48	3.23	5.41	7.28	2.20	3.02	5.03	7.07
	Carcass 3				***Carcass 4***			
Shoulder	3.26	4.38	5.80	7.11	3.81	4.60	5.30	7.82
Breast	3.30	4.69	6.20	7.44	4.03	4.99	5.87	7.63
Leg	2.62	3.25	5.39	7.44	2.20	3.12	5.63	7.56
Loin	1.60	2.76	5.19	6.78	2.86	4.14	5.41	7.74
	Carcass 5				***Carcass 6***			
Shoulder	3.48	4.45	6.05	7.26	3.58	4.88	6.04	7.68
Breast	2.89	4.11	5.97	7.28	3.92	5.09	5.87	7.66
Leg	2.41	3.66	5.55	7.01	2.38	3.94	5.76	7.37
Loin	2.34	3.94	5.38	6.80	2.50	3.53	5.49	6.99
	Carcass 7				***Carcass 8***			
Shoulder	3.95	4.44	5.16	6.54	4.34	4.56	5.21	6.50
Breast	3.79	4.45	5.50	6.31	4.82	4.50	5.13	7.61
Leg	2.41	2.83	4.46	5.32	2.81	3.85	6.08	8.02
Loin	2.25	3.34	4.36	5.55	2.55	3.46	5.00	6.83
	Carcass 9				***Carcass 10***			
Shoulder	3.60	4.08	5.45	6.96	4.12	4.48	5.31	7.68
Breast	3.46	4.34	5.30	6.58	3.90	4.59	5.48	7.38
Leg	2.38	3.23	4.49	5.74	3.18	4.19	4.70	5.89
Loin	2.10	3.21	4.34	5.47	2.95	3.72	4.41	6.75

Appendix H

Lactic acid bacteria: three-way (conventional/skin-on, joint and days on display) analysis of variance results

						P			
					SED	**Main effect**	**Interaction**		
Meat type	**Conventional**		**Skin-on**			-	Meat type x joint	Meat type x day	Joint x day
	4.49		4.24		0.120	0.036			
Joint	**Shoul-der**	**Breast**	**Loin**	**Leg**			0.067		
	$4.36^{a\ b}$	4.68^{a}	4.04^{b}	4.38^{ab}	0.170	0.003		0.034	
Day	**0**	**3**	**6**	**9**		-			0.311
	2.88^{a}	2.90^{a}	5.28^{b}	6.40^{c}	0.170	<0.001			

$^{a, b, c}$ Within a row, different superscripts indicate significantly different (P<0.05) means

Pseudomonas spp.: three-way (conventional/skin-on, joint and days on display) analysis of variance results

						P			
					SED	**Main effect**	**Interaction**		
Meat type	**Conventional**		**Skin-on**			-	Meat type x joint	Meat type x day	Joint x day
	4.24		4.43		0.121	0.130			
Joint	**Shoul-der**	**Breast**	**Loin**	**Leg**		-	0.015		
	4.29	4.59	4.21	4.24	0.172	0.107		0.469	
Day	**0**	**3**	**6**	**9**					0.710
	1.34^{a}	3.52^{b}	5.36^{c}	7.13^{d}	0.172	<0.001			

$^{a, b, c}$ Within a row, different superscripts indicate significantly different (P<0.05) means

Appendix H

TVC: three-way (conventional/skin-on, joint and days on display) analysis of variance results

						P			
					SED	**Main effect**	**Interaction**		
Meat type	**Conventional**		**Skin-on**				Meat type x joint	Meat type x day	Joint x day
	6.22		6.26		0.097	0.622			
Joint	**Shoul-der**	**Breast**	**Loin**	**Leg**			0.173		
	6.35[a]	6.46[a]	6.01[b]	6.14[a b]	0.137	0.005		0.103	
Day	**0**	**3**	**6**	**9**					0.997
	3.98[a]	4.81[b]	7.29[c]	8.89[d]	0.137	<0.001			

[a, b, c] Within a row, different superscripts indicate significantly different (P<0.05) means

Yeasts and moulds: three-way (conventional/skin-on, joint and days on display) analysis of variance results

						P			
					SED	**Main effect**	**Interaction**		
Meat type	**Conventional**		**Skin-on**				Meat type x joint	Meat type x day	Joint x day
	4.73		5.02		0.073	<0.001			
Joint	**Shoul-der**	**Breast**	**Loin**	**Leg**		-	0.623		
	5.26[a]	5.35[a]	4.39[b]	4.49[b]	0.103	<0.001		0.118	
Day	**0**	**3**	**6**	**9**		-			0.006
	3.09[a]	4.00[b]	5.38[c]	7.01[d]	0.103	<0.001			

[a, b, c] Within a row, different superscripts indicate significantly different (P<0.05) means

Appendix J

Shelf life comparison. CIELAB colour measurements on meat from conventionally dressed carcasses

Carc-ass	Muscle	L* (lightness/darkness)						a* (red/green)						b* (yellow/blue)					
		Days displayed						Days displayed						Days displayed					
		1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
1	*Longissimus* 1[1]	40.9	42.5	40.3	40.3	40.7	40.6	14.6	12.7	13.9	13.5	13.3	13.5	9.1	8.7	9.9	9.2	9.2	9.6
	Longissimus 2[1]	39.8	40.8	40.7	40.4	40.7	39.4	14.9	14.2	12.7	11.9	11.5	11.4	9.5	10.0	9.3	7.9	8.0	8.4
	Gluteobiceps 1	40.5	39.0	39.2	38.8	38.8	38.0	13.9	13.2	12.8	11.9	12.1	11.9	9.5	9.6	9.2	8.8	9.1	9.4
	Gluteobiceps 2	42.1	39.5	40.1	38.9	39.0	39.1	12.2	12.2	12.1	11.8	11.9	11.7	9.3	9.6	9.4	9.4	9.1	9.6
2	*Longissimus* 1	40.6	40.4	41.9	40.2	41.7	42.0	19.3	18.1	17.1	15.2	14.6	13.7	11.1	11.0	11.2	10.3	10.8	9.3
	Longissimus 2	41.5	40.2	41.1	41.6	41.0	40.0	17.5	17.3	16.3	14.4	14.1	13.5	9.7	10.1	10.1	9.8	9.5	9.3
	Gluteobiceps 1	43.2	40.2	41.3	43.4	42.4	42.0	16.4	16.5	14.6	11.8	12.2	12.1	9.6	10.7	10.1	8.5	9.2	9.1
	Gluteobiceps 2	40.0	39.2	40.5	39.6	40.7	40.5	16.0	15.0	13.3	13.1	12.3	11.6	9.8	10.4	10.4	10.4	10.1	9.9
3	*Longissimus* 1	39.6	40.5	39.7	40.2	38.5	42.1	15.2	12.8	13.3	12.5	12.9	12.0	9.3	8.0	8.5	7.9	8.3	7.6
	Longissimus 2	40.1	39.5	41.7	38.4	36.0	38.7	13.9	14.0	12.4	13.5	14.2	12.1	7.3	8.9	7.7	8.6	9.4	7.5
	Gluteobiceps 1	40.5	39.5	39.8	39.1	38.3	38.3	14.6	14.6	13.1	13.0	13.2	12.5	8.5	8.8	9.2	8.6	8.8	8.1
	Gluteobiceps 2	42.7	41.0	39.1	39.7	39.2	39.0	13.1	11.8	12.1	12.1	11.8	11.2	8.7	8.4	9.1	9.1	8.7	8.5
4	*Longissimus* 1	39.4	38.4	39.0	36.0	37.9		11.9	11.0	10.2	10.8	10.0		7.5	6.6	6.2	6.4	6.1	
	Longissimus 2	40.6	40.4	39.7	37.3	38.4		13.2	10.4	9.8	10.7	9.2		8.3	6.4	6.2	6.5	5.3	
	Gluteobiceps 1	44.6	43.4	41.4	38.6	38.3		11.8	10.1	9.5	9.8	10.0		7.5	6.4	6.1	6.6	7.2	
	Gluteobiceps 2	39.7	39.4	38.0	38.0	37.9		14.0	11.5	11.3	10.3	10.0		9.7	8.2	7.6	7.3	7.2	
5	*Longissimus* 1	39.0	39.4	38.4	36.0	40.9		14.4	11.7	10.3	10.6	10.3		8.4	6.6	6.0	6.1	6.4	
	Longissimus 2	37.6	40.2	36.3	37.2	37.3		12.7	11.3	11.3	11.1	10.3		7.4	6.5	6.7	6.7	6.2	
	Gluteobiceps 1	40.9	39.5	38.8	36.9	36.9		12.5	10.7	10.1	9.3	8.5		8.3	7.7	7.7	6.8	5.6	
	Gluteobiceps 2	40.0	38.7	37.0	38.2	36.5		13.3	10.9	11.8	10.0	10.6		9.7	7.4	7.6	6.4	7.4	

[1] Duplicate measurements for each sample

Appendix J

Shelf life comparison: colour saturation and hue of meat from conventionally dressed carcasses

Carcass	Muscle	Chroma (colour saturation)						Hue					
		Days displayed						Days displayed					
		1	2	3	4	5	6	1	2	3	4	5	6
1	*Longissimus* 1[1]	17.2	15.4	17.0	16.3	16.1	16.6	31.8	34.5	35.5	34.4	34.7	35.4
	Longissimus 2[1]	17.7	17.3	15.7	14.3	14.0	14.2	32.5	35.3	36.2	33.7	34.9	36.1
	Gluteobiceps 1	16.9	16.3	15.8	14.8	15.1	15.2	34.4	36.0	35.6	36.6	37.0	38.5
	Gluteobiceps 2	15.3	15.6	15.3	15.1	15.0	15.1	37.3	38.2	38.0	38.4	37.4	39.6
2	*Longissimus* 1	22.2	21.1	20.4	18.3	18.2	16.5	29.9	31.3	33.3	34.1	36.3	34.2
	Longissimus 2	20.0	20.0	19.2	17.4	17.0	16.4	29.0	30.4	31.8	34.3	34.1	34.4
	Gluteobiceps 1	19.0	19.7	17.8	14.6	15.3	15.1	30.2	33.0	34.6	35.7	36.9	37.0
	Gluteobiceps 2	18.7	18.2	16.9	16.7	15.9	15.2	31.4	34.8	38.1	38.4	39.3	40.5
3	*Longissimus* 1	17.8	15.1	15.7	14.8	15.3	14.2	31.6	32.0	32.7	32.3	32.8	32.5
	Longissimus 2	15.7	16.5	14.6	16.0	17.0	14.2	27.8	32.4	32.0	32.5	33.5	31.9
	Gluteobiceps 1	16.9	17.1	16.0	15.6	15.9	14.9	30.3	31.1	35.2	33.6	33.5	32.8
	Gluteobiceps 2	15.7	14.5	15.2	15.1	14.6	14.1	33.8	35.3	37.1	37.1	36.4	37.2
4	*Longissimus* 1	14.1	12.8	12.0	12.6	11.8		32.3	30.9	31.0	30.6	31.4	
	Longissimus 2	15.6	12.2	11.6	12.5	10.6		32.0	31.6	32.1	31.1	30.0	
	Gluteobiceps 1	14.0	11.9	11.3	11.9	12.3		32.5	32.5	32.7	33.9	35.6	
	Gluteobiceps 2	17.1	14.1	13.6	12.6	12.3		34.7	35.5	34.1	35.1	35.6	
5	*Longissimus* 1	16.7	13.5	11.9	12.2	12.1		30.4	29.6	30.2	29.9	31.8	
	Longissimus 2	14.7	13.0	13.1	13.0	12.0		30.2	29.8	30.7	31.2	31.1	
	Gluteobiceps 1	15.0	13.2	12.7	11.5	10.2		33.5	35.6	37.1	36.0	33.2	
	Gluteobiceps 2	16.4	13.2	14.1	11.9	12.9		36.1	34.2	32.9	32.7	34.8	

[1] Duplicate measurements for each sample

Appendix J

Shelf life comparison: CIELAB colour measurements on meat from skin-on carcasses

Carc-ass	Muscle	L* (lightness/darkness)						a* (red/green)						b* (yellow/blue)					
		Days displayed						Days displayed						Days displayed					
		1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
1	*Longissimus* 1[1]	42.2	39.6	42.2	43.1	41.0	42.6	15.9	16.3	15.9	16.0	16.2	16.6	9.6	10.1	9.6	10.1	9.6	10.2
	Longissimus 2[1]	42.1	41.0	42.1	40.0	41.0	39.9	17.0	17.1	17.0	16.6	16.7	17.0	10.0	9.8	9.7	9.1	9.4	9.9
	Gluteobiceps 1	42.5	42.3	42.4	41.3	41.7	41.6	18.3	16.3	17.3	15.4	15.8	14.6	9.6	9.1	9.6	8.9	9.1	8.4
	Gluteobiceps 2	40.2	40.7	40.3	41.2	40.7	42.4	17.4	16.1	16.3	15.2	15.2	14.7	10.4	10.4	10.0	9.4	9.4	9.1
2	*Longissimus* 1	40.6	40.9	40.3	39.2	41.1	40.7	15.0	13.2	13.4	12.1	12.3	12.5	9.0	8.6	9.5	8.3	8.2	8.4
	Longissimus 2	42.8	40.6	39.9	39.2	41.2	41.0	14.9	13.8	13.5	13.8	13.5	13.3	9.2	9.9	9.8	10.0	9.6	10.2
	Gluteobiceps 1	45.8	43.7	42.4	41.7	42.4	41.0	14.9	16.3	15.1	14.3	13.6	12.8	9.3	10.7	11.0	10.6	10.3	10.6
	Gluteobiceps 2	44.2	46.1	41.9	42.6	41.5	40.5	13.5	10.0	12.4	11.8	12.4	12.7	9.4	7.4	10.4	9.4	10.1	10.7
3	*Longissimus* 1	43.4	44.4	42.7	42.7	43.6	42.5	11.6	12.0	10.5	11.0	11.2	11.9	8.1	6.7	7.0	8.3	8.6	9.8
	Longissimus 2	42.5	40.0	40.2	42.2	40.2	40.4	14.5	14.0	14.0	10.7	11.6	12.6	8.5	9.5	9.9	8.0	8.9	9.8
	Gluteobiceps 1	44.9	42.6	43.1	44.2	41.9	41.2	16.9	15.8		12.5	13.4	13.3	10.5	11.3	10.0	9.0	10.0	10.5
	Gluteobiceps 2	45.8	42.8	42.8	43.6	42.7	40.7	15.9	15.0	13.7	13.7	13.5	12.2	9.6	10.2	9.7	9.6	9.7	9.6
4	*Longissimus* 1	45.2	47.0	46.6	45.9	47.3		14.8	14.6	14.1	14.5	14.8		8.3	8.6	8.5	8.8	9.2	
	Longissimus 2	46.2	46.7	45.0	46.3	46.7		14.2	14.2	12.7	14.0	14.4		8.1	8.6	7.4	8.7	9.4	
	Gluteobiceps 1	47.7	45.9	45.6	46.0	46.6		14.9	15.0	15.4	15.7	15.5		8.0	8.0	8.3	8.3	8.1	
	Gluteobiceps 2	47.7	47.4	46.1	46.7	47.3		15.4	13.3	13.7	13.0	13.0		10.5	9.4	9.7	9.6	9.7	
5	*Longissimus* 1	38.8	40.8	38.8	39.4	40.2		14.3	11.2	10.3	8.9	8.6		9.4	7.0	6.8	6.4	6.7	
	Longissimus 2	42.6	41.8	42.1	41.6	39.5		14.0	12.2	10.6	10.4	10.5		7.4	6.6	5.8	5.5	6.4	
	Gluteobiceps 1	42.3	42.1	42.1	40.4	42.2		16.3	13.6	12.2	11.4	9.9		9.9	8.5	8.0	7.8	7.1	
	Gluteobiceps 2	41.9	39.3	41.5	39.4	39.2		16.5	14.1	12.0	11.7	11.5		10.1	9.0	8.1	7.8	8.3	

[1] Duplicate measurements for each sample

Appendix J

Shelf life comparison: colour saturation and hue of meat from skin-on carcasses

Carcass	Muscle	Chroma (colour saturation)						Hue					
		Days displayed						Days displayed					
		1	2	3	4	5	6	1	2	3	4	5	6
1	*Longissimus* 1[1]	18.6	19.1	18.6	19.0	18.8	19.4	31.1	31.7	31.1	32.4	30.6	31.7
	Longissimus 2[1]	19.7	19.7	19.5	18.9	19.2	19.7	30.5	29.8	29.8	28.9	29.3	30.1
	Gluteobiceps 1	20.7	18.6	19.8	17.8	18.3	16.8	27.6	29.2	28.9	29.9	29.9	29.8
	Gluteobiceps 2	20.3	19.1	19.1	17.9	17.8	17.3	31.0	32.8	31.7	31.7	31.7	31.7
2	*Longissimus* 1	17.5	15.8	16.4	14.7	14.7	15.1	31.0	33.1	35.3	34.4	33.7	33.8
	Longissimus 2	17.5	17.0	16.7	17.1	16.5	16.7	31.8	35.7	36.2	36.1	35.4	37.3
	Gluteobiceps 1	17.6	19.5	18.7	17.8	17.0	16.7	31.9	33.2	36.0	36.7	37.1	39.6
	Gluteobiceps 2	16.4	12.5	16.2	15.1	16.0	16.6	34.7	36.6	39.9	38.6	39.2	40.1
3	*Longissimus* 1	14.1	13.8	12.6	13.7	14.1	15.4	34.9	29.3	33.5	37.0	37.5	39.3
	Longissimus 2	16.8	16.9	17.1	13.4	14.6	16.0	30.5	34.0	35.1	36.6	37.6	37.9
	Gluteobiceps 1	19.9	19.5	17.4	15.4	16.7	16.9	31.7	35.6	34.9	35.8	36.6	38.4
	Gluteobiceps 2	18.6	18.1	16.8	16.7	16.6	15.5	31.0	34.3	35.5	35.1	35.8	38.3
4	*Longissimus* 1	17.0	17.0	16.4	16.9	17.4		29.4	30.64	31.1	31.4	32.0	
	Longissimus 2	16.3	16.6	14.7	16.5	17.2		29.8	31.28	30.4	31.7	33.1	
	Gluteobiceps 1	16.9	17.0	17.5	17.8	17.5		28.4	28.02	28.3	27.9	27.7	
	Gluteobiceps 2	18.6	16.3	16.8	16.1	16.2		34.5	35.22	35.4	36.4	36.8	
5	*Longissimus* 1	17.1	13.2	12.4	11.0	10.9		33.2	32.13	33.3	35.6	37.7	
	Longissimus 2	15.8	13.8	12.1	11.8	12.3		27.7	28.37	28.7	27.9	31.4	
	Gluteobiceps 1	19.1	16.0	14.6	13.9	12.2		31.4	32.19	33.3	34.5	35.7	
	Gluteobiceps 2	19.3	16.7	14.5	14.0	14.2		31.4	32.54	34.1	33.7	35.9	

[1] Duplicate measurements for each sample

Appendix K

Shelf life comparison: TBAR values (mg/kg) in two muscles after six days display

	Conventional					Skin-on			
	Longissimus		*Glutoebiceps*			*Longissimus*		*Glutoebiceps*	
Carcass	1[1]	2[1]	1	2	Carcass	1	2	1	2
1	0.247	0.314	0.608	0.650	2	0.282	0.301	0.512	0.594
3	0.975	1.154	0.913	1.065	4	0.341	0.411	0.669	0.809
5	0.188	0.158	0.235	0.266	6	0.342	0.397	0.540	0.572
7	0.451	0.461	0.430	0.467	8	0.233	0.225	-	0.354
9	0.594	0.699	0.546	0.594	10	1.082	1.179	0.898	1.059

[1] Duplicate measurements for each sample

Two-way (conventional/skin-on and muscle) analysis of variance results

	Least Squares Means		Treatment	Muscle	Interaction
	Conventional	Skin-on	P		
Gluteobiceps	0.58	0.60	0.999		
Longissimus	0.52	0.48	0.997		
Overall mean	0.55	0.54	0.962	0.536	0.817

Appendix L
Visibility of carcass ink stamp before and after toasting

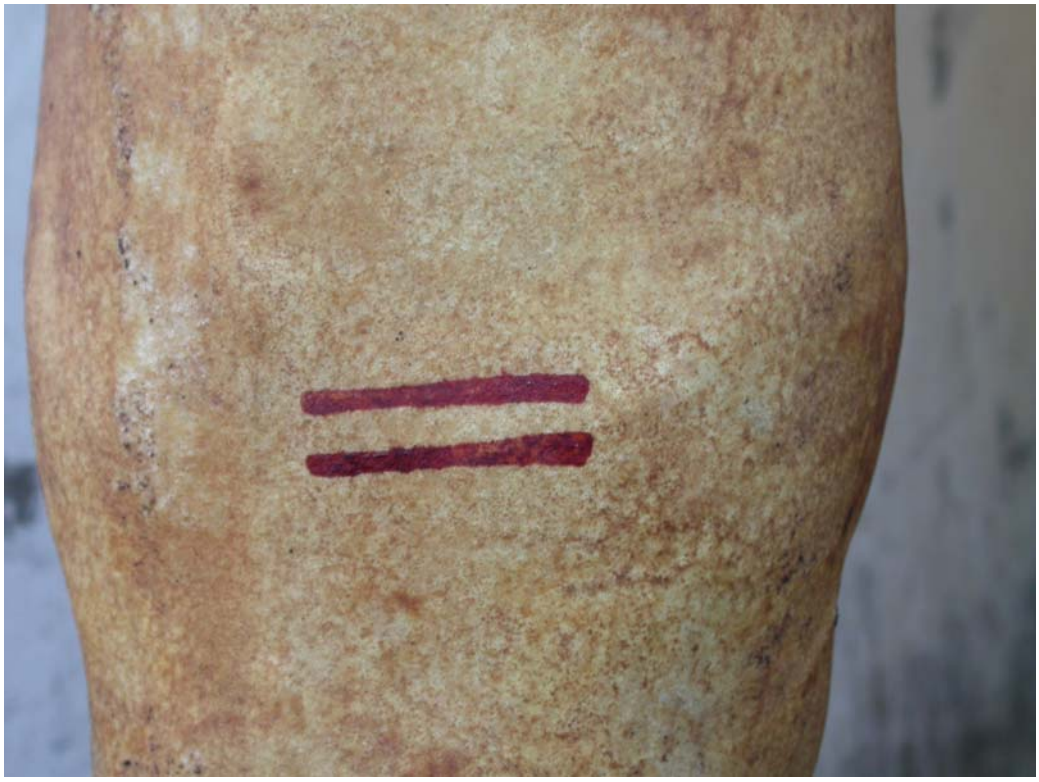


Fig. L1. Visibility of a stamp on a singed carcass before toasting

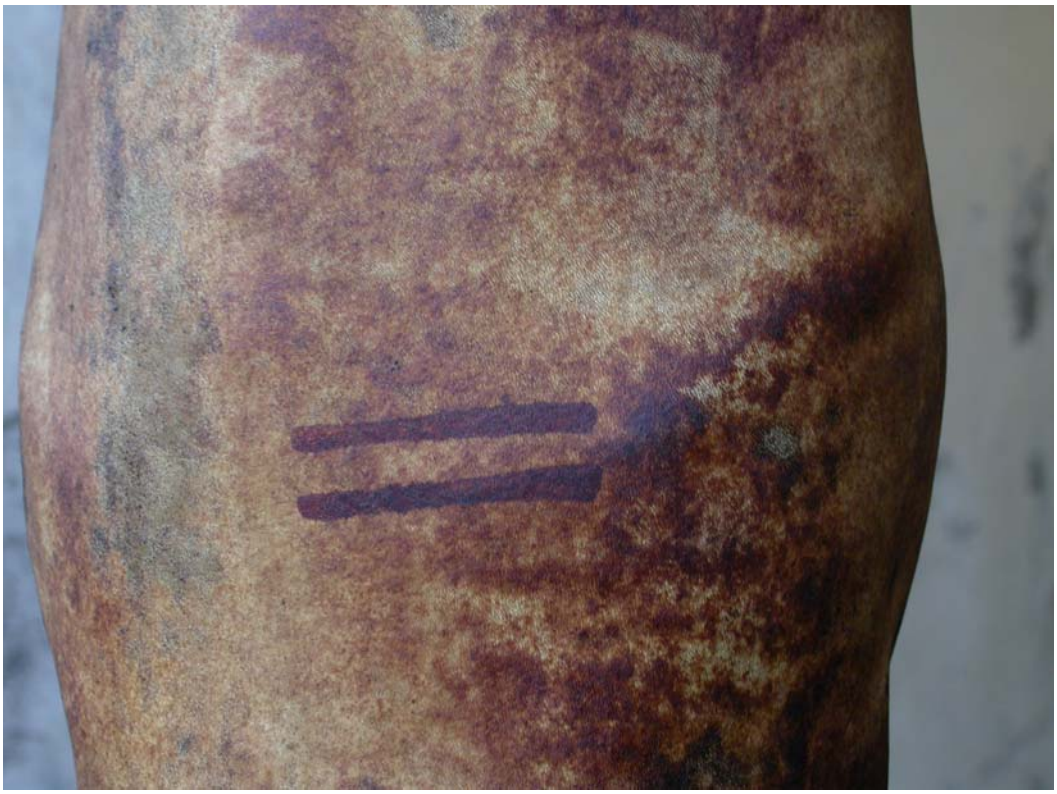
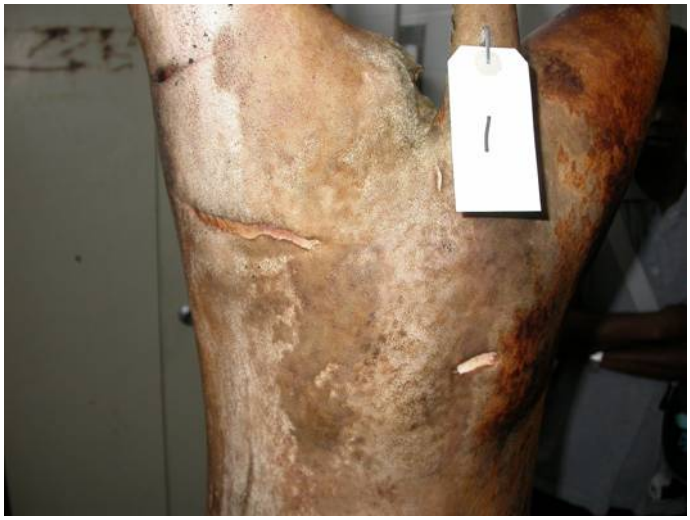


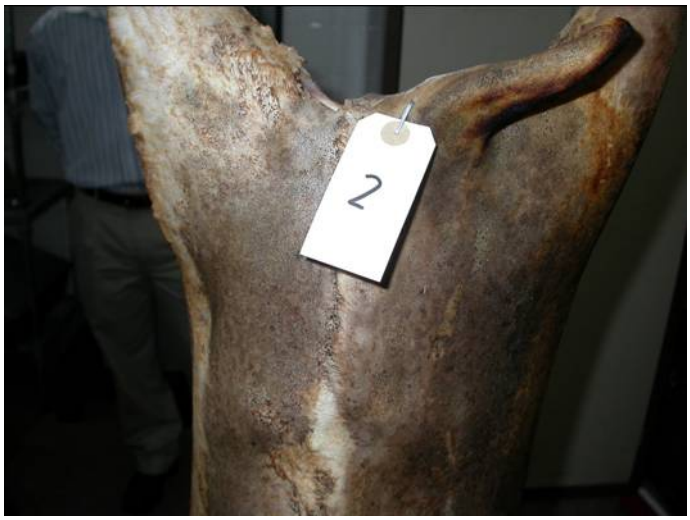
Fig. L2. Visibility of a stamp on a carcass after toasting

Appendix M

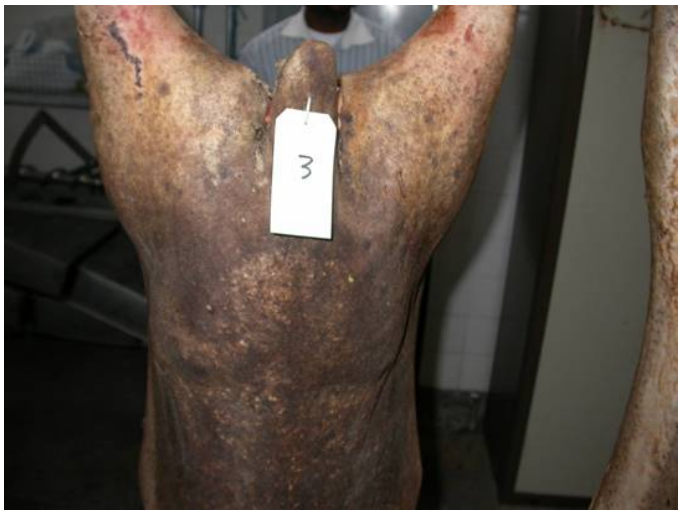
Carcasses used in panel assessment trial



Carcass 1



Carcass 2



Carcass 3

Appendix N

SHEEP CARCASS LESION MONITORING. DATE……

Lesion type	Number of cases										
Abscesses											
Anaemia											
Arthritis											
Fever/septicaemia/toxaemia											
Jaundice											
Melanosis											
Oedema/emaciation											
Pyaemia/generalised abscessation											
Trauma (bruising, fractures, dislocations)											
Tumours											
Other (specify)											