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Quantification of the controls that should be placed on meat prior to mincing

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By

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1. Executive summary

Significant quantities of minced meat are produced in the UK. This is used in catering and the home for a variety of cooked dishes, and in the manufacture of meat preparations and products ranging from burgers and sausages to canned products and chilled or frozen ready meals. While some minced meat is prepared from trimmings remaining after the preparation of joints and cuts, much minced meat is prepared from parts of the carcass for which there is insufficient consumer demand for as joints or cuts, e.g. forequarter beef. In the UK, there is a long-standing tradition of ageing meat for long periods in order to develop more flavour, and improve texture, for the national market. In the UK, ageing has seen a revival in recent years and UK supermarkets are currently marketing beef aged for up to 28 days, lamb aged for 14 days and pork aged for 10 days. In common with the accepted practice of hanging game birds, the hanging of turkeys is also receiving increased interest. Ageing may be carried out in aerobic conditions, so called "dry-ageing" (usually in the form of whole carcasses, sides or quarters), or in anaerobic conditions, so called "wet-ageing" (usually in the form of vacuum-packaged primals or sub-primals). Following ageing the carcasses/sides/primals may be distributed direct to retail outlets for butchery, or more commonly cut into consumer portions, packaged and then distributed to the retailer. Not all the meat can be sold as joints and cuts and the production of mince from the remaining carcass meat is an important economic aspect of the process.

Current legislation (Regulation (EC) No. 853/2004, Annex III, Section V, Chapter III, paragraph 2) imposes strict limits on the age of meat, from slaughter to mincing, that can be used to produce mince. This restricts the use of aged meat in the production of mince.

In 2006 the Food Refrigeration and Process Engineering Research Centre (FRPERC), then part of the University of Bristol, carried out an independent review for the UK Food Standards Agency to critically assess the available scientific literature on the survival and growth of microorganisms that are important for safety and quality during storage of meat and the production of minced meat. This review concluded that there was no scientific evidence to justify the restrictions in Regulation (EC) 853/2004, however nor was there much data on the specific risk.

The aims of this study, conducted with industry, was to:

1. Identify and describe industrial practice and collect available data.
2. Update the 2006 review.
3. Determine the microbiological status of currently produced mince.
4. Assess the likelihood of safety and quality problems using existing chilling and storage data.
5. Make recommendations on the controls that should be put in place for meat to be minced, including aged meat, and how they can be applied within a risk based food safety management system.

This study has updated the 2006 review and added further data collected and supplied by the UK industry on current processing conditions and microbiological status of mince to address knowledge gaps identified in the 2006 review and strengthen the evidence base.

A total of 11 UK meat processors participated in the study with the support of the FSA and British Meat Processors Association (BMPA), of these: 7 processed beef mince, 4 processed

pork mince, 4 processed UK lamb mince, 2 processed New Zealand lamb mince and 1 processed turkey mince.

Current EU (paragraph 2(b), Chapter III, Section V, Annex III of Regulation (EC) 853/2004) limits are that meat must be minced within no more than: 6 days of slaughter for red meat; 3 days of slaughter for poultry meat; and 15 days of slaughter for boned vacuum packed beef and veal. UK supermarkets are currently marketing beef aged for up to 28 days, lamb aged for 14 days and pork aged for 10 days. While the data provided by participating UK processors in this study show that beef, pork, UK lamb, New Zealand lamb and turkey meat may be minced 59, 18, 26, 67 and 6 days after slaughter.

The main points to emerge from this study are that:

1. The literature review identified no clear published scientific literature to support the restrictions on the time between slaughter and production of minced meat. Only one specific scientific publication (**Crowley *et al.*, 2010**) has been located that has looked at the safety and quality of mince produced from cuts and carcasses that have been stored for different periods of time post-slaughter. The results of that particular study not only support the overall conclusion of the 2006 review (that there is no scientific rationale for limiting the storage of meat prior to mince production) it actually identified "advantages in storing beef trimmings in vacuum packs for at least 21 days prior to mincing, in terms of improved mince quality" (**Crowley *et al.*, 2010**). This published study addresses the vacuum-packed storage of beef trimmings and shows no effect at 0°C. This study did not assess "dry-aged" carcass meat. No published studies have been identified that address any other type of meat.
2. The evidence supplied/collected by the participating UK meat processors in this study show that chilled beef, pork, UK lamb, New Zealand lamb and turkey may be stored for up to 59, 18, 26, 67 and 4 days, respectively before being minced. Evidence, and experience and knowledge of industry practices suggests that most UK meat processors are storing meat during ageing at less than 2°C, which would seem to be an acceptable good practice. The data supplied/collected by the participating UK meat processors in this study also shows that Total viable, *Escherichia coli* and Enterobacteriaceae counts from meat after mincing do not substantially increase with the length of time the meat is stored prior to mincing.
3. The literature review identified a small number of publications on the quality of steaks and chops produced from meat that has been stored for up to 35 days and 80 days for beef, 40 days for lamb and 63 days for pork. No similar data have been found for poultry meat. These publications all show that bacterial numbers were higher on meat produced from older meat, however, an acceptable display-life was usually achieved with cuts produced from the older meat.
4. The literature review identified no publications that show that the safety (i.e. pathogen levels) of mince produced from older meat is compromised, or visa versa. The data supplied/collected by the participating UK meat processors in this study show no evidence (both in terms of pathogen levels or indicator organisms) that the safety of mince produced from older meat is compromised.
5. The literature review identified a surprising lack of published data on the storage-life of chilled meat carcasses and bone-in-cuts. The classic studies indicate much shorter storage lives than current industrial practice, as indicated in IIR tables etc. There is little published data on the growth of pathogens on meat carcasses, sides or primals during dry-ageing. More data is available on the storage-life of some vacuum-

packaged primal meat, however this covers a limited range of storage conditions. As would be expected, the data that does exist shows that initial bacterial numbers, and storage atmosphere and temperature are the main factors governing storage life. pH and RH also influence storage life.

6. The literature review found there to be very little published data on the effect of current commercial chilling rates and conditions on changes in bacterial numbers during the process. In most cases, no change or a small reduction (0.5 to 1 $\log_{10}$ cfu cm^{-2}) in number of organisms on the surface has been measured. In one publication, the rate of initial chilling is claimed to make changes of up to 50% in storage life.

7. The effectiveness of chilling can be determined by using the Australian Refrigeration Index Calculator model to calculated the Refrigeration Index (RI) and comparing with RI criteria. A comparison of data supplied by participating UK meat processors in this study using this model shows that effective refrigeration that prevents growth of *E. coli* during the primary chilling process can be achieved in UK abattoirs. The Australian Refrigeration Index Calculator model also indicates that delayed primary chilling of beef sides, where the chiller operates at approximately 10°C during loading (to avoid cold-shortening), does not pose a risk of growth of *E. coli*.

8. Overall, data on the growth of psychrotrophic pathogens would indicate that there is theoretically a greater risk of psychrotrophic pathogens proliferating in meat held for a longer time at a temperature above the minimum for pathogenic growth than in meat stored for a short time. Since mincing is known to distribute bacteria throughout the meat it stands to reason that theoretically mince from aged meat has a higher risk than that from non-aged meat. It can therefore also be said that any aged meat must on this basis present more of a risk than unaged meat. However, this theoretical supposition has not been clearly supported in the literature or in the data supplied by the UK meat processors. Some authors (Dykes *et al*., 2001) imply that that the long period of storage, of particularly *E. coli* O157, in a non-growing state would result in "an excessive recovery period in these cells before growth would occur". While others (**Crowley *et al*., 2010**) have shown that long term chilled storage of meat in vacuum packs may inhibit microbial growth and that mince may actually inhibit microbial growth through the action of free radicals released from muscle and bacterial cells.

9. No specific additional control measures for chilled meats stored for periods longer than specified in the regulations, which differ from those for chilled meat stored for periods in compliance with the regulation, have been identified. Apart from those specifically associated with storage temperatures during ageing/storage prior to mincing. In all cases carcasses should be produced hygienically, with as low a microbial load as possible, and then handled appropriately throughout subsequent storage, cutting and mincing to maintain the microbiological status. The current scientific knowledge allows controls to be identified within procedures based on HACCP procedures and a summary of suggested critical limits, monitoring procedure recommendations and corrective actions for the manufacture of minced meat from meat is given in Section 5.

10. Mince made in the UK from chilled meat stored for long periods is intended to be consumed fully cooked and, for species other than poultry meat, is required to be labelled with cooking information as specified in Regulation (EC) No. 2073/2005. There is no evidence that there is any additional risk of consumption of fully cooked mince made from such meat than from the consumption of fully cooked mince made from unaged meat.

11. The 2006 review concluded that there appeared to be no scientific justification for the time restrictions included in the current legislation and no evidence of an increased risk to human health from meat that has been stored hygienically and at appropriate temperatures for longer than the time limits specified in the legislation. Published studies since that review and the data supplied/collected by the UK meat processors in this study appear to further support and strengthen this conclusion.

Contents

2. Introduction and background

In the UK, a significant amount of meat is converted into minced meat. This is used in catering and the home for a variety of cooked dishes and in the manufacture of meat preparations and products ranging from burgers and sausages to canned products and chilled or frozen ready meals. While some minced meat is prepared from trimmings resulting from the preparation of joints and cuts, much minced meat is prepared from parts of the carcass for which there is insufficient consumer demand for as joints or cuts, e.g. forequarter beef.

After slaughter and evisceration, meat carcasses are primary chilled, either in the form of sides in the case of beef and pork, or whole carcasses in the case of lamb and poultry. Current legislation requires fresh red meat and poultry to be chilled as soon as possible after dressing to <7°C (Regulation (EC) No. 853/2004, Annex III, Section I, Chapter VII, paragraph 1) and <4°C (Regulation (EC) No. 853/2004, Annex III, Section II, Chapter IV, paragraph 8), respectively. Once the meat has reached the required temperature, it can legally be cut, unless it is specifically to be processed warm. To improve tenderness and prevent muscle shortening there will usually be a delay between the meat reaching the desired temperature and cutting, this may be referred to as ageing, maturation or hanging. This may be as short as 2 to 8 hours in the case of chicken and turkey, respectively, or typically 48 hours for beef before cutting, packing, retail distribution or further processing.

In the UK, there is a long-standing tradition of ageing meat for longer time periods in order to develop more flavour, and improve texture, for the national market. In the UK ageing has seen a revival in recent years and UK supermarkets are currently marketing beef aged for up to 28 days, lamb aged for 14 days and pork aged for 10 days. In common with the accepted practice of hanging game birds, the hanging of turkeys is also receiving increased interest. Ageing may be carried out in aerobic conditions, so called “dry-ageing” (usually in the form of whole carcasses, sides or quarters), or in anaerobic conditions, so called “wet-ageing” (usually in the form of vacuum-packaged primals or sub-primals). Following ageing the carcasses/sides/primals may be distributed direct to retail outlets for butchery, or more commonly cut into consumer portions, packaged and then distributed to the retailer. Not all the meat can be sold as joints and cuts and the production of mince from the remaining carcass meat is an important economic aspect of the process. In addition, for practical reasons, UK produced and imported meat (from New Zealand for example) from all species may be stored chilled for varying times, following standard ageing, in order to be transported to, and to ensure a constant supply of raw material at, the mincing plant. Imported shipped chilled vacuum-packaged meats (such as those from New Zealand for example) may spend up to 5 to 6 weeks in transit prior to processing in the UK. Such meats are shipped under tightly controlled conditions, typically at -1±0.5°C, and are known to have practical storage lives of up to 12 weeks (IIR, 2000).

Current legislation (Regulation (EC) No. 853/2004, Annex III, Section V, Chapter III, paragraph 2 imposes strict limits on the age of meat, from slaughter to mincing that can be used to produce mince:

> (2) The following requirements apply to the production of minced meat and meat preparations.
>
> (a) Unless the competent authority authorises boning immediately before mincing, frozen or deep-frozen meat used for the preparation of minced meat or meat preparations must be boned before freezing. It may be stored only for a limited

period.

(b) When prepared from chilled meat, minced meat must be prepared:

(i) in the case of poultry, within no more than three days of their slaughter;

(ii) in the case of animal other than poultry, within no more than six days of their slaughter; or within no more than 15 days from the slaughter of the animals in the case of boned, vacuum-packed beef and veal.

In addition, the following specific temperature criteria are stipulated:

(c) Immediately after production, minced meat and meat preparations must be wrapped or packaged and be:

(i) chilled to an internal temperature of not more than 2°C for minced meat and 4°C for meat preparations;

or

(ii) frozen to an internal temperature of not more than -18°C. These temperature conditions must be maintained during storage and transport

These requirements apply to establishments approved under Regulation (EC) No. 853/2004 that produce minced meat that is not sold directly to the final consumer. It does not apply to minced meat intended for heat treatment before sale, such as cooked pies. The Food Hygiene Regulation requires all food business operators (FBO's) to identify and control food safety hazards using a Hazard Analysis Critical Control Point (HACCP) based approach and Good Manufacturing Practice (GMP).

Regulation (EC) No. 2073/2005 lays down microbiological criteria for foodstuffs. FBO's are obliged to use the criteria in the context of validation and verification of their HACCP based controls and GMP when implementing the general and specific hygiene measures referred to in article 4 of Regulation (EC) No. 852/2004. For minced meat, including meat intended to be eaten fully cooked, food safety criteria are specified for *Salmonella* sp. and process hygiene criteria for aerobic colony count and *Escherichia coli*. The regulation also requires all minced meat made from species other than poultry that fulfils the criteria to be labelled with cooking information. Establishments producing minced meat are required to take samples for microbiological testing at least once a week.

In 2006 the authors of this report carried out an independent review for the UK Food Standards Agency to critically assess the available scientific literature on the survival and growth of microorganisms that are important for safety and quality during storage of meat and the production of minced meat. In addition, data on the microbiological status of minced meat following production and the age of the meat prior to mincing were collected from industry. This project has updated the 2006 review (Appendix 1) and added further data collected and supplied by the UK industry on current processing conditions and microbiological status of mince to address knowledge gaps identified in the 2006 review and strengthen the evidence base.

The aims of this study, carried out with in conjunction with industry, was to:

1. Identify and describe industrial practice and collect available data.
2. Update the 2006 review.

3. Determine the microbiological status of currently produced mince.
4. Assess the likelihood of safety and quality problems using existing chilling and storage data.
5. Make recommendations on the controls that should be put in place for meat to be minced, including aged meat, and how they can be applied within a risk based food safety management system.

3. Information gathering of current industrial practice

A project working-group of 5 UK meat processors was formed under the guidance of the FSA and British Meat Processors Association (BMPA). This initial group of 5 companies produced mince from the following species:

Partner (P),	Species
P1	UK Pork
P2	UK Beef
P3	Turkey
P4	UK Pork UK Lamb New Zealand Lamb
P5	UK Beef UK Lamb

All partners were initially sent a questionnaire (Appendix 2) to identify what data they had available. A follow-up second questionnaire with more specific questions was subsequently sent to project partners (Appendix 3). This questionnaire was also sent to all BMPA members. In addition to the initial 5 core project partners, a further 6 major processors provided data via the BMPA. This second group of 6 companies produced mince from the following species:

BMPA member (M)	Species
M1	UK Beef
M2	UK Beef UK Lamb
M3	UK Beef
M4	UK Pork
M5	UK Beef UK Pork New Zealand Lamb UK Lamb
M6	UK Beef

Using the data gathered in these initial surveys, a detailed protocol for plant operators was established. This allowed them, using their own quality assurance (QA) staff, to regularly track and relate the microbial status of the initial carcass and/or primal meat with the microbial status of final minced meat together with its time/temperature and handling history from primary chilling through to mincing. Separate protocols were designed for red meat and turkey processors. Full details of these protocols are shown in Appendices 4 and 5, respectively. Although these protocols were designed after consultation with all participants, some adaption's were made by individual participants due to the nature of their processes and not all of the data requested in the protocol were recorded. Processors with separate cutting plants particularly found it difficult to supply detailed data that related the microbial status of the initial carcass with the microbial status of final minced meat, since slaughter and mincing were carried out at different sites and the raw material may have come from multiple suppliers. In general, these processors minced meat with the longest storage time before mincing.

The following sections compile the initial data supplied by the participating meat processors and BMPA members, together with the tracked data measured by the participating meat processors, produced according to the specific project protocol.

3.1 Primary chilling

Current EC legislation (Regulation (EC) No. 853/2004) imposes the following temperature controls on the meat:

Annex III, Section I: Meat of domestic ungulates (Red meat)

Section I, Chapter VII

(1) (a) Unless other specific provisions provide otherwise, post-mortem inspection must be followed immediately by chilling in the slaughterhouse to ensure a temperature throughout the meat of not more than 3°C for offal and 7°C for other meat along a chilling curve that ensures a continuous decrease of the temperature. However, meat may be cut and boned during chilling in accordance with Chapter V, point 4. *

(b) During the chilling operations, there must be adequate ventilation to prevent condensation on the surface of the meat.

(2) Meat must attain the temperature specified in point 1 and remain at that temperature during storage.

(3) Meat must attain the temperature specified in point 1 before transport, and remain at that temperature during transport. However, transport may also take place if the competent authority so authorises to enable the production of specific products, provided that:

(a) such transport takes place in accordance with the requirements that the competent authority specifies in respect of transport from one given establishment to another; and

(b) the meat leaves the slaughterhouse, or a cutting room on the same site as the slaughter premises, immediately and transport takes no more than two hours.

* Meat may be boned and cut prior to reaching 7°C when the cutting room is on the same site as the slaughter premises and the meat is subsequently chilled to 7°C.

Annex III, Section II: Meat from poultry and lagomorphs

Section II, Chapter IV

(8) After inspection and evisceration, slaughtered animals must be cleaned and chilled to not more than 4°C as soon as possible, unless the meat is cut while warm.

The literature review (Appendix 1) concluded that the initial chilling rate of carcasses/sides often determines the final eating quality of the meat and, in addition, it is an important factor affecting the growth of spoilage and pathogenic organisms. However, there are very little published data on the effect of current commercial chilling rates and conditions on changes in bacterial numbers during the process. Current EC legislation (see above) places an importance on core meat temperatures, however since microbial contamination of carcasses is primarily a surface phenomenon there is an argument to be made that surface temperatures are far more important than deep temperatures. This is the basis behind the controls in the Australian Export Control (Meat and Meat Products) Orders 2005 and their Refrigeration Index (RI) model.

The following primary chilling parameters were collected/supplied from participating meat processors (Table 1):

Table 1. Primary chilling parameters

Meat type (Source of data)		Chiller temperature (°C)	Chilling time (h)	Carcass/side temperature on exit (°C)
Beef (P2)	Max	10	-	-
	Min	0.9	-	1.9
	Mean	5.6	41	-
Beef (P5)	Max	20	-	1.5
	Min	0.6	-	1.4
	Mean	2.8	96	1.4
Beef (M1)	Max	10	10	-
	Min	0	38	-
	Mean	3.0	48	0.5
Beef (M3)	Max	4.9	146.5	4.9
	Min	2.5	44.8	2.5
	Mean	3.6	83.2	3.8
Beef (M6)	Max	13	-	-
	Min	-0.3	-	-
	Mean	2.0	>48	2.3
Pork (P1)	Max	10	-	3.2
	Min	-	-	2
	Mean	2±1	21	2.5
Pork (P4)	Max	-	-	-
	Min	-	-	-
	Mean	1	20	1
UK Lamb (P4)	Max	-	22	2.7
	Min	-	19	1.5
	Mean	-	-	-
NZ Lamb (P4)	Max	-	-	-
	Min	-	-	-
	Mean	-	12	0
Turkey (P3)	Max	0.5	-	0.4
	Min	0.1	-	0
	Mean	0.3	16	0.2

(-) data not supplied

Examples of primary chilling curves of all species were collated and assessed using the Refrigeration Index (RI) model (see next section). Collected/supplied temperature data from participating UK meat processors shows that generally beef, pork, UK lamb, NZ lamb and turkey carcasses/sides are chilled to <2°C in 48, 20, 22, 12 and 16 hours, respectively. These times correlate with our own experience and knowledge of industry practices and scientifically derived chilling times, and suggests that most UK meat processors are chilling meat in an appropriate time that would seem to meet an acceptable good practice.

Data supplied by beef processors indicate that they are generally operating delayed chilling systems, where the chiller operates at approximately 10°C during loading. This system is used to prevent cold-shortening in non-stimulated sides, but will result in relatively slow chilling rates and is not required if the carcasses have been electrically stimulated. Nether-

the-less the RI assessment (see next section) indicates that it poses little risk of *E. coli* growth.

3.1.1 Assessment of primary chilling data using Refrigeration Index model

Some predictive modelling of the effect of process parameters on the growth potential of a range of pathogens and other microorganisms was carried out in the 2006 review (Section 6). This data and the predictions were re-examined with newer microbial models that are now available. The Refrigeration Index Calculator (Figure 1) in particular (which was not used in the 2006 review) was applied to existing data and to new temperature data supplied by project partners.

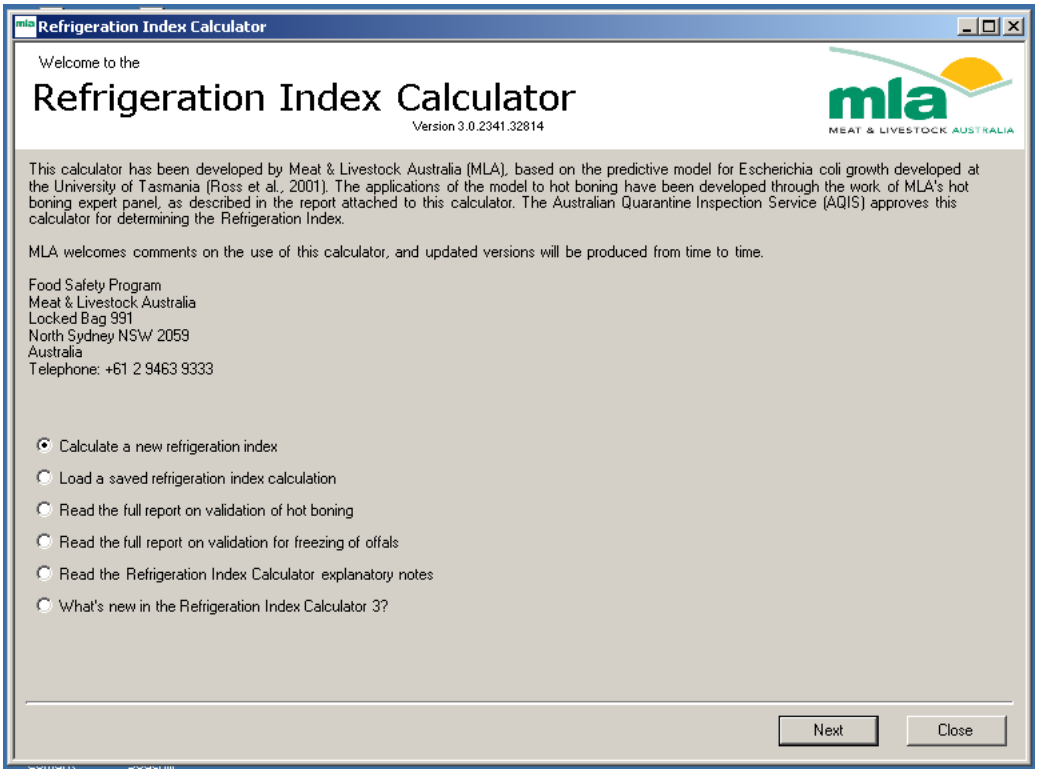

Figure 1. Australian Refrigeration Index Calculator

The Refrigeration Index (RI) is a term used in the Australian Export Control (Meat and Meat Products) Orders 2005. This is as an indication of the effectiveness of refrigeration assessed as the potential for bacterial growth to occur. The RI is calculated using a model that predicts the expected growth of *E. coli* on meat using input temperature and storage time (details of the model are discussed in Section 8.13.1). The model includes values for pH, water activity, and lactate concentration that in addition to temperature, all affect the growth rate of *E. coli*. The current RI model allows for the user to enter data on temperatures of the product over time. The other parameters are set by choosing the type of product. The central idea of the RI is to measure the performance of the chilling process until all the sites of microbiological interest are at or below 7°C. The model assumes that this is the temperature at which *E. coli* and salmonella stop growing. It is important to note that the RI, is an indication of the effectiveness of refrigeration, it is NOT a prediction of the number of *E. coli* in the product.

To achieve the refrigeration index criteria:

(a) the refrigeration index average is to be no more than 1.5; and

(b) 80% of refrigeration indices are to be no more than 2.0; and

(c) no refrigeration index is to be more than 2.5.

The criteria for RI apply to any refrigeration process for carcasses and carcass parts, which means all carcasses, primal cuts, manufacturing product and offal items.

The site of microbiological concern depends on the type of product in question, e.g. the surface for carcasses, the thermal centre of bulk-packed meat and offal and the surface of vacuum packaged cuts at a position as close as possible to the thermal centre of a carton.

As applied in Australia the refrigeration index criteria must be achieved for the whole process from carcass chilling to cooling boned meat to 7°C at the site of microbiological concern.

In general, few UK abattoirs, at present, measure surface temperatures during carcass and side cooling and processing. The emphasis in the EU is on achieving 7°C in the carcass core hence temperature records reflect this. Data, including surface data where possible, was obtained in the research project and entered into the model.

3.1.1.1 Beef

As already stated, it is not common for UK abattoirs to monitor surface temperatures on carcasses and sides during primary chilling so limited data was initially available from participating beef processors of surface temperatures during primary beef chilling. Four beef processors subsequently supplied a typical surface temperature record during primary chilling. Figure 2, Figure 4, Figure 6 and Figure 8 show the application of the Refrigeration Index Calculator to typical carcass surface temperatures measured by these four processors. Accompanying temperature records, including air temperatures, are shown in Figure 3, Figure 5, Figure 7 and Figure 9, respectively.

A summary of all records supplied and RI scores is shown in Table 2. To achieve the RI criteria the average refrigeration index has to be <1.5 and not exceed 2.5. It is clear from the data supplied that three of processors achieve scores <1.5, indicating that such surface cooling rates pose no risk of microbial growth of *E. coli* on the surface of the meat during cooling. However, the three sets of surface temperature data supplied by one plant (P5), give RI scores between 3.07 and 5.85. This indicates that the measured surface cooling rates would pose a risk of microbial growth of *E. coli* on the surface of the meat during cooling and thus fail the RI criteria. A comparison of the temperature records supplied by all processors indicates that these values could be due to the temperature being measured by P5 being sub-surface rather the actual surface, since the temperature/time response in the deep temperature is very similar to that measured by the other beef processors.

Overall, the data indicates that the delayed chilling utilised by some of the participants does not pose a risk to microbial growth of *E. coli* during primary chilling and that current chilling practices in UK beef processors would appear to meet an acceptable good practice.

Table 2. Comparison of supplied primary beef surface cooling data supplied by participating beef processors

Source of data	Replicate	Carcass/side weight (kg)	Chilling time (h)	Final surface temperature (°C)	RI score	Details
P2	1	142.3	41	2.3	0.06	Delayed chilling, initial 10 h >10°C
	2	158	41	2.6	0.63	
	3	156.2	41	2.1	0.48	
P5	1	186	96	1.6	5.85	Delayed chilling, initial 7 h >10°C
	2	163	96	1.4	3.25	
	3	152	96	1.5	3.07	
M3	1	374.6 (carcass)	24	1.1	0.00	No delay
	2	344 (carcass)	31	3.9	0.00	
M6	1	-	48	0.4	0.00	No delay
	2	-	48	0.4	0.00	

(-) data not supplied

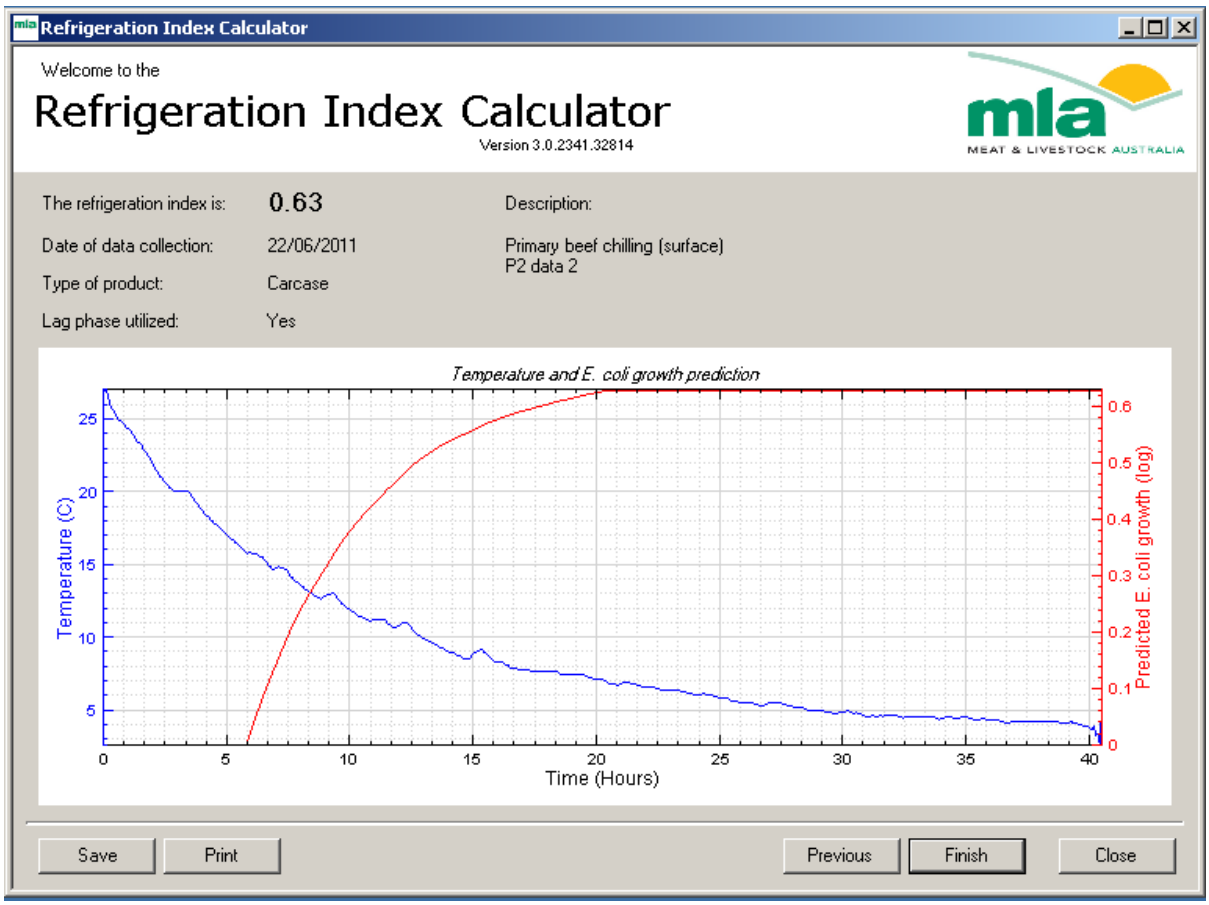

Figure 2. Application of Refrigeration Index Calculator to surface temperatures on a beef side (158 kg) measured during primary cooling in a UK abattoir (data supplied by P2)

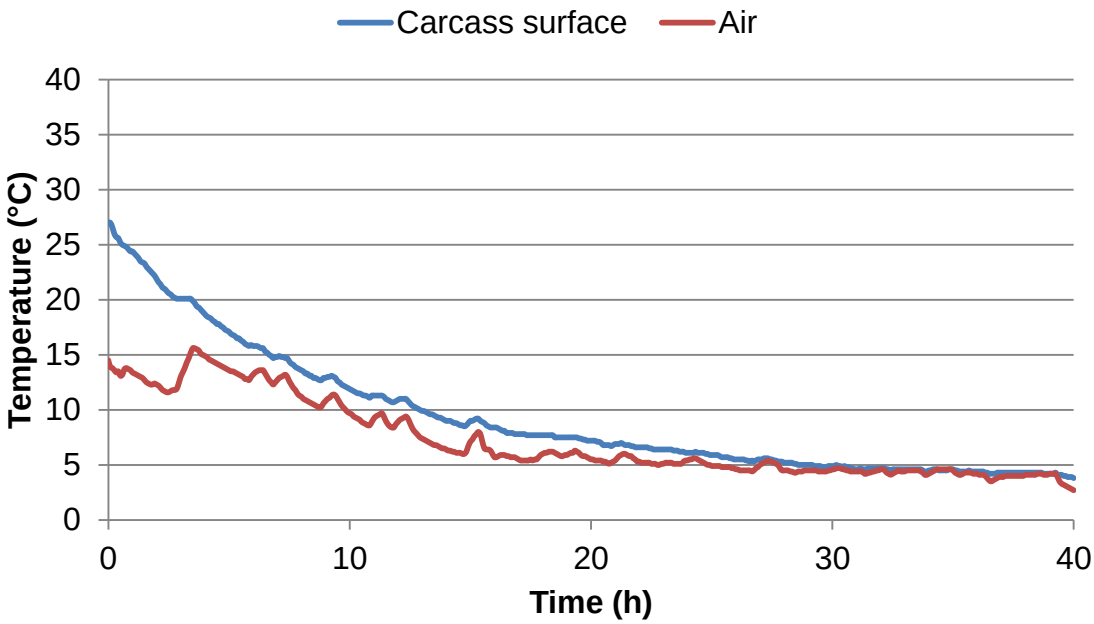

Figure 3. Surface and air temperatures on a beef side (158 kg) measured during primary cooling in a UK abattoir (data supplied by P2)

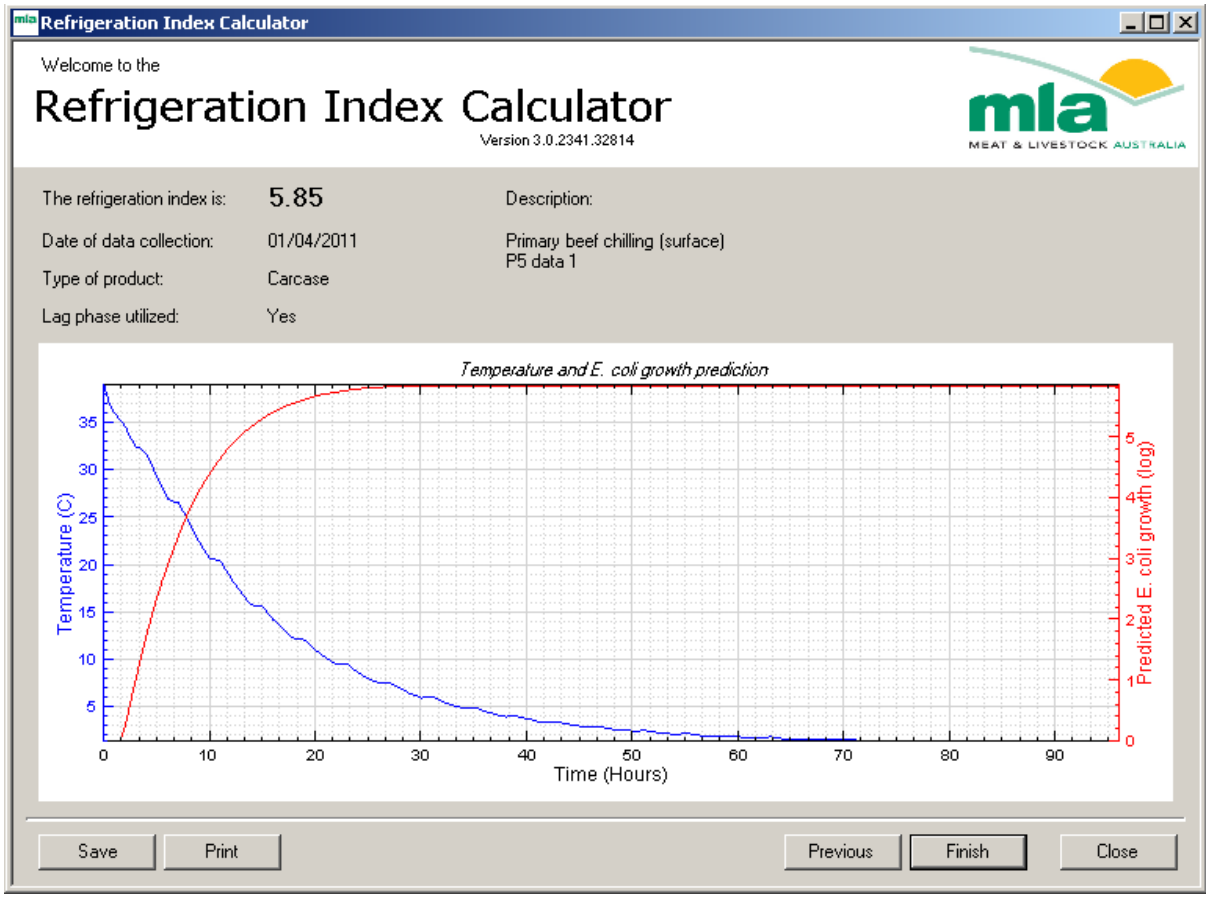

Figure 4. Application of Refrigeration Index Calculator to surface temperatures on a beef side (186 kg) measured during primary cooling in a UK abattoir (data supplied by P5)

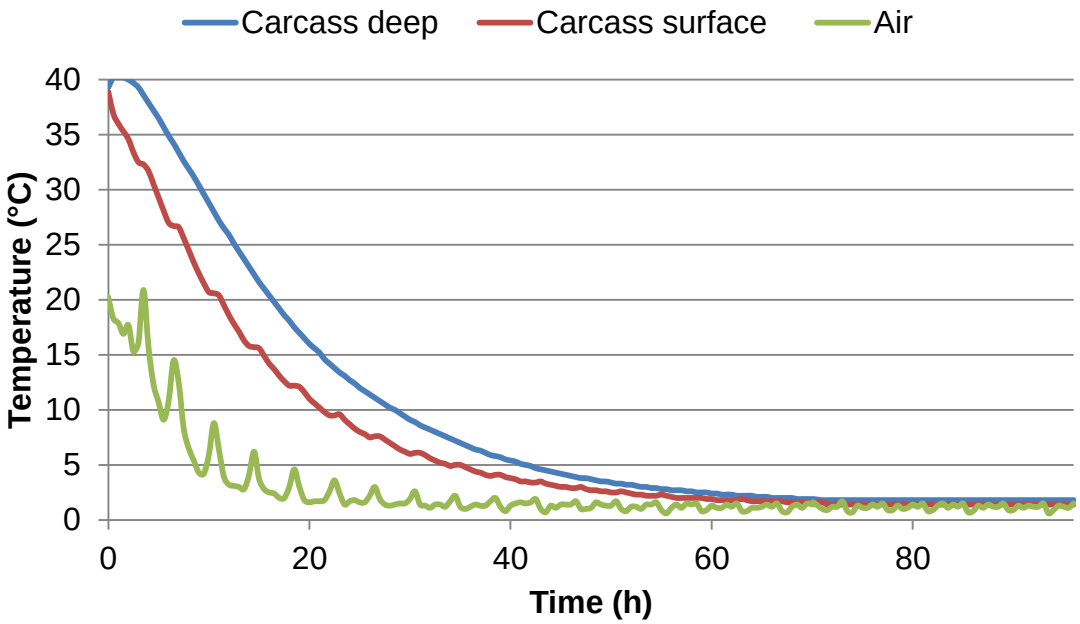

Figure 5. Surface, deep and air temperatures on a beef side (186 kg) measured during primary cooling in a UK abattoir (data supplied by P5)

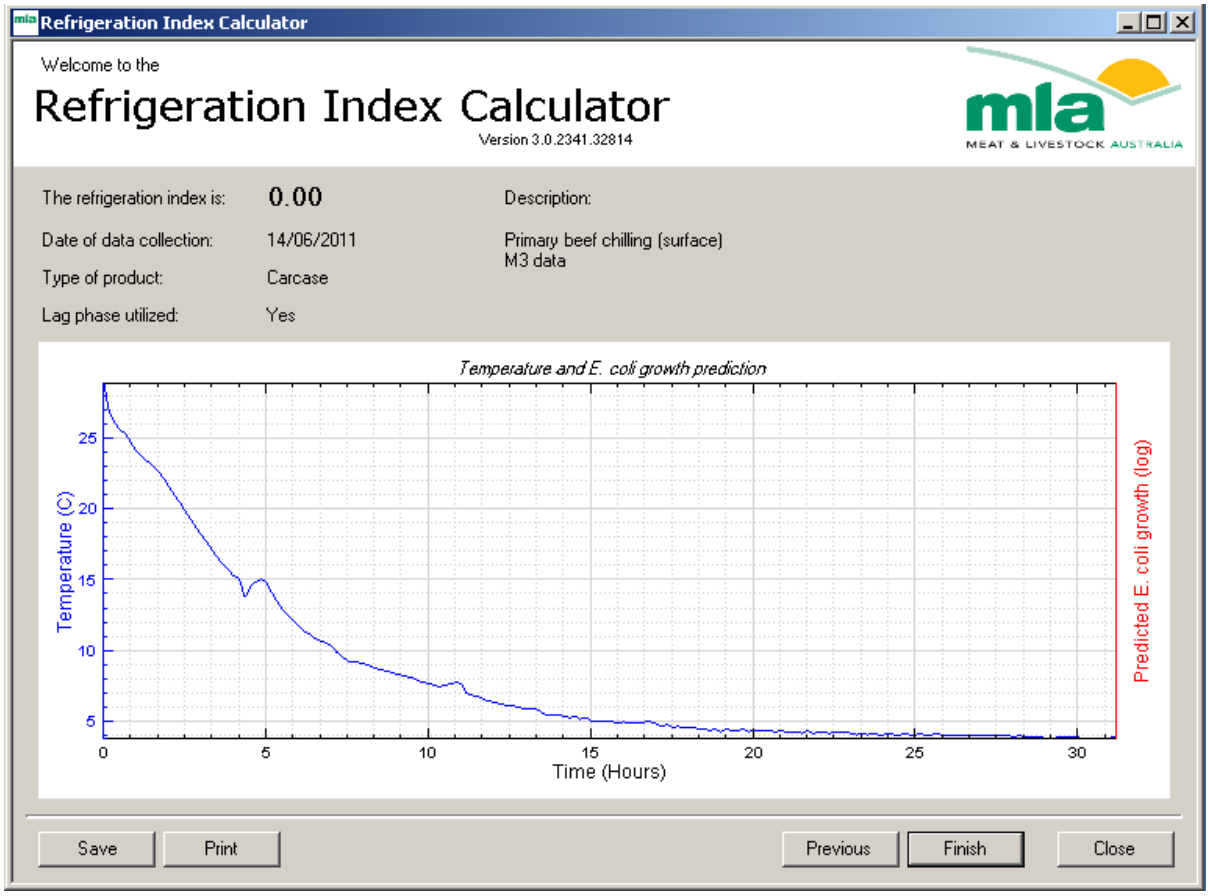

Figure 6. Application of Refrigeration Index Calculator to surface temperatures on a beef side (344 kg carcass) measured during primary cooling in a UK abattoir (data supplied by M3)

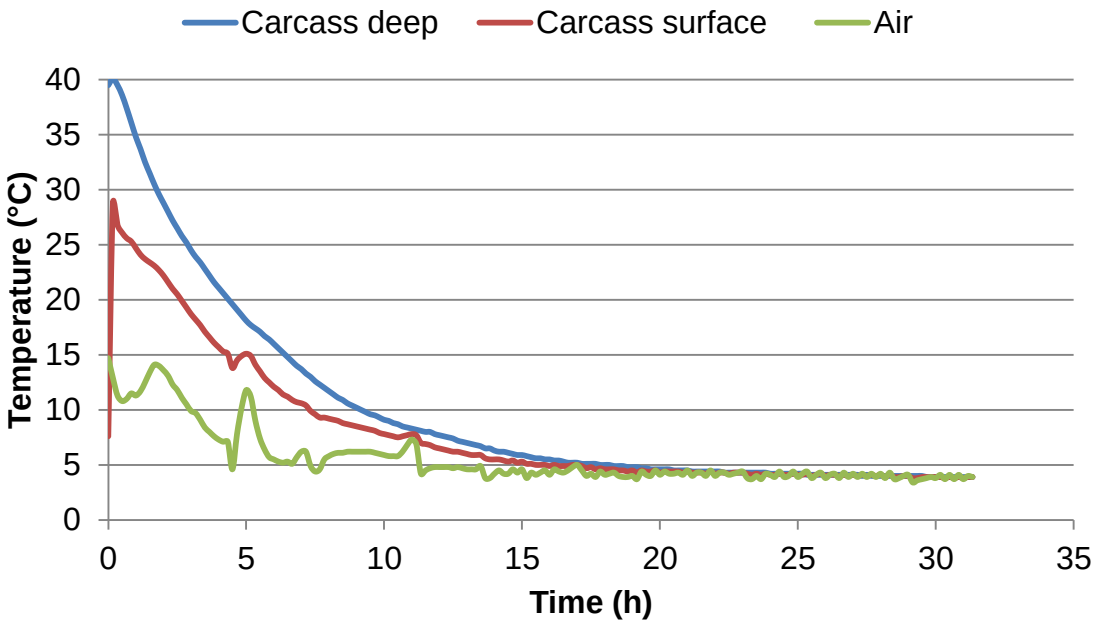

Figure 7. Surface, deep and air temperatures on a beef side (344 kg carcass) measured during primary cooling in a UK abattoir (data supplied by M3)

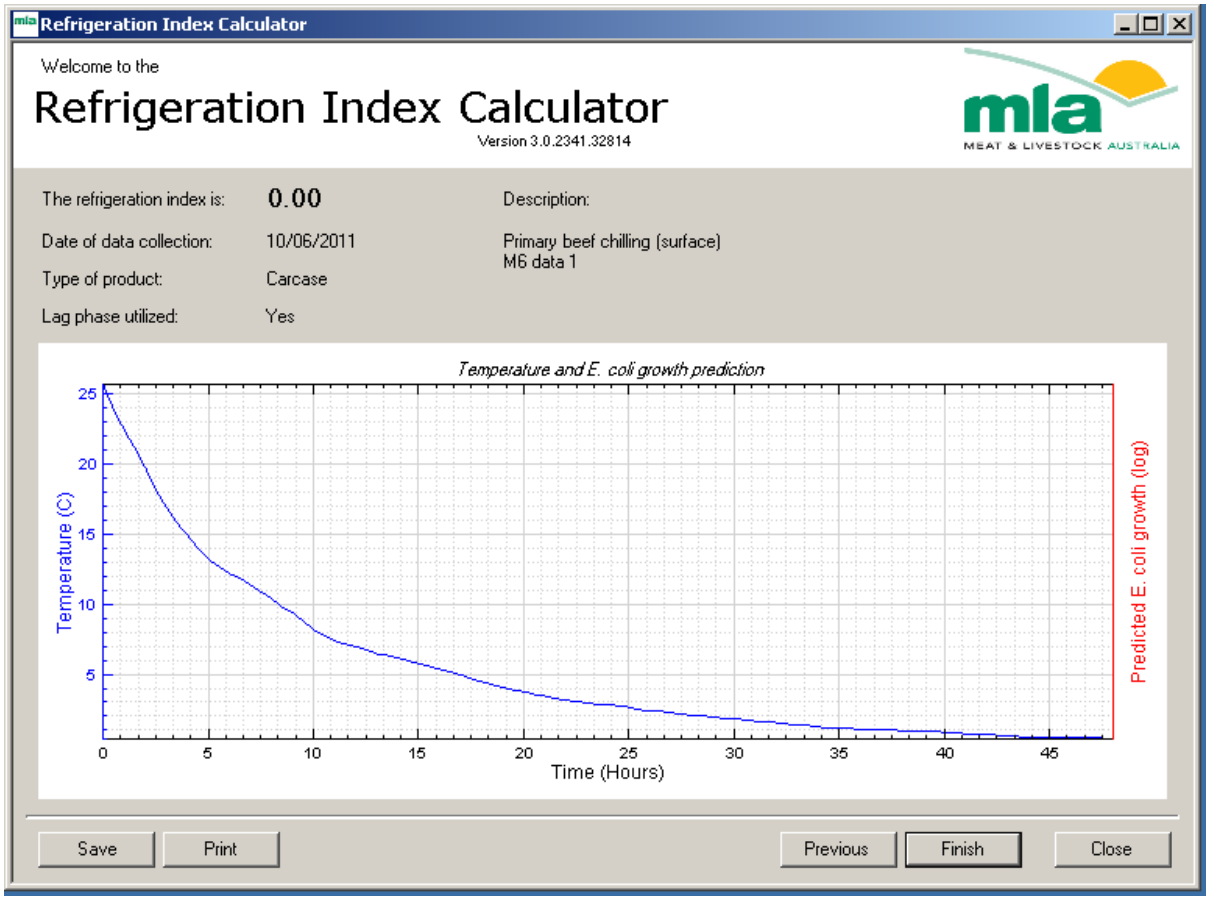

Figure 8. Application of Refrigeration Index Calculator to surface temperatures on a beef side measured during primary cooling in a UK abattoir (data supplied by M6)

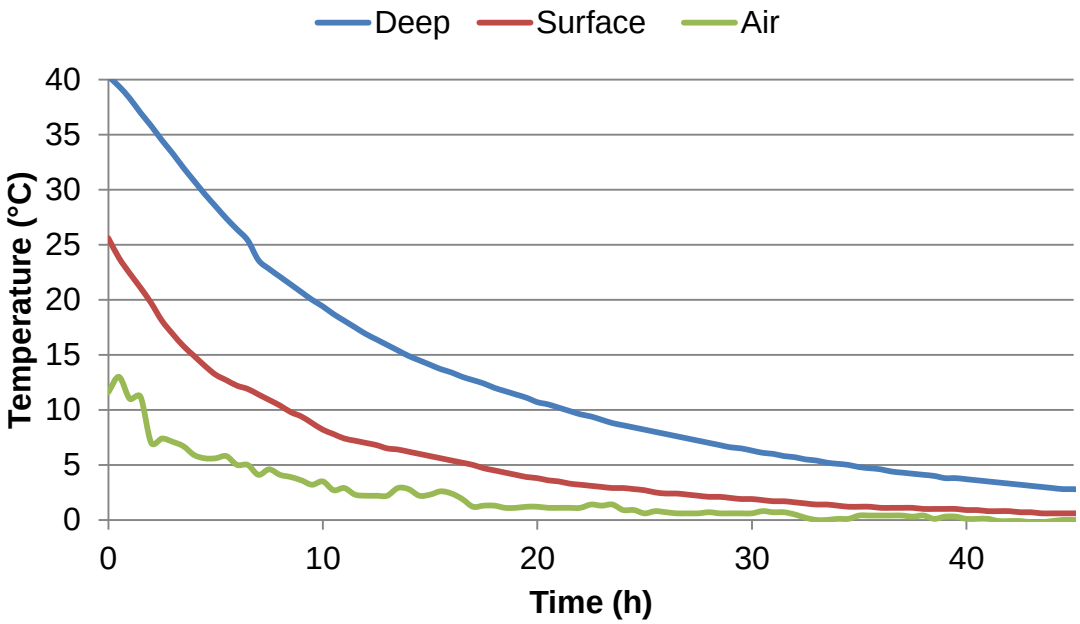

Figure 9. Surface, deep and air temperatures on a beef side measured during primary cooling in a UK abattoir (data supplied by M6)

3.1.1.2 Pork

Figure 10 shows the application of the Refrigeration Index Calculator to carcass surface temperatures measured in a UK pork abattoir during primary chilling. This data was measured by FRPERC at P1's plant. Temperatures were measured in the deep shoulder, surface breast and surface shoulder. Surface temperatures on the breast muscle were the slowest cooling surface temperatures. The model calculates a RI score of 0.00 on this data, indicating that such surface cooling rates pose no risk of microbial growth of *E. coli* on the surface of the meat during cooling.

Figure 11 shows the application of the Refrigeration Index Calculator to carcass surface temperatures measured in a UK mixed species abattoir during primary chilling of a pork carcass. This data was measured by FRPERC in a previous study. Temperatures were measured in the deep hind and surface leg. The model calculates a RI score of 0.00 on this data, indicating that such surface cooling rates pose no risk of microbial growth of *E. coli* on the surface of the meat during cooling.

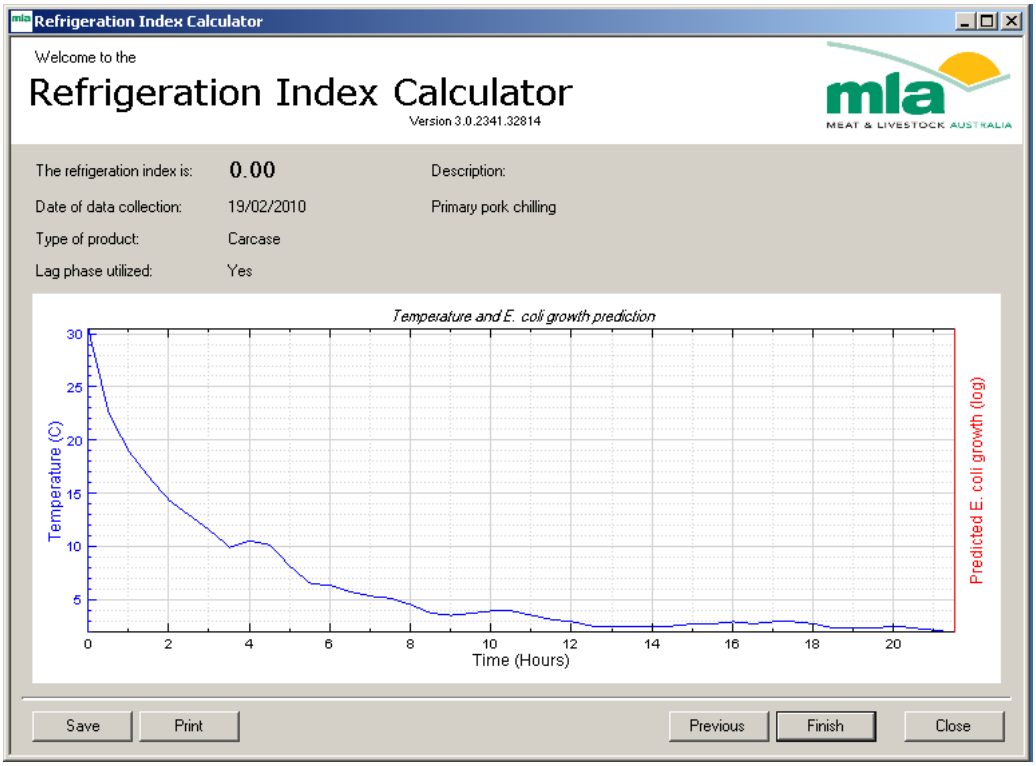

Figure 10. Application of Refrigeration Index Calculator to surface temperatures on a pork carcass measured during primary cooling in a UK abattoir (data measured at P1)

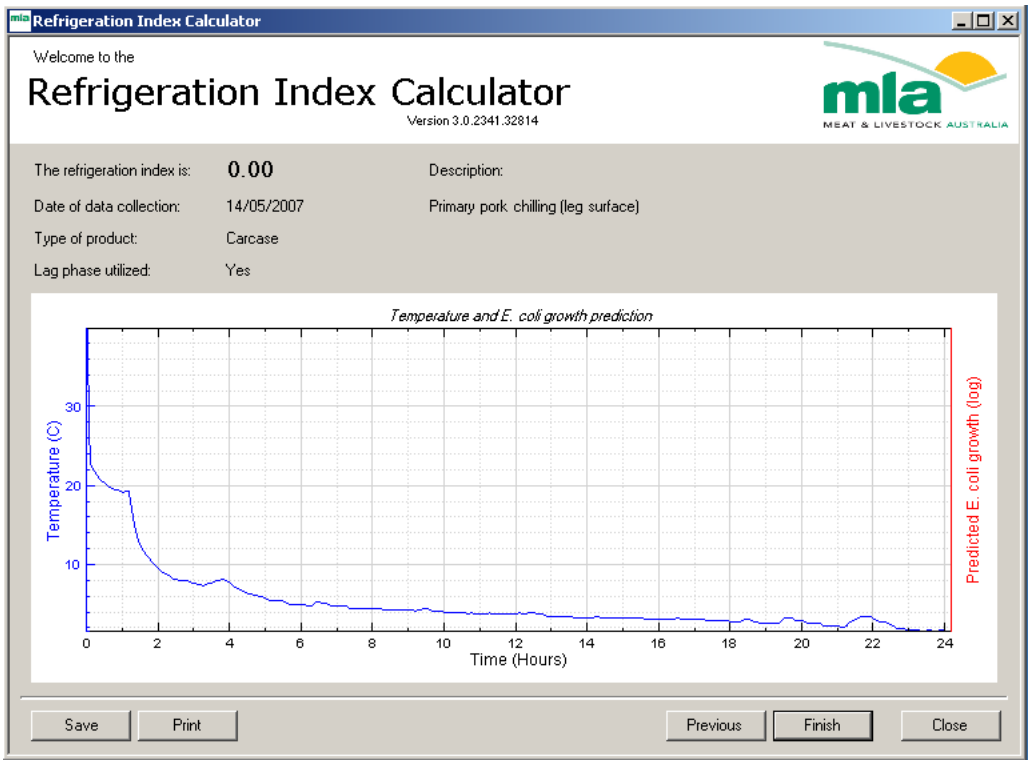

Figure 11. Application of Refrigeration Index Calculator to surface temperatures on a pork carcass measured during primary cooling in a UK abattoir (data measured by FRPERC)

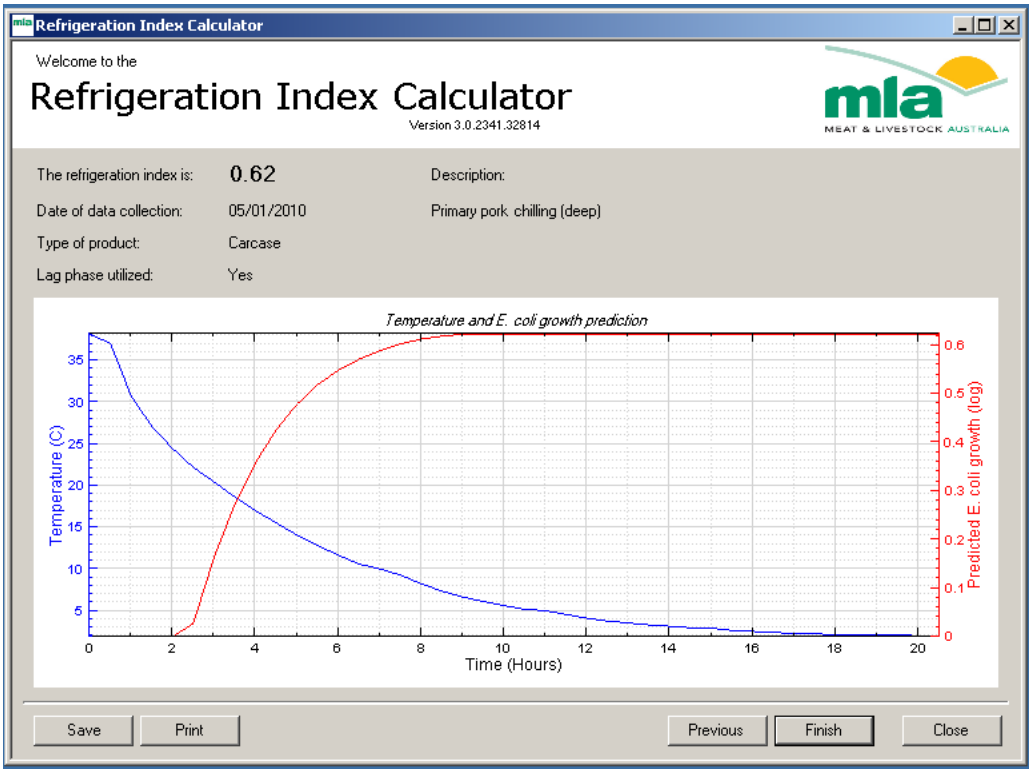

Figure 12. Application of Refrigeration Index Calculator to surface temperatures on a pork carcass measured during primary cooling in a UK abattoir (data supplied by P4)

Figure 12 shows the application of the model to carcass surface temperatures measured in a UK pork abattoir during primary chilling of a pork carcass. This data was measured and supplied by P4. The model calculates a RI score of 0.62 on this data, indicating that such cooling rates poses no risk of microbial growth of *E. coli* on the surface of the meat during cooling, even when applying the model to a deep temperature measurement.

Overall, the data indicates that the chilling practices currently utilised by UK pork processors does not pose a risk to microbial growth of *E. coli* during primary chilling and would appear to meet an acceptable good practice.

3.1.1.3 Lamb

Figure 13 and Figure 14 shows the application of the model to carcass surface temperatures measured in a UK mixed species abattoir during primary chilling of a lamb carcass. Data was measured by FRPERC in a previous study. Both deep and surface temperatures were measured and both plots were modelled. The model calculates a RI score of 0.00 on the surface data, and 1.18 on the deep data. This indicates that such cooling rates pose no risk of microbial growth of *E. coli* on the surface of the meat during cooling and little risk, even when using deep temperature data to calculate the RI score.

Figure 15 and Figure 16 shows the application of the model to deep carcass temperatures measured in a UK and New Zealand abattoir during primary chilling of a lamb carcass. Data was supplied by P4. The model calculates a RI score of 2.55 and 0.46, respectively, indicating that such cooling rates poses little risk of microbial growth of *E. coli* on the surface of the meat during cooling, since this prediction is based on deep temperature data and not surface temperatures. The cooling data from New Zealand indicates that cooling

rates used there are significantly faster than those utilised in the UK and result in an even lower risk of growth of *E. coli*.

Overall, the data indicates that the chilling practices currently utilised by UK and New Zealand lamb processors does not pose a risk to microbial growth of *E. coli* during primary chilling and would appear to meet an acceptable good practice.

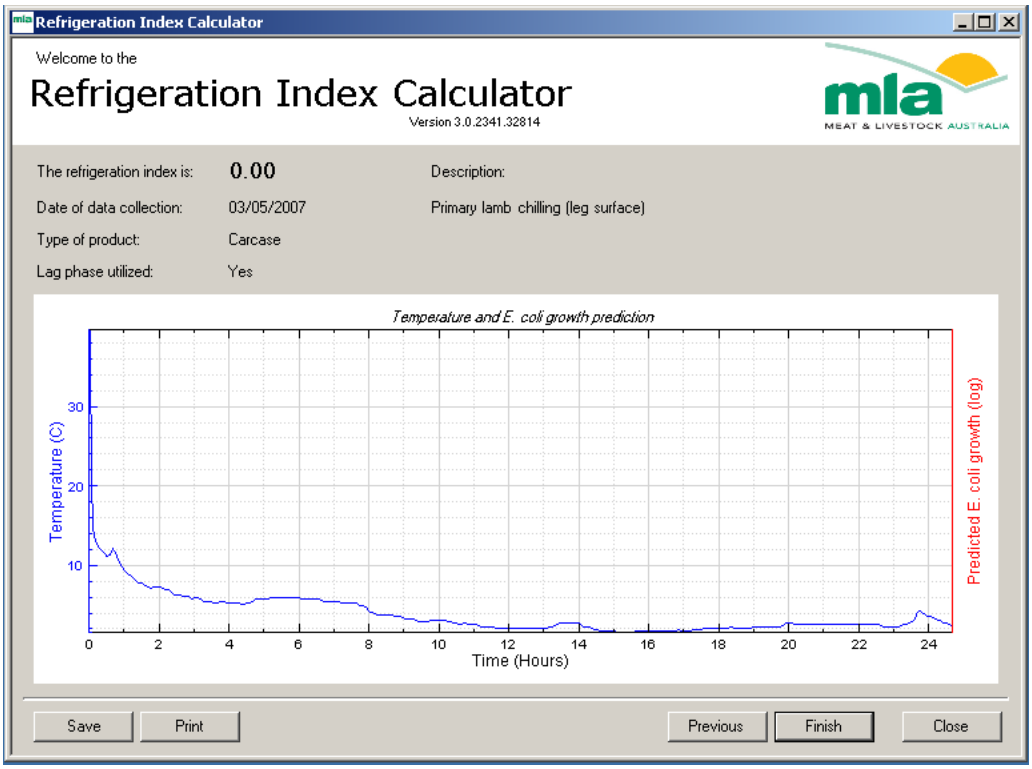

Figure 13. Application of Refrigeration Index Calculator to surface temperatures on a lamb carcass measured during primary cooling in a UK abattoir (data measured by FRPERC)

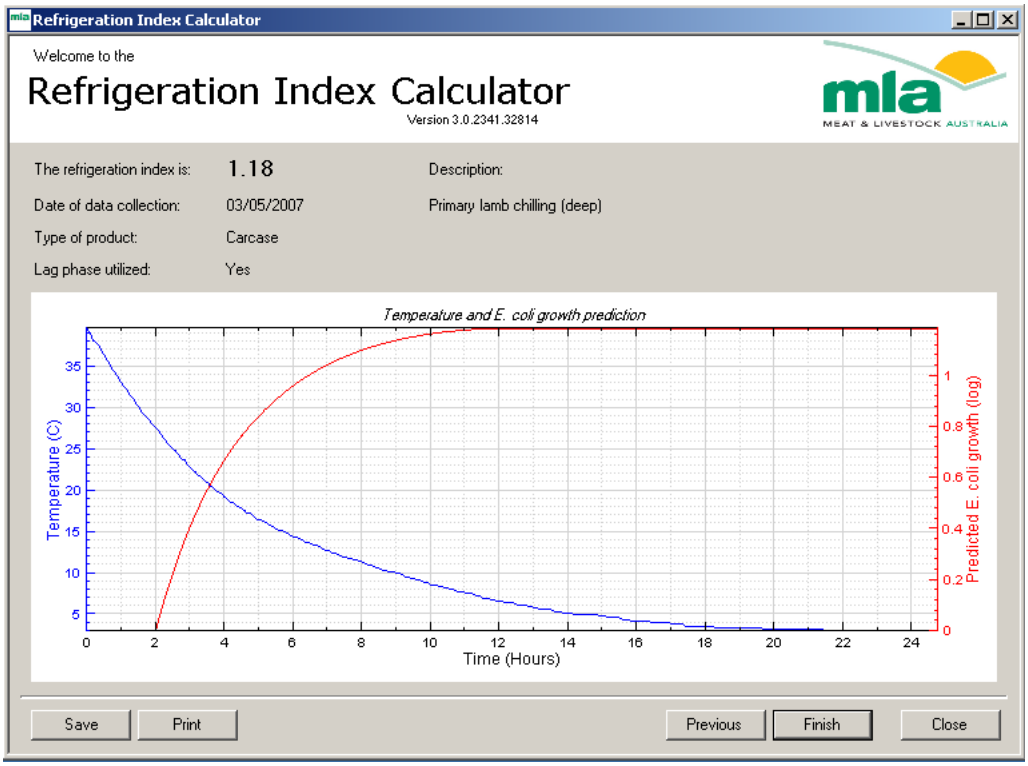

Figure 14. Application of Refrigeration Index Calculator to deep temperatures in a lamb carcass measured during primary cooling in a UK abattoir (data measured by FRPERC)

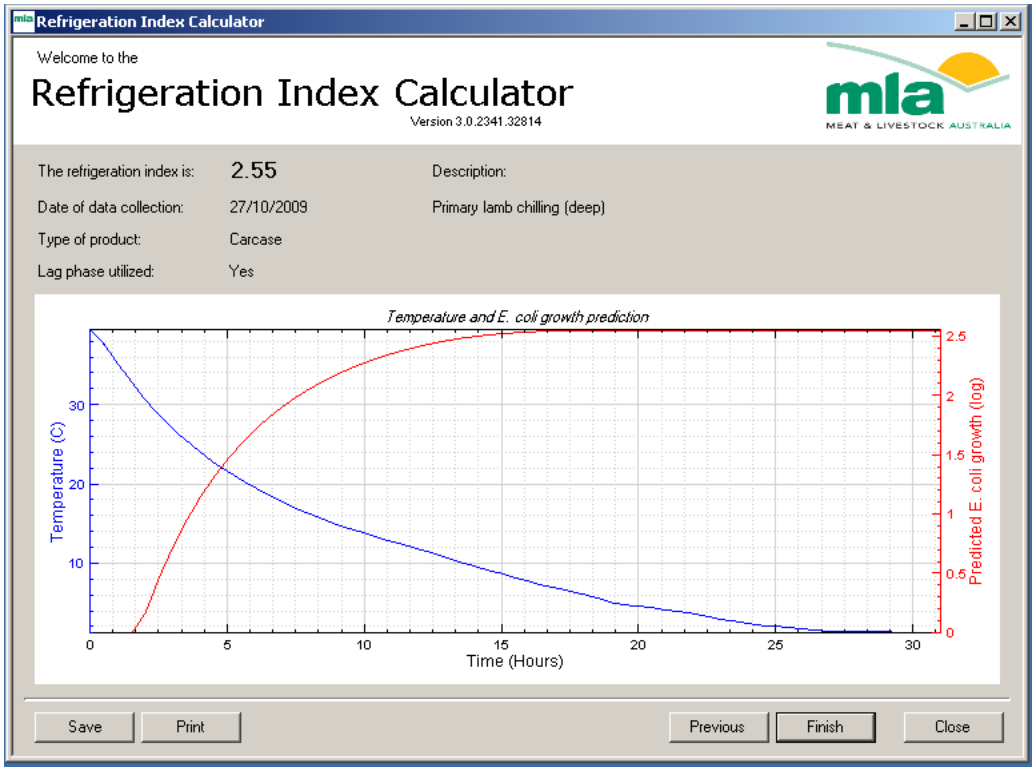

Figure 15. Application of Refrigeration Index Calculator to deep temperatures in a lamb carcass measured during primary cooling in a UK abattoir (data supplied by P4)

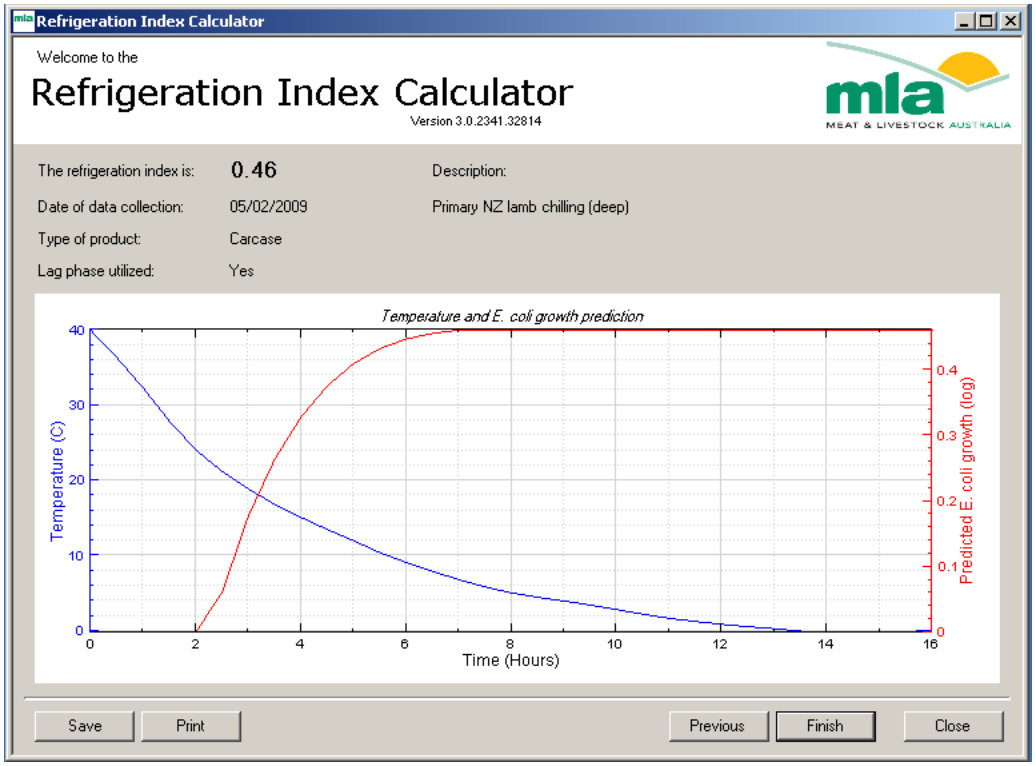

Figure 16. Application of Refrigeration Index Calculator to deep temperatures in a NZ lamb carcass measured during primary cooling in a NZ abattoir (data supplied by P4)

3.1.1.4 Turkey

Figure 17 shows the application of the model to carcass surface temperatures measured in a UK turkey abattoir during primary air chilling of a hen carcass. Data was supplied by P3. Temperatures were measured in the "middle", "top" and "bottom". Temperatures measured in the "middle" were the slowest cooling temperatures and were modelled. The model calculates a RI score of 0.00 on this data, indicating that such cooling rates pose no risk of microbial growth of *E. coli* on the surface of the meat during cooling.

The larger turkey stag carcasses cool slower than hens and are usually chilled in immersion systems rather than air blast systems. Figure 18 and Figure 19 show the application of the model to carcass surface temperatures measured in a UK turkey abattoir during primary chilling in stag carcasses during tank (ice and water, 0°C) chilling. Data was supplied by P3. The slowest cooling carcass temperature measured was modelled. The model calculates a RI score of 0.00 on this data, despite the cooling times being approximately three times that of the hen carcass, indicating that even such slower cooling rates pose no risk of microbial growth of *E. coli* on the surface of the meat during cooling.

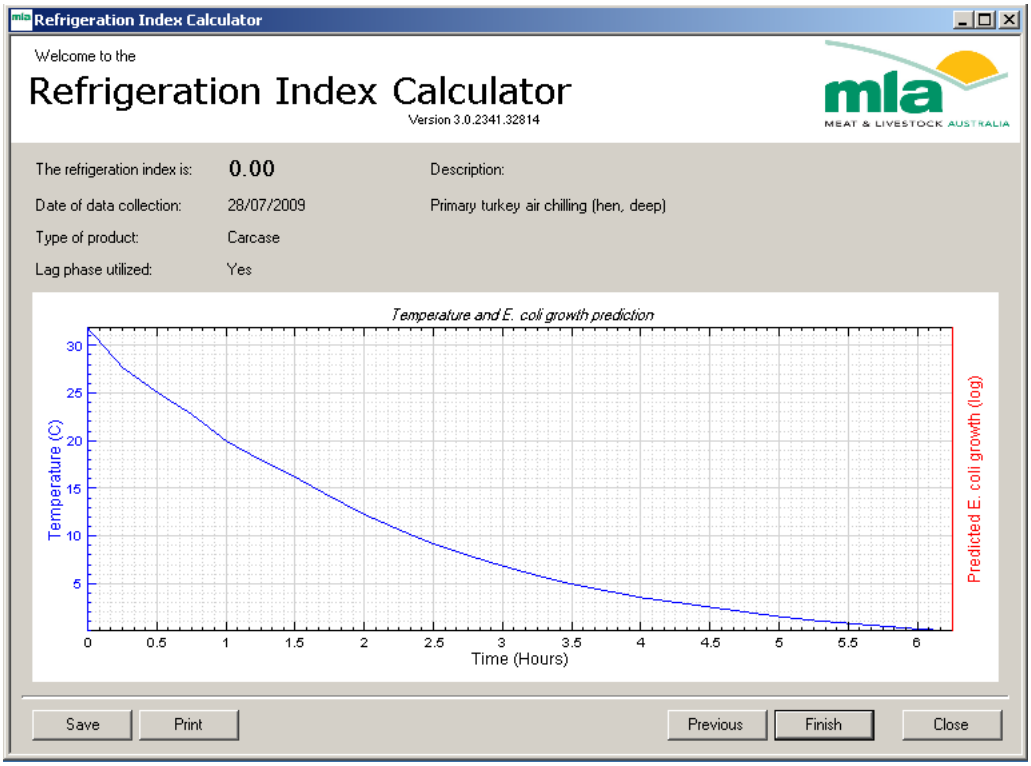

Figure 17. Application of Refrigeration Index Calculator to deep temperatures in a hen turkey carcass measured during primary air cooling in a UK abattoir (data supplied by P3)

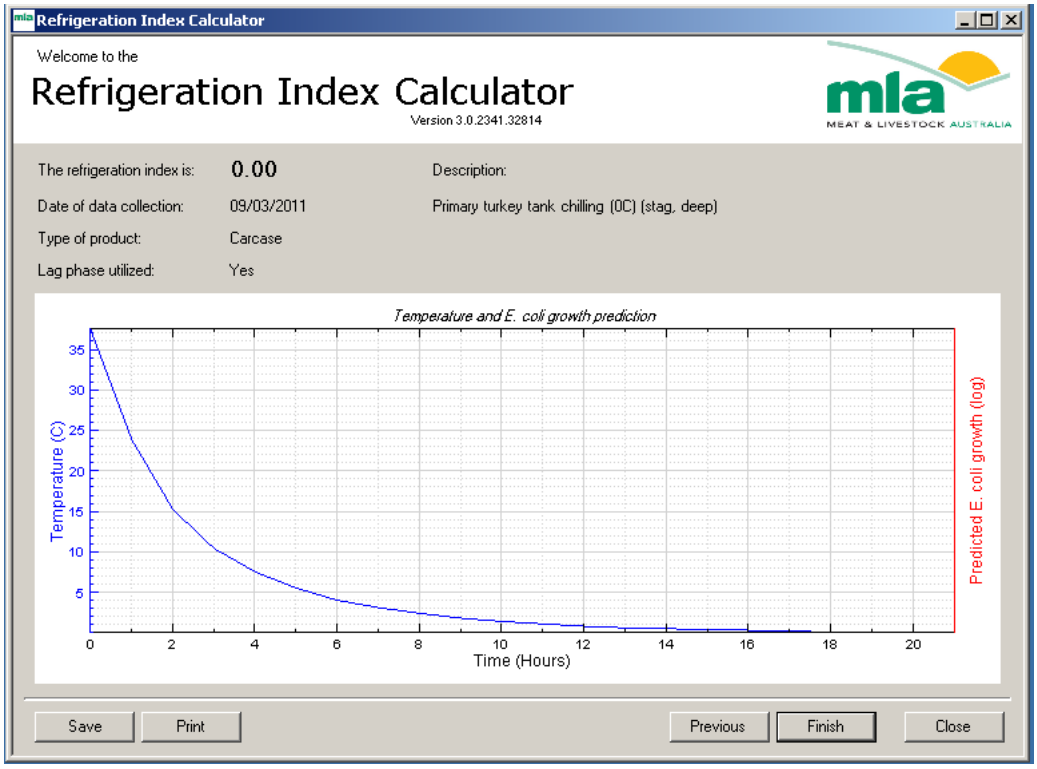

Figure 18. Application of Refrigeration Index Calculator to deep temperatures in a stag turkey carcass measured during tank cooling (ice water at 0°C) in a UK abattoir (data supplied by P3)

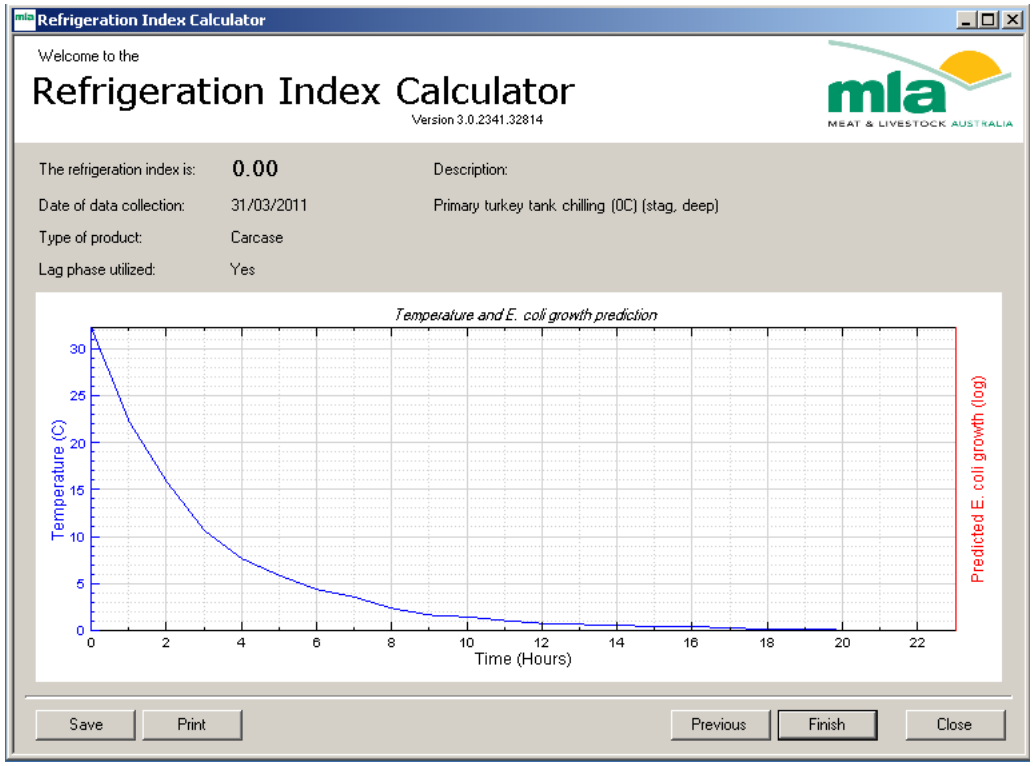

Figure 19. Application of Refrigeration Index Calculator to deep temperatures in a stag turkey carcass measured during tank cooling (ice water at 0°C) in a UK abattoir (data supplied by P3)

3.2 Storage (Ageing)

The following storage parameters shown in Table 3 were collected/supplied from participating meat processors. This data generally shows that product temperatures are maintained at <2°C during most storage operations, which would seem to be an acceptable good practice.

3.3 Cutting and mincing

Current EC legislation (Regulation (EC) No. 853/2004) imposes the following temperature controls on the production of mince:

> (c) Immediately after production, minced meat and meat preparations must be wrapped or packaged and be:
>
> (i) chilled to an internal temperature of not more than 2°C for minced meat and 4°C for meat preparations;
>
> or
>
> (ii) frozen to an internal temperature of not more than -18°C. These temperature conditions must be maintained during storage and transport

The following temperatures and conditions at time of mincing shown in Table 4 were collected/supplied from participating meat processors. This data shows that product temperatures are maintained at <2°C during most storage operations and product temperatures rarely exceed 5°C during what is typically a 2 to 3 hour mincing operation.

Table 3. Pre-mincing storage parameters

Meat type (Source of data)		Chill temperature (°C)	Storage time as carcass/primal (d)	Carcass temperature (°C)	Storage time as packaged primal/trim (d) (v, Vacuum packaged)	Primal/trim temperature (°C)	Frozen storage temperature (°C)	Frozen storage time as packaged primal (mth)
Beef (P2)	Max	-	-	-	-	-		
	Min	-	-	-	-	-		
	Mean	<5		<3	-	<3		
Beef (P5)	Max	1	4	1.8	6 (v)	2.8		
	Min	-1	4	1.4	0	1.7		
	Mean	0	4	1.5	3 (v)	1.8		
Beef (M1)	Max	10	2	-	15	-		
	Min	0	-	-	4	-		
	Mean	3.0	-	-	7	-		
Beef (M2)	Max	2	NA	-	19 (v)	-	-18	18
	Min	-2	NA	-	2 (v)	-	-15	1
	Mean	0	NA	-	7 (v)	-	-15	3
Beef (M3)	Max	9	24 hours	-	28 (v)	-		
	Min	0	5 mins	-	0	-		
	Mean	5	20 mins	-	14 (v)	<2		
Beef (M5)	Max	-	-	-	18 (v)	1.8		
	Min	-	-	-	16 (v)	-1.0		
	Mean	-	-	-	-	0.7		
Pork (P1)	Max	-	-	3.2	-	-		
	Min	-	-	2	-	-		
	Mean	2	-	2.5	-	-		
Pork (P4)	Max	7.8	-		5	12		
	Min	-1.9	-		-	1.5		
	Mean	0.5	-	<4	3	7.7		
Pork (M4)	Max	4	-	-	-	1.0		
	Min	0	-	-	-	0.1		
	Mean	2	-	-	-	0.5		
Pork (M5)	Max	-	-	-	-	1.1		
	Min	-	-	-	-	-1		
	Mean	-	-	-	-	0.1		
UK lamb (P4)	Max	-	-	-	-	-		
	Min	-	-	-	-	-		
	Mean	-1±0.5	4	1	14	-1		
UK lamb (M2)	Max	2	NA	-	19	-	-18	18
	Min	-2	NA	-	2	-	-15	1
	Mean	0	NA	-	7	-	-15	3
UK lamb (M5)	Max	-	-	-	-	2		
	Min	-	-	-	-	-1		
	Mean	-	-	-	-	0.2		
NZ lamb (P4)	Max	-	-	-	60	-		
	Min	-	-	-	44	-		
	Mean	-1±0.5	-	-	-	-1		
Turkey (P3)	Max	-	-	-	3	2.7		
	Min	-	-	-	1	-1.2		
	Mean	<2	1	<2	2	0.3		

(-) data not supplied

Table 4. Mincing parameters

Meat type (Source of data)		Number of days from slaughter	Room temperature (°C)	Mince temperature (°C)	Processing time (h)
Beef (P2)	Max	7	3.8	4.1	-
	Min	5	2.6	-0.7	-
	Mean	6	3.1	1.1	-
Beef (P2)	Max	10	-	-	-
	Min	5	-	-	-
	Mean	8	-	-1	-
Beef (M1)	Max	15	8	2	From debag to pack 1 h
	Min	4	6	-1	10 mins
	Mean	7	7	0	20 mins
Beef (M2)	Max	21	10	+2	15 mins
	Min	2	3	-2	10 mins
	Mean	15	7	0	12 mins
Beef (M3)	Max	28	9	5	1
	Min	3	0	-18	12 mins
	Mean	14	5	-2	20 mins
Beef (M5)	Max	20	-	3.0	-
	Min	7	-	1.0	-
	Mean	13	-	1.7	-
Pork (P4)	Max	17	-	5	3
	Min	3	-	3.5	2
	Mean	8	-		-
Pork (M4)	Max	15	-	3.0	-
	Min	3	-	2.5	-
	Mean	8	-		-
Pork (M5)	Max	18	-	2	-
	Min	7	-	0.7	-
	Mean	12	-	1.5	-
UK lamb (P4)	Max	21	-	5	3
	Min	5	-	3.5	2
	Mean	13	-		-
UK lamb (M2)	Max	21	10	+2	15 mins
	Min	2	3	-2	10 mins
	Mean	15	7	0	12 mins
UK lamb (M5)	Max	18	-	2	-
	Min	7	-	0	-
	Mean	12	-	1.1	-
NZ lamb (P4)	Max	67	-	5	3
	Min	44	-	3.5	2
	Mean	60	-		-
Turkey (P3)	Max	5	-	4	-
	Min	1	-	1.5	-
	Mean	2	-	2.8	-

(-) data not supplied

The following example from one of the participating meat processors shows mean (Figure 20) and maximum (Figure 21) product temperatures measured during boning and mincing operations, final chill and dispatch for turkey mince. These temperatures were taken over 8

trial days between February and March 2010. This data shows that mean temperatures do not exceed 3°C during processing, while maximum processing temperatures are less than 4°C.

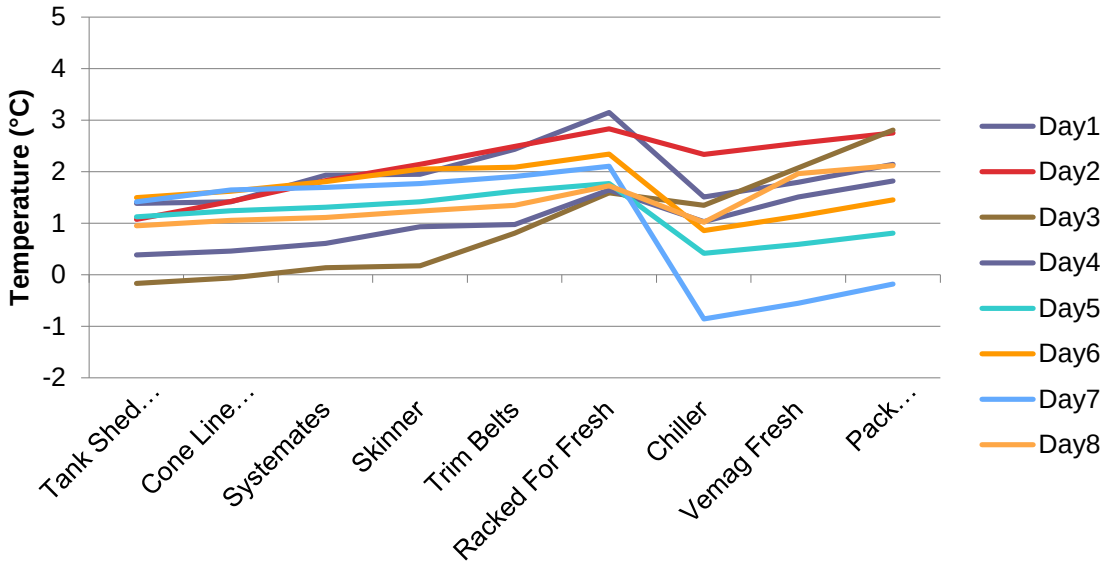

Figure 20. Mean meat temperatures (n=3) during boning, mincing, chilling, and dispatch of turkey mince (data supplied by P4)

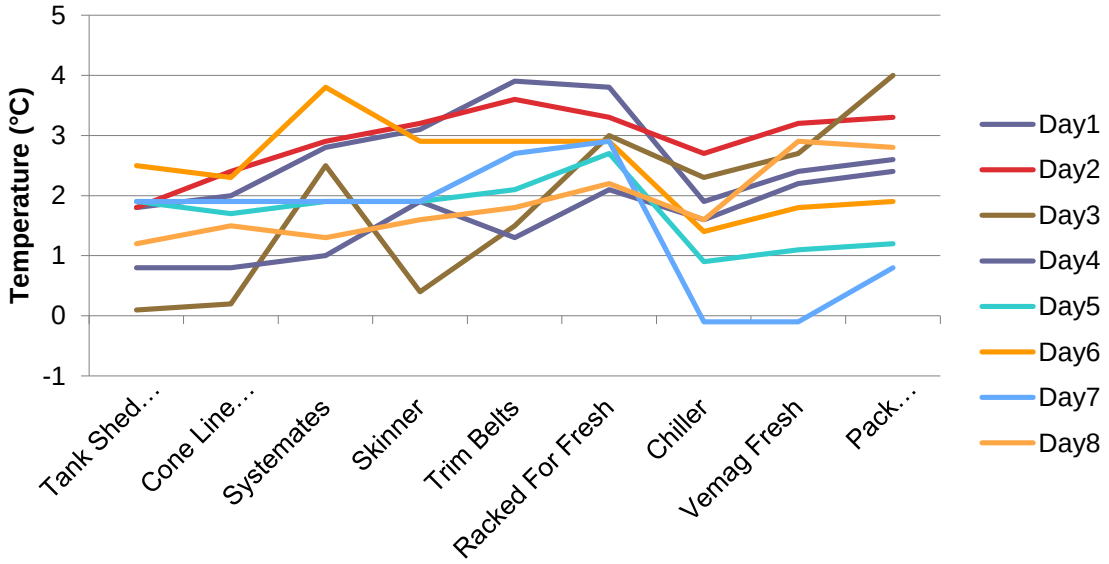

Figure 21. Maximum meat temperatures (n=3) during boning, mincing, chilling, and dispatch of turkey mince (data supplied by P4)

The specific project protocol asked for participating meat processors to measure product temperatures prior to and after mincing. The following temperatures at time of mincing shown in Table 5 were supplied by participating meat processors. This data shows that raw material temperatures are generally <2°C prior to mincing and that the mincing operation causes the temperature to rise by on average 2°C, although a rise of 4°C is possible. A temperature rise is to be expected during mincing due to heat generated from friction, unless a refrigerant, such as ice or solid carbon dioxide, is added during the process. The participating UK meat processors were not asked for specific details regarding their mincing

processes. It would appear from the data supplied that at least one of the participants was using a refrigerate during mincing since the recorded temperatures of the mince after mincing were lower than those of the raw material before mincing. Provided the processors comply with the current legislative requirement (Regulation (EC) No. 853/2004) to chill the mince to ≤2°C immediately after production the small increase in temperature during mincing is unlikely to pose any hazard since there will be insufficient time for extension proliferation of pathogens.

Table 5. Raw material temperatures prior to mincing and mince temperatures immediately after mincing

Species	Source	N=	Raw material temperature (°C)			Mince temperature (°C)		
			Min	Max	Mean (SD)	Min	Max	Mean (SD)
Beef	P2	3	0.7	2.9	1.7	-0.7	4.1	1.1
	P5	3	1.7	2.8	2.1	-1.0	-1.0	-1.0
Pork	P4	80	-0.7	3.8	0.7 (1.1)	0.9	5.6	3.3 (1.4)
Lamb UK	P4	65	-1.2	4.6	1.4 (1.6)	-1.1	8.1	4.0 (2.4)
Lamb NZ	P4	100	-1.1	3.7	1.3 (1.2)	0.1	5.8	4.5 (1.1)
Turkey	-	-	-	-	-	-	-	-

(-) data not supplied

3.3.1 Microbiological data related to age of meat at mincing

Preliminary data was provided by the FSA, BMPA and participating meat processors on microbiological counts on mince together with age of mince at the time of mincing (Table 6). Only data where the age of the meat at mincing was also supplied was analysed. Much data supplied by participating meat processors could not be analysed, and has not been included in this study, because of the lack of such details. This preliminary data could not be related to or correlated with processing temperature/time records, however, the data is useful for analysing trends.

The data supplied appears to show a very similar range of counts irrespective of age of meat at mincing for all of the species types. In general, the data shows that microbiological counts, be they Total viable (Table 6), coliform (Table 7), *E. coli* (Table 8), or Enterobacteriaceae (Table 9), are no higher on mince from aged meat than on mince produced from unaged meat. Detailed plots of this data for individual species are shown in the next section.

Few Salmonella (Table 10) data was provided on beef, but, in general, the data supplied by participating meat processors showed negative counts for mince from all meat species apart from turkey. The turkey data appears to show no higher prevalence of salmonella on mince from aged meat than from unaged meat.

Aerobic plate count (30°C incubation) are considered a useful measure of the bacteriological status of carcasses and meat after chilling or during storage (ICMSF, 1998). Comparisons of overall pooled mean data of TVCs on beef, pork, UK lamb, NZ lamb and turkey mince related to age of meat at time of mincing supplied by participating UK meat processors are shown in Figure 22, Figure 23, Figure 24, Figure 25, and Figure 26, respectively. This data includes both preliminary and tracked data. This data, surprisingly, shows that although levels of TVCs on beef, lamb and turkey overall show a slight increase with age of meat prior to mincing it is very slight. In the case of pork the data supplied actually shows a slight decrease in levels of TVCs with age of meat prior to mincing.

Table 6. Overall summary of Total viable counts (TVCs) on mince produced from meat of known age at mincing as supplied by participating meat processors

Species	Source	N=	Age (d)			TVC (log cfu g^{-1})		
			Min	Max	Mean	Min	Max	Mean (SD)
Beef	FSA	265	3	13	7	3.8	6.3	5.1 (0.5)
	BMPA	96	2	24	8	3.9	5.9	4.9 (0.3)
	M3 (a) *	80	2	59	12	1.0	5.5	3.5 (0.8)
	M3 (b) *	167	1	42	8	<3.0	5.4	3.8 (0.8)
	M5	426	7	20	7	1.6	5.1	4.1 (0.6)
Pork	P4	125	3	18	10	2.7	8.0	4.6 (1.0)
	M4	35	2	6	3.5	3.7	6.4	5.1 (0.7)
	BMPA	29	6	10	7	2.6	5.6	4.5 (0.7)
	M5	70	7	18	12	3.8	4.9	4.5 (0.2)
Lamb UK	P4	227	4	26	11	<3.0	8.3	4.9 (1.1)
	BMPA	25	3	23	8	4.2	6.3	5.0 (0.5)
	M1	50	6	8	7	4.7	5.0	4.9 (0.1)
	M5	65	7	18	12	3.3	5.0	4.4 (0.4)
Lamb NZ	P4	111	37	67	56	2.7	8.5	6.2 (1.4)
Turkey	P3	51	1	4	3	3.4	4.4	3.7 (0.2)

* Two separate data sets supplied.

Table 7. Overall summary of coliform counts on mince produced from meat of known age at mincing as supplied by participating meat processors

Species	Source	N=	Age (d)			Coliform count (log cfu g^{-1})		
			Min	Max	Mean	Min	Max	Mean (SD)
Beef	BMPA	22	2	24	10	1.0	3.5	2.6 (0.7)
Pork	BMPA	8	6	10	7	1.8	3.2	2.5 (0.5)
	M4	7	2	6	5	1.7	2.6	2.1 (0.3)
Lamb UK	-	-	-	-	-	-	-	-
Lamb NZ	-	-	-	-	-	-	-	-
Turkey	-	-	-	-	-	-	-	-

(-) data not supplied

Table 8. Overall summary of *E. coli* counts on mince produced from meat of known age at mincing as supplied by participating meat processors

Species	Source	N=	Age (d)			*E. coli* count (cfu/g)			
			Min	Max	Mean	Min*	Max	Mean (SD) *	%>10
Beef	FSA	265	3	13	7	<10	470	22.9 (58.3)	
	BMPA	93	2	24	7	<10	480	33.6 (59.0)	
	M3(b)	167	1	42	12	<10	>1000	14.8 (78.8)	8 (13/167)
	M5	426	7	20	13	<10	20	-	2 (8/426)
Pork	BMPA	26	6	10	7	<10	20	6.0 (3.2)	12 (3/26)
	P4	125	3	18	10	<10	360	12.2 (44.1)	7 (9/125)
	M4	35	2	6	3.5	<10	120	15.9 (28.4)	22 (8/35)
	M5	70	7	18	12	<10	-	-	0 (0/70)
Lamb UK	BMPA	25	3	23	8	<10	40	23.0 (14.4)	
	P4	227	4	26	11	<10	60	5.4 (3.8)	3 (6/227)
	M1	50	6	8	7	<10	580	78.5 (109.6)	
	M5	65	7	18	12	<10	-	-	0 (0/65)
Lamb NZ	P4	111	37	67	56	<10	110	6.6 (10.6)	5 (5/111)
Turkey	P3	51	1	4	3	<10	110	23.5 (23.6)	69 (35/51)

* for statistical purposes counts <10 have been halved to calculate means.

Table 9. Overall summary of Enterobacteriaceae counts on mince produced from meat of known age at mincing as supplied by participating meat processors

Species	Source	N=	Age (d)			Enterobacteriaceae count (log cfu g^{-1})		
			Min	Max	Mean	Min	Max	Mean (SD) *
Beef	M3(a)	54	2	51	12	1.0	2.7	1.2 (0.4)
	M5	426	7	20	13	<1.0	2.9	1.5 (0.7)
Pork	P4	26	5	18	11	<2.0	5.0	2.6 (1.1)
	M5	70	7	18	12	<1.0	2.6	1.1 (0.5)
Lamb UK	P4	45	5	21	13	<2.0	5.0	2.0 (0.8)
	M5	65	7	18	12	<1.0	2.7	1.0 (0.5)
Lamb NZ	P4	25	45	67	57	<2.0	5.0	3.4 (1.1)
Turkey	P3	5	3	3	3	1.3	2.1	1.8 (0.3)

* for statistical purposes < counts have been halved to calculate means.

Table 10. Overall summary of salmonella data on mince produced from meat of known age at mincing as supplied by participating meat processors

Species	Source	N=	Age (d)			Salmonella
			Min	Max	Mean	Number detected (%)
Beef	BMPA	23	2	13	7	0/23 (0%)
Pork	BMPA	5	6	8	7	0/5 (0%)
	P4	125	3	18	10	0/125 (0%)
Lamb UK	BMPA	3	3	7	6	0/3 (0%)
	P4	226	4	26	11	0/226 (0%)
	M1	6	6	8	7	0/6 (0%)
Lamb NZ	P4	111	37	67	56	0/111 (0%)
Turkey	P3	71	1	6	3	6/71 (8.4%) *

* Of the 6 positives: 1 of the samples was from mince made from 1 day old meat, 3 of the samples were from mince made from 2 day old meat, 1 of the samples was from mince made from 4 day old meat, and 1 of the samples was from mince made from 5 day old meat

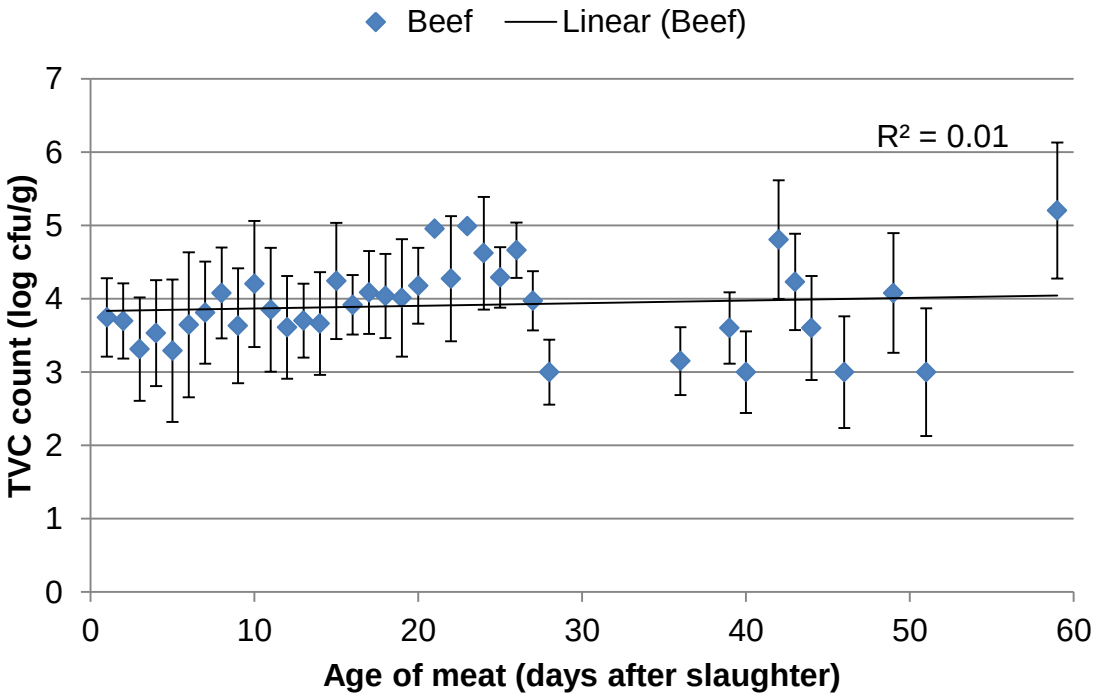

Figure 22. Overall comparison of pooled mean (SD) TVCs (n=1414) on mince produced from beef related to age of meat prior to mincing (pooled total data supplied by UK processors)

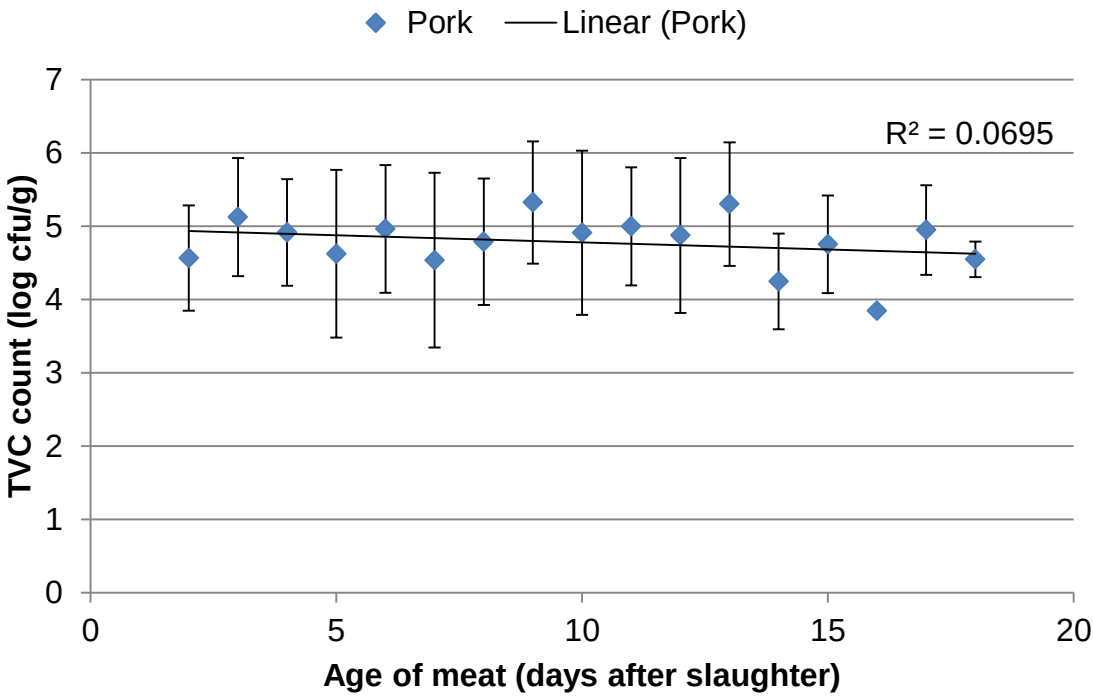

Figure 23. Overall comparison of pooled mean (SD) TVCs (n=545) on mince produced from pork related to age of meat prior to mincing (pooled total data supplied by UK processors)

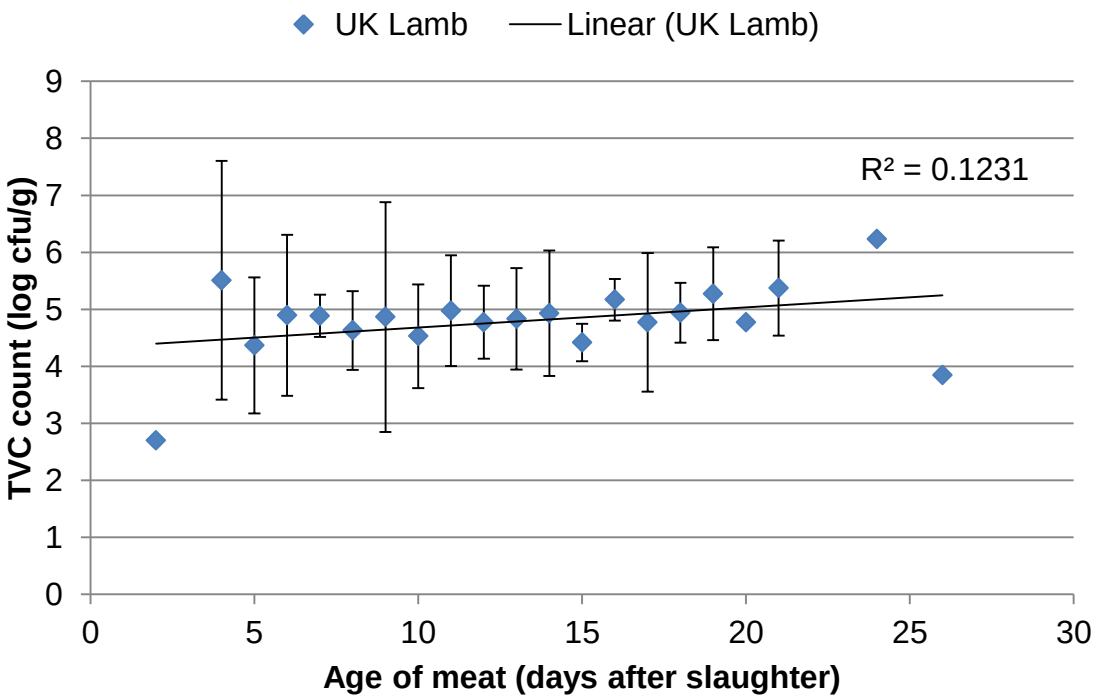

Figure 24. Overall comparison of pooled mean (SD) TVCs (n=407) on mince produced from UK lamb related to age of meat prior to mincing (pooled total data supplied by UK processors)

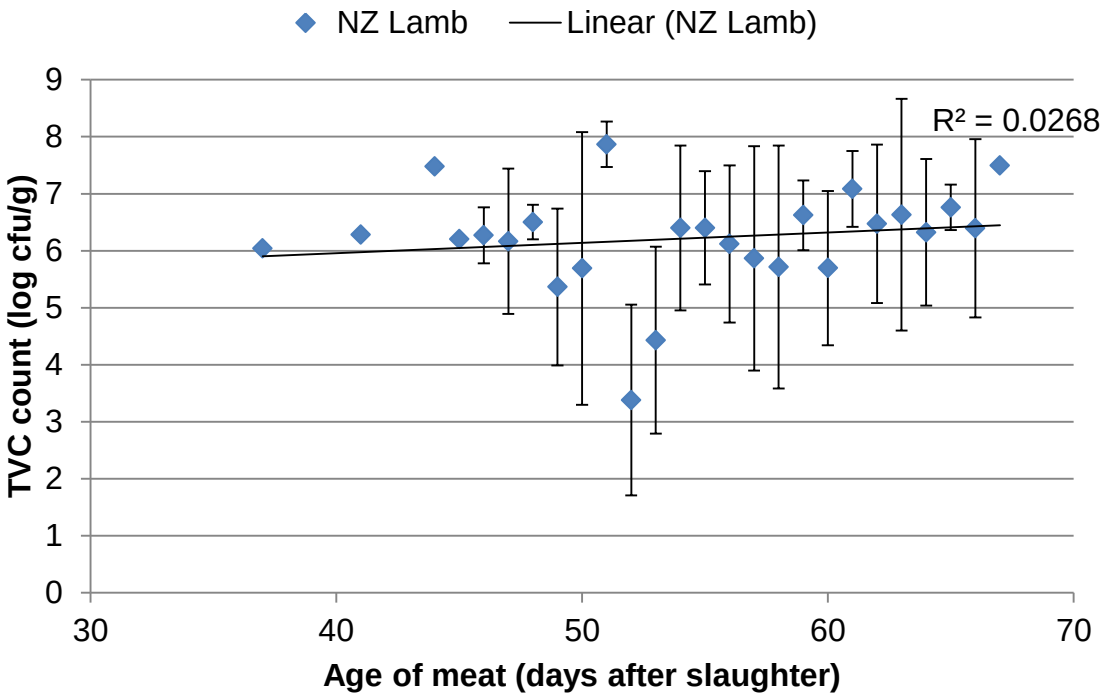

Figure 25. Overall comparison of pooled mean (SD) TVCs (n=211) on mince produced from NZ lamb related to age of meat prior to mincing (pooled total data supplied by UK processors)

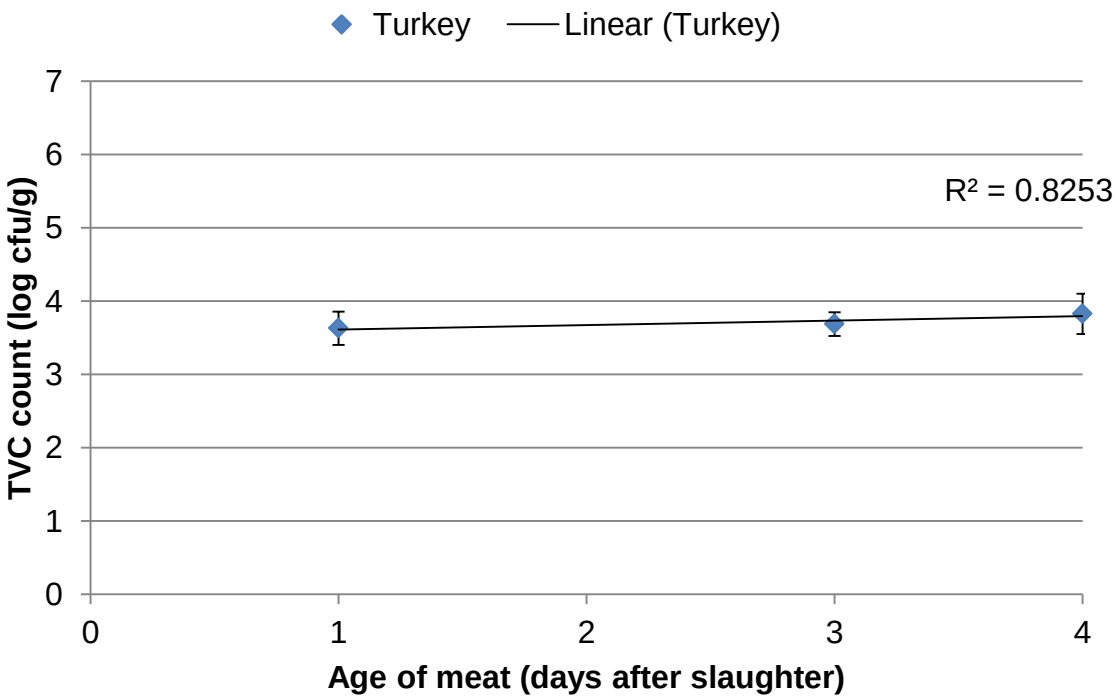

Figure 26. Overall comparison of pooled mean (SD) TVCs (n=111) on mince produced from turkey related to age of meat prior to mincing (pooled total data supplied by UK processors)

3.3.1.1 Beef

Data provided by the FSA, BMPA, M3 (a and b) and M5 on TVCs on mince together with age of mince at time of mincing for beef mince are shown in Figure 27, Figure 28, Figure 29, Figure 30 and Figure 31, respectively. All sets of data show a very similar range of counts (4 to 6 log cfu g^{-1}) irrespective of age (2 to 59 days) of meat at mincing. Only data from one processor shows counts to increase with age of meat.

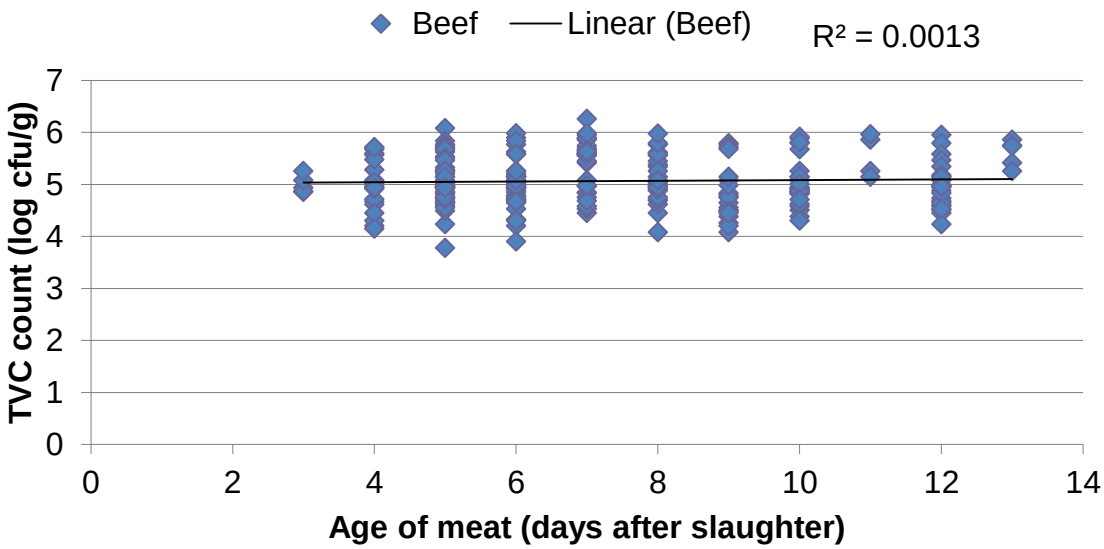

Figure 27. Comparison of reported TVCs (n=265) on mince produced from beef related to age of meat prior to mincing (data supplied by FSA)

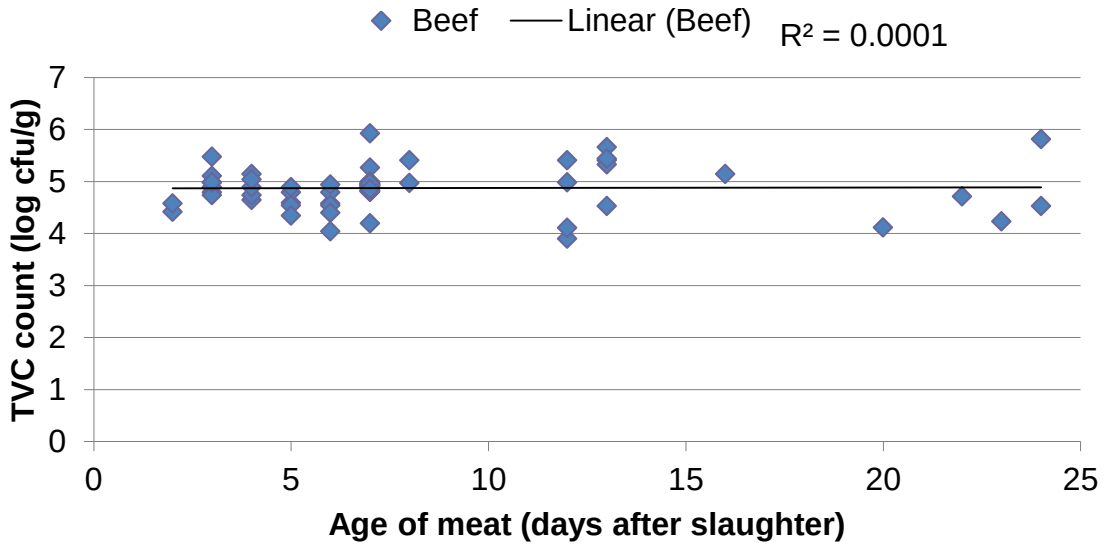

Figure 28. Comparison of reported TVCs (n=96) on mince produced from beef related to age of meat prior to mincing (data supplied by BMPA)

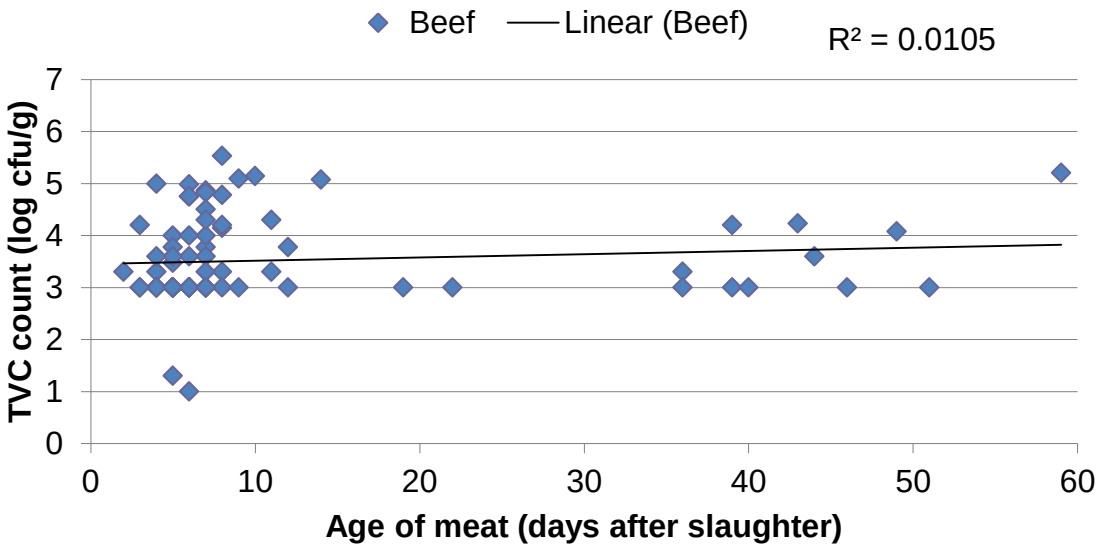

Figure 29. Comparison of reported TVCs (n=80) on mince produced from beef related to age of meat prior to mincing (data supplied by M3(a))

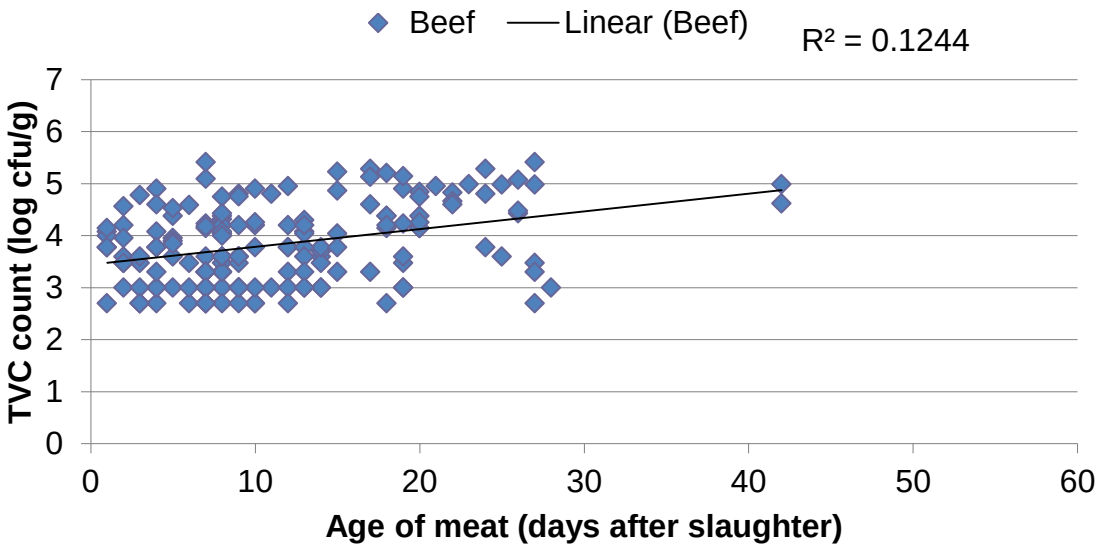

Figure 30. Comparison of reported TVCs (n=167) on mince produced from beef related to age of meat prior to mincing (data supplied by M3(b))

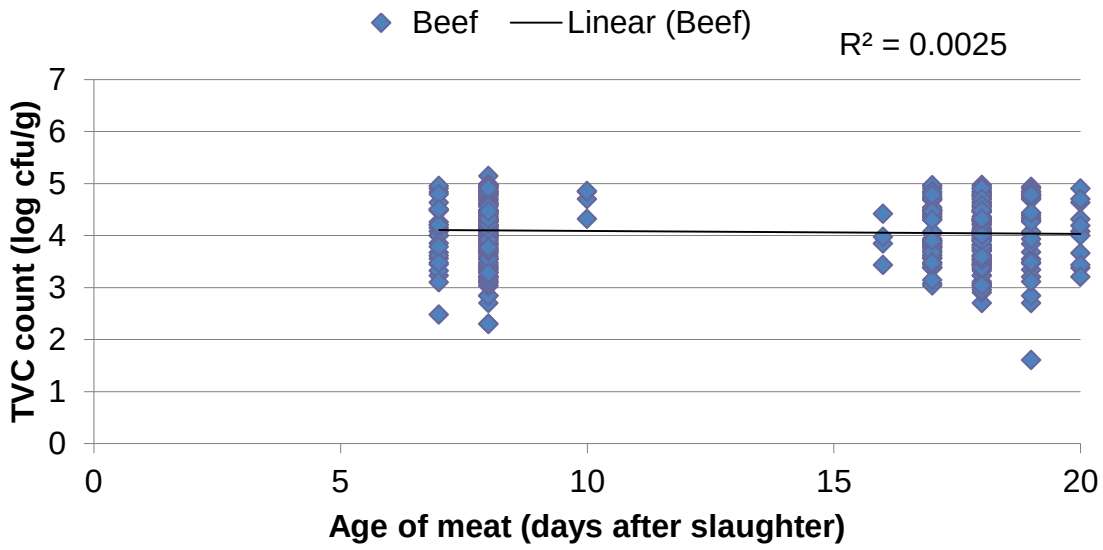

Figure 31. Comparison of reported TVCs (n=426) on mince produced from beef related to age of meat prior to mincing (data supplied by M5)

Data provided by the BMPA on Coliform counts on mince together with age of mince at time of mincing for beef mince is shown in Figure 32. The data show a very similar range of counts (1.0 to 3.5 $\log_{10}$cfu g^{-1}) irrespective of age (2 to 24 days) of meat at mincing.

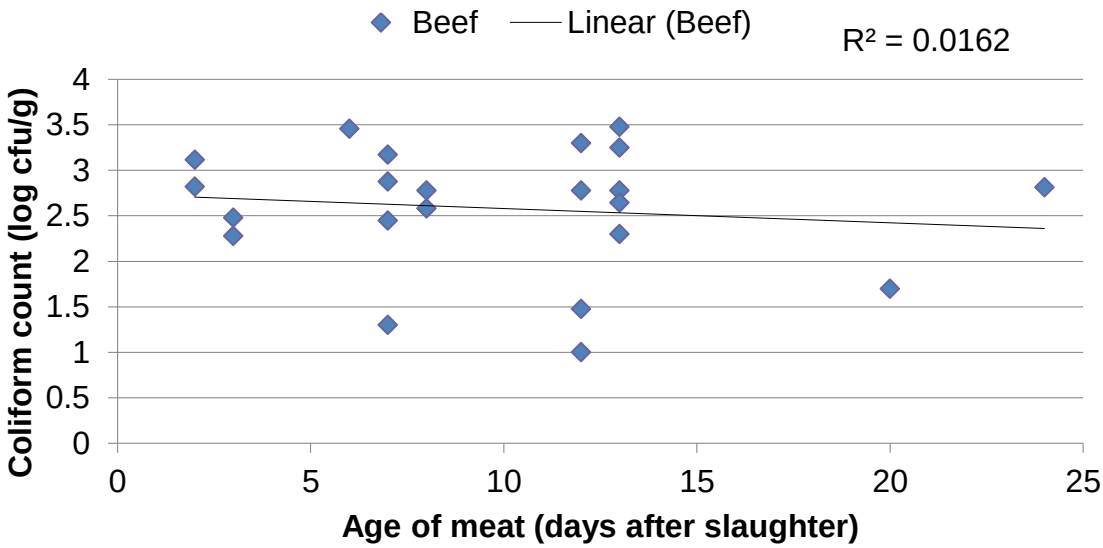

Figure 32. Comparison of reported coliform counts (n=22) on mince produced from beef related to age of meat prior to mincing (data supplied by BMPA)

Data provided by the BMPA and FSA on *E. coli* counts on mince together with age of mince at time of mincing for beef mince is shown in Figure 33 and Figure 34, respectively. All sets of data show a very similar range of counts (<10 to 500 cfu g^{-1}) irrespective of age (2 to 24 days) of meat at mincing. The majority of counts are <100 cfu g^{-1} (and many are <10) irrespective of age of meat at mincing.

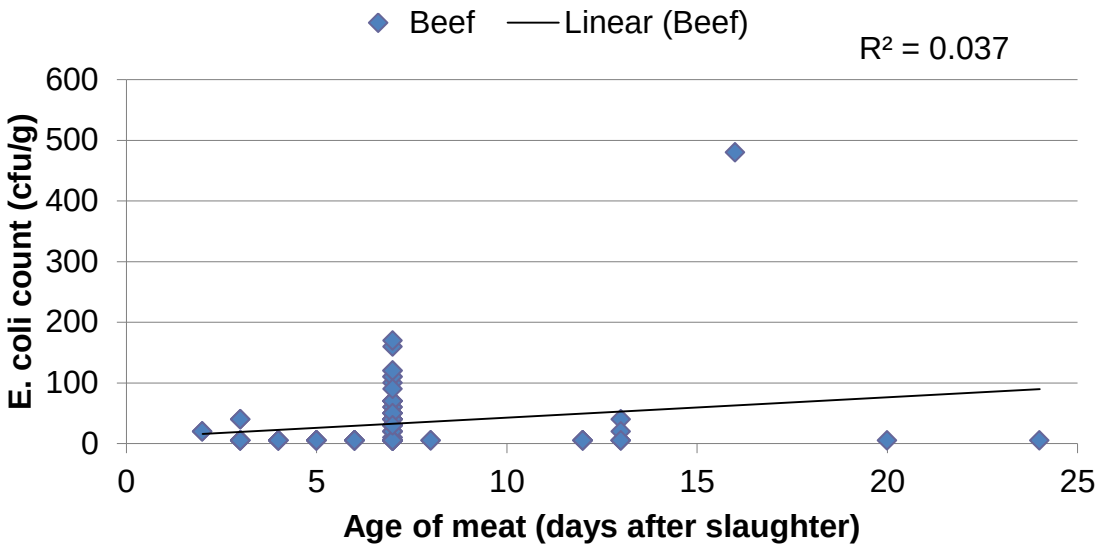

Figure 33. Comparison of reported *E. coli* counts (n=93) on mince produced from beef related to age of meat prior to mincing (data supplied by BMPA)

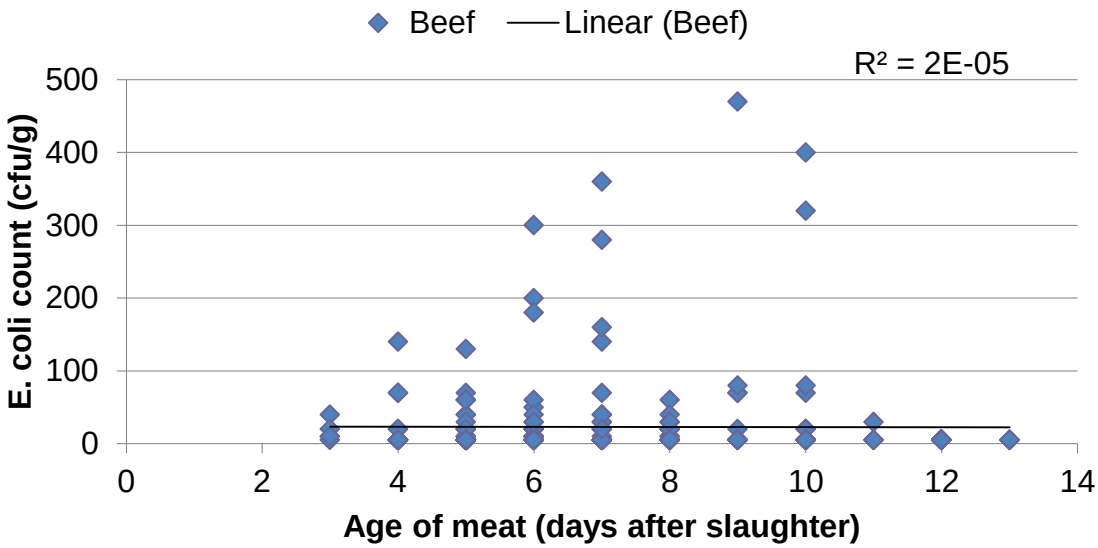

Figure 34. Comparison of reported *E. coli* counts (n=265) on mince produced from beef related to age of meat prior to mincing (data supplied by FSA)

Data provided by M3 and M5 on Enterobacteriaceae counts on mince together with age of mince at time of mincing for beef mince are shown in Figure 35 and Figure 36, respectively. The data shows a very similar range of counts (<1 to 2.9 $\log_{10}$ cfu g^{-1}) irrespective of age (2 to 51 days) of meat at mincing.

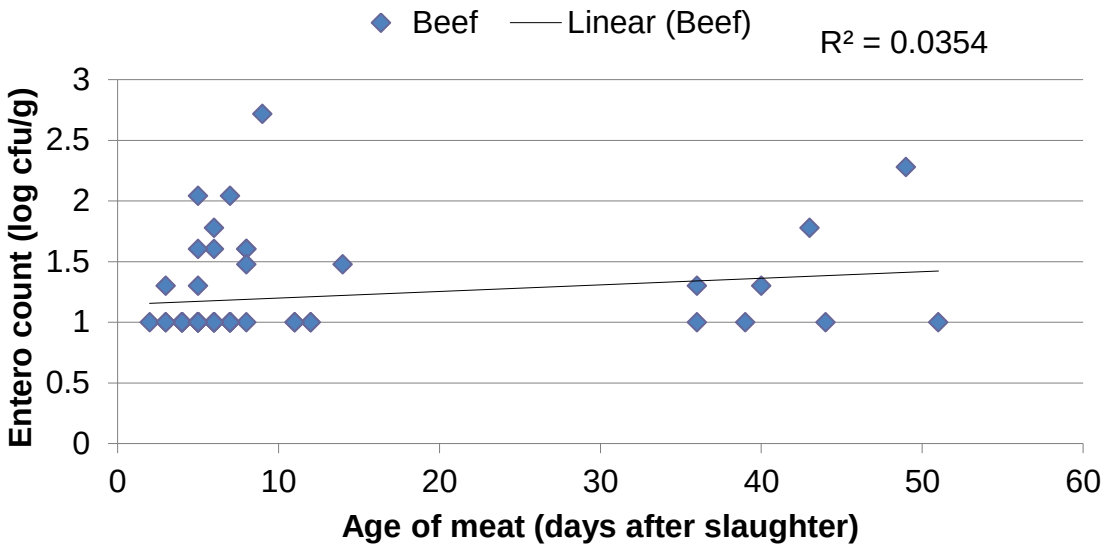

Figure 35. Comparison of reported Enterobacteriaceae counts (n=54) on mince produced from beef related to age of meat prior to mincing (data supplied by M3(a))

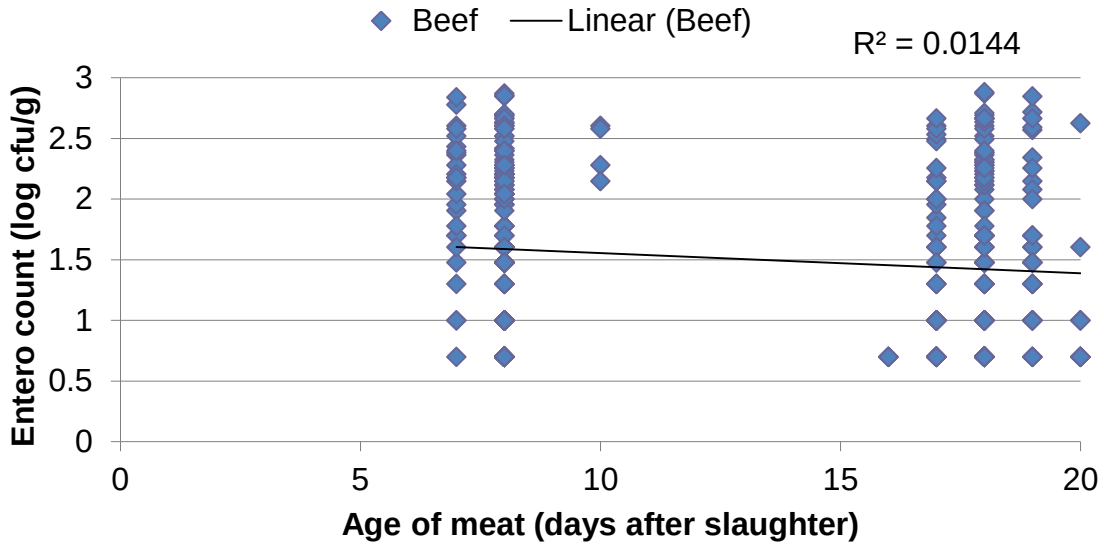

Figure 36. Comparison of reported Enterobacteriaceae counts (n=426) on mince produced from beef related to age of meat prior to mincing (data supplied by M5)

The following tracked data was measured according to the project protocol (Appendix 4) and provided by P2 for beef. An overall comparison of counts is shown in Table 11. Matched carcass, trim and mince microbiological counts and process parameters are shown in Table 12, Table 13 and Table 14, respectively. A comparison of TVC and Enterobacteriaceae counts on matched groups of primal/trim and mince against age of meat are shown in Figure 37 and Figure 38, respectively. Unfortunately none of the data supplied covered aged meat.

Table 11. Overall comparison of beef mince data (data supplied by P2)

	Age (d)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)
Min	5.0	2.0	2.0	0.7
Max	7.0	5.1	4.8	0.7
Mean	6.0	3.6	2.9	0.7
Number	15.0	15.0	15.0	15.0

Table 12. Tracked beef carcass data (data supplied by P2)

Kill date	Chilling time (h)	Chiller temperature (°C)	TVC (log cfu/cm^2)	Enterobacteriaceae (log cfu/cm^2)
06/07/2011	41	<5	3.5	0.6
06/07/2011	41	<5	2.6	0.0
06/07/2011	41	<5	2.5	0.0
06/07/2011	41	<5	3.5	1.0
06/07/2011	41	<5	3.5	1.7
22/06/2011	-	-	3.5	3.2
22/06/2011	-	-	3.5	2.5
22/06/2011	-	-	3.2	0.8
22/06/2011	-	-	3.5	2.0
22/06/2011	-	-	3.5	2.3
29/06/2011	-	-	3.2	1.1
29/06/2011	-	-	3.5	1.9
29/06/2011	-	-	3.5	2.0
29/06/2011	-	-	3.5	3.0
29/06/2011	-	-	3.5	3.2

(-) data not supplied

Table 13. Tracked beef primal/trim data (data supplied by P2)

Details (Primal, Trim etc)	Kill date	Age (d)	Storage temperature (°C)	Surface temperature prior to boning (°C)	Deep temperature prior to boning (°C)	Air temperature in the boning hall (°C)	Vacuum packed (Y/N)	TVC (log cfu/g /cm^2 (swab))	Enterobacteriaceae (log cfu/g)
After chilling-swab - prior to boning	06/07/2011	2	<5	3.3	3.8	8.0	N	3.5	2.4
	06/07/2011	2	<5	2.9	4.5	8.0	N	2.7	0.0
	06/07/2011	2	<5	2.8	4.4	8.0	N	2.0	0.0
	06/07/2011	2	<5	2.3	4.1	8.0	N	2.7	1.5
	06/07/2011	2	<5	2.4	3.8	8.0	N	2.9	1.8
After chilling-meat sample prior to boning	06/07/2011	2	<5	-	-	-	N	5.4	5.0
	06/07/2011	2	<5	-	-	-	N	3.6	3.0
	06/07/2011	2	<5	-	-	-	N	4.3	2.9
	06/07/2011	2	<5	-	-	-	N	4.4	3.3
	06/07/2011	2	<5	-	-	-	N	4.1	3.3
Meat prior to mincing	06/07/2011	6	<5	-	-	-	Y	4.2	<2.3
	06/07/2011	6	<5	-	-	-	Y	5.3	3.9
	06/07/2011	6	<5	-	-	-	Y	3.6	<2.3
	06/07/2011	6	<5	-	-	-	Y	5.1	4.9
	06/07/2011	6	<5	-	-	-	Y	5.3	4.0
After chilling-swab - prior to boning	22/06/2011	2	<5	3.2	4.3	6.0	N	3.5	2.9
	22/06/2011	2	<5	3.7	4.6	6.0	N	3.5	3.2
	22/06/2011	2	<5	3.7	4.6	6.0	N	2.9	2.1
	22/06/2011	2	<5	4.3	4.3	6.0	N	2.5	2.0
	22/06/2011	2	<5	3.8	4.1	6.0	N	2.8	2.1
After chilling-meat sample prior to boning	22/06/2011	2	<5	-	-	-	N	4.9	3.7
	22/06/2011	2	<5	-	-	-	N	3.7	<2.3
	22/06/2011	2	<5	-	-	-	N	3.4	<2.3
	22/06/2011	2	<5	-	-	-	N	4.0	3.3
	22/06/2011	2	<5	-	-	-	N	3.7	<2.3
Meat prior to mincing	22/06/2011	7	<5	-	-	-	Y	3.4	<2.3
	22/06/2011	7	<5	-	-	-	Y	3.7	3.0
	22/06/2011	7	<5	-	-	-	Y	3.3	3.1
	22/06/2011	7	<5	-	-	-	Y	4.0	<2.3
	22/06/2011	7	<5	-	-	-	Y	3.7	<2.3
After chilling-carcass swab - prior to boning	29/06/2011	2	<5	2.7	2.4	-	N	3.5	1.6
	29/06/2011	2	<5	2.4	2.6	-	N	3.5	1.1
	29/06/2011	2	<5	2.2	2.6	-	N	3.2	1.8
	29/06/2011	2	<5	2.0	2.6	-	N	1.3	0.0
	29/06/2011	2	<5	1.9	2.4	-	N	3.0	0.0

(-) data not supplied

Details (Primal, Trim etc)	Kill date	Age (d)	Storage temperature (°C)	Surface temperature prior to boning (°C)	Deep temperature prior to boning (°C)	Air temperature in the boning hall (°C)	Vacuum packed (Y/N)	TVC (log cfu/g /cm^2 (swab))	Enterobacteriaceae (log cfu/g)
After chilling-carcass meat sample prior to boning	29/06/2011	2	<5	-	-	4.6	N	<2.3	<2.3
	29/06/2011	2	<5	-	-	4.6	N	<2.3	<2.3
	29/06/2011	2	<5	-	-	4.6	N	<2.3	<2.3
	29/06/2011	2	<5	-	-	4.6	N	<2.3	<2.3
	29/06/2011	2	<5	-	-	4.6	N	<2.3	<2.3
Meat prior to mincing	29/06/2011	5	<5	-	-	-	N	<2.3	<2.3
	29/06/2011	5	<5	-	-	-	N	2.3	<2.3
	29/06/2011	5	<5	-	-	-	N	3.3	<2.3
	29/06/2011	5	<5	-	-	-	N	<2.3	<2.3
	29/06/2011	5	<5	-	-	-	N	<2.3	<2.3

(-) data not supplied

Table 14. Tracked beef mince data (data supplied by P2)

Kill date	Age (d)	Mincing room temperature (°C)	Vacuum packed (Y/N)	Raw material temperature surface (°C)	Raw material temperature deep(°C)	Mince temperature (°C)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)
06/07/2011	6	2.9	Y	3.1	1.5	4.1	4.2	3.8	<1.0
06/07/2011	6	2.9	Y	3.1	1.5	4.1	4.3	3.9	<1.0
06/07/2011	6	2.9	Y	3.1	1.5	4.1	5.1	4.8	<1.0
06/07/2011	6	2.9	Y	3.1	1.5	4.1	4.5	3.7	<1.0
06/07/2011	6	2.9	Y	3.1	1.5	4.1	4.2	4.1	<1.0
22/06/2011	7	3.8	Y	4.2	2.9	-0.2	4.1	3.3	<1.0
22/06/2011	7	3.8	Y	4.2	2.9	-0.2	3.7	3.1	<1.0
22/06/2011	7	3.8	Y	4.2	2.9	-0.2	4.0	2.3	<1.0
22/06/2011	7	3.8	Y	4.2	2.9	-0.2	3.8	<2.3	<1.0
22/06/2011	7	3.8	Y	4.2	2.9	-0.2	4.0	<2.3	<1.0
29/06/2011	5	2.6	Y	1.7	0.7	-0.7	3.0	<2.3	<1.0
29/06/2011	5	2.6	Y	1.7	0.7	-0.7	3.2	<2.3	<1.0
29/06/2011	5	2.6	Y	1.7	0.7	-0.7	<2.3	<2.3	<1.0
29/06/2011	5	2.6	Y	1.7	0.7	-0.7	<2.3	<2.3	<1.0
29/06/2011	5	2.6	Y	1.7	0.7	-0.7	<2.3	<2.3	<1.0

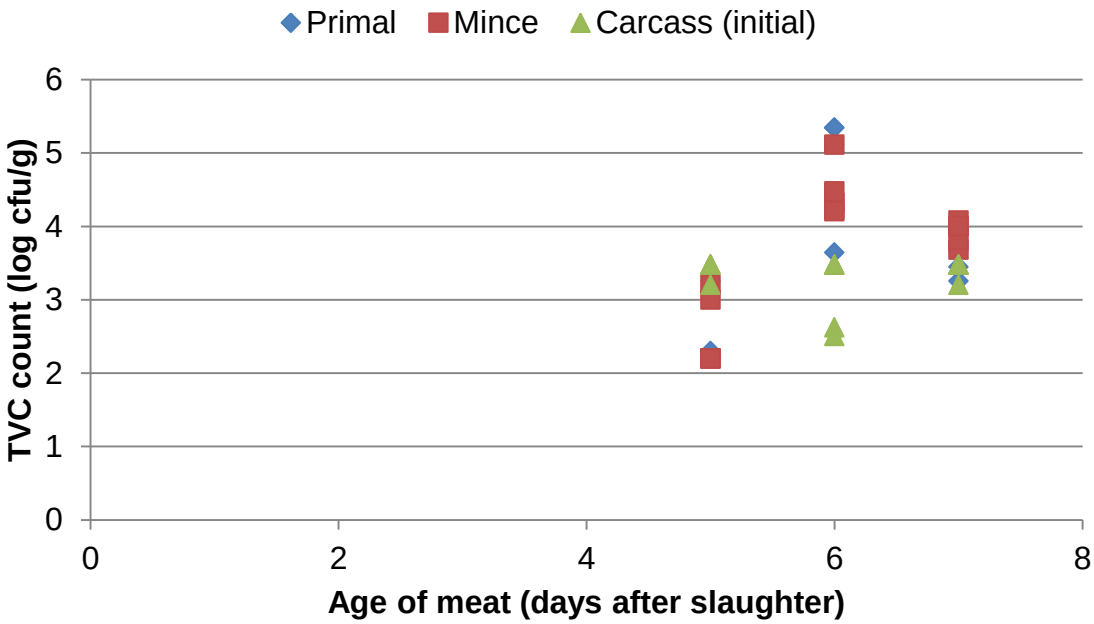

Figure 37. Comparison of TVCs on primal and mince produced from beef (3 batches, 5 replicates per batch) related to age of meat prior to mincing, and initial counts on carcass (data supplied by P2)

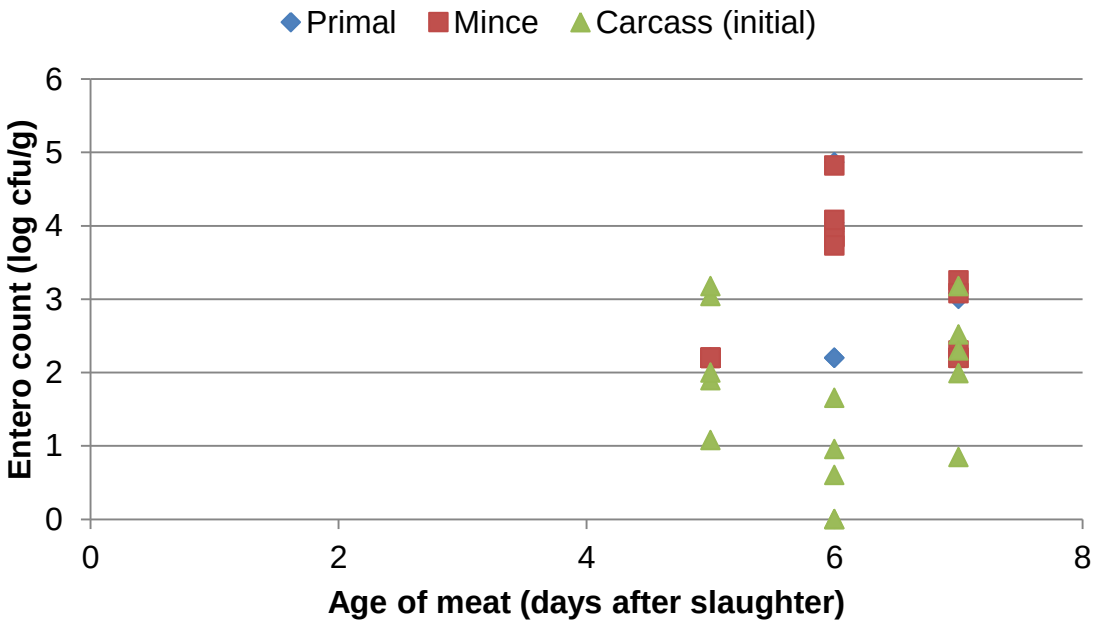

Figure 38. Comparison of Enterobacteriaceae counts on primal and mince produced from beef (3 batches, 5 replicates per batch) related to age of meat prior to mincing (data supplied by P2)

The following tracked data was measured according to the project protocol (Appendix 4) and provided by P5 for beef. An overall comparison of counts is shown in Table 15. Matched carcass, trim and mince microbiological counts and process parameters are shown in Table

16, Table 17 and Table 18, respectively. A comparison of TVC and Enterobacteriaceae counts on matched groups of primal/trim and mince against age of meat are shown in Figure 39 and Figure 40, respectively. Unfortunately none of the data supplied covered aged meat.

Table 15. Overall comparison of beef mince data (data supplied by P5)

	Age (d)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Salmonella (Detected or Not Detected)
Min	5.0	0.7	0.7	0.7	
Max	10.0	5.7	2.1	0.7	
Mean	8.3	4.1	1.3	0.7	
Number	15.0	15.0	15.0	15.0	15
Number detected *					0
% *					0

*Salmonella data only

Table 16. Tracked beef carcass data (data supplied by P5)

Kill date	Chilling time (h)	Chiller temperature (°C)	TVC (log cfu/cm^2)	Enterobacteriaceae (cfu/cm^2)	Salmonella (Detected or Not Detected)
01/04/2011	96	<1	3.12	<0.01	ND
01/04/2011	96	<1	2.5	0.07	ND
01/04/2011	96	<1	5.25	<0.01	ND

Table 17. Tracked beef primal/trim data (data supplied by P5)

Details (Primal, Trim etc)	Kill date	Age (d)	Storage temperature (°C)	Vacuum packed (Y/N)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)	Salmonella (Detected or Not Detected)
Carcass surface excision prior to cutting	01/04/2011	4	<1	N	2.2	-0.3	-	-	-	ND
	01/04/2011	4	<1	N	-0.6	<1.0	-	-	-	ND
	01/04/2011	4	<1	N	1.6	<1.0	-	-	-	ND
Carcass swab prior to cutting	01/04/2011	4	<1	N	3.6	1.5	1.5	1.7	-	ND
	01/04/2011	4	<1	N	2.3	1.8	<1.0	1.3	-	ND
	01/04/2011	4	<1	N	4.6	1.8	<1.0	1.3	-	ND
Trim (85vl Trim)	01/04/2011	5	<1	Y	3.4	1.6	<1.0	<1.0	<1.0	-
	01/04/2011	5	<1	Y	3.5	1.3	<1.0	<1.0	<1.0	-
	01/04/2011	5	<1	Y	2.4	<1.0	<1.0	<1.0	<1.0	-
	01/04/2011	5	<1	Y	3.5	1.5	<1.0	<1.0	<1.0	-
	01/04/2011	5	<1	Y	4.6	1.7	<1.0	<1.0	<1.0	-
Primal (80vl Plate)	01/04/2011	10	<1	Y	3.5	<1.0	<1.0	<1.0	<1.0	-
	01/04/2011	10	<1	Y	4.6	1.6	<1.0	<1.0	<1.0	-
	01/04/2011	10	<1	Y	5.4	1.8	<1.0	1.0	<1.0	-
	01/04/2011	10	<1	Y	3.5	1.3	<1.0	<1.0	<1.0	-
	01/04/2011	10	<1	Y	2.6	<1.0	<1.0	<1.0	<1.0	-
Primal (Flank)	01/04/2011	10	<1	Y	4.6	1.3	<1.0	<1.0	<1.0	-
	01/04/2011	10	<1	Y	3.3	1.7	<1.0	<1.0	<1.0	-
	01/04/2011	10	<1	Y	3.7	1.3	<1.0	<1.0	<1.0	-
	01/04/2011	10	<1	Y	3.3	<1.0	<1.0	<1.0	<1.0	-
	01/04/2011	10	<1	Y	4.7	1.8	<1.0	1.5	<1.0	-

(-) data not supplied

Table 18. Tracked beef mince data (data supplied by P5)

Source	Kill date	Age (d)	Vacuum packed (Y/N)	Raw material temperature (°C)	Mince temperature (°C)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Salmonella (Detected or Not Detected)
Trim (85vl Trim)	01/04/2011	5	Y	2.8	-1	4.0	1.7	<1.0	ND
	01/04/2011	5	Y	2.8	-1	5.7	2.1	<1.0	ND
	01/04/2011	5	Y	2.8	-1	5.0	1.8	<1.0	ND
	01/04/2011	5	Y	2.8	-1	3.8	1.5	<1.0	ND
	01/04/2011	5	Y	2.8	-1	<1.0	<1.0	<1.0	ND
Primal (80vl Plate)	01/04/2011	10	Y	1.8	-1	5.3	1.8	<1.0	ND
	01/04/2011	10	Y	1.8	-1	5.2	1.5	<1.0	ND
	01/04/2011	10	Y	1.8	-1	4.6	<1.0	<1.0	ND
	01/04/2011	10	Y	1.8	-1	3.3	1.3	<1.0	ND
	01/04/2011	10	Y	1.8	-1	3.1	<1.0	<1.0	ND
Primal (Flank)	01/04/2011	10	Y	1.7	-1	4.5	1.3	<1.0	ND
	01/04/2011	10	Y	1.7	-1	3.6	<1.0	<1.0	ND
	01/04/2011	10	Y	1.7	-1	3.7	<1.0	<1.0	ND
	01/04/2011	10	Y	1.7	-1	5.5	1.3	<1.0	ND
	01/04/2011	10	Y	1.7	-1	4.1	1.8	<1.0	ND

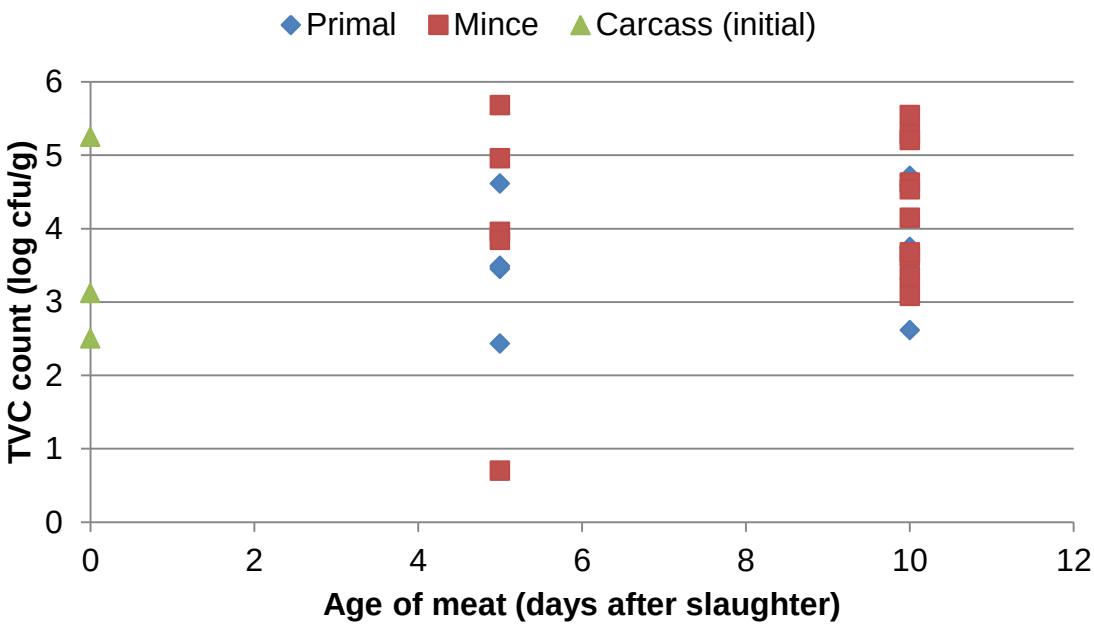

Figure 39. Comparison of TVCs on primal and mince produced from beef (1 batch, 5 replicates per batch) related to age of meat prior to mincing, and initial counts on carcass (data supplied by P5)

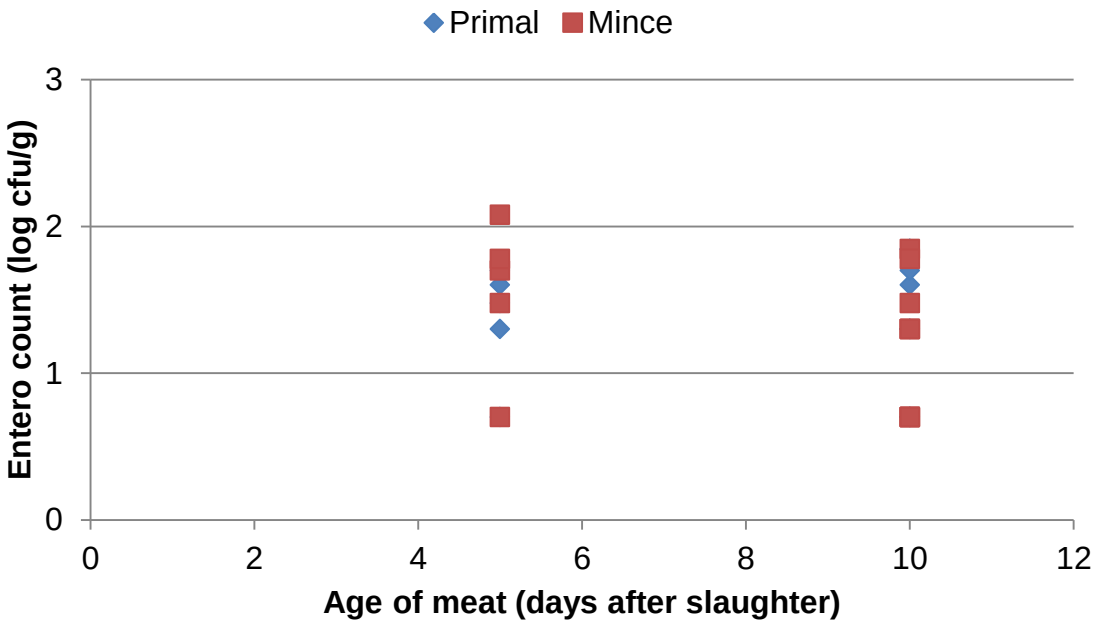

Figure 40. Comparison of Enterobacteriaceae counts on primal and mince produced from beef (1 batch, 5 replicates per batch) related to age of meat prior to mincing (data supplied by P5)

3.3.1.2 Pork

Data provided by the BMPA, P4, M4 and M5 on Total Viable counts on mince together with age of mince at time of mincing for pork mince is shown in Figure 41, Figure 42, Figure 43 and Figure 44, respectively. All sets of data show a very similar range of counts (2.6 to 7.6 log cfu g^{-1}) irrespective of age (2 to 17 days) of meat at mincing. Overall, meat processed by P4 and M5 was older (mean age 9 and 12 days, respectively) in comparison with that processed by M4 (mean age 3.5 days) but mean TVCs were comparable, 5.2, 4.5 and 5.1 $\log_{10}$ cfu g^{-1}, respectively.

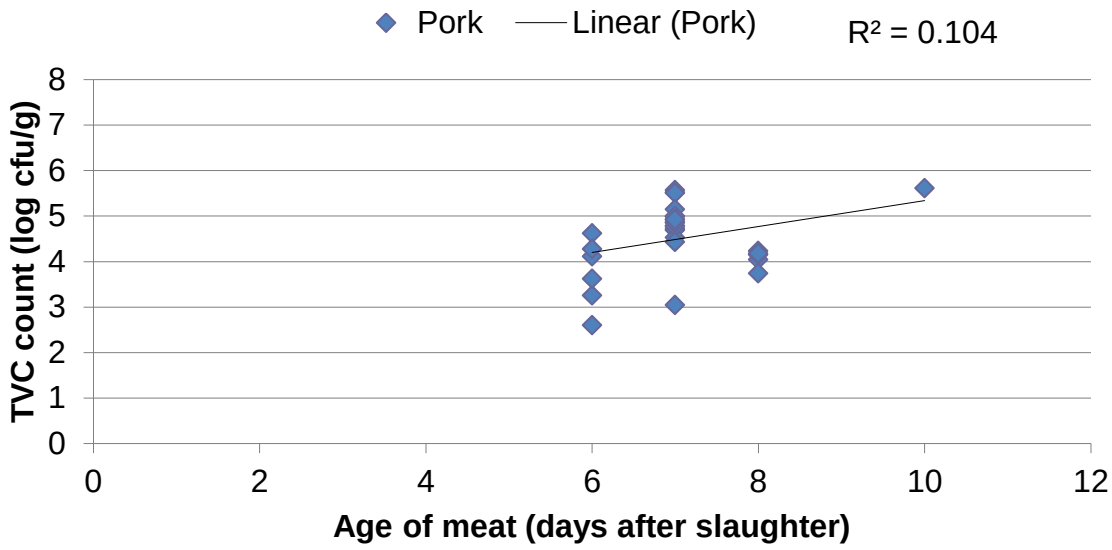

Figure 41. Comparison of reported TVCs (n=29) on mince produced from pork related to age of meat prior to mincing (data supplied by BMPA)

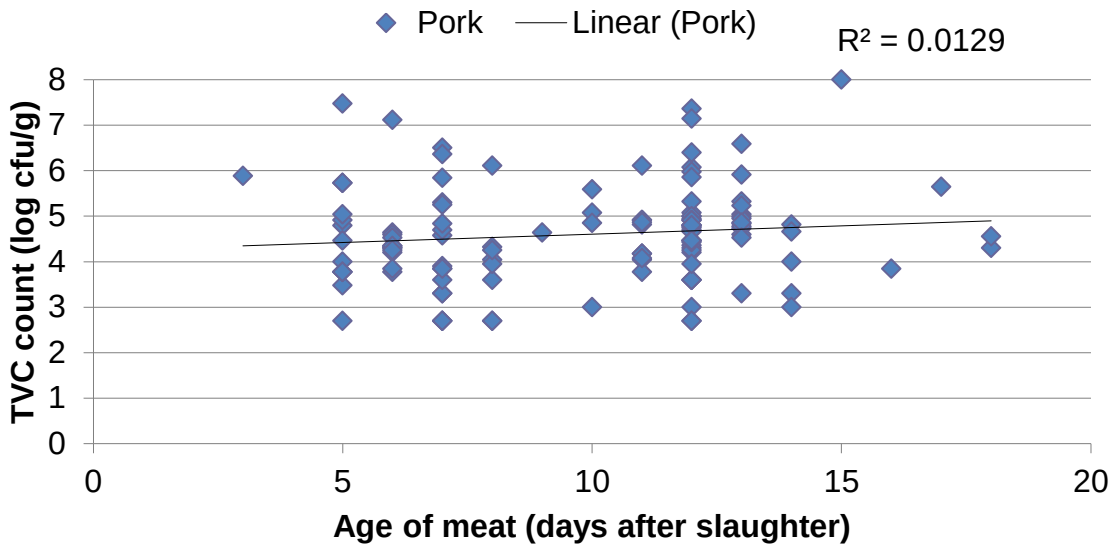

Figure 42. Comparison of reported TVCs (n=125) on mince produced from pork related to age of meat prior to mincing (data supplied by P4)

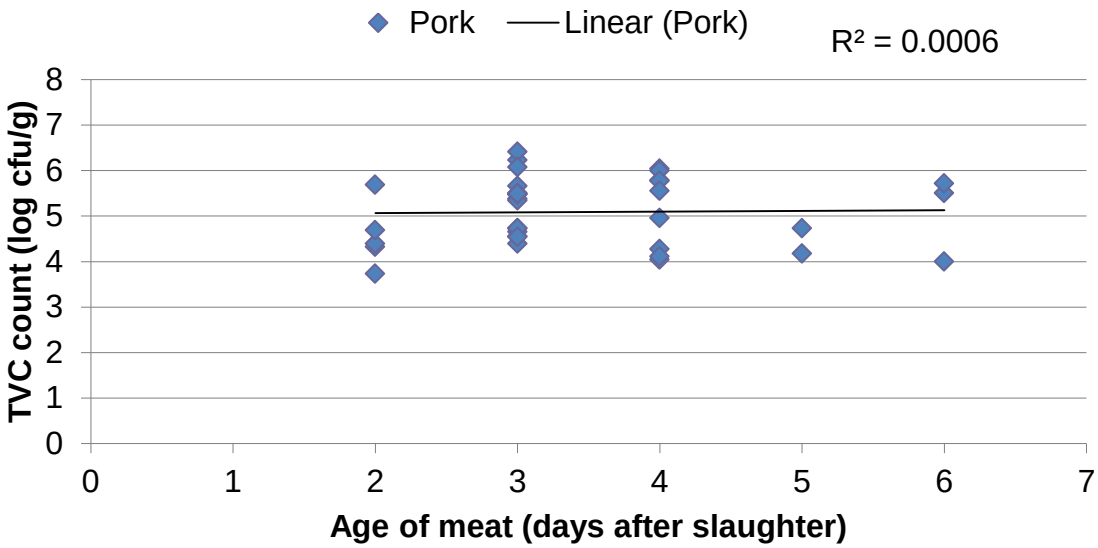

Figure 43. Comparison of reported TVCs (n=35) on mince produced from pork related to age of meat prior to mincing (data supplied by M4)

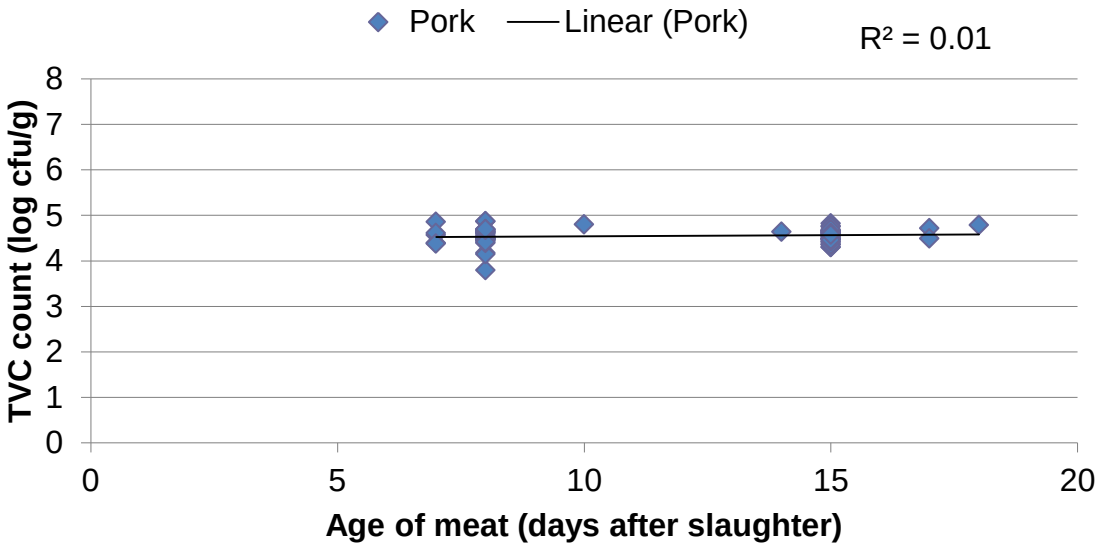

Figure 44. Comparison of reported TVCs (n=70) on mince produced from pork related to age of meat prior to mincing (data supplied by M5)

Data provided by the BMPA and M4 on coliform counts on mince together with age of mince at time of mincing for pork mince are shown in Figure 45 and Figure 46, respectively. The data show a very similar range of counts (1.7 to 3.2 $\log_{10}$ cfu g^{-1}) irrespective of age (2 to 10 days) of meat at mincing.

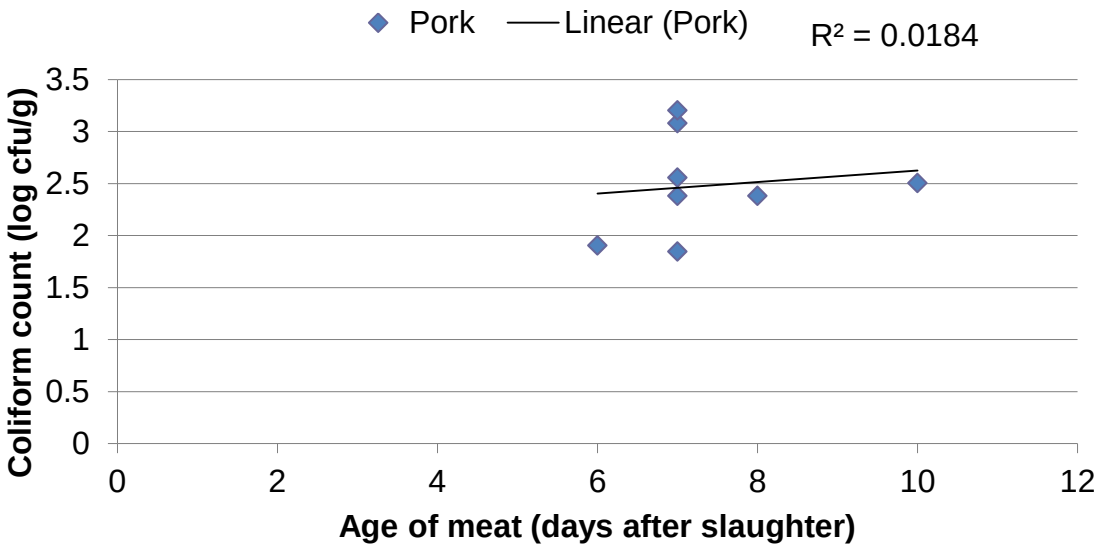

Figure 45. Comparison of reported coliform counts (n=8) on mince produced from pork related to age of meat prior to mincing (data supplied by BMPA)

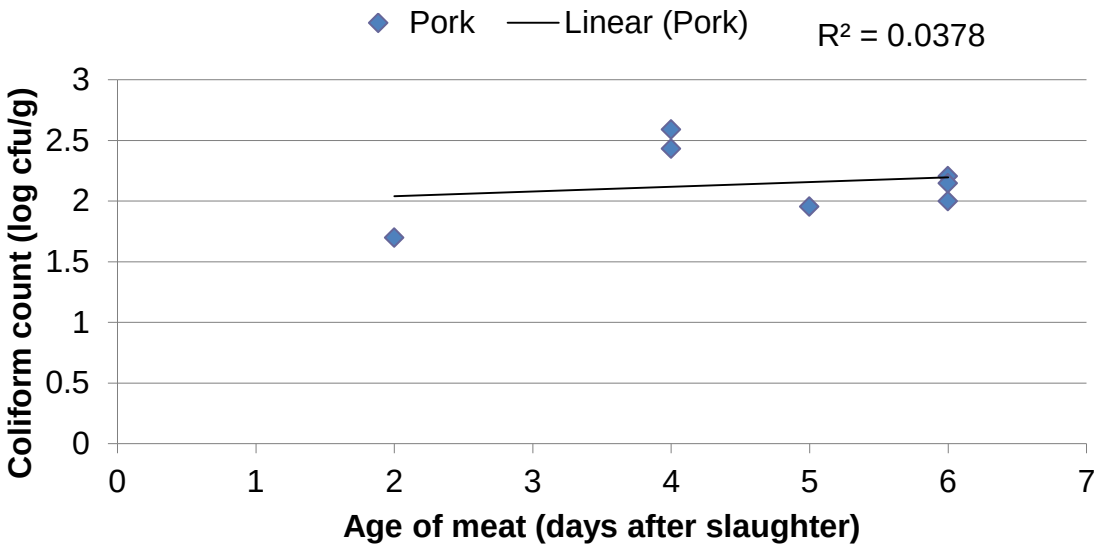

Figure 46. Comparison of reported coliform counts (n=7) on mince produced from pork related to age of meat prior to mincing (data supplied by M4)

Data provided by the BMPA, P4 and M4 on *E. coli* counts on mince together with age of mince at time of mincing for pork mince is shown in Figure 47, Figure 48 and Figure 49, respectively. Data was provided by P4 showed only 9 positive counts out of 125 samples sampled over the time period from August 2009 to February 2011. Overall, the majority of counts supplied are less than the limit of detection (<10 cfu g^{-1}, shown as 5 in the graphs) irrespective of age (3 to 18 days) of meat at mincing.

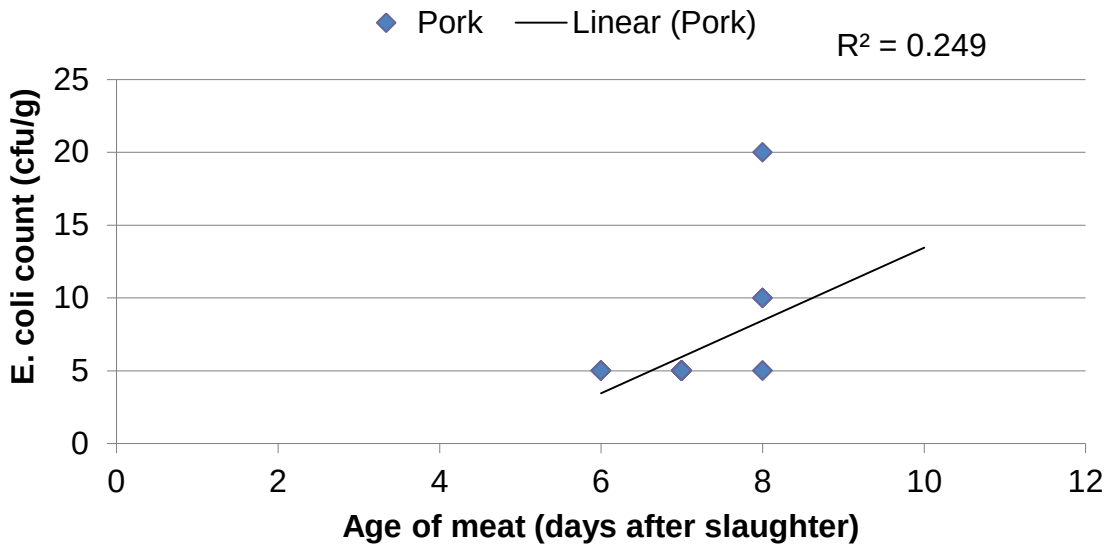

Figure 47. Comparison of reported *E. coli* counts (n=26) on mince produced from pork related to age of meat prior to mincing (data supplied by BMPA)

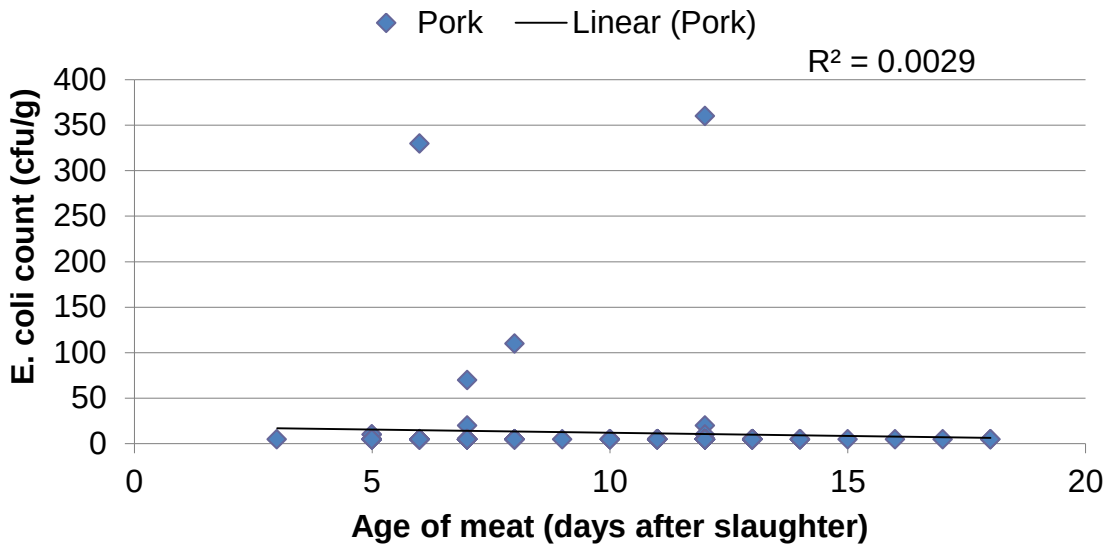

Figure 48. Comparison of reported *E. coli* counts (n=125) on mince produced from pork related to age of meat prior to mincing (data supplied by P4)

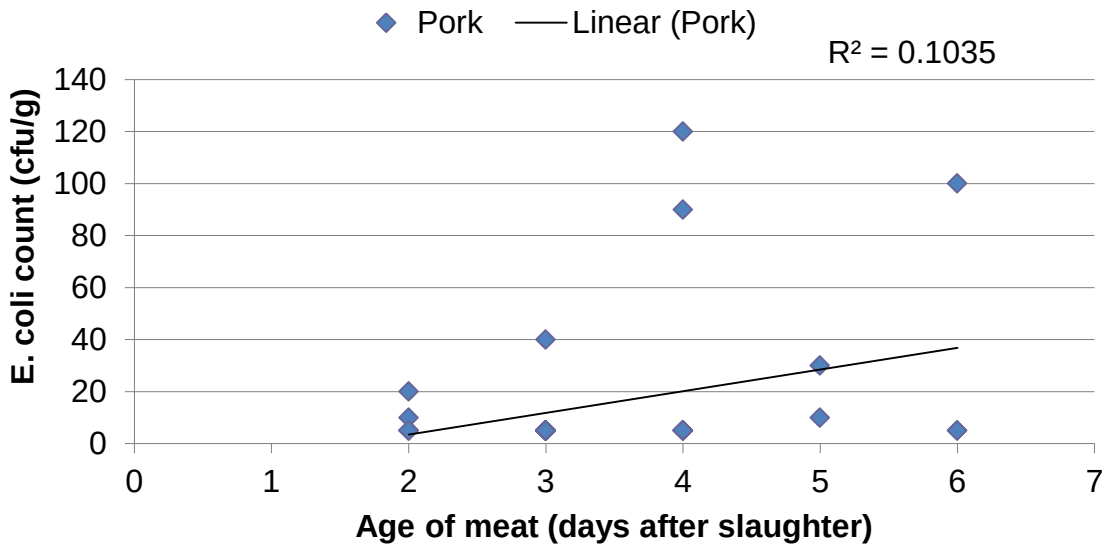

Figure 49. Comparison of reported *E. coli* counts (n=35) on mince produced from pork related to age of meat prior to mincing (data supplied by M4)

Data provided by P4 and M5 on Enterobacteriaceae counts on mince together with age of mince at time of mincing for pork mince is shown in Figure 50 and Figure 51, respectively. Both sets of data show a very similar range of counts irrespective of age (between 5 to 18 days) of meat at mincing. The data from P4 shows a slight increase in count with age of meat.

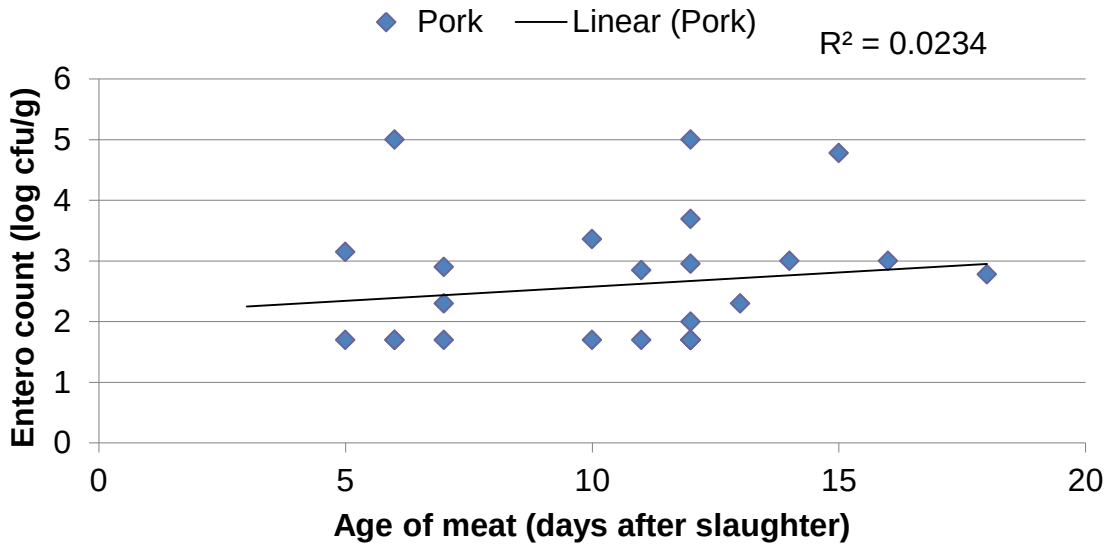

Figure 50. Comparison of reported Enterobacteriaceae counts (n=26) on mince produced from pork related to age of meat prior to mincing (data supplied by P4)

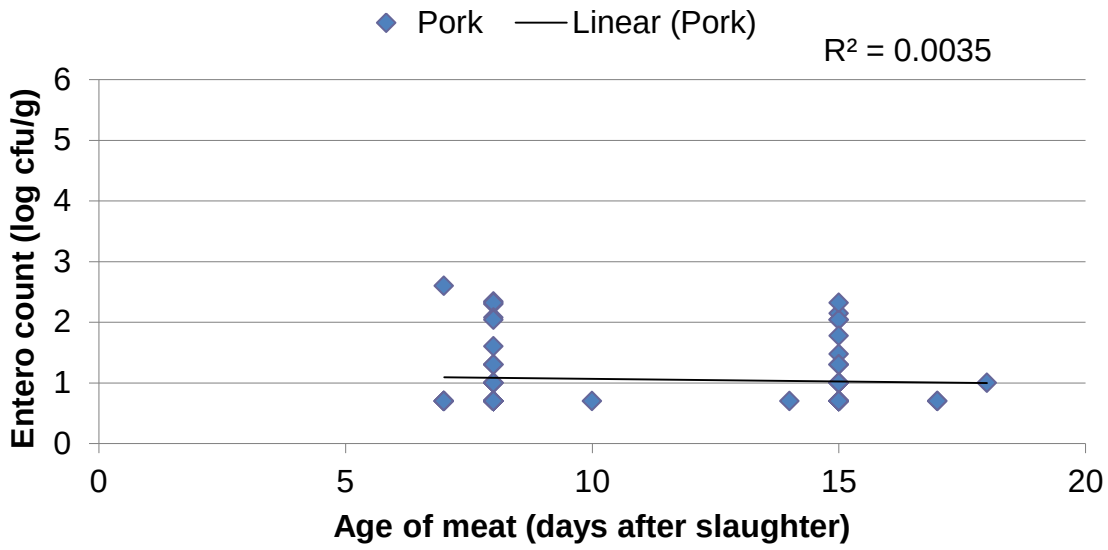

Figure 51. Comparison of reported Enterobacteriaceae counts (n=70) on mince produced from pork related to age of meat prior to mincing (data supplied by M5)

The following tracked data was measured according to the project protocol (Appendix 4) and provided by P4 for pork. An overall comparison of counts is shown in Table 19. Matched carcass, trim and mince microbiological counts and process parameters are shown in Table 20, Table 21 and Table 22, respectively. A comparison of TVC and Enterobacteriaceae counts on matched groups of hockmeat and mince against age of meat are shown in Figure 52 and Figure 53, respectively. Overall, the data show a very similar range of counts irrespective of age of meat at mincing.

Table 19. Overall comparison of pork mince data (data supplied by P4)

		Age (d)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)	Salmonella (Detected or Not Detected)	Clostridia (log cfu/g)	Lactic Acid Bacteria (log cfu/g)	Pseudomonads (log cfu/g)
Overall	Min	4.0	1.7	1.0	0.7	0.7	0.7		0.7	0.7	1.0
	Max	13.0	6.7	4.5	2.0	4.1	1.0		1.0	4.3	5.7
	Mean	8.2	4.7	2.3	0.8	2.3	0.9		0.7	1.6	3.6
	Number	80.0	80.0	79.0	80.0	80.0	80.0	80.0	80.0	80.0	80.0
	Detected							0.0			
	%										
Aged >6 days	Min	7.0	1.7	1.0	0.7	0.7	0.7		0.7	0.7	1.0
	Max	13.0	6.7	4.5	1.3	3.4	1.0		1.0	3.5	5.7
	Mean	8.8	4.7	2.3	0.7	2.2	0.9		0.7	1.5	3.5
	Number	65.0	65.0	64.0	65.0	65.0	65.0	65.0	65.0	65.0	65.0
	Detected							0.0			
	%										
Unaged <6 days	Min	4.0	3.5	1.6	0.7	1.3	0.7		0.7	0.7	3.1
	Max	6.0	6.5	3.5	2.0	4.1	1.0		0.7	4.3	5.6
	Mean	5.3	4.7	2.3	1.1	2.6	0.9		0.7	1.7	4.1
	Number	15.0	15.0	15.0	15.0	15.0	15.0	85.0	15.0	15.0	15.0
	Detected							0.0			
	%										

Table 20. Tracked pork carcass data (data supplied by P4)

Kill date	Chilling time (h)	Chiller temperature (°C)	TVC (log cfu/cm^2)	Enterobacteriaceae (log cfu/cm^2)	E. coli (log cfu/cm^2)	Coliforms (log cfu/cm^2)	Staphylococcus aureus (log cfu/cm^2)	Salmonella (Detected or Not Detected)	Clostridia (log cfu/cm^2)	Pseudomonads (log cfu/cm^2)	Lactic Acid Bacteria (log cfu/g)
02/12/2010	31.15	Average temperature 3	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.3	-
02/12/2010	31.15		<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.3	-
02/12/2010	31.15		4.3	<2.0	<1.0	<2.0	<1.3	ND	<1.0	1.9	-
02/12/2010	31.15		4.3	<2.0	<1.0	<2.0	<1.3	ND	<1.0	2.3	-
02/12/2010	31.15		3.5	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.3	-
03/02/2011	24.3	Average temperature 3.2	3.6	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.3	<1.0
03/02/2011	24.3		4.5	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.3	<1.0
03/02/2011	24.3		4.3	2.6	<1.0	<2.0	<1.3	ND	<1.0	<1.3	<1.0
03/02/2011	24.3		4.5	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.3	<1.0
03/02/2011	24.3		4.6	<2.0	<1.0	<2.0	<1.3	ND	<1.0	1.9	<1.0

(-) data not supplied

Kill date	Chilling time (h)	Chiller temperature (°C)	TVC (log cfu/cm^2)	Enterobacteriaceae (log cfu/cm^2)	E. coli (log cfu/cm^2)	Coliforms (log cfu/cm^2)	Staphylococcus aureus (log cfu/cm^2)	Salmonella (Detected or Not Detected)	Clostridia (log cfu/cm^2)	Pseudomonads (log cfu/cm^2)	Lactic Acid Bacteria (log cfu/g)
09/02/2011	6	Average temperature 4.2	3.5	2.0	<1.0	<2.0	<1.3	ND	<1.0	2.6	1.8
09/02/2011	6		3.5	<2.0	<1.0	<2.0	<1.3	ND	<1.0	1.9	1.0
09/02/2011	6		3.3	<2.0	<1.0	<2.0	<1.3	ND	<1.0	2.3	1.5
09/02/2011	6		3.5	<2.0	<1.0	<2.0	<1.3	ND	<1.0	2.1	1.5
09/02/2011	6		<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	2.2	1.3
09/02/2011	24.5	Average temperature 4.2	4.7	<2.0	<1.0	<2.0	<1.3	ND	<1.0	4.3	2.8
09/02/2011	24.5		5.0	2.6	<1.0	2.3	<1.3	ND	<1.0	3.8	3.4
09/02/2011	24.5		4.2	2.8	<1.0	2.7	<1.3	ND	<1.0	3.2	3.4
09/02/2011	24.5		4.2	<2.0	<1.0	<2.0	<1.3	ND	<1.0	2.9	2.2
09/02/2011	24.5		4.6	2.3	<1.0	<2.0	<1.3	ND	<1.0	2.8	2.8
17/02/2011		Average temperature 4.2	4.5	<2.0	<1.0	<2.0	<1.3	ND	<1.0	3.2	3.5
17/02/2011			5.0	2.3	<1.0	<2.0	<1.3	ND	<1.0	3.9	3.5
17/02/2011			4.4	2.3	<1.0	2.0	<1.3	ND	<1.0	3.6	2.7
17/02/2011			4.7	4.3	<1.0	2.0	<1.3	ND	<1.0	3.2	1.0
17/02/2011			4.6	4.4	<1.0	2.5	<1.3	ND	<1.0	3.5	1.3
21/02/2011		Average temperature 4.4	4.4	2.3	<1.0	2.5	<1.3	ND	<1.0	3.6	<1.0
21/02/2011			4.4	2.0	1.3	<2.0	<1.3	ND	1.7	3.8	<1.0
21/02/2011	20.35		4.0	<2.0	<1.0	2.0	<1.3	ND	1.3	>8.0	<1.0
21/02/2011			4.0	<2.0	<1.0	2.0	<1.3	ND	<1.0	3.6	<1.0
21/02/2011			4.4	<2.0	<1.0	<2.0	<1.3	ND	<1.0	3.8	<1.0
02/03/2011		Average temperature 3.6	3.8	<2.0	<1.0	<2.0	<1.3	ND	<1.0	3.4	-
02/03/2011			3.5	2.5	<1.0	<2.0	<1.3	ND	<1.0	2.5	-
02/03/2011	5 days		4.3	2.3	<1.0	<2.0	<1.3	ND	<1.0	3.6	-
02/03/2011			3.3	<2.0	<1.0	<2.0	<1.3	ND	<1.0	3.3	-
02/03/2011			4.7	<2.0	<1.0	<2.0	<1.3	ND	<1.0	3.6	-
09/03/2011		Average temperature 0.5	4.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	3.6
09/03/2011			4.3	<2.0	<1.0	2.0	<1.3	ND	<1.0	2.3	3.9
09/03/2011	5 days		3.6	<2.0	<1.0	<2.0	<1.3	ND	<1.0	2.8	3.9
09/03/2011			3.8	<2.0	1.3	2.0	<1.3	ND	<1.0	2.3	3.5
09/03/2011			4.4	<2.0	<1.0	2.6	<1.3	ND	<1.0	2.7	4.4
20/04/2011		Average temperature 0.9	4.7	3.1	1.0	3.3	<1.3	ND	<1.0	<1.0	4.4
20/04/2011			3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	2.2
20/04/2011	4 days		4.8	2.5	<1.0	2.8	<1.3	ND	<1.0	<1.0	3.9
20/04/2011			4.3	<2.0	<1.0	2.6	<1.3	ND	<1.0	<1.0	3.3
20/04/2011			4.5	2.5	<1.0	<2.0	<1.3	ND	<1.0	<1.0	4.2

(-) data not supplied

Table 21. Tracked pork primal/trim (hockmeat) data (data supplied by P4)

Kill date	Age (d)	Storage temperature (°C)	Vacuum packed (Y/N)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)	Salmonella (Detected or Not Detected)	Clostridia (log cfu/g)	Lactic Acid Bacteria (log cfu/g)	Pseudomonads (log cfu/g)
02/12/2010	7	Average temperature 3	Y	4.8	2.3	<1.0	<2.0	<1.3	ND	<1.0	<1.0	3.4
02/12/2010	7		Y	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
02/12/2010	7		Y	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
02/12/2010	7		Y	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
02/12/2010	7		Y	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
10/12/2010	5	Average temperature 12.0	Y	3.3	2.8	2.2	<2.0	<1.3	ND	<1.0	1.8	3.8
10/12/2010	5		Y	4.0	2.5	1.9	2.3	<1.3	ND	<1.0	1.8	3.3
10/12/2010	5		Y	>6.0	2.0	1.8	2.3	<1.3	ND	<1.0	1.8	3.1
10/12/2010	5		Y	4.0	2.3	2.3	2.0	<1.3	ND	<1.0	2.7	2.9
10/12/2010	5		Y	4.0	2.3	1.8	<2.0	<1.3	ND	<1.0	1.5	2.9
03/02/2011	8	Average temperature 11.6	Y	4.4	2.0	<1.0	2.3	<1.3	ND	<1.0	<1.0	<1.3
03/02/2011	8		Y	7.4	3.8	<1.0	4.1	<1.3	ND	<1.0	2.7	5.2
03/02/2011	8		Y	5.5	3.7	<1.0	4.1	<1.3	ND	<1.0	3.4	5.2
03/02/2011	8		Y	7.2	4.0	<1.0	4.2	<1.3	ND	<1.0	3.0	5.4
03/02/2011	8		Y	6.9	3.6	<1.0	3.9	<1.3	ND	<1.0	<1.0	<1.3
09/02/2011	7	Average temperature 10.3	Y	7.0	2.9	<1.0	2.0	<1.3	ND	<1.0	1.8	5.2
09/02/2011	7		Y	7.0	2.3	<1.0	<2.0	<1.3	ND	<1.0	2.1	3.0
09/02/2011	7		Y	6.8	<2.0	1.3	2.0	<1.3	ND	<1.0	<1.0	2.6
09/02/2011	7		Y	6.5	2.0	<1.0	<2.0	<1.3	ND	<1.0	1.5	2.9
09/02/2011	7		Y	6.1	<2.0	<1.0	2.0	<1.3	ND	<1.0	1.3	2.8
09/02/2011	8	Average temperature 10.8	Y	3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	2.2	1.6
09/02/2011	8		Y	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	1.9
09/02/2011	8		Y	4.3	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	1.5
09/02/2011	8		Y	4.2	<2.0	<1.0	<2.0	<1.3	ND	<1.0	1.6	2.3
09/02/2011	8		Y	3.5	<2.0	<1.0	2.0	<1.3	ND	<1.0	1.3	1.8
17/02/2011	8	Average temperature 11.9	Y	4.7	2.0	<1.0	2.0	<1.3	ND	<1.0	2.0	3.3
17/02/2011	8		Y	5.8	2.6	<1.0	3.3	<1.3	ND	<1.0	1.3	5.8
17/02/2011	8		Y	4.6	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	4.6
17/02/2011	8		Y	4.7	2.8	<1.0	2.6	<1.3	ND	<1.0	<1.0	4.6
17/02/2011	8		Y	5.2	3.3	<1.0	3.4	<1.3	ND	1.0	1.0	5.3
21/02/2011	8	Average temperature 11.0	Y	5.1	2.8	<1.0	2.0	<1.3	ND	<1.0	<1.0	3.5
21/02/2011	8		Y	4.0	2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	3.0
21/02/2011	8		Y	4.2	2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	3.0
21/02/2011	8		Y	3.7	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	2.7
21/02/2011	8		Y	4.3	2.6	<1.0	<2.0	<1.3	ND	<1.0	<1.0	3.2

Kill date	Age (d)	Storage temperature (°C)	Vacuum packed (Y/N)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)	Salmonella (Detected or Not Detected)	Clostridia (log cfu/g)	Lactic Acid Bacteria (log cfu/g)	Pseudomonads (log cfu/g)
02/03/2011	8	Average temperature 2.0	Y	5.6	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	3.2
02/03/2011	8		Y	5.4	2.0	1.3	<2.0	<1.3	ND	<1.0	<1.0	4.5
02/03/2011	8		Y	5.1	3.0	<1.0	3.0	<1.3	ND	<1.0	1.5	4.4
02/03/2011	8		Y	4.7	2.5	<1.0	2.0	<1.3	ND	<1.0	2.1	3.2
02/03/2011	8		Y	4.9	2.3	<1.0	2.0	<1.3	ND	<1.0	<1.0	4.6
09/03/2011	6	Average temperature 2.6	Y	5.3	3.4	<1.0	3.8	<1.3	ND	<1.0	1.3	4.0
09/03/2011	6		Y	3.9	<2.0	<1.0	2.0	<1.3	ND	<1.0	2.7	4.0
09/03/2011	6		Y	3.7	<2.0	<1.0	2.3	<1.3	ND	<1.0	2.6	3.9
09/03/2011	6		Y	3.7	<2.0	<1.0	2.0	<1.3	ND	<1.0	<1.0	3.4
09/03/2011	6		Y	4.0	2.0	<1.0	2.6	<1.3	ND	<1.0	2.3	3.7
20/04/2011	14	Average temperature 1.5	Y	5.4	3.2	1.0	2.5	<1.3	ND	<1.0	4.6	5.2
20/04/2011	14		Y	4.5	<2.0	<1.0	2.0	<1.3	ND	<1.0	1.6	3.8
20/04/2011	14		Y	5.8	2.7	<1.0	2.7	<1.3	ND	<1.0	1.7	5.1
20/04/2011	14		Y	4.4	2.7	<1.0	2.7	<1.3	ND	<1.0	2.2	4.4
20/04/2011	14		Y	4.6	2.3	<1.0	2.7	<1.3	ND	<1.0	1.8	4.5
22/07/2011	5	Average temperature 0.5	Y	3.9	<1.0	<1.0	<1.0	<1.3	ND	<1.0	1.5	2.2
22/07/2011	5		Y	4.4	<1.0	<1.0	2.1	<1.3	ND	<1.0	1.6	2.5
22/07/2011	5		Y	3.0	<1.0	<1.0	1.8	<1.3	ND	<1.0	<1.0	2.1
22/07/2011	5		Y	3.5	<1.0	<1.0	1.8	<1.3	ND	<1.0	1.5	3.3
22/07/2011	5		Y	3.3	<1.0	<1.0	<1.0	<1.3	ND	<1.0	1.3	2.1
01/08/2011	3	Average temperature 0.2	Y	4.7	1.5	<1.0	2.6	<1.3	ND	<1.0	2.0	3.1
01/08/2011	3		Y	5.0	3.2	<1.0	3.3	<1.3	ND	<1.0	2.4	4.1
01/08/2011	3		Y	4.2	1.0	<1.0	1.7	<1.3	ND	<1.0	2.4	3.8
01/08/2011	3		Y	5.5	2.2	<1.0	1.8	<1.3	ND	<1.0	3.0	4.7
01/08/2011	3		Y	4.7	2.7	<1.0	2.3	<1.3	ND	<1.0	2.4	4.1
03/08/2011	5	Average temperature 0.6	Y	3.1	<1.0	<1.0	1.8	<1.3	ND	<1.0	<1.0	3.5
03/08/2011	5		Y	3.1	1.8	<1.0	2.1	<1.3	ND	<1.0	<1.0	3.3
03/08/2011	5		Y	4.1	2.4	<1.0	3.0	<1.3	ND	<1.0	<1.0	4.5
03/08/2011	5		Y	4.4	2.3	<1.0	2.4	<1.3	D	<1.0	<1.0	4.1
03/08/2011	5		Y	3.6	2.0	<1.0	1.3	<1.3	ND	<1.0	<1.0	3.6
25/08/2011	6	Average temperature 0.4	Y	4.8	2.7	<1.0	2.7	<1.3	ND	<1.0	1.5	3.3
25/08/2011	6		Y	4.7	2.1	<1.0	2.6	<1.3	ND	<1.0	<1.0	3.4
25/08/2011	6		Y	4.1	1.5	<1.0	1.9	<1.3	ND	<1.0	<1.0	2.6
25/08/2011	6		Y	4.5	2.5	<1.0	2.5	<1.3	ND	<1.0	<1.0	3.4
25/08/2011	6		Y	4.5	2.7	<1.0	2.8	<1.3	ND	<1.0	<1.0	3.8
01/09/2011	4	Average temperature 0.5	Y	5.1	3.4	3.8	3.3	<1.3	ND	<1.0	2.7	3.8
01/09/2011	4		Y	6.3	5.3	3.6	5.3	<1.3	ND	3.3	3.2	4.5
01/09/2011	4		Y	3.9	2.8	2.7	2.6	<1.3	ND	<1.0	1.6	2.6
01/09/2011	4		Y	5.0	3.9	3.9	3.7	<1.3	ND	<1.0	1.8	3.2
01/09/2011	4		Y	4.6	3.1	2.7	2.6	<1.3	ND	1.0	1.5	2.7

Kill date	Age (d)	Storage temperature (°C)	Vacuum packed (Y/N)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)	Salmonella (Detected or Not Detected)	Clostridia (log cfu/g)	Lactic Acid Bacteria (log cfu/g)	Pseudomonads (log cfu/g)
01/09/2011	5	Average temperature 0.4	Y	4.5	2.1	<1.0	1.9	<1.3	ND	<1.0	<1.0	2.3
01/09/2011	5		Y	5.8	1.5	<1.0	1.5	<1.3	ND	<1.0	<1.0	2.8
01/09/2011	5		Y	4.9	2.3	<1.0	2.1	<1.3	ND	<1.0	<1.0	4.0
01/09/2011	5		Y	4.0	1.9	<1.0	2.0	<1.3	ND	<1.0	<1.0	3.4
01/09/2011	5		Y	3.9	<1.0	<1.0	<1.0	<1.3	ND	<1.0	<1.0	3.4
08/09/2011	6	Average temperature 0.6	Y	5.0	1.8	<1.0	2.6	<1.3	ND	1.6	<1.0	4.3
08/09/2011	6		Y	4.9	2.0	<1.0	3.1	<1.3	ND	<1.0	<1.0	4.0
08/09/2011	6		Y	5.1	2.4	<1.0	1.7	<1.3	ND	<1.0	<1.0	3.8
08/09/2011	6		Y	5.6	2.0	<1.0	2.5	<1.3	ND	<1.0	<1.0	4.5
08/09/2011	6		Y	4.8	2.4	<1.0	1.3	<1.3	ND	<1.0	<1.0	4.0

Table 22. Tracked pork mince data (data supplied by P4)

Kill date	Age (d)	Vacuum packed (Y/N)	Raw material temperature (°C)	Mince temperature (°C)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)	Salmonella (Detected or Not Detected)	Clostridia (log cfu/g)	Lactic Acid Bacteria (log cfu/g)	Pseudomonads (log cfu/g)
02/12/2010	7	Y	3.8	4.0	4.3	2.3	1.0	2.5	<1.3	ND	<1.0	<1.0	3.4
02/12/2010	7	Y	3.6	3.9	4.3	2.5	<1.0	2.3	<1.3	ND	<1.0	<1.0	3.2
02/12/2010	7	Y	3.3	4.1	3.7	2.0	<1.0	3.0	<1.3	ND	1.0	<1.0	3.5
02/12/2010	7	Y	3.6	4.2	4.4	<2.0	<1.0	2.0	<1.3	ND	<1.0	<1.0	4.4
02/12/2010	7	Y	3.8	4.1	4.2		<1.0	<2.0	<1.3	ND	<1.0	<1.0	3.5
10/12/2010	6	N	1.4	3.0	4.5	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	3.9
10/12/2010	6	N	1.0	3.3	4.9	2.8	<1.0	<2.0	<1.3	ND	<1.0	4.3	3.3
10/12/2010	6	N	1.2	3.0	4.3	<2.0	<1.0	<2.0	<1.3	ND	<1.0	3.9	4.2
10/12/2010	6	N	0.9	2.8	4.8	<2.0	<1.0	<2.0	<1.3	ND	<1.0	1.3	3.1
10/12/2010	6	N	1.1	3.2	3.5	2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	4.0
03/02/2011	8	Y	-0.4	2.5	4.5	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
03/02/2011	8	Y	-0.6	2.8	3.7	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
03/02/2011	8	Y	-0.4	2.6	3.8	2.3	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
03/02/2011	8	Y	-0.7	2.6	4.3	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
03/02/2011	8	Y	-0.3	2.8	4.4	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3

Kill date	Age (d)	Vacuum packed (Y/N)	Raw material temperature (°C)	Mince temperature (°C)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)	Salmonella (Detected or Not Detected)	Clostridia (log cfu/g)	Lactic Acid Bacteria (log cfu/g)	Pseudomonads (log cfu/g)
09/02/2011	7	Y	0.2	5.1	4.3	2.6	<1.0	<2.0	<1.3	ND	<1.0	<1.0	3.8
09/02/2011	7	Y	0.1	4.6	4.6	<2.0	<1.0	<2.0	<1.3	ND	<1.0	1.3	2.9
09/02/2011	7	Y	-0.1	4.7	4.4	<2.0	<1.0	<2.0	<1.3	ND	<1.0	1.3	2.7
09/02/2011	7	Y	-0.1	4.5	4.3	2.3	<1.0	<2.0	<1.3	ND	<1.0	<1.0	2.4
09/02/2011	7	Y	0.3	4.8	4.5	2.0	<1.0	2.3	<1.3	ND	<1.0	<1.0	2.3
09/02/2011	8	Y	0.1	4.3	4.7	<2.0	<1.0	<2.0	<1.3	ND	<1.0	2.3	4.4
09/02/2011	8	Y	0.5	4.8	4.3	2.0	1.3	2.3	<1.3	ND	<1.0	1.3	2.8
09/02/2011	8	Y	0.7	4.9	5.1	2.0	<1.0	<2.0	<1.3	ND	<1.0	2.6	2.6
09/02/2011	8	Y	0.5	4.7	5.0	2.8	<1.0	<2.0	<1.3	ND	<1.0	2.1	2.9
09/02/2011	8	Y	0.2	4.8	4.7	2.8	<1.0	2.0	<1.3	ND	<1.0	1.8	2.4
17/02/2011	8	Y	1.9	5.3	5.0	3.0	1.0	2.7	<1.3	ND	<1.0	1.3	4.4
17/02/2011	8	Y	1.6	4.6	5.0	3.0	<1.0	2.5	<1.3	ND	<1.0	<1.0	2.2
17/02/2011	8	Y	0.4	5.1	5.0	2.5	<1.0	2.7	<1.3	ND	<1.0	<1.0	1.6
17/02/2011	8	Y	1.2	5	5.1	2.6	<1.0	2.0	<1.3	ND	<1.0	<1.0	1.9
17/02/2011	8	Y	0.9	5.3	4.7	2.0	<1.0	2.5	<1.3	ND	<1.0	<1.0	1.9
21/02/2011	8	Y	0.9	3.8	4.7	2.3	<1.0	2.5	<1.3	ND	<1.0	<1.0	4.2
21/02/2011	8	Y	0.7	4.1	4.6	2.6	<1.0	2.0	<1.3	ND	<1.0	<1.0	4.1
21/02/2011	8	Y	0.7	4.4	4.5	4.5	<1.0	<2.0	<1.3	ND	<1.0	<1.0	4.2
21/02/2011	8	Y	0.5	3.9	4.6	2.8	<1.0	2.8	<1.3	ND	<1.0	<1.0	4.3
21/02/2011	8	Y	0.8	4.2	4.5	3.2	<1.0	2.3	<1.3	ND	<1.0	<1.0	4.1
02/03/2011	8	Y	1.6	5.2	4.2	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	3.5
02/03/2011	8	Y	1.2	5.4	4.9	2.5	1.0	<2.0	<1.3	ND	<1.0	2.3	3.2
02/03/2011	8	Y	1.3	5	5.2	2.5	<1.0	<2.0	<1.3	ND	<1.0	2.7	3.5
02/03/2011	8	Y	1	5.4	4.3	2.0	1.0	<2.0	<1.3	ND	<1.0	1.7	3.3
02/03/2011	8	Y	1.4	5.6	4.2	2.5	<1.0	<2.0	<1.3	ND	<1.0	1.6	3.3
09/03/2011	6	Y	2.7	5.2	4.2	3.5	1.0	4.0	<1.3	ND	<1.0	2.2	4.4
09/03/2011	6	Y	2.4	5.5	4.9	2.0	<1.0	4.1	<1.3	ND	<1.0	2.8	4.4
09/03/2011	6	Y	2	4.9	4.7	2.0	1.0	3.8	<1.3	ND	<1.0	2.7	4.3
09/03/2011	6	Y	1.8	5.6	6.0	3.4	<1.0	4.1	<1.3	ND	<1.0	2.2	5.6
09/03/2011	6	Y	2.1	5.3	6.5	3.3	<1.0	3.2	<1.3	ND	<1.0	<1.0	3.8

Kill date	Age (d)	Vacuum packed (Y/N)	Raw material temperature (°C)	Mince temperature (°C)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)	Salmonella (Detected or Not Detected)	Clostridia (log cfu/g)	Lactic Acid Bacteria (log cfu/g)	Pseudomonads (log cfu/g)
22/07/2011	11	N	0.1	2.2	25	4.3	3.0	1.0	2.8	ND	<1.0	<1.0	3.2
22/07/2011	11	N	-0.2	1.9	25	4.1	2.5	<1.0	2.3	ND	<1.0	<1.0	2.6
22/07/2011	11	N	-0.5	1.7	25	4.1	2.9	<1.0	2.7	ND	<1.0	<1.0	2.9
22/07/2011	11	N	-0.6	2.3	25	4.4	2.6	<1.0	2.8	ND	<1.0	<1.0	3.0
22/07/2011	11	N	-0.4	1.8	25	4.1	2.7	1.0	2.8	ND	<1.0	<1.0	2.9
01/08/2011	4	N	1.5	2.9	25	4.7	2.2	2.0	2.6	ND	<1.0	<1.0	2.0
01/08/2011	4	N	0.8	2.5	25	4.5	2.2	1.7	2.5	ND	<1.0	<1.0	<1.0
01/08/2011	4	N	1.7	2.7	25	4.4	1.6	1.9	3.0	ND	<1.0	<1.0	<1.0
01/08/2011	4	N	1.2	2.5	25	4.6	2.6	1.5	1.8	ND	<1.0	<1.0	<1.0
01/08/2011	4	N	1.5	2.5	25	4.6	2.6	1.6	1.3	ND	<1.0	<1.0	<1.0
03/08/2011	8	N	0.2	2.8	25	4.1	2.4	<1.0	2.5	ND	<1.0	<1.0	<1.0
03/08/2011	8	N	0.5	2.4	25	4.9	3.2	<1.0	3.4	ND	<1.0	<1.0	<1.0
03/08/2011	8	N	0.7	2.5	25	<2.0	3.1	<1.0	3.3	ND	<1.0	<1.0	<1.0
03/08/2011	8	N	0.4	2.5	25	4.9	2.5	<1.0	2.7	ND	<1.0	<1.0	<1.0
03/08/2011	8	N	0.5	2.4	25	4.8	3.2	1.0	3.3	ND	<1.0	<1.0	2.5
25/08/2011	11	N	-0.1	1.7	25	4.5	2.5	<1.0	3.0	ND	<1.0	<1.0	1.0
25/08/2011	11	N	-0.7	1.9	25	4.6	2.3	1.0	2.6	ND	<1.0	<1.0	2.0
25/08/2011	11	N	-0.6	2.1	25	5.3	2.4	<1.0	2.9	ND	<1.0	<1.0	1.6
25/08/2011	11	N	-0.7	1.8	25	4.6	2.2	<1.0	2.5	ND	<1.0	<1.0	1.5
25/08/2011	11	N	-0.5	1.9	25	4.6	2.0	<1.0	2.8	ND	<1.0	<1.0	1.5
01/09/2011	11	N	-0.5	1.5	25	6.0	1.3	<1.0	1.6	ND	<1.0	<1.0	<1.0
01/09/2011	11	N	-0.3	1.7	25	5.0	1.0	<1.0	<1.0	ND	<1.0	<1.0	<1.0
01/09/2011	11	N	-0.1	1.4	25	5.7	1.0	<1.0	2.3	ND	<1.0	<1.0	<1.0
01/09/2011	11	N	-0.5	1.4	25	5.1	1.3	<1.0	<1.0	ND	<1.0	<1.0	<1.0
01/09/2011	11	N	-0.2	1.2	25	4.4	1.0	<1.0	2.1	ND	<1.0	<1.0	<1.0
01/09/2011	13	N	0.7	1.1	25	6.4	1.6	<1.0	<1.0	ND	<1.0	<1.0	2.4
01/09/2011	13	N	0.4	0.9	25	6.1	2.5	<1.0	2.5	ND	<1.0	<1.0	2.6
01/09/2011	13	N	0.6	1.4	25	5.7	1.7	<1.0	2.4	ND	<1.0	<1.0	3.2
01/09/2011	13	N	0.7	1.2	25	6.3	1.7	<1.0	2.3	ND	<1.0	<1.0	2.3
01/09/2011	13	N	0.5	1	25	6.7	1.7	<1.0	2.5	ND	<1.0	<1.0	3.3
08/09/2011	7	N	0.8	2.1	25	5.0	2.2	<1.0	2.3	ND	<1.0	<1.0	2.8
08/09/2011	7	N	0.4	2.4	25	5.0	2.9	<1.0	2.8	ND	<1.0	<1.0	2.8
08/09/2011	7	N	0.6	2.6	25	5.1	2.6	<1.0	2.6	ND	<1.0	<1.0	3.5
08/09/2011	7	N	0.5	2.5	25	4.9	2.5	<1.0	2.3	ND	<1.0	<1.0	3.4
08/09/2011	7	N	0.5	2.9	25	5.3	2.7	<1.0	2.7	ND	<1.0	<1.0	3.3

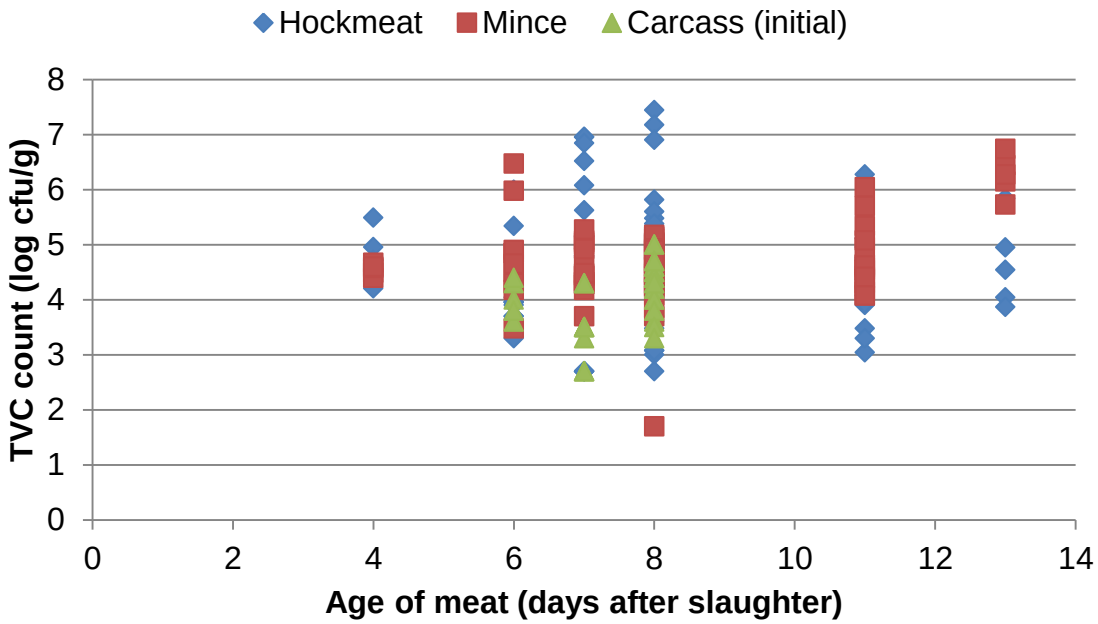

Figure 52. Comparison of reported TVCs on carcass, hockmeat and mince produced from pork (16 batches, 5 replicates per batch; 8 linked batches with carcass counts) related to age of meat prior to mincing (data supplied by P4)

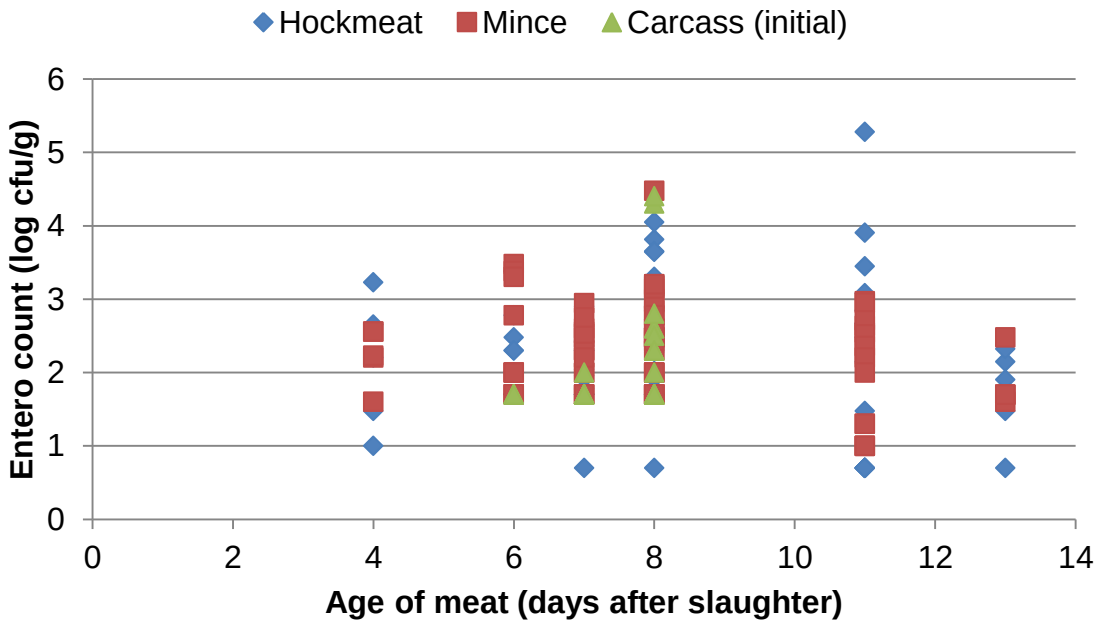

Figure 53. Comparison of reported Enterobacteriaceae counts on hockmeat and mince produced from pork (16 batches, 5 replicates per batch; 8 linked batches with carcass counts) related to age of meat prior to mincing (data supplied by P4)

The following tracked data was measured according to the project protocol (Appendix 4) and provided by M4 for pork. An overall comparison of counts is shown in Table 23. Matched primal/trim and mince microbiological counts and process parameters are shown in Table 24. A comparison of TVCs on matched groups of primal/trim and mince against age of meat is

shown in Figure 54. Overall, the data show a very similar range of counts irrespective of age of meat at mincing.

Table 23. Overall comparison of pork mince data (data supplied by M4)

	Kill date	Age (d)	TVC (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)
Overall	Min	3.0	1.7	0.7	0.7	0.7
	Max	15.0	6.8	2.7	4.2	0.7
	Mean	7.7	5.0	1.0	2.6	0.7
	Number	235	235	235	46	47
Aged >6 days	Min	7.0	1.7	0.7	0.7	0.7
	Max	15.0	6.8	2.6	4.2	0.7
	Mean	9.3	5.1	1.0	2.6	0.7
	Number	143	143	143	29	30
Unaged <6 days	Min	3.0	1.7	0.7	0.7	0.7
	Max	6.0	6.7	2.7	3.6	0.7
	Mean	5.1	4.9	1.1	2.5	0.7
	Number	92	92	92	17	17

Table 24. Tracked pork primal/trim and mince data (data supplied by M4)

Kill date	Age (d)	Vacuum packed (Y/N)	Raw material temperature (°C)	Mince temperature (°C)	Sample	TVC (log cfu/g)	Coliforms (log cfu/g)	Sample	TVC (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)
10/03/2011	14	Y				4.7	2.9		3.7	<1.0	<1.0	<1.0
10/03/2011	14	Y	0.1 - 1.0	2.5 - 3.0	98 vl B/L Shoulder	4.5	2.6	H/E Mince	4.7	<1.0		
10/03/2011	14	Y				3.8	1.6		4.6	1.0		
10/03/2011	14	Y				5.5	3.6		4.9	<1.0		
10/03/2011	14	Y				4.6	2.0		4.5	<1.0		
21/03/2011	8	N				5.6	1.3		3.7	<1.0	2.4	<1.0
21/03/2011	8	N	0.1 - 1.0	2.5 - 3.0	Trim	5.7	3.7	H/E Mince	6.4	1.5		
21/03/2011	8	N				3.7	1.0		6.0	1.7		
24/03/2011	5	Y			98 vl Shell	4.6	2.4		6.1	1.9		
24/03/2011	5	Y				6.0	3.7		6.1	1.7		
21/03/2011	10	Y				3.3	1.8		6.6	<1.0	3.6	<1.0
21/03/2011	10	Y	0.1 - 1.0	2.5 - 3.0	98 vl shell	4.2	3.2	Std Mince	6.6	<1.0		
21/03/2011	10	Y				4.4	2.5		6.4	<1.0		
21/03/2011	10	Y				5.2	2.2		6.8	<1.0		
21/03/2011	10	Y				4.5	1.9		6.4	<1.0		
24/03/2011	13	N			Trim	5.0	3.2		3.7	1.5	1.0	<1.0
25/03/2011	12	N	0.0 - 1.0	2.5 - 3.0		5.0	1.5	H/E Mince	3.6	1.5		
01/04/2011	5	Y				2.5	1.0		2.7	2.0		
01/04/2011	5	Y			99 vl shoulder	5.0	1.3		1.7	<1.0		
01/04/2011	5	Y				2.8	1.0		1.7	<1.0		
29/03/2011	8	N				2.7	1.0		5.7	2.3	3.6	<1.0
27/03/2011	10	N	0.0 - 1.0	2.5 - 3.0	Trim	4.6	1.3	Std Mince	6.8	2.3		
24/03/2011	13	Y				4.4	1.5		5.6	2.3		
25/03/2011	12	Y			99 vl shoulder	3.6	1.0		6.1	2.4		
25/03/2011	12	Y				4.3	1.5		5.8	2.1		
06/04/2011	7	Y				5.5	4.0		3.7	<1.0	<1.0	<1.0
06/04/2011	7	Y	0.0 - 1.0	2.5 - 3.0	98 vl shell 5 P+1	5.5	3.4	H/E Mince	3.6	<1.0		
06/04/2011	7	Y				5.5	3.8		3.5	<1.0		
06/04/2011	7	Y				3.7	1.3		2.7	1.0		
06/04/2011	7	Y				5.0	3.3		3.1	<1.0		
07/04/2011	6	Y			98 vl Shell	3.6	1.7		6.1	<1.0	2.5	<1.0
07/04/2011	6	Y	0.0 - 1.0	2.5 - 3.0		4.6	3.2	Std Mince	6.3	1.3		
07/04/2011	9	N				3.2	1.3		6.3	1.3		
07/04/2011	6	N			Trim	3.4	1.7		6.2	1.3		
07/04/2011	6	N				3.5	<1.0		6.5	1.0		
07/04/2011	11	Y				3.8	1.6		6.2	<1.0	3.6	<1.0
07/04/2011	11	Y	0.1 - 1.0	2.5 - 3.0	98 vl Shell	4.0	<1.0	Std Mince	6.3	<1.0		
07/04/2011	11	Y				3.7	1.9		6.3	<1.0		
07/04/2011	11	Y				3.3	1.3		6.7	<1.0		
07/04/2011	11	Y				4.3	1.9		6.3	<1.0		

Kill date	Age (d)	Vacuum packed (Y/N)	Raw material temperature (°C)	Mince temperature (°C)	Sample	TVC (log cfu/g)	Coliforms (log cfu/g)	Sample	TVC (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)
13/04/2011	7	Gas	0.1 - 1.0	2.5 - 3.0	98 vl Shell	4.4	<1.0	H/E Mince	4.8	<1.0	1.9	<1.0
13/04/2011	7	Gas				4.2	1.0		1.7	<1.0		
13/04/2011	7	Gas				4.0	2.7		3.8	<1.0		
13/04/2011	7	Gas				3.6	1.9		3.7	<1.0		
13/04/2011	7	Gas				4.1	1.5		1.7	<1.0		
18/04/2011	8	Gas	0.1 – 1.0	2.5 – 3.0	Trim	6.7	3.8	H/E Mince	6.4	<1.0	3.6	<1.0
18/04/2011	8	Y			98 vl shell	3.7	<1.0		6.4	<1.0		
18/04/2011	8	Y				2.7	<1.0		6.5	<1.0		
18/04/2011	8	Y				4.0	2.7		6.6	<1.0		
18/04/2011	8	Y				2.7	<1.0		6.4	<1.0		
18/04/2011	8	Gas	0.1 – 1.0	2.5 – 3.0	Trim	4.8	2.0	Std Mince	6.4	<1.0	4.2	<1.0
14/04/2011	12	Y				5.6	<1.0		6.4	<1.0		
18/04/2011	8	Gas			98 vl shell	4.7	<1.0		5.9	<1.0		
18/04/2011	8	Y			Trim	5.9	4.0		6.2	<1.0		
18/04/2011	8	Y				6.4	4.8		6.4	<1.0		
27/04/2011	7	Y	0.1 – 1.0	2.5 – 3.0	98 vl shell	<2.0	2.4	H/E Mince	3.1	<1.0	<1.0	<1.0
27/04/2011	7	Y				2.7	1.6		4.8	<1.0		
27/04/2011	7	Y				<2.0	<1.0		4.3	<1.0		
27/04/2011	7	Y				<2.0	1.8		4.6	<1.0		
27/04/2011	7	Y				4.4	2.1		3.7	<1.0		
28/04/2011	8	Gas	0.1 – 1.0	2.5 – 3.0	Trim	4.4	2.0	Std Mince	6.7	<1.0	3.6	<1.0
28/04/2011	8	Gas				4.7	1.0		6.3	<1.0		
28/04/2011	8	Gas				3.8	<1.0		6.6	<1.0		
28/04/2011	8	Gas				4.4	<1.0		6.6	<1.0		
28/04/2011	8	Gas				4.8	1.8		6.6	<1.0		
29/04/2011	11	Y	0.1 - 1.0	2.5 - 3.0	98 vl shell	4.0	1.5	H/E Mince	5.3	<1.0	3.5	<1.0
29/04/2011	11	Y				2.7	1.0		5.4	<1.0		
29/04/2011	11	Y				3.4	1.0		4.7	<1.0		
29/04/2011	11	Y				3.8	1.8		5.5	<1.0		
29/04/2011	11	Y				<2.0	<1.0		5.4	<1.0		
29/04/2011	12	Y	0.1 - 1.0	2.5 - 3.0	Trim	5.2	3.3	Std Mince	4.4	1.3	4.1	<1.0
29/04/2011	12	Y				5.0	2.1		5.9	<1.0		
29/04/2011	12	Y				4.4	3.0		5.7	<1.0		
29/04/2011	12	Y				3.8	3.7		5.6	1.0		
29/04/2011	12	Y				4.9	2.7		5.6	<1.0		
10/05/2011	8	Y	0.1 - 1.0	2.5 - 3.0	98 vl shell	3.4	1.7	H/E Mince	5.6	<1.0	3.0	<1.0
10/05/2011	8	Y				5.0	2.6		5.5	<1.0		
10/05/2011	8	Y				5.8	3.5		5.5	<1.0		
10/05/2011	8	Y				4.8	2.8		5.6	<1.0		
10/05/2011	8	Y				5.5	2.6		5.5	<1.0		

Kill date	Age (d)	Vacuum packed (Y/N)	Raw material temperature (°C)	Mince temperature (°C)	Sample	TVC (log cfu/g)	Coliforms (log cfu/g)	Sample	TVC (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)
18/05/2011	7	Gas	0.1 - 1.0	2.5 - 3.0	Trim	5.5	2.7	Std Mince	6.7	1.0	4.0	<1.0
18/05/2011	7	Gas				4.4	3.6		6.7	<1.0		
18/05/2011	7	Gas				5.6	<1.0		6.7	<1.0		
18/05/2011	7	Gas				5.6	<1.0		6.8	1.0		
18/05/2011	7	Gas				6.7	4.0		6.8	<1.0		
24/05/2011	7	Y	0.1 – 1.0	2.5 – 3.0	98 vl shell	3.6	3.5	H/E Mince	5.5	<1.0	4.0	<1.0
24/05/2011	7	Y				2.8	1.0		6.1	<1.0		
24/05/2011	7	Y				3.0	1.6		5.6	<1.0		
23/05/2011	8	Gas			Trim	3.3	2.1		5.0	<1.0		
23/05/2011	8	Gas				4.5	3.5		4.5	<1.0		
27/05/2011	6	Gas	0.1 – 1.0	2.5 – 3.0	Trim	4.7	2.6	Std Mince	5.7	<1.0	2.8	<1.0
27/05/2011	6	Gas				4.7	2.2		5.6	1.0		
26/05/2011	7	Gas				5.1	2.2		5.7	1.0		
26/05/2011	7	Gas				5.3	2.0		6.3	1.0		
26/05/2011	7	Gas				5.5	2.2		5.4	<1.0		
01/06/2011	5	Y	0.1 – 1.0	2.5 – 3.0	98 vl shell	2.7	1.5	H/E Mince	4.7	1.5	1.5	<1.0
01/06/2011	5	Y				<2.0	<1.0		6.5	1.9		
01/06/2011	5	Y				2.8	1.0		4.7	2.0		
29/05/2011	5	Y				<2.0	<1.0		5.1	2.1		
29/05/2011	5	Y				<2.0	1.0		4.4	1.6		
31/05/2011	6	Gas	0.1 – 1.0	2.5 – 3.0	Trim	4.7	1.9	Std Mince	6.4	1.0	3.5	<1.0
31/05/2011	6	Gas				4.0	2.8		5.8	1.0		
31/05/2011	6	Gas				3.3	2.0		5.7	<1.0		
31/05/2011	6	Gas				4.9	3.0		5.7	<1.0		
31/05/2011	6	Gas				4.1	1.6		6.0	<1.0		
08/06/2011	5	Gas	0.1 – 1.0	2.5 – 3.0	Trim	5.7	4.2	H/E Mince	5.1	1.5	2.7	<1.0
07/06/2011	6	Y			98 vl shell	4.0	3.9		4.7	1.3		
07/06/2011	6	Y				3.8	2.2		5.0	1.0		
07/06/2011	6	Y				3.9	3.5		4.8	1.3		
07/06/2011	6	Y				3.5	2.7		5.6	1.3		
06/06/2011	10	Gas	0.1 – 1.0	2.5 – 3.0	Trim	4.7	1.9	Std Mince	4.8	1.0	2.0	<1.0
06/06/2011	10	Gas				4.8	2.0		4.5	<1.0		
06/06/2011	10	Gas				5.7	2.4		4.1	<1.0		
09/06/2011	10	Gas				4.8	3.0		5.0	<1.0		
09/06/2011	10	Gas				5.4	3.8		5.0	1.0		
10/06/2011	10	Y	0.1 – 1.0	2.5 – 3.0	98 vl shell	4.1	1.5	H/E Mince	3.9	1.0	2.0	<1.0
10/06/2011	10	Y				4.5	1.7		4.0	<1.0		
10/06/2011	10	Y				4.1	2.4		3.7	1.3		
10/06/2011	10	Y				<2.0	1.0		3.9	1.0		
10/06/2011	10	Y				5.1	3.5		3.9	1.0		

Kill date	Age (d)	Vacuum packed (Y/N)	Raw material temperature (°C)	Mince temperature (°C)	Sample	TVC (log cfu/g)	Coliforms (log cfu/g)	Sample	TVC (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)
15/06/2011	8	Gas	0.1 – 1.0	2.5 – 3.0	Trim	4.3	<1.0	Std Mince	5.7	<1.0	2.8	<1.0
15/06/2011	8	Gas				3.2	1.0		5.6	<1.0		
20/06/2011	3	Y			98 vl shell	3.6	1.6		6.7	<1.0		
20/06/2011	3	Y				3.0	<1.0		6.3	<1.0		
20/06/2011	3	Y				<2.0	<1.0		5.6	<1.0		
17/06/2011	11	Y	0.1 – 1.0	2.5 – 3.0	98 vl shell	4.7	3.5	H/E Mince	6.2	1.6	3.5	<1.0
17/06/2011	11	Y				3.9	1.0		5.9	<1.0		
17/0620/11	11	Y				4.4	1.5		4.5	1.6		
17/0620/11	11	Y				4.7	3.1		4.3	2.4		
17/06/2011	11	Y				6.8	2.9		4.3	2.5		
-	-	-	-	2.5 – 3.0	-	-	-	H/E Mince	5.3	<1.0	2.1	<1.0
-	-	-				-	-		6.0	<1.0		
-	-	-				-	-		5.9	<1.0		
-	-	-				-	-		4.9	<1.0		
-	-	-				-	-		5.3	<1.0		
22/06/2011	13	Y	0.1 - 1.0	2.5 - 3.0	98VL Shoulder	2.9	2.4	Std Mince	5.7	2.6		<1.0
22/06/2011	13	Y				5.0	3.8		5.9	2.4		
22/06/2011	13	Gas			Trim	4.2	1.8		5.6	2.3		
29/06/2011	6	Gas				5.9	2.1		5.2	2.7		
29/06/2011	6	Gas				4.2	1.8		5.7	2.5		
08/07/2011	5	Y	0.1 - 1.0	2.5 - 3.0	98VL Shell	3.4	<1.0	H/E Mince	4.2	<1.0	2.7	<1.0
08/07/2011	5	Y				3.1	<1.0		3.6	<1.0		
08/07/2011	5	Y				<2.0	<1.0		3.9	<1.0		
08/07/2011	5	Y				4.0	<1.0		4.1	<1.0		
08/07/2011	5	Y				3.4	<1.0		4.0	<1.0		
08/07/2011	5	Y	0.1 – 1.0	2.5 – 3.0	98VL Shell	5.4	<1.0	Std Mince	5.6	1.5	3.4	<1.0
08/07/2011	5	Y				4.1	<1.0		5.0	<1.0		
08/07/2011	5	Y				5.5	<1.0		5.8	<1.0		
06/07/2011	7	Gas			Trim	3.7	<1.0		5.0	<1.0		
07/07/2011	6	Gas			D/meat	5.6	<1.0		5.5	<1.0		
11/07/2011	8	Y	0.1 – 1.0	2.5 – 3.0	98 vl shell	3.7	2.7	H/E Mince	4.0	<1.0	2.4	<1.0
11/07/2011	8	Y				2.7	2.1		4.1	<1.0		
11/07/2011	8	Y				3.1	2.3		3.9	<1.0		
11/07/2011	8	Y				2.8	2.7		4.0	<1.0		
11/07/2011	8	Y				3.4	2.3		3.8	<1.0		
18/07/2011	3	Gas	0.1 – 1.0	2.5 – 3.0	Trim	5.3	2.8	Std Mince	5.5	<1.0	3.6	<1.0
18/07/2011	3	Gas				4.8	2.3		5.5	1.7		
18/07/2011	3	Gas				4.8	3.6		5.5	1.7		
12/07/2011	9	Gas				4.3	2.7		5.1	1.5		
15/07/2011	6	Gas			98 vl shell	3.7	2.2		5.5	<1.0		

(-) data not supplied

Kill date	Age (d)	Vacuum packed (Y/N)	Raw material temperature (°C)	Mince temperature (°C)	Sample	TVC (log cfu/g)	Coliforms (log cfu/g)	Sample	TVC (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)
25/07/2011	10	Y	0.1 – 1.0	-	98 vl shell	3.8	2.4	H/E Mince	3.7	<1.0	<1.0	<1.0
25/07/2011	10	Y				4.5	3.1		5.6	1.3		
25/07/2011	10	Y				4.6	2.7		4.9	<1.0		
25/07/2011	10	Y				4.8	1.8		3.9	1.5		
25/07/2011	10	Y				3.9	2.3		3.7	<1.0		
02/08/2011	8	Y	0.1 – 1.0	2.5 – 3.0	98 vl shell	4.5	2.3	H/E Mince	4.2	<1.0	<1.0	<1.0
02/08/2011	8	Y				3.9	1.7		4.2	<1.0		
02/08/2011	8	Y				4.5	2.7		4.3	<1.0		
02/08/2011	8	Y				4.6	3.0		4.1	<1.0		
02/08/2011	8	Y				3.8	2.2		4.8	<1.0		
12/08/2011	5	Y	0.1 – 1.0	2.5 – 3.0	98 vl shell	4.1	2.2	Std Mince	5.0	<1.0	2.7	<1.0
12/08/2011	5	Y				3.7	2.3		4.6	<1.0		
12/08/2011	5	Y				3.8	2.1		5.3	<1.0		
12/08/2011	5	Y				3.2	2.1		5.4	<1.0		
12/08/2011	5	Y			Trim	4.2	2.1		5.5	<1.0		
15/08/2011	3	Y	0.1 – 1.0	2.5 – 3.0	98 vl shell	<2.0	<1.0	H/E Mince	4.1	<1.0	<1.0	<1.0
15/08/2011	3	Y				3.0	2.0		4.1	<1.0		
15/08/2011	3	Y				<2.0	<1.0		3.9	<1.0		
15/08/2011	3	Y				<2.0	<1.0		3.8	<1.0		
15/08/2011	3	Y				3.1	1.9		4.1	<1.0		
17/08/2011	6	Y	0.1 – 1.0	2.5 – 3.0	98 vl shell	3.4	2.2	H/E Mince	3.3	<1.0	2.4	<1.0
17/08/2011	6	Gas				2.8	2.2		3.6	<1.0		
17/08/2011	6	Gas			LMC	3.1	<1.0		3.6	<1.0		
17/08/2011	6	Gas				3.4	2.2		4.3	<1.0		
17/08/2011	6	Gas				3.5	2.8		3.3	<1.0		
22/08/2011	3	Y	0.1 – 1.0	2.5 – 3.0	98 vl shell	4.6	2.2	Std Mince	4.7	1.5	3.2	<1.0
22/08/2011	3	Y				2.7	<1.0		5.6	1.5		
22/08/2011	3	Y				2.7	1.8		4.7	1.5		
22/08/2011	3	Y				4.6	2.1		4.7	1.6		
22/08/2011	3	Y				4.7	3.0		3.6	1.6		
26/08/2011	5	Y	0.1 – 1.0	2.5 – 3.0	98 vl shell	4.1	2.9	H/E Mince	4.6	1.7	1.8	<1.0
26/08/2011	5	Y				4.6	3.1		4.7	1.5		
26/08/2011	5	Y				4.1	3.9		4.8	1.3		
26/08/2011	5	Y				3.8	3.7		4.2	1.7		
26/08/2011	5	Y				4.7	2.4		5.7	1.0		
26/08/2011	6	Gas	0.1 - 1.0	2.5 - 3.0	Trim	2.0	1.9	Std Mince	5.5	1.5	1.7	<1.0
26/08/2011	6	Gas				3.5	2.0		5.1	1.6		
26/08/2011	6	Gas				4.1	<1.0		4.4	1.3		
26/08/2011	6	Gas				3.6	2.5		4.9	1.6		
26/08/2011	6	Gas				3.8	<1.0		4.9	1.3		

(-) data not supplied

Kill date	Age (d)	Vacuum packed (Y/N)	Raw material temperature (°C)	Mince temperature (°C)	Sample	TVC (log cfu/g)	Coliforms (log cfu/g)	Sample	TVC (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)
01/09/2011	7	Gas	0.1 - 1.0	2.5 - 3.0	Trim	3.8	<1.0	Std Mince	4.5	1.3	<1.0	<1.0
02/09/2011	6	Gas				3.2	2.5		5.6	<1.0		
02/09/2011	6	Gas				5.4	3.0		5.0	1.3		
26/08/2011	13	Y				7.3	3.5		4.9	1.8		
02/09/2011	6	Gas				4.3	1.3		5.2	1.3		
02/09/2011	6	Y	0.1 - 1.0	2.5 - 3.0	98 vl shell	4.0	2.3	H/E Mince	4.3	<1.0	<1.0	<1.0
02/09/2011	6	Y				3.7	2.0		4.7	<1.0		
02/09/2011	6	Y				4.5	1.7		3.9	<1.0		
02/09/2011	6	Y				4.0	1.5		4.5	<1.0		
02/09/2011	6	Y				3.3	2.1		4.0	<1.0		
07/09/2011	8	Gas	0.1 - 1.0	2.5 - 3.0	Trim	4.3	3.3	H/E Mince	4.2	1.3	3.3	<1.0
07/09/2011	8	Gas				3.6	1.6		4.2	<1.0		
07/09/2011	8	Gas				<2.0	<1.0		4.4	1.0		
11/09/2011	4	Y			98 vl shell	5.1	4.4		5.4	1.8		
11/09/2011	4	Y				5.5	4.4		4.0	<1.0		
07/09/2011	8	Gas	0.1 - 1.0	2.5 - 3.0	Trim	2.3	2.2	Std Mince	4.2	1.3	2.9	<1.0
07/09/2011	8	Gas				2.5	2.4		4.6	1.6		
07/09/2011	8	Gas				3.4	2.2		4.7	1.0		
07/09/2011	8	Gas				3.1	1.3		4.6	1.6		
07/09/2011	8	Gas				2.8	1.3		4.6	<1.0		
21/09/2011	6	Gas	0.1 - 1.0	2.5 - 3.0	Trim	4.4	3.5	H/E Mince	4.4	<1.0	3.6	<1.0
21/09/2011	6	Gas				3.8	3.7		4.7	<1.0		
21/09/2011	6	Gas				2.8	2.0		4.5	<1.0		
19/09/2011	8	Y			98 vl shell	5.4	3.7		4.4	<1.0		
19/09/2011	8	Y				5.2	4.5		4.2	1.3		
22/09/2011	15	Y	0.1 - 1.0	2.5 - 3.0	98 vl shell	3.9	2.1	H/E Mince	6.1	<1.0	3.7	<1.0
22/09/2011	15	Y				3.4	<1.0		5.1	<1.0		
22/09/2011	15	Y				5.3	<1.0		5.8	<1.0		
22/09/2011	15	Y				4.2	2.0		5.2	<1.0		
22/09/2011	15	Y				4.1	<1.0		4.5	<1.0		
07/10/2011	6	Gas	0.1 - 1.0	2.5 - 3.0	Trim	6.7	3.5	Std Mince	4.6	<1.0	2.7	<1.0
07/10/2011	6	Gas				3.8	1.3		5.1	<1.0		
07/10/2011	6	Gas				2.6	<1.0		6.7	<1.0		
07/10/2011	6	Gas				3.7	2.1		5.6	1.0		
07/10/2011	6	Gas				5.9	2.2		6.0	<1.0		
06/10/2011	8	Y	0.1 - 1.0	2.5 - 3.0	98 vl shell	5.4	4.0	H/E Mince	5.8	1.0	3.6	<1.0
06/10/2011	8	Y				3.9	3.5		5.1	1.0		
06/10/2011	8	Y				5.6	4.4		5.1	1.0		
07/10/2011	8	Gas			Trim	4.5	2.5		4.8	<1.0		
07/10/2011	8	Gas				3.1	<1.0		5.1	1.7		

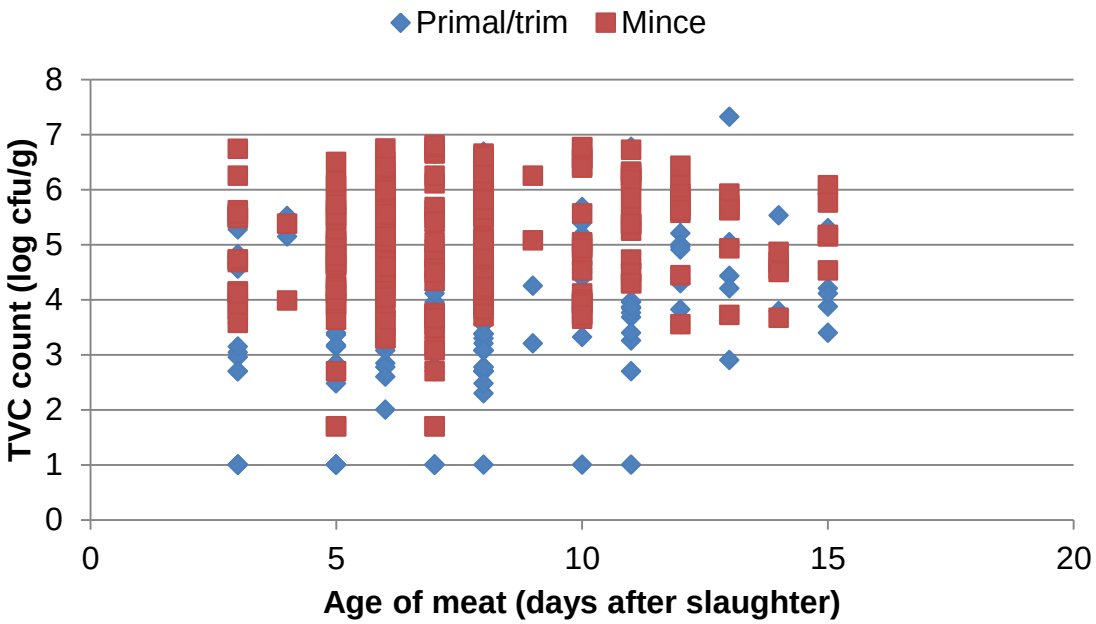

Figure 54. Comparison of reported TVCs on primals/trim and mince produced from pork (47 batches, 5 replicates per batch) related to age of meat prior to mincing (data supplied by M4)

3.3.1.3 Lamb

Data provided by the BMPA, P4 and M5 on TVCs on mince together with age of mince at time of mincing for UK lamb mince is shown in Figure 55, Figure 58, and Figure 59 respectively. The sets of data for UK lamb show a range of counts (3.3 to 8.3 $\log_{10}$ cfu g^{-1}) irrespective of age (3 to 23 days) of meat at mincing. The data set from the BMPA shows a much tighter range in counts than those from P4 and M5. Overall, the data shows a very similar range of counts irrespective of age (3 to 26 days) of UK lamb meat at mincing. The pooled BMPA data shows an increase in count with increase with age of meat, but the data set is quite small.

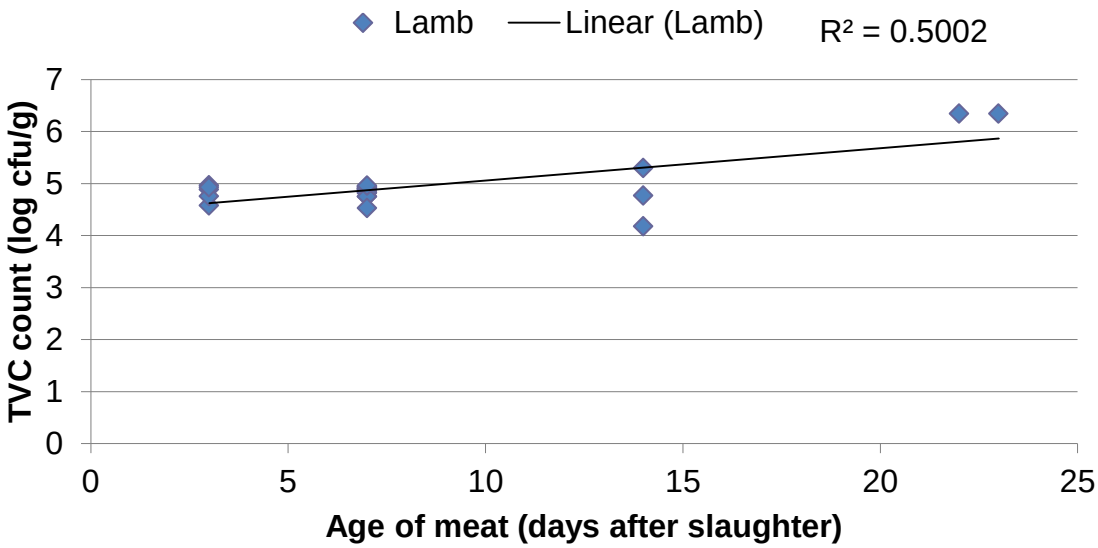

Figure 55. Comparison of reported TVCs (n=25) on mince produced from UK lamb related to age of meat prior to mincing (data supplied by BMPA)

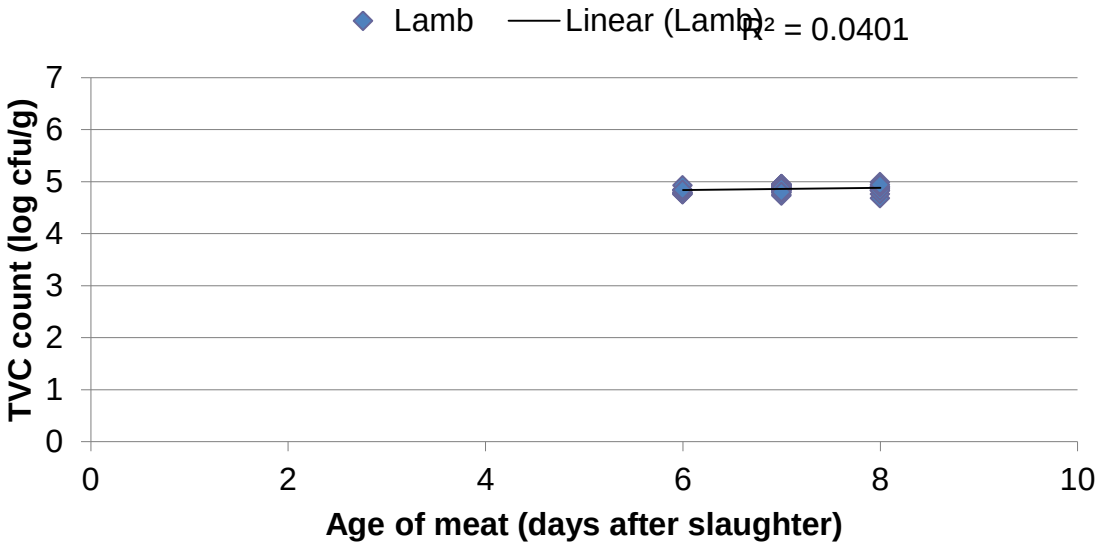

Figure 56. Comparison of reported TVCs (n=50) on mince produced from UK lamb related to age of meat prior to mincing (data supplied by M1)

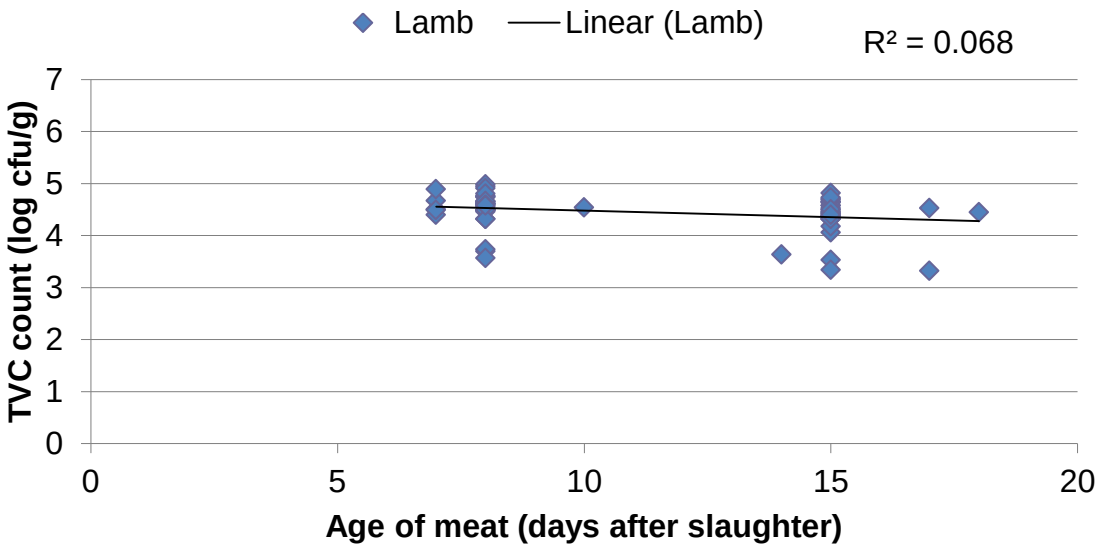

Figure 57. Comparison of reported TVCs (n=65) on mince produced from UK lamb related to age of meat prior to mincing (data supplied by M5)

The data on UK lamb and NZ lamb supplied by P4 is particularly interesting since it shows a similar distribution of TVC values on both UK lamb and NZ lamb despite the great difference in the age of the two groups of samples (as shown in Figure 58 and Figure 59). However, without accompanying time/temperature data is difficult to quantify why there is such a variation in the reported microbiological counts. The data does show a slight increase in counts with age (4 to 67 days) of meat at mincing.

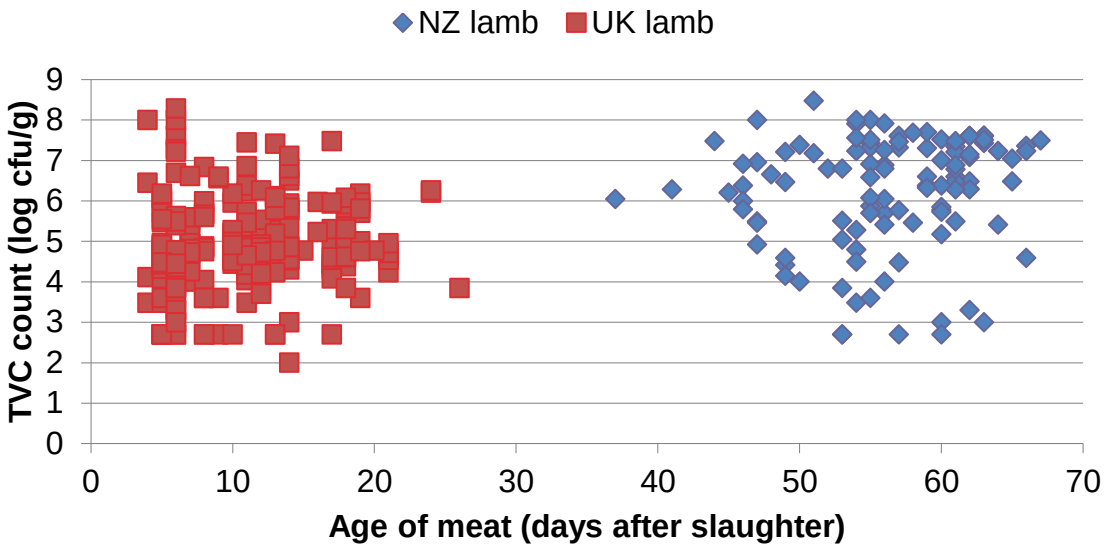

Figure 58. Comparison of reported TVCs on mince produced from UK and NZ lamb (n=227, 111, respectively) related to age of meat prior to mincing (supplied by P4)

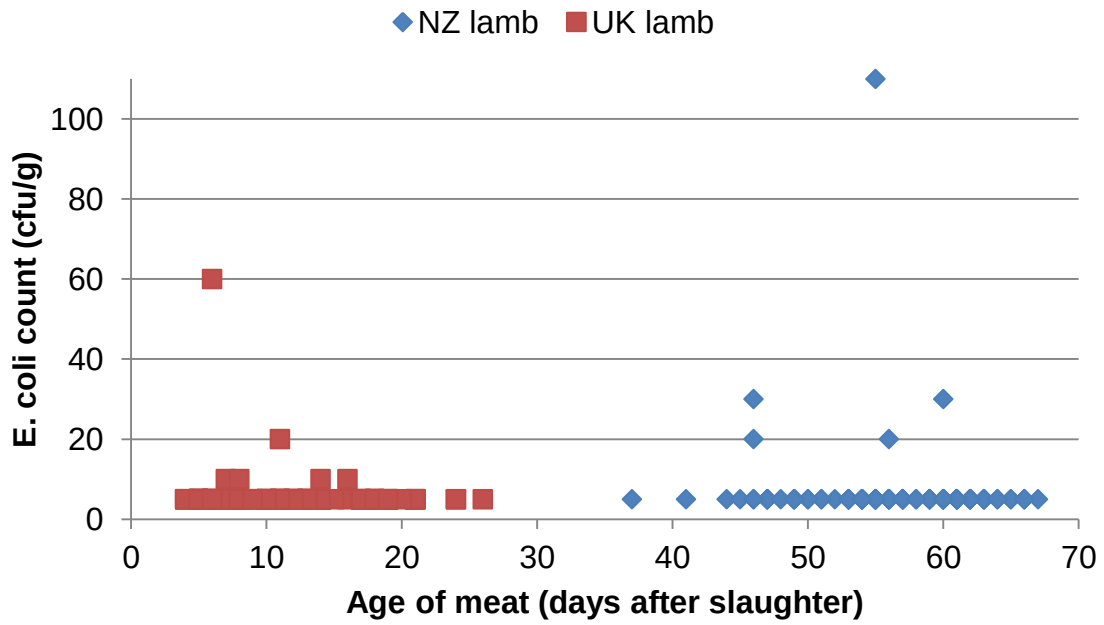

Figure 59. Comparison of reported *E. coli* counts on mince produced from UK and NZ lamb (n=226, 111, respectively) related to age of meat prior to mincing (supplied by P4)

Data provided by project partner P4, the BMPA and BMPA member M1 on *E. coli* counts on mince together with age of mince at time of mincing for UK lamb mince is shown in Figure 59, Figure 60, and Figure 61, respectively. None of this data shows any clear relationship between age (3 to 23 days) of meat at mincing and *E. coli* count.

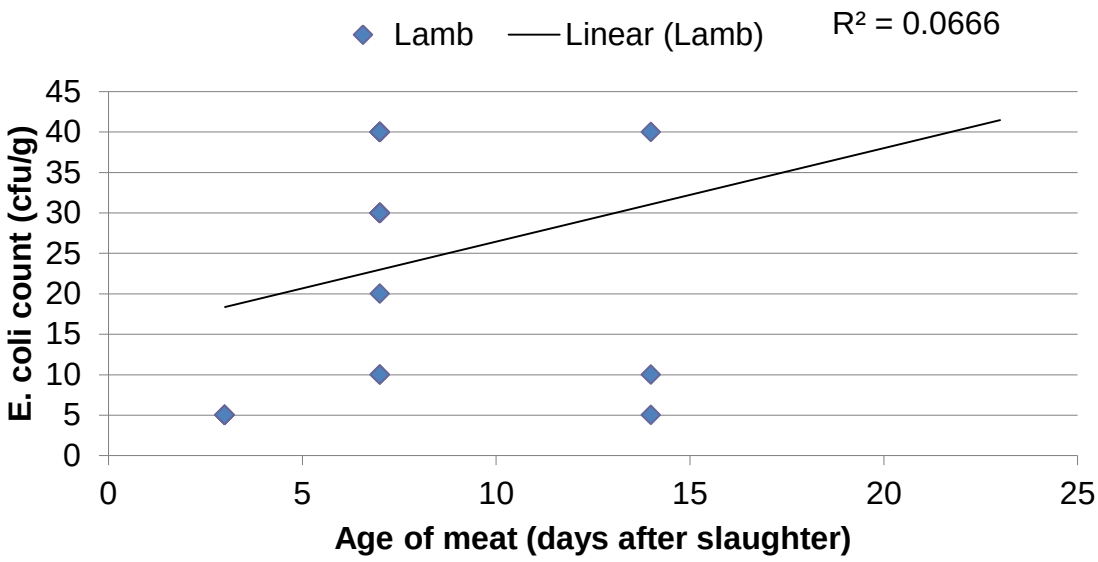

Figure 60. Comparison of reported *E. coli* counts (n=25) on mince produced from UK lamb related to age of meat prior to mincing (data supplied by BMPA)

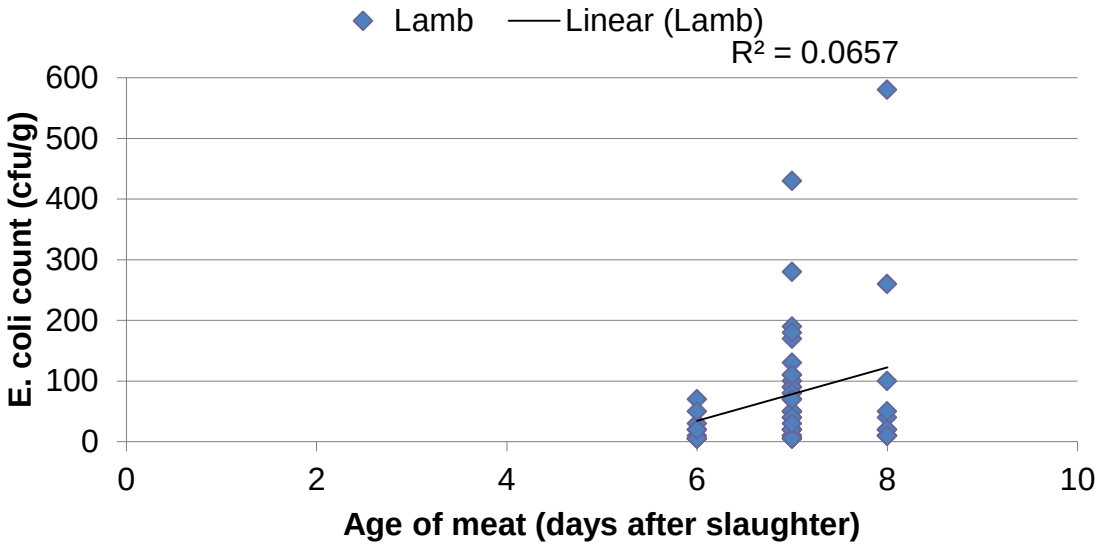

Figure 61. Comparison of reported *E. coli* counts (n=50) on mince produced from UK lamb related to age of meat prior to mincing (data supplied by M1)

Data provided by P4 on Enterobacteriaceae counts on mince together with age of mince at time of mincing for UK and NZ lamb mince is shown in Figure 62. The data shows a very similar range of counts (between <2 (shown as 1.7) to 5 $\log_{10}$ cfu g^{-1}) irrespective of age (5 to 67 days) of meat at mincing, but overall an increase with age of meat. Despite the difference in age between the UK and NZ meat the distribution of Enterobacteriaceae counts are similar. However, data supplied by M5 on Enterobacteriaceae counts on mince together with age of mince at time of mincing for UK lamb mince, Figure 63, shows a much lower distribution in counts than either data set provided by P4.

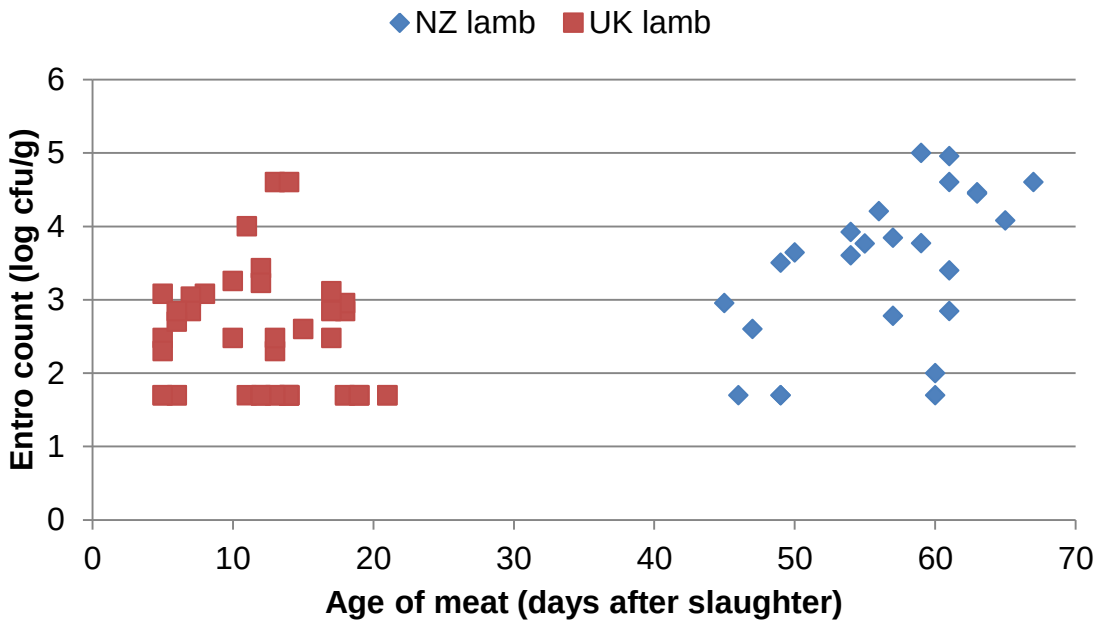

Figure 62. Comparison of reported Enterobacteriaceae counts on mince produced from UK and NZ lamb (n=45, 25, respectively) related to age of meat prior to mincing (data supplied by P4)

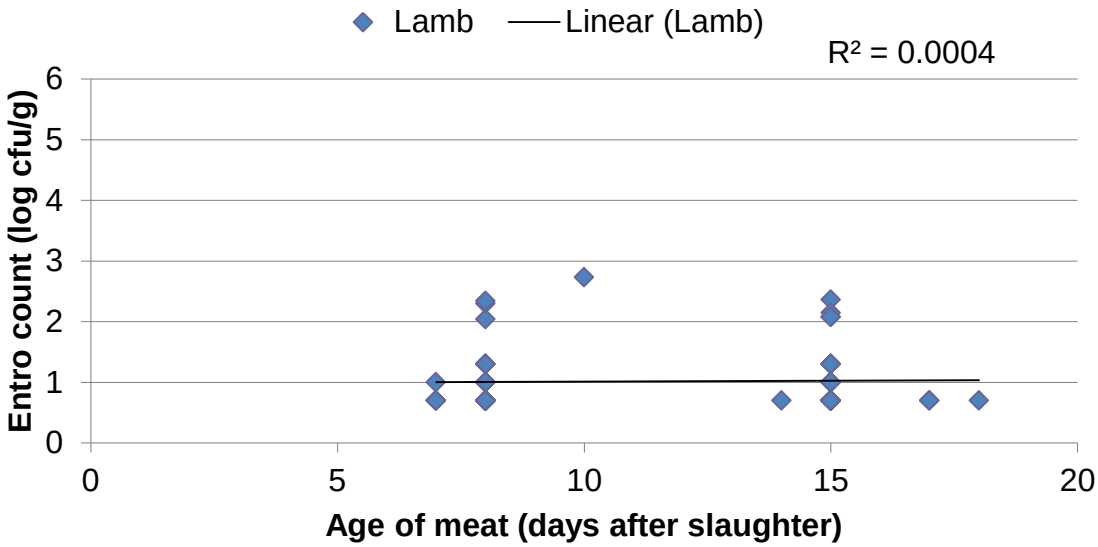

Figure 63. Comparison of reported Enterobacteriaceae counts on mince produced from UK lamb (n=65) related to age of meat prior to mincing (data supplied by M5)

The following tracked data was measured according to the project protocol (Appendix 4) and provided by P4 for UK lamb. An overall comparison of counts is shown in Table 25. Matched carcass, trim and mince microbiological counts and process parameters are shown in Table 26, Table 27 and Table 28, respectively. A comparison of TVCs on matched groups of trim and mince against age of meat is shown in Figure 64. The data set is unfortunately relatively small due to the short processing season for this product by the processor, but

appears to show a slight increase in count with age of meat. Although the range in counts from mince produced from meat that was 6 days old is similar to that of mince produced from meat that was up to 18 days old.

Table 25. Overall comparison of UK lamb mince data (data supplied by P4)

		Age (d)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)	Salmonella (Detected or Not Detected)	Clostridia (log cfu/g)	Lactic Acid Bacteria (log cfu/g)	Pseudomonads (log cfu/g)
Overall	Min	2.0	2.7	0.7	0.7	0.7	0.7		0.7	0.7	1.0
	Max	21.0	6.6	3.6	2.7	3.8	1.0		1.3	4.3	5.9
	Mean	14.1	4.7	1.6	0.8	1.9	0.8		0.7	1.6	3.7
	Number	65	65	65	65	65	65	65	65	65	65
	Detected							0			
	%							0			
Aged >6 days	Min	10.0	3.0	0.7	0.7	0.7	0.7		0.7	0.7	1.0
	Max	21.0	6.6	3.6	2.7	3.8	1.0		1.3	4.3	5.9
	Mean	15.9	4.9	1.5	0.9	1.9	0.7		0.7	1.6	3.9
	Number	55	55	55	55	55	55	55	55	55	55
	Detected							0			
	%							0			
Unaged <6 days	Min	2.0	2.7	1.7	0.7	1.7	1.0		0.7	0.7	1.0
	Max	6.0	5.6	3.2	0.7	2.8	1.0		0.7	3.4	4.1
	Mean	4.0	3.8	2.0	0.7	1.8	1.0		0.7	1.6	2.4
	Number	10	10	10	10	10	10	10	10	10	10
	Detected							0			
	%							0			

Table 26. Tracked UK lamb carcass data (data supplied by P4)

Kill date	Chilling time (h)	Chiller temperature (°C)	TVC (log cfu/cm^2)	Enterobacteriaceae (log cfu/cm^2)	E. coli (log cfu/cm^2)	Coliforms (log cfu/cm^2)	Staphylococcus aureus (log cfu/cm^2)	Salmonella (Detected or Not Detected)	Clostridia (log cfu/cm^2)	Pseudomonads (log cfu/cm^2)
30/11/2010	-	9.8 - 11.2 Average = 10.1	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.3
30/11/2010	-		<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.3
30/11/2010	-		<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.3
30/11/2010	-		<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.3
30/11/2010	-		<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.3
06/12/2010	17.5	Average temperature 3.7	4.0	<2.0	1.0	<2.0	<1.3	ND	<1.0	3.2
06/12/2010	17.5		<3.0	<2.0	1.0	<2.0	<1.3	ND	<1.0	<1.3
06/12/2010	17.5		<3.0	<2.0	1.0	<2.0	<1.3	ND	<1.0	<1.3
06/12/2010	17.5		<3.0	<2.0	1.0	<2.0	<1.3	ND	<1.0	<1.3
06/12/2010	17.5		<3.0	<2.0	1.0	<2.0	<1.3	ND	<1.0	<1.3
14/12/2010	18	Average temperature 0.3	3.3	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.3
14/12/2010	18		<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.3
14/12/2010	18		<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.3
14/12/2010	18		<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.3
14/12/2010	18		<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.3

(-) data not supplied

Kill date	Chilling time (h)	Chiller temperature (°C)	TVC (log cfu/cm^2)	Enterobacteriaceae (log cfu/cm^2)	E. coli (log cfu/cm^2)	Coliforms (log cfu/cm^2)	Staphylococcus aureus (log cfu/cm^2)	Salmonella (Detected or Not Detected)	Clostridia (log cfu/cm^2)	Pseudomonads (log cfu/cm^2)
13/07/2011	-		<-2.0	<-2.0	-	-	-	-	-	-
13/07/2011	-		-1.3	<-2.0	-	-	-	-	-	-
13/07/2011	-	-	-0.5	<-2.0	-	-	-	-	-	-
13/07/2011	-		1.6	-0.4	-	-	-	-	-	-
13/07/2011	-		<-2.0	<-2.0	-	-	-	-	-	-
21/07/2011	-		2.0	<-2.0	-	-	-	-	-	-
21/07/2011	-		-0.3	<-2.0	-	-	-	-	-	-
21/07/2011	-	-	0.7	<-2.0	-	-	-	-	-	-
21/07/2011	-		-0.8	<-2.0	-	-	-	-	-	-
21/07/2011	-		-	-	-	-	-	-	-	-
27/07/2011	-	-	-	-	-	-	-	-	-	-
03/08/2011	-		1.7	1.0	-	-	-	-	-	-
03/08/2011	-		1.7	-0.5	-	-	-	-	-	-
03/08/2011	-	-	1.4	1.3	-	-	-	-	-	-
03/08/2011	-		1.8	0.0	-	-	-	-	-	-
03/08/2011	-		1.8	0.5	-	-	-	-	-	-
12/08/2011	-		0.7	<-2.2	-	-	-	-	-	-
12/08/2011	-		0.4	<-2.2	-	-	-	-	-	-
12/08/2011	-	-	0.8	<-2.2	-	-	-	-	-	-
12/08/2011	-		-	-	-	-	-	-	-	-
12/08/2011	-		-	-	-	-	-	-	-	-
17/08/2011	-	-	-	-	-	-	-	-	-	-
24/08/2011	-	-	-	-	-	-	-	-	-	-
31/08/2011	-	-	-	-	-	-	-	-	-	-
07/09/2011	-	-	-	-	-	-	-	-	-	-
14/09/2011	-	-	-	-	-	-	-	-	-	-

(-) data not supplied

Table 27. Tracked UK lamb trim data (data supplied by P4)

Kill date	Age (d)	Storage temperature (°C)	Vacuum packed (Y/N)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)	Salmonella (Detected or Not Detected)	Clostridia (log cfu/g)	Lactic Acid Bacteria (log cfu/g)	Pseudomonads (log cfu/g)
30/11/2010	-	-	-	-	-	-	-	-	-	-	-	-
30/11/2010	-	-	-	-	-	-	-	-	-	-	-	-
30/11/2010	-	-	-	-	-	-	-	-	-	-	-	-
30/11/2010	-	-	-	-	-	-	-	-	-	-	-	-
30/11/2010	-	-	-	-	-	-	-	-	-	-	-	-
06/12/2010	2	Average temperature 3.0	Y	4.1	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<3.0	3.2
06/12/2010	2		Y	<3.0	<2.0	<1.0	2.0	<1.3	ND	<1.0	2.0	3.1
06/12/2010	2		Y	4.3	<2.0	<1.0	<2.0	<1.3	ND	1.0	2.0	3.1
06/12/2010	2		Y	<3.0	<2.0	<1.0	2.0	<1.3	ND	<1.0	2.3	2.1
06/12/2010	2		Y	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
14/12/2010	3	Average temperature 1.5	Y	4.5	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	3.9
14/12/2010	3		Y	4.9	2.8	<1.0	<2.0	<1.3	ND	<1.0	4.3	3.3
14/12/2010	3		Y	4.3	<2.0	<1.0	<2.0	<1.3	ND	<1.0	4.2	3.9
14/12/2010	3		Y	4.8	<2.0	<1.0	<2.0	<1.3	ND	<1.0	1.3	3.1
14/12/2010	3		Y	3.5	2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	4.0
13/07/2011	12	Average temperature 1.2	Y	4.2	<1.0	<1.0	<1.0	<1.0	ND	<1.0	<1.0	2.3
13/07/2011	12		Y	3.6	<1.0	<1.0	<1.0	<1.0	ND	<1.0	<1.0	3.1
13/07/2011	12		Y	3.7	<1.0	<1.0	<1.0	<1.0	ND	<1.0	<1.0	3.1
13/07/2011	12		Y	3.8	<1.0	<1.0	<1.0	<1.0	ND	<1.0	<1.0	2.4
13/07/2011	12		Y	4.1	<1.0	<1.0	<1.0	<1.0	ND	<1.0	<1.0	2.2
21/07/2011	13	Average temperature 0.2	Y	4.5	<1.0	<1.0	1.3	<1.0	ND	<1.0	1.0	3.8
21/07/2011	13		Y	3.7	<1.0	<1.0	<1.0	<1.0	ND	<1.0	1.0	3.4
21/07/2011	13		Y	4.3	<1.0	<1.0	1.7	<1.0	ND	<1.0	1.0	4.1
21/07/2011	13		Y	4.4	1.9	<1.0	<1.0	<1.0	ND	<1.0	1.0	5.2
21/07/2011	13		Y	3.9	<1.0	<1.0	<1.0	<1.0	ND	<1.0	1.0	3.9
27/07/2011	13	Average temperature 0.0	Y	4.3	2.8	1.3	2.9	<1.0	ND	<1.0	<1.0	4.0
27/07/2011	13		Y	4.2	2.8	<1.0	3.0	<1.0	ND	<1.0	<1.0	4.0
27/07/2011	13		Y	3.8	2.8	1.3	3.0	<1.0	ND	<1.0	<1.0	4.0
27/07/2011	13		Y	3.4	2.9	<1.0	2.8	<1.0	ND	<1.0	<1.0	3.9
27/07/2011	13		Y	3.8	3.0	<1.0	2.9	<1.0	ND	<1.0	<1.0	4.7
03/08/2011	14	Average temperature 0.1	Y	4.2	<1.0	<1.0	<1.0	<1.0	ND	<1.0	<1.0	2.7
03/08/2011	14		Y	4.0	<1.0	<1.0	<1.0	<1.0	ND	<1.0	<1.0	2.7
03/08/2011	14		Y	4.3	<1.0	<1.0	<1.0	<1.0	ND	<1.0	<1.0	3.2
03/08/2011	14		Y	4.0	1.3	<1.0	<1.0	<1.0	ND	<1.0	<1.0	4.3
03/08/2011	14		Y	3.8	<1.0	<1.0	<1.0	<1.0	ND	<1.0	<1.0	2.9

(-) data not supplied

Kill date	Age (d)	Storage temperature (°C)	Vacuum packed (Y/N)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)	Salmonella (Detected or Not Detected)	Clostridia (log cfu/g)	Lactic Acid Bacteria (log cfu/g)	Pseudomonads (log cfu/g)
12/08/2011	18	Average temperature -0.1	Y	4.6	2.5	<1.0	2.7	<1.0	ND	<1.0	<1.0	4.1
12/08/2011	18		Y	5.3	2.6	1.0	2.6	<1.0	ND	<1.0	<1.0	4.5
12/08/2011	18		Y	6.1	1.8	<1.0	3.1	<1.0	ND	<1.0	<1.0	5.0
12/08/2011	18		Y	5.0	2.5	<1.0	1.7	<1.0	ND	<1.0	<1.0	3.8
12/08/2011	18		Y	5.2	2.9	1.3	2.8	<1.0	ND	<1.0	2.1	4.0
17/08/2011	15	Average temperature -0.2	Y	5.4	1.3	<1.0	2.0	<1.0	ND	<1.0	<1.0	4.9
17/08/2011	15		Y	5.4	2.1	<1.0	2.7	<1.0	ND	<1.0	<1.0	4.9
17/08/2011	15		Y	5.6	1.8	<1.0	2.5	<1.0	ND	<1.0	<1.0	5.0
17/08/2011	15		Y	5.3	1.7	<1.0	2.3	<1.0	ND	<1.0	1.3	4.8
17/08/2011	15		Y	6.0	1.6	<1.0	2.6	<1.0	ND	<1.0	<1.0	5.0
24/08/2011	19	Average temperature 0.0	Y	4.7	1.8	<1.0	3.0	<1.0	ND	<1.0	<1.0	4.2
24/08/2011	19		Y	6.1	<1.0	<1.0	2.5	<1.0	ND	<1.0	2.8	4.1
24/08/2011	19		Y	5.3	1.5	<1.0	3.0	<1.0	ND	<1.0	<1.0	3.9
24/08/2011	19		Y	6.2	1.5	<1.0	3.0	<1.0	ND	<1.0	<1.0	4.5
24/08/2011	19		Y	4.0	<1.0	<1.0	2.6	<1.0	ND	<1.0	<1.0	5.7
31/08/2011	16	Average temperature 0.1	Y	5.0	2.6	<1.0	2.8	<1.0	ND	<1.0	2.5	4.4
31/08/2011	16		Y	5.1	2.7	<1.0	3.0	<1.0	ND	<1.0	3.2	4.7
31/08/2011	16		Y	4.7	1.9	<1.0	3.1	<1.0	ND	<1.0	2.3	4.1
31/08/2011	16		Y	5.0	3.3	<1.0	3.1	<1.0	ND	<1.0	2.6	4.4
31/08/2011	16		Y	4.9	2.3	<1.0	3.2	<1.0	ND	<1.0	3.2	4.0
07/09/2011	21	Average temperature 0.1	Y	5.9	2.7	1.3	2.8	<1.0	ND	<1.0	1.8	4.7
07/09/2011	21		Y	5.6	2.6	3.1	3.6	<1.0	ND	<1.0	<1.0	4.6
07/09/2011	21		Y	5.7	2.3	1.5	2.4	<1.0	ND	<1.0	2.1	4.6
07/09/2011	21		Y	5.7	2.5	1.7	3.0	<1.0	ND	<1.0	2.8	4.6
07/09/2011	21		Y	5.8	3.2	1.9	4.1	<1.0	ND	<1.0	1.8	5.3
14/09/2011	21	Average temperature 0.1	Y	6.3	1.9	<1.0	<1.0	<1.0	ND	<1.0	<1.0	4.0
14/09/2011	21		Y	4.3	2.2	<1.0	<1.0	<1.0	ND	<1.0	<1.0	4.8
14/09/2011	21		Y	4.6	3.0	<1.0	2.5	<1.0	ND	<1.0	<1.0	3.0
14/09/2011	21		Y	4.4	<1.0	<1.0	<1.0	<1.0	ND	<1.0	<1.0	3.1
14/09/2011	21		Y	4.6	<1.0	<1.0	<1.0	<1.0	ND	<1.0	<1.0	3.4

Table 28. Tracked UK lamb mince data (data supplied by P4)

Kill date	Age (d)	Vacuum packed (Y/N)	Raw material temperature (°C)	Mince temperature (°C)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)	Salmonella (Detected or Not Detected)	Clostridia (log cfu/g)	Lactic Acid Bacteria (log cfu/g)	Pseudomonads (log cfu/g)
30/11/2010	10	Y	-	7.7	3.7	2.6	<1.0	<2.0	<1.3	ND	<1.0	<1.0	3.0
30/11/2010	10	Y	-	7.6	3.8	<2.0	<1.0	<2.0	<1.3	ND	<1.0	1.0	2.9
30/11/2010	10	Y	-	8.1	3.0	<2.0	1.0	<2.0	<1.3	ND	<1.0	<1.0	2.7
30/11/2010	10	Y	-	7.5	3.3	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	2.7
30/11/2010	10	Y	-	7.6	3.8	<2.0	1.8	<2.0	<1.3	ND	<1.0	<1.0	2.8
06/12/2010	2	Y	0.2	6.1	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
06/12/2010	2	Y	0.1	5.3	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
06/12/2010	2	Y	0.1	6.3	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
06/12/2010	2	Y	0.3	5.2	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
06/12/2010	2	Y	0.2	5.4	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
14/12/2010	6	N	2.9	5.8	5.5	<2.0	<1.0	2.8	<1.3	ND	<1.0	2.0	4.1
14/12/2010	6	N	2.5	5.6	3.9	2.3	<1.0	<2.0	<1.3	ND	<1.0	2.8	4.0
14/12/2010	6	N	4.6	5.3	4.3	2.8	<1.0	<2.0	<1.3	ND	<1.0	3.4	2.9
14/12/2010	6	N	3.2	5.3	4.9	<2.0	<1.0	<2.0	<1.3	ND	<1.0	2.7	4.1
14/12/2010	6	N	3.6	5.7	5.6	3.2	<1.0	<2.0	<1.3	ND	<1.0	2.1	3.9
13/07/2011	14	N	-0.2	0.3	4.4	2.1	<1.0	2.1	<1.0	ND	<1.0	3.4	2.9
13/07/2011	14	N	-0.8	0.1	4.4	<1.0	<1.0	<1.0	<1.0	ND	<1.0	3.4	3.3
13/07/2011	14	N	-0.8	-0.1	4.1	<1.0	<1.0	<1.0	<1.0	ND	<1.0	3.5	3.5
13/07/2011	14	N	-0.8	-0.9	4.4	1.6	<1.0	1.6	<1.0	ND	<1.0	3.6	2.6
13/07/2011	14	N	-0.6	-0.7	4.3	2.1	<1.0	1.0	<1.0	ND	<1.0	3.4	3.4
21/07/2011	14	N	2.5	3.1	4.7	<1.0	<1.0	<1.0	<1.0	ND	<1.0	<1.0	3.8
21/07/2011	14	N	1.9	3.5	4.9	1.9	<1.0	1.7	<1.0	ND	<1.0	2.8	3.6
21/07/2011	14	N	2.1	3.3	4.6	1.7	<1.0	2.4	<1.0	ND	<1.0	<1.0	3.8
21/07/2011	14	N	1.7	3.2	5.1	3.6	<1.0	3.1	<1.0	ND	<1.0	1.8	4.6
21/07/2011	14	N	2.2	3.5	5.0	2.0	<1.0	2.4	<1.0	ND	<1.0	2.6	3.8
27/07/2011	13	N	3.7	6.9	4.3	1.8	1.6	2.8	<1.0	ND	<1.0	<1.0	4.8
27/07/2011	13	N	3.1	6.2	4.5	1.5	1.7	2.0	<1.0	ND	<1.0	1.0	4.8
27/07/2011	13	N	3.9	6.7	5.0	<1.0	1.0	2.2	<1.0	ND	<1.0	<1.0	4.8
27/07/2011	13	N	3.5	7.1	4.8	2.2	2.7	3.8	<1.0	ND	<1.0	1.0	5.1
27/07/2011	13	N	3.1	6.3	4.8	2.4	1.8	2.6	<1.0	ND	<1.0	1.6	5.3
03/08/2011	13	N	1.6	5.4	4.3	2.1	1.5	1.6	<1.0	ND	1.3	<1.0	4.8
03/08/2011	13	N	1.4	5.4	4.4	2.0	<1.0	<1.0	<1.0	ND	<1.0	<1.0	3.6
03/08/2011	13	N	1.3	5.4	4.3	<1.0	<1.0	<1.0	<1.0	ND	<1.0	<1.0	3.5
03/08/2011	13	N	1.3	5.6	4.7	<1.0	<1.0	<1.0	<1.0	ND	<1.0	<1.0	3.9
03/08/2011	13	N	1.5	5.5	4.3	1.5	<1.0	1.0	<1.0	ND	<1.0	<1.0	3.8

(-) data not supplied

Kill date	Age (d)	Vacuum packed (Y/N)	Raw material temperature (°C)	Mince temperature (°C)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)	Salmonella (Detected or Not Detected)	Clostridia (log cfu/g)	Lactic Acid Bacteria (log cfu/g)	Pseudomonads (log cfu/g)
12/08/2011	18	N	2.5	4.5	4.7	<1.0	<1.0	1.0	<1.0	ND	<1.0	<1.0	4.8
12/08/2011	18	N	2.6	4.1	4.7	2.5	<1.0	<1.0	<1.0	ND	<1.0	<1.0	4.0
12/08/2011	18	N	2.5	4.3	4.9	2.4	1.0	2.5	<1.0	ND	<1.0	<1.0	3.2
12/08/2011	18	N	2.4	3.9	4.9	<1.0	<1.0	2.4	<1.0	ND	<1.0	<1.0	4.1
12/08/2011	18	N	2.5	4.2	4.8	2.0	<1.0	1.3	<1.0	ND	<1.0	<1.0	4.3
17/08/2011	16	N	2.7	4.5	4.9	<1.0	<1.0	<1.0	<1.0	ND	<1.0	<1.0	3.7
17/08/2011	16	N	2.5	4.9	5.0	2.1	1.0	3.0	<1.0	ND	<1.0	1.0	4.1
17/08/2011	16	N	2.8	4.3	4.6	<1.0	1.0	1.8	<1.0	ND	<1.0	1.5	3.9
17/08/2011	16	N	2.4	4.5	4.8	<1.0	<1.0	3.0	<1.0	ND	<1.0	<1.0	4.6
17/08/2011	16	N	2.7	4.6	4.9	2.1	<1.0	1.8	<1.0	ND	<1.0	<1.0	4.0
24/08/2011	19	N	2.7	3.2	6.1	<1.0	<1.0	3.7	<1.0	ND	<1.0	<1.0	4.9
24/08/2011	19	N	2.5	3.5	5.0	1.3	<1.0	3.7	<1.0	ND	<1.0	<1.0	5.9
24/08/2011	19	N	2.7	3.8	4.9	<1.0	<1.0	3.1	<1.0	ND	<1.0	1.8	4.8
24/08/2011	19	N	2.8	3.5	4.3	<1.0	<1.0	3.2	<1.0	ND	<1.0	<1.0	4.7
24/08/2011	19	N	2.5	3.4	6.0	<1.0	<1.0	3.5	<1.0	ND	<1.0	1.9	4.7
31/08/2011	16	N	-1.1	-0.4	5.4	<1.0	<1.0	2.1	<1.0	ND	<1.0	4.2	4.5
31/08/2011	16	N	-0.3	-1.1	5.4	<1.0	<1.0	2.3	<1.0	ND	<1.0	4.0	4.5
31/08/2011	16	N	-0.1	-0.9	5.3	<1.0	<1.0	2.5	<1.0	ND	<1.0	4.2	4.5
31/08/2011	16	N	-0.1	-0.6	5.3	<1.0	<1.0	2.9	<1.0	ND	<1.0	4.3	4.0
31/08/2011	16	N	-0.2	-1	5.2	<1.0	<1.0	<1.0	<1.0	ND	<1.0	4.2	4.4
07/09/2011	21	N	-0.7	3.9	6.3	3.1	<1.0	2.9	<1.0	ND	<1.0	3.7	5.3
07/09/2011	21	N	-1.2	3.7	6.4	3.0	<1.0	2.4	<1.0	ND	<1.0	2.1	4.4
07/09/2011	21	N	-0.9	3.4	6.2	3.1	<1.0	2.9	<1.0	ND	<1.0	<1.0	4.2
07/09/2011	21	N	-0.7	3.7	6.6	2.0	1.3	2.4	<1.0	ND	<1.0	2.2	5.1
07/09/2011	21	N	-0.9	3.6	6.1	3.0	<1.0	3.4	<1.0	ND	<1.0	<1.0	4.9
14/09/2011	21	N	0.3	3.4	4.4	<1.0	<1.0	<1.0	<1.0	ND	<1.0	<1.0	2.6
14/09/2011	21	N	0.1	3.2	5.7	1.6	<1.0	<1.0	<1.0	ND	<1.0	<1.0	1.9
14/09/2011	21	N	0.5	2.9	5.0	1.5	<1.0	<1.0	<1.0	ND	<1.0	<1.0	2.5
14/09/2011	21	N	0.2	3.1	6.3	1.5	<1.0	<1.0	<1.0	ND	<1.0	<1.0	1.8
14/09/2011	21	N	0.5	3.5	5.0	1.3	<1.0	<1.0	<1.0	ND	<1.0	<1.0	1.0

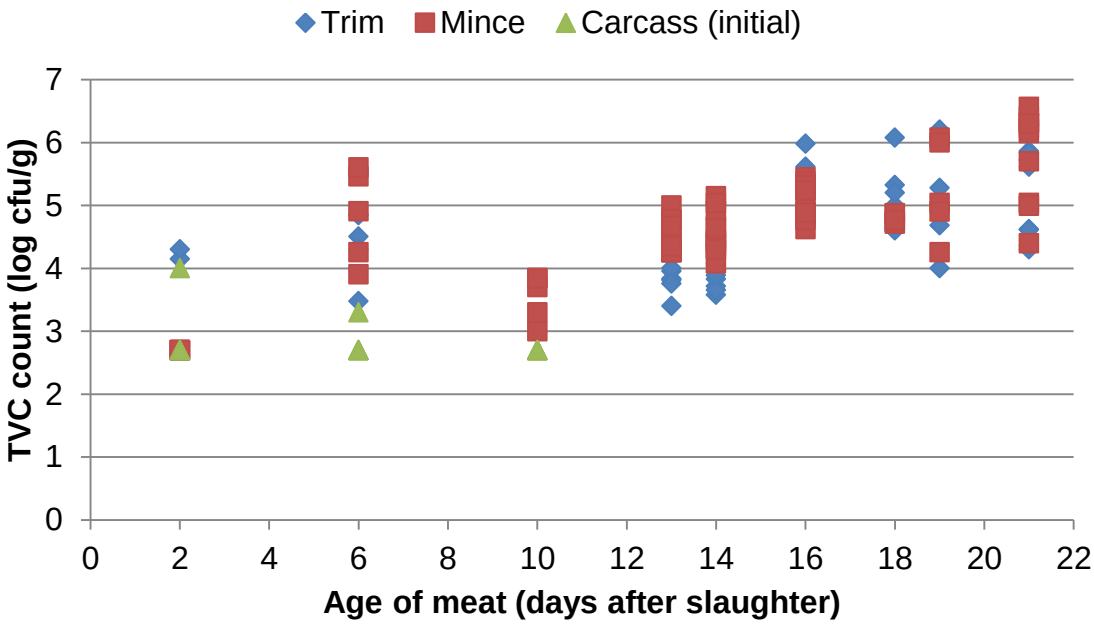

Figure 64. Comparison of reported TVCs on carcass, trim and mince produced from UK lamb (13 batches, 5 replicates per batch; 3 linked batches with carcass counts) related to age of meat prior to mincing (data supplied by P4)

The following tracked data was measured according to the project protocol (Appendix 4) and provided by P4 for NZ lamb. An overall comparison of counts is shown in Table 29. Matched carcass, trim and mince microbiological counts and process parameters are shown in Table 30, Table 31 and Table 32, respectively. A comparison of TVCs on matched groups of trim and mince against age of meat is shown in Figure 65. The data set again indicates no relationship between age of meat and count.

Table 29. Overall comparison of NZ lamb mince data (data supplied by P4)

		Age (d)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)	Salmonella (Detected or Not Detected)	Clostridia (log cfu/g)	Lactic Acid Bacteria (log cfu/g)	Pseudomonads (log cfu/g)
Overall	Min	48.0	2.7	1.7	0.7	1.7	1.0		0.7	0.7	1.0
	Max	61.0	8.0	7.6	1.6	5.9	1.0		2.2	4.9	7.1
	Mean	56.2	6.1	3.4	0.7	3.3	1.0		0.7	2.3	3.9
	Number	100	100	100	100	95	100	100	100	100	95
	Detected							0			
	%							0			

Table 30. Tracked NZ lamb carcass data (data supplied by P4)

Kill date	Chilling time (h)	Chiller temperature (°C)	TVC (log cfu/cm^2)	Enterobacteriaceae (cfu/cm^2)
07/12/2010	-	-	3.4	1.6
07/12/2010	-	-	3.0	0.0
07/12/2010	-	-	3.3	0.0
07/12/2010	-	-	3.0	2.4
13/12/2010	-	-	3.6	14.4
13/12/2010	-	-	2.9	4.0
13/12/2010	-	-	2.7	1.6
13/12/2010	-	-	3.5	110.4
13/12/2010	-	-	2.5	6.4
20/12/2010	-	-	2.5	0.0
20/12/2010	-	-	3.9	1.6
20/12/2010	-	-	3.1	0.0
20/12/2010	-	-	3.4	0.8
20/12/2010	-	-	3.5	13.6

(-) data not supplied

Table 31. Tracked NZ lamb primal/trim data (data supplied by P4)

Details (Primal, Trim etc)	Kill date	Number of days from slaughter	Storage temperature (°C)	Vacuum packed (Y/N)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)	Salmonella (Detected or Not Detected)	Clostridia (log cfu/g)	Lactic Acid Bacteria (log cfu/g)	Pseudomonads (log cfu/g)
Boned shoulder	12/10/2010	51	Retail prep - 11.3	Y	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
	12/10/2010	51		Y	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
	12/10/2010	51		Y	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
	12/10/2010	51		Y	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
	12/10/2010	51		Y	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
Boned Shoulder	15/10/2010	54	Average temperature: 11.8	Y	5.0	2.6	<1.0	<2.0	<1.3	ND	<1.0	2.1	4.6
	15/10/2010	54		Y	4.1	3.3	<1.0	3.6	<1.3	ND	<1.0	1.5	3.5
	15/10/2010	54		Y	5.4	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
	15/10/2010	54		Y	4.9	3.3	<1.0	3.2	<1.3	ND	<1.0	2.2	3.3
	15/10/2010	54		Y	8.0	2.5	<1.0	2.6	<1.3	ND	<1.0	2.3	3.3
Boned shoulder	28/10/2010	48	Retail prep - 11.5	Y	4.9	<2.0	<1.0	<2.0	<1.3	ND	<1.0	1.6	3.6
	28/10/2010	48		Y	4.3	3.1	<1.0	3.1	<1.3	ND	<1.0	1.3	1.3
	28/10/2010	48		Y	4.3	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
	28/10/2010	48		Y	4.2	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
	28/10/2010	48		Y	4.2	<2.0	<1.0	<2.0	<1.3	ND	<1.0	>4.0	1.8
Trim	24/11/2010	58	Average temperature 11.6	Y	3.5	3.0	<1.0	-	<1.3	ND	<1.0	<1.0	-
	24/11/2010	58		Y	5.2	<2.0	<1.0	-	<1.3	ND	<1.0	<1.0	-
	24/11/2010	58		Y	4.7	4.1	<1.0	-	<1.3	ND	<1.0	<1.0	-
	24/11/2010	58		Y	<3.0	4.3	<1.0	-	<1.3	ND	<1.0	<1.0	-
	24/11/2010	58		Y	4.3	3.8	<1.0	-	<1.3	ND	<1.0	<1.0	-
Leg	02/12/2010	55	Average temperature 11.2	y	4.8	3.3	<1.0	4.3	<1.3	ND	<1.0	3.0	4.8
	02/12/2010	55		y	4.9	2.5	<1.0	3.0	<1.3	ND	<1.0	3.2	4.0
	02/12/2010	55		y	4.9	2.9	<1.0	2.0	<1.3	ND	<1.0	3.3	3.8
	02/12/2010	55		y	5.0	2.7	<1.0	2.8	<1.3	ND	<1.0	4.2	3.7
	02/12/2010	55		y	5.3	2.5	<1.0	<2.0	<1.3	ND	<1.0	2.8	3.8
Leg	07/12/2010	51	Average temperature 11.1	Y	7.3	<2.0	<1.0	<2.0	<1.3	ND	<1.0	2.2	5.1
	07/12/2010	51		Y	7.3	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	3.8
	07/12/2010	51		Y	5.9	2.3	<1.0	<2.0	<1.3	ND	<1.0	2.7	4.2
	07/12/2010	51		Y	7.3	<2.0	<1.0	<2.0	<1.3	ND	<1.0	2.8	5.2
	07/12/2010	51		Y	7.2	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	3.0
Leg	08/12/2010	56	Average temperature 11.4	Y	5.2	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	1.3
	08/12/2010	56		Y	5.3	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
	08/12/2010	56		Y	6.1	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	1.9
	08/12/2010	56		Y	5.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	2.8
	08/12/2010	56		Y	4.2	<2.0	1.0	<2.0	<1.3	ND	<1.0	<1.0	2.9

(-) data not supplied

Details (Primal, Trim etc)	Kill date	Number of days from slaughter	Storage temperature (°C)	Vacuum packed (Y/N)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)	Salmonella (Detected or Not Detected)	Clostridia (log cfu/g)	Lactic Acid Bacteria (log cfu/g)	Pseudomonads (log cfu/g)
Leg	09/12/2010	57	Average temperature 10.6	Y	7.0	<2.0	<1.0	3.0	<1.3	ND	<1.0	<1.0	3.2
	09/12/2010	57		Y	6.1	<2.0	<1.0	2.0	<1.3	ND	<1.0	<1.0	3.1
	09/12/2010	57		Y	6.1	<2.0	<1.0	<2.0	<1.3	ND	<1.0	1.6	3.1
	09/12/2010	57		Y	5.1	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	3.2
	09/12/2010	57		Y	7.5	2.3	<1.0	<2.0	<1.3	ND	<1.0	<1.0	3.3
Trim	13/12/2010	57	Average temperature 11.1	Y	4.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
	13/12/2010	57		Y	3.5	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
	13/12/2010	57		Y	4.5	2.3	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
	13/12/2010	57		Y	4.3	2.5	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
	13/12/2010	57		Y	4.4	<2.0	<1.0	2.3	<1.3	ND	<1.0	<1.0	<1.3
Trim	16/12/2010	56	Average temperature 11.9	Y	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
	16/12/2010	56		Y	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
	16/12/2010	56		Y	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
	16/12/2010	56		Y	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
	16/12/2010	56		Y	3.8	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
-	17/12/2010	61	Average temperature 0.5	Y	8.0	2.6	<1.0	2.9	<1.3	ND	<1.0	3.4	2.9
	17/12/2010	61		Y	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<3.0	2.3
	17/12/2010	61		Y	5.3	2.0	<1.0	2.3	<1.3	ND	<1.0	2.0	2.7
	17/12/2010	61		Y	>8.0	<2.0	<1.0	3.0	<1.3	ND	<1.0	2.4	2.3
	17/12/2010	61		Y	>8.0	3.2	1.0	3.0	<1.3	ND	<1.0	2.3	2.3
-	20/12/2010	58	Average temperature 0.5	Y	6.7	2.3	<1.0	3.4	<1.3	ND	<1.0	2.3	4.3
	20/12/2010	58		Y	5.9	3.3	<1.0	3.7	<1.3	ND	<1.0	2.8	4.0
	20/12/2010	58		Y	7.2	3.2	<1.0	3.6	<1.3	ND	<1.0	3.3	4.6
	20/12/2010	58		Y	4.8	2.0	1.0	<2.0	<1.3	ND	<1.0	1.5	3.2
	20/12/2010	58		Y	6.9	3.7	<1.0	3.5	<1.3	ND	<1.0	2.3	3.9
-	29/12/2010	55	Average temperature 1.1	Y	6.5	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	3.0
	29/12/2010	55		y	6.4	<2.0	<1.0	<2.0	<1.3	ND	<1.0	3.0	3.0
	29/12/2010	55		Y	6.3	<2.0	<1.0	<2.0	<1.3	ND	<1.0	1.3	2.1
	29/12/2010	55		y	5.5	<2.0	<1.0	<2.0	<1.3	ND	<1.0	3.0	3.0
	29/12/2010	55		Y	6.7	<2.0	<1.0	<2.0	<1.3	ND	<1.0	4.0	3.1
-	06/01/2011	56	Average temperature 0.4	Y	7.3	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	3.1
	06/01/2011	56		Y	4.3	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	3.2
	06/01/2011	56		Y	4.3	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	3.2
	06/01/2011	56		Y	5.1	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	2.9
	06/01/2011	56		Y	4.9	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	2.9

Details (Primal, Trim etc)	Kill date	Number of days from slaughter	Storage temperature (°C)	Vacuum packed (Y/N)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)	Salmonella (Detected or Not Detected)	Clostridia (log cfu/g)	Lactic Acid Bacteria (log cfu/g)	Pseudomonads (log cfu/g)
Shoulder	10/01/2011	56	Average temperature 1.8	Y	6.6	4.1	<1.0	4.0	<1.3	ND	<1.0	4.7	4.8
	10/01/2011	56		Y	7.8	4.1	<1.0	4.2	<1.3	ND	<1.0	5.4	4.5
	10/01/2011	56		Y	7.8	5.0	<1.0	5.0	<1.3	ND	<1.0	4.6	6.5
	10/01/2011	56		Y	6.7	4.3	<1.0	4.4	<1.3	ND	<1.0	4.5	6.4
	10/01/2011	56		Y	7.5	3.9	<1.0	4.0	<1.3	ND	<1.0	3.8	5.4
-	14/01/2011	59	Average temperature 1.5	Y	6.9	4.6	<1.0	4.6	<1.3	ND	<1.0	<1.0	2.0
	14/01/2011	59		Y	5.9	3.3	<1.0	3.4	<1.3	ND	<1.0	<1.0	3.2
	14/01/2011	59		Y	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
	14/01/2011	59		Y	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
	14/01/2011	59		Y	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
-	17/01/2011	57	Average temperature 2.6	Y	>8.0	2.7	<1.0	3.0	<1.3	ND	<1.0	<1.0	<1.3
	17/01/2011	57		Y	>8.0	2.3	<1.0	2.8	<1.3	ND	<1.0	<1.0	<1.3
	17/01/2011	57		Y	>8.0	2.5	<1.0	2.3	<1.3	ND	<1.0	<1.0	<1.3
	17/01/2011	57		Y	>8.0	<2.0	<1.0	4.7	<1.3	ND	<1.0	<1.0	3.4
	17/01/2011	57		Y	>8.0	<2.0	<1.0	3.2	<1.3	ND	<1.0	<1.0	<1.3
-	24/01/2011	53	Average temperature 0.9	Y	7.4	2.0	<1.0	2.5	<1.3	ND	<1.0	<1.0	<1.3
	24/01/2011	53		Y	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
	24/01/2011	53		Y	3.5	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
	24/01/2011	53		Y	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
	24/01/2011	53		Y	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
Primal	01/03/2011	57	Average temperature 1.2	Y	5.4	3.7	<1.0	3.6	<1.3	ND	<1.0	<1.0	4.3
	01/03/2011	57		Y	5.2	2.3	<1.0	3.7	<1.3	ND	<1.0	<1.0	2.8
	01/03/2011	57		Y	4.6	2.3	<1.0	2.3	<1.3	ND	<1.0	<1.0	3.4
	01/03/2011	57		Y	5.4	2.5	<1.0	3.0	<1.3	ND	<1.0	<1.0	3.3
	01/03/2011	57		Y	5.4	3.1	<1.0	3.7	<1.3	ND	<1.0	<1.0	4.8
Primal	04/03/2011	59	Average temperature 2.1	Y	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	1.8
	04/03/2011	59		Y	4.5	<2.0	<1.0	<2.0	<1.3	ND	<1.0	4.3	2.3
	04/03/2011	59		Y	3.9	<2.0	<1.0	<2.0	<1.3	ND	<1.0	3.7	2.0
	04/03/2011	59		Y	5.9	<2.0	<1.0	<2.0	<1.3	ND	<1.0	4.0	2.7
	04/03/2011	59		Y	4.2	<2.0	<1.0	<2.0	<1.3	ND	<1.0	2.6	3.9

Table 32. Tracked NZ lamb mince data (data supplied by P4)

Kill date	Age (d)	Vacuum packed (Y/N)	Raw material temperature (°C)	Mince temperature (°C)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)	Salmonella (Detected or Not Detected)	Clostridia (log cfu/g)	Lactic Acid Bacteria (log cfu/g)	Pseudomonads (log cfu/g)
12/10/2010	52	N	1.7	4.1	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
12/10/2010	52	N	1.5	4.3	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
12/10/2010	52	N	1.5	4.1	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
12/10/2010	52	N	1.6	4.0	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
12/10/2010	52	N	1.5	4.1	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
15/10/2010	54	Y	1.9	2.2	7.5	5.0	<1.0	5.0	<1.3	ND	<1.0	2.9	4.6
15/10/2010	54	Y	1.3	2.6	6.3	3.6	<1.0	3.6	<1.3	ND	<1.0	<1.0	4.5
15/10/2010	54	Y	1.6	2.1	7.0	4.1	<1.0	4.1	<1.3	ND	<1.0	<1.0	3.5
15/10/2010	54	Y	1.2	3	6.5	4.1	<1.0	3.7	<1.3	ND	<1.0	2.6	4.3
15/10/2010	54	Y	-0.7	2.4	7.2	4.0	<1.0	3.8	<1.3	ND	<1.0	3.0	4.5
28/10/2010	48	Y	2.6	2.0	6.2	3.4	<1.0	<2.0	<1.3	ND	2.2	1.8	3.8
28/10/2010	48	Y	1.7	1.4	7.0	2.8	<1.0	2.8	<1.3	ND	<1.0	2.0	3.6
28/10/2010	48	Y	1.7	1.2	6.4	2.6	<1.0	2.6	<1.3	ND	1.0	1.3	3.6
28/10/2010	48	Y	0.3	0.1	6.2	2.0	<1.0	<2.0	<1.3	ND	<1.0	1.5	3.8
28/10/2010	48	Y	0.6	0.3	6.6	2.7	<1.0	2.3	<1.3	ND	<1.0	3.4	3.6
24/11/2010	58	Y	0.2	5.3	<3.0	3.6	<1.0	-	<1.3	ND	<1.0	<1.0	-
24/11/2010	58	Y	1.3	5.3	3.8	3.3	<1.0	-	<1.3	ND	<1.0	<1.0	-
24/11/2010	58	Y	1.5	5.6	3.9	3.6	<1.0	-	<1.3	ND	<1.0	<1.0	-
24/11/2010	58	Y	1.4	5.1	4.3	3.7	<1.0	-	<1.3	ND	<1.0	<1.0	-
24/11/2010	58	Y	0.3	5.5	<3.0	3.6	<1.0	-	<1.3	ND	<1.0	<1.0	-
02/12/2010	55	Y	1.9	3.7	6.4	3.8	<1.0	3.8	<1.3	ND	<1.0	3.0	2.6
02/12/2010	55	Y	1.2	4.1	5.7	3.3	<1.0	3.2	<1.3	ND	<1.0	2.9	5.0
02/12/2010	55	Y	1	3.9	5.8	3.8	1.0	4.0	<1.3	ND	<1.0	3.8	4.8
02/12/2010	55	Y	1.2	4.2	4.9	3.2	<1.0	3.4	<1.3	ND	<1.0	3.0	4.9
02/12/2010	55	Y	1.8	4.3	6.5	6.6	<1.0	3.6	<1.3	ND	<1.0	3.4	5.2
07/12/2010	51	Y	-0.2	4.8	7.6	4.1	<1.0	3.7	<1.3	ND	<1.0	3.4	5.2
07/12/2010	51	Y	-0.3	5.2	7.9	3.4	<1.0	4.1	<1.3	ND	<1.0	3.3	4.6
07/12/2010	51	Y	-0.1	4.6	>8.0	3.6	<1.0	3.9	<1.3	ND	<1.0	3.4	5.3
07/12/2010	51	Y	-0.9	4.7	7.9	3.5	<1.0	3.8	<1.3	ND	<1.0	4.0	4.0
07/12/2010	51	Y	-0.7	4.5	>8.0	3.4	<1.0	3.6	<1.3	ND	<1.0	4.9	4.6
08/12/2010	56	Y	0.3	5.5	6.1	2.0	<1.0	2.7	<1.3	ND	<1.0	2.5	4.2
08/12/2010	56	Y	-0.4	4.6	5.0	2.5	<1.0	2.8	<1.3	ND	<1.0	2.7	4.2
08/12/2010	56	Y	-0.7	4.8	6.3	2.8	<1.0	2.5	<1.3	ND	<1.0	2.5	4.6
08/12/2010	56	Y	-0.3	5	8.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	2.6	5.6
08/12/2010	56	Y	-0.4	4.7	8.0	3.0	<1.0	3.3	<1.3	ND	<1.0	2.4	4.4

(-) data not supplied

Kill date	Age (d)	Vacuum packed (Y/N)	Raw material temperature (°C)	Mince temperature (°C)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)	Salmonella (Detected or Not Detected)	Clostridia (log cfu/g)	Lactic Acid Bacteria (log cfu/g)	Pseudomonads (log cfu/g)
09/12/2010	57	Y	2.8	3.7	4.5	2.0	<1.0	<2.0	<1.3	ND	<1.0	1.3	4.0
09/12/2010	57	Y	0.7	4.5	4.7	<2.0	<1.0	2.5	<1.3	ND	<1.0	<1.0	4.0
09/12/2010	57	Y	0.5	4.6	5.6	<2.0	<1.0	2.0	<1.3	ND	<1.0	2.0	3.8
09/12/2010	57	Y	0.1	4.8	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
09/12/2010	57	Y	0.4	4.7	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	1.5	3.9
13/12/2010	57	Y	3.0	4.9	4.0	3.4	<1.0	3.9	<1.3	ND	<1.0	1.5	1.3
13/12/2010	57	Y	3.1	4.8	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
13/12/2010	57	Y	3.2	4.1	7.5	3.2	<1.0	2.3	<1.3	ND	<1.0	<1.0	<1.3
13/12/2010	57	Y	3.7	4.8	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
13/12/2010	57	Y	3.4	4.2	<3.0	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
16/12/2010	56	Y	-0.7	4.9	4.2	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
16/12/2010	56	Y	-1.1	5.2	4.6	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
16/12/2010	56	Y	-1	5.5	4.3	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
16/12/2010	56	Y	-0.8	5.3	4.1	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
16/12/2010	56	Y	-1	5.3	4.5	<2.0	<1.0	<2.0	<1.3	ND	<1.0	<1.0	<1.3
17/12/2010	61	Y	1.4	5.3	7.2	4.3	<1.0	4.1	<1.3	ND	<1.0	4.9	4.1
17/12/2010	61	Y	0.8	4.9	7.7	4.0	1.0	4.3	<1.3	ND	<1.0	3.8	4.3
17/12/2010	61	Y	0.7	4.8	7.8	4.4	<1.0	4.3	<1.3	ND	<1.0	3.3	4.6
17/12/2010	61	Y	0.3	4.9	7.8	4.4	<1.0	4.4	<1.3	ND	<1.0	4.4	4.7
17/12/2010	61	Y	0.5	4.7	7.7	4.1	<1.0	4.2	<1.3	ND	<1.0	4.1	2.3
20/12/2010	58	Y	2.4	5.3	8.0	3.7	<1.0	3.7	<1.3	ND	<1.0	2.9	4.6
20/12/2010	58	Y	1.8	5.6	7.8	4.1	1.3	4.2	<1.3	ND	<1.0	3.4	4.5
20/12/2010	58	Y	2.2	5.2	6.9	4.0	1.5	4.1	<1.3	ND	<1.0	4.5	4.2
20/12/2010	58	Y	1.3	5.1	7.8	4.1	1.6	4.2	<1.3	ND	<1.0	4.1	5.0
20/12/2010	58	Y	2.6	5.1	7.6	7.6	1.0	4.1	<1.3	ND	<1.0	3.4	4.3
29/12/2010	55	Y	0.5	4.4	6.7	3.0	<1.0	2.8	<1.3	ND	<1.0	3.6	4.5
29/12/2010	55	Y	0.1	5.1	6.6	3.3	<1.0	3.0	<1.3	ND	<1.0	3.7	4.5
29/12/2010	55	Y	0.1	3.9	6.6	2.8	<1.0	2.5	<1.3	ND	<1.0	3.3	4.6
29/12/2010	55	Y	-0.4	4.6	7.3	2.7	<1.0	3.1	<1.3	ND	<1.0	3.3	4.8
29/12/2010	55	Y	0.7	5	6.5	3.1	<1.0	3.0	<1.3	ND	<1.0	3.3	4.6
06/01/2011	57	Y	2.7	5.4	5.1	4.0	<1.0	3.8	<1.3	ND	<1.0	<1.0	5.2
06/01/2011	57	Y	2.3	5.7	>8.0	4.2	<1.0	3.0	<1.3	ND	<1.0	<1.0	5.6
06/01/2011	57	Y	2.8	5.5	>8.0	4.0	<1.0	3.3	<1.3	ND	<1.0	<1.0	5.5
06/01/2011	57	Y	2.3	5.3	>8.0	4.4	<1.0	4.2	<1.3	ND	<1.0	<1.0	6.9
06/01/2011	57	Y	2.7	5.1	7.5	5.0	<1.0	5.9	<1.3	ND	<1.0	<1.0	7.1

Kill date	Age (d)	Vacuum packed (Y/N)	Raw material temperature (°C)	Mince temperature (°C)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Coliforms (log cfu/g)	Staphylococcus aureus (log cfu/g)	Salmonella (Detected or Not Detected)	Clostridia (log cfu/g)	Lactic Acid Bacteria (log cfu/g)	Pseudomonads (log cfu/g)
10/01/2011	56	Y	1.2	4.5	7.5	4.4	1.0	4.4	<1.3	ND	<1.0	4.4	5.5
10/01/2011	56	Y	1.9	4.2	>6.0	3.5	<1.0	3.3	<1.3	ND	<1.0	3.1	4.6
10/01/2011	56	Y	1.8	4.9	7.4	3.6	<1.0	3.7	<1.3	ND	<1.0	2.7	5.0
10/01/2011	56	Y	2	4.2	7.4	3.8	<1.0	4.1	<1.3	ND	<1.0	4.4	5.6
10/01/2011	56	Y	1.7	4.1	7.4	4.1	<1.0	4.2	<1.3	ND	<1.0	4.9	5.7
14/01/2011	59	Y	1.4	5.4	6.7	3.5	<1.0	4.4	<1.3	ND	<1.0	3.6	5.1
14/01/2011	59	Y	0.9	4.9	6.8	4.5	<1.0	4.6	<1.3	ND	<1.0	4.4	5.6
14/01/2011	59	Y	0.8	5	6.0	3.7	<1.0	4.3	<1.3	ND	<1.0	3.3	4.6
14/01/2011	59	Y	1.6	5.1	6.2	3.8	<1.0	4.7	<1.3	ND	<1.0	3.5	3.5
14/01/2011	59	Y	0.6	5.1	6.6	3.6	1.0	4.6	<1.3	ND	<1.0	3.0	3.0
17/01/2011	57	Y	1.4	5.3	>8.0	4.6	<1.0	4.7	<1.3	ND	<1.0	<1.0	2.9
17/01/2011	57	Y	1.4	5.5	>8.0	4.7	<1.0	4.2	<1.3	ND	<1.0	<1.0	3.2
17/01/2011	57	Y	1.7	5.5	7.0	4.3	<1.0	4.5	<1.3	ND	<1.0	<1.0	1.9
17/01/2011	57	Y	1.6	5.8	>8.0	4.3	<1.0	4.5	<1.3	ND	<1.0	1.5	3.3
17/01/2011	57	Y	1.7	5.8	>8.0	4.6	<1.0	4.6	<1.3	ND	<1.0	1.0	3.0
24/01/2011	59	Y	2.4	4.4	7.2	3.8	<1.0	3.7	<1.3	ND	<1.0	2.1	5.0
24/01/2011	59	Y	2.5	4.6	6.9	3.6	<1.0	3.7	<1.3	ND	<1.0	4.2	5.1
24/01/2011	59	Y	2.6	5.3	5.1	3.7	<1.0	4.0	<1.3	ND	<1.0	4.2	5.1
24/01/2011	59	Y	2.5	4.6	7.0	3.7	<1.0	3.9	<1.3	ND	<1.0	2.3	5.1
24/01/2011	59	Y	2.6	5.3	6.9	3.9	<1.0	3.9	<1.3	ND	<1.0	2.3	4.6
01/03/2011	57	Y	3.2	4.3	5.6	3.3	<1.0	3.5	<1.3	ND	<1.0	<1.0	4.3
01/03/2011	57	Y	3.1	4.1	6.9	3.6	<1.0	3.5	<1.3	ND	<1.0	<1.0	4.4
01/03/2011	57	Y	3	4	6.0	3.5	<1.0	3.6	<1.3	ND	<1.0	<1.0	4.5
01/03/2011	57	Y	3	4.2	5.5	3.3	<1.0	3.3	<1.3	ND	<1.0	<1.0	4.1
01/03/2011	57	Y	3.3	4.4	5.5	3.6	<1.0	3.3	<1.3	ND	<1.0	<1.0	4.0
04/03/2011	60	Y	1.1	4.1	6.1	4.0	<1.0	3.6	<1.3	ND	<1.0	3.5	5.1
04/03/2011	60	Y	0.7	4.2	6.9	3.8	<1.0	2.7	<1.3	ND	<1.0	3.9	5.1
04/03/2011	60	Y	1.1	4	5.8	2.3	<1.0	2.5	<1.3	ND	<1.0	2.9	5.3
04/03/2011	60	Y	1.3	4.3	5.9	3.2	<1.0	3.1	<1.3	ND	<1.0	3.9	4.6
04/03/2011	60	Y	1	4.2	5.9	3.5	<1.0	3.9	<1.3	ND	<1.0	3.6	<1.3

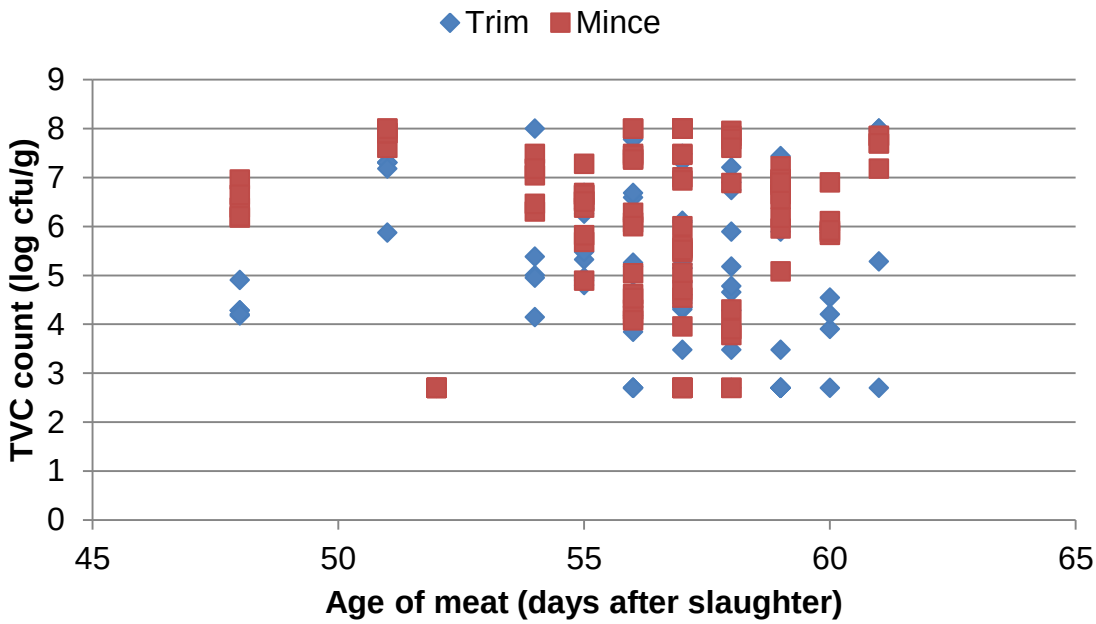

Figure 65. Comparison of reported TVCs on trim and mince produced from NZ lamb (20 batches, 5 replicates per batch) related to age of meat prior to mincing (data supplied by P4)

3.3.1.4 Turkey

Data provided by project partner P3 on Total Viable counts on mince together with age of mince at time of mincing for turkey mince is shown in Figure 66. This data show only a slight increase in Total Viable count with age (1 to 4 days) of meat at mincing.

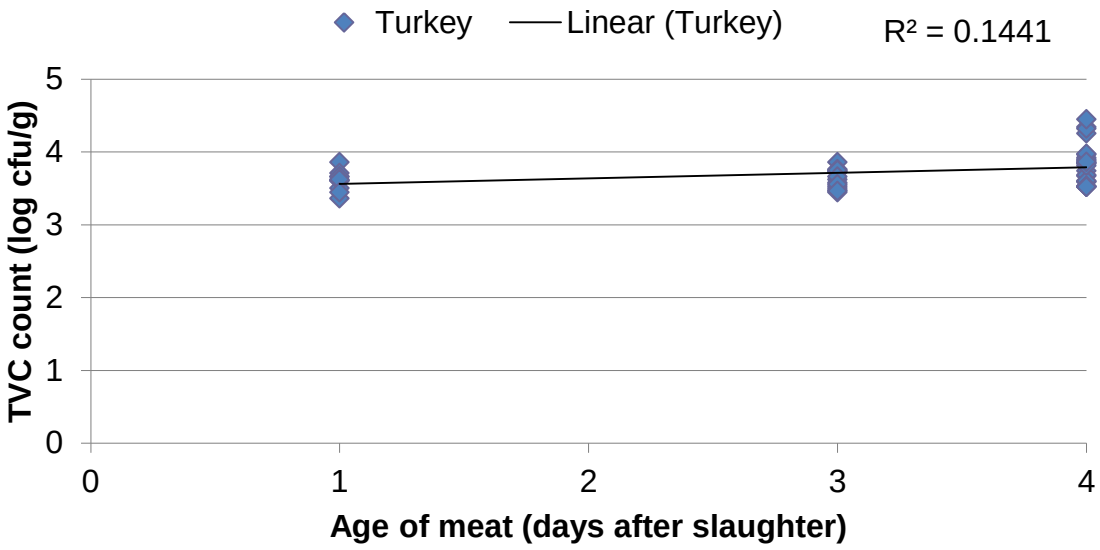

Figure 66. Comparison of reported TVCs (n=51) on mince produced from turkey related to age of meat prior to mincing (data supplied by P3)

Data provided by project partner P3 on *E. coli* counts on mince together with age of mince at time of mincing for turkey mince is shown in Figure 67. This data appears to show that higher counts are proportionately related to age of meat at mincing; however overall there is no relationship between age (1 to 4 days) of meat at mincing and *E. coli* count.

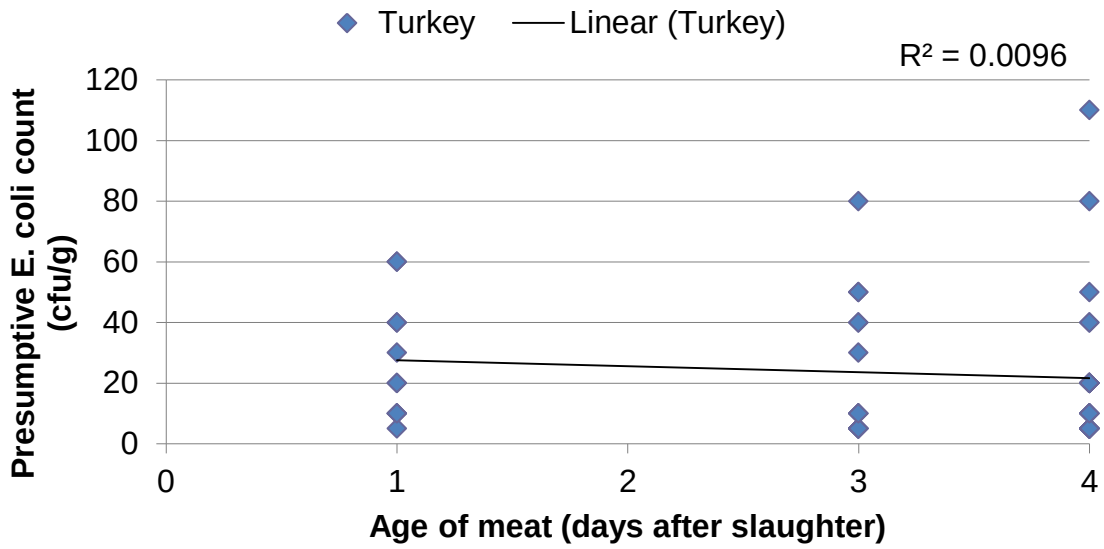

Figure 67. Comparison of reported presumptive *E. coli* counts (n=51) on mince produced from turkey related to age of meat prior to mincing (16/51 were <10 cfu g^{-1}, shown as 5 on graph) (data supplied by P3)

Data provided by project partner P3 on *Pseudomonas* counts on mince together with age of mince at time of mincing for turkey mince is shown in Figure 68. This data shows a slight increase in *Pseudomonas* counts with age (1 to 6 days) of meat at mincing.

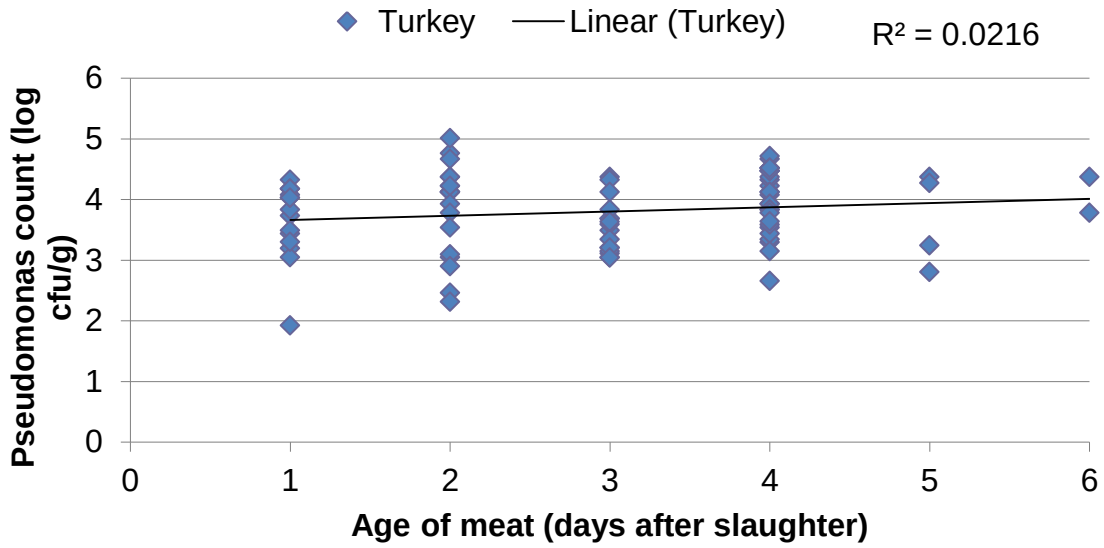

Figure 68. Comparison of reported *Pseudomonas* counts (n=82) on mince produced from turkey related to age of meat prior to mincing (data supplied by P3)

The following tracked data was measured according to the project protocol (Appendix 5) and provided by P3 for turkey. An overall comparison of counts is shown in Table 33. Matched carcass, trim and mince microbiological counts and process parameters are shown in Table 34, Table 35 and Table 36, respectively. This data has not been plotted because unfortunately all of the meat was with the current limits on age when minced.

Table 33. Overall comparison of turkey mince data (data supplied by P3)

	Age (d)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Salmonella (Detected or Not Detected)
Min	1.0	3.1	1.0	0.7	
Max	3.0	4.5	2.3	1.6	
Mean	1.3	3.7	1.8	1.0	
Number	60	60	60	55	55
Number detected *					3
% *					5.5

*Salmonella data only

Table 34. Tracked turkey carcass data (data supplied by P3)

Kill date	Carcass Location	Chilling time (h)	Chiller temperature (°C)	TVC (log cfu/cm^2)	Enterobacteriaceae (log cfu/cm^2)
09/03/11	Post spin chill	-	-	3.6	<1.0
09/03/11	Post spin chill	-	-	4.9	<1.0
09/03/11	Post spin chill	-	-	3.6	1.0
09/03/11	Post spin chill	-	-	3.2	<1.0
09/03/11	Post spin chill	-	-	3.1	1.0
09/03/11	Debone chute	-	-	2.7	<1.0
09/03/11	Debone chute	-	-	4.3	1.9
09/03/11	Debone chute	-	-	3.5	1.0
09/03/11	Debone chute	-	-	<2.3	<1.0
09/03/11	Debone chute	-	-	3.0	1.3
23/03/11	Post spin chill	-	-	4.8	<1.0
23/03/11	Post spin chill	-	-	5.0	1.8
23/03/11	Post spin chill	-	-	5.0	1.8
23/03/11	Post spin chill	-	-	4.6	2.6
23/03/11	Post spin chill	-	-	4.6	1.8
23/03/11	Debone chute	-	-	4.1	<1.0
23/03/11	Debone chute	-	-	3.7	<1.0
23/03/11	Debone chute	-	-	4.2	1.0
23/03/11	Debone chute	-	-	3.9	1.5
23/03/11	Debone chute	-	-	3.6	<1.0
30/03/11	Debone tip	-	-	3.6	<1.0
30/03/11	Debone tip	-	-	3.3	1.0
30/03/11	Debone tip	-	-	3.4	1.0
30/03/11	Debone tip	-	-	3.4	1.0
30/03/11	Debone tip	-	-	4.8	2.3
19/04/11	Post spin chill	-	-	4.4	2.0
19/04/11	Post spin chill	-	-	4.1	1.9
19/04/11	Post spin chill	-	-	4.8	2.4
19/04/11	Post spin chill	-	-	3.4	<1.0
19/04/11	Post spin chill	-	-	3.4	<1.0

(-) data not supplied

Kill date	Carcass Location	Chilling time (h)	Chiller temperature (°C)	TVC (log cfu/cm^2)	Enterobacteriaceae (log cfu/cm^2)
19/04/11	Debone chute	-	-	4.5	1.8
19/04/11	Debone chute	-	-	3.1	1.6
19/04/11	Debone chute	-	-	3.9	1.8
19/04/11	Debone chute	-	-	3.0	1.0
19/04/11	Debone chute	-	-	3.2	<1.0
02/05/11	Post spin chill	-	-	3.0	1.0
02/05/11	Post spin chill	-	-	3.9	2.0
02/05/11	Post spin chill	-	-	3.5	1.3
02/05/11	Post spin chill	-	-	3.4	1.0
02/05/11	Post spin chill	-	-	3.2	1.0
02/05/11	Debone chute	-	-	2.3	1.0
02/05/11	Debone chute	-	-	4.0	2.0
02/05/11	Debone chute	-	-	3.0	<1.0
02/05/11	Debone chute	-	-	3.8	2.0
02/05/11	Debone chute	-	-	3.3	1.0
18/05/11	Post spin chill	-	-	3.6	1.3
18/05/11	Post spin chill	-	-	3.2	1.3
18/05/11	Post spin chill	-	-	4.0	1.8
18/05/11	Post spin chill	-	-	4.0	1.5
18/05/11	Post spin chill	-	-	3.9	2.1
18/05/11	Debone tip	-	-	3.1	<1.0
18/05/11	Debone tip	-	-	3.3	1.3
18/05/11	Debone tip	-	-	3.4	<1.0
18/05/11	Debone tip	-	-	3.6	1.0
18/05/11	Debone tip	-	-	3.6	<1.0
12/07/11	Debone tip	-	-	3.2	<1.0
12/07/11	Debone tip	-	-	3.5	1.6
12/07/11	Debone tip	-	-	3.5	1.0
12/07/11	Debone tip	-	-	2.6	<1.0
12/07/11	Debone tip	-	-	4.0	2.5
18/07/11	Post spin chill	-	-	3.9	2.4
18/07/11	Post spin chill	-	-	3.6	2.1
18/07/11	Post spin chill	-	-	3.6	2.2
18/07/11	Post spin chill	-	-	3.3	1.0
18/07/11	Post spin chill	-	-	3.9	2.4

(-) data not supplied

Kill date	Carcass Location	Chilling time (h)	Chiller temperature (°C)	TVC (log cfu/cm^2)	Enterobacteriaceae (log cfu/cm^2)
18/07/11	Debone tip	-	-	4.0	4.0
18/07/11	Debone tip	-	-	5.3	3.7
18/07/11	Debone tip	-	-	3.4	2.9
18/07/11	Debone tip	-	-	4.5	3.5
18/07/11	Debone tip	-	-	4.7	3.9
25/07/11	Debone tip	-	-	6.3	1.8
25/07/11	Debone tip	-	-	6.5	2.0
25/07/11	Debone tip	-	-	5.6	1.5
25/07/11	Debone tip	-	-	5.5	2.0
25/07/11	Debone tip	-	-	5.9	2.5
11/08/11	Debone tip	-	-	4.5	1.8
11/08/11	Debone tip	-	-	3.9	1.5
11/08/11	Debone tip	-	-	3.9	1.3
11/08/11	Debone tip	-	-	3.3	<1.0
11/08/11	Debone tip	-	-	5.3	3.0

(-) data not supplied

Table 35. Tracked turkey primal/trim data (data supplied by P3)

Details (Primal, Trim etc)	Kill date	Age (d)	Storage temperature (°C)	Vacuum packed (Y/N)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)
Deboned thigh	09/03/11	2	-	N	4.4	2.1	-
Deboned thigh	09/03/11	2	-	N	4.6	2.2	-
Deboned thigh	09/03/11	2	-	N	3.7	2.2	-
Deboned thigh	09/03/11	2	-	N	3.6	1.8	-
Deboned thigh	09/03/11	2	-	N	4.0	2.3	-
Deboned thigh	23/03/11	2	-	N	4.4	3.0	-
Deboned thigh	23/03/11	2	-	N	4.3	2.3	-
Deboned thigh	23/03/11	2	-	N	4.3	2.0	-
Deboned thigh	23/03/11	2	-	N	3.6	2.2	-
Deboned thigh	23/03/11	2	-	N	4.1	2.3	-
Deboned thigh	30/03/11	2	-	N	3.8	2.5	-
Deboned thigh	30/03/11	2	-	N	3.8	2.3	-
Deboned thigh	30/03/11	2	-	N	3.4	2.2	-
Deboned thigh	30/03/11	2	-	N	3.7	2.3	-
Deboned thigh	30/03/11	2	-	N	3.8	2.3	-
Deboned thigh	19/04/11	1	-	N	3.6	1.3	-
Deboned thigh	19/04/11	1	-	N	3.8	2.2	-
Deboned thigh	19/04/11	1	-	N	3.8	2.0	-
Deboned thigh	19/04/11	1	-	N	3.7	1.7	-
Deboned thigh	19/04/11	1	-	N	3.5	1.8	-
Deboned thigh	02/05/11	2	-	N	3.9	1.6	-
Deboned thigh	02/05/11	2	-	N	4.0	2.3	-
Deboned thigh	02/05/11	2	-	N	3.8	2.0	-
Deboned thigh	02/05/11	2	-	N	3.7	1.7	-
Deboned thigh	02/05/11	2	-	N	4.1	2.2	-
Deboned thigh	01/06/11	1	-	N	3.4	1.5	-
Deboned thigh	01/06/11	1	-	N	3.0	1.6	-
Deboned thigh	01/06/11	1	-	N	3.0	<1.0	-
Deboned thigh	01/06/11	1	-	N	2.8	2.0	-
Deboned thigh	01/06/11	1	-	N	3.9	2.2	-

(-) data not supplied

Details (Primal, Trim etc)	Kill date	Age (d)	Storage temperature (°C)	Vacuum packed (Y/N)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)
Deboned thigh	15/07/11	4	-	N	3.6	2.3	2.0
Deboned thigh	15/07/11	4	-	N	3.8	2.4	2.3
Deboned thigh	15/07/11	4	-	N	3.9	2.4	2.0
Deboned thigh	15/07/11	4	-	N	3.7	2.2	1.0
Deboned thigh	15/07/11	4	-	N	3.9	2.3	1.0
Deboned thigh	17/08/11	1	-1	N	3.4	1.5	-
Deboned thigh	17/08/11	1	-1.2	N	3.5	1.8	-
Deboned thigh	17/08/11	1	-0.9	N	3.7	1.6	-
Deboned thigh	17/08/11	1	-0.8	N	4.0	1.9	-
Deboned thigh	17/08/11	1	-0.9	N	3.6	1.5	-
Deboned thigh	23/08/11	2	0.1	N	3.8	2.1	-
Deboned thigh	23/08/11	2	-0.3	N	3.6	2.0	-
Deboned thigh	23/08/11	2	0.1	N	3.5	2.2	-
Deboned thigh	23/08/11	2	-0.6	N	3.6	1.6	-
Deboned thigh	23/08/11	2	-0.4	N	3.7	2.0	-
Deboned thigh	20/09/11	1	2.7	N	3.9	2.0	-
Deboned thigh	20/09/11	1	2.4	N	4.0	2.3	-
Deboned thigh	20/09/11	1	1.3	N	3.4	1.8	-
Deboned thigh	20/09/11	1	1	N	3.3	<1.0	-
Deboned thigh	20/09/11	1	2.5	N	4.1	2.1	-

(-) data not supplied

Table 36. Tracked turkey mince data (data supplied by P3)

Kill date	Age (d)	Vacuum packed (Y/N)	Raw material temperature (°C)	Mince temperature (°C)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Salmonella (Detected or Not Detected)
09/03/11	1	MAP	-	-	3.5	1.8	1.0	D
09/03/11	1	MAP	-	-	3.4	2.0	1.5	D
09/03/11	1	MAP	-	-	4.5	1.6	1.5	D
09/03/11	1	MAP	-	-	3.7	2.0	1.5	ND
09/03/11	1	MAP	-	-	3.6	1.8	1.6	ND
23/03/11	1	MAP	-	-	3.6	2.0	<1.0	ND
23/03/11	1	MAP	-	-	3.4	1.7	<1.0	ND
23/03/11	1	MAP	-	-	3.6	1.8	<1.0	ND
23/03/11	1	MAP	-	-	3.4	1.9	1.3	ND
23/03/11	1	MAP	-	-	3.6	1.8	1.3	ND
30/03/11	1	MAP	-	-	3.8	2.1	1.0	ND
30/03/11	1	MAP	-	-	3.7	1.3	1.0	ND
30/03/11	1	MAP	-	-	3.8	2.3	<1.0	ND
30/03/11	1	MAP	-	-	3.8	1.9	<1.0	ND
30/03/11	1	MAP	-	-	3.6	2.2	1.0	ND
19/04/11	1	MAP	-	-	3.5	2.0	<1.0	ND
19/04/11	1	MAP	-	-	3.6	1.8	<1.0	ND
19/04/11	1	MAP	-	-	3.4	1.6	<1.0	ND
19/04/11	1	MAP	-	-	3.5	1.6	<1.0	ND
19/04/11	1	MAP	-	-	3.5	1.8	<1.0	ND
02/05/11	1	MAP	-	-	3.4	2.1	<1.0	ND
02/05/11	1	MAP	-	-	3.1	1.9	<1.0	ND
02/05/11	1	MAP	-	-	3.3	1.9	1.0	ND
02/05/11	1	MAP	-	-	3.3	1.7	<1.0	ND
02/05/11	1	MAP	-	-	3.3	1.7	<1.0	ND
01/06/11	1	MAP	-	-	3.5	1.6	<1.0	-
01/06/11	1	MAP	-	-	3.7	1.5	<1.0	-
01/06/11	1	MAP	-	-	3.5	1.6	<1.0	-
01/06/11	1	MAP	-	-	3.7	1.7	<1.0	-
01/06/11	1	MAP	-	-	3.6	1.8	1.6	-
15/07/11	3	MAP	-	-	3.8	2.1	1.5	ND
15/07/11	3	MAP	-	-	4.0	2.2	1.6	ND
15/07/11	3	MAP	-	-	4.1	2.0	<1.0	ND
15/07/11	3	MAP	-	-	3.8	1.7	1.0	ND
15/07/11	3	MAP	-	-	3.8	2.2	1.6	ND

(-) data not supplied

Kill date	Age (d)	Vacuum packed (Y/N)	Raw material temperature (°C)	Mince temperature (°C)	TVC (log cfu/g)	Enterobacteriaceae (log cfu/g)	E. coli (log cfu/g)	Salmonella (Detected or Not Detected)
22/07/11	3	MAP	-	-	3.6	1.7	1.3	ND
22/07/11	3	MAP	-	-	3.7	2.1	1.0	ND
22/07/11	3	MAP	-	-	3.7	1.8	1.3	ND
22/07/11	3	MAP	-	-	3.6	1.7	1.3	ND
22/07/11	3	MAP	-	-	3.6	1.9	1.5	ND
09/08/11	1	MAP	-	-	3.7	1.3	<1.0	ND
09/08/11	1	MAP	-	-	3.8	1.7	<1.0	ND
09/08/11	1	MAP	-	-	3.7	1.7	<1.0	ND
09/08/11	1	MAP	-	-	3.7	2.0	1.0	ND
09/08/11	1	MAP	-	-	3.8	1.8	1.0	ND
16/08/11	1	MAP	-	-0.8	3.7	1.9	<1.0	ND
16/08/11	1	MAP	-	-0.7	3.4	1.7	<1.0	ND
16/08/11	1	MAP	-	-1	3.6	1.9	<1.0	ND
16/08/11	1	MAP	-	-0.9	3.7	1.8	<1.0	ND
16/08/11	1	MAP	-	-1	3.6	1.8	1.0	ND
23/08/11	1	MAP	-	1.1	3.7	1.5	-	ND
23/08/11	1	MAP	-	1	3.6	1.3	-	ND
23/08/11	1	MAP	-	1	3.6	1.0	-	ND
23/08/11	1	MAP	-	0.7	3.8	1.7	-	ND
23/08/11	1	MAP	-	1.1	3.5	1.6	-	ND
19/09/11	1	MAP	-	4.2	4.0	1.8	1.5	ND
19/09/11	1	MAP	-	2.5	4.0	1.5	1.3	ND
19/09/11	1	MAP	-	4.1	4.1	1.8	1.0	ND
19/09/11	1	MAP	-	3.4	4.0	1.5	1.3	ND
19/09/11	1	MAP	-	4.1	4.0	1.6	1.3	ND

(-) data not supplied

3.4 Storage and distribution

The following storage and distribution parameters were collected/supplied from participating meat processors (Table 37):

Table 37. Storage and distribution parameters

		Storage			Distribution		
		Room temperature (°C)	Product temperature (°C)	Storage time (h)	Vehicle temperature (°C)	Product temperature (°C)	Storage time (h)
Beef (M1)	Max	2	2	48	3	2	12 (in vehicle)
	Min	0	0	1	0	0	4 (in vehicle)
	Mean	1	1	12	1	1	6 (in vehicle)
Beef (M2)	Max	2	2	48	2	2	5
	Min	-2	-2	1	0	0	1
	Mean	0	0	24	0	0	3
Beef (M3)	Max	+2	+2	48	+2	+2	12
	Min	-2	-2	0	-2	-2	4
	Mean	0	0	24	0	0	7
Pork (P4)	Max	0	-	48	0	-	-
	Min	-2	-	-	-1	-	-
	Mean	-	-	-	-	-	-
UK lamb (P4)	Max	0	-	48	0	-	-
	Min	-2	-		-1	-	-
	Mean	-	0-1			0	-
UK lamb (M2)	Max	2	2	48	2	2	5
	Min	-2	-2	1	0	0	1
	Mean	0	0	24	0	0	3
NZ lamb (P4)	Max	0	-	48	0		-
	Min	-2	-	-	-1	-	-
	Mean	-	0-1	-	-	0	-

(-) data not supplied

The following example from one of the participating meat processors shows ‘typical’ cooling curves for packs of mince initially at 6°C in a Dispatch Chill (Figure 69). The data shows that mince temperatures after packing can be rapidly returned to <2°C from 5-6°C within 2 hours in the dispatch chill

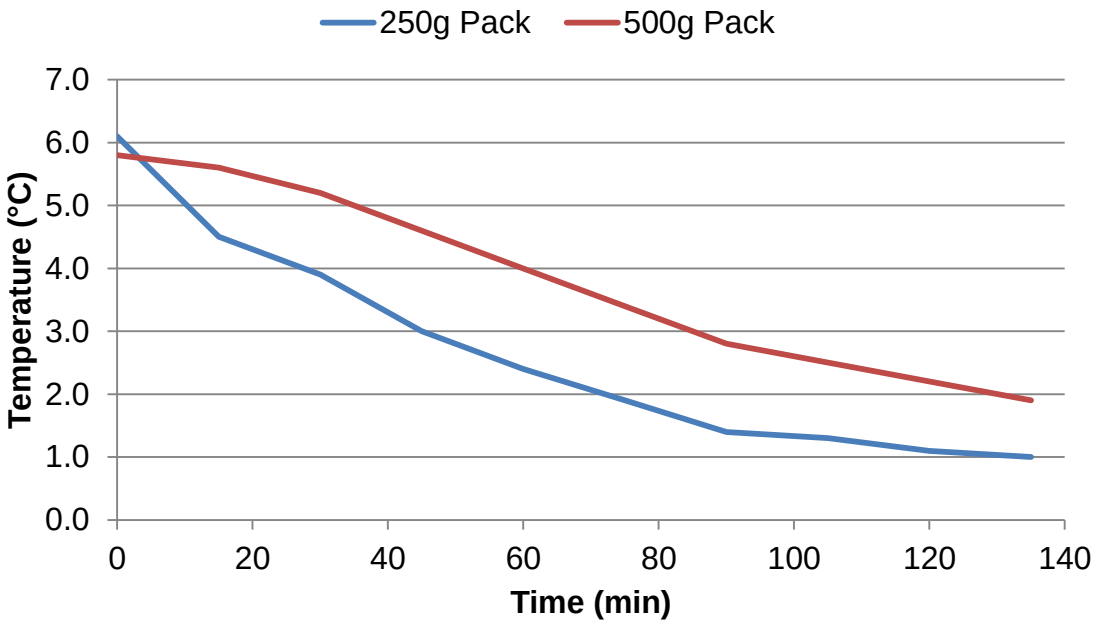

Figure 69. Example of meat temperature fall of mince packed at 6°C in a Dispatch Chill (data supplied by P4)

3.5 Retail

The following retail parameters were collected/supplied from participating meat processors (Table 38). In general there is an assumption that products temperatures are maintained at <2°C during initial storage and distribution operations. They will remain between 3 and 8°C during retail display and stored at up to 10°C in domestic refrigerators.

Table 38. Retail parameters

		Display/domestic conditions		Basis of evaluation, assumed consumer abuse conditions
		Room temperature (°C)	Shelf-life (d) Post-pack (customer)	
Beef (M1)	Max	8	-	Customer codes of practice for shelf life determination, generally 0-2°C for 2 days and then 5-8°C for remainder of life with a 2 hour abuse of approx 20°C.
	Min	6	-	
Beef (M2)	Max	-	9	First 2 days stored at 0-2°C, Days 3-8 stored at 3-5°C, last 2 days stored at 8-10°C
	Min	-	8	
Beef (M3)	Max	-	9	Repeated shelf life testing evaluation, simulating customer abuse including storage at 8 – 10°C for last 2 days.
	Min	-	5	
UK lamb (P4)	Max	-	7 (5)	
	Min	-	-	
UK lamb (M2)	Max	-	9	First 2 days stored at 0-2°C, Days 3-8 stored at 3-5°C, last 2 days stored at 8-10°C
	Min	-	8	
NZ lamb (P4)	Max	-	5 (3)	
	Min	-	-	

(-) data not supplied

3.6 Conclusions

Overall the collected/supplied data from participating meat processors shows that:

3.6.1 Primary chilling

- Temperature data supplied shows that beef, pork, UK lamb, NZ lamb and turkey carcasses/sides are chilled to <2°C in 48, 20, 22, 12 and 16 hours, respectively. These times correlate with our own experience and knowledge of industry practices and scientifically derived chilling times, and suggests that most UK meat processors are chilling meat in an appropriate time that would seem to meet an acceptable good practice.
- An analysis of temperature record data supplied by participating UK meat processors using the Australian Refrigeration Index Calculator model indicates that effective chilling that prevents growth of *E. coli* can be achieved in UK abattoirs for all species.
- The Australian Refrigeration Index Calculator model also shows that delayed primary chilling of beef sides, where the chiller operates at approximately 10°C during loading (to avoid cold-shortening), can be undertaken with no risk of growth of *E. coli*. However, this will depend on procedures being used. We would advise that any beef processors that are operating a delayed primary chilling regime should determine the effectiveness of their chilling regime using the Australian Refrigeration Index Calculator model and comparing to the RI criteria to assess whether this poses any risk.

3.6.2 Storage (Ageing)

- The data provided by participating UK processors in this study show that beef, pork, UK lamb, New Zealand lamb and turkey meat may be may be stored for up to 59, 18, 26, 67 and 6 days after slaughter, respectively, prior to mincing.
- Data provided indicates that product temperatures for all meats are maintained at <2°C during most storage/ageing operations, which would seem to be an acceptable good practice.

3.6.3 Cutting and mincing

- Data supplied shows that product temperatures rarely exceed 5°C during what is typically a 2 to 3 hour mincing operation.
- Overall the data provided shows only a slight increase in Total Viable, *E. coli* or Enterobacteriaceae count with age of meat at mincing and in a number of cases counts are actually lower on mince from aged meat than mince from unaged. Similar results were reported by **Crowley *et al*. (2010)**.
- Aerobic plate count (30°C incubation) may be a useful measure of the bacteriological status of carcasses after chilling or during storage (ICMSF, 1998). Comparisons of overall pooled mean data of TVCs on beef, pork, UK lamb, NZ lamb and turkey mince related to age of meat at time of mincing supplied by participating UK meat processors are shown in Figure 22, Figure 23, Figure 24, Figure 25, and Figure 26, respectively. This data, surprisingly, shows that although levels of TVCs on beef, lamb and turkey show a slight increase with age of meat prior to mincing it is very slight. In the case of pork that data supplied actually shows a decrease in levels of TVCs with age of meat prior to mincing.
- From the limited data supplied there appears to be no evidence that the prevalence of salmonella is any higher on mince produced from aged meat than from unaged meat.

3.6.4 Storage and distribution

- Data supplied shows that mince temperatures after packing can be rapidly returned to <2°C from 5-6°C within 2 hours in dispatch chill.
- Data supplied shows products temperatures are maintained at <2°C during most storage and distribution operations (in compliance with current legislation).

3.6.5 Retail

- Where supplied (Table 38), data from participating UK meat processors indicate that use-by times are calculated on an assumption that products will be held in retail display for up to 5 days at temperatures of 3 to 5°C followed by 2 days consumer storage at 8 to 10°C. The assumption that the consumer will only hold mince for up to 2 days appears a little short.

4. Risk analysis

The following risk analysis is based on that carried out in the review produced for the FSA in 2006. A small number of important papers and reports have been published since the 2006 review (or were not included in the original review) and the 2006 review has been updated and revised to reflect current published scientific opinion (new cited references are in **bold**). Among these is the first study that has specifically addressed the influence of the age of meat prior to mincing on the microbiological quality of the mince produced (**Crowley *et al.*, 2010**). The results of that particular study supports the overall conclusion of the 2006 review that there is no scientific rationale for limiting the storage of meat prior to mince production. The study also identified "advantages in storing beef trimmings in vacuum packs for at least 21 days prior to mincing, in terms of improved mince quality" (**Crowley *et al.*, 2010**). The updated full literature review can be found in the appendix (Section 6).

In the 2006 review it was concluded that based on the known growth temperature limits of pathogenic bacteria associated with meats there was a potential risk of the following psychrotrophic pathogens; *E. coli* H157:H7, *B. cereus*, non-proteolytic *Cl. botulinum*, *L. monocytogenes* and *Y. enterocolitica*, growing on meats during long term chilled storage and ageing under the temperatures used commercially at present. New evidence, reviewed in the revised literature review (Section 6), would indicate that while *L. monocytogenes* may survive on raw meat, there is little evidence that it will grow on either carcass, primal or mince under low refrigerated temperatures, particularly if vacuum packaged or held in 100% CO_2 atmosphere, irrespective of animal species (**Johnson *et al.*, 1988**; **Duffy *et al.*, 2000**; **Sheridan *et al.*, 1995**).

4.1 Assessment of growth/survival of pathogens on meat

In order to set critical limits for temperature-related Critical Control Points (CCPs) in the production of mince from aged meat in their HACCP plans processors and retailers need specific information on the growth of pathogens on their products under the conditions to which their meat will be subjected to. There is a large amount of published data on the effect of temperatures on the growth rates of pathogenic and spoilage organisms under a range of processing conditions (Rosset, 1995; Garcia de Fernando *et al*., 1995; Mead and Hinton, 1996; Doyle, 2002; Tamplin *et al*., 2005). However, it is difficult and time consuming for a processor to extract the specific relevant data from such publications. The ComBase Database, available on-line, consists of thousands of microbial growth and survival curves of specific bacteria on meats. However currently there are gaps and conflicts in the data and it can be difficult to critically assess the data without referring back to the original source. Often it is difficult to identify whether the "meat" is in the form of a carcass, side, quarter, primal, or cut, and whether it was taken immediately from an abattoir or bought from a retailer and is referring to growth under actual/simulated commercial storage, retail display or domestic storage conditions. Despite this wealth of data available on the survival and growth of bacteria on meat there are some areas where information is limited, including:

- The growth/survival of specific pathogens on the surfaces of beef, pork, lamb and poultry carcasses under the refrigerated conditions used commercially during the ageing of meat on the bone.
- The growth/survival of specific pathogens in packaged (vacuum, CO_2 etc.) beef, pork, lamb and poultry primals and sub-primals at the refrigerated conditions used commercially during the ageing and storage of meat.

- The effect of ageing and storing time on the growth/survival of specific pathogens in beef, pork, lamb and poultry mince produced from aged meat.

In contrast here is however considerable information on:

- The growth and survival of specific pathogens in minced meat stored for different times and under different conditions after production.

The available data although limited does allow an assessment of risk of microbial growth during the maturation and storage of meat and production of minced meat from such meat which is described below.

4.2 Pathogens

A number of pathogens capable of causing food poisoning in humans are known to contaminate meat. Assessments of their growth characteristics (based on published information determined on chilled meat or in broth) are listed below. Growth either does not occur at chilled temperatures or where it does occur growth is relatively slow.

4.2.1 Campylobacter *spp.*

***Campylobacter* spp. will not grow at chill (<10°C) temperatures.**

Even poor chilling regimes are unlikely to have much effect on the growth of *Campylobacter* spp. on the surfaces of meat carcasses during primary chilling. An increase of storage time from slaughter to mincing, of properly chilled meat, will not increase the risk from growth of *Campylobacter* spp.

4.2.2 Arcobacter *spp.*

***Arcobacter* spp. will not grow at chill (<10°C) temperatures.**

Forced air chilling has been shown to reduce the incidence of *Arcobacter* spp. on beef carcasses (**De Smet *et al*., 2010**). Poor chilling regimes are unlikely to have much effect on the growth of *Arcobacter* spp. on the surfaces of meat carcasses during primary chilling. An increase of storage time from slaughter to mincing, of properly chilled meat, will not increase the risk from growth of *Arcobacter* spp.

4.2.3 Clostridium perfringens

***Cl. perfringens* will not grow at chill (<10°C) temperatures.**

Poor chilling regimes are unlikely to have much effect on the growth of *Cl. perfringens* on the surfaces of meat carcasses during primary chilling. An increase of storage time from slaughter to mincing, of properly chilled meat, will not increase the risk from growth of *Cl. perfringens*.

4.2.4 Staphylococcus aureus

***Staph. aureus* will not grow in meats at temperatures <7°C.**

Poor chilling regimes, particularly delayed chilled of large carcasses, may have a slight effect on the growth of *Staph. aureus* on the surfaces of meat carcasses during primary chilling. An increase of storage time from slaughter to mincing, of properly chilled meat, will not increase the risk from growth of *Staph. aureus*.

4.2.5 Salmonella *spp.*

The likelihood of growth of salmonellae in meats at temperatures <7°C is low and at <4°C there is little evidence of any growth occurring (Mackey *et al*., 1980; Nissen *et al*., 2000; Mann *et al*., 2004).

Poor chilling regimes, particularly delayed chilled of large carcasses, may have a slight effect on the growth of *Salmonella* spp. on the surfaces of meat carcasses during primary chilling. An increase of storage time from slaughter to mincing, of properly chilled meat, will not increase the risk from growth of salmonellas. Vacuum and MA packaging of meats does not increased the risk of salmonellae growth, and indeed, may decrease the risk from inhibition by the lactic spoilage flora.

4.2.6 Escherichia coli *O157:H7*

The likelihood of growth of *E. coli* O157:H7 at temperatures <7°C is low and at <6°C there is little evidence of any growth occurring.

Poor chilling regimes, particularly delayed chilled of large carcasses, may have a slight effect on the growth of *E. coli* O157:H7 on the surfaces of meat carcasses during primary chilling. On the basis of published data (Mann & Brashears, 2006) an increase of storage time from slaughter to mincing, of properly chilled meat, may theoretically increase the risk from growth of *E. coli* O157:H7, unless the meat is held below 6°C.

4.2.7 Bacillus cereus

The likelihood of growth of *B. cereus* in meats at temperatures <5°C is low.

Poor chilling regimes, particularly delayed chilled of large carcasses, may have a slight effect on the growth of *B. cereus* on the surfaces of meat carcasses during primary chilling. An increase of storage time from slaughter to mincing, of properly chilled meat, may theoretically increase the risk from growth of *B. cereus*, unless the meat is held below 5°C.

4.2.8 Clostridium botulinum *non-proteolytic*

There <u>is a risk</u> of growth of *Cl. botulinum* at temperatures as low as 3°C. Below 3°C there is little evidence of any growth occurring.

Poor chilling regimes, particularly delayed chilled of large carcasses, may have an effect on the growth of non-proteolytic *Cl. botulinum* on the surfaces of meat carcasses during primary chilling. An increase of storage time from slaughter to mincing, of properly chilled meat, may theoretically increase the risk from growth of non-proteolytic *Cl. botulinum*, unless the meat is held below 3°C.

4.2.9 Listeria monocytogenes

There <u>is a theoretical risk</u> of growth of *L. monocytogenes* at temperatures as low as 0 to 1°C. However, published studies have not shown growth to occur at ≤4°C on meats.

Poor chilling regimes, particularly delayed chilled of large carcasses, may have an effect on the growth of *L. monocytogenes* on the surfaces of meat carcasses during primary chilling. However, a study where *L. innocua* was inoculated onto the surface of beef carcasses did not show any growth when the meat was chilled at 4°C over a typical 45 hour chilling regime and stored at 4°C for 72 hours (**Prendergast *et al.*, 2007**).

An increase of storage time from slaughter to mincing, of properly chilled meat, may theoretically increase the risk from growth of *L. monocytogenes*, unless the meat is held below 0°C however due to the slow growth rate at these low temperatures this is unlikely to be a significant risk unless the meat is stored chilled for long periods. In addition, there is published evidence that it will not in fact grow on either carcass, primal or minced meat at temperatures ≤4°C, particularly if vacuum packaged or held in 100% CO_2 atmosphere, irrespective of animal species (**Johnson *et al.*, 1988**; **Duffy *et al.*, 2000**; **Sheridan *et al.*, 1995**).

4.2.10 Yersinia enterocolitica

There is a risk of growth of *Y. enterocolitica* at temperatures as low as 0 to 1°C.

Poor chilling regimes, particularly delayed chilled of large carcasses, may have an effect on the growth of *Y. enterocolitica* on the surfaces of meat carcasses during primary chilling. An increase of storage time from slaughter to mincing, of properly chilled meat, may theoretically increase the risk from growth of *Y. enterocolitica*, even if the meat is held below 0°C.

However, while *Y. enterocolitica* has been shown to grow at low temperatures (Kleinlein & Untermann, 1990), this growth is inhibited and large numbers (as much as 10^9 g^{-1}) of yersinia are required to induce enteritis in healthy humans (Kleinlein & Untermann, 1990). Even if large numbers were to grow during storage these would be reduced by cooking so this pathogen is only likely to be of concern through the consumption of raw minced meat products.

4.3 Conclusions

- Based on the known growth temperature limits of pathogenic bacteria associated with meat there is a potential risk of psychrotrophic pathogens *L. monocytogenes* and *Y. enterocolitica* growing on meats during long term chilled storage at low temperatures (0 to 3°C). However, any growth at such temperatures would be slow.
- Although *Listeria* is a theoretical risk, practical studies have shown that *Listeria* sp. are not capable of growing on meat surfaces at temperatures ≤4°C.
- *Listeria* and *Yersinia* sp are not particularly heat resistant and adequate cooking should be sufficient to destroy any of these types of bacteria. Therefore, these pathogens are only likely to be of concern through the consumption of raw or undercooked minced meat.
- Listeria is a common contaminant on raw meat, unprocessed fruit and vegetables and in the environment and due to this common occurrence, cross contamination to ready-to-eat food from raw meat is not thought to be a significant cause of human infection.
- If higher storage temperatures are used, or breakdowns in the chill chain occur, there is also a potential risk of the growth of pathogens non-proteolytic *Cl. botulinum* (temperatures >3°C), *B. cereus* (temperatures >5°C) and *E. coli* O157:H7 (temperatures >6°C). However, any growth at these temperatures would be slow. Such a breakdown would have to be for a significant amount of time for such pathogens to grow to levels that constitute a risk to human health.
- Mince made in the UK from chilled meat stored for long periods is intended to be consumed fully cooked and, for species other than poultry meat, is required to be labelled with cooking information as specified in Regulation (EC) No. 2073/2005. There is no evidence that there is any additional risk of consumption of fully cooked mince made from such meat than from the consumption of fully cooked mince made from fresh meat.

5. Recommended Critical Controls

On a general level it is clear from the survey results (Section 3), risk analysis (Section 4) and literature review (Section 6) that in order to ensure a safe and long storage-life it is important to:

1. Produce carcasses with the lowest possible initial bacterial numbers.
2. Chill carcasses as fast as possible.
3. Keep an intact cold-chain throughout the entire production chain from the abattoir to the retail display cabinet.
4. Maintain strict sanitary conditions throughout the whole production process, from slaughter through chilling, storage, and fabrication to packaging.
5. Develop and implement a food safety management system based on the principles HACCP, with regular reviews.
6. Introduce facilities, equipment and practices that should limit cross-contamination.
7. Control (and record and regularly inspect) product and environmental temperatures.
8. Determine and verify the storage-life and display-life of all products.

The following critical limits, monitoring procedures and corrective actions for the manufacture of minced meat from chilled meat are recommended.

5.1 Slaughter and dressing

Few specific control measures are required for aged meats that differ from those of "unaged" meat. In both cases, carcasses should be produced hygienically with as low a level of microbiological contamination as possible.

5.2 Primary chilling

The aim of the primary chiller is to reduce the temperature of the meat in a controlled manner.

At present, legislation has required that red meat carcasses be chilled to a maximum temperature of 7°C and poultry carcasses to a maximum temperature of 4°C. No time limits on achieving these times have been set. Since microbial contamination is primarily a surface phenomenon there is an argument to be made that surface temperatures are far more important than deep temperatures (Gill, 2005).

There is a body of data on the primary chilling of individual beef sides, which can be used to predict surface and deep temperatures under controlled conditions. There are less comprehensive data sets for pork and even less data on lamb chilling. There is very little published data on current commercial processes especially when it comes to accurate surface temperature determinations during primary carcass chilling.

There are very little data on the effect of current commercial chilling rates and conditions on changes in bacterial numbers during the process. In most cases no change or a small reduction (0.5 to 1 $\log_{10}$ cfu cm^2) in number of organisms on the surface has been measured. The classic work on the effect of surface drying during chilling on bacterial survival was carried out over a range of chilling rates that are far slower than current commercial practice. More recent work comparing high humidity with conventional chilling has failed to find any difference between the effects of dry and "wet" chilling regimes on bacterial numbers.

Generally:

- If the cooling rate is too slow then there will potentially be problems with bone taint and high drip losses. At extremely slow rates toughening due to hot shortening and microbial problems due to growth of spoilage and potently pathogenic organisms can occur.
- Cold-shortening can occur when muscles contract as a result of cooling too quickly before rigor has taken place. It can be avoided by delaying the start of chilling until the pH is below 6.2, or by electrical stimulation to bring forward the onset of rigor. To completely avoid cold shortening the pH should be below 6 before muscle temperatures reach 18°C or less. To avoid severe cold shortening the pH should be below 6 before muscle temperatures reach 8°C or less. As a general rule cold-shortening may occur if the initial cooling rate reduces the muscle temperature of unstimulated beef or lamb to below 10°C within 10 hours of slaughter. In pork cold-shortening occurs if temperatures between 3 and 5°C are reached before the onset of rigor (normally 3 to 8 hours). Chilling is seldom fast enough for cold-shortening to be a problem in chickens. There is little published data on cold-shortening in turkeys.
- If the cooling rate is variable then an inconsistent product will be produced.
- The chilling system has to cater for a very wide range of carcasses types and weights.
- There should also be an adequate air circulation around the carcasses. The classic reasons for poor air distribution are:
    - Incorrectly positioned fan coils.
    - Supporting structures deflecting airflow.
    - Roof structures stopping distribution.
    - Rooms too long and/or to low in height for fans to be able to distribute air over load space.
    - Large spaces between fan coils causing dead spots.
    - Evaporator coils blocked with ice.
    - Carcasses/sides hung in such a manner that they are in direct contact or produced small channels with still air in them.
- Consideration should be given to temperature rises that occur during loading, defrost cycles and in inactive chills.
- Red meat chilling is currently a batch operation. Consideration should be taken of the time it takes to load and unload chillers, and that it takes longer to fill the chiller than to empty it (Gill, 2005). Thus, carcasses/sides entering the empty chiller at the beginning of the day will in general receive a longer chilling time than those that enter at the end of the day (Figure 70). Often the chiller is filled up over a whole working day and then operated overnight after it is filled.

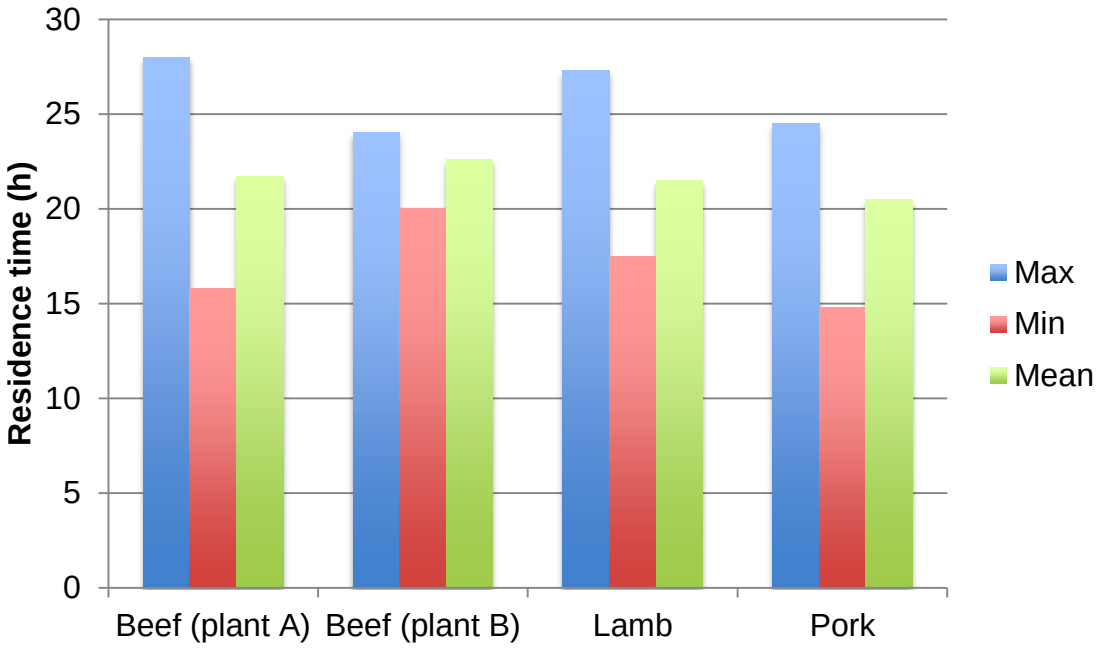

Figure 70. Residence times of carcasses in chillers during primary chilling (source: Gill, 2005)

- The effectiveness of chilling can be determined by calculating the RI index and comparing to the Australian RI criteria using the Australian Refrigeration Index Calculator model.

5.2.1 Critical limits

Current legislation requires red meat carcasses to be chilled to a maximum temperature of 7°C and poultry carcasses to a maximum temperature of 4°C. For storing meat for longer time, particularly that destined for mince production, limits lower temperatures, ideally close to 0±1°C, are to be recommended.

The chilling parameters (air temperature, relative humidity, air flow, carcass grade and spacing) that achieve the greatest reduction/inhibition in microbial levels on the carcasses need to be determined so that these may be used as critical limits. The Australian Refrigeration Index Calculator model may be used to indicate the limits for effective chilling and establish a time limit within which the surface of the carcass/side meat should reach the target temperature.

To avoid cold-shortening processors should also monitor pH/temperature changes with time when validating the chilling parameters. Rapid chilling rates can be used if combined with electrical stimulation. Otherwise, a delayed chilling regime may be used, provided it can be shown to be effective in preventing microbial growth. This can be demonstrated using the Australian Refrigeration Index Calculator model to calculate that RI. To completely avoid cold shortening the pH should be below 6 before muscle temperatures reach 18°C or less. To avoid severe cold shortening the pH should be below 6 before muscle temperatures reach 8°C or less.

As a recommendation to meet all these requirements in an optimal but still cost effective manner the primary chillers should be designed and operated with the aim:

- To ensure that there is sufficient spacing around carcasses/sides to maintain an air velocity of $\geq 1.0 \pm 0.25$ ms^{-1} over all the exposed carcass/side surfaces.

- To reduce the air velocity to 0.25 ms^{-1} at the end of the chilling period or when operating in stand by mode.
- To have sufficient evaporator extraction capability to maintain the above in mid-summer with the maximum load of meat envisaged.
- To have sufficient total refrigeration capacity to maintain all the required temperature performance in all the chillers when operating at maximum capacity
- To operate efficiently at minimum throughput.
- If at all possible, carcasses of similar sizes and shapes should be refrigerated together to achieve uniform results.

5.2.2 Monitoring

The temperature of the surface and the deep muscle should be checked regularly (or preferably, constantly monitored) in a representative number of carcasses/sides to give a set total selected to represent the chilling performance in the entire chiller (for example, 5 out of 40 carcasses/sides).

The abattoir could also establish the air chill pattern that consistently achieves the critical limits based on the temperature of the carcass surface and deep round muscle and monitor air temperature instead. Such an approach permits automation as the air temperature may be automatically monitored and controlled on a continuous basis using a System Control And Data Acquisition (SCADA) or similar system (Bolton *et al*., 2004) or using electronic or chemical Temperature Time Integrators/Indicators. This would also alert the production manager (or other designated personnel) when the critical limits are breached, automatically take immediate corrective action and produce an ongoing record of performance.

The accumulation of microbiological assessments over time may be used as a trend analysis to establish the hygiene and effect of chilling practice over time. Aerobic plate count (30°C incubation) or psychrotrophic counts may be a useful measure of the bacteriological status of carcasses after chilling or during storage (ICMSF, 1998).

5.2.3 Corrective action(s)

Carcasses/sides that have not reached the target temperature should be chilled for an additional period until the target temperature is obtained.

Carcasses/sides that have taken longer to reach the target temperature than the critical limit should not be used for mince production.

5.3 Storage (Ageing)

At present, legislation has required that red meat carcasses be chilled to a maximum temperature of 7°C and poultry carcasses to a maximum temperature of 4°C. No time limits on achieving these times have been set. For ageing meat lower temperatures, ≤0°C, are to be recommended.

The aim of the ageing room(s) is to maintain the meat at a constant temperature, -1.5 to 0±0.1°C. It should therefore be designed on the understanding that the temperature of the meat on loading is at the required temperature.

Ageing rooms operate best if they can be rapidly loaded in one short operation, the room sealed and kept sealed until ageing is complete. The refrigeration system can then be designed to rapidly extract the small amount of heat added during loading and then operate in a maintenance mode. During the maintenance mode, it should be designed to isolate the

meat from any heat ingress through the structure. A false ceiling or air sock air delivery system should be installed to produce a very constant temperature, low air movement throughout the load space. Consideration should be given to temperature rises that occur during loading and defrost cycles.

If weight loss and surface darkening is not thought to be a problem or is even desirable then the evaporator coils should be designed to maintain a relative humidity of approximately 75%. However, some of the best and most cost effective maturation rooms operate with filtered air at a relative humidity approaching 90%.

The storage facilities must be regularly and effectively cleaned. It is very desirable that the evaporator coil and the structure is designed to be easily and completely cleaned. Studies have shown that dirty coils support bacteria and can act as a source of contamination to the ageing meat.

On-line monitoring of both ageing and bacterial growth would be a useful tool for monitoring and controlling the ageing process. A system such as that described by Yano *et al*. (1996) shows promise. They used a biosensor composed of a putrescine oxidase immobilized electrode (which measured putrescine and cadaverine which are produced by bacteria) and a xanthine oxidase immobilized electrode (which measures hypoxanthine and xanthine which accumulate in meat with ageing) as detectors. This system was shown to be useful for quality control of beef ageing at 5 and 10°C, but not at 0°C.

5.3.1 Critical limits

Red meat and poultry (carcasses or parts of the carcass) should ideally be the maintained at a temperature of between -1.5°C to 0°C ±0.5°C during ageing.

A time/temperature limit should be established for the surface of carcass meat and internal temperature of bulk primal meat.

A cleaning protocol, validated as effective, and cleaning schedule for the storage facility should be established.

5.3.2 Monitoring

Temperature monitoring of the air temperature and / or product temperature should be continuous, or at least once every hour, as appropriate.

As for chilling, the abattoir could also establish the air chill pattern that consistently achieves the critical limits based on the temperature of the carcass surface and deep round muscle and monitor air temperature instead. Such an approach permits automation as the air temperature may be automatically monitored and controlled on a continuous basis using a System Control And Data Acquisition (SCADA) or similar system (Bolton *et al*., 2004) or using electronic or chemical Temperature Time Integrators/Indicators. This would also alert the production manager (or other designated personnel) when the critical limits are breached, automatically take immediate corrective action and produce an ongoing record of performance.

The accumulation of microbiological assessments over time may be used as a trend analysis to establish the hygiene and effect of storage practice over time. Aerobic plate count (30°C incubation) or psychrotrophic counts may be a useful measure of the bacteriological status of carcasses/sides/quarters during storage/ageing and of the cleanliness of the storage/ageing facilities (ICMSF, 1998).

Monitoring the adherence to the cleaning protocol and schedule can include the use of rapid surface testing techniques.

5.3.3 Corrective action(s)

Carcasses/bulk meat that have exceeded the time/temperature critical limit should not be used for mince production.

Storage facilities that do not meet the hygiene standard must be re cleaned before unwrapped meat is stored

Refine cleaning protocols when trend results from a rapid method or microbiological testing are above or moving towards established limits.

5.4 Cutting and mincing

Cutting/mincing facilities should be operated at ≤12°C (ideally 10°C). Temperatures lower than 10°C can make working conditions for staff uncomfortable. Localised environmental control should be considered to keep the meat isolated from a higher temperature environment. While these environmental temperatures still permit the growth of *L. monocytogenes*, growth is substantially retarded. The growth of salmonella at 10°C will be inhibited providing product temperatures do not remain at this temperature for more than 12 hours.

Since bacteria are primarily present on meat surfaces, processors should consider the ratio of trimmings containing surfaces that are minced. Adipose surfaces favour the growth of bacteria in comparison with muscle surfaces and thus the proportion of subcutaneous fat may effect overall bacterial levels.

The cleanliness of mincing and cutting equipment is particularly important to prevent cross-contamination.

5.4.1 Critical limits

The temperature of the processing area (boning hall, cutting area, minced meat preparation area, etc.) should be maintained at ≤12°C (ideally 10°C) with an air velocity of <0.5 ms^{-1}.

The temperature history of the meat between cutting/mincing and cooling back to the storage temperature should be known and controlled.

The internal temperature of the meat should be kept at ≤7°C for red meat and ≤4°C for poultry during cutting, mincing and packaging.

Chilled minced red or poultry meat and minced meat preparations should be stored at 0±0.5°C or lower.

Limited periods outside temperature control are permitted, to accommodate the practicalities of handling during preparation, provided that it does not result in a risk to health.

5.4.2 Monitoring

Temperature monitoring of the air temperature and / or product temperature should be continuous or at least twice per day as appropriate.

The temperature history of the meat between cutting/mincing and cooling back to the storage temperature should be known.

The cleanliness of mincing and cutting equipment and the effectiveness of cleaning should be regularly assessed. This may be carried out either using traditional microbiological methods or using non-microbiological rapid methods.

The accumulation of microbiological assessments over time may be used as a trend analysis to establish the hygiene and effect of storage practice over time. Aerobic plate count (30°C

incubation) may be a useful shelf-life test for minced meat (ICMSF, 1998). *E. coli* has been shown to be a useful indicator of plant hygiene (ICMSF, 1998). The ICMSF (1998) recommends that when it is known that the incidence of a pathogen is <1% in samples tested it is not advisable to carry out routine tests for such pathogens. For vacuum-packaged aged meats the fraction of Enterobacteriaceae in the bacterial population may be a useful indicator of plant sanitation and product storage-life (Holley *et al*., 2004).

5.4.3 Corrective action(s)

Excessive periods outside the established temperature limits should result in meat not being used for mince to be sold raw.

5.5 Storage and distribution

Environmental and storage temperatures must be maintained, controlled and monitored at all times. Storage areas should be designed to maintain the correct product temperature. Raw materials should be stored separately from finished products.

Practices that involve the shutting down of power required for environmental and storage temperature maintenance should not be implemented under any circumstances. Contingency plans should be available to ensure the continued safety of products in the event of power failures.

It is particularly important that meat is at the correct temperature before loading since the refrigeration systems used in most transport containers are not designed to extract heat from the load but to maintain the temperature of the load. In the large containers used for long distance transportation meat temperature can be kept within ±0.5°C of the set point.

5.5.1 Critical limits

Chilled minced red or poultry meat should be stored and distributed at <2°C (ideally minced meat from aged meat should be the maintenance of a temperature of -1.5 to 0±0.1°C).

Limited periods outside temperature control are permitted, to accommodate the practicalities of transport and storage, provided that it does not result in a risk to health.

5.5.2 Monitoring

Temperature monitoring of the air temperature and / or product temperature should be continuous, or at least once every hour, as appropriate.

Time-Temperature Integrators/Indicators on the packaging can be used to indicate adequate temperatures during storage and distribution, or abuse of the chill chain.

The accumulation of microbiological assessments over time may be used as a trend analysis to establish the hygiene and effect of storage practice over time. Aerobic plate count (30°C incubation) or psychrotrophic counts may be a useful measure of the bacteriological status of the meat during storage and distribution (ICMSF, 1998).

5.5.3 Corrective action(s)

Excessive periods outside the established temperature limits should result in meat not being used for mince to be sold raw.

5.6 Retail

Environmental and storage temperatures must be maintained, controlled and monitored at all times. Storage areas and retail cabinets should be designed to maintain the correct product temperature.

Products should not be stacked higher than the maximum level indicated in display cases, or in front of air ducts, or too close to heat generating lamps.

In case of breakdown of the refrigeration unit of the display case, the products should be moved to another case or to a cold room (Codex Alimentarius, 1999). If the breakdown of the refrigeration unit of the display case takes place when the establishment is closed, temperature of the products should be checked. If acceptable, the products should be moved to a suitable area; if not, they should be removed from the case, not offered for sale, and destroyed if necessary.

5.6.1 Critical limits

Chilled minced red or poultry meat should be stored and displayed at <4°C (ideally <2°C).

Limited periods outside temperature control are permitted, to accommodate the practicalities of displaying food, provided that it does not result in a risk to health.

5.6.2 Monitoring

Temperature monitoring of the air temperature and / or product temperature should be continuous, or at least once every hour, as appropriate.

Time-Temperature Integrators/Indicators on the packaging can be used to indicate adequate temperatures during storage and distribution, or abuse of the chill chain.

The accumulation of microbiological assessments over time may be used as a trend analysis to establish the hygiene and effect of storage practice over time. Aerobic plate count (30°C incubation) or psychrotrophic counts may be a useful measure of the bacteriological status of the meat during retail display (ICMSF, 1998).

5.6.3 Corrective action(s)

In case of refrigeration unit breakdown, the temperature of the products should be checked. If acceptable, the products should be moved to a suitable area; if not, they should be removed from the case, not offered for sale, and destroyed if necessary (Codex Alimentarius, 1999).

6. Overall conclusions and recommendations

Current legislation (Regulation (EC) No. 853/2004, Annex III, Section V, Chapter III, paragraph 2) imposes strict limits on the age of meat, from slaughter to mincing, that can be used to produce mince. This restricts the use of aged meat in the production of mince.

In 2006 the Food Refrigeration and Process Engineering Research Centre (FRPERC), then part of the University of Bristol, carried out an independent review for the UK Food Standards Agency to critically assess the available scientific literature on the survival and growth of microorganisms that are important for safety and quality during storage of meat and the production of minced meat. This review concluded that there was no scientific evidence to justify the restrictions in Regulation (EC) 853/2004, however nor was there much data on the specific risk.

The aims of this study, conducted with industry, was to:

1. Identify and describe industrial practice and collect available data.
2. Update the 2006 review.
3. Determine the microbiological status of currently produced mince.
4. Assess the likelihood of safety and quality problems using existing chilling and storage data.
5. Make recommendations on the controls that should be put in place for meat to be minced, including aged meat, and how they can be applied within a risk based food safety management system.

A total of 11 UK meat processors participated in the study with the support of the FSA and British Meat Processors Association (BMPA), of these: 7 processed beef mince, 4 processed pork mince, 4 processed UK lamb mince, 2 processed New Zealand lamb mince and 1 processed turkey mince.

Current EU (paragraph 2(b), Chapter III, Section V, Annex III of Regulation (EC) 853/2004) limits are that meat must be minced within no more than: 6 days of slaughter for red meat; 3 days of slaughter for poultry meat; and 15 days of slaughter for boned vacuum packed beef and veal. UK supermarkets are currently marketing beef aged for up to 28 days, lamb aged for 14 days and pork aged for 10 days. While the data provided by participating UK processors in this study show that beef, pork, UK lamb, New Zealand lamb and turkey meat may be minced 59, 18, 26, 67 and 6 days after slaughter.

The main points to emerge from this study are that:

1. The literature review identified no clear published scientific literature to support the restrictions on the time between slaughter and production of minced meat. Only one specific scientific publication (**Crowley *et al.*, 2010**) has been located that has looked at the safety and quality of mince produced from cuts and carcasses that have been stored for different periods of time post-slaughter. The results of that particular study not only support the overall conclusion of the 2006 review (that there is no scientific rationale for limiting the storage of meat prior to mince production) it actually identified "advantages in storing beef trimmings in vacuum packs for at least 21 days prior to mincing, in terms of improved mince quality" (**Crowley *et al.*, 2010**). This published study addresses the vacuum-packed storage of beef trimmings and shows

no effect at 0°C. This study did not assess "dry-aged" carcass meat. No published studies have been identified that address any other type of meat.

2. The evidence supplied/collected by the participating UK meat processors in this study show that chilled beef, pork, UK lamb, New Zealand lamb and turkey may be stored for up to 59, 18, 26, 67 and 4 days, respectively before being minced. Evidence, and experience and knowledge of industry practices suggests that most UK meat processors are storing meat during ageing at less than 2°C, which would seem to be an acceptable good practice. The data supplied/collected by the participating UK meat processors in this study also shows that Total viable, *Escherichia coli* and Enterobacteriaceae counts from meat after mincing do not substantially increase with the length of time the meat is stored prior to mincing.
3. The literature review identified a small number of publications on the quality of steaks and chops produced from meat that has been stored for up to 35 days and 80 days for beef, 40 days for lamb and 63 days for pork. No similar data have been found for poultry meat. These publications all show that bacterial numbers were higher on meat produced from older meat, however, an acceptable display-life was usually achieved with cuts produced from the older meat.
4. The literature review identified no publications that show that the safety (i.e. pathogen levels) of mince produced from older meat is compromised, or visa versa. The data supplied/collected by the participating UK meat processors in this study show no evidence (both in terms of pathogen levels or indicator organisms) that the safety of mince produced from older meat is compromised.
5. The literature review identified a surprising lack of published data on the storage-life of chilled meat carcasses and bone-in-cuts. The classic studies indicate much shorter storage lives than current industrial practice, as indicated in IIR tables etc. There is little published data on the growth of pathogens on meat carcasses, sides or primals during dry-ageing. More data is available on the storage-life of some vacuum-packaged primal meat, however this covers a limited range of storage conditions. As would be expected, the data that does exist shows that initial bacterial numbers, and storage atmosphere and temperature are the main factors governing storage life. pH and RH also influence storage life.
6. The literature review found there to be very little published data on the effect of current commercial chilling rates and conditions on changes in bacterial numbers during the process. In most cases, no change or a small reduction (0.5 to 1 $\log_{10}$ cfu cm^{-2}) in number of organisms on the surface has been measured. In one publication, the rate of initial chilling is claimed to make changes of up to 50% in storage life.
7. The effectiveness of chilling can be determined by using the Australian Refrigeration Index Calculator model to calculated the Refrigeration Index (RI) and comparing with RI criteria. A comparison of data supplied by participating UK meat processors in this study using this model shows that effective refrigeration that prevents growth of *E. coli* during the primary chilling process can be achieved in UK abattoirs. The Australian Refrigeration Index Calculator model also indicates that delayed primary chilling of beef sides, where the chiller operates at approximately 10°C during loading (to avoid cold-shortening), does not pose a risk of growth of *E. coli*.
8. Overall, data on the growth of psychrotrophic pathogens would indicate that there is theoretically a greater risk of psychrotrophic pathogens proliferating in meat held for a longer time at a temperature above the minimum for pathogenic growth than in meat

stored for a short time. Since mincing is known to distribute bacteria throughout the meat it stands to reason that theoretically mince from aged meat has a higher risk than that from non-aged meat. It can therefore also be said that any aged meat must on this basis present more of a risk than unaged meat. However, this theoretical supposition has not been clearly supported in the literature or in the data supplied by the UK meat processors. Some authors (Dykes *et al*., 2001) imply that that the long period of storage, of particularly *E. coli* O157, in a non-growing state would result in "an excessive recovery period in these cells before growth would occur". While others (**Crowley *et al*., 2010**) have shown that long term chilled storage of meat in vacuum packs may inhibit microbial growth and that mince may actually inhibit microbial growth through the action of free radicals released from muscle and bacterial cells.

9. No specific additional control measures for chilled meats stored for periods longer than specified in the regulations, which differ from those for chilled meat stored for periods in compliance with the regulation, have been identified. Apart from those specifically associated with storage temperatures during ageing/storage prior to mincing. In all cases carcasses should be produced hygienically, with as low a microbial load as possible, and then handled appropriately throughout subsequent storage, cutting and mincing to maintain the microbiological status. The current scientific knowledge allows controls to be identified within procedures based on HACCP procedures and a summary of suggested critical limits, monitoring procedure recommendations and corrective actions for the manufacture of minced meat from meat is given in Section 5.
10. Mince made in the UK from chilled meat stored for long periods is intended to be consumed fully cooked and, for species other than poultry meat, is required to be labelled with cooking information as specified in Regulation (EC) No. 2073/2005. There is no evidence that there is any additional risk of consumption of fully cooked mince made from such meat than from the consumption of fully cooked mince made from unaged meat.
11. The 2006 review concluded that there appeared to be no scientific justification for the time restrictions included in the current legislation and no evidence of an increased risk to human health from meat that has been stored hygienically and at appropriate temperatures for longer than the time limits specified in the legislation. Published studies since that review and the data supplied/collected by the UK meat processors in this study appear to further support and strengthen this conclusion.

A range of controls have been suggested based on available data (Section 5). While the scientific literature published since the 2006 review and the new data from industry strengthens our original conclusion made in 2006, we would recommend that further research is funded to specifically look at the influence of post-slaughter storage times and conditions on the safety and quality of aged meat and mince produced from that meat under controlled conditions. This study needs to be controlled and focussed, and contain sufficient replicates and controls, to produce peer-reviewed publications that will scientifically quantify the exact risk and control limits for all meats of concern. Work is particularly required on poultry and game to fill the total gap in published scientific literature in this area and the limited data gathered in this study.

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8. Appendix 1: Literature review

8.1 Introduction

Significant quantities of minced meat are produced in the UK. This is used in catering and the home for a variety of cooked dishes, and in the manufacture of meat preparations and products ranging from burgers and sausages to canned products and chilled or frozen ready meals. While some minced meat is prepared from trimmings from the preparation of joints and cuts, much minced meat is prepared from parts of the carcass for which there is insufficient consumer demand as joints or cuts, e.g. forequarter beef. It is widely recognised that minced meats pose more of a health risk than intact muscle because they can be contaminated throughout during the mincing operation (ICMSF, 1998; Barlow *et al*., 2006).

After slaughter and evisceration, meat carcasses are primary chilled, either in the form of sides in the case of beef and pork, or whole carcasses in the case of lamb and poultry. EU legislation requires fresh red meat and poultry to be chilled to <7°C and <4°C, respectively. Once the meat has reached the required temperature it can legally be cut. To improve tenderness and prevent muscle shortening there will usually be a delay between the meat reaching the desired temperature and cutting. This may be as short as 2 to 8 hours in the case of chicken and turkey, respectively, or typically 48 hour for beef before cutting, packing and retail distribution.

In the UK, there is a long-standing tradition of ageing meat for longer time periods in order to develop more flavour, and improve texture, for the national market. Ageing may be carried out in aerobic conditions, so called "dry-ageing" (usually in the form of whole carcasses, sides or quarters), or in anaerobic conditions, so called "wet-ageing" (usually in the form of vacuum-packaged primals or sub-primals). Following ageing the carcasses/sides/primals may be distributed direct to retail outlets for butchery, or more commonly cut into consumer portions, packaged and then distributed to the retailer. Not all the meat can be sold as joints and cuts and the production of mince from the remaining carcass meat is an important economic aspect of the process.

In addition for practical reasons UK produced and imported meat from all species may be stored chilled for varying times following standard ageing in order to be transported to and ensure a constant supply of raw material at the mincing plant.

8.2 Ageing

The terms 'conditioning', 'ageing', 'ripening', 'maturing', 'hanging' and 'the resolution of *rigor*' have all been applied to the practice of storing meat for periods beyond the normal time taken for cooling and setting, to improve its tenderness after cooking. Consumer assessments of unaged beef are variable, ranging from 'moderately tough' to 'moderately tender' whilst beef conditioned for 9 days at 1°C receives largely favourable reactions, being scored 'moderately' to 'very' tender (Dransfield, 1985). Ageing imposes a severe limitation on processing conditions because it is a slow process.

The major change that takes place in meat during ageing occurs in the muscle fibre. Ageing is caused by the presence of proteolytic enzymes in the muscle that slowly catalyse the breakdown of some of the muscle proteins. This causes weakening of the muscle so that the meat is more readily pulled apart in the mouth and is therefore tenderer. Two groups of enzymes are thought mainly responsible; calpains, which are active at neutral pH shortly after slaughter; and cathepsins, which are active at acid pH after *rigor* (Offer *et al*., 1988).

Rates of ageing differ widely between species. The tenderness of meat improves approximately as the logarithm of the storage time. Most of the improvement in tenderness therefore takes place in the initial storage period and tenderness eventually reaches a maximum. Table 39 shows the 1st order rate constants derived from the exponential decay of toughness of cooked muscles with time (Dransfield, 1986). Beef, veal and rabbit have a rate constant of 0.17 per day, which means that 80% of the theoretically-possible tenderising occurred in 10 days at 1°C. Although beef and veal condition at the same rate, veal is tenderer and therefore can reach an acceptable tenderness in 5 days at 1°C. Lamb conditions slightly faster than beef, and pig meat about twice as fast as beef. Chicken has a much higher rate and 80% of the tenderising will occur in about 10 hours. Although ageing is rapid in poultry meat, deboning before sufficient tenderisation has taken place can result in tough meat. Studies to determine the minimum amount of ageing required before deboning show that at least 2 and possibly 4 hours are required in chicken (**Sams, 1999**) and at least 6 and possibly 8 hours in turkeys (**Fanatico, 2003**).

Table 39. Variation in rate of ageing among species (source: Dransfield, 1986)

	Rate (day^{-1})	Time for 50% tenderising (days)	Time for 80% tenderising (days)
Beef	0.16 (0.04)	4.3	10.0
Veal	0.17 (0.03)	4.1	9.5
Rabbit	0.17 (0.06)	4.1	9.5
Lamb	0.21 (0.05)	3.3	7.7
Pork	0.38 (0.11)	1.8	4.2
Chicken	5.23 (1.68)	0.1	0.3

Longissimus muscles from four species were stored at 1-4°C (cf Dransfield *et al.*, 1980b) and rates calculated (cf Dransfield *et al.*, 1980a). Values are the rate of tenderising with standard errors and the time taken after stunning for 80% of the complete tenderising to occur.

In the UK ageing has seen a revival in recent years and UK supermarkets are currently marketing beef aged for up to 28 days, lamb aged for 14 days and pork aged for 10 days. In common with the accepted practice of hanging game birds, the hanging of turkeys is also receiving increased interest.

8.3 Growth of pathogens and spoilage organisms on meat

8.3.1 Pathogens

A number of bacterial pathogens capable of causing food poisoning in humans are known to contaminate red meat. Those of most importance (in alphabetical order) are *Bacillus cereus*, *Campylobacter* spp., *Clostridium botulinum*, *Clostridium perfringens*, pathogenic serotypes of *Escherichia coli* (principally *E. coli* O157:H7), *Listeria monocytogenes*, *Salmonella* spp., *Staphylococcus aureus* and *Yersinia enterocolitica* (Nottingham, 1982; Mead & Hinton, 1996, ICMSF, 1998). *L. monocytogenes* is commonly associated with meat, but its public health significance in relation to raw meat is unclear (Mead & Hinton, 1996). The ICMSF (1998) quote that "there is no evidence that multiplication of *L. monocytogenes* on raw poultry during storage is a factor in human listeriosis", however they do cite a control study where undercooked chicken was a factor in human listeriosis. There is also increasing concern with *Arcobacter* spp. in foods of animal origin that is raising public health concerns (**Shah *et al*., 2011**).

The essential characteristics of pathogenic microorganisms can be found in numerous texts. There is a certain degree of conflicting data concerning the importance of various pathogens with regard to meat safety and the effect of specific temperatures or packaging atmospheres on their growth or inhibition. Inhibition temperatures for various species quoted by Rosset

(1982) are shown in Table 40. Other minimum and optimum growth temperatures for pathogens commonly associated with meat are show in Table 41, and generation times shown in Table 42. Reviews of data on minimum growth temperatures for pathogens under a range of different atmospheric packaging conditions have been published by García de Fernando *et al*. (1995) and Nychas & Skandamis (2005).

Table 40. Effect of temperature on the inhibition of pathogens (adapted from Rosset, 1982)

15°C	Inhibition of *Arcobacter* growth
10°C	Inhibition of *Staphylococcus aureus* toxin production Inhibition of *Clostridium botulinum* (type A and B) toxin production
6.7°C	Inhibition of *Staphylococcus aureus* growth
6.5°C	Inhibition of *Clostridium perfringens* growth
5.2°C	Inhibition of *Salmonella* growth
3.3°C	Inhibition of *Clostridium botulinum* (type E) toxin production

Table 41. Minimum and optimum growth temperatures for pathogens associated with red meats (sources: García de Fernando *et al*., 1995; Mead & Hinton, 1996; Doyle, 2002; Tamplin *et al*., 2005; Shah *et al*., 2011)

	Minimum temperature (°C)	Optimum temperature (°C)
Campylobacter spp.	30	42-43
Arcobacter spp.	15	
Clostridium perfringens	12	43-47
Clostridium botulinum proteolytic	10	
Staphylococcus aureus	7	
Pathogenic *Escherichia coli* strains	7	35-40
Escherichia coli O157:H7	6 to 7	42
Salmonella spp.	5	35-43
Bacillus cereus	5	
Clostridium botulinum non-proteolytic	3	
Aeromonas hydrophila	-0.1 to 1.2	
Listeria monocytogenes	-1 to 0	30-37
Yersinia enterocolitica	-2	28-29

Table 42. Generation times for foodborne bacteria in raw meat

Bacteria	Temperature (°C)	Time (h) Lag	Generation	Ref.
Salmonella spp.	12.5		6.79	Mackey *et al*. (1980)
Clostridium perfringens	12		11.5	Lund *et al*. (2000)
Escherichia coli O157:H7, pH 5.7	12	16.2	6.0	Walls & Scott (1996)
Escherichia coli O157:H7, pH 6.3	12	2.78	3.9	Walls & Scott (1996)
Salmonella spp.	10		13.87	Mackey *et al*. (1980)
Salmonella Typhimurium	10	45	9.65	Smith (1985)
Yersinia enterocolitica	10		12.73	Logue *et al*. (1998)
Escherichia coli SF	8.2	40	6.9	Smith (1985)
Bacillus cereus	5		8.3	Lund *et al*. (2000)
Yersinia enterocolitica	5		16.53	Logue *et al*. (1998); Lund *et al*. (2000)
Listeria monocytogenes	4		22.8	Lund *et al*. (2000)
Listeria monocytogenes	4		9.3	Pawar *et al*. (2000)
Escherichia coli O157:H7	2		no growth	Ansay *et al*. (1999)

Some pathogens, such as *L. monocytogenes*, are capable of growth at chill temperatures below 5°C. These are often cited as being of particular concern in relation to refrigerated meats since refrigeration can not be relied on to prevent growth (Doyle, 1987). On the other hand, psychrotrophic pathogens are not particularly heat resistant and adequate cooking should be sufficient to destroy any such pathogens. Illnesses caused by *L. monocytogenes* and *E. coli* are often due to inadequate cooking before ingestion.

Investigations into the effect of different storage atmospheres on pathogenic growth at low temperatures appear to show that Carbon dioxide (CO_2) enriched atmosphere produce the greatest inhibitory effect on psychrotrophic pathogens (*Y. enterocolitica*, *Aeromonas hydrophila* and *L. monocytogenes*). García de Fernando *et al*. (1995) concluded that "*at a normal meat pH (i.e. 5.5) and at a low temperature (e.g. 1°C) the growth of psychrotrophic pathogens is stopped when the CO_2concentration is 40%*". However, high pH meat (≥6) and/or higher storage temperatures will support growth of such pathogens.

8.3.2 Spoilage organisms

General data are available on the attainable chilled storage lives for many meats, such as that shown in Table 43, published by the International Institute of Refrigeration. However, much is based on 'learned' opinion rather than peer reviewed scientific studies.

Table 43. Chilled storage times (source: IIR, 2000)

	Storage time (days (SD)) in temperature range (°C):			
	-4.1 to -1.1	-1 to 2	2.1 to 5.1	5.2 to 8.2
Beef	40 (26)	34 (32)	10 (8)	9 (9)
Lamb	55 (20)	41 (46)	28 (34)	
Pork	50 (58)	22 (30)	16 (16)	15 (18)
Poultry	32 (18)	17 (10)	12 (11)	7 (3)

In most cases the limiting factors that control the chilled storage life of meat are based on bacterial growth. 'Off' odours and slime caused by microorganisms are detected when populations reach *ca* 7 to 8 $\log_{10}$ cfu cm^{-2} (Gill, 1996). Temperature is the principal factor affecting the rate of microbial growth and hence the shelf-life of chilled meat. The lower the

temperature, the longer the shelf-life. Shelf-life may also be extended by packaging under aerobic atmospheres rich in carbon dioxide, or by packaging under anaerobic conditions (Gill, 1996). The initial bacterial loading of the meat will always limit the maximum shelf-life (Blixt & Borch, 2002; Kennedy *et al*., 2004).

Reduction in temperature below the optimum causes an increase in generation time, i.e. the time required for a doubling in number. It is an accepted crude approximation that bacterial growth rates can be expected to double with every 10°C rise in temperature (Gill, 1986). Below 10°C, however, this effect is more pronounced and chilled storage life is halved for each 2 to 3°C rise in temperature. Thus the generation time for a pseudomonad might be 1 hour at 20°C, 2.5 hours at 10°C, 5 hours at 5°C, 8 hours at 2°C, or 11 hours at 0°C (Harrigan & Park, 1991). In the usual temperature range for chilled meat, -1.5 to 5°C, there can be as much as an eight-fold increase in growth rate between the lower and upper temperature. Storage of chilled meat at -1.5±0.5°C would attain the maximum storage life without any surface freezing.

8.4 Microbial quality of carcasses

The initial level of bacterial contamination will of course affect the storage life. Over forty years ago Ayres (1955), in his comprehensive review of microbiological contamination in slaughtering, concluded that an aerobic population of 4.0 to 5.0 $\log_{10}$ cfu cm^{-2} and an anaerobic population of between 3.7 and 4.7 $\log_{10}$ cfu g^{-1} would be reasonable for wholesale cuts of meat. Surveys over the past 20 years have shown that in general levels of between 1 and 4 $\log_{10}$ cfu cm^{-2} can be expected on meat carcasses prior to chilling. There are very little data on the effect of current commercial chilling rates and conditions on changes in spoilage and pathogenic bacterial numbers during the chilling process. In most cases no change or a small reduction (0.5 to 1 $\log_{10}$ cfu cm^2) in number of organisms on the surface has been measured. There is a great debate regarding the role of surface drying during primary chilling. It is also not clear whether the new emphasis in the UK meat industry on more traditional methods in meat manufacture which is seeing a move away from rapid chilling systems to delayed chilling systems is having any effect on bacterial numbers during chilling.

8.4.1 Effect of rigor changes on microbial growth

The way in which animals are handled before slaughter will affect the bio-chemical processes that occur before and during rigor mortis. The resulting metabolites influence the growth of microorganisms on meat.

During the onset of rigor mortis, which may take up to 24 hours, oxygen stored in the muscle is depleted and the redox potential falls from above +250 mV to -150 mV. Such a low redox value combined with the initial muscle temperature of 38°C provides ideal growth conditions for mesophilic microorganisms. Stress and excitement caused to the animal before slaughter will cause the redox potential to fall rapidly, possibly allowing proliferation of such microorganisms before cooling (Dainty, 1971).

Concurrent with the fall in redox potential is a fall in pH from an initial value in life of around 7 to a stable value around 5.5 (in beef), the 'ultimate pH' (Table 44). This is due to the breakdown of glycogen, a polysaccharide, in the muscle tissue to lactic acid. Lactic acid cannot be removed by the circulation system nor oxidised, so it accumulates, and pH falls until the glycogen is all used or the breakdown stops. The pH has an important role in the growth of microorganisms; the nearer the pH is to the ultimate value the more the growth is inhibited (Dainty, 1971).

Table 44. pH of meats

	Time to ultimate pH (h)	Ultimate pH	pH	Reference
Beef		5.5		Dainty, 1971
Beef		5.4-5.7		
Lamb		5.4-5.7		
Pork		5.4-5.7		
Poultry breast		5.8		ICMSF, 1998
Poultry leg		6.4-6.7		ICMSF, 1998
Poultry skin		≥6.6		ICMSF, 1998
Chicken	5	5.7-6.0		Thielke *et al*., 2005
Chicken mince			6.18	Saucier *et al*., 2000
Turkey		5.9		El Rammouz *et al*., 2004
Turkey mince			5.95	Saucier *et al*., 2000

Stress or exercise before slaughter can deplete an animal's glycogen reserves, consequently producing meat with less lactic acid and a relatively high ultimate pH, this gives the meat a dark, firm, dry (DFD) appearance. Alternative terms are 'dark cutting' and 'high-pH meat'. The condition occurs in pork, beef and mutton, but is of little economic importance in mutton (Newton & Gill, 1981). DFD meat provides conditions that are more favourable for microbial growth than in normal meat (Dainty, 1971; Newton & Gill, 1981). The preferred substrate for growth of pseudomonads, the dominant spoilage bacteria in meat stored in air at refrigerated temperatures, is glucose. Only when glucose is exhausted do they break down amino acids, producing the ammonia and sulphur compounds that are detectable as spoilage odours and flavours. In meat containing no glucose, as is the case with some DFD meat, amino acids are broken down immediately and spoilage becomes evident at cell densities of 6 $\log_{10}$ cfu cm^{-2} (Gill, 1982). This is lower than in normal meat, where spoilage becomes apparent when numbers reach *ca*. 8 $\log_{10}$ cfu cm^{-2}. Thus, given the same storage conditions DFD meat spoils more rapidly than normal-pH meat. The microbiology of DFD meat has been comprehensively reviewed by Newton & Gill (1981).

Another quality defect resulting from slow chilling, especially in pork, is Pale Soft Exudative (PSE) meat. As the name suggests PSE meat is very pale and soft and produces large amounts of drip in the pack. There is little significant difference in pH or chemical composition between PSE and normal meat. There is no evidence that the spoilage of PSE meat is any different to that of normal meat (Gill, 1982).

8.5 Microbial growth on carcasses/sides during primary chilling

The aim of the primary chiller is to reduce the temperature of the meat in a controlled manner. Although it is often quoted that EU legislation requires red meat carcasses/sides be chilled to a maximum temperature of 7°C and poultry carcasses to a maximum temperature of 4°C, this is not strictly true as there is a provision for warm boning in both cases. No time limits on achieving these times have been set. Since microbial contamination of carcasses is primarily a surface phenomenon, there is an argument to be made that surface temperatures are far more important than deep temperatures (Gill, 2005). In Australia their Export Control (Meat and Meat Products) Orders 2005 require the monitoring of meat surface temperatures during chilling and require that the rate of chilling is sufficient to achieve a certain Refrigeration Index (RI) criteria. The Refrigeration Index (RI) is the value obtained by using a recognised predictive model to calculate the potential growth of *E. coli* at the site of microbiological concern (for more details of the model used to calculate the RI see Section 8.13.1).

Current EC legislation (Regulation (EC) No. 853/2004) imposes the following temperature controls on the meat:

Annex III, Section I: Meat of domestic ungulates (Red meat)

Section I, Chapter VII

(1) (a) Unless other specific provisions provide otherwise, post-mortem inspection must be followed immediately by chilling in the slaughterhouse to ensure a temperature throughout the meat of not more than 3°C for offal and 7°C for other meat along a chilling curve that ensures a continuous decrease of the temperature. However, meat may be cut and boned during chilling in accordance with Chapter V, point 4. *

(b) During the chilling operations, there must be adequate ventilation to prevent condensation on the surface of the meat.

(2) Meat must attain the temperature specified in point 1 and remain at that temperature during storage.

(3) Meat must attain the temperature specified in point 1 before transport, and remain at that temperature during transport. However, transport may also take place if the competent authority so authorises to enable the production of specific products, provided that:

(a) such transport takes place in accordance with the requirements that the competent authority specifies in respect of transport from one given establishment to another; and

(b) the meat leaves the slaughterhouse, or a cutting room on the same site as the slaughter premises, immediately and transport takes no more than two hours.

* Meat may be boned and cut prior to reaching 7°C when the cutting room is on the same site as the slaughter premises and the meat is subsequently chilled to 7°C.

Annex III, Section II: Meat from poultry and lagomorphs

Section II, Chapter IV

(8) After inspection and evisceration, slaughtered animals must be cleaned and chilled to not more than 4°C as soon as possible, unless the meat is cut while warm.

There is currently little data on the effect of current commercial chilling rates and conditions on changes in spoilage and pathogenic bacterial numbers during the chilling process. There is an emphasis in the UK Red Meat Industry towards more traditional methods in meat manufacture including the use of delayed chilling systems as opposed to rapid chilling systems and there is no information to show if these methods are having any effect on bacterial numbers.

Generally:

- If the cooling rate is too slow, problems with bone taint and high drip losses can result. At extremely slow rates toughening due to hot shortening and microbial problems due to growth of spoilage and potently pathogenic organisms can occur.
- If the initial cooling rate is too fast irreversible changes due to cold-shortening can occur and the meat will remain tough even after extensive ageing and cooking, unless electrical stimulation is employed. If electrical stimulation is not employed, carcass

temperatures (including the surface muscle) must not go below 10°C in the first 10 (beef and lamb) or 3-5 (pork) hours of cooling to avoid cold-shortening.

- There should also be adequate air circulating around the carcasses. Classic examples for poor air distribution are incorrectly positioned fan coils, supporting structures deflecting airflow, large spaces between fan coils causing dead spots and carcasses/sides hung in such a manner that they are in direct contact or produced small channels with still air in the.
- Consideration should be given to temperature rises that occur during loading, defrost cycles and in inactive chills.
- As already mentioned, red meat chilling in the UK is currently a batch operation. Consideration should be taken of the time it takes to fill the chiller, and that it takes longer to fill the chiller than to empty it (Gill, 2005). Thus carcasses/sides entering the empty chiller at the beginning of the day will in general receive a longer chilling time than those that enter at the end of the day.

In 1986, Shaw *et al.*'s review (**Shaw *et al.*, 1986**) of microbiological aspects of meat chilling (a follow up to Kitchell's review in 1972 **(Kitchell, 1972)**) concluded that: "A systematic study including a range of chill temperatures, relative humidities and air speeds has yet to be performed and it is therefore still difficult to predict the effect of different chilling systems on overall bacterial numbers on carcass surfaces." This still appears to be the case.

8.5.1 Beef

The classic work of **Scott & Vickery (1939)** in Australia has been extensively quoted by **Kitchell (1972)**, Nottingham (1982) and **Shaw *et al.* (1986)**. The study by **Scott & Vickery (1939)** has had a considerable effect on chilling developments and industrial attitudes during the past 70 years. As a result of their work, surface drying during chilling has been thought to be critical to the microbial quality of the carcass. There appears to have been no attempt to duplicate the work under the much faster rates of surface chilling that have been common over the past 40 years. Many microbiologists have quoted from the summary or reviews of the summary. Some of the authors own detailed statements appear to have been forgotten.

For example:

"In the previous section it has been shown that while reduced drying during cooling may allow considerable increases of bacteria to occur, the effects of desiccation *per se* have not been demonstrated."

"Scott has shown that the growth of *Achromobacter* No. 7 is inhibited when the water content of the muscle substrate are below 90% of the dry weight."

It is also interesting that the statement "Given the same rate of cooling, if the air flow was halved bacterial numbers increased 26-fold in 72 hours." Appears to be based on data from cooling regimes that produced substantially different rates of surface cooling. However even if the data is not directly applicable the changes in water activity and conditions surrounding surface bacteria resulting from covering the surface with a glass dish are likely to mirror those produced when two carcasses touch. This is very likely to happen when warm carcasses are in transport.

Nottingham & Wyborn (1975) found that chilling time had a significant effect on the level of bacterial flora of beef. In these studies, designed primarily to look at ageing at elevated temperatures, various chilling regimes, using air velocities ranging from 0.2 to 1.5 ms^{-1}, were used to chill beef sides (Table 45 and Table 46). The relative humidity usually decreased

during chilling from the region of 95-100% at load-in to about 85% at the end of chilling. Chiller temperatures were found to have little effect on the level of bacteria for up to 24 hours, no increase in count being apparent when chilling at 7, 10, or 18°C. Chilling time was more significant than temperature. On sides chilled at 7°C for 48 hours there was only a slight increase in bacterial counts, but more than a 100-fold increase occurred on sides chilled at 10°C for 68 hours. Nottingham (1982) concluded that this indicates that chilling requirements should be expressed in terms of time as well as temperature. Only in sides subjected to a multi stage fast chilling regime (using air below 0°C) did the deep-bone temperature reach 7°C, the EU requirement, in 24 hours. However, tenderness evaluation of this meat showed that many of the muscles had been cold-shortened and were unacceptably tough. The bacterial counts from the flank, neck and under the foreshank increased more than those from the other areas examined. This was attributed to the effectiveness of drying in suppressing microbial growth, the surface of the hindquarter in cooling slower and being exposed to more air movement drying faster than the other areas (Nottingham, 1982).

Table 45. Effect of chilling regime on the bacteria on beef (source: Nottingham & Wyborn, 1975)

				Average surface bacterial count at 37°C (log cfu cm^{-2})					
Chilling conditions				Sampling positions					
Temperature (°C)	Time (h)	Sides		Leg	Aitch	Flank	Brisket	Neck	Average
7 (normal)	48	8	Before	2.17	1.97	2.81	2.79	1.79	2.30
			After	2.01	2.36	2.76	2.76	2.62	2.50
7 (rapid) *	48	4	Before	2.42	1.72	1.85	2.52	2.53	2.21
			After	2.10	1.59	2.21	2.34	2.24	2.10
7	21-24	19	Before	2.99	2.58	3.00	2.41	3.10	2.82
			After	2.38	2.30	2.81	2.39	2.86	2.33
10	20	3	Before	2.37	2.58	2.40	1.46	2.41	2.24
			After	2.38	2.59	1.70	2.19	1.53	2.08
18	24	1	Before	2.26	3.26	2.90	2.38	3.85	2.93
			After	2.30	4.81	2.08	2.92	3.00	3.02
10	68	6	Before	2.37	3.15	2.80	3.36	3.70	3.08
			After	4.44	4.29	4.63	5.36	6.52	5.25

*Multi stage cooling: chiller pre-cooled to –6°C, air temperature reduced to –12°C within 4 h of slaughter, rise to 0°C for further 8 h before equilibrium at 7°C for remainder of the time

Table 46. Effect of chilling regime on the bacteria on beef (source: Nottingham & Wyborn, 1975)

Chilling conditions				Average surface bacterial count at 25°C (log cfu cm^{-2}) Sampling positions					
Temperature (°C)	Time (h)	Sides		Leg	Aitch	Flank	Brisket	Neck	Average
7 (normal)	48	8	Before	2.38	2.33	3.07	3.14	2.05	2.59
			After	2.34	2.53	3.36	3.34	3.02	2.92
7 (rapid) *	48	4	Before	2.71	2.07	2.04	2.67	2.72	2.44
			After	2.58	1.72	2.56	2.65	2.51	2.40
7	21-24	10	Before	3.20	2.79	3.23	2.54	3.24	3.00
			After	3.01	2.44	3.20	2.77	3.16	2.92
10	20	3	Before	2.50	2.67	2.68	1.65	2.53	2.41
			After	2.58	2.71	2.08	2.21	1.66	2.25
18	24	1	Before	2.51	3.43	3.08	2.41	3.94	3.07
			After	2.53	4.81	2.20	3.11	3.11	3.15
10	68	6	Before	2.61	3.03	2.82	3.36	3.66	3.10
			After	4.78	4.43	5.54	5.58	7.06	5.47

* Multi stage cooling: chiller pre-cooled to –6°C, air temperature reduced to –12°C within 4 h of slaughter, rise to 0°C for further 8 h before equilibrium at 7°C for remainder of the time

Nortjé & Naudé (1981) reported that chilling reduced the mean total aerobic count, measured at 10 positions on a beef carcass, from 2.95 to 2.30 $\log_{10}$ cfu cm^{-2}. Similar results were obtained by **Thomas *et al.* (1977)** who compared chilling and holding beef carcasses at 3°C with conditioning at 13°C for 8 hours followed by chilling at 3°C. At 46 hrs post-mortem there was a difference of 0.7 log in psychrotrophs and 0.3 log in mesophiles, the 3°C treatment resulted in lower counts for both types of bacteria.

Greer & colleagues (**Greer & Jones, 1997**; Greer *et al*., 1990) found minimal differences between the microbial qualities of beef from spray chilled and conventionally chilled beef carcasses.

An extensive survey of the microbiological quality of Australian beef carcass and frozen bulked packed beef was reported by **Vanderline *et al.* (1998)**. A total of 1063 beef carcasses were sampled from 49 abattoirs, representing both the domestic and export industry in the country, over a 12-month period. To evaluate the microbiological quality of the meat, samples were collected after a minimum of 12 hours chilling at the end of the slaughter and dressing process. The microbiological quality of carcasses varied significantly from works to works and between types of works, i.e., domestic and export (Table 47). APCs on carcasses from export works were similar to those obtained in Canada (**Charlebois, 1991**). The majority of carcasses sampled in the current survey had no detectable *E. coli* and coliforms. The distribution of numbers of *E. coli* on Australian beef carcasses was again similar to that of faecal coliforms found on beef carcasses produced in Canada (**Charlebois, 1991**). However, the incidence of *Campylobacter* spp. was lower than that reported on US carcasses. Since it has been reported that *Campylobacter* spp. are susceptible to surface drying (**Grau, 1987**) **Vanderline *et al.* (1998)** attributed this difference to the practice of spray chilling in the US. The standard Australian practice of operating a 5-day week was found to have a significant effect on microbiological quality. Cattle killed on a Friday were generally chilled over the weekend and de-boned on the Monday of the following week. Holding temperatures during extended chilling cycles were usually in the range of 7 to 12°C to prevent the formation of 'hard fat', which is difficult to bone and has occupational health and safety

implications. These temperatures can allow the growth of bacteria such as *E. coli* and salmonellas and it was evident from the results (Table 47) that this happened. APCs (25°C) in frozen boneless bulk packed beef samples collected from export establishments were lower than the APCs in domestic samples. This was attributed to stricter temperature controls applied in export abattoirs (to satisfy other countries that are more demanding in terms of hygienic quality and shelf-life, processors are more careful with meat to be exported). The APC (5°C) found in domestic samples was significantly higher than that found in export samples, and accounted for a large percentage (69%) of the total count. In export samples, only 16% of the total bacteria counted were capable of growing at low temperatures. In Australian works targeting the domestic market, carcasses were usually transported off-works to be de-boned. Once de-boned and packaged, cartons could be further transported to be frozen. It was postulated that temperatures during transportation could be high enough to allow significant growth of psychrotrophic bacteria while remaining low enough to control the growth of *E. coli* and coliforms. Assuming that the samples analysed during the two surveys at these plants gave a true estimation of the microbiological quality of the product, the authors compared the two samples' categories to determine if any relationship exists between them. Regression analysis of the data showed a significant relationship implied that the number of bacteria present on the meat were directly proportional to the microbiological quality of the carcasses entering the boning room.

Table 47. Number and incidence of bacteria on frozen boneless bulk packed beef and beef carcasses, processed in domestic and export works, after overnight and weekend chilling (source: Vanderline *et al.*, 1998)

	Overnight chill				Weekend chill		frozen boneless bulk packed beef			
Bacteria	Domestic		Export		Export		Domestic		Export	
APC (25°C/72 hrs)	3.71[a]	(144)[b]	2.89	(738)[b]	4.26	(161)[b]	4.26	(139)[b]	2.50	(790)[b]
APC (5°C/336 hrs)	2.92	(144)[b]	1.84	(138)[b]	3.85	(161)[b]	4.10	(139)[b]	1.70	(790)[b]
E. coli (biotype I)	27.1%	(5)[c]	17.5%	(9)[c]	39.7%	(27)[c]	20.9%	(8)[c]	15.9%	(15)[c]
Coliforms	46.5%	(9)[c]	34.4%	(12)[c]	63.3%	(62)[c]	65.5%	(19)[c]	33.8%	(15)[c]
Salmonella spp.	1.4%	(2/144)[d]	0.27%	(2/738)[d]	-[e]	(0/161)[d]	2.24%	(3/134)[d]	0.38%	(3/787)[d]
Campylobacter spp.	0.81%	(1/124)[d]	0.19%	(1/533)[d]	-	(0/96)[d]				
Listeria spp.	15%	(3/20)[d]	0.77%	(1/130)[d]	-	(0/40)[d]				
Staphylococcus spp.	20%	(15/75)[d]	22.3%	(68/305)[d]	52.9%	(45/85)[d]				
E. coli O157: H7	-	(0/144)[d]	0.5%	(4/732)[d]	-	(0/161)[d]	-	(0/119)[d]	-	(0/685)[d]

[a] log_{10} cfu g^{-1};[b] Number of samples analysed; [c] Geometric mean of the most probable number of bacteria per gram, for positive samples only; [d] number of positive samples over the number of samples analysed; [e] Organism not detected by the method used

A series of studies have been carried out in Canada by Gill (**Gill & Jones, 1997; Gill & Bryant, 1997)** assessing the hygienic performance of meat cooling processes and comparing temperature histories with actual microbiological counts. Studies on beef (**Gill & Bryant, 1997**) compared carcasses cooling processes at two abattoirs. For each process temperature histories were collected with temperatures measured from the deep-leg, the aitch-bone pocket surface, and randomly selected surface sites of carcasses passing through. Swab samples were obtained from a randomly selected site on each of 25 randomly selected carcasses entering and 25 leaving each process. At both abattoirs, in 1 out of 25 carcasses a high minimum temperature was measured that was indicative of ineffective cooling.

At abattoir A, carcasses resided in the chiller for between 15.8 and 28.0 hours. The minimum deep-leg temperature measured in 24 of the 25 carcasses ranged from 3.5 to 14°C, with a minimum deep-leg temperature of 19°C in the 25th. The minimum temperature obtained at aitch-bone pocket site ranged from -4.3 to 9.8°C with 17 temperatures being <3°C. At

abattoir B, carcasses resided in the chiller for between 20.0 and 24.0 hours. The minimum deep-leg temperature measured in 24 of the 25 carcasses ranged from 1.5 to 7.5°C with 20.3°C in the 25th. The minimum temperatures attained at the aitch-bone pocket site for 24 of the 25 carcasses ranged from -3.0 to 2.8°C, with 11.3°C being measured in the remaining carcass.

Using these temperature histories *E. coli* proliferation models showed that numbers on carcasses would increase by about 1 log unit at abattoir A and 0.3 log units at abattoir B. However, enumeration of bacteria (Table 48) showed that cooling reduced mean numbers of APCs, coliforms and *E. coli* on carcasses at abattoir A by <0.5 log units. While at abattoir B APCs were reduced by about 0.5 log units and coliform and *E. coli* counts by 2 log units. The findings indicated that, while "temperature history data may be used to monitor the maintenance of standard operating procedures in such processes", microbiological data was required to properly access the hygienic effects of carcass cooling processes.

Table 48. APC (log_{10} cfu cm^{-2}), coliform (log_{10} cfu 100 cm^{-2}) or *E. coli* (log_{10} cfu 100 cm^{-2}) counts obtained from randomly selected sites on randomly selected carcasses entering or leaving the chillers at 2 beef abattoirs (source: Gill & Bryant, 1997)

Abattoir		Stage of the process	Statistics			
			Mean	SD	n°	log A
A	APC	Entry	3.06	0.92	0	4.03
		Exit	3.04	0.68	0	3.58
	Coliform	Entry	1.25	0.70	0	1.81
		Exit	0.46	0.89	8	1.37
	E. coli	Entry	0.02	0.55	11	0.37
		Exit	0.27	0.43	18	0.06
B	APC	Entry	2.35	0.82	0	3.12
		Exit	1.87	0.73	0	2.48
	Coliform	Entry	1.13	0.88	1	2.02
		Exit	-0.23	0.39	15	-0.06
	E. coli	Entry	1.08	0.90	1	2.01
		Exit	-0.26	0.32	15	-0.14

n° = number of samples from which bacteria were not recovered; values of –0.5 100 cm^{-2} were assumed for samples in which coliforms or E. coli were not detected; log A, estimated log of the arithmetic mean.

Laboratory studies by **Kinsella *et al*. (2006)** on the survival of bacteria, including *Salmonella* Typhimurium DT104, attached to beef carcass surfaces, failed to identify any chilling regime that gave consistent and meaningful reductions in surface bacterial counts while not seriously compromising the quality of the carcasses in terms of excessive amounts of weight loss. The study concluded that chilling was not a satisfactory process for use as a CCP in beef chilling. In addition, this study found that the RH of the chill did not have a significant effect on bacterial survival and concluded that carcass surface a_w was unlikely to be a major factor in reducing carcass surface counts.

Due to the presence of Listeria on meat and its ability to grow at refrigeration temperatures, it is surprising that there is little data on its survival on meat carcasses and cuts during chilling and processing. A recent study has determined the survival and growth of *L. innocua* on hot and cold beef carcass surfaces (**Prendergast *et al*., 2007**). Four sites, the neck, outside round, brisket and fore- shank/brisket, were inoculated with *L. innocua*: (i) immediately after dressing while hot and (ii) when cold after chilling. After inoculation, all carcasses were chilled at 4°C and stored at 4°C for 72 hours. Chilling took 45 hours to reduce temperatures

in the outside round to 4°C. Survival of *L. innocua* on cold surfaces declined during storage and was less than on hot carcasses at all times. Data on the survival of *L. innocua* in broth (maximum recovery diluent) indicated that counts could not be compared with those on carcasses, in particular on cold carcasses. The results of this study indicate that *L. innocua* survives on hot carcass surfaces during chilling, but declines over time on cold surfaces. The authors postulated that the decrease in *L. innocua* counts on cold surfaces may be related to a synergy between the combined stresses of low available water (a_w) and low temperature.

Table 49. Occurrence of arcobacters on beef carcasses at different sampling sites and processing times in two abattoirs (source: De Smelt *et al*., 2010)

Sampling site	Post-evisceration (n=179)	Post-chill (24 h post-mortem) (n=68)
Fore-leg	44 (24.6%)	3 (4.4%)
Chest	35 (19.6%)	3 (4.4%)
Flank	0 (0.0%)	2 (2.9%)
Rump	3 (1.7%)	1 (1.5%)
Number of carcasses with at least one contaminated site	37 (37.4%)	5 (7.4%)

Some pathogens, particularly campylobacter, have been reported to be sensitive to air chilling. A recent survey of two Belgian beef abattoirs (**De Smelt *et al*., 2010**) showed that the occurrence of arcobacters were lower after chilling than before (Table 49). In the survey, beef carcasses were sampled in two unrelated Belgian abattoirs on each of four occasions. There are little details regarding the chilling conditions in either abattoir, beyond the sides being "stored in forced air cooling rooms for at least 24 hours until a core temperature of 7°C was reached".

8.5.2 Pork

The microbiology of pork carcasses differs in some respect from that of beef and lamb in that the skin remains on the carcass (Nottingham, 1982). As well as differences in the micro-flora, the drying characteristics of the skin are different to that of beef and lamb subcutaneous tissue. An audit of three pork processing plants by **Knudtson and Hartman (1993)** high-lighted the chilling operation as having an important influence on enterococci counts. However, the differences between the different operations were not quantified.

Some indirect evidence for the effect of chilling rates of pigs on their bacteriological condition was published by **Jul (1957)**. The brines used in bacon factories curing pigs cooled quickly and slowly were compared. The bacterial counts were 2.2 and 7.5 x 10^5 cfu ml^{-1}, respectively. It appeared, therefore, that the meat cooled quickly introduced fewer bacteria into the brine, presumably because the greater cooling rate controlled bacterial growth.

In contrast, **Cooper (1968)** reported higher counts with an even faster rate of chilling bacon pigs. Surface counts on carcasses after chilling (presumably composite samples from the rind and the internal surfaces) in an abattoir with "rapid" chilling equipment were compared with those from 7 other abattoirs with normal quick-chill equipment. The results were 2.96 and 2.55 $\log_{10}$ cfu cm^{-2} respectively. At the time normal quick chilling reduced the internal temperature of the meat to 3°C within 14 hours by means of air circulating at 2.5 ms^{-1}, starting at a temperature of 10°C and falling linearly during cooling to 0°C at 14 hours. The rapid chilling process started with air temperatures of -7°C or lower and air speeds of 2 to 3

ms^{-1} deliberately to reduce weight losses. Desiccation during chilling was reduced from 2.1% to 1.5%.

Studies by **Greer & Dilts (1987; 1988)** found very little difference between the effect of conventional air chilling, rapid air chilling and spray chilling of pork carcasses on bacterial numbers (Table 50).

Table 50. Effect of chilling treatment on mesophilic bacteria (log_{10} cfu cm^{-2}) on pork carcasses

	Greer & Dilts (1987)		Greer & Dilts (1988)	
	Conventional [1]	Rapid ("blast") [2]	Conventional [1]	Spray [3]
Before chill	3.60	3.54	2.53	2.77
After chill	3.49	3.63	2.12	2.52

[1] at 1°C for 24 h, [2] -25°C for 1 h followed by 1°C for 23 h [3] 60 s cycles every 15 min for initial 10 h at 1°C followed by 1°C for 14 h

Studies on the "ultra rapid" chilling of pig carcasses (**James *et al.*, 1983**) and other alternative methods of pig chilling (**Gigiel *et al.*, 1989**) have shown no significant difference of chilling method or time on bacterial numbers (Table 51 and Table 52, respectively).

Table 51. Mean APCs (log_{10} cfu cm^{-2}) incubated at 37°C and 25°C from freshly slaughtered pig and vacuum-packed joints stored at 0°C for 2 days (n=30 carcasses, 15 sides) (source: James *et al.*, 1983)

		Rapid chilling		Conventional chilling	
	APC temp (°C)	Side	Carcass	Side	Carcass
Freshly slaughtered	37	3.63	3.49	3.40	3.43
	25	4.23	4.16	4.00	4.09
Vacuum-packed joints	37	2.99	2.79	3.04	2.99
	25	3.53	3.38	3.62	3.60

Table 52. Mean APCs of samples taken from the abdomen lateral and medial surfaces of pig carcasses before and after chilling using a variety of chilling treatments (source: Gigiel *et al.*, 1989)

	Pre-chill		Post-chill		Difference	
	Lateral surface	Medial surface	Lateral surface	Medial surface	Lateral surface	Medial surface
High humidity	3.32^{a}	2.29^{a}	2.81^{a}	1.55^{a}	-0.51	-0.74
Delay + high humidity	3.36^{a}	2.35^{a}	2.97^{a}	2.12^{ab}	-0.39	-0.23
Delay + spray	3.41^{a}	2.19^{a}	3.38^{a}	2.62^{b}	-0.03	0.43
Rapid chill + high humidity	3.42^{a}	2.36^{a}	3.20^{a}	2.62^{b}	-0.22	0.26
Rapid chill + conventional	3.60^{a}	2.31^{a}	3.18^{a}	2.35^{b}	-0.42	0.04
Conventional	3.59^{a}	2.27^{a}	3.23^{a}	2.10^{ab}	-0.36	-1.17

Studies on pork cooling by Gill & Jones (1997) followed the same procedure as that described above for beef (Gill & Bryant, 1997). Only one abattoir was assessed. The carcasses were spray-cooled. Carcasses resided in the chiller for between 14.8 and 24.5 hrs. Most of the pork carcasses attained deep-leg and aitch-bone pocket surface temperatures

<7°C. However, temperatures remained >13°C in 8% of carcasses. Using these temperature histories *E. coli* proliferation models showed that growth would be undetectable, but that APCs would increase by <1 log unit. Enumeration of bacteria (Table 53) showed that bacteria on pig carcasses behaved much as would be expected from the temperature histories.

Table 53. APC (log_{10} cfu cm^{-2}), coliform (log_{10} cfu $100cm^{-2}$) or *E. coli* (log_{10} cfu 100 cm^{-2}) counts obtained from randomly selected sites on randomly selected carcasses entering or leaving the chiller at a pork abattoir (source: Gill & Jones, 1997b)

	Stage of the process	Statistics			
		Mean	SD	n°	log A
APC	Entry	1.06	0.82	0	1.83
	Exit	2.04	0.68	0	2.57
Coliform	Entry	0.15	0.77	12	0.83
	Exit	0.13	0.69	11	0.68
E. coli	Entry	-0.04	0.59	13	0.35
	Exit	-0.07	0.65	15	0.42

n° = number of samples from which bacteria were not recovered; values of –0.5 100 cm^{-2} were assumed for samples in which coliforms or E. coli were not detected; log A, estimated log of the arithmetic mean.

Laboratory based studies by **Chang *et al.* (2003)** showed both "*industry-specific blast*" or "*conventional"* chilling processes to reduce inoculated microbial counts on skin-on and skin-off pork surfaces. The samples were inoculated with porcine faecal slurries with and without pathogens (*L. monocytogenes*, *S.* Typhimurium, and *C. coli*) and subjected to what could be considered highly unusual and unrepresentative cooling regimes, in that the "*industry-specific blast*" used high velocity -20°C air for the first 60 min of treatment, while the "*conventional chilling*" was carried out in a refrigerator at 4°C with a relatively static air movement. Never-the-less, both treatments reduced microbial counts, by as much as 2 log_{10} cfu cm^{-2} in some cases. There was little difference in the effect on different microorganisms with the exception of *C. coli*, which was more sensitive to the "*industry-specific blast*" treatment.

Gill & Landers (2004) found that chilling reduced the numbers of *E. coli* but not the numbers of aerobes on detained carcasses. After cooling, the log mean number of aerobes and *E. coli* on detained carcasses were each about 0.5 log unit more than the log mean numbers on routinely processed carcasses, but numbers of coliforms on the two types of carcass were similar. There were small increases in the numbers of coliforms and *E. coli* on carcasses during their movement from the cooler to the breaking facility. Full details of the chilling process are not described, however it did involve an initial rapid cooling stage using air at -20°C and 5 ms^{-1} for the first hour of operation, carcasses were cooled overnight (sprays were not used).

A survey of four Irish pig abattoirs (**Lenahan *et al.*, 2009**) that examined the potential use of chilling as a CCP found that while chilling generally reduced Enterobacteriaceae on carcasses, increases were also observed. Reductions occurred on 57% of the carcasses examined, 17% showed no change, while 26% of carcasses showed increased counts. Details of the chilling processes used in the four abattoirs are not described.

In contrast to many studies, **Bolton *et al.* (2002)** observed an increase in counts after chilling pork carcasses. APCs after final washing were between 3.6 and 4.0 log_{10} cfu cm^{-2} while final carcass loadings post-chill were between 4.5 and 4.7 log_{10} cfu cm^{-2}. Unfortunately, no data was published on the method of chilling employed or the temperatures or times. Since this

was a small pig abattoir it is possible that the chilling unit was simply inefficient, or undersized, and the carcasses took far to long to cool thus allowing bacterial growth.

8.5.3 Lamb/sheep

Smith and colleagues (**Smith *et al.*, 1976**) reported a slight reduction during the chilling of lamb carcasses. Chilling lamb at 0°C or 16°C for 16 hours followed by storage at 0°C for a further 96 hours resulted in a difference of 0.5 l $\log_{10}$ cfu cm^{-2} in counts.

Sauter *et al*. (1979) reported substantial reductions in bacterial numbers on lamb carcasses chilled for 24 hours at -2.2°C (Table 54). Reductions were greater on lightweight carcasses (reduction in APCs of 1.1 $\log_{10}$ cfu cm^{-2}) than on heavy weight carcasses (reduction in APCs of 0.48 $\log_{10}$ cfu cm^{-2}). Fat cover was found to have an effect on bacterial numbers; carcasses having ≤0.36 cm fat cover had significantly higher psychrophilic counts (of the order of 1 $\log_{10}$ cfu cm^{-2} after 7 days storage at 3.3°C).

Table 54. Bacterial numbers ($\log_{10}$ cfu cm^{-2}) on lamb carcasses before and after chilling (air blast at -2.2°C for 24 h) (source: Sauter *et al*., 1979)

	Light carcasses (average slaughter weight of 50.9 kg)			Heavy carcasses (average slaughter weight of 59.5 kg)		
	Before chill	After 24 h chill	Difference	Before chill	After 24 h chill	Difference
Total aerobes	3.81	2.71	1.10	3.71	3.23	0.48
Anaerobic-facultative	3.76	2.11	1.65	2.85	2.40	0.45
Coliforms	2.86	1.59	1.27	2.70	2.59	0.11
Psychrotrophs	3.11	2.94	0.17	2.92	2.92	0.01
Lactic acid bacteria	-	-	-	2.04	1.62	0.42
Enterococci	-	-	-	1.48	1.23	0.25
E. coli	1.87	1.40	0.47	1.72	1.61	0.10
C. perfringens	<1.00	<1.00	-	<1.00	<1.00	-

Audits in New Zealand carried out in a plan to improve the shelf-life of vacuum packed chilled lamb have shown that optimising the chilling practice of plants can have a significant effect on storage life (Gill, 1987). It was found that the significance of the relatively small numbers of microorganisms added to carcasses during dressing was greatly magnified by their growth during carcass cooling. Small changes to the chilling practices, such as ensuring adequate air movement around carcasses, extended the storage life by up to 50%.

Studies on lamb cooling by Gill & Jones (1997) followed the same procedure as that described above for beef (Gill & Bryant, 1997). Only one abattoir was assessed. The carcasses were air-cooled. Carcasses resided in the chiller for between 17.5 and 66.8 hours. All the lamb carcasses attained deep-leg and aitch-bone pocket surface temperatures <7°C.

Using these temperature histories *E. coli* proliferation models showed that growth would be undetectable, but that APCs would increase by >1 log unit. However, enumeration of bacteria (Table 55) showed that cooling reduced mean numbers of APCs, coliforms and *E. coli* on carcasses by 0.5, 1.5 and 2 log units, respectively. Again, the findings indicated that factors other than simply temperature determine the behaviour of the microflora on carcasses during cooling.

Table 55. APC (log_{10} cfu cm^{-2}), coliform (log_{10} cfu 100 cm^{-2}) or *E. coli* (log_{10} cfu 100 cm^{-2}) counts obtained from randomly selected sites on randomly selected carcasses entering or leaving the chiller at a lamb abattoir (source: Gill & Jones, 1997)

	Stage of the process	Statistics			
		Mean	SD	n°	log A
APC	Entry	3.02	0.52	0	3.33
	Exit	2.67	0.41	0	2.86
Coliform	Entry	2.48	0.97	1	3.56
	Exit	1.23	0.80	2	1.97
E. coli	Entry	2.12	1.12	2	3.57
	Exit	0.82	0.76	3	1.49

n° = number of samples from which bacteria were not recovered; log A, estimated log of the arithmetic mean.

8.5.4 Poultry

The effect of different chilling methods and rates of chilling on microorganisms on poultry has been comprehensively reviewed by James *et al*. (2006). Numerous publications show that, in general, the numbers of microorganisms on the surface of poultry carcasses are reduced during the chilling process. However, this reduction is usually slight, of the order of 0.5 to 1 log. Surface drying during air chilling has been cited by a number of authors as advantageous in reducing surface bacteria, particularly campylobacters, during poultry chilling. However, overall the literature would appear to show greater reductions when using immersion-chilling systems.

8.6 Microbial growth on unpackaged carcasses/sides/primals during storage/ageing (dry ageing)

General data are available on the attainable chilled storage lives for many meat carcasses (Table 56). However, as previously mentioned, much is based on 'learned' opinion rather than peer reviewed scientific studies.

Table 56. Practical Storage Life of aerobically chilled meats, PSL is the time that the product is still of acceptable quality, assuming good initial bacteriological quality and normal pH (IIR, 2000)

Product	Temperature (°C)	Packaging	PSL d = day w = week m = month
Beef carcasses	4	Unwrapped	10-14 d
Beef carcasses	–1.5 to 0	Unwrapped	3-5 w
Veal	–1.5 to 0	Unwrapped	3 w
Pork carcasses	4	Unwrapped	8 d
Pork carcasses	–1.5 to 0	Unwrapped	3 w
Lamb carcasses	–1.5 to 0	Unwrapped	3-4 w
Chicken, eviscerated	4	Perm. Plastic	1 w
Chicken, eviscerated	0	Perm. Plastic	2 w
Chicken, eviscerated	–2	Perm. Plastic	3-4 w

There appears to be surprisingly little data on the growth of microorganisms on meat carcasses/sides/primals during unwrapped/dry storage/ageing.

Temperature is the prime factor controlling the storage-life of, and bacterial growth on, unwrapped carcass meat. Classical literature (Ingram & Roberts, 1976) says that odour and slime will be apparent after approximately 14.5 and 20 days respectively with beef sides

stored at 0°C (Figure 71). At 5°C, the respective times are significantly reduced to 8 and 13 days. These data are contradicted by the 21 days or more that beef now is kept for traditional "dry-ageing".

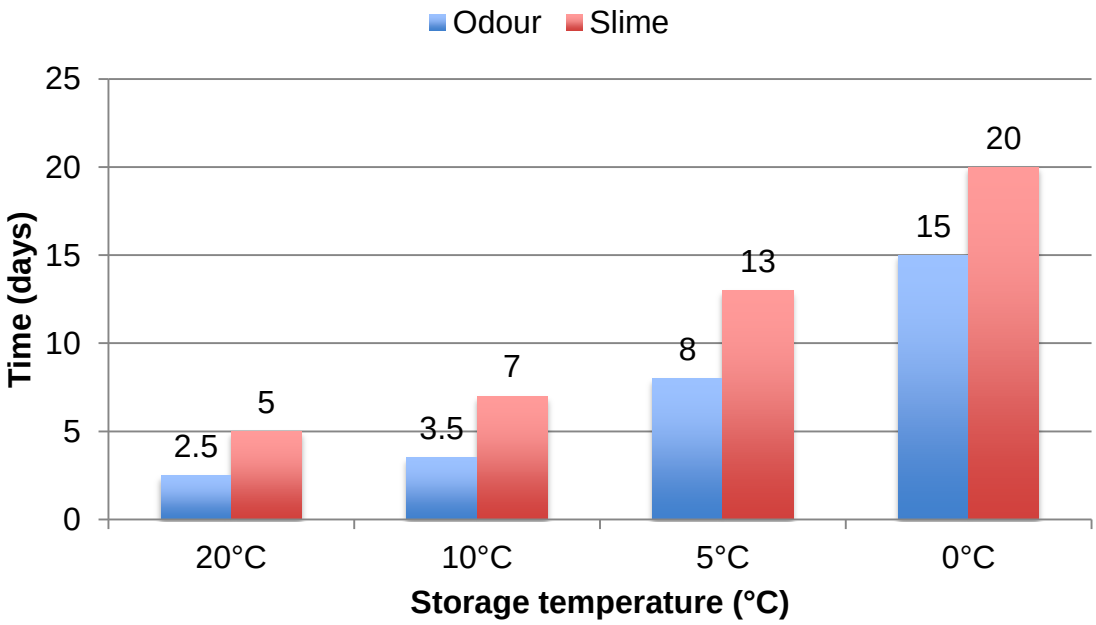


Figure 71. Time (days) for odour or slime to be detected on beef sides with average initial contamination stored at different temperatures (source: Ingram & Roberts, 1976)

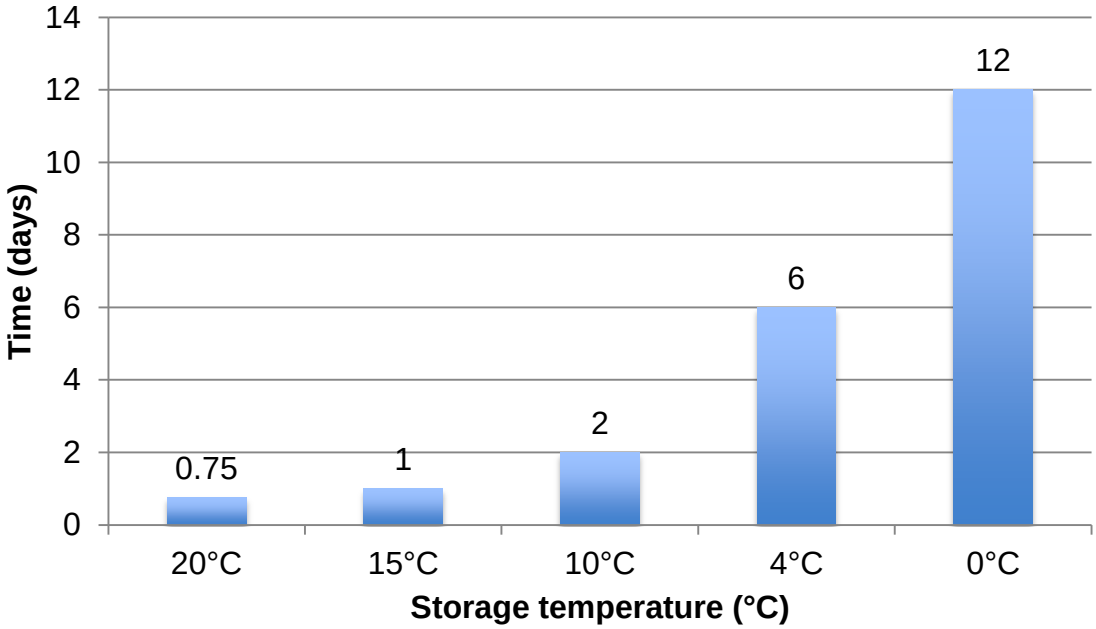


Figure 72. Time (days) for odour to be detected on chicken carcasses with average initial contamination stored at different temperatures (source: Regez *et al.*, 1988)

Similar literature on chicken carcasses (Regez *et al.*, 1988) show that odour will be apparent after approximately 12 days with chicken carcasses stored at 0°C (Figure 72). However,

longer storage times have been reported of 17 to 19 days at -1°C, and 8 to 10 days at 4°C (Mielnik *et al*., 1999).

High pH will limit the storage-life of beef carcasses. UK Meat Research Institute (Hudson & Roberts, 1972) work showed that bacteria grow faster on the surface of high pH sides than low pH (Figure 73).

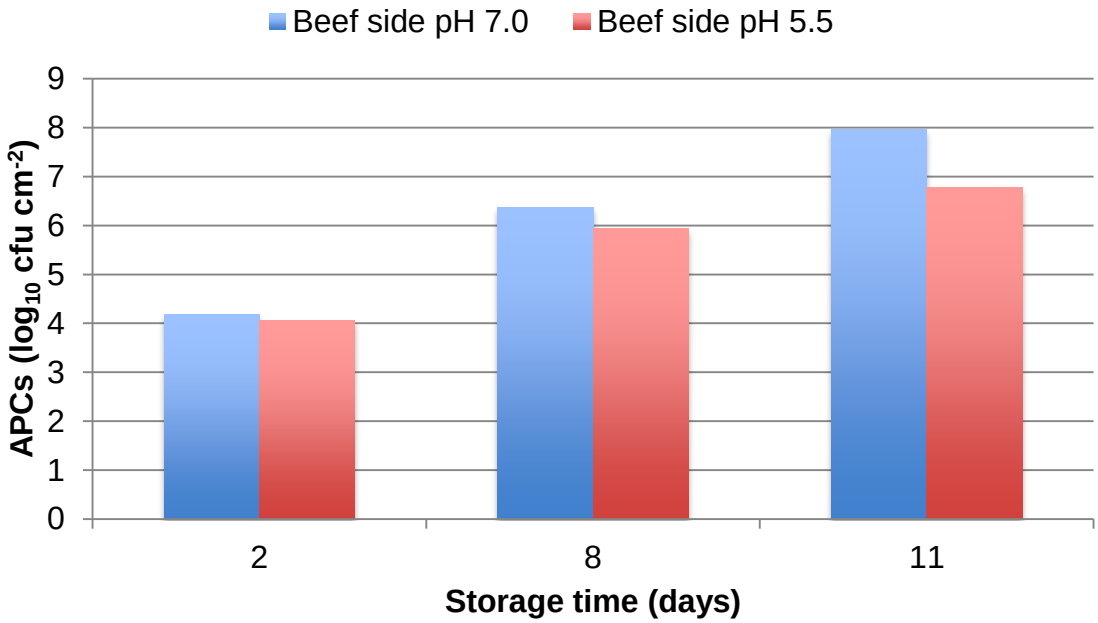


Figure 73. Growth of bacteria on beef sides with different pHs stored at 1°C (source: Hudson & Roberts, 1972)

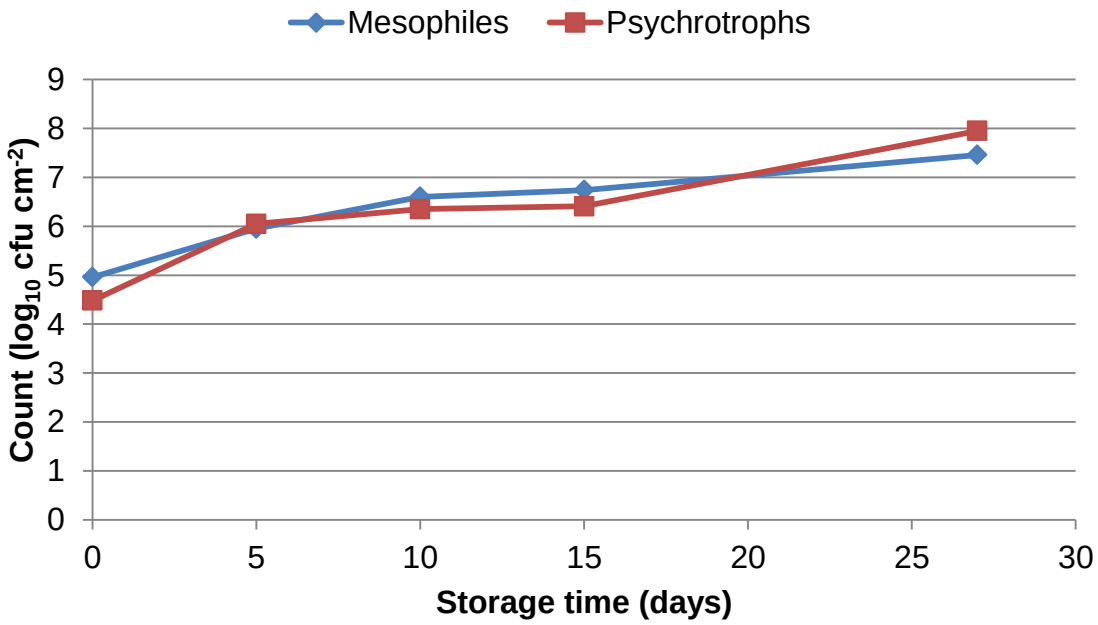


Figure 74. Growth of bacteria on lamb carcasses stored at 3±1°C (source: Prieto *et al*., 1991)

Lamb carcasses are typically believed to have a shorter storage-life than beef carcasses. One reason for this is the belief that initial levels of contamination are higher on sheep carcasses

than those of beef. However, Prieto *et al*. (1991) recorded storage-lives of between 23-29 days for lamb carcasses (pH >5.8,) stored at 3±1°C and 95±5% RH despite relatively high initial mesophilic counts of 5 $\log_{10}$ cfu cm^{-2} (Figure 74). Both mesophiles and psychrotrophs increased throughout the storage-life.

There is much industrial belief that the surface of meat carcasses must be allowed to dry or storage-life will be compromised. There appears to be no clear scientific studies that stored carcasses under a range of industrial conditions to either prove or disprove this belief. Studies comparing conventionally and spray chilled beef carcasses have shown little difference between bacterial numbers (Greer *et al.,* 1990). Initial APCs on conventionally chilled carcasses aged for 7 days at 1°C reduced from 2.92 to 2.87 $\log_{10}$ cfu cm^{-2}, while counts on spray chilled carcasses aged under the same conditions slightly rose from 2.52 to 2.54 $\log_{10}$ cfu cm^{-2}. A recent study by **Tittor *et al*. (2011)** compared both dry and wet chilling and ageing of beef under simulated conditions. Samples were obtained from a harvest facility prior to antimicrobial interventions and were inoculated with a cocktail mixture of *E. coli* O157:H7 or *Salmonella* spp. to achieve a target inoculation of 6 $\log_{10}$ cfu cm^{-2}. Wet chilled and aged samples were then suspended, sprayed (10°C) continuously for 15 min and then sprayed for 1 min every 17 min for 17 hours, and vacuum packed after 48 hours. Dry chilled and aged samples were suspended in refrigeration (3°C) with an air velocity of 0.25 ms^{-1} and a relative humidity of 80%. A large initial reduction of *E. coli* O157:H7 and *Salmonella* was observed, regardless of tissue type and chilling method. Fewer *E. coli* O157:H7 were detected on wet chilled samples at 24 and 36 hours; however, plate counts were higher from wet aged samples excised at 7 through 28 days. Final plate counts were 1.03 and 3.67 $\log_{10}$ cfu cm^{-2} for dry and wet aged samples, respectively. Fewer *E. coli* O157:H7 microorganisms were detected on fat samples from each sampling time, with the exception of 28 days, compared with lean samples. Similar trends were observed in the reduction of *Salmonella* for chilling or ageing method and tissue type, resulting in final counts of 1.25 and 3.67 $\log_{10}$ cfu cm^{-2} for dry and wet aged samples, respectively. These findings show that chilling and ageing are critical control points and that pathogen numbers may decrease during these operations. However, the levels of pathogens used are unrealistically high and in general lower storage temperatures are used commercially in the UK for ageing. Due to the difference in the chilling methods the results unfortunately do not show a true comparison of dry and wet ageing.

Specific surfaces of a carcass can have very high levels of initial contamination. Beef subcutaneous fat has been shown to have a high initial microbial load and a capacity to support extensive bacterial growth (Lasta *et al*., 1995). Initial values of total viable counts increasing from an initial value of 5.4 $\log_{10}$ cfu cm^{-2} to 10.0 after 11 days in a "moist" environment at 5°C (Figure 75), however, no noticeable deterioration in the appearance of the sample was found after 14 days. This type of material is often incorporated in manufactured products and could contaminate the product or provide a cross contamination source.

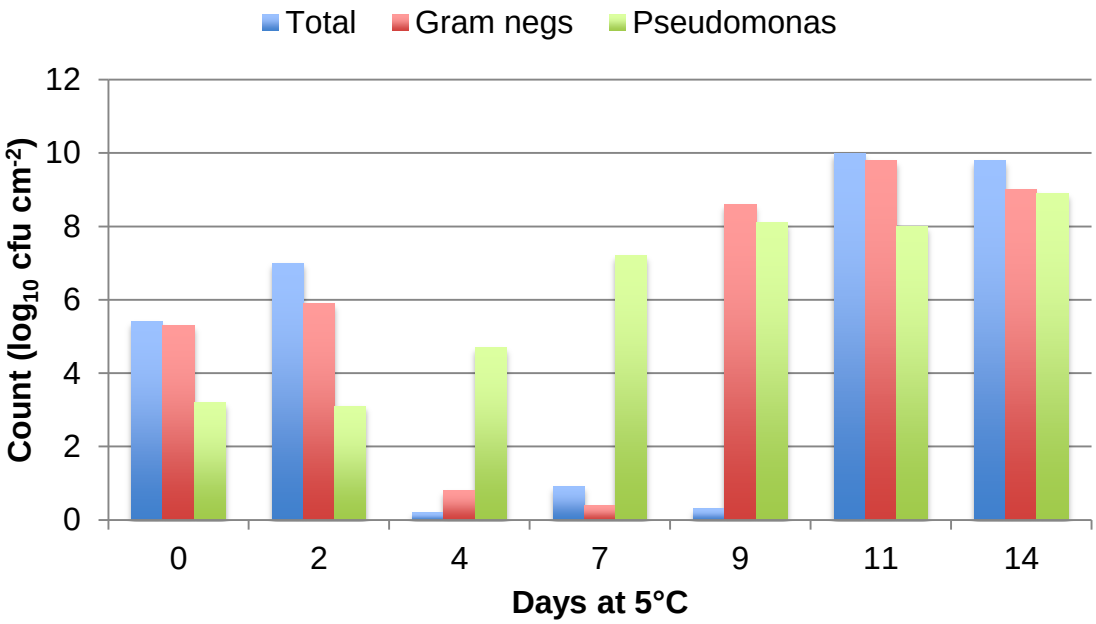


Figure 75. Growth of bacteria on naturally contaminated beef brisket fat stored at 5°C (source: Lasta *et al.*, 1995)

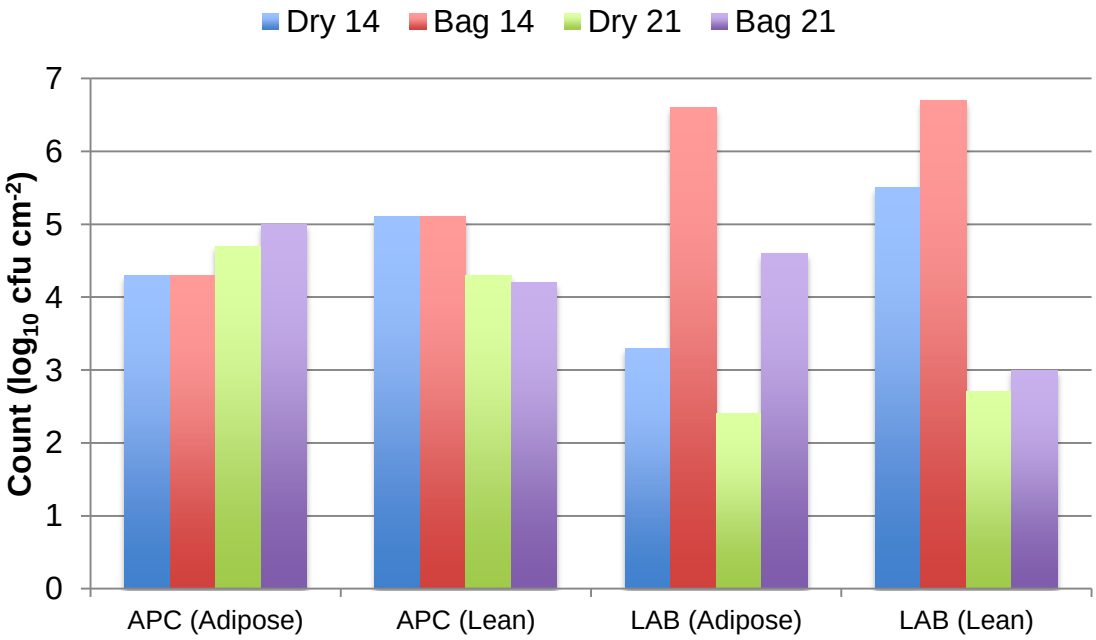


Figure 76. Total aerobic plate (APC) and lactic acid bacteria (LAB) counts of adipose and lean tissue from beef strip loins dry-aged or bagged in moisture permeable packaging for 14 or 21 days at 2.5±0.4°C, 87±3% RH (source: Ahnström *et al.*, 2006)

One of the particular differences between "dry-ageing" and "wet-ageing", apart from differences in weight loss, is the growth of Lactic Acid Bacteria (LAB) in the anaerobic conditions provided for "wet ageing". The growth of LAB has been shown to inhibit the growth of other microorganisms, thus extending shelf-life. Experiments by **Ahnström *et al.* (2006)** have show that a product of similar quality to that of "dry-aged" can be produced using a novel highly moisture permeable bag. This allowed a similar degree of weight loss to occur as in traditional dry-aged samples but significantly reduced trim losses (due to drying

and discolouration) and increased LAB counts on adipose and lean tissues (Figure 76). Results also showed a significant reduction in total APCs during ageing of both dry-aged and "bagged" samples, between ageing for 14 days and 21 days.

Further research (**DeGeer *et al.*, 2009**) compared traditional dry-ageing and bagged dry-ageing of beef shell and strip loins aged for between 21 and 28 days at 2.2°C, 50% RH under UV lighting (Figure 77). At the end of ageing, APCs and yeast and mould counts were similar for three of the treatment combinations, whereas the counts for shell loins aged in the bag were elevated by about 2 logs and 1 log, respectively. Overall, counts were higher on beef aged for 28 days than for 21 days (Table 57).

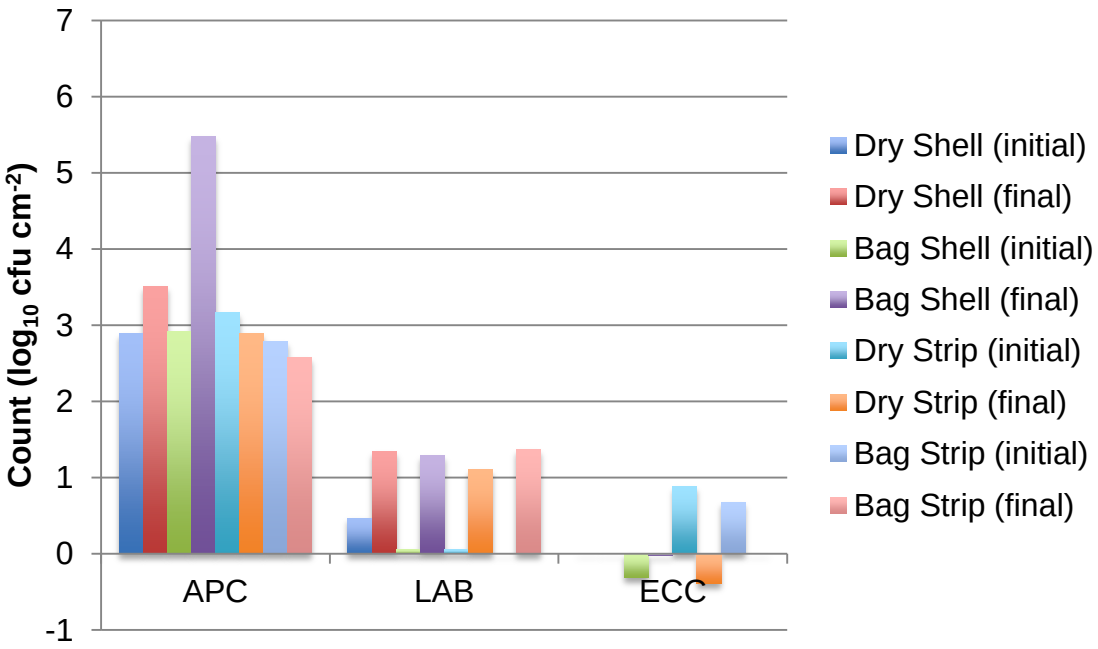


Figure 77. Total aerobic plate (APC), lactic acid bacteria (LAB) and *E. coli*/coliform (ECC) counts of beef shell and strip loins dry-aged or bagged in moisture permeable packaging for between 21 and 28 days at 2.2°C, 50% RH with UV lighting (source: DeGeer *et al.*, 2009)

Table 57. Total aerobic plate (APC), *E. coli*/coliform, yeasts and moulds, and lactic acid bacteria (LAB) counts of beef shell and strip loins dry-aged or bagged in moisture permeable packaging for 21 and 28 days at 2.2°C, 50% RH with UV lighting (source: DeGeer *et al.*, 2009)

	21 days		28 days	
	Initial	Final	Initial	Final
APC	7.0	7.3	6.6	9.4
E. coli and coliforms	1.0	TFTC *	1.1	0.5
Yeasts and moulds	0.7	TFTC	0.4	0.7
LAB	0.3	4.2	1.1	1.8

* TFTC: Too Few To Count

8.6.1 Microbial contamination of chill rooms

Psychrophilic spoilage microorganisms have been shown to persist on structural surfaces, including refrigeration coils, within chill rooms and have been shown to have a role in carcass contamination (Stringer *et al*., 1969; Ockerman *et al*., 1977; Newton *et al*., 1978; Gustavsson & Borch, 1989; Mafu *et al*., 1989; Nortjé *et al*., 1990; Evans *et al*., 2004).

The potential for the fans used in air chilling to disseminate moulds and bacteria has been identified in a number of reviews (Richmond, 1991; Houston, 1996) but very little work has been carried out to evaluate whether this is in fact the case. Stringer *et al*. (1969) noted higher airborne counts during chilling than after. Gustavsson & Borch (1989) found that a resident environmental microflora consisting mainly of *P. fluorescens* in a Swedish beef abattoir chiller contributed to carcass contamination through direct contact and by aerosols. An survey of a variety of chillers and chilled storage rooms across the food industry (including red meat and poultry processing plants) by Evans *et al*. (2004) found bacterial contamination on all evaporator cooling coils in all the 15 plants visited. In general counts were greatest in rooms with unwrapped product, and greatest in red meat and poultry plants than other food plants. While high counts of spoilage organisms were present in some cases (up to 5 $\log_{10}$ cfu cm^{-2}) very few pathogens were isolated.

Similarly, the chill room environment may be a potential reservoir for bacteria. Mafu *et al*. (1989) found a high prevalence of salmonella (12.5%) on the floor of the chill room in a Canadian abattoir, they attributed this to the "*coming and going of workers*" between the slaughter area (25% prevalence) and this room. The floors were also found to be highly contaminated in an earlier study by Stringer *et al*. (1969). Counts were found to rise during an 18 hour chilling period.

Condensation in the chiller has also been identified as a possible source of cross-contamination. However, few studies have addressed this issue. A study by Ockerman *et al*. (1977) in the US suggested that condensate could potentially contribute significantly to the microbial load of a pork carcass but that "*condensation was not as big a problem as sanitation during the cutting operation*".

Since carcasses are exposed to the environment within chill rooms for such a long time, particularly in ageing (maturation) rooms, the sanitation of such rooms is particularly important. Some authors (Stopforth & Sofos, 2005) cite this as possibly more important than the cleaning of the slaughter and fabrication lines. Stopforth & Sofos (2005) recommend ideally using alternating chill rooms to allow enough time to thoroughly cleanse the room between unloading and reloading.

8.7 Microbial quality of cuts

After the animal has been slaughtered, dressed and chilled, the resulting carcass or part-carcass (e.g. beef quarter) is subjected to further treatment before the meat is used. Butchery (cutting) subdivides the carcass or part-carcass into smaller portions, joints, cuts, etc. Simple processing including packaging may follow. Butchery can take place within the abattoir, in premises adjacent to the abattoir or carcasses/sides can be transported to a large centralised butchery operation, or to catering or retailing premises, either directly from the abattoir or via a meat market.

Current legislation (Regulation (EC) No. 853/2004) imposes strict temperature controls on the meat and cutting environment:

Annex III, Section I: Meat of domestic ungulates (Red meat)

Section I, Chapter V

(2) The work on meat must be organised in such a way as to prevent or minimise contamination. To this end, food business operators must ensure in particular that:

(b) during cutting, boning, trimming, slicing, dicing, wrapping and packaging, the meat is maintained at not more than 3°C for offal and 7°C for other meat, by means of an ambient temperature of not more than 12°C or an alternative system having an equivalent effect;

(3) However, meat may be boned and cut before it reaches the temperature referred to in point 2(b) in accordance with Chapter VII, point 3.

(4) Meat may also be boned and cut prior to reaching the temperature referred to in point 2(b) when the cutting room is on the same site as the slaughter premises. In this case, the meat must be transferred to the cutting room either directly from the slaughter premises or after a waiting period in a chilling or refrigerating room. As soon as it is cut and, where appropriate, packaged, the meat must be chilled to the temperature referred to in point 2(b).

Annex III, Section II: Meat from poultry and lagomorphs

Section II, Chapter V

(1) The work on meat must be organised in such a way as to prevent or minimise contamination. To this end, food business operators must ensure in particular that:

(b) during cutting, boning, trimming, slicing, dicing, wrapping and packaging, the temperature of the meat is maintained at not more than 4°C by means of an ambient temperature of 12°C or an alternative system having an equivalent effect;

(2) However, meat may be boned and cut before it reaches the temperature referred to in point 1(b) when the cutting room is on the same site as the slaughter premises, provided that it is transferred to the cutting room either:

(a) directly from the slaughter premises; or

(b) after a waiting period in a chilling or refrigerating room.

(3) As soon as it is cut and, where appropriate, packaged, the meat must be chilled to the temperature referred to in point 1(b).

Numerous studies show that the breaking up of the carcass or side is a Critical Control Point (CCP) and substantial cross contamination occurs during these processes. This is relatively unsurprising since the initial breaking up of the carcass or side involves a large number of stages and the side is extensively manually handled. Gill & Jones (1999) quote 16 separate operations in the breaking of a beef carcass at one processing plant. Cutting and boning should be carried out at ambient temperatures below 12°C to comply with EU regulations. At this temperature, salmonella requires at least 8 to 15 hours to double in number assuming there is no lag phase, and *L. monocytogenes* would double in 6 to 9 hours (Mackey & Roberts, 1991). At 10°C the generation times of *E. coli*, *Staphylococcus aureus*, or *L. monocytogenes* are all greater than 5 hours (Sumner & Krist, 2002). After an analysis of salmonella growth on pork cuts and in pork mince, Mann *et al*. (2004), recommended that processors should ensure that the time product spends in the processing area should be no more than 12 hours when operating at 10°C and no more than 6 hours when operating at

room temperatures. Mackey & Roberts (1991) were of the opinion that boning operations should normally be completed within about 2 hours so there is insufficient time for extension proliferation even of the more psychrotrophic listeria. Similarly Sumner & Krist (2002) were of the opinion that the practice of re-warming beef to 10°C for "a few hours" prior to boning (to soften the fat) did not present a significant safety risk, particularly if a lag phase occurred.

According to Greer *et al*. (1983) the case-life of retail beef steaks are related to the psychrotrophic bacterial content on the wholesale ribs and steaks and to the degree of sanitation at the retail level. While, Chandran *et al.* (1986) showed that producing beef steaks under strict sanitary cutting procedures could improve their microbiological and sensory characteristics. There was no statistical difference in APCs on steaks from carcasses processed under strict sanitary slaughter and dressing conditions compared with those produced conventionally. However, at all storage intervals, steaks cut under strict sanitary procedures had lower bacterial counts than those obtained from the conventional cutting procedure (Table 58). The differences in APCs were approximately 2 $\log_{10}$ cfu cm^{-2} at the first four storage intervals (0, 7, 14, 21 days) and about 1 $\log_{10}$ cfu cm^{-2} at the next three storage intervals (28, 35, 42 days).

Table 58. Mean APCs (25°C/48 h; $\log_{10}$ cfu cm^{-2}) of vacuum-packaged steaks as influenced by hygiene of the slaughter-dressing and cutting procedures (source: Chandran *et al.*, 1986)

	Slaughter-dressing		Cutting	
Days of storage	Conventional	Strict sanitary	Conventional	Strict sanitary
0	2.34	2.04	3.25	1.13
7	3.48	3.66	4.79	2.01
14	4.31	4.71	5.83	3.19
21	5.27	5.67	6.45	4.50
28	6.18	6.07	6.77	5.53
35	6.75	6.46	7.11	6.03
42	6.67	6.75	7.06	6.36

The distribution of microflora was also affected. At day 0, the microflora of steaks produced under conventional conditions (Table 59) had a higher percentage of typical gram-negative spoilage bacteria (*Pseudomonas, Moraxella, and Acinetobacter*) than those produced under strict sanitary procedures. The microflora of steaks produced under conventional conditions was dominated by *Pseudomonas* spp., whereas both *Micrococcus* and *Pseudomonas* spp. were major parts (25%) of the microflora of steaks produced under strict sanitary conditions. The microflora of steaks stored for 42 days was dominated by lactic acid bacteria, particularly *Lactobacillus cellobiosus*, *Lactobacillus plantarum* and *Leuconostoc mesenteroides*. In parallel, a sensory evaluation revealed that steaks produced under strict sanitary practices had generally less off-odour. It was concluded that this difference in off-odour was most likely related to the fact that bacterial counts on steaks produced under strict sanitary conditions were lower than those on conventionally produced steaks.

A study by Jericho *et al.* (1996) on beef again showed the cutting operation to be a significant source of microbial contamination. During cutting, there was a significant increase in APCs, by as much as 2 $\log_{10}$ cfu cm^{-2}, only 20 min after carcasses had left the chill room. Slightly lower counts were measured on "cut" surfaces than surfaces "not cut" in the cutting room. This implied that it was the general handling during cutting that caused much of the contamination. Similar finding were made by Gill & McGinnis (2000), they found that APCs, coliforms and *E. coli* were about 1, 3 and 3 $\log_{10}$ cfu cm^{-2} units more, respectively, after breaking than on carcasses entering the process. The large number of coliforms

recovered was of particular concern but unfortunately the researchers were unable to establish a source of this contamination.

Table 59. Distribution (%) of microbiological types on day 0 of storage of vacuum-packaged steaks obtained by conventional and strict sanitary slaughter-dressing and cutting procedures (source: Chandran *et al.*, 1986)

Microbiological type	Conventional slaughter-dressing		Strict sanitary slaughter-dressing	
	Conventional cutting	Strict sanitary cutting	Conventional cutting	Strict sanitary cutting
Pseudomonas spp.	66.8	25.0	56.0	35.7
Acinetobacter-Moraxella spp.	12.7	3.5	1.2	
Staphylococcus spp.	0.2	17.7	1.2	
Micrococcus spp.	2.3	30.2	13.4	41.4
Yeasts	<0.1		11.1	
Brochothrix thermosphacta	4.7	1.7	6.2	6.2
Coryneform bacteria	0.7	16.7	1.7	16.7
Lactobacillus cellobiosus	3.2	3.1	8.7	
Lactobacillus coryneformis		2.1		
Lactobacillus plantarum	2.5		0.5	
Leuconostoc paramesenteroides	6.9			

A number of studies have shown that bacterial counts increase on pork during cutting operations (Homann *et al.*, 1992; Bouvet *et al.*, 2002). Most authors conclude that some factor other than contamination during slaughtering-dressing is influencing the level of contamination on cut meat, such as cross-contamination from the hands of personnel, or inadequate cleaning and sanitising of equipment and contact surfaces. The storage-life of vacuum packaged pork has been shown to be directly related to the initial numbers of bacteria present and the degree of sanitation at the processing plant. To achieve a storage life of ≥7 weeks, initial APCs of ≤2 $\log_{10}$ cfu cm^{-2} and a storage temperature of -1.5°C is quoted by Holley *et al*. (2004). In their trials vacuum-packaged boneless pork loin pieces with initial counts around 3 log could be stored at -1.7±1°C for up to 8 weeks. They recommended using the fraction of Enterobacteriaceae in the bacterial population in vacuum-packaged pork stored at -1.5°C as a useful indicator of plant sanitation and product storage-life. Less than 5% incidence of Enterobacteriaceae would indicate acceptable sanitation, and would allow a "prediction of product quality ≥30 days in advance of the end of the desired product storage life".

8.8 Microbial growth on packaged primals and cuts during storage/ageing (wet ageing)

The shelf-life of meat can be greatly extended by packaging under various atmospheres (vacuum, 100% carbon dioxide (CO_2), MAP (CO_2 rich atmosphere (20-30%) etc)) and storage at low temperatures. Vacuum-packaging is the most widely used method of extending the storage-life of fresh meat, and is often used for the purpose of ageing primals (so called "wet ageing"). However, vacuum-packaging has an effect on the colour of the meat, hence meat is usually displayed for retail in various Modified Atmospheres (MA) containing oxygen to give a "fresh" appearance to the meat. Carbon monoxide (CO) and nitrogen (N_2) rich atmospheres are also receiving some attention. For practical reasons such a practice is restricted for red meat to primals, sub-primals and cuts.

General data on the attainable chilled storage lives for many types of meat are shown in Table 60. However, again much is based on 'learned' opinion rather than peer reviewed scientific studies. There is a large variation in published shelf-lives of meats due to the nature of the investigations. Some investigations are of long-term storage-life at low storage

temperatures (-1.5 to 1°C) whilst others are of short-term display-life of retail packs under retail conditions (3-4°C). As may be expected, bulk storage-lives are many weeks, while display-lives are a matter of days.

Table 60. Practical Storage Life of chilled cuts of meat, PSL is the time that the product is still of acceptable quality, assuming good initial bacteriological quality and normal pH (source: IIR, 2000)

Product	Temperature (°C)	Packaging	PSL d = day w = week m = month	Notes
Beef, boneless joints	-1.5 to 0	Vacuum packed	12 w	
Beef, retail cuts	4	Oxygen permeable pack.	2-5 d	
Beef, retail cuts	4	Vacuum packed	2 w	
Beef, retail cuts	2	MAP	9-12 d	80%O_2+20%CO_2
Pork, joints	-1.5 to 0	Vacuum packed	3-5 w	
Pork, retail cuts	4	Oxygen permeable pack.	3 d	
Lamb	-1.5	CAP (100% CO_2)	16 w	
Lamb and mutton	-1.5 to 0	Vacuum packed	10 w	

Differences in meat pH, tissue composition (adipose or muscle), environmental composition (oxygen concentration) and initial microbial population and numbers probably account for the differences in storage-life between beef, lamb and pork. The microflora of vacuum-packaged meats radically change during storage and essentially vacuum-packed beef undergoes a natural fermentation process due to the rapid growth of lactobacilli (Lactic Acid Bacteria (LAB)) that prevents the growth of other spoilage bacteria. In lamb the growth of lactobacilli does not appear to be sufficient thus possibly limiting its storage-life (Gill, 1984). In general vacuum-packaged beef has the longest storage-life, of 11 to 12 weeks (Gill & Penney, 1985), followed by lamb, 6 to 8 weeks (Gill & Penney, 1985), followed by pork, 4 to 6 weeks (Egan *et al*., 1986). However, more recent studies have shown much longer storage-lives, up to 8 weeks now for vacuum-packaged pork (Holley *et al*., 2004), are possible for all meats. The degree of vacuum used can have a great effect on shelf-life with levels above 600 mm Hg being recommended (Newton, 1977).

As mentioned earlier, pH can have a significant effect on storage-life. In New Zealand studies, microbial numbers on high pH (>6.0) beef cuts, vacuum-packaged in polyvinylidene chloride (PVDC) reached maximum levels in 6 weeks at +1°C compared with 12 weeks for normal pH beef (Gill & Penney, 1986). In metalized polyester or aluminium foil laminate vacuum packs times were respectively 9 and 15 weeks.

Greer *et al*. (1990) found little difference between the storage-life of vacuum-packaged beef primals from spray or conventionally chilled carcasses stored for 10 weeks at 1°C. Bacterial generation times were higher on primals from spray-chilled carcasses (4.16 days compared to 3.87 days) but lag times were longer (15.04 days compared to 12.86 days).

Bell *et al*. (1996) detected no major off odours after 14 weeks at -0.1°C from hot boned bull beef that had been cooled and stored in vacuum or CO_2 packs. At opening the appearance of the striploins was also acceptable. However, over ageing was believed to have reduced the retail display life of the meat. The authors thought that the process could produce high quality beef for catering use with a storage life of 10 weeks.

Lee & Yoon (2001) reported that while APCs exceeded a level of 7 $\log_{10}$ cfu cm^{-2} by 52 days (7 weeks) in vacuum-packaged beef chuck stored at 0°C, no off-odour was detected until 66 days (10 weeks). Beef chucks obtained from US steer carcasses were placed in cartons after

vacuum packaging in gas tight film. These were then transported by refrigerated ship to Korea. After arrival at the laboratory (37 days after packaging), the cuts were stored at 0°C additionally for 39 days and analyzed. Although after 52 days of storage total aerobic counts exceeded 7 logs, Enterobacteriaceae and *Pseudomonas* counts showed growth retardation (Figure 78). *Brochothrix thermosphacta* was not found at the level of 2 $\log_{10}$ cfu cm^{-2} over the storage time.

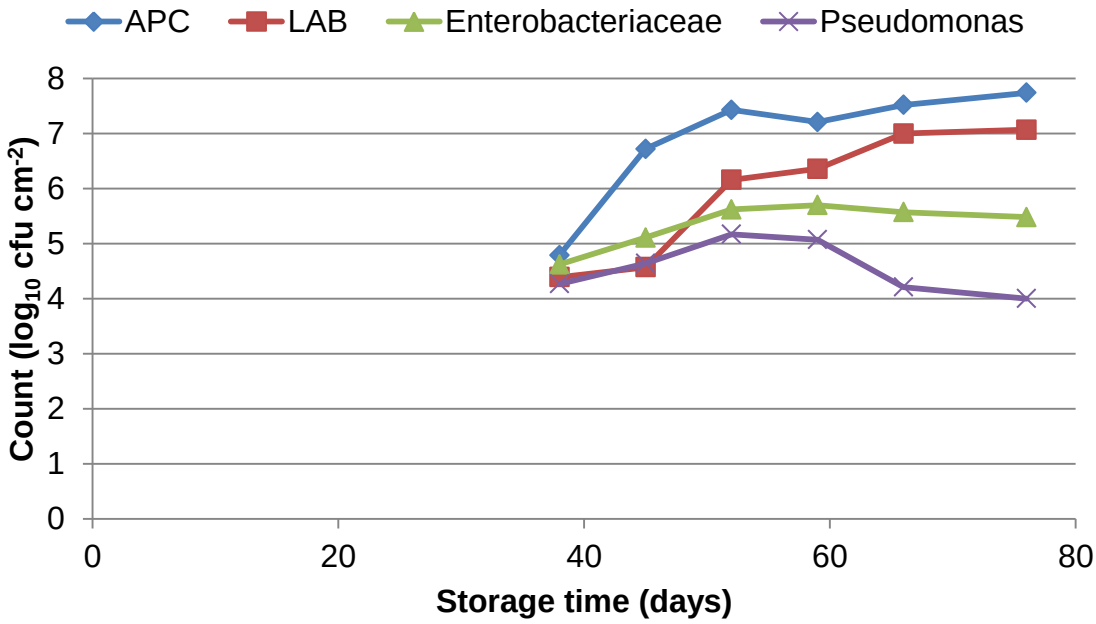


Figure 78. Microbial counts of imported vacuum-packaged beef chuck transported by ship from US to Korea and stored at 0°C (source: Lee & Yoon, 2001)

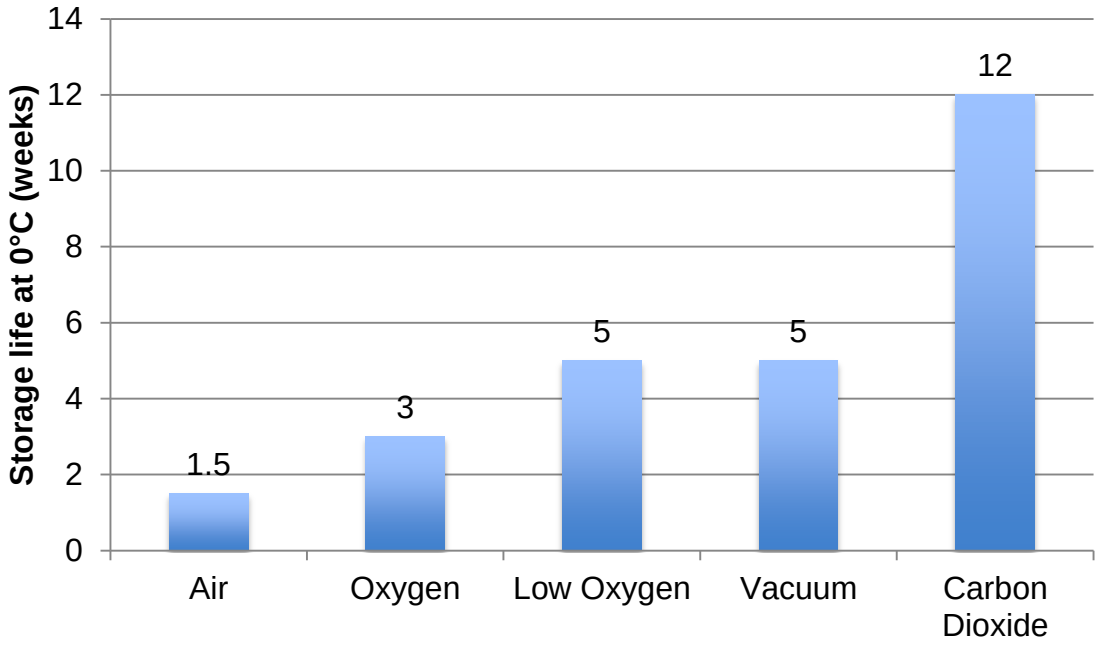


Figure 79. Storage-life of chilled pork stored in different atmospheres at 0°C (source: Jeremiah, 1997)

Generally recognised storage-lives of chilled pork stored in different atmospheres at 0°C are shown in Figure 79. The average storage-life of vacuum-packaged, North American, chilled pork imported into Japan in the mid-90s was 6 weeks. This gave the meat a limited residual storage life in Japan of 2 to 5 days, making it difficult to distribute and merchandise the product. A test shipment produced under high hygienic standards was received in Japan 8 weeks after slaughter and found to have a residual storage life of 4 to 6 weeks in Japan (Jeremiah, 1997).

In vacuum-packaged pork primals, Egan *et al*. (1986) have also shown that the temperature of storage and pH determines both the storage-life and the nature of the changes during storage (Table 61).

Table 61. Storage-life and nature of spoilage of vacuum-packaged pork (source: Egan *et al.*, 1986)

	0°C		5°C	
Meat pH	Storage life (weeks)	Spoilage characteristics	Storage life (weeks)	Spoilage characteristics
5.4 to 5.8	6	Flavour changes souring	3 to 4	Flavour changes souring
6.2 to 6.5	4 to 5	Variable	2 to 3	Greening, odour of H_2S, putrefaction

At a lower temperature Jeremiah *et al*. (1995a, b) have shown that off-flavour development, coinciding with lactic acid bacteria reaching maximum numbers, currently restricts the storage-life of CO_2 or vacuum packaged pork to 9 weeks at -1.5°C. Based on appearance, CO_2 packaged pork loin had a storage life of over 15 weeks and vacuum-packaged slightly over 12 weeks. Only small differences were found between pork loins from DFD, PSE and normal quality groups. They believed that reducing the current levels of microbial contamination would allow storage life to be extended to me*et al*l domestic and export requirements.

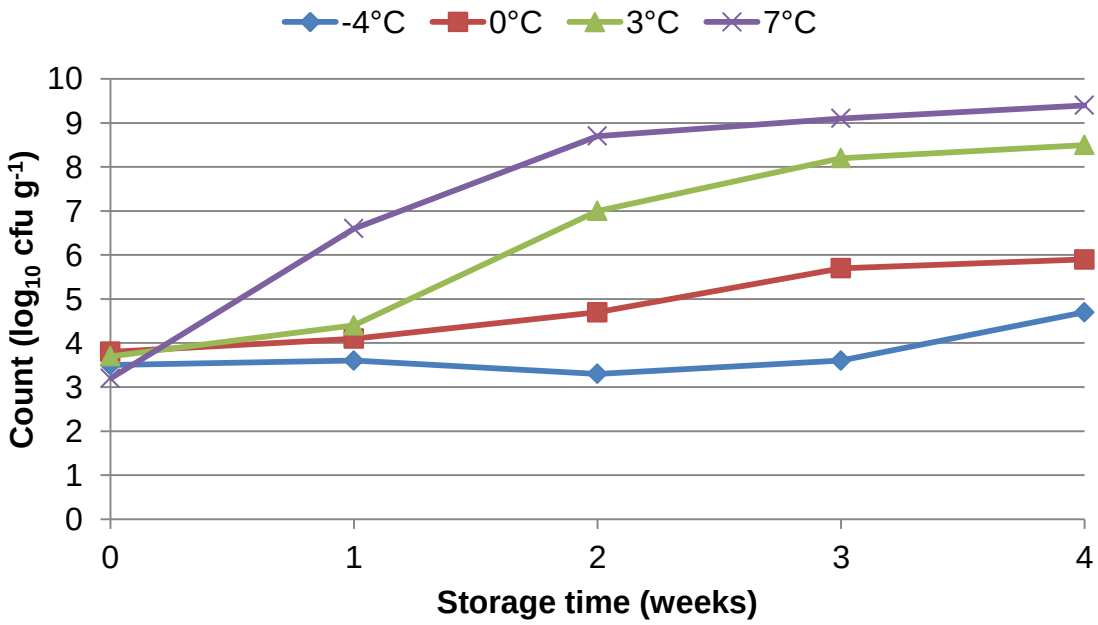


Figure 80. Growth of psychrotrophic bacteria on vacuum-packaged cubed pork at -4, 0, 3 and 7°C (source: Lee *et al.*, 1985)

The effect of temperature and packaging on the storage-life of pork was clearly demonstrated by Lee *et al*. (1985) and Gill & Harrison (1989). Only small changes in microbial numbers

(Figure 80), pH, drip and off-odour were vacuum or vacuum plus gas flushed packs of pork after 49 days storage at -4°C (Lee *et al*., 1985). Green discolouration was significant after 2 weeks at 3°C and 7°C, and 4 weeks at 0°C. The amount of drip loss increased substantially with both length and temperature of storage (Figure 81).

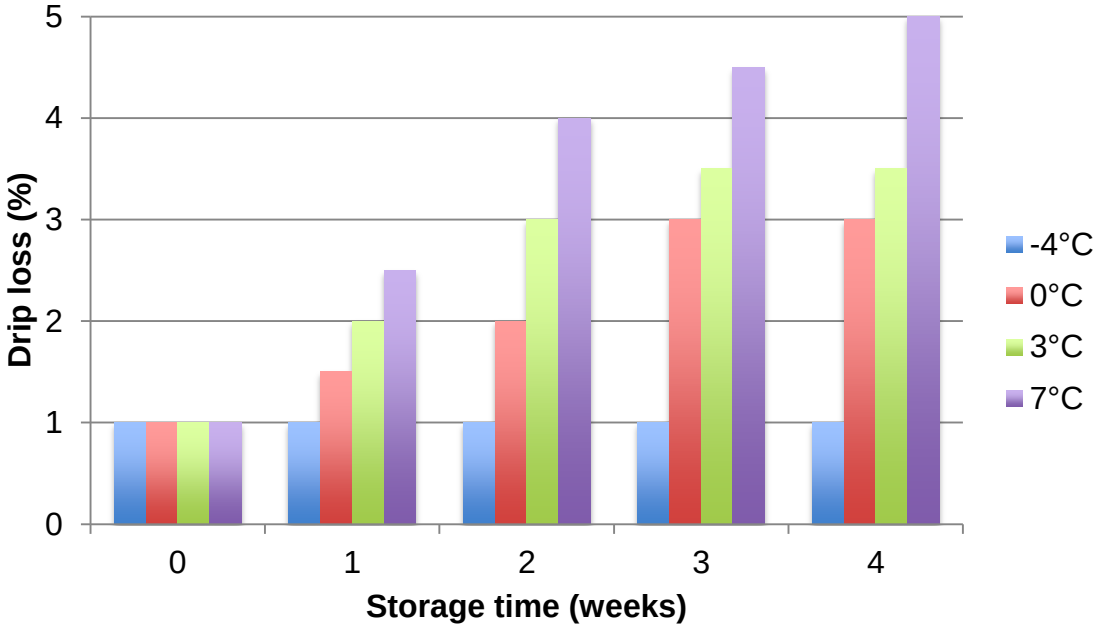


Figure 81. Drip loss from vacuum-packaged cubes of pork stored at -4, 0, 3 and 7°C (source: Lee *et al*., 1985)

Gill & Harrison (1989) found that vacuum-packaged cuts of pork *longissimus dorsi* muscle (skin on) were grossly spoiled by *Brochothrix thermosphacta* after 2 weeks storage at 3°C compared with 5 weeks at -1.5°C. Cuts packaged under CO_2 spoiled after 5.5 weeks storage at 3°C. Growth of *B. thermosphacta* was suppressed when the pork was stored under CO_2 at -1.5°C. Growth of Enterobacteriaceae caused gross spoilage of an increasing proportion of cuts between 18 and 26 weeks. Until spoilage occurred the eating quality of the pork was little affected by the length of storage.

Table 62. Growth of bacteria (log_{10} cfu cm^{-2}) on pork loin cuts stored at 0°C (source: Scholtz *et al*., 1992)

Packaging	Storage (weeks)	Total count	Lactic acid bacteria	Pseudomonads	Enterobacteriaceae
100% CO_2	0	3.6	3.4	1.6	ND
	1	4.1	3.4	3.5	1.0
	2	4.2	3.4	3.8	1.2
	3	5.8	4.6	4.2	1.5
MAP	0	3.4	3.0	2.9	1.1
(25% CO_2 75% O_2)	1	4.7	3.5	4.6	0.9
	2	6.7	4.5	5.3	2.5
	3	8.0	6.0	7.2	4.4
Vacuum	0	3.4	2.8	2.6	ND
	1	6.6	4.5	5.5	2.9
	2	7.1	5.8	6.8	4.4
	3	7.8	6.8	7.1	4.9

An evaluation of different packaging systems for extending the storage-life of pork loin cuts by Scholtz *et al*. (1992) showed that a storage-life of 3, 2 or 1 week at 0°C could be achieved using 100% CO_2, MAP (25% CO_2 75% O_2), or vacuum packaging, respectively (Table 62). Enterobacteriaceae counts remained low for all the packaging treatments during storage, particularly in the case of the CO_2 treatment. The colour of the cuts were affected somewhat by the high CO_2 atmosphere but were considered acceptable.

Storage-life of as long as 8 weeks for vacuum-packaged boneless pork loins stored at -1.7±1°C (Figure 82) have been reported by Holley *et al*. (2004).

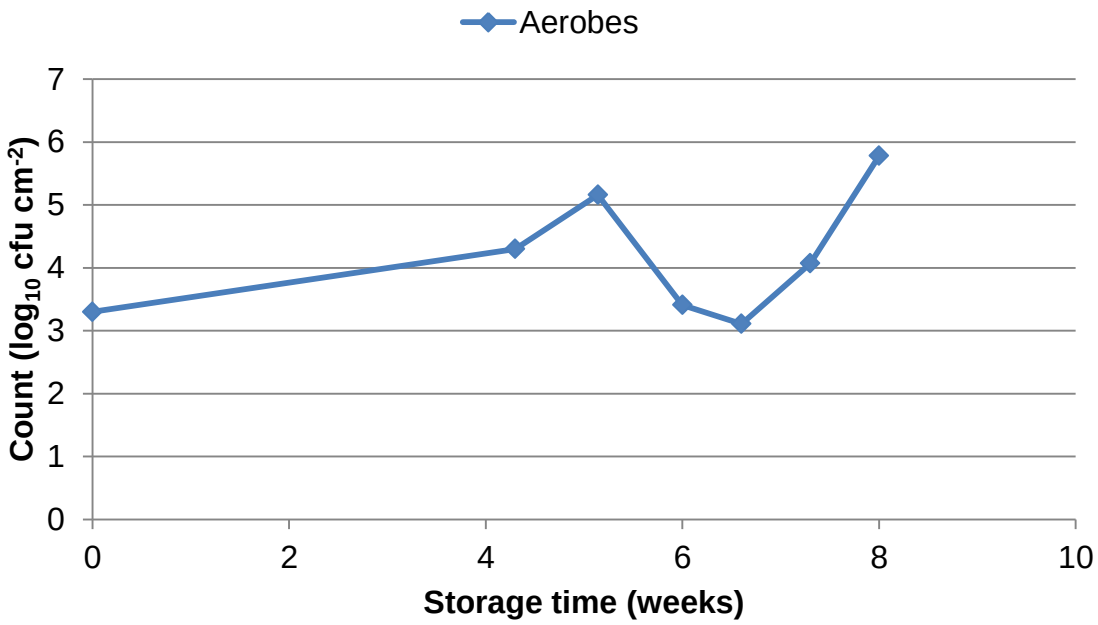


Figure 82. Growth of aerobic bacteria on vacuum-packaged fresh boneless pork loins during storage at -1.7±1°C (source: Holley *et al*., 2004)

While the use of Carbon Monoxide (CO) has been shown to benefit the maintenance of a bright, pink-red fresh pork colour, it does not aid the storage-life of pork (Wilkinson *et al*., 2006). A comparison of the storage-life of pork chops packaged in either a 100% CO_2 atmosphere or a mixture of 80% CO_2, 19.6% N_2, and 0.4% CO stored at 3°C for up to 8 weeks showed a greater growth of aerobes and anaerobes on meat stored in the CO atmosphere (Figure 83).

In audits carried out in New Zealand to improve the storage-life of vacuum-packaged chilled lamb, changing the chilling practice was found to have the largest effect (Gill, 1987). It was found that the significance of the relatively small numbers of organisms added to carcasses during dressing was greatly magnified by their growth during carcass cooling. Small changes to the chilling practices alone extended the storage life by up to 50%. Studies on lamb have shown that it is possible to ensure a storage-life of at least 12 weeks for vacuum-packaged lamb cuts (Gill & Penney, 1985). Some MIRINZ studies (Newton *et al*., 1976) have reported even longer storage-lives with up to 15 weeks (at a vacuum level of 300 mm Hg) and 19 weeks (at a vacuum level of 580 mm Hg) for vacuum-packaged lamb legs, loins and shoulders stored at -1°C. A delay of 24 hours between cutting and packaging appeared to favour the growth of *Microbacterium thermosphactum* rather than *Lactobacillus*.

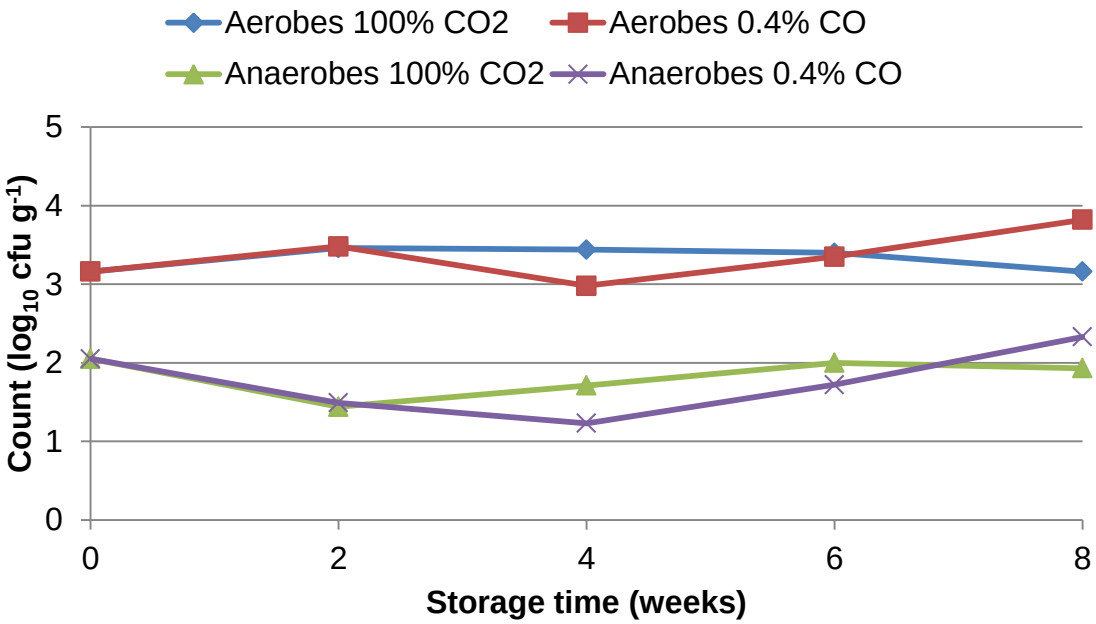


Figure 83. Effect of gas atmosphere on the growth of aerobic and anaerobic bacteria on pork chops stored at 3°C (source: Wilkinson *et al*., 2006)

Sheridan *et al*. (1997) investigated the effect of vacuum and modified atmosphere packaging (80% O_2, 20% CO_2; 50% CO_2, 50% N_2; and 100% CO_2) on the storage-life of lamb primals stored at 5 and 0°C. They showed that in general there was little difference in total bacterial counts, irrespective of atmosphere, in primals held at 5°C after 4 weeks. There were significant differences in counts on primals packaged in different atmospheres at 1°C after 4 weeks, with the lowest counts on primals held in a 100% CO_2 atmosphere. In the case of *B. thermosphacta*, pseudomonad and Enterobacteriaceae counts there were significant differences in counts between the different atmospheres at either storage temperature. Again, the lowest counts were generally on primals held in a 100% CO_2 atmosphere.

8.9 Microbial quality of cuts from aged meat

A number of studies have shown that there is an interaction between storage time of primals/sub-primals and display-life in retail display. The type of packaging, atmosphere and temperature will also have a large effect on shelf-life and display-life.

Figure 84 show the relationship between bacterial counts on vacuum-packaged beef knuckles and ribs kept at 1 to 3°C for up to 5 weeks and Figure 85 counts on steaks cut from these primals after different storage periods and then displayed for 5 days.

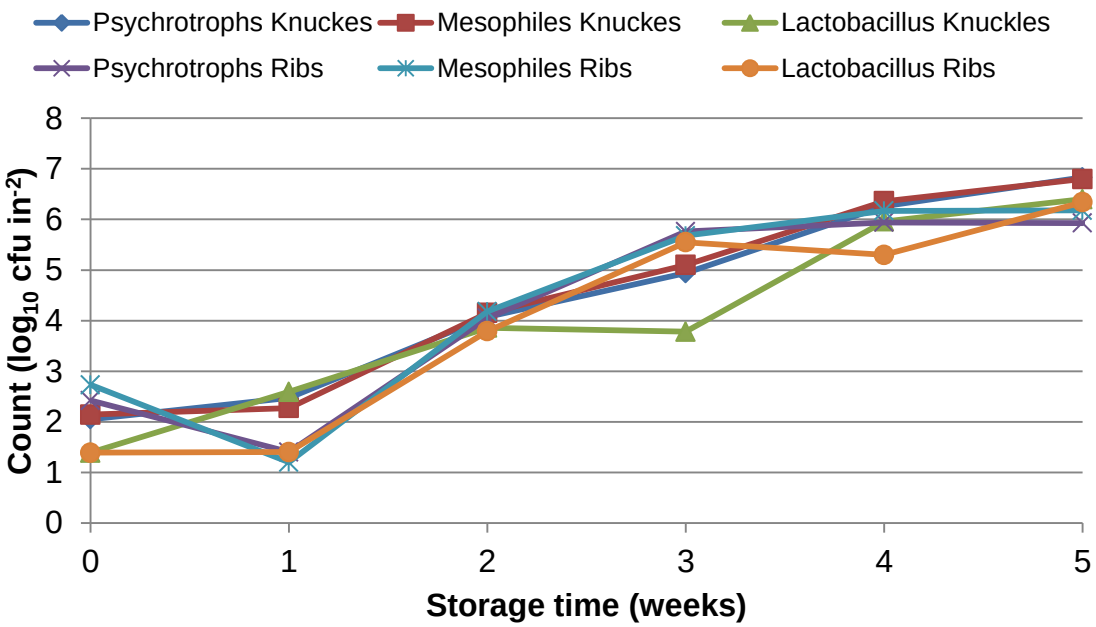


Figure 84. Growth of bacteria on vacuum-packaged beef knuckles and ribs stored at 1 to 3°C (source: Seideman *et al*., 1976)

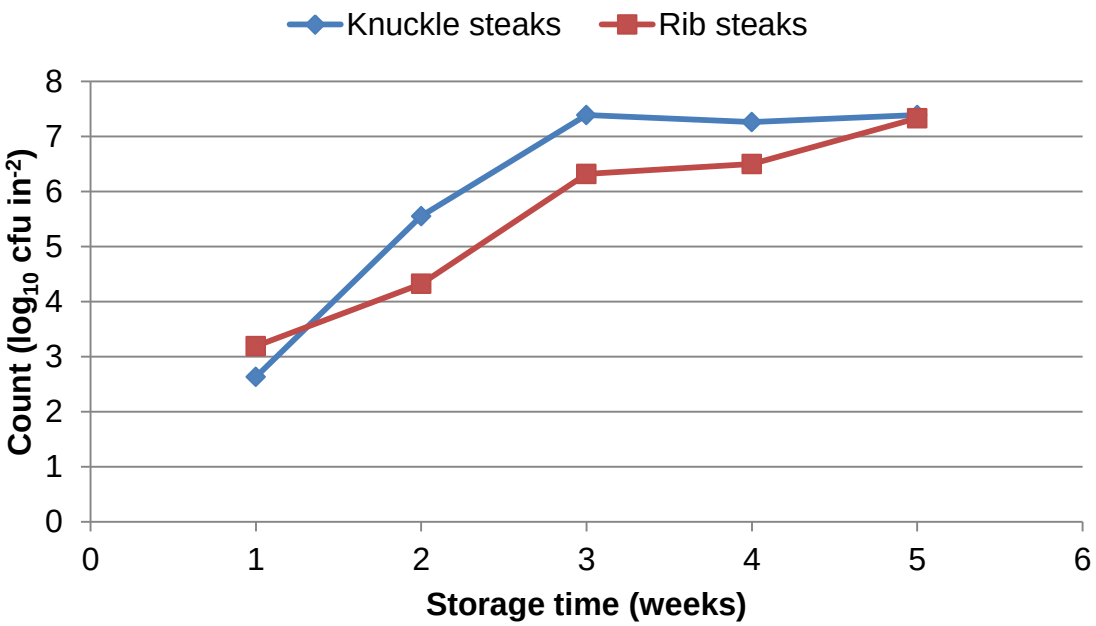


Figure 85. Psychrotrophic bacterial counts on beef knuckle and rib steaks after 5 days of retail display (1 to 3°C) according to the storage of the vacuum-packaged primal (source: Seideman *et al*., 1976)

Dixon *et al*. (1991) showed that vacuum-packaged beef sub-primals from carcasses processed under strict sanitary procedures plus the use of a hot lactic acid intervention could be stored for 80 days at 1°C and produce acceptable steaks, however they only had a 1 day acceptable display shelf-life (Figure 86). Cuts from sub-primals produced under standard procedures were only acceptable from sub-primals stored for 20 days.

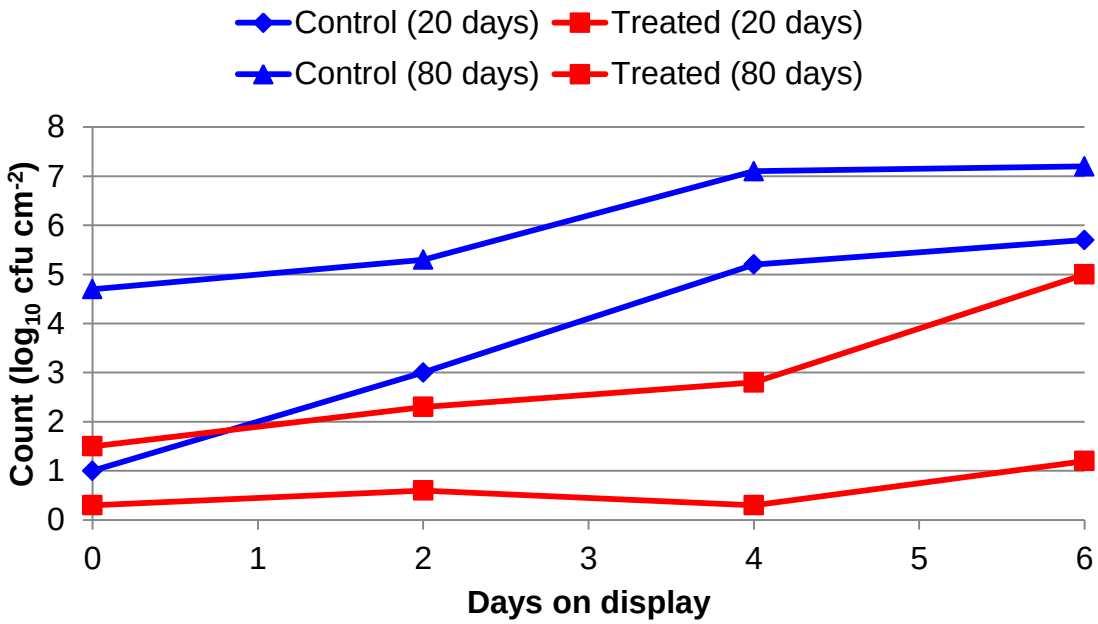


Figure 86. Mean aerobic plate counts on beef rib eye steaks, fabricated from control and treated sub-primals stored for 20 to 80 days at 1°C, displayed in PVC film for 0 to 6 days at 4±1°C (source: Dixon *et al*., 1991)

Nortjé & Shaw (1989) reported that beef loin steaks from primals that had been aged for 3 weeks in vacuum packs discoloured more rapidly and off-odours developed sooner than those from meat that had been hung in air for one week or vacuum packed for one week. The poorer storage stability was explained by higher initial levels of bacteria due to growth during ageing. Rancidity development was only detected in the 3 week aged steaks that were stored at 6°C.

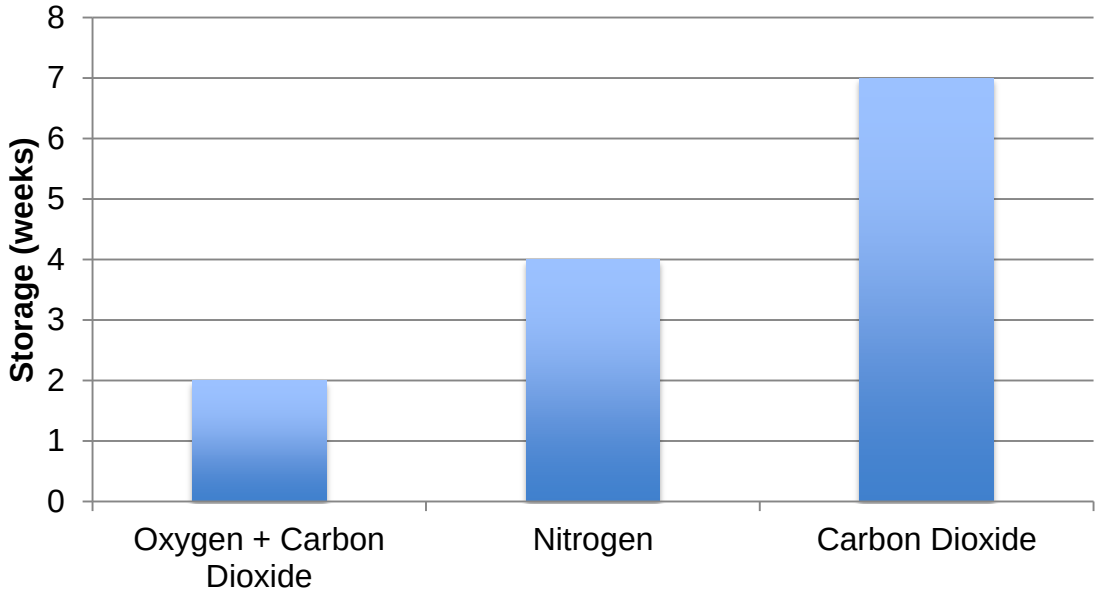


Figure 87. Storage periods of beef loins stored in different atmospheres at -1.5°C capable of producing steaks with a display-life of 2 days or longer (source: Gill & Jones, 1994a)

A study by Gill & Jones (1994a) showed that master packs with a CO_2 atmosphere could be stored for up to 7 weeks at -1.5°C and provide steaks with a display-life of 2 or more days (Figure 87).

A study by Reagan *et al*. (1971) implied that the display-life of lamb chops from vacuum-packaged primals is reduced in comparison to "freshly" prepared chops. Fresh lamb chops fabricated 8 days post-mortem and displayed immediately showed a 1.25 day advantage of increased display-life in comparison to chops from loins vacuum-packaged 8 days post-mortem, stored under vacuum for 8 days, fabricated and subsequently displayed. However, there was little overall difference in the average display-life (3.5 days) of either fresh chops or those from vacuum-packaged loins stored for up to 40 days at 0°C.

Greer *et al*. (1993) published a relationship between the retail display-life of pork from CO_2 packaged primals and the length of time the primals had been stored:

Essentially, there was a 1 day reduction in display-life for every 6 weeks in CO_2 storage.

- On appearance criteria: display-life (days) = 4.60 - 0.15 × (number of weeks in storage in CO_2 at -1.5°C)
- On odour criteria: display-life (days) = 5.03 - 0.17 × (number of weeks in storage in CO_2 at -1.5°C)

Pork loins stored for 24 days at had only 1 day of display-life. For practical purposes loin primals in stored in CO_2 at -1.5°C had a storage-life of around 9 to 15 weeks.

While there have been a number of studies that have looked at the impact of ageing times on the display-life of meats few appear to have looked at the effect of ageing time and display on pathogenic growth. In one of the few studies Dykes *et al*. (2001) investigated the growth of inoculated (at two different levels, 10^3 and 10^5 cfu g^{-1}) *E. coli* O157 and salmonella (*S.* Typhimurium and *S.* Brandenberg) on beef steaks stored under ageing and retail conditions. Vacuum or 100% CO_2 packaged beefsteaks were stored at -1.5°C for 6 weeks (to simulate ageing in pack) followed by 2 weeks at 4°C (to simulate retail display). They reported no significant changes in numbers of any of the inoculated pathogens during storage at -1.5 or 4°C in either of the packaging atmospheres. The authors noted that similar studies have shown slight reductions in numbers of these pathogens during storage. The authors also concluded that the long period of storage, of particularly *E. coli* O157, in a non-growing state would result in "*an excessive recovery period in these cells before growth would occur*".

8.10 Microbial quality of mince

The microbiological quality of minced meat is largely determined by the microbiological quality of the meat used in its production. The ICMSF (1998) note that minced meat prepared at retail often have greater microbial loads than those produced centrally, since they are often prepared from scrap meats and trimmings that have been stored for several days, rather than produced from fresh or frozen meat with lower counts. During mincing microorganisms present on the surface of the meat are distributed throughout the minced meat. Mincing itself may also increase the temperature of the meat. The extent of this increase depends on the process. The mincer itself may constitute a significant source of cross-contamination if not effectively cleaned before use and between batches.

The effects of temperature and time on pathogen growth discussed earlier relating to cutting are equally relevant here. As with boning if mincing is completed within a few hours, and carried out under semi-refrigerated conditions, there is insufficient time for extension

proliferation of pathogens, even of the more psychrotrophic listeria (Mackey & Roberts, 1991; ICMSF, 1998; Mann *et al*., 2004).

Current legislation (Regulation (EC) No. 853/2004) imposes strict temperature controls on the meat during and after mincing:

> Annex III, Section V: Minced meat, meat preparations and mechanically separated meat (MSM)
>
> Section V, Chapter III
>
> (1) The work on meat must be organised in such a way as to prevent or minimise contamination. To this end, food business operators must ensure in particular that the meat used is:
>
> (a) at a temperature of not more than 4°C for poultry, 3°C for offal and 7°C for other meat; and
>
> (b) brought into the preparation room progressively as needed.
>
> (2) The following requirements apply to the production of minced meat and meat preparations.
>
> (c) Immediately after production, minced meat and meat preparations must be wrapped or packaged and be:
>
> (i) chilled to an internal temperature of not more than 2°C for minced meat and 4°C for meat preparations; or
>
> (ii) frozen to an internal temperature of not more than -18°C.
>
> These temperature conditions must be maintained during storage and transport.

Eisel *et al.* (1997) carried out a microbiological survey of the relationship between microbial levels for incoming meat on levels in finished minced beef in a US red meat processing plant. It showed that while environmental sources of contamination existed in the processing plant most of the microorganisms came from the incoming raw meat. The survey highlighted the need to reduce microbiological populations on highly contaminated areas of the carcass, such as the brisket and skirt areas. Average APCs ranged from 3 $\log_{10}$ cfu g^{-1} for the retail cuts to 6.9 $\log_{10}$ cfu g^{-1} for the brisket area of beef carcasses. For carcass beef, the brisket and skirt areas were more contaminated compared with the round and flank. The authors postulated that the brisket and skirt areas were probably more susceptible to microbiological contamination during slaughtering because cattle are hung by the hind legs. This may promote contamination on anterior parts of the carcass due to closer proximity to floor (splash) and rinsing liquid travelling from the posterior down to the anterior. Boxed beef, the other ingredient of ground beef, also had a comparatively high APC, generally near 4.7 $\log_{10}$ cfu g^{-1}. Mean *E. coli* counts were generally low, ranging from 1 to 2 $\log_{10}$ cfu g^{-1}. Microbiological concentrations for frozen samples of carcass beef and boxed beef from different suppliers were similar. There was no correlation between a high APC and a high coliform count. Overall, APCs on the finished minced beef were very similar to counts on the incoming meat with an average of 4.6 $\log_{10}$ cfu g^{-1}. There was no indication of an increase due to the mincing process itself.

A survey of the microbiological quality of beef trimmings on the quality of retail mince by Gill & McGinnis (1993) indicated that display temperatures had a significant effect on the overall quality of the mince. It also showed that there was often a significant time between

the trimmings being vacuum-packaged and the meat being minced. This could be greater than 14 days, and was mainly due to the need of wholesalers and retailers to build up stocks of raw materials to cope with fluctuations in supply and demand. During storage of up to 18 days before mincing most trimmings developed a flora of lactobacilli, of up to 7 $\log_{10}$ cfu g^{-1}. Though numbers of coliforms and *E. coli* increased little or not at all, respectively. The survey showed a wide range of storage conditions and temperature fluctuations during chilling, transport and storage of the trimmings prior to mincing and display. Increased total counts and numbers of coliforms and *E. coli* increased in displayed mince indicating poor temperature control.

A survey of hamburger processors and suppliers of manufacturing beef suppliers by Gill *et al*. (1996; 1997) led to a recommendation that manufacturing beef for such products should have no more than 1 $\log_{10}$ cfu g^{-1} of *E. coli.* Gill *et al*. (1997) showed that, as might be expected, there is a clear relationship between the microbial quality of the incoming raw material used for the manufacture of hamburger patties and the microbial quality of the finished hamburger patties.

A survey of the microbiological quality of beef trimmings and final minced beef by Scanga *et al*. (2000) showed that final minced beef samples had a 13.6 and 1.5% incidence of *L. monocytogenes* and *Salmonella* spp., respectively. Trimmings with higher fat content, had higher APCs, those that had, nominally, 30% fat the highest APCs. The authors believed that this was due to greater amount of exposed surface on such trimmings rather than a characteristic of tissue type. However, other authors have noted higher rates of growth on adipose surfaces than muscle surfaces (Lasta *et al*., 1995). The authors recommended overall that processors "*focus their efforts on reducing the microbial counts on incoming raw materials, especially those containing large proportions of subcutaneous fat*".

Incidences of *Cl. perfringens* of 54% (64/118) in beef mince samples and 73% of (40/55) in turkey mince samples have been reported (**Ali & Fung, 1991**). As ICMSF (1998) note, although *Cl. perfringens* numbers are often small, its spores may survive cooking and subsequent growth in processed foods (such as chilli, stews etc.) may constitute a health risk.

Following an analysis of salmonella growth in pork mince Mann *et al*. (2004) recommended that raw materials and finished product should spend no more than 12 hours in the processing area when operating at 10°C, or no more than 6 hours when operating at room temperatures. Mann & Brashears (2006) suggested the same limit when operating at room temperatures with regard to potential for growth of *E. coli* O157:H7.

8.11 Microbial quality of mince from aged meat

While studies have looked at the microbiological quality of the in-coming meat used for mince production, and the effect of delays during mincing, only one recent publication (**Crowley *et al*., 2010**) has been identified that has looked specifically at the effect of length of meat storage before mincing on the subsequent storage-life or safety. This study was carried out specifically following the initial challenge by the Food Standards Agency regarding the lack of scientific justification of current controls.

In this study (**Crowley *et al*., 2010**), beef trimmings, from six beef carcasses (mean side weight 133 kg) chilled at 4°C for 72 hours prior to boning, were stored aerobically for 7 or 10 days and in vacuum packs for 7, 10, 14 or 22 days at 0 or 5°C prior to mincing, followed by aerobic storage at 0 or 5°C for up to 7 days. Samples were examined daily to determine TVCs, Pseudomonas, Lactic acid bacteria, *Brochothrix thermosphacta*, and Enterobacteriaceae counts, colour and odour. Overall, the results showed that mincing reduced counts, particularly of Pseudomonas, *B. thermosphacta* and Enterobacteriaceae,

particularly when stored at 0°C. The authors postulated that this was probably due the action of free radicals released from muscle and bacterial cells. Where growth occurred in mince the rate/day was calculated for APCs, and for Pseudomonas, LAB and *B. thermosphacta* counts (Table 63). Storage of vacuum-packed trimmings for 22 days resulted in improved mince colour and inhibition of the growth of Pseudomonas.

Table 63. Specific growth rates of Pseudomonas, APCs, LABs and *Brochothrix thermosphacta* on immediately minced and post-storage mince from trimmings, stored aerobically or in vacuum packs at 5°C (source: Crowley *et al*., 2010)

Storage conditions	Mince storage (°C)	Rate per day (SD)			
		Pseudomonas	APCs	LABs	*B. thermosphacta*
	5	2.18 (0.47)			
Aerobic 7 days	5	2.44 (0.51)	2.18 (0.70)		3.11 (0.38)
Aerobic 10 days	0	1.57 (0.36)	0.83 (0.30)	1.73 (0.13)	
	5	3.34 (0.24)	2.69 (0.45)		3.10 (0.90)
Vac pac 7 days	5	2.17 (0.70)			
Vac pac 10 days	5	2.02 (0.34)		1.91 (0.20)	
Vac pac 14 days	5	4.77 (0.61)	1.85 (0.27)	1.43 (0.47)	
Vac pac 22 days	5			1.55 (0.38)	

8.12 Microbial growth on mince during storage

8.12.1 Pathogens

Mackey *et al*. (1980) quote published minimum growth temperatures for salmonella in pork and beef mince ranging from 4 to 7°C. Their studies did not show salmonellas to growth at 7 to 8°C. Ingham *et al*. (2004) found a sight increase (0.2 log) in the growth of inoculated salmonella in minced beef held at room temperature for 2 hours. There was no growth in minced beef held for up to 4 hours at 10°C.

A comparison of salmonella growth in minced pork and boneless pork chops held at 4.4, 7.2 and 10°C by Mann *et al*. (2004) showed that salmonella grew at faster rates in minced pork (Figure 88). There was a lag in the growth of salmonella populations in minced pork for 24 and 32 hours at 10 and 7.2°C, respectively. Thus processing pork at 7.2 or 10°C would not lead to any significant growth of salmonella or increase in APCs provided the time spent in the processing area did not exceed 12 hours. Significant growth was observed at 6, 24, and 72 hours when samples were held at room temperature, 10 and 7.2°C, respectively. No significant growth was observed at 4.4°C. Background flora in ground pork samples increased significantly after 10 hours at room temperature and after 12 hours for samples held at 10 and 7.2°C. Background flora in samples held at refrigeration temperatures did not increase until 72 hours. Background flora in the boneless chops increased significantly after 6 hours at room temperature and after 24 hours when held at 10 and 4.4°C. These results illustrate that meat processors can utilize a variety of time and temperature combinations as critical limits to minimize Salmonella growth during production and storage of raw pork products.

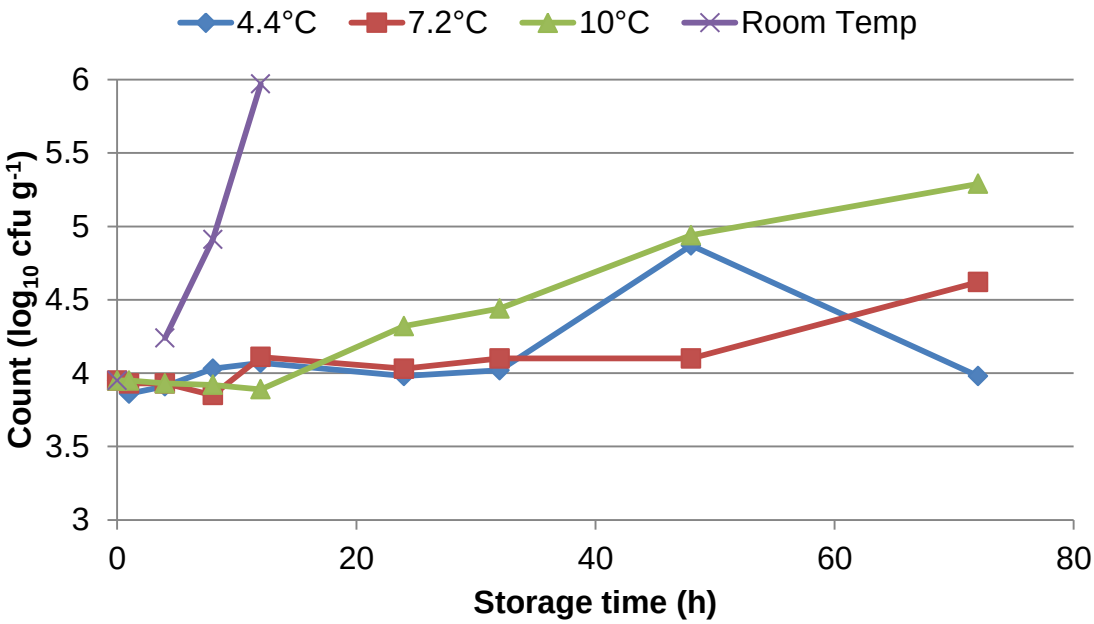


Figure 88. Growth of salmonella in minced pork at various temperatures (source: Mann *et al.*, 2004)

A study of the growth of selected inoculated pathogens in wrapped minced beef by Goepfert & Kim (1975) showed no growth of *B. cereus* (5 strains), *Cl. perfringens* (5 enterotoxigenic strains), *Staph. aureus* (5 strains, including producers of A, B, C, D and E enterotoxins) stored at 1, 4.5, 7 or 12.5°C for up to 14 days. Only *E. coli* and *Salmonella* spp. (*S.* Typhimurium, *S. Illinois*, *S. infantis*, *S. london* and *S. tennessee*) were able to grow, and then only at the highest temperature of 12.5°C.

A number of studies have shown that although *L. monocytogenes* will survive in minced meats, it does appear to grow during refrigerated storage, particularly when stored under modified atmospheres.

L. monocytogenes has been shown to survive in minced beef, but not to grow, during refrigerated storage for 14 days at 4°C (**Johnson *et al.*, 1988**). The minced beef was inoculated with *L. monocytogenes* type 1 or type 4 at a level of 5×10^5 to 7×10^6 cfu g^{-1} and then packaged in either oxygen-permeable or oxygen-impermeable bags. Packages were sampled at random at 0, 2, 3, 5, 7, 11, and 14 days post-inoculation, and assayed for *L. monocytogenes* counts and pH. The number of *L. monocytogenes* in ground beef remained constant throughout the sampling period, and survival was not affected by package permeability to oxygen. The pH of the meat increased slightly during storage, but was always in the in the range pH 5.6 to 5.9.

In another unrelated study, inoculated *L. monocytogenes* or *L. innocua* were show also shown to survive, but not grow, for 28 days at 0°C (**Duffy *et al.*, 2000**). Minced beef was inoculated with low levels (1.2-1.7 $\log_{10}$ cfu g^{-1}) of *L. monocytogenes* or *L. innocua*, or a combination of the two strains. Inoculated samples were stored at 0 or 10°C under two packaging atmospheres (aerobic and vacuum) for up to 28 days. The only significant increases in numbers of *Listeria* spp. occurred in samples held at 10°C under aerobic conditions. In vacuum packs, growth of both strains was inhibited. Under aerobic conditions meat pH increased from an initial value of pH 5.85 to c.8.85 within 28 days. The pH of vacuum packaged meat declined to c. 4.95 during the same period. These differences in pH may be

related to differences in the nature and effects of different background microflora that were observed to develop under each of these packaging conditions.

Similar results were reported by **Ellouze & Augustin (2010)** who reported that inoculated *L. monocytogenes* did not grow in MAP (30% CO_2) packaged minced beef under a range of simulated retail and domestic refrigerated storage conditions.

Similarly *L. monocytogenes* has not been shown to grow in lamb mince (or pieces) for 42 days at 0°C (**Sheridan *et al.*, 1995**). Storage under the following modified atmospheres was studied: (i) vacuum pack, (ii) 80% 0_2/20% CO_2, (iii) 50% CO_2/50% N_2, and (iv) 100% CO_2. On lamb pieces at 5°C, growth of *L. monocytogenes* occurred in air and all the modified atmospheres, except 100% CO_2. *L. monocytogenes* growth on minced lamb at 5°C was reduced compared with lamb pieces. Growth did not occur in vacuum packaged mince or in an atmosphere containing 100% CO_2. At 0°C, growth of the organism was completely inhibited on pieces and mince in all the modified atmospheres tested and in air. It was noted that pH did not increase or decrease in a regular manner throughout the storage period Thus pH was eliminated as a factor controlling the growth of *L. monocytogenes* on modified atmosphere packaged lamb.

The growth of *Y. enterocolitica*, *L. monocytogenes*, *E. coli* O157:H7 and strains of *Salmonella* were compared in minced beef packed in modified atmospheres of 60% CO_2/40% N_2/0.4% CO (high CO_2/low CO mixture), 70% O_2/30% CO_2 (high O_2 mixture) and in chub packs (stuffed in plastic casings) and stored at 4 and 10°C by Nissen *et al*. (2000). At 4°C the shelf-life, based on colour stability and background flora development, was prolonged (14 days) for the high CO_2/low CO mixture compared to the two other packaging methods, but at 10°C the shelf life was <8 days for all the packaging methods. Growth of *Y. enterocolitica* was nearly totally inhibited both at 4 and 10°C in the high CO_2/low CO mixture, while the bacterial numbers in the samples packed in the high O_2 mixture increased from about 10^2 bacteria/g at day 0 to about 10^4 at day 5 at 4°C and to 10^5 at 10°C. Growth in the chub packs was even higher. *L. monocytogenes* showed very little growth at 4°C in all treatments. At 10°C there was slow growth from about 10^3 bacteria/g to about 10^4 at day 5 in the high CO_2/low CO mixture, while the numbers in the high O^2 mixture and the chub packs were about 10 times higher. Growth of *E. coli* O157:H7 at 10°C in the ground beef was nearly totally inhibited in both the high CO_2/low CO mixture and the high O_2 mixture. Growth in the chub packs was higher, as the number of bacteria increased 3 log in 5 days. The Salmonella strains (*S.* Typhimurium, *S. dublin*, *S. enteritidis* and *S. enterica*) in the ground beef stored at 10°C for 5 and 7 days grew to a higher number in the high CO_2/low CO_2 mixture than in the high O_2 mixture.

Background microflora was shown by Vold *et al*. (2000) to inhibit the growth of *E. coli* O157:H7 in ground beef stored either aerobically or anaerobically at 12°C. Under aerobic conditions and a background microflora *E. coli* O157:H7 grew to a maximum concentration of about 6 $\log_{10}$ cfu g^{-1} after 10 days, while with no background microflora growth reached this level after only 4 days. Tamplin (2002) compared real and predicted (using the Pathogen Modelling Program) growth of *E. coli* O157 in raw minced beef stored at 10°C. On retail minced beef the mean maximum population density (MPD) and exponential growth rate (EGR) for were 5.09 $\log_{10}$ cfu g^{-1} and 0.019 $\log_{10}$ cfu h^{-1}, respectively, and no lag phase was observed. Both the EGR and the MPD increased with decreasing fat levels, and the EGR and MPD decreased as the ratio of competitive flora to *E. coli* O157:H7 increased. Further studies (Tamplin *et al*., 2005) investigated the growth of 10 strains of *E. coli* O157:H7 on minced beef at storage temperatures from 5 to 46°C. Growth occurred from 6 to 45°C, with the absence of a lag period at 6, 8 and 10°C. At 6°C the mean MPD and specific growth rate

(SGR) were 4.71 $\log_{10}$ cfu g^{-1} and 0.003 ln h^{-1}, respectively. Mann & Brashears (2006) recently published data showing a slight, though not statistically significant, rise in numbers of inoculated *E. coli* O157:H7 in minced beef at temperatures as low as 4.4°C after 72 hours. Less than 1 log of growth was observed after 48 hours at 10°C. Significant increases were observed in numbers after 6 to 8 hours at room temperature (22-23°C). Despite these studies that show growth of inoculated *E. coli* O157:H7 at low temperatures, Ingham *et al*. (2004) found no growth of inoculated *E. coli* O157:H7 in minced beef, and beef, pork and chicken pieces, held at room temperature for 2 hours or at 10°C for 4 hours.

Table 64. Mean inoculated *Y. enterocolitica* 0:3 and natural APC numbers ($\log_{10}$ cfu g^{-1}) at 28 days on lamb pieces and mince packaged in air and different gas atmosphere stored at 5 or 0°C (source: Doherty *et al*., 1995)

	Y. enterocolitica 0:3				APC			
Storage temperature (°C)	5	0	5	0	5	0	5	0
	Pieces		Mince		Pieces		Mince	
Air	9.54	5.82	9.40	4.75	12.27	9.41	11.98	8.20
Vacuum pack	8.11	5.88	6.50	2.68	8.55	6.14	9.07	5.25
80%O2/20%CO2	6.84	1.16	2.40	0.78	9.37	5.40	8.95	3.87
50%CO2/50% N2	8.52	3.86	5.25	1.29	8.93	5.11	7.75	4.59
100%CO2	5.56	1.56	1.05	0.00	7.70	4.03	6.44	2.68

Y. enterocolitica is known to grow at lower temperatures than other pathogens. *Y. enterocolitica* has been shown to increase in minced beef by 1 $\log_{10}$ cfu g^{-1} within 14 days at 1°C and 3.5 log within 14 days at 4°C (Kleinlein & Untermann, 1990). The presence of a heavy competitive flora inhibited the growth rate of yersinia, and CO_2 fully inhibited growth at 4°C. Work on lamb (Doherty *et al*., 1995) has shown that inoculated *Y. enterocolitica* serotype O:3 grows better on pieces than mince and that growth at low temperatures is inhibited by atmospheres containing either a high concentration of O_2 or a high concentration of CO_2 (Table 64).

8.12.2 Spoilage organisms

It is generally considered that beef mince has a longer storage-life than lamb and pork, and that poultry mince has a shorter storage-life than red meat mince. This has been attributed to either a lower hygienic status during processing and/or a higher incidence of high pH meat in such meats (Blixt & Borch, 2002). A study of the shelf-life (at 4°C) of vacuum-packed minced pork and beef by Blixt & Borch (2002) showed that samples with the same initial bacterial loads did show differences in the rates of spoilage and bacterial growth, but they were more related to other intrinsic factors of the meat than species. These factors were the pH and concentrations of L-lactate and glucose-6-phosphate. Stern *et al*. (1992) also found no significant difference between the spoilage rates of beef and turkey mince, regardless of treatment or origin of species. Saucier *et al*. (2000) noted a slight difference in the numbers and growth of total aerobic mesophilic counts between chicken mince (higher) than in turkey mince throughout storage at 1°C.

There is a large variation in published storage/shelf-lives of minced meats (Table 65). Some of these variations are due to the nature of the investigations. Some investigations have been of long-term storage-life of "mother" packs of mince held at low storage temperatures (-1.5 to 1°C) whilst others are of short-term display-life of retail packs under retail conditions (3-4°C). As may be expected, bulk storage-lives can be up to 4 weeks, while display-lives are a matter of days.

Table 65. Storage-life of packs of minced meat

Meat	Temperature (°C)	Atmosphere	Shelf-life (days)	Reference
Beef	4	Oxygen permeable pack	1-2	IIR, 2000
Beef	4	Vacuum	7-14	IIR, 2000
Beef	2	$80\%O_2+20\%CO_2$	3-5	IIR, 2000
Beef	-1.5	Vacuum	32	Gill & Jones. 1994b
Beef	1	$24\%O_2+50\%CO_2+25\%N_2+1\%CO$	29	Lüno *et al*., 1998
Goat	4	Vacuum	28	Babji *et al*., 2000
Goat	4	Aerobic	3	Babji *et al*., 2000
Chicken	3	Vacuum	8	Linton *et al*., 2004
Chicken	1	$60\%CO_2+8\%O_2+30\%N_2$	>15	Saucier *et al*., 2000
Chicken	1	$20\%CO_2+80\%N_2$	>15	Saucier *et al*., 2000
Turkey	1	$60\%CO_2+8\%O_2+30\%N_2$	>15	Saucier *et al*., 2000
Turkey	1	$20\%CO_2+80\%N_2$	>15	Saucier *et al*., 2000
Ostrich	4	Vacuum	6	Seydim *et al*., 2006
Ostrich	4	High Nitrogen	6	Seydim *et al*., 2006
Ostrich	4	Aerobic	6	Seydim *et al*., 2006
Ostrich	4	High Oxygen	3	Seydim *et al*., 2006

Gill & Jones (1994b) compared the storage-life and display-life of vacuum-packaged minced beef stored at -1.5°C, with retail packs master packaged under atmospheres of N_2, CO_2 or O_2 + CO_2 (2:1) stored at 2°C. The appearance of the product displayed after storage in a vacuum-pack, for times up to 32 days, became unacceptable within 48 hours in a retail cabinet at 4±2°C. A product stored in any of the master packs for 1 day appeared unacceptable after 6 hours of display. The display life of products stored under N_2 or CO_2 was similar to that of the vacuum-packaged products when storage times were between 2 and 24 days but the display life was shorter when the storage times were 28 or 32 days. The spoilage flora on products stored in vacuum pack or under O_2 + CO_2 did not attain the maximum numbers of 7 $\log_{10}$ cfu g^{-1} during either storage or display. Those maximum numbers were attained on products stored under N_2 and CO_2 after 16 and 28 days storage respectively. Some products stored under N_2 for 16 days or longer developed moderate or strong off-odours during display that were ascribable to microbial action. Other products developed only slight, non-microbial off-odours during display. The authors concluded that retail-ready packs or ground beef master-packaged under an oxygen-depleted atmosphere could then have a useful storage life of about 30 days in commercial circumstances.

A combination of MAP (70% O_2 + 20% CO_2 + 10% N_2) high oxygen / carbon monoxide (70% O_2 + 20% CO_2 + 9% N_2 + 1% CO) and low oxygen / carbon monoxide (24% O_2 + 50% CO_2 + 25% N_2 + 1% CO) were investigated for packaging fresh minced beef by Luño *et al*. (1998). The atmosphere containing low oxygen / carbon monoxide was found to give the best all round effects on storage-life. Psychrotrophic counts were greatly reduced, so that $\log_{10}$ cfu cm^{-2} was under 7.5 at 29 days of storage at 1°C.

The display-life of goat mince may be as short as 3 days for aerobic packages, whereas vacuum packed goat mince will last 28 days, at 4±1°C (Babji *et al*., 2000). High pH and an initial heavy carcass contamination, promotes the rapid multiplication of facultative anaerobes leading to spoilage of the mince. During storage, putrid odours in aerobically packed mince and sulphide odours in vacuum packs were observed.

Work by Saucier *et al*. (2000) shows how gas mixture that can maintain a desirable colour in mince poultry meat may be less effective than others with respect to the microbial profile of meat. The storage-life of ground chicken and turkey meat at 1°C packaged under a modified

atmosphere containing O_2 and a high level of CO_2 (62% CO_2, 8% O_2, and 30% N_2) was compared with a gas mixture without O_2 (20% CO_2 and 80% N_2). Meat packaged under no O_2 had a more appealing colour than the meat packaged under O_2 + high CO_2. While meat packaged under either of the gas mixtures tested had similar counts for presumptive pseudomonads, *Staphylococcus aureus*, and lactic acid bacteria after 15 days at 1°C, coliforms and *E. coli* counts were lower in meat packaged under O_2 + high CO_2.

Oxidation has been found to be the main limiting factor for the display-life of minced ostrich meat (Seydim *et al*., 2006). Ostrich mince was "below saleable quality" in less than 6 days displayed at 4±1°C under either high N_2, vacuum or aerobic atmospheres, under a high O_2 atmosphere the display-life was less than 3 days.

8.13 Predictive modelling of microbial growth on meats

Numerous mathematical models have been developed to predict the growth of microorganisms on foods. These range from empirically-based curve fitting exercises at their simplest, to complex relationships describing the effect of environmental factors, e.g. temperature and pH.

For the growth process of bacteria at a given temperature, a simple model such as that shown below can be used (WHO, 2002):

$$N = N_0 \exp(\mu(t - \lambda))$$

Where N is the number of bacteria, N_0 the initial number of bacteria, μ the specific growth rate, t is time, and λ the lag time.

This type of model can be applied to published growth rate data such as that that can be found in the on-line ComBase database (http://www.combase.cc/) and can be used as an indication of growth of specific bacteria at a static temperature.

8.13.1 Models for predicting microbial growth during chilling of meats

A few specific models have been developed to predict the growth of bacteria on meats during chilling and chilled storage (a review of some models relevant to the meat industry was published by McDonald & Sun (1999)). A number of these use the Temperature Function Integration (TFI) technique to calculate the overall growth (Dickson *et al*., 1992; Gill *et al*., 1991a; Gill & Jones, 1992). This technique refers to the calculation of bacterial growth from product temperature histories and data relating bacterial growth rate to temperature. The numerical values are termed by some (Jones, 1993; Lovatt *et al*., 2006) as the Process Hygiene Index (PHI).

To use TFI, a time-temperature curve is used which represents that found in chilling. In general, this is measured experimentally. This curve is then integrated with a bacterial growth model. In general, the bacterial growth models have been derived by curve fitting growth data for specific bacteria under specific conditions under static temperatures. To date few of these models have been combined with dynamic heat and mass transfer models. Though recent versions of "*Food Product Modeller"* a commercial finite difference heat transfer based program developed by MIRINZ has began to incorporate these microbiological models.

A model for the growth of coliform organisms on lamb meat was derived by Smith (1985). Generation times at 40, 35, 30, 25, 20, 15 and 10°C were measured experimentally and equations derived relating generation time and lag to temperature using the method developed by Ratkowsky *et al*. (1982). The following models were derived:

Lag	Generation
$\sqrt{1/lag} = \frac{t - 3.0}{29.09}$	$\sqrt{rate} = \frac{t - 3.4}{18.58}$

Where $\sqrt{1/lag}$ expresses the lag rate (h), $\sqrt{rate}$ expresses the growth rate (as generations h^{-1}), and t the temperature (°C).

It was taken that the minimum temperature for growth was 8°C. Experimental results of generation and lag times for a strain of *S.* Typhimurium treated in the same way gave longer generation and lag times at temperatures below 15°C. No reports of this model being used with the TFI technique have been located.

Dickson *et al*. (1992) calculated the following general model to describe lag and generation times as exponential-decay functions of temperature for *S.* Typhimurium on beef surfaces:

$$y = D + E(e^{-Ft})$$

Where y expresses the lag rate or growth rate (as generations h^{-1}) and t the temperature (°C). D, E and F are derived parameters, thus:

Tissue	Lag	Generation
Lean	$y = 1.72 + 59.02(e^{-0.12t})$	$y = 0.188 + 7.65(e^{-0.09t})$
Fatty	$y = 1.68 + 338.27(e^{-0.167t})$	$y = 0.257 + 5.104(e^{-0.092t})$

Data was generated by incubating beef samples inoculated with *S.* Typhimurium ATCC 14028 at 15, 20, 25, 30, 35 and 40°C and analysed at 2 hour intervals. Data from each growth curve was fitted to the Gompertz equation. Validation studies of this model showed no significant difference between observed and predicted bacterial populations on isolated lean and fatty beef tissues cooled at either 6 or $9°Ch^{-1}$ (by a stepwise reduction in an incubator, 2 or 3°C every 20 min).

Three main models have been developed to describe the growth of *E. coli* and pseudomonads on the surface of meat carcasses during cooling and utilised in New Zealand for assessing carcasses cooling regimes.

Gill *et al*. (1991a) produced the following model to describe the relationship between temperature and the rate of aerobic growth of *E. coli*:

$y = 0$	when t is >47°C
$y = 2.66$	when t is between 40 and 47°C
$y = (0.027t + 0.55)^2$	when t is between 30 and 40°C
$y = (0.0513t - 0.17)^2$	when t is between 7 and 30°C
$y = 0$	when t is <7°C

Where y expresses the growth rate (as generations h^{-1}) and t the temperature (°C).

The model was developed from data for aerobic growth of a wild type strain in half-strength Brain Heart Infusion. It is an extension of that used by Lowry *et al*. (1988) in estimating *E. coli* proliferation during thawing of meat. Lowry *et al*. (1988) showed a good correlation between calculated and directly determined *E. coli* growth in bench scale studies. The average directly determined growth and the calculated growth generally differed by less than one generation. However, determined growth was significantly lower than the calculated growth when predicted growth exceeded 15 generations, since the actual flora was

approaching maximum numbers by this point. Gill *et al*. (1991a) did not report any validation studies for the extended model on beef carcass surfaces, or how well the model matched measured microbial growth. This model has been used to assess the "hygienic adequacy" of air chilling (Gill *et al*., 1991a; Gill & Bryant, 1997) and spray chilling (Gill *et al*., 1991b; Jericho *et al*., 1998) of beef carcasses, air chilling of lamb carcasses (Gill & Jones, 1997) and spray chilling of pig carcasses (Gill & Jones, 1997). An investigation of two beef abattoirs by Gill & Bryant (1997) showed that *E. coli* generations calculated from temperature histories indicated that counts on carcasses would increase by about 1 log unit at abattoir A and 0.3 log units at abattoir B. However, enumeration of bacteria showed that cooling reduced mean numbers of APCs, coliforms and *E. coli* on carcasses at abattoir A by <0.5 log units. While at abattoir B APCs were reduced by about 0.5 log units and coliform and *E. coli* counts by 2 log units. The authors concluded that, while "temperature history data may be used to monitor the maintenance of standard operating procedures in such processes", microbiological data was required to properly access the hygienic effects of carcass cooling processes.

A model was also developed to describe the relationship between temperature and the rate of anaerobic growth of *E. coli* (Reichel *et al*., 1991):

$y = 0$	when t is >45°C
$y = 1.77$	when t is between 40 and 45°C
$y = (0.0163t + 0.676)^2$	when t is between 30 and 40°C
$y = (0.0433t - 0.15)^2$	when t is between 7 and 30°C
$y = 0$	when t is ≤7°C

Where y expresses the growth rate (as generations h^{-1}) and t the temperature (°C).

Gill & Jones (1992) calculated the following model to describe the relationship between temperature and the rate of growth of pseudomonads:

$y = 0$	when t is >35°C
$y = 1$	when t is between 25 and 35°C
$y = (0.033x + 0.27)^2$	when t is between -2 and 25°C
$y = 0$	when t is <-2°C

Where y expresses the growth rate (as generations h^{-1}) and t the temperature (°C).

Use of this model, as well as the aerobic *E. coli* model, on data collected during the air chilling of lamb carcasses and spray chilling of pork carcasses (Gill & Jones, 1997) predicted that *E. coli* growth would be undetectable on either types of carcass, but that APCs would increase by >1 and <1 log unit on the lamb and pork carcasses, respectively. However, counts on lamb carcasses showed that cooling reduced mean numbers of APCs, coliforms and *E. coli* on carcasses by 0.5, 1.5 and 2 log units, respectively. Though, counts on the pork carcasses behaved much as was expected from the predictions based on the temperature histories. This model was also used to assess the efficiency of storage during cross continental transport of beef sides and quarters (Gill & Phillips, 1993).

Table 66. PHI criteria for lamb and beef (number of generations)

	M	m	c	n	Reference
Beef	14	10	20%	≥20	Gill *et al*. (1991a)
Beef	14	9	20	≥20	Gill *et al*. (1991a)
Lamb	9	6	60%	≥5	Jones (1993)
Beef	19	14	60%	≥5	Jones (1996)
New Zealand regulations	14	10	80%		MAF (1997)

PHI criteria for sheep and beef (Table 66 and Table 67) have been published by a number of studies. In general, these criteria have been set by recording time-temperature curves in carcasses subjected to what have been considered to be carried out under Good Manufacturing Practice (GMP) and calculating the resulting TFI generations based on mainly the model proposed by Gill *et al*. (1991a). Lovatt *et al*. (2006) added an additional criterion based on the initial number of *E. coli* present:

Log_2(maximum acceptable number)=Log_2(initial number before cooling) + maximum allowable PHI

Table 67. PHI criteria and growth that may be allowed from the initial numbers of *E. coli*, while keeping predicted numbers below acceptable M and m values (source: Lovatt *et al*., 2006)

	M (log_2 cfu cm^{-2})	M (log_2 cfu cm^{-2})	I (log_2 cfu cm^{-2})	Maximum growth, M-I (Generations)	60^{th} percentile growth, m-I (Generations)
Beef	13.3	6.6	1.1	12.2	5.5
Lamb	14.0	7.4	-3.7	17.7	11.1

The accuracy of the overall prediction is reliant on the accuracy of the temperature data and the accuracy of the model. Most models assume that time and temperature are the only factors limiting growth. However, there is concern that other factors are present that inhibit growth (such as surface drying; Jones, 1993) and that consequentially TFI methods over estimate microbial growth and "should not be seen as describing any "real" growth occurring at the monitored site (Jones, 1993). Jones (1993) argues that nevertheless the estimated growth will "assure the process because "actual" growth will not exceed the predicted number of generations". Similar observations have been made by Gill *et al*. (1991a, b), Armitage (1997) and Bell *et al*. (1998). Armitage (1997) reported a study comparing quantitative microbiological counts on lamb carcasses subjected to a range of ageing (conditioning) treatments with TFI predictions. TFI results showed a value of 10 generations (3 log_{10} potential growth), however the microbiological survey results showed only a slight rise (<0.5 log_{10}) in counts. Armitage (1997) put forward the following points as possible explanations for the discrepancy between the quantitative microbiological results and the TFI prediction:

1. Although the overall increase in mean APCs did not exceed one generation, at the 99.9th percentile (+3SD) the increase in APCs was larger and represented approximately 2.25 generations of growth.
2. Whilst it might be possible for *E. coli* to increase by a factor of 3 log_{10} (say -2 to +1 log_{10}) without a detectable change in the APC count, the process was not designed to

select for mesophiles, i.e., the temperature parameters would be more likely to have potentially promoted growth of psychrotrophic bacteria. The APC results do not reflect any change in the composition of the flora that may have occurred during chilling.

3. The temperature history used to calculate the TFI was calculated for a PM grade of lamb. This type of lamb is moderately heavy with a heavy fat cover and represents approximately 20% of the total lambkill. Sixty percent of New Zealand lambs are lighter or have less fat cover, and therefore would be expected to cool more rapidly than the PM grade, with a consequential reduction in the rate of bacterial proliferation.

4. TFI uses a model for *E. coli* growth that is only limited by temperature. The growth model makes no allowances for a reduction in available water that could be expected to occur as the surface of the carcass dries during cooling. Because the numerical increase in *E. coli* is dependent on moisture, the actual increase must be expected to be less than the predicted increase if any degree of surface drying takes place.

5. The temperature/time schedules that suggested a potential 3 $\log_{10}$ *E. coli* proliferation reflected physical conditions that might occur during the warmest months of the year. The microbiological survey results used represented two years production and included periods of the year where ambient temperatures were considerably less than the temperatures used in the TFI calculations.

6. The TFI calculations must be considered to be conservative in that whilst good agreement can be demonstrated between observed and predicted values in vitro, in practice the observed value is frequently less than the predicted value (Gill & Harrison, 1985). In carcass cooling studies where the surfaces of microbial concern were uncovered, the correlation between predicted and observed E. coli counts was poor and numerous counts extending through the 1 $\log_{10}$ range were observed for a given predicted value.

7. Except for temperature, all other characteristics that could be expected to favour the growth of *E. coli* are also assumed to be present, including *E. coli* having a selective advantage in the presence of competing organisms.

Despite the discrepancy between the quantitative microbiological results and the TFI results, Armitage was of the opinion that TFI was still a "rapid, cost effective method of quantifying a temperature dependent process in terms of the potential for microbial proliferation", though it "could not be relied on to validate a process outcome in the absence of quantitative microbiology".

McMeekin *et al*. (2002) criticise Gill's original model as based only on the temperature response of *E. coli* using a limited data set. They cite their own models for the growth of *E. coli* (Presser *et al*., 1997; 1998) as providing greater precision, however these more complex models require knowledge of the water activity, pH and lactate concentration:

$$\sqrt{rate} = 0.0247933 \times \sqrt{(a_w - 0.934)} \times (t - 4) \times \left(1 - \frac{10^{3.9}}{10^{pH}}\right) \times \sqrt{1 - \frac{[LAC]}{[10.7] \cdot \left(1 + 10^{pH - 3.86}\right)}} \times \sqrt{1 - \frac{[LAC]}{[823.4] \cdot \left(1 + 10^{3.86 - pH}\right)}}$$

Where $\sqrt{rate}$ expresses the growth rate (as 1/generations min^{-1}), *t* the temperature (°C), LAC is the total concentration of lactic acid (mM) and a_w is the water activity.

Summer & Krist (2002) report that this model has been applied in Australia to the cooling process of hot (30-35°C) beef trim (using: lag 5 generations; pH 6.2; lactate 80 mM; a_w

0.992), as well as distribution and retail storage (using: no lag; pH 6.5; no lactic acid; a_w 0.992), and the assessment of the risk of warming of carcass meat to enable easy boneing. This model has been further improved and refined (Ross *et al*., 2003) and expressed by Mellefont *et al*. (2003) as:

$$\sqrt{rate} = 0.2790 \times \left((t - 4.14) \times \left(1 - \exp(0.2636(t - 49.55))\right)\right) \times \sqrt{(a_w - 0.9508)} \times \sqrt{\left(1 - 10^{(3.909 - pH)}\right)} \times \sqrt{\left(1 - 10^{(pH - 8.860)}\right)} \times \sqrt{\left(1 - \left([LAC] / \left(10.433\left(1 + 10^{(pH - 3.86)}\right)\right)\right)\right)} \times \sqrt{\left(1 - \left([LAC] / \left(995.509\left(1 + 10^{(3.86 - pH)}\right)\right)\right)\right)} \pm 0.0054$$

Where $\sqrt{rate}$ expresses the growth rate (1/generation time (h)), *t* the temperature (°C), LAC is the total concentration of lactic acid (mM) and a_w is the water activity.

This model is used as the Refrigeration Index model in Australia. The RI Calculator allows the selection of a number of products. The parameters associated with each product types are indicated in the table below:

	Model parameters		
	pH	Lactate (mM)	a_w
Carcass	6.5	51.7	0.993
Boxed trim	6.5	51.7	0.993
Lean Primal	5.4	86.5	0.993
Fat Primal	6.8	0	0.990
Offal	6.8	25	0.995
Mechanically separated meat	6.8	51	0.995

The Refrigeration Index is the sum of *E. coli* growth under changing temperatures over the time taken for the meat to cool to less than 7°C. Thus, the growth of *E. coli* is calculated over small time intervals where the temperature is assumed to be effectively constant, and then the growth in all of the time intervals are added together. The RI indicates how many *E. coli* (actually expressed as $\log_{10}$ *E. coli* numbers) would result if one cell was initially on the meat.

Over a small time interval, *t*=0 to *t*=*t*, the number (*N*) of *E. coli* will increase according to the following equation:

$$\log_{10} N_t - \log_{10} N_0 = (t - t_0) r 0.30103$$

Where *r* is the relative growth rate from the predictive equation.

The RI is simply the sum of $(\log_{10} N_t - \log_{10} N_0)$ for all of the time intervals for which temperature readings are available.

To achieve the refrigeration index criteria as set out in the Australian Export Control (Meat and Meat Products) Orders 2005:

(a) the refrigeration index average is to be no more than 1.5; and

(b) 80% of refrigeration indices are to be no more than 2.0; and

(c) no refrigeration index is to be more than 2.5.

8.13.2 Modelling growth of microorganisms in meat during storage

A number of models for predicting the growth of salmonella on chicken meat were critically assessed by the WHO when risk assessing salmonella in eggs and broiler chickens (WHO, 2002). They cited the model of Whiting (1993) for predicting salmonella survival at temperatures between 4 and 9°C, but overall concluded that there were no suitable models to estimate survival and die-off for salmonellas in or on chickens. For their risk assessment, it was assumed that the salmonella population remains static below the growth rate. In their own risk assessment they used the growth model developed by Oscar (1999) for *S.* Typhimurium:

$$LGR = \exp\left(-6.225 - \left[0.0114 \times NaCl\right] + \left[0.3234 \times Temp\right] + \left[0.002 \times \left\{NaCl \times Temp\right\}\right] - \left[0.0085 \times NaCl^2\right] - \left[0.0045 \times Temp^2\right]\right)$$

This model has a temperature range of 10 to 40°C so its usefulness for modelling growth during storage, distribution, retail and consumer handling is questionable, apart from perhaps modelling the effects of abuse of the cold-chain, particularly during transport from retail to the home. The WHO report cited the lack of suitable models for estimating bacterial growth during processing and chilling, and the lack of overall temperature data to base risk assessments on. The modelling approach used by WHO (2002) has also been used by Food Standards Australia New Zealand (2005) for the risk assessment of salmonella in chicken meat. A stochastic modelling approach was used for assessing the risk of campylobacteriosis from consumption of contaminated poultry meat. Growths of other pathogens were not modelled.

Venter *et al*. (2006) have generated a number of mathematical indices of the growth of specific bacteria on vacuum-packed beef stored at 5 and 18°C. This was carried out to investigate the proliferation of the various microorganisms at initial storage temperatures as well as to simulate conditions where a breach in the cold chain might occur. As may be expected, the results show that at these two temperatures, the various genera reacted very differently with specific hazards originating from the predominance of certain groups. The initial microbial load played a pivotal role in the patterns of growth at both 5 and 18°C. The following relationships were generated for bacteria at 5°C:

Bacteria	Equation	Coefficient
APC	$Y = \frac{a}{\left[1 + e^{-(x - x_0)/b}\right]}$	$a = 2.5 \times 10^{8}$ $b = 1.23 \times 10^{-1}$ $x_0 = 4.98 \times 10^{0}$
E. coli	$Y = a\left(1 + x\right)^{b}$	$a = 4.7 \times 10^{2}$ $b = 3.3 \times 10^{0}$
Coliforms	$Y = y_0 + \frac{a}{\left[1 + e^{-(x - x_0)/b}\right]}$	$a = 4.87 \times 10^{7}$ $b = 7.25 \times 10^{-1}$ $x_0 = 9.89 \times 10^{0}$ $y_0 = 6.31 \times 10^{3}$

8.13.3 Modelling growth of microorganisms in mince during storage

A number of studies have developed specific models for predicting the growth of pathogens (Tamplin, 2002; Tamplin *et al*., 2005; Oscar, 2006) and spoilage bacteria (Koutsoumanis *et al*., 2006) in minced meats during storage.

Tamplin and others (Tamplin, 2002; Tamplin *et al*., 2005) have compared real and predicted (using the Pathogen Modelling Program) growth of *E. coli* O157 in raw minced beef stored at different temperatures. Initial studies by Tamplin (2002) on the growth of *E. coli* O157:H7 in minced beef compared growth and predictions at 10°C. The version of PMP used (5.1) at pH 5.9 predicted a maximum population density (MPD) of 9.13 $\log_{10}$ cfu g^{-1}, an exponential growth rate (EGR) of 0.052 $\log_{10}$ cfu h^{-1}, and a lag time of 56.3 hours. Similar parameter values were observed for the growth of *E. coli* O157:H7 sterilized minced beef; however, no lag phase was observed. However, on retail minced beef the mean MPD and EGR for were 5.09 and 0.019, respectively, and no lag phase was observed. Further studies (Tamplin *et al*., 2005) investigated the growth of 10 strains of *E. coli* O157:H7 on minced beef at storage temperatures. Growth occurred from 6 to 45°C, with the absence of a lag period at 6, 8 and 10°C. At 6°C the mean MPD and specific growth rate (SGR) were 4.71 $\log_{10}$ cfu g^{-1} and 0.003 ln h^{-1}, respectively. Discrepancies were found between observed growth and predictions using version 6.1 of PMP. Growth was observed at lower temperatures than those available in the PMP model. An extended Ratkowsky model (Ratkowsky *et al*., 1983) was suggested to model growth at temperatures below 10°C.

Oscar (2006) has developed a tertiary model for predicting the growth of *S.* Typhimurium on minced chicken at temperatures from 10 to 40°C. This model allows for the effect of a low initial density of *S.* Typhimurium and a competitive microflora.

Koutsoumanis *et al*. (2006) have developed a microbial model for the combined effect of temperature and pH on spoilage of minced beef and pork under dynamic temperature conditions. The changes in microbial flora and sensory characteristics of fresh ground meat (beef and pork) with pH values ranging from 5.34 to 6.13 were monitored at different isothermal storage temperatures (0 to 20°C) under aerobic conditions. At all conditions tested, pseudomonads were the predominant bacteria, followed by *Brochothrix thermosphacta*, while the other members of the microbial association (e.g., lactic acid bacteria and Enterobacteriaceae) remained at lower levels. The results from microbiological and sensory analysis showed that changes in pseudomonad populations closely followed sensory changes during storage and could be used as a good index for spoilage of aerobically stored ground meat. The kinetic parameters of the spoilage bacteria were modelled by using a modified Arrhenius equation for the combined effect of temperature and pH:

$$\ln(\mu_{\max}) = \ln(\mu_{ref}) - d_m \cdot (pH_{ref} - pH) - \frac{E_{Am}}{R} \cdot \left(\frac{1}{T} - \frac{1}{T_{ref}}\right)$$

$$\ln(\lambda) = \ln(\lambda_{ref}) - d_\lambda \cdot (pH_{ref} - pH) - \frac{E_{A\lambda}}{R} \cdot \left(\frac{1}{T} - \frac{1}{T_{ref}}\right)$$

Where T is the absolute temperature (K), E_A the activation energy (kJmol^{-1}), R the universal gas constant, T_{ref} the reference temperature (T_{ref}=273K), pH_{ref} the reference pH condition (pH=5.7), μ_{ref} (h^{-1}) and λ_{ref} are the maximum specific growth rate and lag phase at reference storage conditions (T_{ref} and pH_{ref}), respectively, and d_μ and d_λ are parameters expressing the effect of pH on the maximum specific growth rate and lag phase, respectively. For the different spoilage bacteria in minced meat, the parameters are the following:

Bacteria	Coefficient
Pseudomonads	$l_{ref}(h) = 40.2$
	$E_{al}(kJ/mol) = 68.8$
	$d_l = 1.22$
B. thermosphacta	$l_{ref}(h) = 20.7$
	$E_{al}(kJ/mol) = 67.0$
	$d_l = 1.73$
Lactic acid bacteria	$l_{ref}(h) = 36.2$
	$E_{al}(kJ/mol) = 97.0$
	$d_l =$ Not significant
Enterobacteriaceae	$l_{ref}(h) = 63.5$
	$E_{al}(kJ/mol) = 93.5$
	$d_l = 0.581$

The developed models were further validated under dynamic temperature conditions using different fluctuating temperatures. Graphical comparison between predicted and observed growth and the examination of the relative errors of predictions showed that the model predicted satisfactorily growth under dynamic conditions. Predicted shelf-life, based on pseudomonads growth, was slightly shorter than shelf life observed by sensory analysis with a mean difference of 13.1%.

Cassin *et al*.'s risk assessment model on *E. coli* O157:H7 in hamburgers (Cassin *et al*., 1998) highlighted reducing bacterial growth during storage by reducing storage temperatures as the most effective hypothetical intervention for reducing food poisoning. A risk mitigation strategy based on storage temperature control was predicted to result in a 80% reduction in illness compared to 46% and 16% reductions achieved with strategies based on pre-slaughter screening and hamburger cooking, respectively. This approach could be used to assess the safety of mince produced from aged meat.

8.13.3.1 ComBase Predictor and the Pathogen Modelling Program

ComBase Predictor and the Pathogen Modelling Program are readily available modelling programs that allow the estimation of the growth of a range of pathogenic, indicator and spoilage organisms under a range of intrinsic and extrinsic conditions. In order to assess the usefulness of the ComBase Predictor and the Pathogen Modelling Programs a series of predictions were carried out to estimate the growth of various pathogens on meats at different temperatures during the long storage times used commercially for ageing meats.

ComBase Predictor allows the estimation of the growth of a range of pathogenic, indicator and spoilage organisms at static temperatures under a range of intrinsic and extrinsic conditions (Table 68). These models are based on the growth of these organisms in liquid media.

Table 68. Microbial growth models available on ComBase Predictor, in order of minimum growth temperature of microorganism

Microorganism	Temperature (°C)		pH	
	Min	Max	Min	Max
Clostridium perfringens	15	52	5	8
Clostridium botulinum (proteolytic)	14	40	4.7	7.2
Bacillus licheniformis	13	34	4	7.6
Bacillus subtilis	10	34	4.3	7.8
Escherichia coli	10	30	4.5	7
Staphylococcus aureus	7.5	30	4.3	7.1
Salmonella	7	30	3.9	7.4
Bacillus cereus	5	34	4.9	7.4
Clostridium botulinum (non-proteolytic)	4	30	5.1	7.5
Aeromonas hydrophila	2	25	4.6	7.5
Listeria monocytogenes/innocua	1	35	4.4	7.5
Yersinia enterocolitica	0	30	4.4	7.1
Brochothrix thermosphacta	0	30	5	5.7

Under conditions simulating meat (pH 5.8) ComBase Predictor estimates the following growths (log_{10} cfu g^{-1}) in salmonella, non-proteolytic *Cl. botulinum*, *L. monocytogenes* and *Y. enterocolitica* at a range of storage temperatures, aerobic conditions and times related to the recommended times for the storage of meat destined for mince, and those times used for ageing:

Salmonella	Temperature (°C)			Details
With CO_2 (0%)	7	10	12	
72 h (3 d)	0.10 a	0.69	0.34	pH 5.8 / NaCl 0.5% / CO_2 0%
144 h (6 d)	0.49	2.54	1.37	pH 5.8 / NaCl 0.5% / CO_2 0%
360 h (15 d)	2.84	7.31	5.35	pH 5.8 / NaCl 0.5% / CO_2 0%
504 h (21 d)	4.50	7.52 c	7.23	pH 5.8 / NaCl 0.5% / CO_2 0%
1008 h (42 d)	7.50 b	7.52 d	7.52 e	pH 5.8 / NaCl 0.5% / CO_2 0%

Saturation (h): a) 69.12, b) 967.68, c) 453.60, d) 463.68, e) 665.28

Salmonella	Temperature (°C)			Details
With CO_2 (30%)	7	10	12	
72 h (3 d)	0.06	0.44	1.41	pH 5.8 / NaCl 0.5% / CO_2 30%
144 h (6 d)	0.23	1.65	3.78	pH 5.8 / NaCl 0.5% / CO_2 30%
360 h (15 d)	1.69	6	7.52 b	pH 5.8 / NaCl 0.5% / CO_2 30%
504 h (21 d)	2.9	7.43	7.52 c	pH 5.8 / NaCl 0.5% / CO_2 30%
1008 h (42 d)	6.79	7.52 a	7.52 d	pH 5.8 / NaCl 0.5% / CO_2 30%

Saturation (h): a) 604.80, b) 345.60, c) 342.72, d) 342.52

Salmonella With CO_2 (40%)	Temperature (°C) 7	10	12	Details
72 h (3 d)	0.05	0.35	1.21	pH 5.8 / NaCl 0.5% / CO_2 40%
144 h (6 d)	0.18	1.38	3.38	pH 5.8 / NaCl 0.5% / CO_2 40%
360 h (15 d)	1.38	5.39	7.51	pH 5.8 / NaCl 0.5% / CO_2 40%
504 h (21 d)	2.44	7.25	7.51	pH 5.8 / NaCl 0.5% / CO_2 40%
1008 h (42 d)	6.11	7.52 a	7.52 b	pH 5.8 / NaCl 0.5% / CO_2 40%

Saturation (h): a) 665.28, b) 383.04

Salmonella With CO_2 (100%)	Temperature (°C) 7	10	12	Details
72 h (3 d)	0.02 a	0.09	2.10	pH 5.8 / NaCl 0.5% / CO_2 100%
144 h (6 d)	0.04 b	0.34	5.07	pH 5.8 / NaCl 0.5% / CO_2 100%
360 h (15 d)	0.26	2.25	7.52 c	pH 5.8 / NaCl 0.5% / CO_2 100%
504 h (21 d)	0.57	3.68	7.52 d	pH 5.8 / NaCl 0.5% / CO_2 100%
1008 h (42 d)	2.24	7.38	7.52 e	pH 5.8 / NaCl 0.5% / CO_2 100%

Saturation (h): a) 69.12, b) 126.72, c) 273.60, d) 272.16, e) 282.24

Clostridium botulinum (non-proteolytic)	Temperature (°C) 4	5	6	7	10	12	Details
72 h (3 d)	0.00	0.00	0.00	0.00	0.10	1.97	pH 5.8 / NaCl 0.5% / CO_2 0%
144 h (6 d)	0.00	0.00	0.00	0.02	3.29	6.03	pH 5.8 / NaCl 0.5% / CO_2 0%
360 h (15 d)	0.00	0.14	1.28	3.49	6.04 c	6.04 f	pH 5.8 / NaCl 0.5% / CO_2 0%
504 h (21 d)	0.11	1.21	3.53	5.86	6.04 d	6.04 g	pH 5.8 / NaCl 0.5% / CO_2 0%
1008 h (42 d)	3.35	5.89	6.04 a	6.04 b	6.04 e	6.04 h	pH 5.8 / NaCl 0.5% / CO_2 0%

Saturation (h): a) 826.56, b) 584.64, c) 244.80, d) 241.92, e) 241.92, f) 144, g) 151.20, h) 161.28

Listeria monocytogenes/ *innocua* with CO_2 (%)	Temperature (°C) 1	2	3	4	5	6	7	10	12	Details
72 h (3 d)	0.01	0.02	0.03	0.05	0.08	0.14	0.26	1.27	2.53	pH 5.8 / NaCl 0.5% / CO_2 0%
144 h (6 d)	0.04	0.08	0.14	0.28	0.54	0.97	1.57	4.21	6.54	pH 5.8 / NaCl 0.5% / CO_2 0%
360 h (15 d)	0.47	0.93	1.60	2.48	3.56	4.86	6.30	7.52 d	7.52 g	pH 5.8 / NaCl 0.5% / CO_2 0%
504 h (21 d)	1.13	1.91	2.92	4.15	5.62	7.00	7.48	7.52 e	7.52 h	pH 5.8 / NaCl 0.5% / CO_2 0%
1008 h (42 d)	3.91	5.48	7.02	7.5	7.52 a	7.52 b	7.52 c	7.52 f	7.52 i	pH 5.8 / NaCl 0.5% / CO_2 0%

Saturation (h): a) 866.88, b) 685.44, c) 604.80, d) 309.60, e) 312.48, f) 322.56, g) 216.00, h) 221.76, i) 221.76

Listeria monocytogenes/ *innocua* with CO_2 (30%)	Temperature (°C) 1	2	3	4	5	6	7	10	12	Details
72 h (3 d)	0.01	0.01	0.02	0.02	0.04	0.06	0.10	0.56	1.37	pH 5.8 / NaCl 0.5% / CO_2 30%
144 h (6 d)	0.02	0.04	0.06	0.11	0.21	0.40	0.73	2.57	4.41	pH 5.8 / NaCl 0.5% / CO_2 30%
360 h (15 d)	0.18	0.38	0.76	1.34	2.10	3.05	4.18	7.42	7.52 e	pH 5.8 / NaCl 0.5% / CO_2 30%
504 h (21 d)	0.48	0.95	1.64	2.53	3.62	4.93	6.37	7.52 c	7.52 f	pH 5.8 / NaCl 0.5% / CO_2 30%
1008 h (42 d)	2.35	3.52	4.95	6.54	7.42	7.52 a	7.52 b	7.52 d	7.52 g	pH 5.8 / NaCl 0.5% / CO_2 30%

Saturation (h): a) 947.52, b) 766.08, c) 423.36, d) 423.36, e) 295.20, f) 302.40, g) 302.40

Listeria monocytogenes/ *innocua* with CO_2 (40%)	Temperature (°C)									Details
	1	2	3	4	5	6	7	10	12	
72 h (3 d)	0.01	0.01	0.01	0.02	0.03	0.05	0.08	0.41	1.07	pH 5.8 / NaCl 0.5% / CO_2 40%
144 h (6 d)	0.02	0.03	0.05	0.08	0.15	0.29	0.54	2.13	3.78	pH 5.8 / NaCl 0.5% / CO_2 40%
360 h (15 d)	0.13	0.28	0.56	1.04	1.71	2.55	3.57	7.16	7.52 d	pH 5.8 / NaCl 0.5% / CO_2 40%
504 h (21 d)	0.35	0.72	1.30	2.09	3.07	4.25	5.63	7.52 b	7.52 e	pH 5.8 / NaCl 0.5% / CO_2 40%
1008 h (42 d)	1.92	2.97	4.27	5.80	7.15	7.5	7.52 a	7.52 c	7.52 f	pH 5.8 / NaCl 0.5% / CO_2 40%

Saturation (h): a) 866.88, b) 473.76, c) 483.84, d) 331.20, e) 332.64, f) 342.72

Listeria monocytogenes/ *innocua* with CO_2 (100%)	Temperature (°C)									Details
	1	2	3	4	5	6	7	10	12	
72 h (3 d)	0	0	0.01	0.01	0.01	0.01	0.02	0.06	0.16	pH 5.8 / NaCl 0.5% / CO_2 100%
144 h (6 d)	0.01	0.01	0.01	0.02	0.03	0.05	0.08	0.42	1.09	pH 5.8 / NaCl 0.5% / CO_2 100%
360 h (15 d)	0.03	0.05	0.08	0.15	0.30	0.56	0.99	3.11	5.17	pH 5.8 / NaCl 0.5% / CO_2 100%
504 h (21 d)	0.06	0.10	0.20	0.40	0.77	1.31	2.01	5.02	7.19	pH 5.8 / NaCl 0.5% / CO_2 100%
1008 h (42 d)	0.35	0.72	1.31	2.10	3.09	4.28	5.66	7.52 a	7.52 b	pH 5.8 / NaCl 0.5% / CO_2 100%

Saturation (h): a) 947.52, b) 665.28

Yersinia enterocolitica with CO_2 (0%)	Temperature (°C)									Details
	1	2	3	4	5	6	7	10	12	
72 h (3 d)	0.29	0.43	0.63	0.89	1.22	1.62	2.07	3.79	5.21	pH 5.8 / NaCl 0.5% / CO_2 0%
144 h (6 d)	1.29	1.76	2.30	2.93	3.65	4.46	5.35	7.22	7.30 s	pH 5.8 / NaCl 0.5% / CO_2 0%
360 h (15 d)	5.03	6.11	6.95	7.25	7.30 g	7.30 j	7.30 m	7.30 p	7.30 t	pH 5.8 / NaCl 0.5% / CO_2 0%
504 h (21 d)	6.93	7.26	7.30 c	7.30 e	7.30 h	7.30 k	7.30 n	7.30 q	7.30 u	pH 5.8 / NaCl 0.5% / CO_2 0%
1008 h (42 d)	7.30 a	7.30 b	7.30 d	7.30 f	7.30 i	7.30 l	7.30 o	7.30 r	7.30 v	pH 5.8 / NaCl 0.5% / CO_2 0%

Saturation (h): a) 665.28, b) 564.48, c) 473.76, d) 483.84, e) 403.20, f) 403.20, g) 338.40, h) 342.72, i) 342.72, j) 295.20, k) 292.32, l) 302.40, m) 252.00, n) 252.00, o) 262.08, p) 165.60, q) 171.36, r) 181.44, s) 129.60, t) 129.60, u) 131.04, v) 141.12

Yersinia enterocolitica with CO_2 (30%)	Temperature (°C)									Details
	1	2	3	4	5	6	7	10	12	
72 h (3 d)	0.09	0.13	0.19	0.28	0.41	0.60	0.85	1.95	2.96	pH 5.8 / NaCl 0.5% / CO_2 30%
144 h (6 d)	0.40	0.61	0.89	1.26	1.70	2.23	2.83	5.11	6.74	pH 5.8 / NaCl 0.5% / CO_2 30%
360 h (15 d)	2.38	3.12	3.97	4.95	6.00	6.87	7.23	7.30 i	7.30 l	pH 5.8 / NaCl 0.5% / CO_2 30%
504 h (21 d)	3.83	4.85	5.95	6.88	7.24	7.30 e	7.30 g	7.30 j	7.30 m	pH 5.8 / NaCl 0.5% / CO_2 30%
1008 h (42 d)	7.23	7.30 a	7.30 b	7.30 c	7.30 d	7.30 f	7.30 h	7.30 k	7.30 n	pH 5.8 / NaCl 0.5% / CO_2 30%

Saturation (h): a) 947.52, b) 806.40, c) 665.28, d) 564.48, e) 483.84, f) 483.84, g) 423.36, h) 423.36, i) 259.20, j) 262.08, k) 262.08, l) 201.60, m) 201.60, n) 201.60

Yersinia enterocolitica with CO_2 (40%)	Temperature (°C)									Details
	1	2	3	4	5	6	7	10	12	
72 h (3 d)	0.02	0.10	0.14	0.20	0.30	0.44	0.63	1.57	2.49	pH 5.8 / NaCl 0.5% / CO_2 40%
144 h (6 d)	0.28	0.43	0.64	0.94	1.32	1.77	2.30	4.37	6.08	pH 5.8 / NaCl 0.5% / CO_2 40%
360 h (15 d)	1.85	2.49	3.24	4.11	5.10	6.14	6.95	7.30 g	7.30 j	pH 5.8 / NaCl 0.5% / CO_2 40%
504 h (21 d)	3.09	3.98	5.01	6.11	6.97	7.26	7.30 e	7.30 h	7.30 k	pH 5.8 / NaCl 0.5% / CO_2 40%
1008 h (42 d)	6.86	7.25	7.30 a	7.30 b	7.30 c	7.30 d	7.30 f	7.30 i	7.30 l	pH 5.8 / NaCl 0.5% / CO_2 40%

Saturation (h): a) 927.36, b) 786.24, c) 665.28, d) 564.48, e) 473.76, f) 483.84, g) 295.20, h) 302.40, i) 302.40, j) 223.20, k) 221.76, l) 221.76

Yersinia enterocolitica with CO_2 (80%)	Temperature (°C)									Details
	1	2	3	4	5	6	7	10	12	
72 h (3 d)	0.03	0.04	0.06	0.08	0.11	0.17	0.24	0.75	1.38	pH 5.8 / NaCl 0.5% / CO_2 80%
144 h (6 d)	0.10	0.14	0.22	0.33	0.51	0.76	1.10	2.59	3.99	pH 5.8 / NaCl 0.5% / CO_2 80%
360 h (15 d)	0.69	1.06	1.53	2.11	2.80	3.60	4.54	7.15	7.30 e	pH 5.8 / NaCl 0.5% / CO_2 80%
504 h (21 d)	1.36	1.93	2.62	3.45	4.41	5.49	6.56	7.30 c	7.30 f	pH 5.8 / NaCl 0.5% / CO_2 80%
1008 h (42 d)	3.95	5.08	6.3	7.11	7.29	7.30 a	7.30 b	7.30 d	7.30 g	pH 5.8 / NaCl 0.5% / CO_2 80%

Saturation (h): a) 866.88, b) 725.76, c) 433.44, d) 443.52, e) 316.80, f) 322.56, g) 322.56

The Pathogen Modelling Program (v. 7) also allows the estimation of the growth of a range of pathogenic, indicator and spoilage organisms at temperatures under a range of intrinsic and extrinsic conditions (Table 69 and Table 70). Again, these models are primarily based on the growth of these organisms in liquid media.

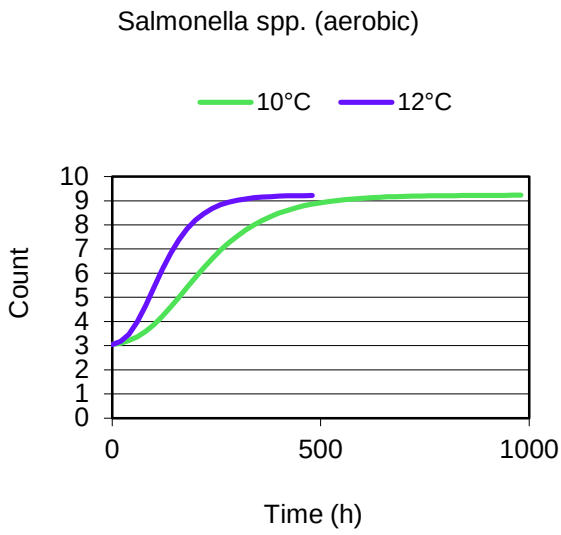
Table 69. Microbial aerobic growth models available on Pathogen Modelling Program (7), in order of minimum growth temperature of microorganism

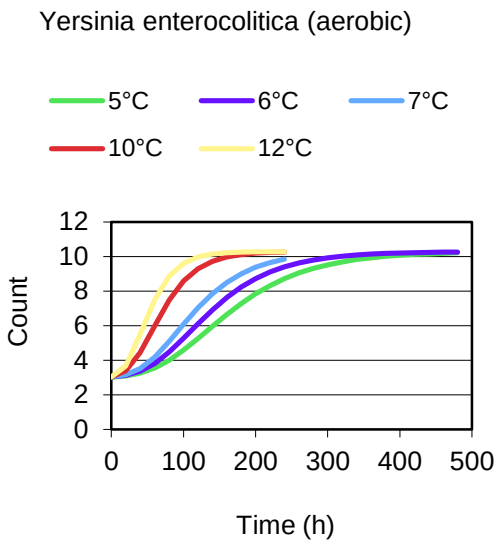
Aerobic Growth	Temperature (°C)		pH	
Organism	Min	Max	Min	Max
Salmonella spp.	10	30	5.6	6.8
Staphylococcus aureus	10	42	4.5	9
Shigella flexneri	10	37	5	7.5
Aeromonas hydrophila	5	42	5.3	7.3
Bacillus cereus	5	42	4.7	7.5
Escherichia coli 0157:H7	5	42	4.5	8.5
Yersinia enterocolitica	5	42	4.5	8.5
Listeria monocytogenes	4	37	4.5	7.5

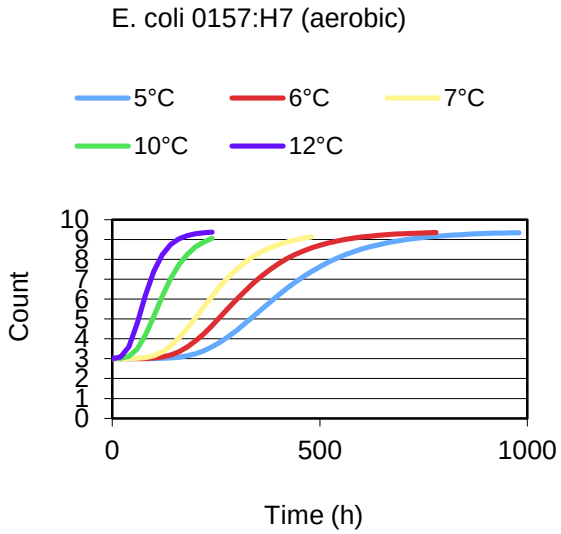
Table 70. Microbial anaerobic growth models available on Pathogen Modelling Program (7), in order of minimum growth temperature of microorganism

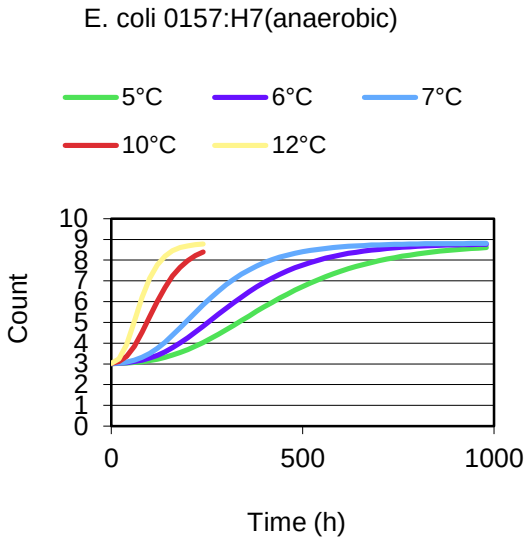
Anaerobic Growth	Temperature (°C)		pH	
Organism	Min	Max	Min	Max
Clostridium perfringens	19	37	6	6.5
Shigella flexneri	12	37	5.5	7.5
Staphylococcus aureus	12	42	5.3	9
Bacillus cereus	10	42	5	9
Aeromonas hydrophila	5	30	5.3	7.3
Escherichia coli 0157:H7	5	42	4.5	8.5
Listeria monocytogenes	4	37	4.5	8

Under conditions simulating meat (pH 5.8), the Pathogen Modelling Program estimates the following growths (log_{10} cfu g^{-1}) in *Salmonella* spp., *E. coli* O157:H7 and *Y. enterocolitica* at a range of storage temperatures and times:









Overall both ComBase Predictor and the Pathogen Modelling program (v. 7) are currently limited in their usefulness for assessing the growth/survival of pathogens in meat during ageing, since they are unable to predict the survival of pathogens below their minimum growth temperature. In many cases, the minimum temperature that they are able to predict growth at is relatively high. That said, ComBase Predictor indicates that *L. monocytogenes* and *Y. enterocolitica* may potentially proliferate on meat during ageing even at low temperatures. However, few published data appear to support this hypothesis.

8.14 Conclusions

The 2006 review of published literature on the effect of the age of meat before mincing on the microbiological quality of the mince concluded that there appeared to be no scientific justification for the time restrictions included in the current legislation and no evidence of an increased risk to human health from meat that has been stored hygienically and at appropriate temperatures for longer than the time limits specified in the legislation. Published studies since that review appear to further support and strengthen this conclusion.

9. Appendix 2: Survey questionnaire 1

As part of Objective 1, all project partners were sent the following questionnaire. The BMPA also sent this questionnaire to members.

AGE OF MEAT ON MINCING FSA PROJECT REQUIREMENTS

To meet the key aims of this project we will need to obtain as quickly as possible data on the temperature history of the your meat from immediately pre-chill to the point of mincing and through to distribution together with any correlating microbial data.

Please could you indicate on the table below what data you have readily available or possible to obtain with help? If you have readily available data, could you please also provide us with examples of any most recently gathered data (either in hard, or preferable soft (excel files for example) form)?

Company:			
Contact:			
	Readily Available	Possible to collect	Example included
Hot weight of carcass/sides pre-chill			
Time(s) spent in primary chill			
Conditions within primary chilling system(s) temperatures, velocities and RH if appropriate			
Temperature history of carcass/sides during primary chilling			
Description of processing stages from removal from primary chill to mincing			
Conditions in different stages of the process			
Details on any meat temperatures recorded during the process			
Details of any wrapping/packaging systems used during the process			
Details of any weight and weight losses measured during the process			
Details of any microbial sampling carried out during the process			
Data on microbial status of meat prior to mincing			
Data on microbial status of minced meat			
Conditions subsequent to packing of minced meat, i.e. storage, distribution…			
Temperature history of minced meat after mincing			

10. Appendix 3: Survey questionnaire 2

Following the first questionnaire a further more specific questionnaire was sent to project partners.

AGE OF MEAT ON MINCING FSA PROJECT REQUIREMENTS 2

We would like to thank project partners for their help so far. Following on from our initial questionnaire, we would like project partners to supply us with specific data on the following processing parameters. We understand that some partners will have supplied us with some of this information before, and apologise for asking again, but we still have quite a few gaps and particularly want to know what variations may be, as well mean temperatures and times.

Company:	
Contact:	

Species:	

Primary chilling parameters

	Chiller temperature (°C)	Chilling time (h)	Product temperature on exit (°C)
Max			
Min			
Mean			

Pre-mincing storage parameters

	Room temperature (°C)	Storage time as unwrapped carcass/primal (d)	Storage time as packaged primal (d)	Vacuum packed (Y/N)
Max				
Min				
Mean				

Mincing parameters

	Number of days from slaughter to mincing	Room temperature (°C)	Product temperature (°C)	Processing time (h)
Max				
Min				
Mean				

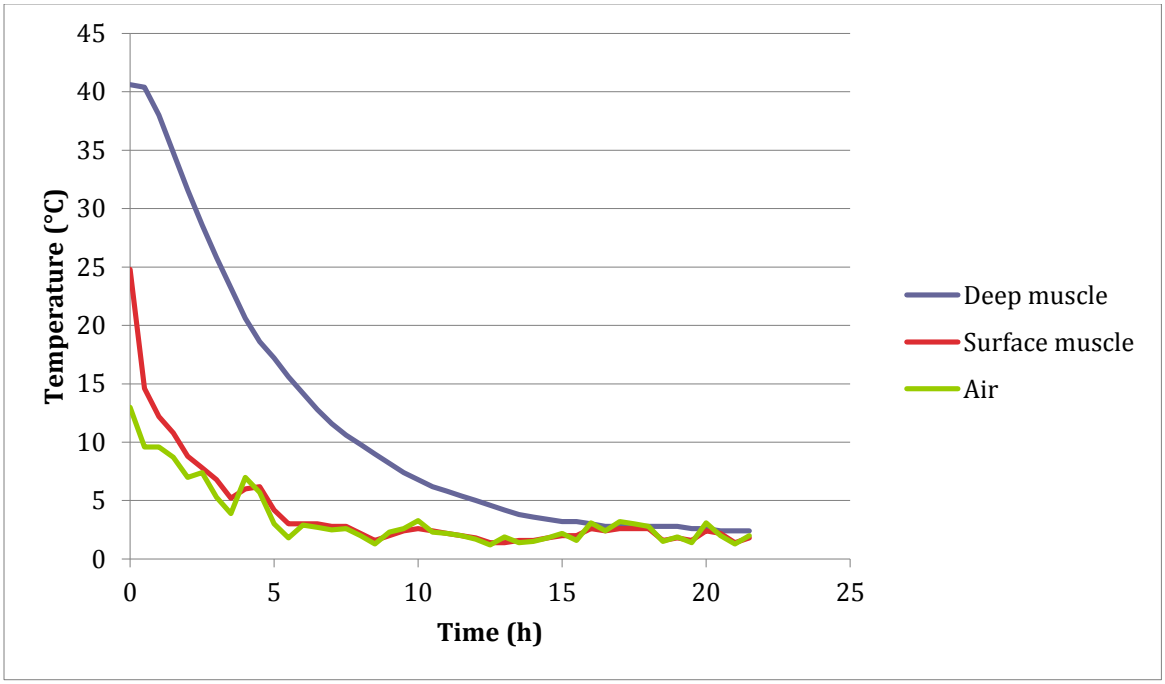
Storage and distribution parameters

	Storage (pre-distribution)			Distribution		
	Room temperature (°C)	Product temperature (°C)	Storage time (h)	Vehicle temperature (°C)	Product temperature (°C)	Storage time (h)
Max						
Min						
Mean						

Retail parameters

	Shelf-life (d)	Basis of evaluation, assumed consumer abuse conditions
Max		
Min		

If you have not already supplied us with one, we would like an example of a primary cooling curve for your process, such as that shown below, and a HACCP plan of your mincing process.



11. Appendix 4: Temperature and microbial testing protocol for meat destined to be minced: Red meat

Protocol

The protocol should be carried out with a minimum of five carcasses/pieces of meat/minced meat from the same batch of animals/meat/minced meat at least once per week. The aim is to ideally track and relate the microbial status of the initial carcass with the microbial status of final minced meat together with its time/temperature and handling history from primary chilling through to mincing. Where this is not possible carcass to minced meat from the same batch or day's production should be tracked.

- **Primary chilling:**
    - ***Select five carcasses from the top 10% weight percentile from a batch.***
    - ***Record the weight, slaughter time and time of loading into the chiller***
    - ***Take a whole carcass swab (see http://www.ukmeat.org/RedMeatCarcasses.htm for method) after final inspection to determine the initial microbial state of the carcass surface immediately prior to chilling. Determine the total aerobic plate count and count of Enterobacteriaceae as cfu per cm^2 (see http://www.ukmeat.org/LabTesting.htm for recommended methods).***
    - ***Hygienically insert a thin probe (approximately 3 mm diameter) under the surface tissue of each carcass so that the sensing tip is no more than 1 mm under the surface. Care must be taken when inserting the probes that contamination of the carcass surface does not occur. The recommended position to locate the surface probe/sensor for beef, lamb and pork is at the point end of the brisket/hand or on the outside of the neck (see*** Figure 90***).***
    - ***Record the temperature of the sensor at intervals of not more than 30 minutes throughout the chilling period.***
    - ***Record the time of entry and removal from the primary chiller.***
    - ***During the total chilling period, record any normally measured data on the air temperature in the chiller.***
- **Chilled storage/ageing/transportation:**
    - ***Record the time of loading into the storage rooms. If the carcass is broken down before ageing, record the time and temperature in the cutting room.***
    - ***Record the air temperature (in all cases) and relative humidity (if possible, in the case of dry ageing or unwrapped transportation or storage) at intervals of not more than 30 minutes throughout the storage period. During the total chilled storage period record any data on the air temperature normally measured***
    - ***Record the time of removal from the storage system.***
- **Cutting/trimming:**
    - ***The microbial state of the carcass/meat surface immediately prior to cutting/trimming should be determined by surface swab of 5 carcasses/sides,***

or take a surface excision 25g sample of 5 large pieces of meat immediately prior to cutting/trimming. Examine for total aerobic plate count and Enterobacteriaceae.

- ***Record the surface and deep meat temperature following sampling.***
- ***Record the time in, and temperature of, the cutting room.***

- **Mincing:**
  - ***Take a 25g surface excision sample of 5 large pieces of meat, or 5 x 25g samples of trim, to determine the microbial state of the meat immediately prior to mincing. Examine for total aerobic plate count and Enterobacteriaceae.***
  - ***Record the surface and deep meat temperature of the meat prior to mincing and following microbial sampling.***
  - ***Record the temperature of the mince immediately after mincing.***
  - ***Record the time in and temperature of the cutting room.***
  - ***Take 5 x 25g samples of minced meat immediately following mincing and test for total aerobic plate count,* Escherichia coli *and Enterobacteriaceae.***

Data delivery: ***An accompanying excel spreadsheet has been supplied with this protocol for the presentation of microbiological and temperature data. Please supply, where possible, actual temperature data rather than scanned temperature curves.***

The excel spreadshe*et al*so contains space for any additional data on other microorganisms you may also test for, this is not a specific requirement of this project, but would be appreciated if you have it.

Background and supporting information for the protocol

The microbial quality of meat destined for mincing and the mince produced will primarily be determined by the following factors:

1. The microbial status of the surface of the carcass prior to initial chilling.
2. The time/temperature history of the meat, especially its surface, during primary chilling, chilled storage and chilled transportation.
3. The surface water activity (surface dryness) of the meat from slaughter to mincing.
4. Change in microbial status of the meat surface during any handling operation from chilling through to mincing.

It is therefore important to be able to trace and relate the initial and final microbial status of the meat with its time/temperature and handling history from primary to chill to mincing. Following the protocol, described in this document, will achieve that aim.

Sampling will depend on the species and exact process performed at your plant, and whether the mincing operation is separate to the primary processing and slaughter operation. A general sampling scheme is shown in Figure 89.

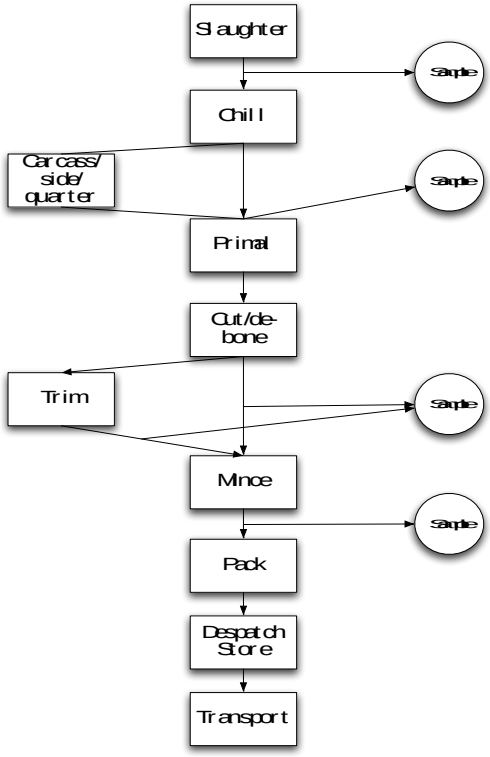


Figure 89. General flow diagram of process and sampling: red meat

The protocol should be carried out with a minimum of five carcasses/pieces of meat/minced meat from the same batch of animals/meat/minced meat at least once per week. The aim is to ideally track the meat from these carcasses from primary chilling through to mincing. Where this is not possible meat from the same batch or day's production should be tracked.

Primary chilling

If the surface of a carcass is cooled rapidly then bacterial growth will not occur and in some cases the number of bacteria will be slightly reduced. If the surface dries during chilling this effect is enhanced.

The rate of cooling of a meat carcass will primarily be controlled by the following factors:

1. The weight/size of the carcass.
2. The amount of fat cover.
3. The air temperature over the surface of the carcass throughout the chilling operation.
4. The air velocity over the surface of the carcass throughout the chilling operation.

In a commercial carcass chilling system the air temperature and air velocity over the surface of the carcass will vary with:

- Position of the carcass within the chamber.
- The number of carcasses within the chill and the loading pattern.
- Space between carcasses.
- Time after loading.
- Position and opening of chill room door(s).

The slowest cooling surface situation will occur on a large carcass with a good fat cover, which is in contact with surrounding carcasses, in an area of the chill room with little air movement. An experienced operator will have knowledge of the slowest cooling areas within a chill room. Carcasses positioned in these areas should be used in the protocol.

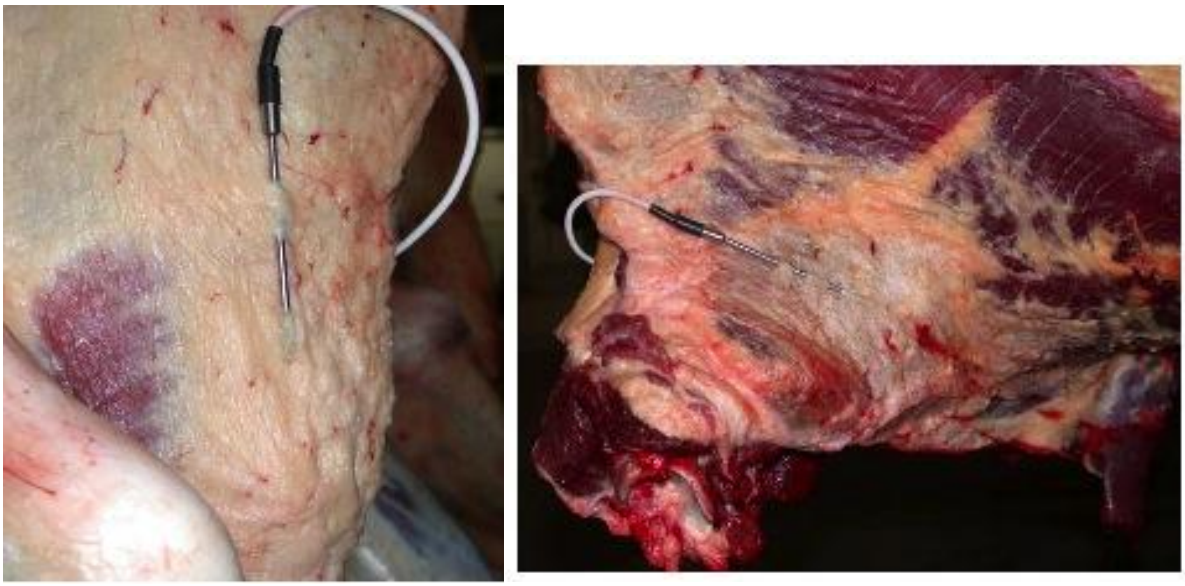


Figure 90. Recommended placement of the temperature probe on the (1) brisket of a beef side (right), (2) neck (left) of a beef side

Chilled storage/ageing/transportation

Meat is stored/aged/transported in one of two forms:

1. Bone in (Dry aged) - Hung on rails as a whole carcass, side or quarter.
2. Bone out (Wet aged) – Processed into primals, vacuum packed and stored on racks.

In form 1 the relative humidity and movement of the air surrounding the meat is important and needs to be monitored. In the wet situation, only the temperature of the air is important.

Microbiological testing

Wherever possible we have tried to utilise sampling methods and techniques that are already undertaken by meat plants.

- Red meat carcasses are tested weekly for total aerobic plate count and Enterobacteriaceae as part of the current EU microbiological criteria for meat plants (http://www.ukmeat.org/pdf/MicroCriteria.pdf). Results from this testing can be used providing that some meat from the carcasses sampled or the carcasses from the same batch of animals are destined to mince.
- ***25g samples of deboned meat should be sampled prior to mincing (surface for large pieces and on a weight basis for smaller pieces).***
- Minced meat is tested for total aerobic plate count, *Escherichia coli* and Salmonella as part of the current EU microbiological criteria for meat plants. Details of microbiological testing can be found on the FSA supported site: www.ukmeat.org. Results from this testing can be used ideally when the samples have been taken from mince produced from the carcasses/meat sampled. ***The samples should in addition be tested for Enterobacteriaceae to enable a correlation with the carcass testing results.***

Testing should be according to the laboratory protocols specified by the most recent version of ISO 4833 (total aerobic plate counts), ISO 21528-2 (Enterobacteriaceae), ISO 16649 (*E. coli*). Original copies of these standardised protocols are available for purchase from the British Standards website.

For the convenience of plant operators and to ensure that they are able to instruct their laboratories how to correctly process carcass swabs and other types of meat samples, the FSA has prepared a series of standard sample submission forms and Standard Operating Procedures (SOPs). These forms and SOPs are available in PDF format for direct download and are available at http://www.ukmeat.org/LabTesting.htm.

Data on any other microorganisms you may also test meat carcasses, meat prior to mincing and mince for together with as much information on the sample history is also greatly appreciated but is not a requirement of this project

12. Appendix 5: Temperature and microbial testing protocol for meat destined to be minced: Turkey

Protocol

The protocol should be carried out with a minimum of five carcasses/pieces of meat/minced meat from the same batch of animals/meat/minced meat at least once per week. The aim is to ideally track and relate the microbial status of the initial carcass with the microbial status of final minced meat together with its time/temperature and handling history from primary chilling through to mincing. Where this is not possible carcass to minced meat from the same batch or day's production should be tracked.

- **Primary chilling:**
    - ***Select five carcasses from the top 10% weight percentile from a batch.***
    - ***Record the weight, slaughter time and time of loading into the chiller***
    - ***Take a whole carcass swab (see http://www.ukmeat.org/RedMeatCarcasses.htm for method) after final inspection to determine the initial microbial state of the carcass surface immediately prior to chilling. Determine the total aerobic plate count and count of Enterobacteriaceae as cfu per cm^2 (see http://www.ukmeat.org/LabTesting.htm for recommended methods).***
    - ***Hygienically insert a thin probe (approximately 3 mm diameter) under the surface tissue of each carcass so that the sensing tip is no more than 1 mm under the surface. Care must be taken when inserting the probes that contamination of the carcass surface does not occur. The recommended position to locate the surface sensor depends on how the turkey carcasses are hung and the chilling method. With individually hung carcasses, the recommended probe position is at the point where the wing and the breast meet. Where carcasses are hung on racks (see*** Figure 90***) a between carcass temperature is recommended.***
    - ***Record the temperature of the sensor at intervals of not more than 30 minutes throughout the chilling period.***
    - ***Record the time of entry and removal from the primary chiller.***
    - ***During the total chilling period, record any normally measured data on the operating temperatures in the chiller.***
- **Chilled storage/maturation:**
    - ***Record the time of loading into the storage rooms. If the carcass is broken down before maturation, record the time and temperature in the cutting room.***
    - ***Record the air temperature (in all cases) and relative humidity (if possible) at intervals of not more than 30 minutes throughout the storage period. During the total chilled storage period record any data on the air temperature normally measured***
    - ***Record the time of removal from the storage system.***

- **Cutting/trimming:**
    - ***The microbial state of the carcass/meat surface immediately prior to cutting/trimming should be determined by surface swab of 5 carcasses/sides, or take a surface excision 25g sample of 5 large pieces of meat immediately prior to cutting/trimming. Examine for total aerobic plate count and Enterobacteriaceae.***
    - ***Record the surface and deep meat temperature following sampling.***
    - ***Record the time in, and temperature of, the cutting room.***
- **Mincing:**
    - ***Take a 25g surface excision sample of 5 large pieces of meat, or 5 x 25g samples of trim, to determine the microbial state of the meat immediately prior to mincing. Examine for total aerobic plate count and Enterobacteriaceae.***
    - ***Record the surface and deep meat temperature of the meat prior to mincing and following microbial sampling.***
    - ***Record the temperature of the mince immediately after mincing.***
    - ***Record the time in, and temperature of, the cutting room.***
    - ***Take 5 x 25g samples of minced meat immediately following mincing and test for total aerobic plate count,* Escherichia coli *and Enterobacteriaceae.***

Data delivery: ***An accompanying excel spreadsheet has been supplied with this protocol for the presentation of microbiological and temperature data. Please supply, where possible, actual temperature data rather than scanned temperature curves.***

The excel spreadshe*et al*so contains space for any additional data on other microorganisms you may also test for, this is not a specific requirement of this project, but would be appreciated if you have it.

Background and supporting information for the protocol

The microbial quality of meat destined for mincing and the mince produced will primarily be determined by the following factors:

1. The microbial status of the surface of the carcass prior to initial chilling.
2. The time/temperature history of the meat, especially its surface, during primary chilling, chilled storage and chilled transportation.
3. The surface water activity (surface dryness) of the meat from slaughter to mincing.
4. Change in microbial status of the meat surface during any handling operation from chilling through to mincing.

It is therefore important to be able to trace and relate the initial and final microbial status of the meat with its time/temperature and handling history from primary to chill to mincing. Following the protocol, described in this document, will achieve that aim.

Sampling will depend on the species and exact process performed at your plant, and whether the mincing operation is separate to the primary processing and slaughter operation. A general sampling scheme is shown in Figure 89.

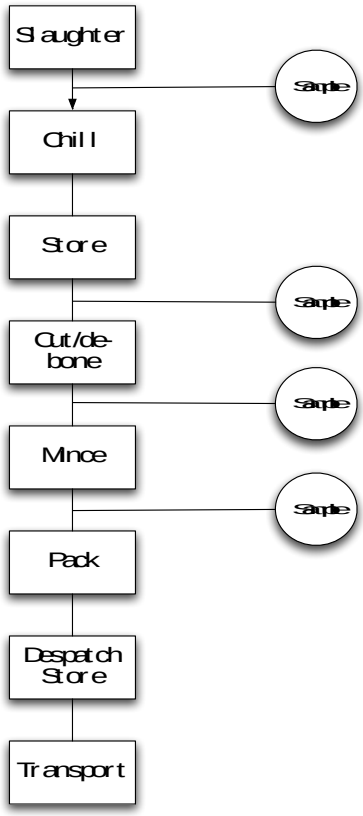


Figure 91. General flow diagram of process and sampling: turkey

The protocol should be carried out with a minimum of five carcasses/pieces of meat/minced meat from the same batch of animals/meat/minced meat at least once per week. The aim is to ideally track the meat from these carcasses from primary chilling through to mincing. Where this is not possible meat from the same batch or day's production should be tracked.

Primary chilling

If the surface of a carcass is cooled rapidly then bacterial growth will not occur and in some cases the number of bacteria will be slightly reduced. If the surface dries during chilling this effect is enhanced.

The rate of cooling of a meat carcass will primarily be controlled by the following factors:

1. The weight/size of the carcass.
2. The air temperature over the surface of the carcass throughout the chilling operation.
3. The air velocity over the surface of the carcass throughout the chilling operation.

In a commercial carcass chilling system the air temperature and air velocity over the surface of the carcass will vary with:

- Position of the carcass within the chiller.
- The number of carcasses within the chiller and the loading pattern.
- Space between carcasses.

- Time after loading.
- Position and opening of chiller door(s).

The slowest cooling surface situation will occur on a large carcass with a good fat cover, which is in contact with surrounding carcasses, in an area of the chill room with little air movement. An experienced operator will have knowledge of the slowest cooling areas within a chill room. Carcasses positioned in these areas should be used in the protocol.

Figure 92. Turkey rack for primary chilling

Microbiological testing

Wherever possible we have tried to utilise sampling methods and techniques that are already undertaken by meat plants.

- Data on total aerobic plate counts and Enterobacteriaceae which is not currently required under the microbiological criteria for poultry carcasses **is required for this project.** ***A side sponge technique on the carcass surface using the methodology for beef and lamb should be undertaken (http://www.ukmeat.org/RedMeatCarcasses.htm).***
- ***25g samples of deboned meat should be sampled prior to mincing (surface for large pieces and on a weight basis for smaller pieces).***
- ***Where samples are taken on a weight basis 25g samples should be taken for Salmonella not 10g as specified in the regulation. Samples for ACC and Enterobacteriaceae should also be 25g.***
- Minced meat is tested for total aerobic plate counts, *Escherichia coli* and Salmonella as part of the current EU microbiological criteria for meat plants. Details of microbiological testing can be found on the FSA supported site: www.ukmeat.org. Results from this testing can be used ideally when the samples have been taken from mince produced from the carcasses/meat sampled. ***The samples should in addition be tested for Enterobacteriaceae to enable a correlation with the carcass testing results.***

Testing should be according to the laboratory protocols specified by the most recent version of ISO 4833 (total aerobic plate counts), ISO 21528-2 (Enterobacteriaceae), ISO 16649

(*E. coli*). Original copies of these standardised protocols are available for purchase from the British Standards website.

For the convenience of plant operators and to ensure that they are able to instruct their laboratories how to correctly process carcass swabs and other types of meat samples, the FSA has prepared a series of standard sample submission forms and Standard Operating Procedures (SOPs). These forms and SOPs are available in PDF format for direct download and are available at http://www.ukmeat.org/LabTesting.htm.

Data on any other microorganisms you may also test meat carcasses, meat prior to mincing and mince for together with as much information on the sample history is also greatly appreciated but is not a requirement of this project.

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***References in bold were not used in the 2006 review.**

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