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FINAL REPORT

Project Armis No.4885

Commercial Systems for the Ultra-Rapid Chilling of Lamb

The National Food Centre

RESEARCH & TRAINING FOR THE FOOD INDUSTRY

RESEARCH REPORT NO 48

Contents

COMMERCIAL SYSTEMS FOR ULTRA-RAPID CHILLING OF LAMB

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SUMMARY

The overall objective was to devise a rapid chilling system for the Irish lamb processing industry.

The objective of the first trial was to assess the effect of ultra-rapid chilling in air at - 4°C, -10°C and -20°C and subsequent ageing on the appearance and tenderness of lamb carcasses.

Chilling at -20°C gave less evaporative weight loss than chilling at other sub-zero temperatures and conventional chilling at +4°C. This was achieved without causing adverse effects on carcass quality or meat tenderness. Ageing improved the tenderness of ultra-rapidly chilled lamb and had little effect on the visual appearance of the carcasses.

The objective of the next trial was to investigate the effect of carcass splitting, which produces faster chilling rates and reduces skeletal constraint of muscles, on the tenderness of rapidly and conventionally chilled lamb.

No difference in tenderness was found between split and unsplit carcasses that were conventionally chilled. Splitting ultra-rapidly chilled lamb carcasses led to an increase in tenderness when compared to unsplit ultra-rapidly chilled carcasses. It was more likely that the increased tenderness observed in split ultra-rapidly chilled carcasses was due to a faster rate of pH fall rather than the reduction in skeletal constraint.

The next task was to compare the effects of immersion chilling and conventional air chilling on meat tenderness and evaporative weight loss in lamb carcasses. Much faster rates of chilling may be achieved by immersion in liquids and the effects of these faster chilling rates on lamb carcass attributes were examined.

Immersion chilling gave less weight loss than air chilling at the same temperature. For both air and immersion chilling, evaporative weight loss was reduced at lower temperatures. In general, immersion chilling had no effect on tenderness compared to air chilling at any chilling temperature. The main tenderising effect of ageing took place between 1 and 5 days post-mortem but longer ageing times (up to 9 days) may be required for lamb carcasses rapidly

chilled in air or by immersion, to reduce the incidence of tough meat. This may have consequences on subsequent shelf life as well as storage costs and may not be readily accepted by the meat industry.

The next task was to assess the level of interest in industry. This required costings of the process and a survey of several lamb processors focusing on their perceptions of rapid chilling in general, its advantages and disadvantages, and the implications of adopting the new system.

The payback period for the cost of installing the ultra-rapid chilling system in a lamb factory was estimated at between 714 and 917 days depending on factory throughput, lamb prices and optional extras.

In general, the industry will not adopt the proposed system in the short to medium term. While it is seen to have a number of advantages, capital cost and higher operating costs may be obstacles. The complexity of the system and possible effect on meat quality are not deterrents. The industry is modifying and fine-tuning its existing chilling systems with low levels of capital investment and thus welcomes any research in this area.

The final objective was to introduce the ultra-rapid chilling process to industry *via* a factory trial. Lambs were ultra-rapidly chilled and then exported to France for assessment.

French buyers had no reservations about accepting ultra-rapidly chilled lambs as the process did not adversely affect the criteria on which they buy lambs.

INTRODUCTION

A rapid chilling process for lambs was developed at The National Food Centre (Sheridan *et al.*, 1998; McGeehin *et al.*, 1999). This ultra-rapid chilling process utilises temperatures of -20°C and reduces carcass chilling time to 7 hours allowing same day dispatch to continental markets. It also reduces the rate of evaporative weight loss from lamb carcasses by up to 1% compared to conventional lamb chilling. The process needs evaluation as to its commercial viability. The effect of the process on the carcass appearance is important because any adverse effect would result in a downgrading of the carcasses and consequently a lower market value. Finally, the financial considerations of taking up this new technology need to be calculated. This is required to allow industry to assess the process properly and give an informed opinion of the feasibility of ultra-rapid chilling.

CARCASS APPEARANCE

The aim of this work was to assess the effect of different air chilling regimes on the appearance and evaporative weight loss of lamb carcasses (weight range 15.4 - 24.5 kg). Four chilling regimes were used 1) -20°C for 3.5h followed by +4°C for 20.5h, 2) -10°C for 3.5h followed by +4°C for 20.5h, 3) - 4°C for 4h followed by +1°C for 20h and 4) +4°C for 24h. A trained laboratory panel judged carcass appearance for flank colour, fat colour, wetness, veining and overall acceptability. The results are shown in Table 1.

The wetness of carcasses was similar for all chilling regimes throughout the ageing period. The conditions in which carcasses are kept after rapid chilling have a major impact on the appearance and weight loss of the carcasses. An equilibrium phase after rapid chilling is recommended (Bowater, 1986; McGeehin *et al.*, 1999) during which the carcasses are held at +4°C with a high relative humidity to promote condensation onto the cold carcasses and thus reduce overall weight loss. However, if relative humidity is too high, condensation onto the carcasses can be excessive, causing the carcasses to appear wet and undesirable (Cutting, 1973). Excessive condensation was not a problem in this study, as carcasses chilled at - 4°C, -10°C or -20°C were not

Table 1: Visual appraisal by a laboratory judging panel of lamb carcasses from four air chilling regimes at 2, 6 and 9 days after slaughter.

Chilling regime	+4°C	-20°C	-10°C	-4°C	s.e.d.[f]	d.f.[g]
Flank colour[a]						
Day 2	2.7^{x}	2.6^{x}	2.3^{x}	3.0^{x}	0.5	50
Day 6	2.6^{x}	2.6^{x}	2.5^{x}	2.9^{x}	0.5	32
Day 9	3.0^{x}	2.9^{x}	2.3^{x}	3.1^{x}	0.4	44
Fat colour[b]						
Day 2	3.4^{x}	3.4^{x}	3.6^{x}	3.5^{x}	0.4	50
Day 6	3.3^{x}	3.2^{x}	3.3^{x}	3.4^{x}	0.3	32
Day 9	3.4^{x}	3.4^{x}	3.2^{x}	3.3^{x}	0.3	44
Wetness[c]						
Day 2	2.2^{x}	2.7^{x}	2.7^{x}	2.1^{x}	0.4	50
Day 6	2.0^{xy}	2.4^{y}	2.5^{y}	1.6^{x}	0.3	32
Day 9	2.2^{xy}	2.6^{y}	2.6^{y}	2.0^{x}	0.3	44
Vein colour[d]						
Day 2	3.8^{x}	3.1^{y}	3.8^{x}	3.6^{xy}	0.3	50
Day 6	3.5^{x}	3.3^{x}	3.6^{x}	3.3^{x}	0.4	32
Day 9	3.7^{x}	3.7^{x}	3.4^{x}	3.1^{x}	0.4	44
Overall acceptability[e]						
Day 2	3.6^{x}	3.7^{x}	3.6^{x}	4.1^{x}	0.3	50
Day 6	3.8^{x}	3.4^{x}	3.6^{x}	4.1^{x}	0.3	32
Day 9	3.7^{x}	3.6^{x}	3.4^{x}	3.6^{x}	0.4	44

$^{x\text{-}y}$ Treatments are different ($P<0.05$) if they have no common superscript letter reading across (e.g. X and XY are not different)

[a] 5 point scale (1= pale pink; 5= very red)

[b] 5 point scale (1= yellow; 5= white)

[c] 5 point scale (1= very dry; 5= very wet)

[d] 5 point scale (1= very dark; 5= slightly red)

[e] 5 point scale (1= very poor; 5= very good)

[f] standard error of the difference

[g] degrees of freedom

significantly wetter than the conventionally chilled carcasses at any time after slaughter. No difference was found in flank or fat colour, or overall acceptability between any of the regimes during ageing and although vein colour was found to be slightly darker after 2 days in the –20°C chilled carcasses, this was not evident at 6 or 9 days. These findings suggest that rapidly chilled lamb carcasses would not be discriminated against in an open market based on their visual appearance.

Evaporative weight losses for the four air chilling regimes are shown in Table 2. Carcasses chilled at -20°C had significantly lower weight losses (1.32%) than all other regimes ($P<0.05$). This is similar to the findings of Sheridan *et al.* (1998) who found evaporative weight losses of 1.50% for rapidly chilled lamb carcasses compared to 1.89% for conventionally chilled lamb. Any reduction in evaporative weight loss is positive, as all carcasses are sold on a weight basis. Chilling at -10°C or -4°C did not significantly lower the evaporative weight loss of the carcasses, compared to conventional chilling.

Table 2: Evaporative weight loss for lamb carcasses from four air chilling regimes.

Regime	24 hr weight loss (%)
+4°C	1.86[y]
-4°C	1.80[y]
-10°C	1.64[y]
-20°C	1.32[x]
s.e.d.[a]	0.12
d.f.[b]	67

[x-y] Treatments are different ($P<0.05$) if they have no common superscript letter

[a] standard error of the difference

[b] degrees of freedom

CHILLING RATES

Immersion chilling

Immersion chilling was used in an attempt to achieve increased rates of chilling in whole carcasses. Immersion chilling has the advantage of high surface heat transfer coefficients giving short chilling times and reducing evaporative weight losses (Frazerhurst *et al.*, 1972; Kesava-Rao *et al.*, 1992). Polyproplyene glycol (50% solution) was a suitable refrigerant because, although it is relatively viscous at low temperatures, it is non toxic, non corrosive, colourless, odourless and nearly tasteless (Frazerhurst *et al.*, 1972). Immersion chilling has been successfully applied to the processing of poultry, with the majority of birds in the UK and USA being chilled this way (Brown *et al.*, 1988). The objective was to compare the effects of immersion chilling and conventional air chilling on meat tenderness and evaporative weight loss in lamb carcasses.

Two modes of chilling (air and immersion) and four chilling temperatures were examined (-14°C, -8°C, -2°C and +4°C). Very little difference was found in deep round temperatures after 2 hours of chilling between all the chilling regimes. The loin temperatures, however, did differ significantly because this muscle is nearer the surface of the carcass. Chilling at -14°C in glycol gave the fastest rate of temperature fall and these carcasses had reached sub-zero temperatures within 2 hours. As expected, chilling at +4°C in air gave the slowest rate of chilling.

Much faster rates of chilling were expected from the immersion chilling regimes. However, chilling in glycol had relatively little effect on carcass temperature compared to air chilling. The reason for this was because the carcasses chilled in glycol were wrapped in a plastic covering to avoid contact with the glycol. Meat chilled directly in glycol cannot be called fresh meat. This plastic covering, along with the air that it trapped, acted as an insulator against heat loss and therefore the carcasses did not cool as quickly as expected.

Mean evaporative weight loss values for the different chilling regimes are shown in Figure 1. Immersion chilling led to significant reductions in evaporative weight loss ($P < 0.001$) compared to air chilling at the same

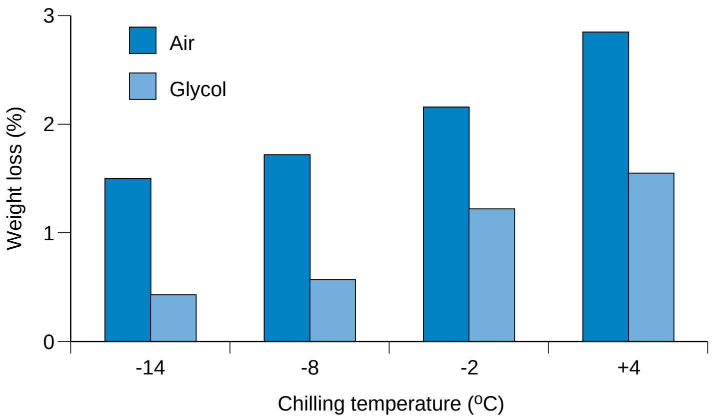

Figure 1: Evaporative weight loss values for lamb carcasses chilled in air or by immersion in glycol, measured 24 hours after slaughter.

temperature. Average savings in weight loss of approximately 1% were made when carcasses were chilled in glycol rather than in air. This reduction in weight loss with immersion chilling was again a consequence of wrapping the carcasses in plastic to avoid contact with the glycol, thus minimising contact with air and preventing evaporation from taking place. For both air and immersion chilling, evaporative weight losses were reduced as chilling temperatures decreased.

Mean shear force values after ageing for 1, 5 and 9 days are given in Table 3. Immersion chilling had no effect on shear force tenderness compared to air

Table 3: Tenderness values (Newtons) for lamb carcasses chilled in air or by immersion in glycol at 1, 5 and 9 days after slaughter.

Regime		Day 1	Day 5	Day 9
-14°C	air	$^{a}93.8^{x}$	$^{b}53.2^{xy}$	$^{b}44.6^{xy}$
	glycol	$^{a}69.2^{y}$	$^{b}36.8^{y}$	$^{b}34.3^{y}$
-8°C	air	$^{a}68.4^{y}$	$^{ab}53.4^{xy}$	$^{b}40.0^{xy}$
	glycol	$^{a}71.5^{y}$	$^{b}41.1^{xy}$	$^{b}32.9^{y}$
-2°C	air	$^{a}66.3^{y}$	$^{a}44.8^{xy}$	$^{a}45.0^{xy}$
	glycol	$^{a}73.8^{y}$	$^{b}56.2^{x}$	$^{b}55.3^{x}$
+4°C	air	$^{a}82.2^{xy}$	$^{b}49.7^{xy}$	$^{b}36.3^{y}$
	glycol	$^{a}82.0^{xy}$	$^{b}49.6^{xy}$	$^{c}37.4^{y}$
s.e.d.[c]		9.7	9.5	8.1
d.f.[d]		38	38	38

$^{x-y}$ Regime effect. Means in the same column with no common superscript letter are different ($P<0.05$).
$^{a-b}$ Time effect. Means in the same row with no common superscript letter are different ($P<0.05$).
[c] standard error of the difference
[d] degrees of freedom

chilling except for carcasses chilled at -14°C. Carcasses chilled at -14°C in air were significantly tougher (93.8 N) at 1 day post-mortem than carcasses chilled at the same temperature in glycol (69.2 N) but this difference was not significant after 5 days ageing. By 9 days post-mortem, all chilling treatments produced meat as tender as that from the conventionally chilled carcasses (+4°C air) with the exception of the carcasses chilled at -2°C in glycol. Meat with a shear force score above 45 N is deemed to be slightly tough (Shackleford *et al*, 1991).

Lamb is normally aged for 5-6 days but in this trial the carcasses were aged for 9 days. Ageing had a positive effect on tenderness in all regimes. The main tenderising effect of ageing took place between day 1 and day 5 when the shear force value (averaged over all 8 treatments) dropped from 76 N to 48 N. A further reduction to 41 N was observed with ageing to 9 days post-mortem.

In general, immersion chilling had no effect on tenderness compared to air chilling at any of the chilling temperatures at any time post-mortem. The main tenderising effect of ageing took place in 5 days but longer ageing times (up to 9 days) may be required for some lamb carcasses to reduce the incidence of tough meat. However, this may have consequences on subsequent shelf life. There are also considerations of capital and storage costs which may not be readily accepted by the meat industry.

Effect of carcass splitting before chilling

The effect of splitting carcasses longitudinally was examined. Whole (unsplit) and split carcasses were ultra-rapidly chilled (-20°C for 3.5 hours followed by chilling at +4°C for 20.5 hours) and conventionally chilled (+4°C for 24 hours), giving a total of 4 treatments. Forty lambs were used. Tenderness (N) was measured mechanically after 5 days of ageing.

Carcass splitting reduces skeletal restraint and gives faster chilling rates because it eliminates the carcass cavity and consequently both sides of the split carcass are in contact with the chilled air and therefore cool more quickly. Carcass splitting, to remove the spinal column, may become an EU requirement for lamb due to growing concern about BSE-related diseases.

Many studies have been undertaken to compare the tenderness of intact carcasses with that of excised muscles. Few, however, have looked at the effect on tenderness of carcass splitting, which also reduces skeletal constraint.

Mean shear force values (Newtons) for the different chilling regimes are given in Table 4. No difference in tenderness was found between split and unsplit carcasses that were conventionally chilled. Splitting ultra-rapidly chilled lamb carcasses led to an increase in tenderness when compared to unsplit rapidly chilled carcasses. The tenderness of ultra-rapidly chilled meat is linked to the rate of pH fall (McGeehin, 1998). If pH is high in the early hours post-mortem, cold shortening can occur, causing the meat to toughen. In this study, the rapidly chilled unsplit carcasses had a slow rate of pH fall (mean 4 hour pH was 6.44). This slower rate of pH fall, coupled with the low temperatures used in the ultra-rapid chilling regime, caused the meat to toughen. The rapidly chilled split carcasses, however, produced tender meat by 5 days post-mortem. These carcasses had the fastest rate of temperature

Table 4: Tenderness values (Newtons) for loins of lamb carcasses after ageing for 1 and 5 days. Carcasses were either split or unsplit and chilled in air ultra-rapidly or conventionally.

Regime	n	Day 1	Day 5	pH at 4 h
Split +4°C	10	$^{a}68.9^{xy}$	$^{b}45.8^{xy}$	6.61
Unsplit +4°C	10	$^{a}71.0^{xy}$	$^{b}50.1^{xy}$	6.57
Split -20°C	10	$^{a}58.3^{x}$	$^{b}41.5^{x}$	6.21
Unsplit -20°C	10	$^{a}88.6^{y}$	$^{b}57.7^{y}$	6.44
s.e.d.[c]		9.7	7.7	0.09
d.f.[d]		36	36	36

$^{x\,y}$ Regime effect: means in the same column with no common superscript letter are different (P<0.05).
$^{a\,b}$ Time effect: means in the same row with no common superscript letter are different (P<0.05).
[c] standard error of the difference
[d] degrees of freedom

fall but also had a fast rate of pH fall (mean 4 hour pH was 6.21), so the possibility of cold shortening was avoided. Since carcass splitting had no effect on tenderness in conventional chilling, it is likely that the more rapid rate of pH fall was responsible for the increased tenderness observed in the rapidly chilled split carcasses; there was no evidence of toughening due to any reduction in skeletal constraint.

A large variation in tenderness was observed in this experiment also, with 22 of the 40 carcasses producing tough meat after 5 days ageing. Chilling rate was not a cause of this variation as equal numbers of tough carcasses were observed in both the ultra-rapid chilling and the conventional chilling regimes. Similar findings were observed by McGeehin (1998), who concluded that the occurrence of tough carcasses, under conventional and ultra-rapid chilling conditions, was due to natural variation that could not be explained by temperature or pH. There is also increasing evidence that tenderness is hereditary and recent studies have identified genes in meat animals that influence tenderness (Taylor and Davis, 1998).

BIOCHEMISTRY

Storage and subsequent ageing of meat at refrigerated temperatures results in a significant improvement in tenderness (Koohmaraie *et al*, 1987; Koohmaraie, 1988). The majority, if not all, of this improvement is the result of degradation of myofibrillar proteins by a group of enzymes called the calpains (Goll *et al.*, 1992; Koohmaraie, 1988, 1992; Taylor *et al.*, 1995). We examined the effect of ultra-rapid chilling (-20°C) compared to conventional chilling (+4°C) on the calpain system in lamb during 5 days ageing. The aim was to explain why ultra-rapid chilling produces meat as tender as that from conventional chilling. Mean shear force values are shown in Table 5. No significant difference in tenderness was observed between the two chilling regimes at 1 or 5 days post-mortem. For both chilling regimes, there was a significant decrease in shear force between 1 day and 5 days post-mortem.

Figures 2 and 3 show the mean activities for the different types of calpains (μ- and m-calpain). No significant difference was found between the two chilling

Table 5: Tenderness values (Newtons) in loins of intact lamb carcasses that were chilled in air either conventionally or ultra-rapidly and aged for 5 days.

Regime	n	Day 1	Day 5
+4°C	18	$^{a}64.8^{x}$	$^{b}38.1^{x}$
-20°C	18	$^{a}77.3^{x}$	$^{b}40.4^{x}$
s.e.d.[c]		7.5	3.3
d.f.[d]		29	23

[x y] Treatment effect: means in the same column with no common superscript letter are different (P<0.05).

[a b] Time effect: means in the same row with no common superscript letter are different (P<0.05).

[c] standard error of the difference

[d] degrees of freedom

n: number of samples

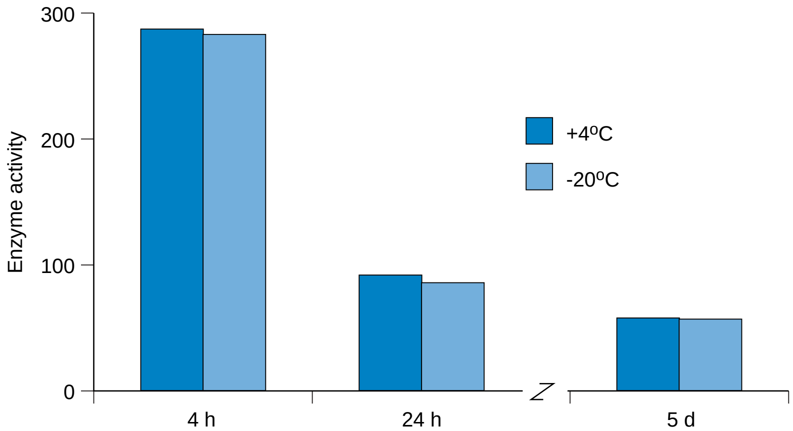

Figure 2: Mean μ-calpain activity (units.kg^{-1} muscle) in loin muscles from lamb carcasses that were ultra-rapidly or conventionally chilled and subsequently aged for 5 days at 4ºC.

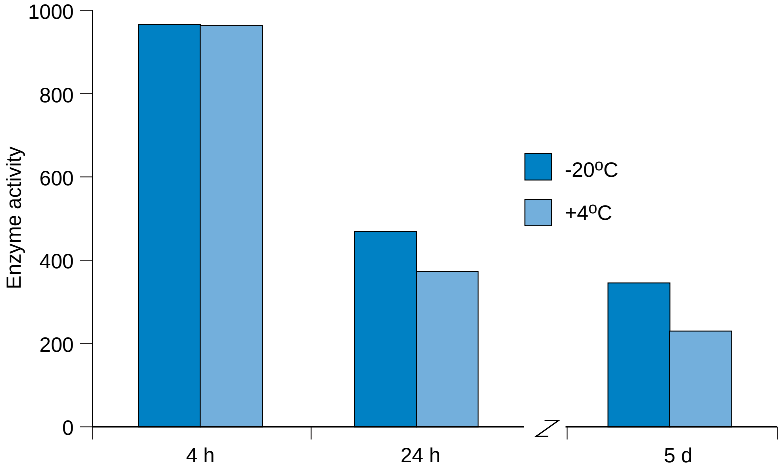

Figure 3: Mean m-calpain activity (units.kg^{-1} muscle) in loin muscles from lamb carcasses that were ultra-rapidly or conventionally chilled and subsequently aged for 5 days at 4ºC.

regimes in µ-calpain activity at any stage post-mortem. m-Calpain activity was the same in both regimes at 4 and 24 hours post-mortem but ultra-rapid chilling resulted in significantly higher m-calpain activity at 5 days post-mortem ($P<0.05$). The activities of µ- and m-calpain decreased with ageing in both chilling regimes.

Extensive research on the relationship between the calpains and meat tenderisation suggests that µ-calpain rather than m-calpain is mainly responsible for tenderisation (Marsh *et al.*, 1981; Vidalenc *et al.*, 1983; Ducastaing *et al.*, 1985; Koohmaraie *et al.*, 1986). The present study showed no significant difference in µ-calpain between the two chilling regimes at any stage post-mortem. This was not surprising as no tenderness differences were found between the two chilling regimes so differences in enzyme activity would not be expected. The study was unable to elucidate the role of the calpain system in the tenderisation of ultra-rapidly chilled lamb. More work is needed to investigate the degradation of myofibrillar proteins in meat under conditions which produce differences in tenderness.

COSTINGS: NET COST OF CONVENTIONAL AND ULTRA-RAPID CHILLING

The net cost was evaluated using the payback period[1] approach. The primary costs and benefits addressed were:

1. capital costs of the equipment. The higher capacity requirements of the refrigeration equipment (primarily compressors) and a humidifier result in increased capital costs. Optional extras include electrical stimulation equipment and a pH meter.

2. capital costs of constructing a chill unit. The ultra-rapid chilling regime requires temperatures that are lower than those currently used in lamb factories and so will require the construction of a new chill to cold store specifications. In addition, space will be required for the equilibration period. To compare like with like, the cost of building a new chill to accommodate the conventional system also needs to be calculated. Finally, the costs of an automatic line for carcasses in the ultra-rapid chill need to be included.

3. energy costs. Faster chilling will increase energy costs. In addition, steam humidification will result in additional energy costs.

4. evaporative weight loss costs. Fast chilling can reduce weight loss. This is the main gain associated with the process.

Costs and benefits were calculated for throughputs of 5,000, 10,000 and 20,000 lambs per week. These throughputs represent the majority of lamb slaughtering in Ireland.

The value of the reduction in weight loss was calculated using two different scenarios. The first is based on the actual average price for lambs for the three year period from 1996 to 1998 and the second is based on the projected[2] average price for lambs for the three year period 1999 to 2001. A 20kg carcass is assumed.

[1] The payback period is the length of time it takes for the costs of the system to be recouped from the benefits accrued as a result of adopting the system.

[2] These prices are projected by the FAPRI-Ireland partnership and are expected to fall.

It must be noted that these costs and benefits are approximations only. The actual cost for an individual factory will be influenced by many factors including level of throughput and the condition and capacity of existing facilities.

Table 6 provides a summary of the payback period for various scenarios. It shows that the payback period is influenced by the level of throughput, lamb prices and the extent to which factories adopt recommended optional extras to the system, e.g. low voltage electrical stimulation (ES). The payback period is shorter with higher lamb prices, higher levels of throughput and without the optional extras.

Table 6: Summary of payback period for the cost of installing the ultra-rapid lamb chilling system.

	No. of lambs slaughtered per week		
Scenario	5,000	10,000	20,000
With ES, 1996-1998 average lamb prices	812 days	748 days	717 days
Without ES, 1996-1998 average lamb prices	801 days	742 days	714 days
With ES, 1999-2001 projected lamb prices[1]	917 days	843 days	809 days
Without ES, 1999-2001 projected lamb prices[1]	904 days	837 days	805 days

[1] FAPRI-Ireland projections

ES: electrical stimulation

SURVEY OF INDUSTRY: ATTITUDES TO AND PERCEPTIONS OF ULTRA-RAPID CHILLING

A survey of senior management in 5 export-licensed meat processing companies was conducted to ascertain their attitudes to and perceptions of the NFC ultra-rapid chilling process for lambs. This was undertaken to identify potential obstacles to widespread adoption of the recommended system.

The industry saw the reduction in weight loss figures as advantageous but was concerned that they would have to pass all on of these savings to farmers. However, the interviewers felt that the industry underestimated the potential cost savings that could accrue if weight loss figures were reduced.

It was acknowledged that the proposed system would necessarily result in higher running costs. However, a lack of familiarity with their current running costs meant that they could not give a definitive view on whether the increased energy costs would be an obstacle to them adopting the system.

Reduced time to market was not viewed as a significant reason to adopt the system. This is because many factories are getting their lambs to market quickly under their current regime; also, much of the trade is with France and lambs are targeted to reach France over the weekend, which reduces time pressure.

While respondents viewed the estimated capital costs as prohibitive, the estimated payback period quoted was seen as reasonable and within industry 'rules of thumb'.

Respondents did not feel that buyers in the trade would raise problems in adopting the system. Their buyers are generally wholesalers who are mainly interested in the physical appearance of the carcass rather than details of the chilling process.

COMMERCIAL TRIAL

Ultra-rapid chilling was carried out in an Irish factory so that any outstanding issues associated with the process could be addressed. Forty lambs were used, half of which were chilled ultra-rapidly and the other half conventionally (as the factory would normally chill them). After chilling, the lambs were shipped to France in the normal fashion. Upon arrival, commercial buyers who were informed of the purpose of the trial inspected them. They were able to distinguish between some ultra-rapidly chilled and commercially chilled carcasses. Some ultra-rapidly chilled carcasses were deemed to have lost their bloom according to the buyers. During the equilibration phase of the trial, relative humidity was maintained at 90%. In the authors' opinion, a reduction of this figure (to 80%) would address the issue of " bloom loss".

Buyers also commented critically about carcasses with slight/thin fat cover being wet and also about lambs that they suspected of being fed meal rather than grass. This comment applied to both conventionally and ultra-rapidly chilled carcasses. In general, buyers had no reservations about accepting ultra-rapidly chilled lambs and they did not foresee any consumer difficulties with the process.

RECOMMENDATIONS TO INDUSTRY

The main advantages of ultra-rapid chilling lamb are the reduced evaporation losses (up to 1%) and shorter chilling times. For minimum weight loss, rapid chilling should be carried out at –20°C for 3.5 hours with airspeed of 1.5 m/s followed by subsequent equilibration at +4°C. Greater than 90% humidity is required during the equilibration phase to minimise evaporative weight loss. Under these conditions, meat tenderness and carcass appearance are not adversely affected compared to conventional chilling at +4°C.

However, there are cost implications as discussed above. Before companies apply the technology, a detailed cost benefit analysis must be carried out. It seems from a quality point of view that ultra-rapidly chilled lamb is equal with respect to appearance and eating quality.

The work also found that the variation in quality with the lamb herd is high regardless of chilling regimes. The variation in fat cover and the genetic make-up of the animals are probably the main causes of this. It is important that the Irish lamb industry addresses the consistency of its product. For instance, it is known that chilling rates have a profound effect on eating quality but if there is a high variation of fat cover, the chilling rates will be substantially different and will result in a highly inconsistent product.

In conclusion, ultra-rapidly chilled lamb offers clear advantages over conventionally chilled lamb. Cost benefits should be established but consistency of lamb grades should also be addressed.

CONCLUSIONS

- Chilling at -20°C led to the most significant reductions in evaporative weight loss when compared to chilling at other sub-zero temperatures and to conventional chilling at +4°C.
- Splitting ultra-rapidly chilled lamb carcasses led to an increase in tenderness when compared to unsplit rapidly chilled carcasses.
- Immersion chilling led to reductions in weight losses when compared to air chilling at the same temperature. In general, immersion chilling had no effect on tenderness compared to air chilling.
- The payback period for the cost of installing the ultra-rapid chilling system in a lamb factory was estimated at between 714 and 917 days depending on factory throughput, lamb prices and optional extras.
- In general, the industry will not adopt the proposed system in the short to medium term. While it is seen to have a number of advantages, the high capital costs and higher operating costs may be obstacles. The complexity of the system and possible effect on meat quality are not deterrents. The industry is, however, working on its existing chilling systems and modifying and fine-tuning them with low levels of capital investment and thus welcomes any research in this area.
- French buyers had no reservations about accepting ultra-rapidly chilled lambs as the process did not adversely affect the criteria on which they buy lambs.

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