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DEVELOPMENT OF METHODS TO REDUCE THE ENERGY REQUIRED TO CONSERVE MEAT WITHOUT COMPROMISING ITS QUALITY.

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Livestock Products Quality and Processing

Contents

Tables and Figures

Abbrevations used in text

AABF	Automated air blast freezer
AQIS	Australian Quarantine and Inspection Service
ADF	African Development Fund
ATP	Adenosine triphosphate
Cfu	Colony forming units/cm^2
CIE	Commission Internationale de l'Eclairage
CSC	Cold Storage Company (of Malawi)
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DFD	Dry, firm, dark (muscle)
E. coli	Escherichia coli
ES	Electrical stimulation
EU	European Union
FQ	Forequarter
GDP	Gross Domestic Product
h	hour
HQ	Hindquarter
HVES	High voltage electrical stimulation
LHS	Left hand side.
LVES	Low voltage electrical stimulation
M.	Muscle
Meatco	The Meat Corporation of Namibia
NCA	Northern Communal Areas (Namibia)
PPS	Pulses per second
PSE	Pale, soft, exudative (muscle)
RHS	Right hand side
RRA	Rapid Rural Appraisal
RSA	Republic of South Africa
t	metric tons
't'	students t test (statistics)
SADCC	Southern African Development Coordination Committee
v	volts
VCF	Veterinary Cordon Fence

1. Summary.

1. The movement of animals for urban slaughter can result in considerable economic loss through injury, mortality and reduction in carcase weight. The development of peri-urban or more rural slaughterhouses to service larger urban markets would require investment in additional facilities for refrigerated conservation of fresh meat.

2. Peri-urban abattoirs tend to operate hot meat production and hot meat distribution systems. One option would be to produce frozen meat, which is somewhat less 'time temperature critical' in transit than the chilled product, particularly where the infrastructure is poor. Energy costs can be minimised by direct freezing hot boned meat; investment costs could be lowered by reducing the need to chill 'bone-in' carcase meat.

3. The initial carcase chilling process can account for about 30% of the total electrical energy used to operate conventional abattoirs where chilled bone-in or bone-out meat leaves the premises at 48 h post mortem. Almost 30% of a bone-in beef carcase is inedible material (bone, sinew, excess fat); energy savings in not chilling this fraction are increased by the need for less energy in re-heating the material during rendering. Hot boning will reduce energy consumption in the chilling procedure by more than 50%, since better means of cold transfer can be established.

4. Hot boning followed by more efficient, accelerated chilling can result in the muscle being more susceptible to rigor shortening due to the loss of the muscle-bone attachment. This can result in severe decreases in meat tenderness and darkening due to the compaction of meat fibres reducing the light scattering effect of the fresh cut meat surface. One option being pursued in Canada consists of hot boning lower value cuts, leaving the remainder (largely HQ) chilled in a conventional carcass form.

5. Prevention of cold-toughening caused by rapid chilling is usually achieved by the use of electrical stimulation (ES), applied conventionally to the animal after slaughter, or to eviscerated body or carcase side during dressing. ES accelerates the onset of *rigor mortis*, but its conventional application to whole carcases may reduce the processors flexibility to exploit the pre-rigor properties in lower grade meat. Rapid boning after slaughter may allow the option of applying ES to excised muscles depending on end-use. The effectiveness of ES is related to the individual responsiveness of each muscle and factors such as stress and changing current density across the carcase. ES tends to be less effective in older animals. The application of ES to excised muscles might offer the dual advantage of giving a more homogeneous effect between animals and allowing processors increased flexibility of end use.

6. Hot boning represents an increased opportunity for surface contamination of the hot, sticky muscles. Reports by workers in Australia, Canada, and Europe indicate that hot boning carried under good conditions of hygiene has no effect on the extent or type of microbiological proliferation, provided that hot meat is cooled quickly after boning. Australian practice tends to favour the use of pre-chilling procedures prior to boning and strict temperature control during the boning and packing operation. Current Australian regulations require hot boned meat to be cooled to +8°C within six hours (h) of boning in order to control microbiological proliferation.

7. This rate of temperature reduction requires the use of blast chillers, or more commonly blast or plate freezes. Industrial air blast freezers can only achieve this rate of cooling if the meat enters the freezing cycle at 25°C. Carcase pre-cooling procedures prior to and during hot boning are mandatory, adding significantly to energy use and the investment costs of temperature controlled facilities. Plate freezers are able to reduce the temperature of hot meat to 8°C in 8 h (or less), working with initial meat temperatures of 35°C prior to freezing.

8. Plate freezers or contact cold transfer uses 60% less energy than blast freezers, but chilling rate is sensitive to surface contact effects. Attempts to mechanise the loading and unloading operation have not been successful, and there is an added element of additional handling costs in their use, although this can be minimised by good line layout. The ability to achieve high rates of cooling in hot meat (>4°C per h) make them suitable for hot boning, although this could suggest that an element of cold-shortening would still occur in electrically-stimulated (ES) meat.

9. The research programme examined the effectiveness of applying ES to hot excised primal muscle blocks in comparison with high voltage ES applied to whole carcase sides from culled ewes. The effects of rapid hot boning, ES systems and rapid cooling on meat quality were investigated in combination with an assessment of the effect of different rates of subsequent chilling on the microbiological integrity of the product.

10. A field visit was undertaken to three countries in sub-Saharan Africa to investigate the potential for the application of new technologies in their meat industries. The potential for the introduction of new technology into the meat processing systems in Tanzania, Malawi and Namibia was determined; these countries were selected as being representative of poor, medium and well developed meat processing industries.

11. A model boning system developed for culled ewes removed 6 primal muscle blocks from an individual carcase side within 30 minutes of slaughter. Hot boning

increased the yield in primal meat (over cold boning practice) by 3.8% and 4.8% of original carcase weight compared with carcases that were cooled at 2.0 and 4.5°C per h respectively. Recovered meat yield, which consisted of primal muscles and meat trimmings from the bones, was increased by 2.7 and 3.8% of original carcase weight compared to cold boned carcases cooled under slow and rapid chilling conditions. The proportion of boning meat trim in the total of recovered meat was 10% less than that obtained for cold boning, reflecting the ease of the hot boning schedule on small-stock. The application of ES to hot excised primal muscles had no effect on the extent of the increase in meat yield due to hot boning.

12. ES was applied conventionally to carcase sides at 0.25 hours *post mortem*. This resulted in a reduction in average muscle pH of 0.22 pH units (over non-stimulated controls) at one hour *post mortem*, and was able to reduce primal muscle pH to <6.2 pH units at ten hours *post mortem* in carcases chilled at 4.5°C per h. Variation in the rate of pH fall between muscles was unaffected, but inter-animal variation was increased by ES.

13. ES was applied to hot excised primal muscles under partial confinement in a modified wine press within 0.8 h of slaughter. Stimulation at 120 and 380v resulted in the primal muscles undergoing an immediate localised contraction, which was partially sustained over the two minute stimulation period. The application of high voltage ES to primal muscles could be made intrinsically safer for workers than the application of ES to carcase sides, although both technologies are required to be isolated from operational personnel. The design of primal muscle stimulators must take account of the possibility of cross contamination between primal muscles.

14. ES applied to primal muscles resulted in an average reduction in muscle pH (over non-stimulated controls) at one h *post mortem* of 0.20 and 0.16 pH units for 120 v and 380 v applications, respectively. The acceleration in muscle pH fall tended to be most rapid in primal muscles receiving a 380 v stimulus; all stimulated primal muscles, except FQ muscles stimulated at 120v, achieved pH < 6.2 at 10 h *post mortem*.

15. Conventionally-applied ES can protect against the effects of toughness resulting from the rapid cooling of muscles from lower grade animals. The application of ES to excised muscles may offer similar protection, although it did not reduce the variability of response between muscles and animals. The localised application of electric fields did not affect the extent of water-holding properties of retail meat, retail colour development and colour stability or reduce variation.

16. Application of ES to hot excised muscles, including the additional handling operation in a hot boning system, had no effect on the level of microbiological proliferation when carried out under good slaughter and rapid cooling conditions. Hot boning, followed by slow cooling, led to an unacceptable proliferation of microorganisms in retail storage; the addition of a primal ES processing step had no effect. **Current Australian regulations, requiring hot meat to be reduced to 8°C within 6 hours of boning in order to retain microbiological integrity, remain appropriate to small hot-processing facilities.**

17. ES could be successfully applied to hot excised muscles from culled ewe carcases, although it did not offer any advantage in performance, within the electrical parameters tested, over existing conventional ES. Direct freezing of hot boned meat would avoid carcase chilling, although it would be important to assess the microbiological implications under field conditions.

18. A survey was carried out in three African countries to establish the demand for accelerated processing technology in relation to the potential developments of their respective meat-processing industries. Development in the meat sectors in Malawi and Tanzania is likely to be limited and, in the short-term, will not be concerned with improvements in meat quality. There may be longer-term potential for addressing meat quality issues in relation to marketing export meat in Tanzania.

19. Developments, which might make use of some of the outputs, are currently taking place in the Meat Corporation of Namibia (Meatco) abattoirs operating in the Northern Communal Areas. Local facilities are being upgraded to produce hot boned plate-frozen block meat, from cattle produced from smallholder based cattle producers, for export to existing markets in South Africa. Immediate assistance was requested by Meatco on the application of conventional ES technology to the carcases of poorer grade animals. The exploitation of pre-rigor properties of lower value muscles, i.e. the application of ES to hot excised muscles to increase product flexibility, is somewhat ahead of their current requirements.

20. The technical potential and market demand for exploiting the pre-rigor properties in low grade or improved tropical cattle is unknown. The communal areas in Namibia may provide a useful model for assessing the potential of the future development of hot boning practices in the region.

2. Introduction.

2.1. Background.

21. Livestock destined for slaughter in urban abattoirs tend to originate within extensive catchment areas or from distant agricultural zones. Movement of animals to urban slaughter can result in direct losses in animal value through injury or loss in carcase weight, and expose livestock to considerable stress through mixing or changes in environment. The effect of long-term stress associated with animal movement, will have greater consequences in poorer grade animals, reducing the retail value of carcase meat which may extend to a decrease in microbiological integrity.

22. Rapid expansion of urban populations in developing countries is beginning to exert environmental and operational pressure on urban abattoirs. The siting, age and condition of many of these facilities restricts the opportunity for the structural investment necessary to lessen their environmental impact. This problem may also extend to the wide range of support services, e.g. tanneries, that tend to be associated with urban slaughterhouses. Environmental restrictions in developed countries have forced the closure of many urban slaughter facilities, their role being replaced by cold stores distributing a higher volume of refrigerated product.

23. The development of peri-urban or more rural facilities, which are often sited nearer to the source of animal production, may offer a more viable option for future long-term investment. Rural abattoirs tend to service small local markets through low-cost hot meat distribution systems and, as such, would have to introduce extensive improvements in the transport and storage of carcase meat in order to service more distant urban centres. This could be met by the introduction of refrigeration, although the transfer of chilled meat requires the establishment of an extensive and reliable cold chain, and the need to address new methods of wholesale marketing.

24. Freezing has been a useful technique in the development of many meat industries, particularly where producers were faced with large distances or difficult distribution practices. Frozen meat is somewhat more resistant than chilled meat to the danger of spoilage caused by short-term temperature abuse. A number of countries in the SADCC region make use of freezing as a means of meat and offal distribution. The disadvantage of freezing lies in the energy cost associated with the production and distribution system. Production costs of freezing can be reduced through the introduction of contact freezing technology and would appear to be most beneficial when combined with hot boning (the removal of meat from hot carcases), thus reducing the investment costs associated with the refrigeration and handling of chilled carcases.

25. Hot boning has had little reported effect on the quality of meat from higher grade, feed-lot animals, although these findings are based on experience from operations where boning is carried out under temperature-controlled conditions. Electrical stimulation (ES) technology is often applied to prevent pre-rigor toughening associated with a more rapid removal of heat associated with these hot-boning operations.

26. Less information is available on the effectiveness of ES technologies on poorer quality meat or on the implications of poor temperature control within the overall slaughter and hot boning process. Under these conditions the handling of hot meat would be expected to have a considerable impact on the microbiological quality of the final product, particularly where product hygiene is compromised by poor slaughter and boning practices.

2.2. Project objectives.

27. This project investigated the option for extending existing hot meat practices, where all or part of the carcase could be diverted to a shelf-stable, frozen product. It examined the implications of hot-boning, freezing, and other technologies in relation to the subsequent effects on meat quality from lower grade animals.

28. The objectives, set out in the project memorandum, were as follows:

a. To assess production and energy requirements of hot meat processing and conservation practices.

b. To determine the effects of freezing, hot boning and electrical stimulation on the quality of meat from lower quality animals.

c. To reassess microbiological criteria in small-scale hot meat processing practices.

d. To conduct an RRA-type survey of current meat processing practices and constraints to change and market potential in three African countries.

3. Project activities

29. The following is a synopsis of activities over the project life.

30. **April 92 - March 93.** Reviews were undertaken of recent progress in the technologies of hot boning and electrical stimulation, applied to small stock. An experimental horizontal plate freezer was commissioned at NRI. Background information on the practical aspects of industrial plate freezing technology was obtained during a visit to CSIRO, Australia. Discussions were held with meat works engineers and CSIRO staff. A number of simulations were carried out on the CSIRO mathematical model profiling freezing performance in both blast and plate freezers. Two meat processing studies were undertaken in collaboration with the University of Nottingham, examining the effects on yield and quality of a hot boning protocol, where HVES was conventionally applied to the carcase side of culled ewes. This required the development of a rapid hot-boning procedure for small stock, and the adaption of standard tests for measuring quality changes in smaller excised muscles.

31. **April 93 - March 94.** The previous studies were extended to evaluate the performance of conventional methods for evaluating quality changes in ES meat. Revisions were made to the hot boning schedule and safe operational procedures were developed for the application of high voltage electrical stimulation technology to primal cuts. A preliminary study was undertaken to examine the application of ES technology to hot excised primal cuts. A survey was made of the commercial meat producing sectors in Tanzania, Malawi and Namibia, representing low, medium and high levels of development. This addressed the likely uptake of ES, hot boning and plate freezing technologies over the short and long term.

32. **April 94 - March 95.** A study was undertaken to examine the effectiveness of ES technology applied to hot excised primal cuts from culled ewe carcases in comparison to the conventional application of high voltage ES applied to carcase sides. Experimental trials were carried in collaboration with the University of Nottingham, and were extended to include a linked assessment of the microbiological implications of a process, where hot excised primal muscles were subjected to additional handling operations.

4. Assessment of production and energy requirements.

4.1. Hot boning practices.

33. Conventional meat processing practices involve the slaughter, dressing and chilling of carcases, followed by butchering into carcase primal cuts, packaging and shipment. All stages subsequent to carcase dressing are carried out in a cooled environment; primal cuts from beef sides are conventionally removed from carcases previously chilled to deep muscle temperatures of <5°C over the previous 24 or 48 h period.

34. Hot boning procedures differ in that primal cuts are removed from the hot carcase within three h of slaughter, packaged, and chilled as primal muscles or cartonned as manufacturing meat pieces (typically <100mm in one dimension) over a 24 h period or less. (N.B. Hot cutting is a distinct process, applying most often to small stock, where the hot carcase is sectioned into 'bone-in' joints for freezing).

35. Hot boning lines for beef currently operate in New Zealand, USA, Canada and in Botswana. Three Australian meat-works operate hot boning systems (one beef and two sheep hot cutting (bone-in) plants) but the uptake of the technology has been very low. Existing cold boning operations cannot be adapted to hot processing, since this would require extensive changes in product flow. Hot boning procedures are an extension to the slaughter line and require the introduction of rapid chilling systems using forced air tunnel chillers, blast or contact (plate) freezers. These systems are more efficient in terms of the rate of heat transfer, since less free air is required in providing convection. Contact freezing makes use of conduction thorough the bottom supporting plate, and depending on carton fill, utilises conduction or convective heat transfer to the top plate.

36. Hot boning has little effect on product quality although wholesale customers have difficulty with the alteration of muscle shape. This may downgrade certain cuts (e.g. hindquarter rump) and upgrade others (e.g. forequarter chuck). Hot boning enables processors to take advantage of the pre-rigor properties of lower value meat, which is now being advocated as a major advantage for the process (Aalhus et al., 1994). Pre-rigor meat has superior functional characteristics, including greater water-holding capacity and better emulsifying properties (West, 1982). Aalhus et al. (1994) have devised a hybrid processing system, in which forequarters are hot boned whilst making use of existing facilities to conventionally chill and cold-cut higher value 'bone-in' hindquarters.

37. Hot boning allows for more rapid and uniform chilling, although this can increase the risk of cold-induced toughening (Follett et al., 1974). This reaction, termed 'cold shortening', results from the super-contraction of muscle prior to the onset of *rigor mortis*; a related process, termed 'thaw rigor', can induce toughening if the muscle is frozen in the pre-rigor state. Electrical stimulation (ES) technology can reduce the problem of toughening, by accelerating the onset of *rigor mortis*, although this procedure would lessen the processing advantages associated with muscles in the pre-rigor state.

4.2. Electrical stimulation technology.

38. ES is applied to accelerate *post mortem* muscle biochemistry, which it does in the form of 'immediate' and longer term effects. The stimulus initially activates muscle short-term energy reserves (e.g. creatine phosphate), which remain available after slaughter. Activation leads to rapid muscle glycolysis, leading to a reduction in muscle pH. This initial process is followed by a more gentle acceleration of muscle glycolysis, through mobilisation of glycogen reserves. The loss in the glycolytic reserve in muscle prevents a cold-induced contraction as its temperature is reduced below 10°C.

39. ES is conventionally applied to the slaughtered animal or dressed side. Low voltage technology (typically <100v) is applied within four minutes of death and induces a contraction in muscles via the motor-end plates through the still functioning central nervous system. Low-voltage ES (LVES) must not be applied until bleeding has finished in order to comply with animal welfare requirements.

40. The metabolic response of individual muscles to LVES will vary across the carcase, depending on nerve integrity and muscle reactivity. The immediate metabolic response is difficult to control in extensively-reared livestock, particularly where the animals have been highly stressed. Under normal circumstances muscle reactivity relates to type of muscle, breed, longer term stress and immediate pre-slaughter stress. Over-stimulation can induce a very rapid fall in muscle pH (at >35°C), leading to heat-induced toughening or to a type of PSE (pale soft exudative) condition in slow-chilled deep muscle. LVES is however a low-cost and relatively safe technology.

41. High voltage ES (typically >450v) is applied later in the dressing process, typically to the eviscerated carcase or split carcase side, and acts by direct depolarisation of muscle end-plates. Circumstances leading to the PSE condition are avoided since ES is carried out when the temperature and oxygen tension have been reduced. The response to the stimulus will decline with time, although this can be compensated for by increasing the applied voltage.

42. The avoidance of reliance on a nervous pathway gives better overall control of the onset of *rigor mortis* in muscles that are **directly** in the current pathway. The use of additional electrodes can reduce the variability of muscle response to HVES over the carcase side, by applying more localised electric fields (Solomon, 1988). High voltage application requires higher capital expenditure for reasons of safety.

43. The application of ES technology to the animal or carcase side, to avoid cold shortening in higher value primal muscles, reduces the opportunity to optimise some of the meat-processing characteristics in lower grade meat. Binding and emulsifying properties in pre-rigor meat are increased by the high availability of phosphate (as ATP) immediately *post mortem*. ES produces a rapid reduction in ATP levels and is disadvantageous in low value muscles since the subsequent reduction in active phosphate moieties lowers the potential binding characteristics in processing meat.

44. ES will accelerate the rate of pH fall in muscle but has no effect on ultimate muscle pH. The technology has no effect in DFD (Dry Firm Dark) meat, where stress typically results in muscle with a high ultimate pH, leading to a much-shortened shelf-life. Accelerated processing can lead to the problem of identification and separation of DFD meat, in order to ensure that the meat is not held under extended vacuum chill storage. The dark colouration is a poor initial indictor of DFD in older stock, which tends to exhibit deeper pigmentation due to the increased levels of muscle myoglobin with age. The Danish Meat Research Institute (Hald - private communication 1992) has used the absence of an effect on muscle pH after the localised application of ES (on the loin muscle) to identify potentially dark-cutting animals prior to hot boning operations.

4.3. Microbiological aspects of hot boned meat.

45. Inadequate cooling can lead to the uncontrolled growth of mesophilic and psychrotrophic enteric pathogens, which are currently regarded as one of the most serious health risks associated with fresh meat (Lee et al., 1985). Hot boning *per se* has little effect on the microbiological integrity of primal or retail packed meat, although much depends on the rate of initial chilling (Oblinger, 1983).

46. Key work in this area was carried out in re-heated meat by Herbert and Smith at CSIRO in the 1970's (reviewed by Herbert and Smith, 1980). These authors suggested that excised meat at 30°C should be cooled to +8°C in six h (equivalent in a hot beef processing operation to eight h *post mortem*) in order to limit the increase in microbiological growth over this period to less than 10 generations. The work carried out by Herbert and Smith still forms the basis of the temperature specifications currently required by the Australian Quarantine and Inspection Service (AQIS) for hot meat

packers.

47. Work in the USA in the 1970s suggested that hot boned beef primal cuts could be held at an elevated temperature (e.g. holding at 16°C for eight h after excision to promote pH fall and thus avoid cold shortening) and still limit the growth of mesophilic and psychrotrophic bacteria to less than 10 generations. Fung et al. (1981) claimed to be able to hold primal cuts at 21°C for up to ten h post mortem without unacceptable changes in wholesale or retail product safety. This claim has been disputed, particularly in respect of the growth of potential pathogens. Reichel et al. (1991) have recently re-specified the quality requirements in hot beef processing with respect to *E. coli*. They suggested that 80% of the calculated values for proliferation should not exceed 10 generations, with none exceeding 14 generations.

48. It is necessary to differentiate the potential for microbial growth between whole primal muscles and that in trimmings, the latter having a higher surface area to weight ratio and, therefore, assumed to offer a better overall substrate for microbial growth. Kotula (1981) reported that total aerobic count at 5°C and 25°C was significantly increased in hot boned beef trimmings, but this was not accompanied by an increase in the counts for selected pathogens (fecal coliforms and *E. coli*).

49. Primal muscles from sheep and goats would be smaller than those from beef carcases and would be expected to be exposed to the risk of higher surface contamination through greater handling contact. Evidence of this problem is somewhat inconclusive; in some boning trials counts for psychrotrophic and lactic acid bacteria were similar for hot or cold boned primal muscles. Field et al. (1974) reported that microbial counts in hot boned mutton carcases were 10 times lower than those from chilled carcases.

50. There is no evidence that ES has any significant effect on the proliferation of micro-organisms in beef or lamb carcases (Mrigudat et al., 1980). Some claims have been made for an inhibitory effect in experiments which were conducted under rigorous control (e.g. Slavik et al., 1991), but these have not been substantiated. There has been no work on the effect of subjecting hot, excised muscles to further handling abuse prior to chilling if, for instance, ES were to be applied subsequently to excised muscles.

4.4. Energy costs associated with the refrigeration of meat.

51. Refrigeration has been estimated to account for 35% of the energy used in conventional meat processing (Collett and Gigiel, 1986). Conventional chilling of beef carcases to a deep muscle temperature of +5°C requires a minimum of 140 KJ of energy per kg carcase meat over a fourty eight h cycle, with 30% of the energy use being

equivalent to the basal load associated with facility cooling. Many of the recent developments in new technology have concentrated on increasing the rate of heat loss, where relatively higher energy densities are applied over shorter times in order to minimise the weight loss in the product due to evaporation. The detailed analysis by Collett and Gigiel (1986) suggested that the economic cost of the weight loss was 25 times that of the potential energy expenditure under rapid chilling conditions.

52. Henrickson (1982) has calculated that hot boning offered a 67% energy saving over conventional chilling of beef carcases. This advantage was derived from the use of more efficient chilling procedures, where more efficient heat removal could be combined with a reduction in basal load by the use of tunnel chillers and the fact that bone and fat (30% of carcase weight) are removed from the chilling process. A more practical series of trials was carried out by the CSIRO, Australia, in the mid-1980s; unpublished commercial data put the overall energy saving due to hot boning nearer to 50% over that used in conventional carcase chilling practice, owing for the need to operate various carcase pre-chilling options prior to hot boning.

53. The rate of heat removal from cartonned hot meat demanded under the AQIS specification requires the use air blast or contact (plate) freezing technology. Blast freezers have been largely automated and feature commonly in larger meat works; up to 40% of their energy requirement is used in creating the air blast. Plate or contact freezers are more efficient in terms of energy use, but require additional labour for the loading and unloading operation. An automated plate freezer plant, featuring automatic carton loading and unloading, was installed as a development unit in Australia (Visser, 1986). This was troubled by mechanical failure and has now been returned to manual operation.

54. Plate freezers have the advantage of being low maintenance technology in comparison to blast freezers; the capital cost of blast freezers and plate freezers is broadly similar (e.g. capital equivalent cost of £50,000 for 12t per day plant), since plate freezers typically operate sixteen to twenty two h duty freezing-cycles compared to the normal thirty eight to fourty six h freezing-cycles operated in most blast freezers. Adoption of plate freezer technology is most widespread in Australia, where there is a ready market for frozen meat for manufacturing purposes. Plate freezers have been installed as successful replacements for old chamber freezing facilities in meat works in South Africa, Namibia and Botswana.

55. Plate freezing of boned chilled meat requires 25% of the energy demand of conventional bone-in carcase freezers and is claimed to offer a 45% saving in energy use over blast freezers (Visser, 1977). Visser (1986) identified further savings in freezing hot

boned meat due to the reduction in chiller meat handling and an increase in boning productivity. The extent of the claimed savings over conventional chilling and blast freezing technologies (amounting to 120 US dollars per ton frozen carcase meat from a new purpose built abattoir) are considered to be an accurate assessment of the practical advantages offered by the technologies (Powell, CSIRO - private communiation). The regularity of shape in plate-frozen blocks represents a significant handling advance, since it permits greater loading factors during storage and transport and can reduce the energy needed to extract intrusive heat.

56. The coupling of hot boning technology and plate freezing offers the lowest energy option for the production of frozen meat blocks. The implications of changes in quality in lower grade meat have not been widely reported; there is little information of the practical advantages of rapid temperature fall on the microbiological integrity of hot boned primal meat from small stock. The use of ES technology may assist in the maintenance of some quality attributes and act against others. The localised application of ES to excised primal cuts may provide an opportunity to exploit the manufacturing properties of lower grade muscles or increase the overall response of some muscles compared to that in conventional ES technology.

57. The costs of processing meat for frozen blocks are comparatively high and are site specific. The process is essentially one of supply to urban markets over medium distances, e.g. 150 - 200 km, on reliable roads replacing the movement of livestock by that of meat. One animal occupies 4 m^3, whereas the meat can be reduced to four cartons occupying 0.1m^3. About 10 vehicles of 10 heads of cattle are required to transport sufficient animals to make up a meat load of 6250 kg which can be carried in one animal. Further benefits include the avoidance of loss of weight and stress related quality reductions due to travel without a following period of rest. Rural slaughter retains more income within the community, allows the exploitation of the byproduct resource and reduces environmental damage in urban areas.

5. Experimental findings.

5.1. Plate freezer performance.

5.1.1. Modelling industrial performance.

58. A number of simulations were carried out at the CSIRO Meat Laboratory, Brisbane, using a chiller freezer model to evaluate the comparative performance of current freezing technology in the temperature reduction of hot boned meat. The model makes use of a number of algorithms based on those developed in New Zealand (Cleland, 1990) for freezing of conventionally-chilled cold-boned meat in large scale industrial freezer units. Data on the freezing performance of hot meat was obtained by CSIRO staff during a number of semi-commercial trials in the late 1980s, arising from the original work on the comparison of blast and plate freezing technology using re-heated meat reported by Herbert (1980). The working approximations for hot meat freezing serve to identify the extent of variations in cooling rates with respect to carton size, carton type and cooling practice.

59. The model was used to compare the likely performance of industrial blast and plate freezers, cooling meat packed in standard 27 kg (150 mm product internal thickness) corrugated cardboard box and lid meat cartons which are used for local distribution or in the more durable solid laminated walled box and lid cartons. Laminated cartons are increasingly favoured for export, since the corners of the cross-banded carton stand up better to poor handling practice.

60. The comparative performance of air blast freezers working at their most economic temperature (-40°C) is given in Appendix 1: Figure 1.1. The cross-hatched areas represent the extent of the variation of achieving the -2°C freezing point throughout the carton. Industrial automatic air blast freezers (AABF) were able to reduce the internal temperature of hot (30-35°C) meat in corrugated cardboard cartons to +8°C in eight h; this is extended to nine h if solid board cartons were used. These cooling rates were slower than those stipulated by AQIS, with 50% or less of carton mass achieving a temperature of 8°C in six h after hot meat enters the freezer at 30-35°C. Air blast freezers could be operated on hot meat within the AQIS threshold by increasing the severity of cooling conditions e.g. decreasing the air temperature to -55°C or by reducing carton thickness; both would impose a severe increase in cost.

61. An alternative strategy for AABF operations is to reduce meat temperature to <30°C, prior to it entering the freezing cycle. In the USA, hot beef processing systems (Henrickson, 1982) include carcase pre-chilling stages (for up to 60 min post dressing),

followed by boning in a +10°C environment. This can result in a reduction in the temperature of the deep muscle to <30°C prior to packing at two h *post mortem*. The need for a carcase pre-chilling stage adds considerably to investment costs, particularly in situations where chilling is not currently practised. Carcase pre-chilling will decrease the yield advantage of hot boned meat over conventional cold boning practice; pre-chilling of high grade beef reduced the yield advantage of hot boning by 50% (Powell - personal communication 1992).

62. Simulations indicated that cooling rates to 0°C in ABBF operations varied considerably across the thickness of the carton, ranging in the rate of temperature reduction from 5.4 to 2.2°C per h. This variation was carried forward and accentuated as meat entered the freezing cycle. The rate of freezing is conventionally expressed in terms of the time taken to reached meat temperature from 0 to -10°C and block depth, i.e. cold penetration rate. Penetration rates in corrugated cartons ranged from 0.11 cm per h at 24% of slab interior depth to 0.47 cm per h internally, reflecting the variation in temperature profile across the carton and the reduction in specific heat (and cold transfer) as meat freezes.

63. Corresponding data for the chilling performance of cartoned meat in plate freezers working at their conventional operational threshold (-35°C) are given in Appendix 1: Figure 1.2. The use of contact or plate freezing technology would achieve the specified AQIS rate of cooling, since internal rates of cooling from 35 to 8°C were achieved in corrugated or solid board cartons within six h, equivalent to a minimum cooling rate to 0°C of 4.5°C per h. Differences in cooling rates (illustrated as the hatched area under the -2°C isotherm) across the carton thickness were considerably narrower than those obtained under AABF simulations. Cooling rate showed some sensitivity to type of carton, where slower cooling rates in corrugated cartons reflected higher material insulation value. Cooling performance to AQIS specification will reduce >90% of the hot meat (loaded at +35°C) to a temperature of +10°C at six h *post mortem*, at which time beef muscle pH could be anticipated to be higher than pH 6.2, thus exposing muscles to a severe risk of cold-shortening.

64. Plate freezing limited the difference in freezing rates across the carton. Freezing rates (penetration from 0 to -10°C) in corrugated box cartons ranged from 0.78 cm per h at 24% of slab interior depth to 0.65 cm per h internally; penetration rates were faster in solid board cartons ranging from 1.67 cm per h at 24% of slab interior depth to 0.94 cm per h internally. The advantages of faster freezing rates in solid board cartons would not justify their additional cost. Australian meat processors, using plate freezers for freezing cold boned beef, reported less problems with corner failure in solid board cartons, caused

by meat expansion as it freezes between -2 and -18°C.

65. The CSIRO model is unable to predict changes in rates due to variation in contact effects in partial carton loads, e.g. cartons containing individual primal muscles in comparison to cartons containing full boxed loads of 100mm size specification manufacturing meat. There is an assumed homogeneity in cooling rates between cartons containing meat of different visible lean, although this difference may be minor.

5.1.2. Small-scale performance.

66. Actual performance trials were carried out on the smallest commercially available plate freezing unit (capacity 120 kg; 83mm plate gap), currently installed at NRI. These and other exercises were used to determine the sensitivity of freezing rates to contact effects, and were designed to simulate mould freezing, i.e. where meat blocks are packaged after freezing in metal trays. An example of the variation in freezing performance is given as Appendix 1: Figure 1.3; the hatched area in the figure represents variation in freezing rates between different muscle blocks at the -10°C isotherm.

67. Penetration rates to -10°C in ewe primal muscle blocks removed from the forequarter varied from 1.5 to 2.2 cm per h, which was approximately equivalent to the performance from industrial (160 mm plate gap) models. Freezing in the forequarter packs was predominantly through contact with the bottom plate, since the gap between top and bottom plates after hydraulic clamping was in excess of average muscle thickness, resulting in limited contact with the top plate. This had the effect of extending the freezing cycle time and increasing the variability in freezing rates between muscles. Penetration rates in primal hindquarter muscle blocks ranged from 2.4 to 2.6 cm per h, since these muscles were larger, promoting higher surface area contact with both plates.

68. Performance monitored over the subsequent research programme gave overall average penetration rates in the FQ primal muscles of 1.0 to 1.8 cm per h and in the HQ muscles of 1.5 - 2.8 cm per h. Cellular damage associated with freezing of beef is decreased as freezing rate increases, and is minimial at freezing rates in excess of 3.33 cm per h (Grujic et al., 1993). Slow freezing rates encourage the growth of large intracellular ice crystals which physically disrupt cellular integrity and lead to an increase in weight (drip) loss on thawing. Industrial plate freezers will be unable to offer energy-efficient freezing rates in excess of 3 cm per h and an element of increased drip loss due to freezing seems inevitable under normal operating conditions.

69. Hot boning and plate freezer operations are most energy efficient when freezing full cartons of cubed manufacturing meat (hot or cold boned). ES technology, which can

be applied to reduce the risk of cold- shortening, may be compromised under very rapid chilling conditions in he exterior regions of the cartons. Attempts to apply sufficient ES to prevent cold-shortening in the thinner FQ or loin muscles under rapid chilling conditions would expose deep muscle regions to high temperature and low pH conditions prior to freezing, which may act to reduce the overall value of the cartoned product.

5.2. Effects of hot boning and conventional ES application.

5.2.1. Development of a hot boning ES-side schedule.

70. Culled ewes (mostly Leicester) were selected as the most appropriate model for use in the experimental programme, representing highly variable, low quality animals. Animals were full-mouthed, barren ewes, and were purchased as complete lots (12 to 16 animals) from a local market. The use of culled ewes presents problems of widespread carcase variability and differences in the susceptibility of these animals to the stress of handling prior to slaughter. Some element of selection for size and condition was made during the latter stages of the programme.

71. Slaughter and boning operations were carried out within 1.2 hours of slaughter. Hot and cold carcase side weights were recorded after slaughter and prior to boning in order to determine evaporation losses during chilling and over the boning operations. High voltage ES (450v, 12.5 pulses per second (pps); 30 seconds positive polarity, 30 seconds negative polarity) was applied to individual carcase sides at 0.25-0.35 h *post mortem*, using electrodes embedded in the distal region of the *M. biceps femoris* muscle (HQ) and in the *M. lateral head triceps*.

72. An initial hot boning procedure was developed which maximised the size of primal cuts that could be removed from vertically suspended carcase sides. Boning lines followed conventional cold cutting separation practice, although individual muscle seams were followed where possible. Primal cuts were removed in the following order:

a. HQ flank to 6th rib.

b. Neck (and shin); neck piece removed by cutting at the 5th cervical vertebra, boned and combined with FQ and HQ shins.

c. FQ primal cut (a); this consisted of muscles superior to the scapula and demarcated by cuts made at the 6th rib and 5th cervical vertebra.

d. FQ primal cut (b): FQ muscles inferior to scapula and demarcated as in (c) and including brisket.

e. Loin; Loin muscle, from 6th rib extended to 6th lumbar and sacral junction and including the fillet.

f. HQ primal cut; separation at cranial junction of rump and loin/fillet and incorporating topside, silverside, top rump, and rump primal muscle areas.

73. Primal cuts were packed in synthene bags, vacuum-packed after removal of pH samples and cooled for 24 h as a single layer in baskets in air at -1 or +3°C and 3 metres per second. Primal cuts were then plate-frozen as a single layer from 0 to -35°C over a 12 hour cycle.

74. Corresponding carcase sides were cold boned after chilling in similar air conditions for 24 hours. Data for the trial are tabulated in Appendix 2; Tables 2.1 to 2.5. Animal size during these initial trials varied between the trial groups, reflecting the variety of finish in animals over the mid-summer period. The effects of hot boning and ES were examined statistically by applying students 't' tests to grouped mean LHS and RHS data.

5.2.2. Hot boning yield and performance of HVES.

75. Killing, dressing, ES and hot boning procedures were completed over an eight h processing day (killing at 1.2 hour intervals) by a single specialist slaughterman /boner, in order to retain a consistent cutting schedule and level of trim. Hot boning was completed within 0.95 h *post mortem*, whilst cold boning was undertaken at 22-24 h *post mortem*; yield data are given in Appendix 2: Table 2.1. Conventionally chilled carcase sides lost an average of between 3.9 and 4.7% of hot side weight over the chilling cycle. Chiller weight loss was increased in higher finished carcases, although higher fat levels more than offset additional losses during cold boning, resulting in average losses of 5.8 and 8.7% of hot side weight for high and low finish carcase sides respectively.

76. The hot boning schedule of low finish carcases did not produce an increase in primal weight or recovered meat yield over that from the corresponding cold boned carcases. Hot boning of high finish carcases was more successful, confining the overall weight loss to 3.1% of hot side weight, and leading to significant ($p<0.001$) reductions in overall weight loss in the overall trial. Small increases in hot boned primal cut weight and in the weight of bone trimmings contributed equally to an average overall increase of

1.7% in recovered meat yield over cold boned treatments in these trials.

77. The boning schedule was accelerated in a further trial on high finish carcases, by reducing the extent of secondary trimming of primal muscles after removal from the carcase side. Operations were completed within 0.8 h *post mortem*. Hot boning under these circumstances produced a 2% advantage in the weight of recovered meat over conventional cold boning, the weight gain being accounted for by an increase in the weight of meat trimmings removed from the bone.

78. Application of HVES to carcase sides causes a physical contraction, which accelerates glycolysis in response to the energy demand by the muscle. Glycolytic activity in muscle is most conveniently measured by monitoring the fall in muscle pH. Muscles differ in their biochemical response to ES, depending on fibre type and in their location with respect to the current pathway (Asghar and Henrickson, 1982). The effectiveness of HVES was assessed in this and subsequent trials by measuring the pH fall in samples taken from selected muscles of the HQ (*M. semimembranosus* - deep muscle), the loin (*M. longissimus dorsi* at the 10th rib) and FQ (*M. triceps brachii*).

79. Considerable variation was recorded in the effectiveness of HVES (as judged by pH fall) between different muscles and between individual animals (Appendix 2: Table 2.2.). HVES accelerated the fall in muscle pH over that recorded in non-stimulated (corresponding) carcase sides. This resulted in significant ($p<0.01$) differentials between each at one h *post mortem* ranging over 0.24 to 0.34 pH units in the FQ muscles of the various animals tested, 0.17 to 0.43 pH units in the loin and 0.47 to 0.54 pH units in the HQ. The differential was partly retained at 24 h *post mortem*.

80. Cooling rates in both the carcase sides and primal packs were influenced by muscle conformation (flaccidity) and variation in fat cover. Rapid chilling conditions resulted in a wider variation of cooling rate values in excised muscles (FQ 4.5°C per h compared to HQ 3.0°C per h) than in carcase sides (FQ 4.8°C per h compared to HQ 4.2°C per h). Initial muscle pH values were consistently higher in the heavier higher fat cover primal packs and carcase sides; muscle pH values at twenty four h *post mortem* were lower than those from corresponding low fat cover carcases reflecting more rapid pH fall bought about by a slower cooling rate.

81. The physical and biochemical reaction to HVES declines rapidly with time, which would be important in circumstances where ES were to be applied to hot excised muscles. The physical reaction to a local HVES was monitored over between 30 and 135 min *post*

mortem in both FQ and HQ primal muscle areas (Appendix 2: Figure 2.1.). The contractional force induced by HVES in FQ muscle was reduced rapidly with time, resulting in 50% loss of its 0.5 h *post mortem* activity at 0.92 h *post mortem*; reduction in HQ reactivity was somewhat slower, loosing 50% of its 0.5 h *post mortem* value at 1.1 h *post mortem*. The difference between the rates of decline in physical response may have been largely influenced by fall in muscle temperature, since 50% activities in both muscles occurred at between 33 and 34°C.

82. Earlier work by Chrystall et al., (1980) had indicated that the biochemical effect of the direct application of HVES to hind legs of young lambs persisted for only 30 min *post mortem*. The extent of retention in the physical response in culled ewes suggested that HVES might be applied successfully to excised muscles over a longer time-frame.

5.2.3. Effects on meat quality.

83. A number of quality indicators were measured on thawed samples prepared from primal cuts; methods were adapted from those conventionally applied to the study of the changes in meat quality in high value beef primal cuts. These indicative methods related to water loss (primal drip loss, retail drip loss, water holding capacity, cooking loss), to physical damage to muscle structure (drip protein content, myofibrillar protein solubility and myofibrillar fragmentation index) and to consumer acceptance (cooked muscle toughness, retail colour stability).

84. The application of HVES and hot boning had little overall effect on the water holding characteristics of either primal cuts or retail packs (Appendix 2: Table 2.3.). This was consistent with normal findings in beef and lamb carcases e.g. Taylor et al. (1984); Rashid et al. (1982). Hot boning had no significant effect on meat toughness (shear value). HVES applied to carcases significantly ($p < 0.05$) reduced objective toughness in cold boned HQ primal muscles; there was little overall effect on toughness in FQ and loin primal muscles.

85. Results from other quality indicators, such as myofibrillar fragmentation index (MFI) and muscle protein solubility, did not appear to reflect changes in toughness between samples. This may have been due to the higher component of age-related non-myofibrillar factors, such as decreased collagen solubility, which may influence muscle toughness. Analysis of drip protein, which has been considered useful for evaluating the effects of ES in freezing (Sacks et al., 1993), appeared to be of little value in this instance in primal meat from culled ewes.

86. The extent of colour development, or colour stability over time was unaffected by HVES (Appendix 2: Table 2.4 and Table 2.5.). Loss of colour stability in ovine muscle is characterised by a rapid reduction in the CIE a^* or "redness" value, as oxy-myoglobin is rapidly oxidised to met-myoglobin. HVES, in association with hot boning, appeared to result in an acceleration in the decline of the CIE a^* value in the HQ and loin packs assessed after three days retail display. HVES did not appear to reduce consistently the variation in colour values between animals.

5.2.4. Summary of effects of hot boning.

87. Hot boning of culled ewes was completed successfully, although a boning schedule incorporating extensive seaming appeared to be of limited benefit in increasing weight recovery. The conventional application of HVES to carcase sides appeared to offer protection against cold-shortening in some muscles but its performance varied considerably between muscles and animals. Hot boning and conventional HVES had little effect on other meat quality attributes.

5.3. Effects of hot boning and ES applied to hot excised muscles.

88. Preliminary work indicated that hot excised muscles would respond to the direct application of ES, although the extent of the variation in performance was unknown. The research programme was directed towards a comparison of the effectiveness of applying low (120v) or high (380v) voltage ES to hot excised primal cuts. These treatments were compared against cold boned primal cuts taken from alternate sides which had received either no stimulus or conventional (450v) HVES. An additional variable, chilling rate, was added to the programme matrix in order to distinguish the effects of slow (<2.5°C /h) and rapid (4.5°C /h) chilling on the microbiological quality of hot boned primal muscles.

5.3.1. Development of a hot boning primal-ES schedule.

89. The need for speed in applying HVES to excised primal cuts led to a re-appraisal of the cutting regime given in paragraph 67. The neck, from the atlas to the 5th cervical vertebra, was removed as a bone-in piece and was trimmed after completion of all other boning procedures. The rump was excised as an additional primal pack by its horizontal separation from the silverside. Killing, dressing and primal hot boning operations were completed within 45 min *post mortem*.

90. ES was carried out in a modified wine press, with primal muscles being located between wire mesh electrodes fitted to the inward facing surfaces of high density polyethylene insulator plates. Primal cuts were clamped in the press between the

electrodes, giving an electrode separation distance of between 20 and 30 cm, depending on primal muscle mass. ES characteristics were similar to those used for whole carcase stimulation (pulse width 10 msec, pulse frequency 12.5 pps), except that voltages of 120 and 380v were applied over a two min duration. Partial restraint of the primal muscles during ES was achieved by the application of a 45N turning moment (by torque wrench) to the press.

91. Individual primal muscles were consolidated and stimulated as two batches per LHS carcase side as follows;

Primal Stimulation (a): The FQ (above scapula) and FQ (below scapula) primal muscle block were placed on the lower electrode, so that cut muscle surfaces from both primal muscles made direct electrical contact. The excised loin primal muscle was laid over the FQ primal muscle blocks, dorsal side downwards, so that the interior face of the *M. longissimus dorsi* muscle was in direct contact with upper electrode.

Primal stimulation (b): The HQ primal muscle block was placed in contact with the lower electrode, ensuring that the *M. semimembransosus* muscle made direct electrical contact; the rump and fillet muscles were laid over the HQ primal muscle block and covered by the flank, which was laid so that its interior face made direct contact with the upper electrode.

92. Muscle pH samples were removed immediately before primal-ES and after holding primal muscles for 30 min after stimulation under ambient temperature (20°C) conditions. Primal cuts were weighed, placed in folded synthene bags (to allow for further pH samples to be taken at 4, 10, and 24 h *post mortem*) and loaded as a single layer into 50 l perforated baskets. Rapid chilling was carried out in air at -1°C; slower chilling was achieved by holding primal muscles for 10 h at 21°C, followed by chilling at +3°C for a further 14 h period. High voltage ES was applied alternately to RHS carcase sides; these were chilled under similar regimes and cold boned at 24 h *post mortem*. After chilling, primal cuts were held at -1°C for a further 24h, before being plate frozen as a single layer from 0 to -35°C over a twelve h cycle.

93. A microbiological assessment was made by swabbing thawed primal muscle cuts immediately prior to retail butchery and by swabbing retail cuts after 3 days retail display at +5°C. Primal (thaw) drip and retail drip losses, objective toughness (shear) and colour stability were assessed as previously described.

94. Results relating to these trials are tabulated in Appendix 3 (Tables 3.1. to 3.19) and discussed below. The significance of differences between treatments were analysed using student 't' tests applied to treatment means; coefficient of variation was used to compare variation within corresponding data sets. Relationships between data sets were analysed where appropriate using linear regression (least mean squares).

5.3.2. Electrical stimulation performance.

95. Culled ewe carcases (RHS) were given conventional HVES (450v) after splitting at 0.25 h *post mortem*; hot boning of the corresponding LHS of each carcase commenced with excising FQ muscles and was completed within 0.7 h *post mortem*. Excised FQ and HQ muscles were stimulated (120 or 450v) for 120 seconds; electrode polarity was reversed after the first 60 seconds of stimulation. Stimulation data are given in Appendix 3: Table 3.1. FQ and HQ were stimulated at an average of 0.55 h and 0.65 h *post mortem* respectively. Muscle temperature at primal stimulation differed significantly ($p<0.001$), averaging 34.7 °C in the FQ and 37.3°C in the HQ, reflecting the faster rate of heat loss in the thinner FQ muscles.

96. Application of both 120 and 380v stimuli resulted in a localised contraction, which appeared to lessen in intensity over the stimulation period. Muscle response was still evident at 380v when electrical polarity was changed after stimulation for the first minute. The packing effect caused by the application of pressure under no applied voltage was marginally larger in FQ primal muscles, since these were comparatively smaller and were more able to deform through tearing along intermuscular seam lines. The application of ES to hot excised primal muscles resulted in an inconsistent increase in packing effect. The packing effect was marginally greater at 380v but is likely to be of little practical value.

97. Energy inputs were calculated on the basis of indicated current, and the use of a 12.5 pulse per second, 10 msec pulse width electrical cycle. Variation in energy application, calculated in relation to kg weight, was similar for muscles and voltage tested, giving coefficients of variation ranging from 31 to 33%. Regression analysis suggested that there was no relationship between energy applied (KJ/kg), muscle temperature and *post mortem* time. The effect of temperature showed the highest relative correlation to energy, although this accounted for <20% (regression coefficient = 0.423; p - not significant) of the variation in applied energy. Intermuscular fat level, animal age, path continuity and length of pathway (as opposed to muscle mass) would be expected to effect resistance and drawn current. Greater understanding of the factors contributing to the variation in energy input and their effects, if any, on meat quality would be necessary if the process were to be developed further.

98. The stimulation of confined primal muscles represented a considerable improvement in safety procedure compared with the stimulation of free carcase sides. There were small losses in measurable drip from the primal cuts as they reacted to ES under pressure. These amounted to less than 0.1% of primal mass weight based on drip measurement over the processing operation. The cross-transfer of exudate between muscles in a commercial process would require the introduction of appropriate sanitising measures.

99. The effectiveness of ES applied to excised muscles compared to ES applied to carcase sides was assessed by determining changes in muscle pH (Appendix 3: Tables 3.2. to 3.4). Conventionally applied HVES (450 v) reduced muscle pH at one h *post mortem* (over that in the non-stimulated control carcase sides) by an average of 0.16 pH units in the FQ (*M. triceps brachii*) over a mean pH value of pH 6.48 in the control. HVES reduced loin (*M. longissimus dorsi*) pH by 0.24 pH units (mean pH 6.45 in the control) and by 0.20 pH units in the HQ (*M. semimembranosus*) muscle (mean pH of 6.48).

100. Slow chilling permitted rapid pH fall in untreated control carcases, giving pH values of <5.9 at ten h *post mortem* in the three muscles tested. HVES under these circumstances had little advantageous effect, although it did reduce the variation in muscle pH fall between animals, reducing the coefficient of variation from 23 to 14%.

101. Rapid chilling significantly ($p<0.01$) reduced muscle pH fall over the first ten h period in carcase sides. The average muscle pH in the untreated control carcases was <pH 6.2. at ten h *post mortem* in the three muscles tested. Muscle pH in HVES-treated carcase sides was reduced to <6.2. at ten h *post mortem*, although HVES appeared least effective in accelerating pH fall in the loin (*M. longissimus dorsi*) muscle. HVES, applied to carcase sides, did not appear to reduce variation in muscle pH between muscles or animals under rapid chilling conditions.

102. The application of ES to excised muscles produced an immediate reduction in muscle pH (over the 30 min period after stimulation), although this was not consistent between muscles. Average muscle pH in the loin was reduced by 0.20 and 0.21 pH units (compared to an average pH of 6.63 in the non-stimulated controls) using 120 and 380v respectively. A similar level of pH reduction was measured in HQ muscles, pH being reduced by 0.25 and 0.19 pH units (compared to a mean pH of 6.63 in the non-stimulated control) at 120 and 380 v, respectively. The application of ES had less effect on the immediate pH fall in FQ muscles, with average pH reductions of 0.06 and 0.09 pH units (mean pH 6.70 in the control) for 120 and 380 volt treatments. There was some variation

in the initial pH reduction within each primal muscle treatment group (average coefficient of variation for all muscles ranging from 1.7 to 3.6%), which was not directly related to the energy input described earlier.

103. The extent of the initial pH reduction to primal ES in the *M. semimembranosus* muscle was lower than the 0.32 pH unit reported by Chrystall et al. (1980), in the direct application of a 200v stimulus for 120 seconds to entire lamb legs at 30 min *post mortem*. Newbold and Small (1985) showed that the extent of the initial muscle pH reduction under localised 12v ES application in lamb *M. semitendensosus* muscle was related to pre-stimulation pH. Data from Newbold and Small (1985) suggests that localised ES would reduce muscle pH in *M. semitendenosus* muscle at a pre-stimulation pH of 6.7 by 0.2 pH units, which is similar to that recorded here for primal ES applied to *M. semimembranosus* muscle in culled ewes.

104. The application of primal ES under slow chilling conditions had no significant effect on the subsequent rate of muscle pH fall over that in non-stimulated hot boned control muscles. All hot excised muscles achieved a pH of 6.2 units or less at ten h *post mortem*; the rate of pH fall was not significantly faster at higher ES voltages. Rapid chilling reduced the rate of muscle pH fall in all hot boned treatments, with the effect of faster temperature fall remaining significant ($p<0.05$) in non-stimulated hot boned muscles at 24 h *post mortem*. The application of primal ES at 120v, followed by rapid chilling conditions, was unable to introduce sufficient acceleration in pH in FQ primal muscles in order to achieve an average pH of <6.2 at ten h *post mortem*. This threshold was achieved in all other primal ES treatments, and was equivalent to the performance of HVES applied to the carcase side.

105. The application of ES to primal muscles had no effect in reducing inter-animal variation in the rate of subsequent muscle pH fall. The electrical parameters used in this preliminary study may not necessarily be the most appropriate in terms of the acceleration in the rate of muscle pH fall or in the reduction in inter-animal variation.

5.3.3. Hot boning yield.

106. Yield data for the modified hot boning and primal stimulation procedure, compared against cold boning performance under both slow and rapid cooling protocols, are given in Appendix 3: Tables 3.5 and 3.6. Separate calculations, based on differences between corresponding LHS and RHS carcase pairs, were made to determine the yield advantage of hot boning. Non-stimulated and HVES-treated carcase sides lost an average of 3.6% of hot mass weight due to evaporation over a 24 h slow chilling cycle, with further losses on boning amounting to an average of 4.3% loss on hot mass weight.

Rapid chilling confined the equivalent to an overall loss of between 3.5 and 3.9% of hot mass weight. HVES applied to carcase sides had no significant effect on evaporation or boning losses over non-stimulated carcase sides.

107. Overall weight losses during the hot boning and primal restraint procedure averaged 1.4% of carcase mass. Calculations based on paired data indicated that hot boning, followed by rapid or slow chilling, increased primal muscle weight by 4.8 and 3.8% respectively over that recovered from the corresponding cold boned sides. Similarly, hot boning increased recovered meat (primal meat plus bone trimmings) by 3.8 and 2.7% over that from rapid and slow chilled cold boned carcase sides. Hot boning significantly ($p<0.05$) reduced the proportion of meat trimmings in the overall yield of recovered meat compared to that from rapidly chilled carcases.

108. The application of ES to primal muscles did not significantly affect weight loss on boning or hot excised primal weight. Recovered meat weight was not significantly effected by primal stimulation at 120 or 380v. Hot boning and primal ES treatments consistently returned lower proportions of meat trimmings, reflecting the ease in excising whole muscles from the carcase. The mean proportion of meat trimmings in the total of recovered meat over all hot boning treatments was reduced by 12.0 and 10.4% compared to the respective proportions produced from cold boning rapid or slow chilled carcases. Hot boning was generally quicker than conventional cold boning operations, although the extent of this advantage was more apparent when the fat temperature in the cold boned carcase was below 5°. A recent survey has been completed in Australia, analysing occupational health in the beef boning industry (Caple and Barrow, 1992). The findings indicated that hot boning operations have a lower incidence of occupational injury. Hot boning is considered to be both quicker and more efficient, leading to less boner fatigue. These advantages appear to be directly transferable to small-stock boning.

5.3.4. Effect on meat quality.

109. The effect of the application of ES to primal muscles on thawed drip loss, retail drip loss and objective toughness is given in Appendix 3: Tables 3.7. to 3.9. Hot boning increased the overall extent of primal drip loss, when compared to cold boning, although the increases were only significant ($p<0.05$) for rapidly chilled unstimulated muscles. Weight losses for these hot boned rapidly chilled muscles ranged from 0.9 to 1.6% of original primal pack weight, and would probably not be apparent to a wholesaler. Smaller increases in drip loss, averaging 0.4 to 0.9% of original pack weight, were recorded in slow-cooled hot boned muscles compared with the cold boned primal muscles.

110. Hot boning alone had no significant effect on retail drip loss, although there was a tendency for increasing retail drip losses to reflect previous increases in primal drip loss (regression coefficient = 0.85; $p<0.05$). Inter-animal variation in retail drip was decreased under slow cooling conditions. Hot boning produced an overall increase in average muscle toughness (shear value), when compared to non-stimulated cold boned carcases. Shear value was significantly ($p<0.05$) increased in rapidly cooled FQ muscles, amounting to a 21% increase in objective toughness over rapidly-cooled cold boned muscles. Inter-animal variation was increased in FQ muscles under both chilling regimes. Hot boning had no significant effects on the toughness of other muscles, but did appear to decrease inter-animal variation in loin and HQ muscles.

111. Rapid chilling had no effect on thaw drip loss over any of the treatments. It would be expected to increase primal drip loss, due to the increased presence of condensate at the bagged muscle surface, but this effect was overwhelmed by subsequent losses in intracellular fluid. Rapid chilling significantly ($p<0.05$) increased retail drip loss in packs from unstimulated cold boned primal HQ muscles but had no effect elsewhere. Rapid chilling alone increased FQ toughness as described earlier but had no significant effects in other treatments.

112. HVES applied to carcases marginally increased primal thaw drip in all treatments, with actual increases ranging from 0.21 to 0.39% of original muscle weight over both chilling regimes. The effect on inter-animal variation was variable, with HVES acting to increase variation in all muscles under rapid chilling conditions and to decrease sample variation under slow cooling. HVES applied to carcases significantly ($p<0.05$) decreased retail drip loss in the rapidly cooled loin muscle; inter-animal variation in retail drip was increased under rapid chilling and decreased under slow cooling.

113. HVES applied to rapid cooling carcases significantly ($p<0.05$) reduced mean objective toughness (shear value) in loin muscle, amounting to a 14% reduction in toughness over muscles from non-stimulated carcases. The reduction in loin toughness was accompanied by a reduction in inter-animal variation. HVES applied to carcases appeared to slightly toughen FQ and HQ muscles which were cooled slowly. Low and high voltage ES can induce muscle toughness through a rigor-shortening reaction which may result from the induction of a very rapid pH fall in muscles which are at temperatures above 30°C (Marsh, 1983).

114. ES applied to primal muscles had no effect on thaw drip loss in muscles cooled slowly or rapidly. Inter-animal variation was reduced under rapid chilling conditions; average coefficients of variation for FQ, loin and HQ muscles were 40.2, 23.4 and 24.1%

for non-stimulated hot excised primal muscles, primal ES-120v and primal ES-380v treatments, respectively. Variation under slow chilling regimes was largely unaffected.

115. Primal ES had no significant effects on retail drip, other than that introduced by hot boning. The application of ES to excised muscles did not appear to alleviate the increase in toughness due to hot boning. Primal ES-120v had some effect in reducing toughness, although this amounted to a 13% reduction over the unstimulated hot boned muscle; it had no effect on toughness in other muscles, either under rapid or slow cooling conditions. The application of a 380v stimulus did not reduce toughness significantly in any treatment; there was a tendency to lower comparative values in muscles under rapid chilling conditions. Primal ES appeared to introduce a small increase in toughness due to heat rigor under slow cooling conditions; primal 380v ES reduced inter-animal variation in the majority of treatments.

116. The effect of ES on the development of initial meat colour for FQ, loin and HQ retail sections is given in Appendix 3: Tables 3.10 to 3.13. Colour values in these tables have been determined as CIE cylindrical co-ordinates of lightness (L^*), chroma (C^*) [derived as $((a^*)^2+(b^*)^2)^{-2}$], and hue (H°) [derived as $\tan^{-1}(b^*/a^*)$]. Hot boning had a limited effect on the development of initial colour, significantly ($p<0.01$) increasing L^* values in rapidly chilled FQ muscles compared with cold boned non-stimulated FQ muscles. Hot boning had little overall advantage in L^* value in other treatments, and had no effect on redness (chroma C^*) or colour depth (hue H°). FQ muscles from culled ewes tend to be marbled (contain high levels of intermuscular fat), and hot boning may have increased the reflectance of this component rather than increase muscle oxy-myoglobin content.

117. Rapid cooling of the carcase resulted in a significant ($p<0.05$) reduction in initial L^* values in the majority of cold boned treated muscles, compared with those that which were cooled slowly. This trend was also present to a more limited extent in non-ES and primal-ES hot boned loin and HQ muscle treatments. Rapid cooling tended to result in lower C^* values over all treatments, although this was only significant in HVES cold boned FQ muscles, non-stimulated cold boned loin muscles and non-stimulated hot boned FQ muscles. Rapid chilling tended to increase comparative H° values, although this was only significant in primal ES 120v treated loin muscles.

118. The application of HVES to carcase sides had no effect on L^* value, but did reduce C^* value in HQ muscles cooled slowly. Slow cooling resulted in small increases in H° value. HVES is generally claimed to enhance meat colour development and stability (Smith, 1985) although this finding is most noticeable in the loin of high-grade

beef carcases. HVES did not offer any reduction in inter-animal variability in colour development.

119. The application of primal ES 120v had no effect on muscle L^*, C^* or H° value. Primal 380v ES significantly ($p<0.05$) increased muscle C^* value in the loin, although it is doubtful if changes of this order would be evident to the majority of consumers. There were no effects in other treatments and primal ES had no effect on inter-animal variation in muscle colour.

120. All retail packs were reassessed after three days storage at 5°C; data for colour stability are given in Appendix 3: Tables 3.13 to 3.15. The initial advantage in L^* value shown by rapidly chilled hot boned FQ muscle was maintained ($p<0.01$), as was a smaller advantage in L^* and H° value in other hot boned treatments. Inter-animal variation was not affected within the treatment groups.

121. Rapid chilling of the initial primal muscles resulted in consistently lower L^* values in the majority of treatments, although this was only significant ($p<0.05$) in cold boned HVES-treated loin and HQ muscles, non-stimulated hot boned loin muscles and primal 380v ES treated loin and HQ muscles. The variation in L^* value in all treatments was unaffected over the three day display period. Average coefficients of variation for L^* fell marginally over the three day, from 5.6 to 5.3% in the hot excised treatment groups and from 6.7 to 5.3% in the cold boned treatment groups respectively.

122. Reductions in the C^* were recorded over the three day period for all treatments, although these were only significant ($p<0.01$) in cold boned slow chilled HVES treated FQ, loin and HQ muscles. Reduction of this order in the C^* value, which equates to the loss in surface redness due to the deepening of the sub-surface met-myoglobin layer, would be apparent to consumers. Average coefficients of variation for C^* increased over the three day period from 6.0 to 9.8% in the hot excised treatment groups and from 7.0 to 8.7% in the cold boned treatment groups, respectively.

123. The change in the H° value over the display cycle was more widespread, although significant effects were limited to slow chilled primal ES-120v loin muscles and slow chilled primal ES-380v HQ muscles. Slow cooling of primal muscles led to a large increase in the variation in H° value in the retail packs from all hot and cold boned treatments. Average coefficients of variation for H° increased from 5.8 to 17.4% in the hot excised treatment groups and from 5.9 to 13.7% in the cold boned treatment groups respectively. Some aspects of H° value were probably influenced by microbial proliferation.

124. Both HVES applied conventionally and ES applied to excised muscles had limited effects on the quality of meat from culled ewes. The application of more direct electrical fields by stimulating primal muscles enhanced muscle pH fall, and offered a small advantage in reduction in meat toughness induced through hot boning. Primal ES did not reduce the inherent variability of ES technology when related to its effect on meat quality from lower grade animals. However ES applied to primal muscles produced no adverse effects on the water-holding properties of muscles under investigation or on retail colour development and loss in colour stability over time. The ES variables applied to excised muscles, e.g. pulse characteristics, voltage and application time, were based on those used in the conventional application of ES to whole carcases and may not necessarily be optimal for stimulating primal muscles.

5.3.5. Microbial assessment.

125. Aerobic microorganisms (plate count at 5, 25 and 37°C), presumptive coliforms and presumptive *Staphylococcus aureus* were determined in primal muscles prior to retail butchery; data are given in Appendix 3: Tables 3.16 to 3.17. Mean aerobic psychrotrophic and mesophilic counts in rapidly chilled cold boned primal muscles ranged from log 2.7 to log 3.4 cfu (colony forming units) /cm^2, which are within the log 5 level of product acceptability. There was a considerable spread of results within each treatment group, reflecting variations in microbiological load over the different primal muscles sampled. The presence of *Staphylococcus aureus*, which is a microorganism which tends to reflect poor product handling, was within an acceptable log 2.0 level; presumptive coliforms, which can be a gross indicator of poor personal hygiene, were absent.

126. Slow initial cooling in carcases resulted in a general increase in aerobic psychrotrophic and mesophilic microorganisms recovered at 25°C. There were significant ($p<0.05$) increases in the level of *Staphylococcus aureus* suggesting higher levels of environmental contamination during chilling. The level of mesophilic organisms recovered at 35°C, which can generally indicate human contamination, and the presumptive coliform count were largely unaffected, since carcase muscle temperature was less than 5°C at boning. HVES applied to carcase sides had no effect on the proliferation of microorganisms or on the variation within treatment groups, regardless of chilling regime.

127. Hot boning, followed by rapid chilling, had no effect on the level of psychrotrophic or mesophilic microorganisms recovered at 35°C, but did significantly ($p<0.05$) reduce the aerobic mesophile count recovered at 25°C. This finding, which appears to suggest that hot boning was carried out in good environmental conditions, may

more appropriately reflect the short term protective effect offered by antibodies in hot muscle (Gill and Penny, 1979).

128. Hot boning, followed by slow chilling, did not significantly increase the level of microbiological proliferation in primal muscles when compared to those from slow chilled carcases. However more valid comparisons must be made to 'best practice', i.e. to levels of contamination on rapidly chilled primal products. Slow chilling resulted in significant ($p<0.05$) increases in mesophilic microorganisms recovered at 25 and 35°C and for *Staphylococcus aureus* when compared to levels recovered from rapidly chilled hot boned primal muscles. The previous advantage of hot boning in the reduction of the mesophile count recovered at 25° was lost. The extent of the overall increase in aerobic count at 5, 25 and 35° (log 2.08, log 1.09 and log 0.67 cfu/cm^2) in slow chilled hot boned primal muscles indicates that the environment may have contributed a more significant effect on a reduction in microbial acceptability than the hot boning process itself. The extent of increases in coliforms and *Staphylococcus aureus* (log 2.81 and log 1.28 cfu/cm^2) were greater than the 10 generations recommended under AQIS regulations if thawed primal muscles were taken to be the end of the overall chilling process.

129. The application of primal ES, followed by rapid chilling, had no significant effect on the level of microbial proliferation over that introduced within the hot boning process. There were no significant differences due to applied voltage. Primal ES had no significant effect, above that due to hot boning, on the proliferation of microorganisms under slow chilling conditions, although the extent of proliferation would come within AQIS guidelines.

130. Microbiological growth was determined in retail packs after three days storage at 5°C (Appendix 3: Tables 3.18 to 3.19). Mean levels of aerobic psychrotrophic and mesophilic microorganisms from rapidly chilled cold boned primal muscles ranged from log 3.00 to 1.51 cfu/cm^2 (recovered over the incubation range of 5 to 35°C). Slow chilling of carcases increased the level of aerobic psychrotrophic and mesophilic microorganisms by more than 100 generations, although this was not statistically significant due to the large inter-sample variation. Aerobic mesophile counts of slow chilled carcases ranged from log 5.87 at 25°C to log 3.93 cfu/cm^2 at 35°C.

131. Aerobic counts of log 6.5 to log 7.0 cfu/cm^2 can be considered to mark the upper limit of retail acceptability. Retail packs from slow chilled primal muscles have average aerobic counts within this limit, although levels of log 3.0 cfu/cm^2 for *Staphylococcus aureus* would indicate cause for concern. HVES applied to carcase sides had no significant effect on the extent of or variation in microbial proliferation.

132. Retail packs from hot boned rapid chilled muscles showed significant ($p<0.05$) increases in aerobic psychrotrophic count, with less significant proliferation in mesophilic microorganisms recovered at 25 and 35°C. The application of primal ES had no further effect on the extent of microbial growth over that associated with hot boning, although the majority of muscle packs had levels of psychrotroph counts that were at or in excess of the limit in retail acceptability. The mean level of presumptive coliforms and *Staphylococcus aureus* were 100 fold higher than retail packs from rapidly chilled cold boned muscles.

133. Retail packs from slow chilled hot boned primal muscles showed significant ($p<0.05$) increases in aerobic microbial counts compared with retail packs from rapidly chilled cold boned muscles. The application of primal ES had no significant effect on the extent of microbial growth, although here was a tendency for mesophilic microorganisms recovered at 25 and 35 °C to increase with increasing voltage. The average aerobic psychrotrophic and mesophile (35°C) count in these packs was in excess of log 7.2 and log 3.84 cfu/cm^2, respectively, which were log 3.3 and log 1.9 higher than rapidly chilled cold boned packs. Levels of presumptive coliforms and *Staphylococcus aureus* were log 1.5 and log 2.0 cfu/cm^2 higher than in cold boned retail packs; both counts are above the levels conventionally set for retail acceptability, with some packs being considered unsafe.

134. The results quoted here were obtained within an organised hot boning system, operating to hygiene levels which equate with good manufacturing practice. Data from these trials need to be re-evaluated within growth models proposed by Gill et al. (1991) in order to more accurately describe microbial growth in selected muscles under hot meat regimes. Rapid chilling according to AQIS specifications (cooling of hot meat to <8°C in six h) was essential in maintaining micobiological integrity over an extended retailing operation. More stringent temperature-reduction requirements appear to be indicated where hot meat, conserved for retail sale, is subject to early temperature abuse such as boning in ambient temperatures.

6. A survey of meat processing industries in three African countries.

6.1. Background.

135. The project objectives called for an RRA type survey of producers to establish the extent for the future uptake of hot boning and plate freezing technologies. This was to be undertaken within the context of a review of future developments and demands in the meat industries of selected countries. It was considered more appropriate to base this assessment on an initial survey of commercial meat producers and their local/national government support agencies.

136. The visit was undertaken from 7-24 November 1993 by D.Silverside (Meat Technologist) and M. Pritchard (Socio-economist), assessing meat-processing systems and future technological demands in three African countries (NRI Visit Report No. R2119(S) Silverside and Pritchard, 1994). The countries were selected to reflect poorly (Tanzania), moderately (Malawi) and well (Namibia) developed meat processing and marketing systems. Discussions were focused on aspects of meat distribution practices, including plate freezing, the possibilities for the introduction of this or associated technologies, and an identification of research priorities in the development of their respective meat-handling industries.

6.2. Tanzania.

137. Agriculture occupies 80 per cent of the population and accounts for 56 per cent of gross domestic product (GDP). Cattle production is largely made up of smallholder producers in the pastoral and agro-pastoral sector. The national herd comprises 13.2 million head of cattle, of which approximately 65,000 head are improved animals held on the small commercial farms of the National Ranching Company. The main surplus cattle-producing regions lie in the north and north-west of the country whilst the main consumption and deficit areas are in the coastal regions and in the southern part of the country.

138. Cattle trading is a private sector enterprise, with traders competing to arrange the purchase from producers or from primary markets, and consigning them to terminal livestock markets for sale to butchers. The transport of livestock is mainly by long-distance trekking or by rail. Both systems have suffered from under-investment, with a decline in the functional transport system, and disrepair in the dipping and holding facilities that serviced the trekking routes. Both systems of transport result in injuries and/or losses in condition *en route*. The unregulated and excessive use of long-distance trekking through informal routes results in 10-20 per cent weight losses and 7-10 per cent mortality (Colby, 1994). The transport of animals to urban markets such as Dar es

Salaam can take four weeks and transport costs can form 80 per cent of marketing costs (Silverside and Pritchard, 1994).

139. There is very little meat wholesaling and individual butchers control most of the retail trade. The products are limited to hot cuts of sliced primal meat or meat with bones, with very little differentiation on the basis of quality or into other products. A small number of higher-income retail outlets service the restaurant and hotel-catering sector; these make use of local freezing to store meat not sold on the day of slaughter. Consumer preference is for fresh hot meat, with outlets limiting their daily turnover to one carcase. Consumers in Dar es Salaam used to purchase frozen meat but local butchers now think that the prospect of selling frozen meat is low. There might be some potential in servicing the meat markets in Mtwara and Lindi, although there would be considerable problems associated with infrastructure, particularly in electricity supply.

140. The decline in transport infrastructure is seen as a major constraint to the development of commercial activities. There is a proposed African Development Fund (ADF) project to rehabilitate certain stock routes, and there are other donor funds being used for upgrading of rail and road links. Priority is to be given to the rehabilitation of livestock markets and stock routes, veterinary support, repair to railway wagons and vocational training. These proposals cover minor rehabilitation work and appear not to address the major structural problems within the present industry. A new model abattoir is to be built at Dodoma (under a separate project submitted to the ADF) which may present a single opportunity for the introduction of appropriate boning and extended conservation procedures.

141. Tanzania has a large national herd and considerable potential for the development of livestock and meat industries. New abattoir investment is being planned by a number of institutions, although these facilities would largely provide hot meat for local urban markets. Members of the meat industry see the acquisition of market data as the key priority issue in order to attract new investment. Opportunities for the introduction of accelerated processing technology in the short-term are limited. There is longer-term potential for export to neighbouring countries, which would require the introduction of additional abattoirs (based on the Dodoma model) operating chilling or freezing systems.

6.3. Malawi.

142. Agriculture occupies 73 per cent of the population, and accounts for 33 per cent of GDP; only 13 per cent of householders keep cattle. Fifty per cent of cattle production is concentrated in the central region with the remainder evenly distributed to the north and south of the country. Livestock production largely remains within smallholder mixed

farmers, with some ranching/feed-lot and stall-feeding schemes in the central and southern regions. The output from the smallholders sector has been in decline, due to disease and drought problems; population pressure leading to an inability to increase the national herd; and the liberalisation of livestock prices having a negative impact on the supply response due to low price elasticities.

143. The majority of animals are slaughtered in very basic facilities, often at the roadside. Butchers throughout the country slaughter and sell hot meat in towns and villages; small-holders get comparatively higher prices from these butchers since the parastatal purchase price penalises lower-grade animals. Twenty per cent of cattle are slaughtered in two parastatal abattoirs, managed under the Cold Storage Company (CSC) and administered under the Agricultural Marketing and Development Corporation. The CSC is not profitable, with annual cattle throughput having dropped from 24,000 in 1983 to 16,000 per year in 1992. The parastatal has problems in obtaining higher-grade animals in order to reduce its unit slaughter cost.

144. The abattoirs at Lilongwe and Blantyre have suffered from under-investment, and are probably beyond realistic refurbishment. The units currently take in higher-grade livestock (from feed-lot and stall-feeding units), taking advantage of the relatively good infrastructure to access nearby production areas. Chilled meat from the abattoirs is distributed by road to major retailers catering largely to high-income consumers. Retail prices for meat in the informal sector are considerably higher than those for fish, which still provides the majority of muscle-protein intake to most householders.

145. None of the conditions identified in the project memorandum for the introduction of accelerated-processing technology are evident in Malawi. The potential for increased livestock production is limited by the lack of available land for grazing or production of feed. Losses in livestock during slaughter and processing are thought to be small. Improvements in meat quality and the introduction of new technologies are seen as being of low priority.

6.4. Namibia.

146. Agriculture in relatively important, occupying 34 per cent of the population and contributing 11.3 per cent of GDP. The beef industry dominates the agricultural sector of Namibia, contributing 75 per cent of gross agricultural income (Meat Board, 1992). The meat industry in Namibia has similarities to that in Zimbabwe and Botswana, in that it consists of highly-developed ranching enterprises and a communal sector based on pastoral and agro-pastoral units. Cattle are produced in two areas which are delineated by a Veterinary Cordon Fence (VCF). Cattle production in the disease-free zone to the south

of the VCF consists of large-scale commercial farms, with some small-scale communal areas distributed amongst them. Production in the zone to the north of the VCF is based on communal production.

147. The commercial areas contribute the great majority of marketed livestock and have historically received the bulk of government subsidies and support prices. The sub-sector produces high-quality livestock and is very profitable, due to the high price attracted by these animals as slaughter-stock or for further fattening in South Africa. Production in the southern zone communal areas is largely on a subsistence basis, with herd increases during drought-free years and 'offtake' in response to seasonal income needs and as distress sales in drought years.

148. Cattle production in the northern communal areas is characterised by traditional sub-Saharan pastoral and agro-pastoral systems, with herd sizes related to socio-cultural practices. These reflect status within the community and the role of cattle in traditional exchanges and rituals within precarious agro-ecological zones. Offtake levels are low and positive attributes are at variance with commercial slaughtering criteria, with old mature oxen attracting higher prices. Disposal is usually regulated by social needs and annual cash requirements, such as school fees.

149. The majority of cattle are sold to local butchers at rural markets, often through traders, organised by traditional authorities such as Tribal Councils. These butchers slaughter in the bush and sell the meat 'off the bone' with no grading or weighing. Prices paid for livestock at these markets are based on weight.

150. The Meat Corporation of Namibia (Meatco), a private nationwide production and marketing concern, operates three abattoirs south of the VCF. These facilities have licences to export meat to South Africa and the European Union (EU). Commercial beef carcases are subjected to HVES prior to a chilling protocol (initial 10 h chilling at 14°C; remaining period at 1°C) designed to reduce deep muscle temperature to 2°C in 24 h. Loin muscle pH in export carcases must be less than 5.9 at ten h *post mortem* to avoid shipping cold-shortened or DFD carcases. A vacuum-packed chilled product is supplied to the EU, reaching the wholesale customer by rail and sea in a minimum of six weeks. Frozen manufactured meat, from forequarters, occasionally makes up some of the EU export quota.

151. Low-quality manufacturing meat is produced from communal sector animals for export to South Africa. Chilled meat is deboned, and frozen in 27 kg cartons in plate freezers, which have been purchased from Italy or Australia. The latter are more robust

but more expensive. Plate freezers have a minimum repay period of 2.5 years. Meatco considers plate freezers are excellent value and blast freezing is no longer considered a viable investment.

152. The Government of Namibia has increasingly tried to integrate communal and commercial sectors of the livestock production industry. Meatco has expanded its activities to operations north of the VCF, since the commercial areas in the south are unlikely to be able to increase their production beyond current levels. Meat from livestock procured in the Northern Communal Areas (NCA) could only be used for canned meat for export to South Africa. Recently Meatco has received approval for its northern communal facilities to export frozen cuts to South Africa. Animals must be held in quarantine for 21 days prior to slaughter and meat must be held frozen in storage for 14 days prior to shipment. This has significantly increased the potential profitability of the northern operations, although Meatco will have to increase and maintain the quality of carcases that it procures from communal farmers. Delivered livestock are currently in such bad condition that Meatco uses its quarantine farms as short-term fattening stations.

153. Meatco are currently refurbishing two abattoirs in this area in order to comply to export regulations, and is persuading farmers to sell animals to local procurement agents acting on their behalf. Both abattoirs are being fitted with plate freezers; one slaughterhouse will operate as a conventional chilling, cold boning and freezing plant, whilst the other facility will operate a hot-boning and direct freezing system. Meatco have yet to adapt ES parameters to local stock and recognise that they will have major problems with carcase shrinkage (weight loss), cold-shortening in low-grade animals, and meat colour, which may or may be related to DFD, animal breed and age.

154. The NCA processing operation exhibits all the assumed criteria necessary for the adoption of the technologies under investigation at NRI, i.e. losses associated with transport, meat supply to distant markets. Distribution of meat is through a modern fleet of refrigerated vehicles, along good roads to markets in South Africa. Meatco uses un-refrigerated, insulated vehicles for the local transport of plate-frozen meat blocks. Meatco uses HVES technology in its abattoirs south of the VCF for slaughtering high-grade commercial cattle. Its main need relates to the effectiveness of ES on the quality of meat from NCA communal cattle. They were not convinced that stimulation of primal muscles would offer any advantage over ES applied conventionally to poor-grade carcases, but could offer local facilities to NRI to carry out adaptive research work in applying ES to poor quality animals, or more urgently, to investigate the reasons for inferior meat colour.

155. Expansion of livestock production, in response to a market in South Africa, would be of benefit to poor communal farmers, particularly if they can be persuaded to sell animals produced for meat or later participate in a scheme for the improvement of local livestock quality. The choice of hot boning and plate freezing would offer opportunities to assess the operational implications of this type of operation for the benefit of other producers in the immediate region. The limited availability of feed may restrict opportunities for carcase finishing. This and sociological factors may impede efforts at herd improvement that would be required to increase operational efficiency.

7. Conclusions.

156. The development of peri-urban or more rural abattoirs may offer a better financial and environmental option for the replacement of existing urban-sited slaughter facilities. Rural abattoirs tend to operate low-cost hot meat distribution systems. The servicing of more distant urban markets would require the introduction of refrigerated conservation practices, which could be adopted in addition to existing practices.

157. Freezing has been a useful technique in the development of meat industries, particularly where the intervening infrastructure between the producer and consumer is extensive or poorly developed. Simulations confirmed that industrial plate freezers could reduce hot meat to <8°C within six hours of chilling, which is the current microbiological specification for hot processing in Australia. Hot boning and contact freezing, without carcase chilling, would represent the most energy-efficient option for the production of frozen meat blocks. An operation of this type is proposed for the northern regions of Namibia.

158. Rapid chilling in contact freezers would result in losses in product value through cold-induced toughening. ES can be used to protect muscles against this reaction by accelerating *rigor mortis*. The conventional application of ES to carcase sides, using electrical parameters adapted to local animal populations, may still result in a wide range of biochemical response in low-grade animals. The application of ES to carcase sides in freezing operations has the disadvantage of not allowing processors to exploit the pre-rigor processing properties of currently low-value muscles.

159. This programme evaluated the effect of applying localised ES to primal muscle blocks after excision in order to make the hot boning process more flexible. A rapid hot boning schedule, developed in culled ewes, increased primal meat yield by 3.8% of original carcase weight compared with carcase chilling and cold boning operations. Hot boning reduced the proportion of meat trimmings (residual meat from bones) in the total amount of meat recovered, in keeping with the higher efficiency of hot boning systems.

160. ES applied to hot excised muscles under partial restraint within 0.8 hour of slaughter accelerated the fall in muscle pH, although this was more effective using a high voltage 380v stimulus. Low voltage stimulation (120v) was partially ineffective in reducing pH to <6.2 at ten hours *post mortem* in muscles chilled at 4.5°C per hour. Localised ES did not reduce the variation in the subsequent rate of muscle pH compared with that recorded in conventionally-stimulated carcases.

161. Localised ES induced a contractile force in hot boned muscles although this had no significant effect on muscle toughness compared to conventionally-stimulated carcases. The application of ES to primal muscles did not offer any improvement in the extent of or variation in meat quality in muscles from culled ewes.

162. The application of ES to hot boned primal muscle blocks, which represents an additional handling step in hot boning operations, had no effect on microbial quality when muscles were chilled rapidly. Hot boning, followed by slow cooling, resulted in an unacceptable proliferation of microorganisms in the retail product in all treatments. Australian regulations requiring hot meat to be reduced to 8°C in six hours remain appropriate to small hot-processing facilities. Microbial specifications for hot boning at ambient temperatures will need re-appraisal under field conditions.

163. A survey of the meat industries in three Africa countries highlighted the differences in the development status of their respective meat industries. All are capable of considerable development, although there are major constraints relating to feed availability, the supply of slaughter stock, and the development of an appropriate transport/ slaughter/ retail infrastructure. The opportunities for the introduction of new technology in Tanzania and Malawi are limited; improvement in meat quality is not seen as a short-term issue.

164. Developments are taking place in the Northern Communal Areas of Namibia, which are relevant to the concepts investigated in the research programme. Local facilities are being upgraded to supply hot boned frozen meat to markets in South Africa. There is industry-led demand for the re-assessment of ES parameters applied to lower grade animals in sub-Saharan Africa.

165. The lack of a perceived advantage in the stimulation of primal muscles will prevent its further development in the short-term, except perhaps as a tool for assessing the variation in ES performance when it is applied to animals under stress. There is a need to examine the potential for improving low-grade meat for processing, particularly where the local constraints against improvement in animal quality will remain large. The development of livestock production in the NCA of Namibia could offer a model for integrating farmers with distal market demand.

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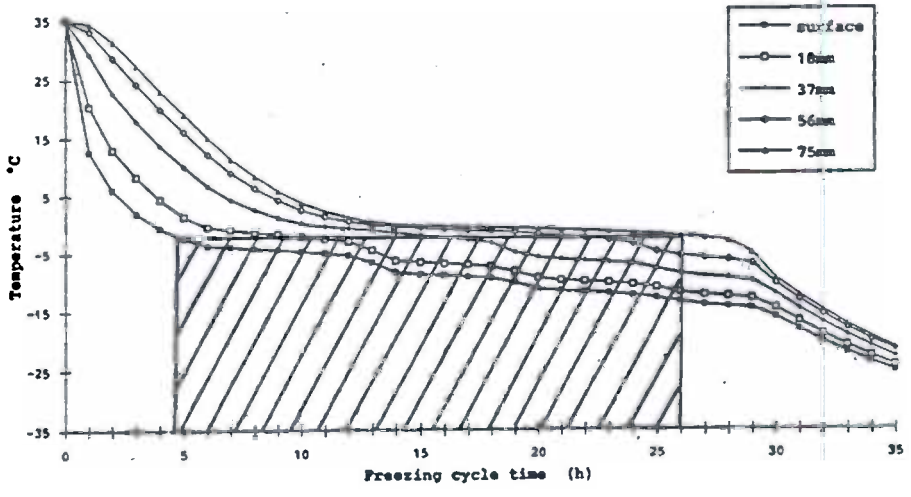
Figure 1.1. The effect of different carton types on temperature reduction in manufacturing meat using blast freezing technology.

(Data derived using CSIRO model. Carton thickness 150 mm, box load 27 kg, initial meat temperature 35°C; blast freezer operating at -40°C on a nominal 48 freezing (to -18°C) hour cycle. The shaded area represents the extent of the range of chilling times to -2°C).

a. Corrugated wall and lid carton.



b. Solid wall and lid carton.

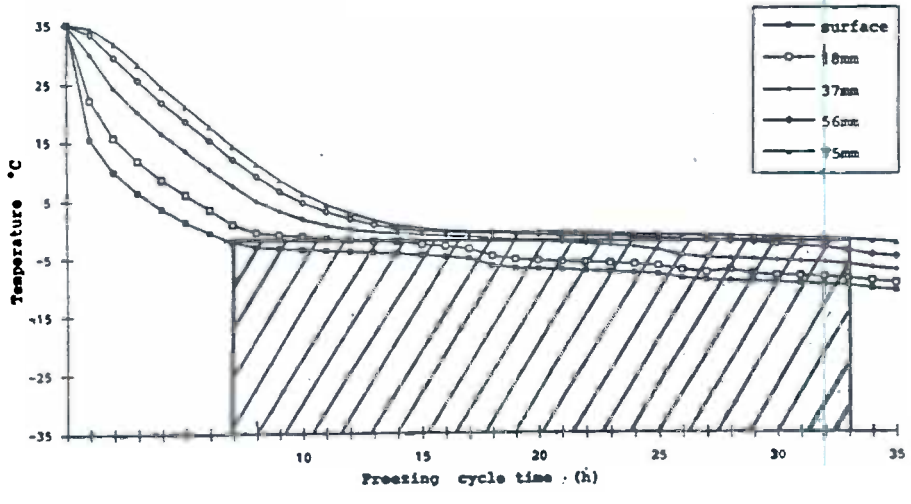
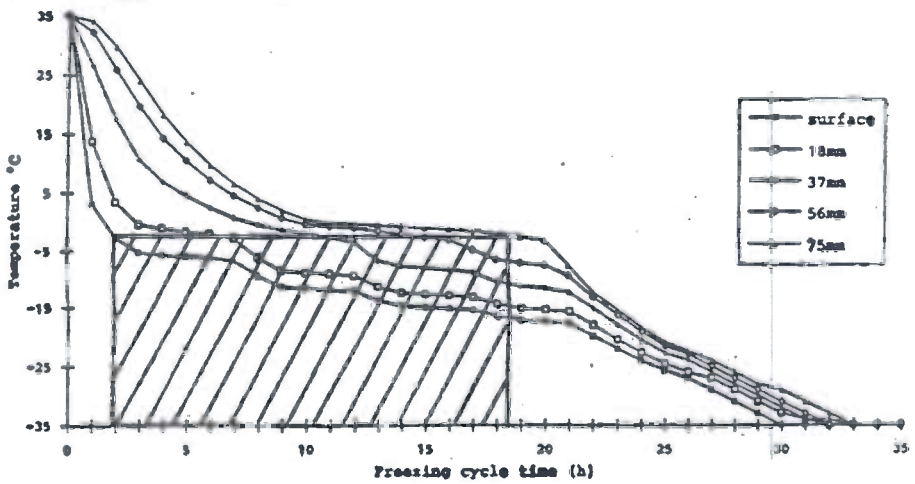


Figure 1.2. **The effect of different carton types on temperature reduction in manufacturing meat using plate freezing technology.**
(Data derived using CSIRO model. Carton thickness 150 mm, box load 27 kg, initial meat temperature 35°C; plate freezer operating at -35°C on a nominal 30 hour freezing (to -18°C) cycle. The shaded area illustrates the extent of the range of chilling times to -2°C).

a. **Corrugated wall and lid carton.**



b. **Solid wall and lid carton.**

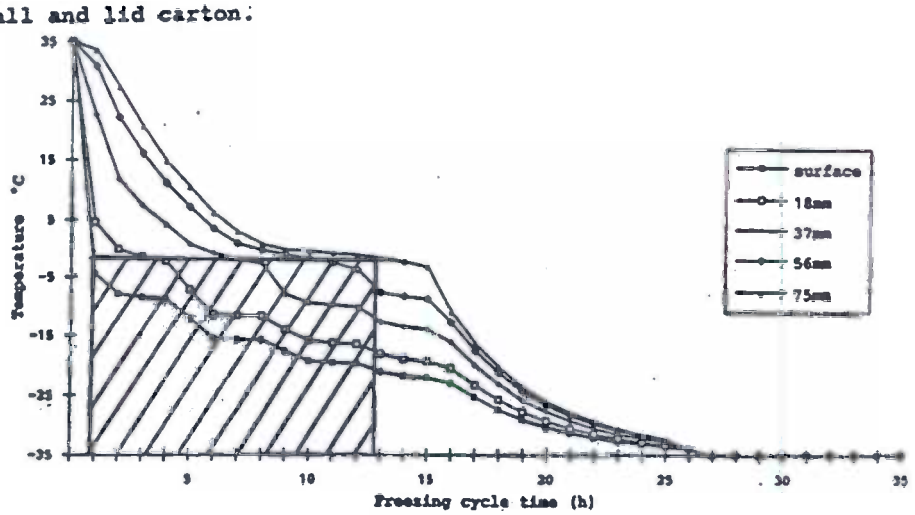
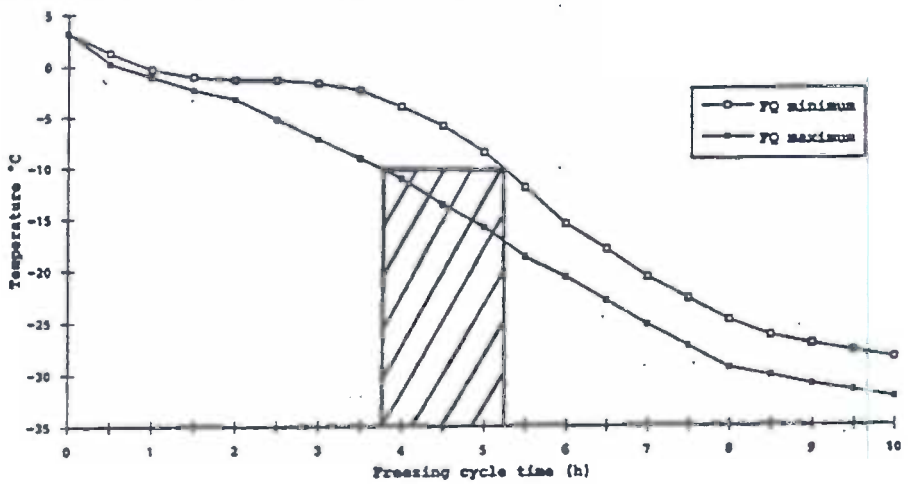


Figure 1.3. The effect of different muscle blocks on temperature reduction in manufacturing meat using plate freezing technology.

(Data derived using tray packed blocks using NRI 120 kg capacity plate freezer. Plate gap of 83 mm, initial meat temperature 3°C; plate freezer operating at -30°C on a nominal 8 hour freezing cycle to -21°C. The shaded area illustrates the extent of the range of freezing times to -10°C).

a. Forequarter blocks - average weight 1.6 kg.



b. Hindquarter blocks - average weight 2.5 kg.

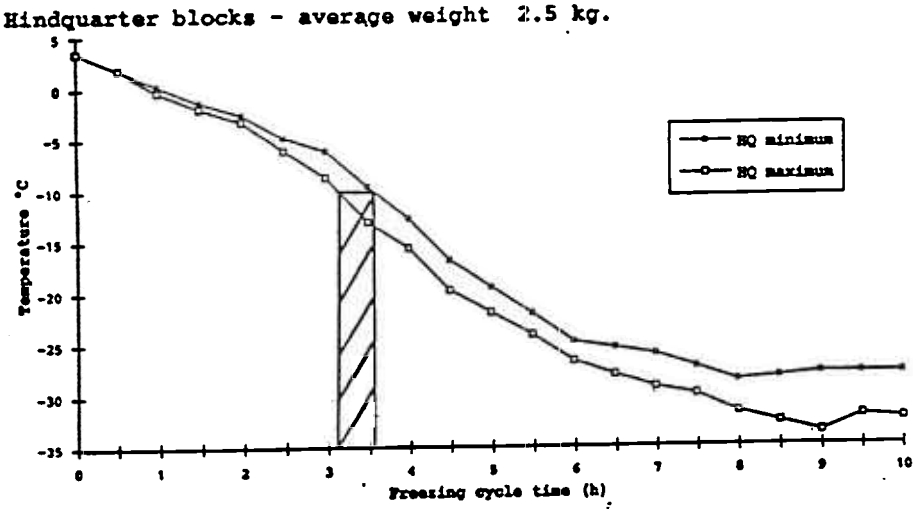


Table 2.1. The effect of hot boning and HVES applied to carcases on recovered meat yield.
(Data given as mean (SD); n=6 culled ewe carcases per treatment).

Treatments	Carcase traits under different treatments				Effect of treatments[1]	
	Hot boned		Cold boned			
	(side-ES[2])	(no ES)	(side-ES)	(no ES)	Hot boning (p<)	ES (p<)
Measurements						
Hot carcase wt (kg)	13.26 (3.00)	19.05 (1.97)	19.04 (2.05)	13.26 (3.00)	Nt	Nt
Cold carcase wt (kg)			18.15 (1.83)	12.74 (2.95)	Nt	Nt
Primal muscle wt (kg)	9.09 (0.80)	11.71 (0.97)	11.61 (1.12)	9.16 (2.37)	Nt	Nt
Recovered meat wt[3] (kg)	9.37 (0.23)	12.39 (11.02)	12.24 (1.09)	9.31 (2.38)	Nt	Nt
Total fat and bone wt (kg)	2.84 (0.26)	6.07 (0.62)	5.70 (0.62)	2.80 (0.28)	Nt	Nt
Dissection total wt (kg)	12.21 (2.80)	18.46 (1.79)	17.94 (1.80))	12.11 (2.80)	Nt	Nt
Performance indicators						
Side evaporation loss[4] (%)			4.67 (1.59)	3.92 (1.40)	Nt	nsd
Weight loss on boning[5] (%)	7.92 (2.00)	3.10 (1.12)	.16 (2.30)	4.95 (1.60)	<0.001	nsd
Weight of trimmings as % of recovered meat[6]	2.99 (0.90)	5.49 (0.55)	5.13 (1.31)	1.63 (0.34)	nsd	nsd

Notes
1. Tested by grouping treatment data. Nt - not tested; nsd - no significant difference at p>0.05 level.
2. HVES (450v) applied to carcase side.
3. Recovered meat is based on primal meat and additional trimmings from bones after removal of primal muscle blocks.
4. Weight loss during chilling expressed as % of initial hot weight.
5. Weight loss expressed for hot or cold boning as % of hot or cold carcase weight respectively.
6. % meat trimming of total recovered meat from hot or cold boned carcases.

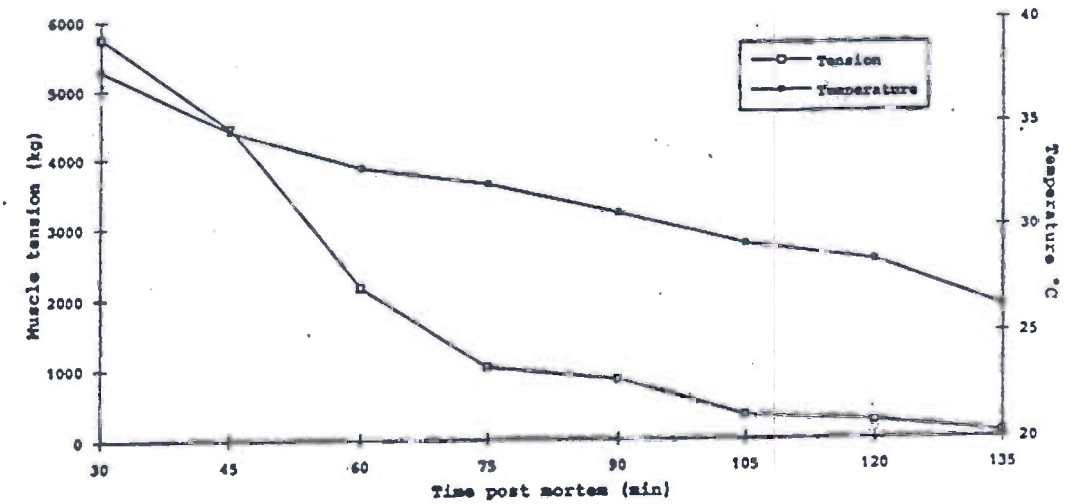
Table 2.2. The effect of hot boning and HVES applied to carcases on pH in primal FQ, loin and HQ muscles.
(Data given as mean (SD); n=6 culled ewe carcases per treatment).

Treatments	pH values under different treatments					
	Hot boned		Cold boned		Effect of treatments[1]	
	(side-ES[2])	(no ES)	(side-ES)	(no ES)	Hot boning (p<)	ES (p<)
Time (h)[3]						
Forequarter[4]						
0.5[5]	6.73 (0.17)	6.85 (0.12)	6.85 (0.10)	6.81 (0.14)	nsd	nsd
1	6.13 (0.22)	6.62 (0.13)	6.38 (0.08)	6.47 (0.11)	nsd	<0.01
24	5.90 (0.13)	6.01 (0.13)	5.93 (0.12)	6.10 (0.14)	nsd	nsd
Loin[6]						
0.5	6.65 (0.14)	6.70 (0.09)	6.72 (0.08)	6.69 (0.13)	nsd	nsd
1	6.36 (0.19)	6.84 (0.10)	6.41 (0.06)	6.53 (0.07)	nsd	<0.001
24	5.83 (0.31)	5.74 (0.11)	5.82 (0.11)	6.20 (0.30)	nsd	nsd
Hindquarter[7]						
0.5	6.78 (.13)	6.74 (0.17)	6.82 (0.15)	6.74 (0.12)	nsd	nsd
1	6.00 (.28)	6.75 (0.18)	6.30 (0.09)	6.54 (0.07)	nsd	<0.001
24	5.88 (.16)	5.77 (0.14)	5.87 (0.14)	6.16 (0.08)	nsd	nsd
	Cooling rates of different treatments					
Forequarter[8] (°C/h)	4.55 (0.36)	3.93 (0.41)	4.06 (0.37)	4.64 (0.30)		
Hindquarter	3.71 (0.40)	3.86 (0.40)	3.76 (0.14)	3.91 (0.20)		

Notes
1. Tested by grouping treatment data. Nsd; no significant difference at p>0.05 level.
2. HVES (450v) applied to carcase side.
3. Time in hours post mortem.
4. pH sample removed from the M. triceps brachii muscle.
5. Pre-stimulation sample removed at 0.5 h post mortem.
6. pH sample removed from the M. longissimus dorsi muscle at 10th rib.
7. pH sample removed from the M. semimembranosus muscle.
8. Mean cooling rate as °C per h to 8 h post mortem.

Figure 2.1. **The change in response to localised ES with time in FQ and HQ muscle areas.** *(HVES stimulus (350 v, 12.5 pps) applied to ovine FQ and HQ muscles in situ; contraction force measured as isometric contraction over 220 mm electrode separation distance).*

a. Change in response in FQ muscle



b. Change in response in HQ muscle

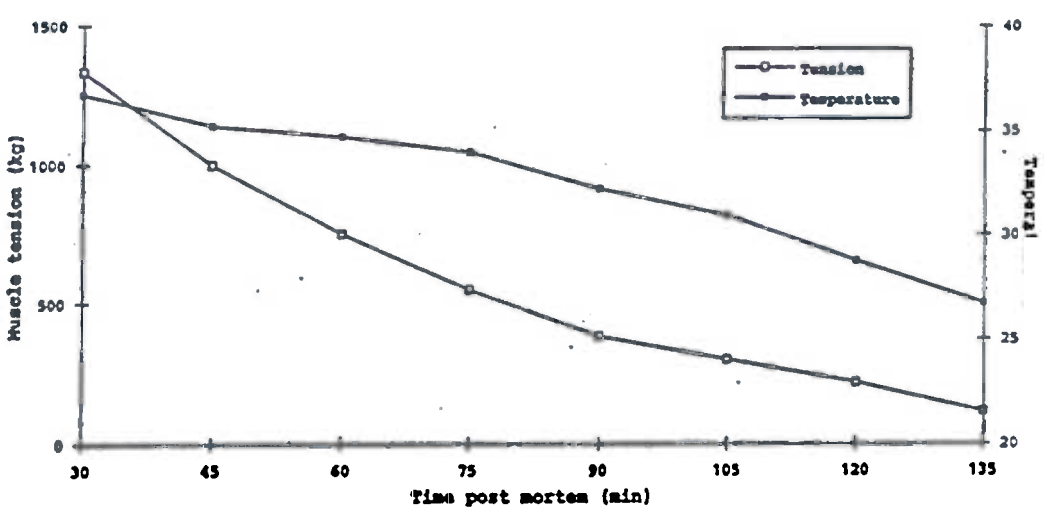


Table 2.3. The effect of hot boning and HVES applied to carcases on meat quality in FQ, loin and HQ primal muscles and retail packs.

(Data given as mean (SD); n=6 culled ewe carcases per treatment).

Treatments	Meat quality indicators under different treatments				Effect of treatments[1]	
	Hot boned		Cold boned			
	(side-ES[2])	(no ES)	(side-ES)	(no ES)	Hot boning (p<)	ES (p<)
Forequarter						
a). Primal drip loss[3] (%)	2.8 (1.62)	3.5 (1.40)	2.5 (0.57)	2.1 (1.16)	nsd	nsd
b). Retail drip loss[4] (%)	2.1 (0.29)	1.5 (0.72)	1.6 (0.19)	2.0 (0.53)	nsd	nsd
c). MFI[5]	110.4 (23.04)	117.8 (11.80)	128.6 (9.49)	108.4 (20.56)	nsd	nsd
d). Objective toughness[6] (N)	85.5(16.16)	85.5 (23.72)	74.4 (14.20)	83.1 (20.88)	nsd	nsd
Loin						
a). Primal drip loss (%)	7.0 (1.71)	7.0 (1.56)	5.5 (2.05)	5.7 (1.37)	nsd	nsd
b). Retail drip loss (%)	2.7 (0.63)	1.9 (0.94)	1.5 (0.64)	2.1 (0.60)	nsd	nsd
c). Objective toughness (N)	74.1 (25.82)	64.7 (16.74)	60.0 (9.87)	84.8 (27.49)	nsd	nsd
Hindquarter						
a). Primal drip loss (%)	5.8 (1.66)	5.1 (0.58)	4.0 (1.19)	5.8 (0.87)	nsd	nsd
b). Retail drip loss (%)	2.6 (0.60)	2.3 (1.03)	1.6 (0.52)	2.6 (0.60)	nsd	nsd
c). MFI	137.8 (8.53)	124.7 (15.90)	124.1 (15.95)	137.0 (12.15)	nsd	nsd
d). Objective toughness (N)	81.2 (12.68))	72.2 (17.21)	68.4 (9.78)	121.0 (47.67)	nsd	<0.05

Notes
1. Significance of difference between treatments; nsd is not significant at p<0.05 level.
2. HVES (450v) applied to carcase side.
3. Primal drip loss is weight loss in primal muscles after thawing.
4. Retail drip loss is weight loss after 3 days retail display.
MFI; myofibrillar fragmentation index given as turbity; higher score index indicates increased physical breakdown in muscle.
Objective toughness as shear value in meat sample cooked to +75°C internal.

Table 2.4. The effect of hot boning and HVES applied to carcases on initial colour development in FQ, loin and HQ retail packs.

(Data given as mean (SD); n=6 culled ewe carcases per treatment).

Treatments	Colour values under different treatments				Effect of treatments[1]	
	Hot boned		Cold boned			
	(side-ES[2])	(no ES)	(side-ES)	(no ES)	Hot boning (p<)	ES (p<)
CIE colour values[3]						
Forequarter						
L^* value	37.0 (2.14)	39.6 (1.36)	39.2 (1.66)	36.6 (1.98)	nsd	nsd
a^* value	21.6 (1.36)	23.0 (0.89)	22.9 (1.23)	21.7 (1.91)	nsd	nsd
b^* value	5.0 (0.86)	7.2 (0.90)	6.9 (0.91)	4.9 (1.29)	nsd	nsd
Loin						
L^* value	33.6 (5.04)	36.2 (2.94)	35.5 (2.16)	32.7 (3.14)	nsd	nsd
a^* value	20.4 (1.82)	22.7 (0.88)	22.3 (0.59)	19.8 (1.39)	nsd	nsd
b^* value	3.3 (1.98)	5.8 (0.87)	5.2 (1.03)	2.2 (2.41)	nsd	nsd
Hindquarter						
L^* value	32.2 (1.43)	32.6 (2.49)	33.1 (1.94)	31.2 (1.93)	nsd	nsd
a^* value	21.7 (2.02)	22.2 (1.64)	21.6 (1.35)	20.9 (0.91)	nsd	nsd
b^* value	2.9 (0.94)	3.2 (2.01)	3.8 (2.20)	2.7 (0.66)	nsd	nsd

Notes
1. Significance of difference between treatments; nsd is not significant at $p<0.05$ level.
2. HVES (450 v) applied to carcase side.
3. CIE Lab values; L^* value light (high); dark (low).
   a^* value red (high); brown (low).
   b^* value yellow (high); blue (low)

Table 2.5. The effect of hot boning and HVES applied to carcases on colour stability in FQ, loin and HQ retail packs.
(Data given as mean (SD); n=6 culled ewe carcases per treatment. Colour assessment carried out after 72 h display).

Treatments	Colour values under different treatments				Effect of treatments[1]	
	Hot boned		Cold boned			
	(side-ES[2])	(no ES)	(side-ES)	(no ES)	Hot boning (p<)	ES (p>)
CIE colour values[3]						
Forequarter						
L^* value	37.3 (1.94)	40.4 (1.64)	40.3 (1.96)	38.3 (2.16)	nsd	nsd
a^* value	15.2 (1.91	17.0 (1.91)	17.0 (1.68)	15.1 (1.90)	nsd	nsd
b^* value	4.7 (0.96)	6.0 (0.61)	5.5 (0.90)	4.6 (1.15)	nsd	nsd
Loin						
L^* value	35.0 (2.34)	37.1 (3.40)	35.9 (2.19)	34.0 (3.56)	nsd	nsd
a^* value	13.4 (2.76)	17.2 (2.31)	17.1 (1.10)	15.0 (1.40)	nsd	nsd
b^* value	3.1 (1.99)	4.4 (1.37)	3.4 (0.91)	2.0 (1.84)	nsd	nsd
Hindquarter						
L^* value	33.5 (2.04)	32.9 (3.27)	33.3 (1.97)	32.2 (1.51)	nsd	nsd
a^* value	12.5 (1.68)	16.6 (1.40)	16.7 (1.11)	13.9 (1.14)	nsd	nsd
b^* value	2.4 (1.20)	3.1 (1.76)	3.0 (1.26)	2.0 (1.02)	nsd	nsd

Notes
1. Significance of difference between treatments; nsd is not significant at $p<0.05$ level.
2. HVES (450 v) applied to carcase side.
3. CIE Lab values; L^* value light (high); dark (low).
   a^* value red (high); brown (low).
   b^* value yellow (high); blue (low)

Table 3.1 The application of ES to excised FQ and HQ primal muscles.

(Data given as mean (SD); n=6 culled ewe carcases per treatment).

	Performance of ES variables applied to primal muscles				
	ES applied Volts	**Time post mortem h**	**Muscle Temperature °C**	**Indicated energy (KJ/kg)**	**Packing Effect (degrees)**
Treatment group					
a. FQ primal muscles					
a. 0 volt	0.0 (0.00)	0.58 (0.06)	35.1 (1.62)	0.0 (0.0)	109.5 (45.6)
b. 120 volt	120.3 (1.67)	0.57 (0.06)	34.7 (1.94)	0.77 (0.24)	135.2 (60.9)
c. 380 volt	380.0 (4.29)	0.53 (0.11)	34.7 (2.64)	12.48 (4.04)	118.8 (41.6)
b. HQ primal muscles					
d. 0 volt	0.0 (0.00)	0.68 (0.06)	37.5 (1.23)	0.0 (0.00)	89.2 (54.8)
e. 120 volt	120.6 (1.67)	0.68 (0.06)	37.5 (1.14)	0.74 (0.23)	107.9 (29.8)
f. 380 volt	379.8 (1.79)	0.65 (0.08)	36.8 (1.31)	13.07 (4.43)	115.8 (36.5)
Effect between muscles (p<)[1]					
0 volt	**nsd**	**<0.001**	**<0.001**	**nt**	**nt**
120 volt	**nsd**	**<0.001**	**<0.001**	**nsd**	**nsd**
380 volt	**nsd**	**<0.001**	**<0.001**	**nsd**	**nsd**

Notes. Significance of difference between treatment means.
Nsd; No significant difference at p<0.05 level.
nt; not tested

Table 3.2. The effect of hot boning, ES applied to sides or primal muscles, and rapid or slow chilling rate on muscle pH fall in primal FQ muscles.

(Data given as mean (SD); n=6 culled ewe carcases per treatment).

Treatments	pH values under different treatments					Effect of treatments[1]		
	Hot boned			Cold boned				
	ES-0 v	ES-120v[2]	ES-380v	ES-0v	ES-450[3]v	HB/CB (p<)	ES-HB (p<)	ES-CB (p<)
a. Rapid chill (4.5°C /h).								
Time post mortem (h)								
0.5	6.90 (0.08)	6.81 (0.13)	6.85 (0.12)	6.90 (0.09)	6.74 (0.17)	nsd	nsd	<0.05
1.0	6.71 (0.06)	6.65 (0.17)	6.64 (0.13)	6.71 (0.04)	6.54 (0.12)	nsd	nsd	<0.05
10	6.34 (0.07)	6.24 (0.20)	6.19 (0.18)	6.37 (0.07)	6.16 (0.14)	nsd	nsd	<0.01
24	6.31 (0.13)	6.17 (0.19)	6.14 (0.18)	6.21 (0.15)	6.10 (0.13)	nsd	nsd	nsd
b. Slow chill (2.0°C /h).								
Time post mortem (h)								
0.5	6.84 (0.08)	6.76 (0.09)	6.83 (0.14)	6.80 (0.09)	6.78 (0.11)	nsd	nsd	nsd
1.0	6.70 (0.23)	6.63 (0.14)	6.60 (0.19)	6.68 (0.09)	6.56 (0.18)	nsd	nsd	nsd
10	5.79 (0.13)	5.95 (0.17)	5.88 (0.16)	5.94 (0.24)	5.90 (0.12)	nsd	nsd	nsd
24	5.90 (0.14)	5.96 (0.17)	5.94 (0.20)	5.84 (0.20)	5.90 (0.14)	nsd	nsd	nsd
Effect of cooling rate (p<)								
pH_{10h}	<0.001	<0.05	<0.05	<0.001	<0.001			
pH_{24h}	<0.001	nsd	nsd	<0.001	<0.01			

Notes.

1. Treatments; HB/CB - effect of hot boning compared with cold boning at (0v).
   ES-HB - effect of ES applied to primal muscles compared to HB (0v).
   ES-CB - effect of ES applied to sides compared to CB (0)v.
   (p<); significance of difference between means. Nsd; no significant difference at p<0.05 level.
2. Primal ES applied at 120 or 380v to excised primal muscles
3. HVES (450v) applied to carcase side.

Table 3.3. **The effect of hot boning, ES applied to sides or primal muscles, and rapid or slow chilling rate on muscle pH fall in primal loin muscles.**
(Data given as mean (SD); n=6 culled ewe carcases per treatment).

Treatments	pH values under different treatments					Effect of treatments[1]		
	Hot boned			Cold boned				
	ES-0 v	ES-120v[2]	ES-380v	ES-0v	ES-450[3]v	HB/CB (p<)	ES-HB (p<)	ES-CB (p<)
a. Rapid chill (4.5°C /h).								
Time post mortem (h)								
0.5	6.81 (0.15)	6.73 (0.09)	6.66 (0.11)	6.87 (0.13)	6.75 (0.19)	nsd	nsd	nsd
1.0	6.63 (0.17)	6.40 (0.11)	6.35 (0.15)	6.81 (0.15)	6.46 (0.15)	nsd	<0.05	<0.01
10	6.08 (0.24)	6.08 (0.16)	5.91 (0.19)	6.21 (0.09)	6.10 (0.13)	<0.01	nsd	nsd
24	5.89 (0.16)	5.86 (0.22)	5.78 (0.13)	5.98 (0.14)	5.92 (0.19)	<0.05	nsd	nsd
b. Slow chill (2.0°C /h).								
Time post mortem (h)								
0.5	6.65 (0.19)	6.68 (0.08)	6.80 (0.19)	6.77 (0.13)	6.79 (0.14)	nsd	nsd	nsd
1.0	6.60 (0.24)	6.40 (0.13)	6.48 (0.23)	6.67 (0.17)	6.44 (0.18)	nsd	nsd	<0.05
10	5.62 (0.14)	5.68 (0.21)	5.65 (0.18)	5.95 (0.17)	5.73 (0.29)	nsd	nsd	nsd
24	5.57 (0.09)	5.63 (0.17)	5.66 (0.21)	5.73 (0.14)	5.64 (0.19)	nsd	nsd	nsd
Effect of cooling rate (p<)								
pH_{10h}	<0.01	<0.01	<0.01	<0.001	<0.01			
pH_{24h}	<0.01	nsd	nsd	<0.01	<0.01			

Notes.
1. Treatments; HB/CB - effect of hot boning compared with cold boning at (0v).
ES-HB - effect of ES applied to primal muscles compared to HB (0v).
ES-CB - effect of ES applied to sides compared to CB (0)v.
(p<); significance of difference between means. Nsd; no significant difference at p<0.05 level.
2. Primal ES applied at 120 or 380v to excised primal muscles
3. HVES (450v) applied to carcase side.

Table 3.4. The effect of hot boning, ES applied to sides or primal muscles, and rapid or slow chilling rate on muscle pH fall in primal HQ muscles.
(Data given as mean (SD); n=6 culled ewe carcases per treatment).

Treatments	pH values under different treatments					Effect of treatments[1]		
	Hot boned			Cold boned				
	ES-0 v	ES-120v[2]	ES-380v	ES-0v	ES-450[3]v	HB/CB (p<)	ES-HB (p<)	ES-CB (p<)
a. Rapid chill (4.5°C /h).								
Time post mortem (h)								
0.5	6.81 (0.13)	6.75 (0.12)	6.77 (0.08)	6.83 (0.21)	6.72 (0.17)	nsd	nsd	nsd
1.0	6.65 (0.18)	6.40 (0.18)	6.50 (0.23)	6.71 (0.27)	6.49 (0.17)	nsd	nsd	nsd
10	6.17 (0.24)	5.97 (0.24)	5.86 (0.19)	6.24 (0.19)	5.94 (0.16)	nsd	<0.05 (380)	<0.01
24	5.88 (0.19)	5.87 (0.19)	5.81 (0.19)	5.88 (0.17)	5.83 (0.18)	nsd	nsd	nsd
b. Slow chill (2.0°C /h).								
Time post mortem (h)								
0.5	6.67 (0.07)	6.74 (0.17)	6.72 (0.13)	6.73 (0.25)	6.72 (0.14)	nsd	<0.05	nsd
1.0	6.61 (0.11)	6.46 (0.13)	6.44 (0.22)	6.68 (0.25)	6.47 (0.14)	nsd	nsd	nsd
10	5.70 (0.22)	5.81 (0.16)	5.76 (0.19)	5.81 (0.21)	5.70 (0.16)	nsd	nsd	<0.005
24	5.64 (0.06)	5.72 (0.10)	5.73 (0.09)	5.74 (0.22)	5.68 (0.18)	nsd	nsd	nsd
Effect of cooling rate (p<)								
pH_{10h}	<0.005	nsd	nsd	<0.001	<0.01			
pH_{24h}	<0.05	nsd	nsd	nsd	nsd			

Notes.
1. Treatments; HB/CB - effect of hot boning compared with cold boning at (0v).
ES-HB - effect of ES applied to primal muscles compared to HB (0v).
ES-CB - effect of ES applied to sides compared to CB (0)v.
(p<); significance of difference between means. Nsd; no significant difference at p<0.05 level.
2. Primal ES applied at 120 or 380v to excised primal muscles
3. HVES (450v) applied to carcase side.

Table 3.5. The effect of hot boning and HVES applied to primal muscles on recovered meat yield under slow chilling conditions. *(Data given as mean (SD); n=6 culled ewe carcases per treatment. Carcases and primal packs held at 2°C for 10 h post mortem followed by chilling to +3°C over further 10 h).*

Treatments	Carcase traits under different treatments					Effect of treatments[1]		
	Hot boned			Cold boned				
	ES-0v	ES-120v[2]	ES-380v	ES-0v	ES-450[3]v	HB/CB (p<)	ES-HB (p<)	ES-CB (p<)
Measurements								
Hot carcase wt (kg)	13.97 (2.73)	12.84 (1.31)	14.00 (2.52)	13.45 (2.40)	13.97 (1.94)	nsd	nsd	nsd
Cold carcase wt kg				13.01 (2.41)	13.43 (2.01)	nt	nt	nsd
Primal pack wt (kg)	9.98 (2.17)	8.88 (1.00)	10.03 (2.30)	9.16 (2.15)	9.66 (1.71)	nsd	nsd	nsd
Recovered meat wt [4] kg	10.71 (2.29)	9.57 (1.06)	10.74 (2.32)	9.95 (2.16)	10.47 (1.74)	nsd	nsd	nsd
Total fat and bone wt (kg)	3.11 (0.41)	2.99 (0.19)	3.16 (0.29)	2.97 (0.23)	2.85 (0.16)	nsd	nsd	nsd
Dissection total wt (kg)	13.82 (2.68)	12.56 (1.17)	13.90 (2.53)	12.92 (2.32)	13.32 (1.83)	nsd	nsd	nsd
Performance indicators.								
Side evaporation loss[5] (%)				3.27 (1.17)	3.87 (1.04)	nt	nt	nsd
Weight loss on boning[6] (%)	1.07 (0.43)	2.18 (1.39)	0.71 (0.64)	3.94 (1.23)	4.65 (1.89)	<0.001	nsd	nsd
Weight of meat trimmings as % of recovered meat[7]	6.82 (1.03)	7.21 (0.86)	6.66 (1.03)	7.94 (0.70)	7.74 (1.31)	nsd	nsd	nsd

Notes
1. Treatments; HB/CB - effect of hot boning compared with cold boning at (0v).
ES-HB - effect of ES applied to primal muscles compared to HB (0v).
ES-CB - effect of ES applied to sides compared to CB (0)v.
(p<); significance of difference between treatments; nt not tested; nsd is not significant at p<0.05 level.
2. Primal ES where ES (120v or 380v) applied to hot excised primal muscles.
3. HVES (450v) applied to carcase side.
4. Recovered meat is based on primal meat and additional trimmings from bones after removal of primal muscle blocks.
5. Weight loss during chilling expressed as % of initial hot weight.
6. Overall weight loss for chilling and boning expressed as % of hot carcase weight.
7. % meat trimming of total recovered meat from hot or cold boned carcases.

Table 3.6. The effect of hot boning and HVES applied to primal muscles on recovered meat yield under rapid chilling conditions. *(Data given as mean (SD); n=6 culled ewe carcases per treatment. Carcases and primal packs chilled in air at -1°C for 24 h).*

Treatments	Carcase traits under different treatments					Effect of treatments[1]		
	Hot boned			Cold boned				
	ES-0v	ES-120v[2]	ES-380v	ES-0v	ES-450[3]v	HB/CB (p<)	ES-HB (p<)	ES-CB (p<)
Measurements								
Hot carcase wt (kg)	13.91 (2.44)	13.78 (1.86)	13.43 (0.73)	13.77 (1.68)	13.63 (1.98)	nsd	nsd	nsd
Cold carcase wt kg				13.13 (1.45)	13.19 (2.01)	nt	nt	nsd
Primal pack wt (kg)	9.88 (1.97)	9.58 (1.52)	9.37 (0.68)	9.72 (1.14)	9.43 (1.54)	nsd	nsd	nsd
Recovered meat wt [4] kg	10.52 (2.11)	10.27 (1.62)	10.06 (0.72)	10.48 (1.09)	10.21 (0.54)	nsd	nsd	nsd
Total fat and bone wt (kg)	3.15 (0.42)	3.21 (0.37)	3.21 (0.29)	2.60 (0.19)	2.90 (0.40)	<0.01	nsd	nsd
Dissection total wt (kg)	13.67 (2.47)	13.48 (1.90)	13.27 (0.73)	13.08 (1.17)	13.1 (1.84)	nsd	nsd	nsd
Performance indicators.								
Side evaporation loss[5] (%)				4.65 (2.14)	3.23 (0.85)	nt	nt	nsd
Weight loss on boning[6] (%)	1.73 (1.21)	2.18 (0.76)	.19 (0.46)	5.01 (2.34)	3.82 (1.53)	<0.001	nsd	nsd
Weight of meat trimmings as % of recovered meat[7]	6.08 (0.66)	6.72 (0.65)	6.86 (0.54)	7.25 (0.70)	7.64 (0.71)	<0.05	nsd	nsd

Notes
1. Treatments; HB/CB - effect of hot boning compared with cold boning at (0v).
ES-HB - effect of ES applied to primal muscles compared to HB (0v).
ES-CB - effect of ES applied to sides compared to CB (0)v.
(p<); significance of difference between treatments; nt not tested; nsd is not significant at p<0.05 level.
2. Primal ES where ES (120v or 380v) applied to hot excised primal muscles.
3. HVES (450v) applied to carcase side.
4. Recovered meat is based on primal meat and additional trimmings from bones after removal of primal muscle blocks.
5. Weight loss during chilling expressed as % of initial hot weight.
6. Overall weight loss for chilling and boning expressed as % of hot carcase weight.
7. % meat trimming of total recovered meat from hot or cold boned carcases.

Table 3.7. **The effect of hot boning, ES applied to sides or primal muscles, and rapid or slow chilling on meat quality in FQ primal muscles and retail packs.**
(Data given as mean (SD); n=6 culled ewe carcases per treatment).

Treatments	Meat quality indicators under different treatments					Effect of treatments[1]		
	Hot boned			Cold boned				
	ES-0v	ES-120v[2]	ES-380v	ES-0v	ES-450[3]v	HB/CB (p<)	ES-HB (p<)	ES-CB (p<)
a. Rapid chill (4.5°C /h).								
Primal drip (%)[4]	2.43 (0.91)	2.66 (0.74)	2.67 (0.99)	1.44 (0.51)	1.80 (0.77)	<0.05	nsd	nsd
Retail drip (%)[5]	1.23 (0.34)	1.18 (0.23)	1.36 (0.30)	1.04 (0.24)	1.19 (0.27)	nsd	nsd	<0.05
Objective toughness[6] (N)	106.4 (27.97)	92. (17.29)	85.9 (19.76)	87.5 (18.94)	92.4 (18.63)	<0.05	<0.05 (380v)	nsd
a. Slow chill (2.0°C /h).								
Primal drip (%)	1.92 (0.66)	2.80 (1.32)	2.42 (0.80)	1.56 (1.00)	1.79 (0.63)	nsd	nsd	nsd
Retail drip (%)	1.23 (0.33)	1.31 (0.31	1.14 (0.39)	1.14 (0.30)	1.21 (0.25)	nsd	nsd	nsd
Objective toughness (N)	105.3 (23.69)	104.9 (13.42)	108.9 (17.45)	97.1 (18.03)	103.8 (17.22)	nsd	nsd	nsd
Effect of cooling rate (p<)								
Primal drip	nsd	nsd	nsd	nsd	nsd			
Retail drip	nsd	nsd	nsd	nsd	nsd			
Toughness	nsd	<0.05	<0.01	nsd	nsd			

Notes

1. Treatments; HB/CB - effect of hot boning compared with cold boning at (0v).
   ES-HB - effect of ES applied to primal muscles compared to HB (0v).
   ES-CB - effect of ES applied to sides compared to CB (0)v.
   (p<); significance of difference between treatments; nsd is not significant at p<0.05 level.
2. Primal ES where ES (120v or 380v) applied to hot excised primal cuts.
3. HVES (450v) applied to carcase side.
4. Primal drip loss is weight loss in primal cuts after thawing.
5. Retail drip loss is weight loss after 3 days retail display.
6. Objective toughness as shear value in meat sample cooked to +75°C internal.

Table 3.8. The effect of hot boning, ES applied to sides or primal muscles, and rapid or slow chilling on meat quality in loin primal muscles and retail packs.
(Data given as mean (SD); n=6 culled ewe carcases per treatment).

Treatments	Meat quality indicators under different treatments					Effect of treatments[1]		
	Hot boned			Cold boned				
	ES-0v	ES-120v[2]	ES-380v	ES-0v	ES-450[3]v	HB/CB (p<)	ES-HB (p<)	ES-CB (p<)
a. Rapid chill (4.5°C /h).								
Primal drip (%)[5]	2.99 (1.06)	2.80 (0.84)	3.19 (0.60)	2.08 (0.41)	2.47 (1.47)	<0.05	nsd	nsd
Retail drip (%)[6]	2.10 (0.58)	2.09 (0.70)	1.91 (0.44)	1.81 (0.30)	1.54 (0.41)	nsd	nsd	<0.05
Objective toughness[7] (N)	89.9 (20.81)	97.8 (26.12)	77.4 (13.04)	86.5 (21.90)	74.4 (11.79)	nsd	nsd	<0.05
b. Slow chill (2.0°C /h).								
Primal drip (%)	2.64 (0.96)	3.94 (1.60)	2.64 (1.24)	1.71 (1.13)	2.09 (1.20)	nsd	nsd	nsd
Retail drip (%)	1.72 (0.31)	1.88 (0.29)	1.84 (0.46)	2.10 (0.68)	1.59 (0.31)	nsd	nsd	<0.01
Objective toughness (N)	83.6 (13.13)	82.6 13.67)	78.1 9.85)	83.1 (20.59)	79.4 (16.37)	nsd	nsd	nsd
Effect of cooling rate (p<)								
Primal drip loss	nsd	nsd	nsd	nsd	nsd			
Retail drip	nsd	nsd	nsd	nsd	nsd			
Toughness	nsd	nsd	nsd	nsd	nsd			

Notes
1. Treatments; HB/CB - effect of hot boning compared with cold boning at (0v).
ES-HB - effect of ES applied to primal muscles compared to HB (0v).
ES-CB - effect of ES applied to sides compared to CB (0)v.
(p<); significance of difference between treatments; nsd is not significant at p<0.05 level.
2. Primal ES where ES (120v or 380v) applied to hot excised primal cuts.
3. HVES (450v) applied to carcase side.
4. Primal drip loss is weight loss in primal cuts after thawing.
5. Retail drip loss is weight loss after 3 days retail display.
6. Objective toughness as shear value in meat sample cooked to +75°C internal.

Table 3.9. **The effect of hot boning, ES applied to sides or primal muscles, and rapid or slow chilling on meat quality in HQ primal muscles and retail packs.**
(Data given as mean (SD); n=6 culled ewe carcases per treatment).

Treatments	Meat quality indicators under different treatments					Effect of treatments[1]		
	Hot boned			Cold boned				
	ES-0v	ES-120v[2]	ES-380v	ES-0v	ES-450[3]v	HB/CB (p<)	ES-HB (p<)	ES-CB (p<)
a. Rapid chill (4.5°C /h).								
Primal drip (%)[5]	3.97 (1.89)	3.46 (0.43)	3.47 (0.57)	2.37 (0.53)	2.64 (0.53)	<0.01	nsd	nsd
Retail drip (%)[6]	2.10 (0.46)	1.80 (0.52)	1.80 (0.55)	1.28 (0.25)	1.60 (0.45)	<0.001	nsd	<0.05
Objective toughness[7] (N)	105.6 (16.48)	103.0 (14.81)	95.8 (15.73)	104.4 (23.89)	102.1 (20.62)	nsd	nsd	nsd
b. Slow chill (2.0°C /h).								
Primal drip (%)	3.20 (0.97)	3.84 (2.55)	3.77 (1.54)	2.70 (1.31)	2.91 (1.67)	nsd	nsd	nsd
Retail drip (%)	1.86 (0.45)	1.82 (0.47)	1.94 (0.53)	1.56 (0.44)	1.72 (0.66)	nsd	nsd	nsd
Objective toughness (N)	100.1 (15.31)	103.0 (16.22)	102.6 (15.37)	95.4 (21.40)	108.4 (13.48)	nsd	nsd	<0.01
Effect of cooling rate (p<)								
Primal drip	nsd	nsd	nsd	nsd	nsd			
Retail drip	nsd	nsd	nsd	<0.05	nsd			
Toughness	nsd	nsd	nsd	nsd	nsd			

Notes

1. Treatments; HB/CB - effect of hot boning compared with cold boning at (0v).
   ES-HB - effect of ES applied to primal muscles compared to HB (0v).
   ES-CB - effect of ES applied to sides compared to CB (0)v.
   (p<); significance of difference between treatments; nsd is not significant at p<0.05 level.
2. Primal ES where ES (120v or 380v) applied to hot excised primal muscles.
3. HVES (450v) applied or not to carcase side.
5. Primal drip loss is weight loss in primal cuts after thawing.
6. Retail drip loss is weight loss after 3 days retail display.
7. Objective toughness as shear value in meat sample cooked to +75°C internal.

Table 3.10. The effect of hot boning, ES applied to sides or primal muscles, and rapid or slow chilling on initial colour development in FQ retail packs.

(Data given as mean (SD); n=6 culled ewe carcases per treatment).

Treatments	Colour values under diffferent treatments					Effect of treatments[1]		
	Hot boned			Cold boned				
	ES-0v	ES-120v[2]	ES-380v	ES-0v	ES-450[3]v	HB/CB (p<)	ES-HB (p<)	ES-CB (p<)
a. Rapid chill (4.5°C /h).								
CIE colour values[4]								
L^*	39.1 (2.32)	37.4 (1.99)	37.3 (1.93)	36.7 (1.90)	36.7 (2.52)	<0.01	nsd	nsd
C^*	24.3 (1.65)	23.3 (1.32)	24.5 (1.52)	24.0 (2.04)	23.5 (2.00)	nsd	nsd	nsd
H°	30.5 (2.37)	30.0 (1.66)	30.4 (1.27)	30.3 (1.72)	30.2 (1.94)	nsd	nsd	nsd
b. Slow chill (2.0°C /h).								
CIE colour values								
L^*	38.8 (2.64)	38.3 (2.72)	38.8 (1.79)	38.4 (2.70)	38.0 (2.21)	nsd	nsd	nsd
C^*	25.8 (1.39)	24.0 (1.46)	25.3 (1.25)	25.1 (1.74)	25.0 (1.57)	nsd	nsd	nsd
H°	30.0 (1.82)	28.8 (1.64)	30.1 (1.18)	29.4 (1.33)	29.8 (1.61)	nsd	nsd	nsd
Effect of cooling rate (p<)								
L^*	nsd	nsd	nsd	<0.05	<0.05			
C^*	<0.05	nsd	nsd	nsd	<0.05			
H°	nsd	nsd	nsd	nsd	nsd			

Notes

1. Treatments; HB/CB - effects of hot boning compared with cold boning at (0v).
   ES-HB - effect of ES applied to primal cut compared to HB (0v).
   ES-CB - effect of ES applied to sides compared to CB (0)v.
   (p<); Significance of difference between treatments; nsd is not significant at p<0.05 level.
2. Primal ES where ES (120v or 380v) applied to hot excised primal cuts.
3. HVES (450v) applied to carcase side.
4. CIE colour values; L^* - metric lightness - light (high); dark (low).
   C^* - metric chroma value: derived as $((a^*)^2 + (b^*)^2)^{-2}$.
   H° - metric hue angle: derived as $\tan^{-1}(b^*/a^*)$.

Table 3.11. **The effect of hot boning, ES applied to sides or primal muscles, and rapid or slow chilling on initial colour development in loin retail packs.**
(Data given as mean (SD); n=6 culled ewe carcases per treatment).

Treatments	Colour values under diffferent treatments					Effect of treatments[1]		
	Hot boned			Cold boned				
	ES-0v	ES-120v[2]	ES-380v	ES-0v	ES-450[3]v	HB/CB (p<)	ES-HB (p<)	ES-CB (p<)
a. Rapid chill (4.5°C /h).								
CIE colour values[4]								
L^*	35.4 (2.50)	34.9 (2.70)	34.5 (2.37)	34.2 (1.70)	34.7 (4.40)	nsd	nsd	nsd
C^*	23.3 (1.64)	23.6 (1.94)	24.6 (1.39)	21.5 (1.65)	23.3 (2.12)	<0.01	<0.05	<0.01
H°	30.7 (2.57)	31.0 (1.90)	30.4 (1.77)	30.3 (2.27)	29.9 (2.19)	nsd	nsd	nsd
b. Slow chill (2.0°C /h).								
CIE colour values								
L^*	37.6 (1.60)	36.2 (2.44)	36.6 (1.57)	36.3 (2.62)	36.3 (2.59)	nsd	nsd	nsd
C^*	24.6 (1.65)	24.1 (2.16)	24.5 (2.07)	24.0 (1.54)	23.9 (1.84)	nsd	nsd	nsd
H°	29.7 (1.54)	28.9 (1.84)	29.9 (1.29)	29.6 (1.35)	29.8 (1.65)	nsd	nsd	nsd
Effect of cooling rate (p<)								
L^*	<0.05	nsd	<0.05	<0.01	<0.05			
C^*	nsd	nsd	nsd	<0.001	nsd			
H°	nsd	<0.05	nsd	nsd	nsd			

Notes

1. Treatments; HB/CB - effects of hot boning compared with cold boning at (0v).
   ES-HB - effect of ES applied to primal cut compared to HB (0v).
   ES-CB - effect of ES applied to sides compared to CB (0)v.
   (p<); Significance of difference between treatments; nsd is not significant at p<0.05 level.
2. Primal ES where ES (120v or 380v) applied to hot excised primal cuts.
3. HVES (450v) applied to carcase side.
4. CIE colour values; L^* - metric lightness - light (high); dark (low).
   C^* - metric chroma value: derived as $((a^*)^2 + (b^*)^2)^{-2}$.
   H° - metric hue angle: derived as $\tan^{-1}(b^*/a^*)$.

Table 3.12. **The effect of hot boning, ES applied to sides or primal muscles, and rapid or slow chilling on initial colour development in retail packs from HQ muscles.**
(Data given as mean (SD); n=6 culled ewe carcases per treatment).

Treatments	Colour values under diffferent treatments					Effect of treatments[1]		
	Hot boned			Cold boned				
	ES-0v	ES-120v[2]	ES-380v	ES-0v	ES-450[3]v	HB/CB (p<)	ES-HB (p<)	ES-CB (p<)
a. Rapid chill (4.5°C /h).								
CIE colour values[4]								
L^*	33.8 (1.92)	33.4 (1.60)	32.6 (1.81)	33.6 (1.98)	32.7 (1.46)	nsd	nsd	nsd
C^*	23.3 (1.23)	23.0 (0.94)	23.4 (1.27)	22.8 (1.49)	22.7 (1.36)	nsd	nsd	nsd
H°	29.3 (2.64)	29.8 (2.21)	29.4 (1.60)	29.9 (1.27)	29.6 (2.72)	nsd	nsd	nsd
b. Slow chill (2.0°C /h).								
CIE colour values								
L^*	34.8 (1.75)	35.8 (2.07)	34.2 (.12)	34.4 (1.90)	34.3 (1.53)	nsd	nsd	nsd
C^*	23.7 (1.04)	22.6 (0.88)	23.0 (.41)	23.4 (1.34)	23.3 (1.19)	nsd	nsd	nsd
H°	28.4 (2.25)	28.4 (1.63)	29.0 (.10)	28.9 (1.56)	28.8 (1.40)	nsd	nsd	nsd
Effect of cooling rate (p<[5])								
L^*	nsd	<0.005	<0.05	nsd	<0.005			
C^*	nsd	nsd	nsd	nsd	nsd			
H°	nsd	nsd	nsd	nsd	nsd			

Notes

1. Treatments; HB/CB - effects of hot boning compared with cold boning at (0v).
   ES-HB - effect of ES applied to primal cut compared to HB (0v).
   ES-CB - effect of ES applied to sides compared to CB (0)v.
   (p<); Significance of difference between treatments; nsd is not significant at p<0.05 level.
2. Primal ES where ES (120v or 380v) applied to hot excised primal cuts.
3. HVES (450v) applied to carcase side.
4. CIE colour values; L^* - metric lightness - light (high); dark (low).
   C^* - metric chroma value: derived as $((a^*)^2 + (b^*)^2)^{-2}$.
   H° - metric hue angle: derived as $\tan^{-1}(b^*/a^*)$.

Table 3.13. **The effect of hot boning, ES applied to sides or primal muscles, and rapid or slow chilling on initial colour stability in FQ retail packs.**

(Data given as mean (SD); n=6 culled ewe carcases per treatment. Colour assessed after 72 h display).

Treatments	Colour values under diffferent treatments					Effect of treatments[1]		
	Hot boned			Cold boned				
	ES-0v	ES-120v[2]	ES-380v	ES-0v	ES-450[3]v	HB/CB (p<)	ES-HB (p<)	ES-CB (p<)
a. Rapid chill (4.5°C /h).								
CIE colour values[4]								
L^*	40.6 (2.25)	39.0 (2.76)	38.6 (1.86)	38.0 2.04)	38.2 (1.72)	<0.005	<0.05	nsd
C^*	18.8 (1.88)	17.9 (1.95)	18.2 (1.31)	19.1 1.50)	18.9 (1.36)	nsd	nsd	nsd
H^o	34.3 (3.77)	33.5 (2.86)	33.8 (4.20)	32.9 2.61)	31.9 (3.08)	nsd	nsd	nsd
b. Slow chill (2.0°C /h).								
CIE colour values								
L^*	39.8 (2.18)	39.3 (2.26)	39.6 (1.88)	38.8 (1.77)	39.1 (1.56)	nsd	nsd	nsd
C^*	18.5 (1.15)	17.4 (1.56)	18.2 (1.81)	18.7 (1.46)	17.7 (1.41)	nsd	nsd	nsd
H^o	33.6 (8.66)	37.2 (6.80)	34.3 (9.05)	33.3 (7.59)	36.7 (4.44)	nsd	nsd	nsd
Effect of cooling rate (p<)								
L^*	nsd	nsd	nsd	nsd	nsd			
C^*	nsd	nsd	nsd	nsd	<0.001			
H^o	nsd	nsd	nsd	nsd	<0.05			

Notes

1. Treatments; HB/CB - effects of hot boning compared with cold boning at (0v).
   ES-HB - effect of ES applied to primal cut compared to HB (0v).
   ES-CB - effect of ES applied to sides compared to CB (0)v.
   (p<); Significance of difference between treatments; nsd is not significant at p<0.05 level.
2. Primal ES where ES (120v or 380v) applied to hot excised primal cuts.
3. HVES (450v) applied to carcase side.
4. CIE colour values; L^* - metric lightness - light (high); dark (low).
   C^* - metric chroma value: derived as $((a^*)^2 + (b^*)^2)^{-2}$.
   H^o - metric hue angle: derived as $\tan^{-1}(b^*/a^*)$.

Table 3.14. **The effect of hot boning, ES applied to sides or primal muscles, and rapid or slow chilling on initial colour stability in loin retail packs.**

(Data given as mean (SD); n=6 culled ewe carcases per treatment. Colour assessed after 72 h display).

Treatments	Colour values under diffferent treatments					Effect of treatments[1]		
	Hot boned			Cold boned				
	ES-0v	ES-120v[2]	ES-380v	ES-0v	ES-450[3]v	HB/CB (p<)	ES-HB (p<)	ES-CB (p<)
a. Rapid chill (4.5°C /h).								
CIE colour values[4]								
L^*	36.2 (1.86)	36.3 (2.50)	35.0 (2.21)	35.3 (1.92)	35.7 (1.80)	nsd	nsd	nsd
C^*	18.0 (1.41)	17.2 (1.04)	17.6 (2.11)	17.8 (1.60)	18.0 (1.59)	nsd	nsd	nsd
H°	32.5 (3.83)	33.2 (4.23)	32.5 (2.78)	31.3 (3.05)	31.2 (3.97)	nsd	nsd	nsd
b. Slow chill (2.0°C /h).								
L^*	38.4 (2.34)	37.8 (2.27)	37.5 (1.87)	36.9 (2.98)	37.3 (2.44)	nsd	<0.05	nsd
C^*	17.0 (1.61)	16.2 (2.94)	16.8 (2.64)	17.6 (1.89)	16.4 (1.88)	nsd	nsd	nsd
H°	36.3 (3.43)	41.1 (8.25)	37.1 (7.10)	35.7 (7.30)	36.9 (5.60)	nsd	nsd	nsd
Effect of cooling rate (p<)								
L^*	<0.05	nsd	<0.01	nsd	<0.05			
C^*	nsd	nsd	nsd	nsd	<0.01			
H°	<0.05	<0.01	nsd	<0.05	<0.01			

Notes

1. Treatments; HB/CB - effects of hot boning compared with cold boning at (0v).
   ES-HB - effect of ES applied to primal cut compared to HB (0v).
   ES-CB - effect of ES applied to sides compared to CB (0)v.
   (p<); Significance of difference between treatments; nsd is not significant at p<0.05 level.
2. Primal ES where ES (120v or 380v) applied to hot excised primal cuts.
3. HVES (450v) applied to carcase side.
4. CIE colour values; L^* - metric lightness - light (high); dark (low).
   C^* - metric chroma value: derived as $((a^*)^2 + (b^*)^2)^{-2}$.
   H° - metric hue angle: derived as $\tan^{-1}(b^*/a^*)$.

Table 3.15. **The effect of hot boning, ES applied to sides or primal muscles, and rapid or slow chilling on initial colour stability in HQ retail packs.**
(Data given as mean (SD); n=6 culled ewe carcases per treatment. Colour assessed after 72 h display).

Treatments	Colour values under diffferent treatments					Effect of treatments[1]		
	Hot boned			Cold boned				
	ES-0v	ES-120v[2]	ES-380v	ES-0v	ES-450[3]v	HB/CB (p<)	ES-HB (p<)	ES-CB (p<)
a. Rapid chill (4.5°C /h).								
CIE colour values[4]								
L^*	35.5 (2.14)	35.3 (1.94)	34.1 (1.67)	34.4 (1.90)	34.1 (1.39)	nsd	nsd	nsd
C^*	15.9 (1.40)	15.0 (1.40)	15.9 (1.67)	16.8 (1.39)	16.6 (1731)	nsd	nsd	nsd
H°	36.4 (4.54)	38.7 (2.85)	35.0 (28.9)	33.9 (2.91)	33.9 (4.57)	nsd	nsd	nsd
b. Slow chill (2.0°C /h).								
L^*	35.7 (1.51)	36.4 (1.61)	35.7 1.58)	34.7 (1.93)	35.5 (1.54)	nsd	nsd	nsd
C^*	15.2 (0.80)	14.8 (1.29)	14.9 1.68)	16.0 (1.23)	14.9 (0.89)	nsd	nsd	<0.01
H°	39.6 (2.23)	41.8 (7.22)	39.7 5.87)	38.0 (5.33)	39.7 (4.98)	nsd	nsd	nsd
Effect of cooling rate (p<)								
L^*	nsd	nsd	<0.05	nsd	<0.01			
C^*	nsd	nsd	nsd	nsd	<0.001			
H°	<0.05	nsd	<0.05	nsd	<0.001			

Notes

1. Treatments; HB/CB - effects of hot boning compared with cold boning at (0v).
   ES-HB - effect of ES applied to primal cut compared to HB (0v).
   ES-CB - effect of ES applied to sides compared to CB (0)v.
   (p<); Significance of difference between treatments; nsd is not significant at p<0.05 level.
2. Primal ES where ES (120v or 380v) applied to hot excised primal cuts.
3. HVES (450v) applied to carcase side.
4. CIE colour values; L^* - metric lightness - light (high); dark (low).
   C^* - metric chroma value: derived as $((a^*)^2 + (b^*)^2)^{-2}$.
   H° - metric hue angle: derived as $\tan^{-1}(b^*/a^*)$.

Table 3.16 **The effect of hot boning, ES applied to sides or primal muscles, and rapid or slow chilling on aerobic psychrotrophic and mesophilic microbiological count in thawed primal muscles.**
(Data given as log (SD) of mean of FQ, loin and HQ muscles; n=6 culled ewe carcases per treatment).

Treatments	Aerobic plate counts under different treatments					Effect of treatments[1]		
	Hot boned			Cold boned				
	ES-0v	ES-120v[2]	ES-380v	ES-0v	ES-450[3]v	HB/CB (p<)	ES-HB (p<)	ES-CB (p<)
a. Rapid chill (4.5°C /h).								
Log cfu/cm^2								
APC_5[4]	3.11 (3.60)	3.71 (3.61)	1.88 (4.15)	2.85 (.16)	3.60 (3.41)	nsd	nsd	nsd
APC_{25}	2.77 (2.71)	3.62 (3.89)	5.02 (5.47)	3.39 (.46)	3.28 (3.50)	<0.01	nsd	nsd
APC_{35}	2.63 (2.86)	2.97 (3.47)	2.47 (2.66)	2.66 (.93)	2.40 (2.64)	nsd	nsd	nsd
b. Slow chill (2.0°C /h).								
Log cfu/cm^2								
APC_5	4.93 (5.40)	5.19 (5.51)	4.68 (4.86)	4.70 (5.31)	4.82 (5.50)	nsd	nsd	nsd
APC_{25}	5.25 (5.51)	5.27 (5.41)	5.06 (5.49)	5.28 (5.92)	4.59 (4.87)	nsd	nsd	nsd
APC_{35}	3.33 (3.34)	3.59 (3.67)	3.58 (3.58)	2.28 (3.78)	1.98 (3.49)	nsd	nsd	nsd
Effect of primal cooling rate (p<)								
APC_5	nsd	nsd	<0.05	nsd	nsd			
APC_{25}	<0.05	<0.01	nsd	nsd	<0.05			
APC_{35}	<0.01	<0.05	<0.001	nsd	nsd			

Notes

1. Treatments; HB/CB - effect of hot boning compared with cold boning at (0v)
   ES-HB - effect of ES applied to primal muscles compared to HB (0v)
   ES-CB - effect of ES applied to sides compared to CB (0)v
   (p<); significance of difference between means. Nsd; no significant difference at p<0.05 level.
2. Primal ES where ES (120v or 380v) applied to hot excised primal muscles.
3. HVES (450v) applied or not to carcase side.
   APC_5; APC_{25}; APC_{35}; Aerobic Plate Count at 5°C, 25°C and 35°C respectively.
   cfu/cm^2; (mean) log colony forming units per sq cm surface.

Table 3.17. **The effect of hot boning, ES applied to sides or primal muscles, and rapid or slow chilling on presumptive *coliform* and Staphylococcus aureus microbiological count in thawed primal muscles.**
(Data given as log (SD) of mean of FQ, loin and HQ muscles; n=6 culled ewe carcases per treatment).

Treatments	*Coliform* and Staphylococcus aureus count under different treatments					Effect of treatments[1]		
	Hot boned			Cold boned				
	ES-0v	ES-120v[2]	ES-380v	ES-0v	ES-450[3]v	HB/CB (p<)	ES-HB (p<)	ES-CB (p<)
a. Rapid chill (4.5°C /h).								
Log cfu/cm^2								
Coliforms[5]	0.67 (1.33)	0.79 (1.45)	0.43 (1.09)	0.0 (0.0)	0.0 (0.0)	nsd	nsd	nsd
Staphyloccocus aureus	3.10 (3.65)	3.53 (3.94)	3.45 (4.03)	2.28 (2.36)	1.87 (1.83)	nsd	nsd	<0.05
b. Slow chill (2.0°C /h).								
Log cfu/cm^2								
Coliforms	3.46 (3.95)	2.41 (2.93)	3.80 (4.10)	0.04 (0.59)	-0.32 (0.40)	nsd	nsd	nsd
Staphyloccocus aureus	4.18 (4.24)	4.14 (4.20)	4.50 (4.82)	3.43 (3.43)	3.33 (3.86)	<0.001	nsd	nsd
Effect of primal cooling rate								
Coliforms	nsd	nsd	<0.05	nsd	nsd			
Staphylococcus aureus	<0.01	<0.05	nsd	<0.05	nsd			

Notes

1. After 3 days display at +5°C; data from HQ, loin and FQ primal packs,
2. Treatments; HB/CB - effect of hot boning compared with cold boning at (0v)
   ES-HB - effect of ES applied to primal muscles compared to HB (0v)
   ES-CB - effect of ES applied to sides compared to CB (0)v
   (p<); significance of difference between means. Nsd; no significant difference at p<0.05 level.
   Primal ES where ES (120v or 380v) applied to hot excised primal muscles.
   HVES (450v) applied to carcase side.
   Presumptive count as log of colony forming units per cm^2.

Table 3.18. **The effect of hot boning, ES applied to sides or primal muscles, and rapid or slow chilling on aerobic psychrotrophic and mesophilic microbiological count in retail packs[1] from thawed primal muscles.**
(Data given as mean log (SD) of FQ, loin and HQ muscles; n=6 culled ewe carcases per treatment).

Treatments	Aerobic plate counts under different treatments					Effect of treatments[2]		
	Hot boned			Cold boned				
	ES-0v	ES-120v[3]	ES-380v	ES-0v	ES-450[4]v	HB/CB (p<)	ES-HB (p<)	ES-CB (p<)
a. Rapid chill (4.5°C /h).								
Log cfu/cm^2								
APC_5[5]	7.05 (7.46)	6.86 (7.4)	7.60 (7.93)	3.00 (3.23)	4.29 (4.95)	<0.05	nsd	nsd
APC_{25}	6.32 (6.86)	6.65 (6.11)	7.50 (3.00)	3.07 (3.33)	3.61 (3.89)	nsd	nsd	nsd
APC_{35}	3.34 (3.00)	3.61 (3.95)	4.17 (1.78)	1.51 (1.53)	2.20 (2.73)	nsd	nsd	nsd
b. Slow chill (2.0°C /h).								
Log cfu/cm^2								
APC_5	7.60 (8.06)	8.28 (8.71)	7.57 (7.81)	5.63 (6.08)	5.31 (7.74)	<0.05	nsd	nsd
APC_{25}	7.81 (8.19)	7.81 (8.07)	7.80 (7.73)	5.87 (6.15)	5.51 (5.84)	<0.05	nsd	nsd
APC_{35}	5.90 (6.27)	6.90 (7.26)	6.98 (7.48)	3.93 (5.47)	1.31 (3.69)	nsd	nsd	nsd
Effect of primal cooling rate (p<)								
APC_5	nsd	nsd	nsd	nsd	nsd			
APC_{25}	nsd	<0.05	nsd	nsd	nsd			
APC_{35}	nsd	nsd	nsd	nsd	nsd			

Notes

1. Treatments; HB/CB - effect of hot boning compared with cold boning at (0v)
   ES-HB - effect of ES applied to primal muscles compared to HB (0v)
   ES-CB - effect of ES applied to sides compared to CB (0)v
   (p<); significance of difference between means. Nsd; no significant difference at p<0.05 level.
2. Primal ES where ES (120v or 380v) applied to hot excised primal muscles.
3. HVES (450v) applied or not to carcase side.
4. APC_5; APC_{25}; APC_{35}; Aerobic Plate Count at 5°C, 25°C and 35°C respectively.
   cfu/cm^2; (mean) log colony forming units per sq cm surface.

Table 3.19. **The effect of hot boning, ES applied to sides or primal muscles, and rapid or slow chilling on presumptive *coliform* and Staphyloccoccus aureus microbiological count in retail packs[1] from thawed primal muscles.**
(Data given as log (SD) of mean of count for FQ, loin and HQ muscles; n=6 culled ewe carcases per treatment).

Treatments	*Coliform* and Staphylococcus aureus count under different treatments					Effect of treatments[2]		
	Hot boned			Cold boned				
	ES-0v	ES-120v[3]	ES-380v	ES-0v	ES-450[4]v	HB/CB (p<)	ES-HB (p<)	ES-CB (p<)
a. Rapid chill (4.5°C /h).								
Log cfu/cm^2								
Coliforms[5]	1.82 (2.26)	2.55 (3.18)	3.25 (3.75)	0.0 (0.0)	0.59 (1.16)	nsd	nsd	nsd
Staphyloccocus aureus	3.06 (3.66)	3.32 (4.92)	3.43 (4.03)	1.97 (1.16)	1.83 (1.99)	nsd	nsd	nsd
b. Slow chill (2.0°C /h).								
Log cfu/cm^2								
Coliforms	1.74 (2.07)	1.43 (2.85)	0.90 (1.27)	1.37 (1.87)	0.16 (0.62)	nsd	nsd	nsd
Staphyloccocus aureus	4.51 (4.85)	3.82 (4.08)	4.48 (4.87)	2.97 (3.37)	3.20 (3.85)	<0.05	nsd	nsd
Effect of primal cooling rate (p<)								
Coliforms	nsd	nsd	nsd	nsd	nsd			
Staphylococcus aureus	nsd	nsd	nsd	nsd	nsd			

Notes

1. After 3 days display at +5°C; data from HQ, loin and FQ primal packs,
2. Treatments; HB/CB - effect of hot boning compared with cold boning at (0v)
   ES-HB - effect of ES applied to primal muscles compared to HB (0v)
   ES-CB - effect of ES applied to sides compared to CB (0)v
   (p<); significance of difference between means. Nsd; no significant difference at p<0.05 level.
3. Primal ES where ES (120v or 380v) applied to hot excised primal muscles.
4. HVES (450v) applied to carcase side.
5. Presumptive count as log of colony forming units per cm^2.

NRI PROJECT COMPLETION REPORT

1. Basic Data:

Project Title: Development of methods to reduce the energy required to conserve meat without compromising its quality

EITHER (NON-RESEARCH)		OR (RESEARCH)	
NRI Project Code		**NRI Project Code**	R5176 (A0314)
Client	ODA	**Client**	RNRRS
Programme		**Programme**	Livestock Production
Problem Area		**System/Purpose**	Livestock Products, Quality and Processing

Contract value to NRI	£187K
Project completion date	31.03/95

2. Rating of implementation phase

Outputs	Delivery to schedule	Cost	Total
2	2	4	8

3. Likelihood of achieving project's objectives. (See notes on basis for scoring)

3

4. Comments and lessons for NRI: (continue overleaf if necessary)

a. The practical aspects of the research programme were not completed within a suitable real time frame: this led to a substantial accumulation of data requiring analysis in the last half year of the project. Outputs were thus delayed

b. Considerable emphasis was placed on the measurement of quality attributes (to align with other workers results). This level of detail is of little value and relevance to management in meat industries in representative countries.

c. There was considerable difficulty in carrying out the research programme where a high component of the work related to the practical application of the technology under development. This led to problems in maintaining momentum when experienced staff were unavailable.

5. Approval Sequence

Position	Name	Signature	Date
Project Leader	David Hector		
DPR HOD	Dr M Gill		
Regional Director/ Manager (for non research projects)			
Production Systems Leader or Programme Manager for research			

RNRRS PROJECT COMPLETION SUMMARY SHEET

DATE sheet completed: 9th Nov 1995

TITLE OF PROJECT:	DEVELOPMENT OF METHODS TO REDUCE THE ENERGY USED TO CONSERVE MEAT WITHOUT COMPROMISING ITS QUALITY.
R NUMBER:	R5176
RNRRS PROGRAMME:	Livestock Production
PROGRAMME MANAGER (INSTITUTION):	Dr M. Gill (Natural Resources Institute)
SUB-CONTRACTOR:	University of Nottingham
RNRSS PROGRAMME PURPOSE:	Marketing of eggs, Milk, Meat for Urban Populations Improved
RNRSS PRODUCTION SYSTEM:	Peri-Urban Interface
BENEFICIARIES:	Meat processors
GEOGRAPHIC FOCUS:	Sub Saharan Africa

	Planned	Actual
START DATE:	1st April 1992	1st April 1992
FINISH DATE:	31st March 1995	31st May 1995
TOTAL COST:	£232K	£187K

1. Project purpose:

Peri-urban abattoirs in developing countries tend to operate hot meat production and distribution systems; servicing the increasing urban market would require the introduction of refrigeration and an appropriate distribution system. Frozen meat is relatively less temperature sensitive than chilled meat where infrastructure is poor although overall energy efficiency would be important in minimising costs. The project examined the conservation and distribution of lower quality meat from rural abattoirs in the tropics, using hot boning and meat cutting practices, in combination with electrical stimulation (ES) applied to muscles, pressure moulding and rapid freezing methods, with a view to minimising energy inputs to the production system. Culled ewes were used as a model for animals of poorer meat quality.

2. Outputs:

Initial carcase chilling represents 30% of the total electrical energy required to run conventional refrigerative abattoirs. Hot boning offers a 50% reduction in energy usage associated with a conventional carcase chilling operations. Contact or plate freezing of hot boned meat offers a 65% reduction in energy use compareed with that used in blast freezing, and offers a more rapid temperature reduction. Excised pre-rigor muscle is much more susceptible to rigor shortening and consequent toughening under very rapid chilling conditions; this problem can be partially avoided in high quality meat by its good response in terms of accelerated pH fall brought about by ES.

High voltage ES applied locally to ovine muscles after excision appeared to be as effective as conventional ES applied to carcase sides in accelerating pH fall, although it did not reduce the variation between muscles. Both ES applications were marginally successful in preventing rigor shortening. ES applied to excised muscles under pressure offered no advantage in pH fall or reduction in subsequent muscle toughness. The hypothesis that ES conditions could be adapted to particular muscle end use has not been confirmed in culled ewes under the conditions tested.

The application of ES to excised muscles, which represents an additional handling step in a hot boning process, had no effect on microbiological quality of the cold boned thawed product if muscles were cooled to <8^{o}C within 6 h of hot boning. Microbiological counts were significantly higher when the cooling rate was reduced , giving a muscle temperature of 8^{o}C at 11 h after hot boning, although the extent of the increase was not effected by ES applied to excised muscles. Carcase dressing and boning operations at high ambient temperature would require adherance to the stricter cooling specification, which could be achieved using plate freezing technology.

Technologies such as ES and contact freezing are of limited interest to the meat processing sectors in Tanzania and Malawi, which will continue to be poorly developed. Two abattoirs in the Northern Communal Areas of Namibia are to use hot processing and plate freezing technology for the production of block meat.

3. Contribution of Outputs to Project Goal.

The possibility of stimulating excised muscles has been demonstrated, although its comparative effectiveness in beef carcases compared with conventional ES is unknown. The relatively performance of conventional ES on low quality animals is directly applicable to Meatco suituation in Namibia; further work in this area should await the results of their first attempts to introduce rapid processing technology.

4. Publications.

Report on a visit to Tanzania, Malawi and Namibia to identify the possibilities for the application of the technologies of hot boning, electrical stimulation and plate freezing to local meat production. D.E. Silverside and M. Pritchard (1994). NRI Report R2119 (S).

5. Internal reports.

The performance of HVES on culled ewes (2); A pathfinder exercise on the effect of stimulating excised muscles; Final Technical Report.

6. Other dissemination of results.

Two scientific papers are in preparation; first drafts are to be completed by December 1995.

a). The effectiveness of the application of ES to hot excised primal muscles.

b). The effect of ES application and cooling rate on the quality of hot excised muscles.

7. Follow-up indicated/planned.

Meatco (Namibia) consider the adaption of conventional ES parameters to local cattle (and muscle colour in older cattle) to be high priority problems and have requested technical assistance in these areas.

Signed _____ Dr D. Hector

NRI PROJECT SUMMARY FORM

FOR COMPLETION BY PROJECTS OFFICE

NRI Project Code	A0314	Economic Sector Code	31110
Previous Code/s	A0028	NRED Project Code	R5176

PROJECT SUMMARY

1. Project Title: Development of methods of reduction of the energy required to conserve meat without compromising its quality.

File #: RAF 9294 630/639/002A

Short title: Freezing & processing meat *(max 25 characters)*

Source of Funding and Status: *(please ring appropriate letters)*

Geog Div	Research Strategy	PDC	CNRAC	Other HQ	non-ODA	Status
T	A F X	I J S	D M N O R V	B Q	C H	A B

Client *(ie. HQ commissioning source: non-ODA Contract)*: NRED

MIS code: 793-629-066-YK

Previous MIS Codes: 793-629-002-YK

2. Dates

Inception: [ ] *(see guidance notes)*

Start: 1-Apr-92 Finish: 31-Mar-95 Report due: 31-Mar-95

3. Terms of Reference / Project Objectives:

1. To assess energy and production requirements of hot meat processing and conservation procedures.
2. To relate effects of freezing and other procedures on meat quality from lower grade animals.
3. To reassess microbiological criteria in small scale meat processing operations.
4. To conduct a RRA type survey of current meat processing practices constraints to change and market potential in 2 countries.

4. Project Outputs:

1. Recommendations on product handling procedures related to energy use and conservation.
2. Recommendations regarding hygiene and process operations in small scale boning and processing of facilities.
3. A description of current practices and opportunities for change.

5. Name(s) and address(es) of collaborating institute(s)

In the UK: University of Nottingham (Facility)

Overseas:

Version 1 12/2/93

A0314 — Amendment 2 — 24/1/94

BUDGETS

R 5.76

6. Manpower Budget - Staff Time MIS Code:

(Max 3 year input)

Time in DAYS * Pay Band	1993/94 B1	B2	B3	B4	Fees***	1994/95 B1	B2	B3	B4	Fees***
Lead Resource Centre: Livestock		40	145		63650		30	120	80	73695
Management **										
Collaborating: MRS			23		7590					
Technical Services				0.2	52					
Library				0.4	104					
Fish			2.5		825					
Agroprocessing			0.3		99					
LT O'seas										
=(Annual limit) Total time/fees***		40	171	0.6	72320		30	120	80	73695

For use ONLY if start date after 1/4/93:

Time in DAYS * Pay Band	1995/96 B1	B2	B3	B4	Fees***	1996/97 B1	B2	B3	B4	Fees***
Lead Resource Centre: Livestock										
Management **										
Collaborating: MRS										
Technical Services										
Library										
Fish										
Agroprocessing										
LT O'seas										
=(Annual limit) Total time/fees***										

* *1 m/month = 21.3 days, 1 m/year = 213 days EXCEPT LT O'seas when 1 m/month = 22.7 days and 1 m/year = 272 days*

** *Except NRED*

NB Management & LT O'seas assumed to be Lead Resource Centre unless otherwise specified

*** *Fees are inflate*

7. Associated costs (to nearest £)
(Max 3 year input)

Type of expenditure:			MIS Codes	1993/94	1994/95	1995/96	1996/97
Visits	T & S	Overseas		9000	6000		
	T & S	UK		500			
Capital							
Consumables				800	1500		
External Consultants	(Total fees + direct costs)						
Local imprest/Post accounts							
Training							
Overseas allowances							
Other: Freight					1000		
Total associated costs at base year rate				10300	8500		
Financial Limit *				10300	8670		

* *Max associated costs using inflators*

8. Total Costs

	1993/94	1994/95	1995/96	1996/97
Annual limit (from previous page)	72320	73695		
Financial limit (from above)	10300	8670		
Annual budget limit (Annual limit + Financial limit)	82620	82365		

Contract value *ie total of annual and financial limits during the three-year period of this PSF, using inflators* 164985

Total Project costs (throughout lifetime)

9. Parallel funded projects: Contribution, additional to the above, from collaborating Institute(s)/Programmes/Funding sources etc

Name of Contributor

Type of Contribution

Project code/s (where applicable)

Values:	Total	1993/4	1994/5	1995/6	1996/7

LIAISON ARRANGEMENTS

10. Project Leader | D Silverside

Resource Centre | Livestock

Reporting arrangements | Through Livestock Programme Manager to NRED

FOR ODA PROJECTS ONLY

ODA HQ/Development Division contact

ODA HQ Department /Dev Div

ODA HQ Administrative contact

ODA HQ Department

PROJECT CLASSIFICATION

(To be completed by Project Leader)

11. Project classification | Manager

Strategy Area	RAFS	Dr R Cooke
Programme	Livestock Production	Dr M Gill
Problem Area	Livestock PQP	Mr D Silverside

12. Type of Project *(please tick relevant box/s)*

Basic ☐ Applied Strategic ☐ Applied Specific ☐ Experimental Development ☐ Technology Transfer ☐ Service to Headquarters ☐

13. Research Strategy Profile

Commodity/Commodity group | Livestock

Discipline | Livestock Production & Nutrition

14. Benefiting Countries or Regions | Africa/South Africa

15. Country where work will be undertaken | UK

Benefiting agro-ecological Zone: *(please tick relevant box/s)*

Arid/semi-arid ☐ Humid tropical lowlands ☐ Sub-humid / savanna ☐ Irrigated ☐ Highlands ☐

16. Women in Development *(see guidance notes before ticking relevant box/s)*

Specific ☐ Integrated ☐ Relevant ☐ Non-relevant ☐

PROJECT APPROVAL

17. Environmental Impact		Positive ☐	Neutral ☐	Negative ☐	
	Signed	J Bennett	Date	27/11/92	
18. SSG Support	Signed	R Grimble	Date	3/12/92	

19. Approval of project as part of NRI's work programme

A. Problem Area Manager	Signed		Date	
Programme Manager	Signed	M Gill	Date	3/12/92
Lead R C Manager	Signed	M Gill	Date	3/12/92

B. For all projects in excess of £10,000, and all NRD funded projects, irrespective of value

Strategy Area Manager	Signed	R Cooke	Date	3/12/92

C. ODA Manager — **I confirm that the MIS codes quoted in this PSF are valid for this work**

(Where appropriate, not NRRD)	Signed		Date	

20. Environmental Appraiser's comments

21. SSG Appraiser's comments

A0314

PROJECT TITLE: Development of methods of reduction of the energy required to conserve meat without compromising its quality.

27 Nov 1991
21 Oct 1992

DESCRIPTION: To develop a freezing process for the conservation and distribution of lower grade cut meat from rural abattoirs in the tropics. The planned process involves a combination of hot boning, meat cutting, electrical stimulation of the meat, pressure moulding and different freezing methods. Meat quality and microbiological status will be maintained or improved.

MIS CODE: 793-629-066-YK

FILE REF:

PROJECT STRUCTURE	INDICATORS OF ACHIEVEMENT	HOW TO ASSESS INDICATORS	IMPORTANT ASSUMPTIONS FOR SUCCCESS
WIDER OBJECTIVES			
1. To improve the living standards of resource-poor livestock owners and processors through the provision of recommendations on improvements to the quality of livestock products and reduction of processing losses.	Adoption of results by scientists and technologists involved in adaptive research.	Monitoring of reports of national livestock and meat production services and enterprises.	Initial identification of research needs remain relevant.
		Interest in publications and progress shown by livestock and meat production scientists.	Interest of extension services in livestock products delivery. Adoption of results by extension services.
2. To improve yield from livestock production	Increase in meat yield by 5%, one year after start of production in rural abattoirs.	Comparative boning room data	That a localises system of slaughter and processing by the proposed system is adopted.
3. To supply meat with the potential for a wider range of uses than currently enjoyed.	Graded meat supply at a wider range of prices than current, one year after start of production by the new technology in rural abattoirs.	Market survey data	The proposed technology produces meat with a broad range of qualities suitable for a range of functions; the market for such products exists.
4. To improve export opportunities for meat.	Demand for meat in export markets increases by 5%, one year after start of the proposed new production system.	Market survey data	Markets and infrastructure for the product exist or can be developed; meat supply is available to meet the demand.
IMMEDIATE OBJECTIVES			
1. To optimise energy inputs into refrigerated meat production, preservation and distribution systems.	The measured energy inputs to the experimental system at their lowest possible by March 1995.	Reference to scientific press.	Discriminators are sufficiently sensitive to measure differences in meat quality; availability of suitable raw materials.
2. To devise a system of processing meat from lower grade stock using perhaps hot boning, raised pressure electrical stimulation, and/or different freezing methods without compromising microbiological or other meat quality parameters.	Comparable objective quality standards of meat attained or improved by March 1995.	Reference to NRI publications list.	That all parameters are measurable and their control is sufficiently sensitive to be applied
3. To conduct a RRA type survey of current practices and constraints to change and market potential.	Survey conducted in 2 locations by August 1993.	Report on survey.	That representative locations can be identified and survey conducted.

OUTPUTS

1.Recommendations regarding the optimal physical, economic and energy processing criteria for the production of quality frozen meat.	Two scientific papers by March 1995.	Reference to NRI publications list	That all parameters are measurable and their control is sufficiently sensitive to be applied.
2. A description of a meat freezing system for poor quality beef and smallstock meat as an alternative to livestock or chilled meat distribution systems in ldc's.	One manual and three scientific papers by March 1995.	Reference to scientific press, file records, NRI publications lists.	Technology transfers to tropical countries.
3. A description of current practices and opportunities for change.	One brief review paper by December 1993.	Reference to NRI publications list.	Availability of data.

INPUTS (£000s)

1. Staff: Approx 51 mm

Value	
92/3	£63,600
93/4	£88,300
94/5	£69,400

2. Travel & Subsistence

Value	
92/3	£800
93/4	£8,000
94/5	£3,000

3. Equipment support costs

Value	
92/3	£0
93/4	£0
94/5	£0

4. Capital Costs

Value	
92/3	£0
93/4	£0
94/5	£0

5. Consumables

Value	
92/3	£0
93/4	£1,000
94/5	£1,000

6. Equipment installation/hire of facilities

Value	
92/3	£0
93/4	£1,000
94/5	£1,000

Sustained staff inputs

	92/3	93/4	95/6	Totals
Staff	63,000	88,300	69,400	221,300
T&S	800	8,000	3,000	11,800
Equpt	0	0	0	0
Support				
Capital	0	0	0	0
Consumables	0	1,000	1,000	2,000
Eq install/ hire	0	1,000	1,000	2,000
Totals:	0	98,300	74,400	237,100