ANTE-MORTEM FACTORS WHICH INFLUENCE CARCASS SHRINKAGE AND MEAT QUALITY

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Summary

Poor handling of animals ante-mortem can reduce economic value and may prejudice animal welfare. There is a tendency for the meat industry to become centralised into fewer, larger plants operating at faster line speeds so that animals must travel further to slaughter. The marketing process can thus be prolonged. The procedures associated with it are inherently stressful and lack of care in handling can result in losses of carcass yield and reduced meat quality. Major factors reducing yield are deprivation of food and water and long transport. Pigs lose about 0.1% carcass weight per hour of fast after an initial 9 to 18 hour period; sheep lose between 0.08 and 0.15% per hour. In cattle, carcass yield may be reduced by <1 to 8% over the initial 48 hours. Water deprivation increases losses. The effects of transport are less well defined, but most studies have shown losses additional to those attributable to inanition. Prolonged fasting can also reduce edible offal weights, make carcass dressing more difficult and have meat hygiene implications. Lean meat quality can be influenced through the production of PSE or DFD conditions or by direct effects on palatability. Longer transport and lairage tend to promote DFD and reduce the incidence of PSE in pigs. Stress immediately before stunning, particularly in race systems and restraining conveyors, is a cause of PSE. Modern genotypes of pigs, which are prone to extreme excitability, exacerbate the problem while carefully designed automatic handling systems in lairages go some way to alleviating stress and improving quality. Dark cutting beef is produced by mixing unfamiliar cattle, especially bulls, during marketing. Sheep may also produce DFD meat if subjected to fairly severe preslaughter handling, particularly if poorly nourished. Recent work has shown that the eating quality of beef can also be affected by preslaughter stresses, including inanition, in ways not related to DCB and which are as yet poorly understood.

Introduction

The way we handle animals ante-mortem has been highlighted in recent years for two reasons. First, in an increasingly competitive market, and with the emphasis on quality of the final product, the economic losses caused by poor handling are becoming more widely realised. Second, consumers in many countries have become more aware of the ethics of meat production. They want their meat produced in ways that take account of animal welfare. Indeed, welfare-friendly products may command a premium price. Ante-mortem handling is seen as just as much a part of this concern for the animal's welfare as are the husbandry practices followed during rearing.

The slaughtering industry in many countries is becoming centralised into fewer, larger plants. Marketing times and the distances animals must travel to slaughter are therefore likely to have increased. This is particularly true if stock are sold through live auctions or are exported so the marketing process includes several stages of assembly and transport. For example, pigs are exported from The Netherlands to southern Europe for slaughter, journeys of about 1500 km which may take up to 40 hours (Lambooy *et al.*, 1985). Sheep are exported from the U.K. to southern France, journeys taking 24 hours, including a sea crossing. Cattle reared extensively in Australia frequently spend two to five days in the marketing process but it may take as long as two weeks from mustering to slaughter (Wythes and Shorthose, 1984). Aalhus *et al.* (1990) suggested that in Canada, some pigs could potentially be deprived of feed and water for up to 72 hours before slaughter. The introduction of computer auctions, where animals are sold without the need to take them to central collection points, may have welfare and quality benefits if handling is reduced. Another problem is that larger slaughter plants often operate at higher line speeds than small plants. The need to move and process animals rapidly also inevitably lends to potentially more stress in the period immediately before slaughter.

Even when carried out with due care and consideration, the marketing process is inherently stressful. Animals are removed from their home environment, loaded and unloaded from transport vehicles, subjected to often long journeys and held in unfamiliar surroundings. They may be exposed to various stressors such as noise, unfamiliar smells, deprivation of food and water, vibration, extremes of temperature, breakdown of social groupings, close confinement and overcrowding. How the animal responds to these stresses can lead to reductions in carcass yield and meat quality. Yield is reduced by losses of live and potential carcass weight (shrinkage) caused by combinations of inanition and handling stress. Lean meat quality can be affected through the production of pale, soft, exudative (PSE) or dark, firm, dry (DFD) meat and also in less well understood ways which influence eating quality.

Carcass shrinkage

Loss of potential carcass yield could be caused by both loss of protein and fat and by loss of water (dehydration). If an animal is deprived of food (fasted) it will mobilize body tissues to provide energy for maintaining the vital functions of the body. More loss is possible if the animal is subjected to greater energy demands, such as those needed to maintain balance or to thermoregulate in transport. Thermoregulation may involve greater loss of body water through sweating or panting. In longer transport particularly, animals can become dehydrated.

Carcass shrinkage in pigs

Reviews of earlier work on the effects of fasting on carcass yield in pigs can be found in Ingram (1964), Wajda and Denaburski (1983), Warriss (1982; 1987) and Tarrant (1989). Live weight begins to be lost almost immediately after feed withdrawal at a rate of between about 0.12 and 0.20% per hour. A large part of this loss, particularly initially, is attributable to loss of urine and faeces. It is less clear when carcass weight loss begins but this is probably between about 9 and 18 hours after the last meal reflecting the relatively rapid passage of food through the pig's gut. Most recent studies have found rates of carcass loss, determined over fasting periods of 48 hours or more, to vary between 0.06 and 0.14% per hour (Table 1). Where pigs have not been given access to water during the whole period of fasting, the rate of loss tends to be higher. Overall, an average working figure of 0.1% per hour would appear reasonable. Carcass weight loss accounts for up to about a third of total live weight loss over the first 24 hours of fasting and up to a half between 24 and 48 hours.

Jones *et al.* (1988) showed that there were no differences in the effects of fasting on the carcass yield of pigs of different stress-susceptibility genotypes. The influence of ambient temperature during fasting is not clear. High temperatures could increase weight loss by greater loss of moisture from the respiratory tract,

Table 1. Rates of carcass shrinkage in fasted pigs found in recent studies.

Source	*Rate of loss (% per h)*	*Comments*
Jones *et al.*, 1988	0.06	no transport water available
Eikelenboom *et al.*, 1991	0.03 - 0.09	transport 2 to 3 h '0'h = 5h off *ad lib*
Guise, 1990	0.10	fast from 1 to 25h
Warriss and Down, 1985	0.11	4h transport and lairage '0'h = 4h of *ad lib*
Warriss, 1982	0.13	1h transport
Jones *et al.*, 1985	0.14	4km transport no water '0'h=17h from last meal

especially through panting. Groups of pigs can tolerate low temperatures to some degree by huddling together, so modifying their immediate microclimate and reducing body heat loss.

Although the rates of carcass loss appear small, they result in significant economic losses under commercial conditions. For a 90 kg pig (live), a loss of between 0.8 and 1.6 kg of potential carcass yield might be expected after deprivation of food for 24 hours. *This is equivalent to the loss of value of more than one pig for every 100 marketed.* Under normal commercial conditions pigs are of course subjected to additional stresses pre-slaughter besides food deprivation. It is unclear how these additional stresses affect the response to fasting. However, in a study reported by Guise (1990), the influence of holding pigs overnight in lairage without food was examined in a large commercial plant. The average reduction in carcass weight caused by the long lairage was 1.03 kg, equivalent to 1.4% of the carcass yield of the pigs slaughtered on the day of arrival.

That the loss in yield is largely attributable to loss of protein and, to a lesser degree, fat, rather than loss of water, is supported by evidence that the reduced yield is maintained after curing (Warriss & Down, 1985; Jones *et al.*, 1985). It might be expected that the equilibration of water which takes place during curing would reduce the losses if these were due mainly to loss of tissue moisture. This does not happen.

How the other major ante-mortem stress --transport -- affects carcass yield is less clear because few studies have examined it in isolation. In an experiment conducted in summer, transport for one hour resulted in a non-significant loss of 0.6% carcass yield while a journey lasting six hours reduced it by 2% (Warriss *et al.*, 1983). The pigs given the long journey showed evidence of dehydration suggesting that, in contrast to fasting, transport yield losses are largely attributable to tissue water losses. Mayes *et al.* (1988) transported pigs about 400 miles followed by periods of fasting from 24 to 72 hours. Transport reduced carcass yield by between 1.0 and 1.9 killing out percentage units. There is some information on the effects of very long transport times (29 hours) on pigs exported from The Netherlands to Italy (Lambooy *et al.*, 1985). Carcass weight was reduced by 4kg, mainly due to water loss.

Shrinkage in ruminants

Because of their proportionally larger guts, and the fact that the rumen acts as a store of nutrients and water, ruminants are generally less susceptible than pigs to inanition. The gut contents of adult cattle can account for over 20% of the live weight and form a major component of live weight losses over the initial 24 hours of food deprivation. Gut fill is larger in animals on high roughage pasture than in those fed grain diets and in animals which have recently drunk. Previous diet and access to water are therefore important factors influencing the patterns of live weight loss in ruminants. Even if food is offered, there is evidence that under conditions of stress some ruminants may be reluctant to take it and this may extend effective fasting times under commercial marketing conditions. If food is unavailable, water consumption may also be reduced to very low levels in sheep.

Results from studies on sheep in New Zealand, Australia and the U.S. (see: Warriss *et al.*, 1987; Thompson *et al.*, 1987) have indicated average live weight losses ranging from 0.09 to 0.34% per hour, and rates of carcass loss varying from 0.08 to 0.15% per hour, with the onset of carcass loss occurring between 12 and 24 hours after deprivation. A U.K. study (Warriss *et al.*, 1987) found a live weight loss between 0 and 72 hours of 0.14% per hour and a carcass loss of 0.085% per hour (Table 2). There was evidence that, unlike the situation in pigs, dehydration may have been important in explaining some of the loss. Thompson *et al.* (1987) found carcass weight to be lost in a slightly curvilinear fashion so the rate of loss after 24 hours (0.15% per hour) was higher than that calculated over 96 hours of fast (0.080% per hour). Less loss was recorded in fatter and heavier lambs. Transport for up to 6 hours had no extra effect above that of fasting (Thompson *et al.*, 1987) or only very small (1.7% lighter), non-significant, effects (Warriss *et al.*, 1990).

Table 2. Influence of fasting on weights (kg) of body components in sheep.

	Fast (h)				
	0	***24***	***48***	***72***	
Live wt at slaughter	32.3	30.6	29.8	29.2	***
Hot carcass weight	16.4	16.0	15.7	15.4	***
% loss in chilling	4.7	4.7	4.5	4.2	ns
Liver weight	0.63	0.52	0.48	0.45	***
Gut contents	4.6	3.6	3.7	3.3	***

In adult cattle, the range and pattern of live weight loss with longer periods of fasting that have been found in different studies are very variable (Shorthose and Wythes, 1988; Warriss, 1990). Loss tends to be greater when both food and water are unavailable under conditions of high ambient temperature. Based on data collected from twenty-six publications, Shorthose and Wythes (1988) produced a relationship showing mean losses of live weight of about 7% after 12 hours, 9% after 24 hours, 10% after 48 hours and 11% after 72 hours. Reported losses in carcass yield are also very variable. Some authors have demonstrated reductions in killing-out percentage within 24 hours of food deprivation whereas other studies have found no material effects after times ranging up to 4 days. Recorded losses in carcass yield after a 48 hour fast range from <1% to 8% (Warriss, 1990). The variation is undoubtedly attributable to those factors which also influence live weight loss. One of the most important is whether water is also withheld. Rates of loss appear to be up to three times higher in this case.

Like pigs, cattle during marketing are subjected to other stresses, such as transport, during the fasting period. A lot of our knowledge of the effects of transport on shrink comes from work on cattle in North America and Australia. In journeys ranging in length from 500 to 2000 km animals have lost between about 6 and 12% of their live weight (see: Warriss, 1990). Carcass weight losses range from 0 to 4% in journeys up to 2000 km. Canadian workers (Jones *et al.*, 1988) compared the effects of *ideal* marketing (cattle fasted for 24 hours and transported 3 km to slaughter) with those of more commercial handling (fasting for up to 72 hours and transport for up to 640 km). Compared with the *ideal* situation, fasting steers and heifers for 48 hours and transport for 320 km reduced live weight by 4.5% and carcass yield by 1.0%. A 72 hour fast with a 680 km transport spread over two days resulted in loss of 5.3% live weight and 1.5% carcass weight. It also reduced body fat by 0.8%. In a later study (Jones *et al.*, 1990) water, as well as food, was withheld from steers. The animals were given a very short transport (5 km) to the slaughter plant. Live weight was lost most rapidly initially and amounted to 10.6% by 48 hours. Carcass losses were observable by 24 hours and by 48 hours were 6.5%. These losses are high compared with those found in studies where only feed has been withheld illustrating the importance of dehydration in reducing yields.

Other considerations relating to inanition

Long periods without food or water may have various other undesirable effects on carcass quality. With longer deprivation periods the stomach contents of ruminants become more watery increasing the chances of head, tongue and carcass contamination either through regurgitation or through accidental cutting of the gut wall during carcass dressing . There may be a build-up of pathogenic bacteria such as *salmonellae* in the gut. Long periods of fast lead to significant losses in the weight of edible offal, particularly the liver, and removal of the hide or fleece may become more difficult because of dehydration of the subcutaneous tissues.

Marketing and lean meat quality

The main attributes of meat quality that are affected by marketing procedures are the colour, waterholding capacity and palatability of the lean. However, other characteristics, such as spoilage potential, can also be influenced. This is because stressful marketing may predispose animals to produce PSE or DFD meat or may reduce quality by other, less well understood, mechanisms. Acute stress around the time of slaughter leads to PSE pork by stimulating the rate of immediate post-mortem acidification so that low pH values are reached in the muscle when carcass temperature is still high. This causes changes in the muscle proteins which produce poor waterholding and pale colour (high light scattering) in the subsequent meat. The problem is considerably greater in genotypes that are susceptible to stress, identifiable by reference to their sensitivity to the anaesthetic gas halothane or, now, by a specific gene probe to the Ryanodine receptor (Fujii *et al.*, 1991; Houde and Pommier, 1993). In a survey of pork from pigs killed in Quebec, Pommier and Houde (1993) found that 91% of nn animals, and 80% of Nn pigs produced PSE meat.

Chronic stress leads to DFD meat by depleting muscle glycogen so that the extent of post-mortem acidification is reduced. Muscle proteins remain above their isoelectric point at the high ultimate pH, waterholding capacity is high and the meat surface appears dark (low light scattering). Classically the term *chronic* has been thought of as meaning tens of minutes or hours but it is clear that glycogen depletion can occur in some muscles very quickly so that even what appears to be short-term stress may lead to DFD meat. Recently Karlsson *et al.* (1992) have suggested that when 30% or more of the type IIB fibres in a muscle are depleted of glycogen there will be a tendency to the development of DFD even if the overall glycogen concentration is little affected. Type II fibres (glycolytic) may be more prone to depletion by physical exercise stress while Type I fibres (oxidative) are more responsive to emotional stress acting through sympathetic arousal and adrenaline secretion. Muscles with different fibre complements therefore react differently to different types of stress. DFD meat can occur in all species; in cattle it is often referred to as dark cutting beef (DCB).

The incidence of PSE and DFD pork

Incidences of up to about 20% for PSE and 35% for DFD have been reported in various studies (Warriss, 1987) although often the levels are much lower than this. Nevertheless, recent surveys have highlighted the extent of the problem in the U.S. (Cassens *et al.*, 1992) where 16% of hams were found to be PSE and 10% DFD. In Australia, Warner and Eldridge (1988) reported overall incidences of PSE and DFD of 10% and 15% respectively in pigs killed in a Victorian abattoir. Trout (1992) recorded average incidences of 32% for PSE and 15% for DFD in five large Australian plants with considerable individual variation. Data presented for Canadian pigs by Fortin (1989) imply very high incidences of pale meat, averages ranging from 20% to 90% for batches of commercial pigs subjected to various preslaughter handling procedures. However, it is likely that these are overestimates of the true prevalence of the problem as would be perceived by consumers. This illustrates a major difficulty with trying to assess the extent of the problems; that is, the lack of single definitive characteristics which everyone agrees on to define either PSE or DFD conditions.

Effects of transport and lairage on pork quality

This topic has been reviewed (Warriss, 1987). How pigs react to transport can be influenced by their stress-susceptibility. Very stress-susceptible pigs may produce high incidences of PSE meat after the stress associated with only short transport distances. More stress-resistant animals may show little or no reaction over moderate distances under good conditions. Most pigs will show some evidence of fatigue and muscle glycogen depletion after longer transport, particularly under poor conditions, leading to an increased incidence of DFD meat. Important elements of the conditions of transport are stocking density and ventilation of the vehicle. Too high stocking densities and poor ventilation in hot weather are likely to reduce pork quality as also are poor transporter design, road conditions and driving technique. As well as very high ambient temperatures, very low ones may also be stressful to pigs (Honkavaara, 1991). Longer transport can allow some recovery from the stress of loading so that the level of PSE is reduced. This effect will be reinforced if muscle glycogen is depleted during transport.

Lairage can allow some recovery from the stress of transport and unloading especially in more stress resistant pigs. Rest for up to about four to six hours tends to reduce the incidence of PSE meat. Extending the lairage time will probably reduce PSE even further but may increase the levels of DFD meat. This is especially so if pigs are held overnight without food. Fernandez *et al.* (1991) found that, irrespective of time held (2 to 24hours), whether unfamiliar pigs were mixed or even provision of sugar solution to drink, glycogen levels were depleted by 12 to 16% when animals were held in lairage. Glycogen depletion may nevertheless be insufficient to elevate ultimate pH. This appears particularly true in at least some strains of the Hampshire breed and their crosses. These have extremely high muscle glycogen concentrations (up to 70% higher in 'white' muscles when compared with other breeds) leading normally to very low ultimate pH values. Even when subjected to long lairage these pigs do not appear to produce meat with high ultimate pH (Wassmuth and Glodek, 1992). It is important that conditions in the lairage do allow the animals to rest. Mixing groups of unfamiliar pigs leads to fighting. The problem is particularly acute with uncastrated male pigs. The physical exertion associated with fighting depletes muscle glycogen stores and leads to DFD meat. It may also increase the incidence of PSE meat if the stress occurs immediately preslaughter.

These effects of increasing transport and lairage times are well illustrated by the results of Malmfors (1982) for Swedish pigs (Table 3) and those of Fortin (1989) for Canadian animals (Table 4). The responses to transport and lairage can be additive. In the work of Malmfors (1982) pigs subjected to both a short transport and a short lairage produced 22% PSE carcasses and 9% DFD. Long transport followed by long lairage reduced PSE to 9% but increased DFD to 11%.

Table 3. Effect of transport and lairage on pork quality in Swedish pigs.

	Transport (km)			*Liarage (h)*		
	<35	*60*	*>90*	*<0.3*	*3*	*6*
% PSE	14.0	10.3	10.3	16.0	9.3	9.0
% DFD	3.7	5.0	6.3	2.7	3.7	8.7

Controlling feed withdrawal periods

Long fasting periods contribute to muscle glycogen depletion. It has been suggested that prolonged feed withdrawal periods could be used deliberately to reduce muscle glycogen levels and hence, by limiting the extent of post-mortem

Table 4. Effect of transport and lairage on pork quality in Canadian pigs.

	Transport (h)		*Lairage (h)*		
	<1	*2*	*<0.3*	*3*	*6*
% pale loins	59.4	40.9	63.4	46.0	45.9

muscle acidification, reduce the incidence of PSE meat (Eikelenboom *et al.*, 1991). Although the results of Murray *et al.* (1989) certainly indicated considerable progressive reductions in the incidence of soft, exudative pork with longer fasts up to 48 hours in both Nn and nn halothane genotypes, Fischer *et al.* (1986) could not materially reduce the levels of PSE meat in German pigs, which appeared to be of a very stress-susceptible genotype, even with fasts up to 72 hours. They concluded that extended fasting, combined with handling stress, did lower carbohydrate levels but that this did not usefully alleviate the PSE problem. Any small improvements in the loin and ham muscles had to be set against the increased incidence of DFD in the shoulder meat and reduced carcass yield. Eikelenboom *et al.* (1991) also found increased DFD incidences with longer fasts.

Practical concerns with the handling of pigs

Larger slaughter plants often operate higher line speeds and the need to handle animals faster may not be matched by improvements in handling facilities and practices. Higher speeds and the need for coercion may then result in greater stress suffered by the pigs and poorer meat quality. Increasing problems have been recorded with pigs which appear to be very excitable (Grandin, 1991). These pigs are very difficult to move without inducing considerable stress and consequently are very prone to producing PSE meat. The problem is particularly associated with lean or heavily-muscled genotypes and with animals reared under conditions of little environmental stimulation. Excitability can be reduced by environmental enrichment during rearing (Grandin, 1989) but in the longer term breeders must address the need for selection for calm temperament.

Recently, Danish workers have developed new designs of lairage which improve the practical handling of pigs (Barton-Gade *et al.*, 1992). These designs incorporate smaller pens holding only fifteen individuals and automatic push gates to move the animals. Keeping the pigs in small groups reduces aggression and skin damage. Automatic moving gates are less stressful than the actions of human beings and make the pigs easier to move. The incidence of DFD meat, but not PSE, is reduced, as is the amount of bloodsplash.

To facilitate handling pigs rapidly for electrical stunning most large plants use races leading to restraining conveyors. Current methods of carbon dioxide gas stunning also require use of enclosed race systems to direct pigs into the individual compartments of the stunning unit. Pigs find such close confinement and restraint stressful and the design of better systems which subject the animals to the least possible stress is an area of active investigation at present.

Marketing effects on lean meat quality in ruminants

Ruminants seem to be generally more resilient than pigs. There is, nevertheless, evidence that ante-mortem stress is detrimental to beef palatability although the effects vary in size and the causal mechanisms are unclear (see: Warriss, 1990).

A series of papers by Wythes and her colleagues from Australia (Wythes *et al.*, 1988a; 1988b; 1989) has demonstrated the benefits of quietly resting cattle with feed, either in transit or in lairage, on meat tenderness. Resting steers trucked 125 km for 26.5hours, compared with only 2.5hours, improved tenderness by 15%. Resting for 52 hours, compared with 4 hours, improved tenderness of meat from cows transported 1390 km by road and rail by 13%. A 96 hour rest improved tenderness of meat from bullocks transported 650 km by rail by 23% when compared with animals rested only 24 hours. The beneficial effects of longer holding periods were lost if the animals were periodically disturbed.

Canadian work has demonstrated potentially very important influences of stress and food and water deprivation in cattle. Work by Jeremiah *et al.* (1988a; 1988b) using bulls and steers showed that normal preslaughter stress (mixed groups of animals transported 160 km and slaughtered up to 24hours after leaving the feedlot) produced beef that was less tender, less juicy and had poorer flavour than that from animals subjected to minimal stress (killed within 4 hours and given only a 4 km journey to slaughter). Jones *et al.* (1990) subjected mixed groups of steers to inanition for up to 48 hours. There were progressive increases in ultimate pH, the meat became darker and showed improved water holding capacity, all presumably reflecting the influence of food deprivation on muscle glycogen concentrations. Possibly the most important effect however was a progressive increase in instrumentally-measured toughness. Meat from steers given no food or water for 48 hours had shear force values 22% higher than that from control animals slaughtered directly off food and water.

This effect was confirmed by a second Canadian study (Jeremiah *et al.*, 1992). In this, young bulls were deprived of food and water for up to 36 hours and the meat assessed by both laboratory taste panels and consumers. Not only were there significant decreases in tenderness, but flavour and juiciness were progressively poorer with longer deprivation times. Overall palatability ratings were significantly lower after only 12 hours.

The exact reasons for these effects on eating quality are unclear. Some increase in toughness could be expected with small increases in pH_u if the meat had been cooked at relatively low temperatures ($\approx 70^{\circ}C$). Under these conditions, the relationship between texture and pH_u is curvilinear (Purchas, 1990) with maximum toughness around pH 6. However, at higher cooking temperatures ($\approx 80^{\circ}C$) this relationship changes and higher pH is associated with more tender meat.

A better understood problem is that of depletion of muscle glycogen to low enough levels to produce DFD meat. The lean meat quality of sheep is little influenced by preslaughter fasting for up to 72 hours (Warriss *et al.*, 1987) or transport for up to 6 hours (Warriss *et al.*, 1990) although muscle glycogen levels are progressively reduced with longer food deprivation. However, combinations of stressors, such as can occur under more severe marketing systems, will deplete glycogen to levels where ultimate pH is elevated. Lambs in New Zealand are washed preslaughter by swimming them through a tank of water. This may be repeated with very dirty animals so they are washed up to three times. The process leads to higher ultimate pH in the meat of some animals. In lambs also suffering from other stresses, such as inadequate nutrition or shearing, the ultimate pH may be elevated materially (Bray, *et al.*, 1989). Carcasses from shorn, underfed and washed animals showed 80% of pH_u values six compared with 12% in carcasses from control lambs. DFD is therefore a significant problem in New Zealand lambs, Petersen (1984) recording 7% of carcasses in one plant with a pH_u in the LD≈6. About 15% of lambs had values ≈5.8, indicating that some glycogen depletion had occurred due to adverse treatment. The use of beta-adrenergic agonists to improve carcass quality can promote DFD meat in sheep also subjected to the stresses associated with preslaughter handling (Warriss *et al.*, 1989).

Dark cutting in cattle is a major problem. Much of our knowledge of the condition and its aetiology was summarised by Warriss (1990). The recorded incidence varies widely. Young bulls are most prone, prevalences of over 25% having been recorded in Finnish animals (Puolanne and Aalto, 1980) and in The Netherlands in bulls sold through cattle markets (Van Laack *et al.*, 1989). Culled cows are also very susceptible, steers less so and heifers least, unless these are in oestrus (Kenny and Tarrant, 1988).

The major cause of dark cutting is allowing unfamiliar animals to mix (Price and Tennessen, 1981). The resulting agonistic behaviour directed at re-establishing dominance hierarchies takes the form of butting, pushing, mounting and chin resting. The physical exertion associated with this, probably together with the effects of the associated psychological stress, depletes muscle glycogen and leads to elevated ultimate pH in the meat. It is the inherently more aggressive nature of young bulls that makes them so susceptible. The severity of dark cutting is closely correlated with the extent of the physical activity, particularly mounting, in bulls (Warriss, 1984; Kenny and Tarrant, 1987) and in heifers in oestrus (Kenny and Tarrant, 1988).

Marketing procedures which result in mixing, or prolong the time of mixing, of cattle that have been reared in different groups increase the prevalence of dark cutting. Problems therefore can arise with animals reared in individual stalls, as are young bulls in many European countries, or in animals marketed through live auctions where subsequent mixing is almost unavoidable. Mixing in lairage is particularly a problem. Matzke *et al.* (1985) found that bulls held in individual pens preslaughter produced up to five times fewer dark cutting carcasses than bulls held in pairs. Lairage of mixed groups for 1.5 hours results in significant increases in dark cutting (Augustini *et al.*, 1980). Overnight lairage seriously increases the problem (Fabiansson *et al*, 1984; Wajda and Wichlacz, 1984). Ingre *et al.* (1989) studied the incidence of dark cutting in bulls which had been reared in loose housing or tethered in stalls and were then held in lairage, mixed or unmixed, for up to 48 hours. Only unmixed, loose-housed bulls slaughtered immediately on arrival at the abattoir showed no dark cutting. Even unmixed groups with apparently established social hierarchies produced 13% dark cutting after 24 hours in lairage and 30% after 48 hours. Mixing groups of bulls, particularly if individually stall-reared, led to 80 to 100% dark cutting. If long lairage is unavoidable animals should be haltered or penned individually. Another approach is to try to discourage agonistic behaviour. An electrified wire grid just above the heads will reduce or prevent dark cutting , particularly if the animals are also kept in the dark (Kenny and Tarrant, 1987; Bartos *et al.*, 1988). After the stress of mixing, full recovery of muscle glycogen levels can take up to eleven days, although 48 hours rest with food and water may allow enough repletion to prevent dark cutting (Warriss, 1990).

Other handling factors can also influence the prevalence of dark cutting but these generally have only a small effect compared with that of mixing unfamiliar animals. Longer transport distances may increase dark cutting but the effect is often small (Puolanne and Aalto, 1980; Price and Tennessen, 1981). Jones and Tong (1989) found, based on data from a very large survey carried out in Canada, that the frequency of dark cutting increased as distance from farm to abattoir increased from 100 km (0.78%) to over 300 km (0.98%). But the largest effect was attributable to slaughter plant. There was a nearly six-fold difference in the frequency of DCB between the plant with the lowest level (0.26%) and that with the highest (1.79%). Between-plant differences have also been seen in other studies and this implies that various factors other than mixing and associated with handling in lairage may be important.

Conclusions

There is ample evidence that prolonged food withdrawal and transportation cause carcass shrinkage. The effects are best defined for the influence of fasting on pigs and sheep. We have less information for cattle, where different studies show considerable variation in results. The exact influence of transport *per se* is also poorly defined. We understand the general principles governing formation of PSE and DFD pork but interactions between the effects of different handling procedures, and with genotype, make it difficult to predict exactly the consequences of different transport and lairage times. The major cause of DCB is mixing unfamiliar cattle but other factors influence the extent of the problem and these are little understood. Ante-mortem stress can also reduce eating quality in ways unrelated to its effects on the occurrence of PSE and DFD. The elucidation of these is a research priority.

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