

MiniReview

Effect of pre-slaughter animal handling on carcass and meat quality

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Abstract: Animal handling is a growing issue of concern in many countries around the world. Developed countries in particular show keen interest in the way animals are handled throughout production to processing. In such countries animal welfare is increasingly becoming a primary matter in the process of keeping animals either as pets or for food and at homes or on farms. Not only are they protecting the rights of these animals but poor animal handling has adverse effects on the animal, carcass and meat quality. Poor quality animal and meat will have poor processing properties, functional quality, eating quality, and more likely to be unaccepted by consumers. Lesser attention has been paid by most developing countries on this issue. By this review, it is expected that developing countries also take interest in proper pre-slaughter handling of animals due to their beneficial effect on meat and carcass qualities. This review highlights the factors to consider in handling animals and their effect on meat and carcass quality.

Keywords: Animal handling, carcass and meat quality, consumers, pre-slaughter

Introduction

Pre-slaughter handling involves all the activities and processes animals undergo prior to sticking. These activities and processes take place on the farm, during transportation, marketing and at the slaughter plant. Although it takes several days and efforts to raise an animal to desirable age, weight and quality, their condition may change appreciably within few days prior to slaughter which will adversely reduce their weight, affect the meat quality and subsequently reduce profit.

This will happen if animals are subjected to poor handling conditions before slaughtering. This is so, because animals are exposed to all kinds of stresses ranging from physical such as high ambient temperature, vibration and changes in acceleration, confinement, noise, and crowding; to psychological such as the breakdown of social groupings and mixing with unfamiliar animals, unfamiliar or noxious smells and novel environment (Warriss, 2000) during pre-slaughter handling.

Animals could also suffer from pre-slaughter stresses arising from bruises, injuries, starvation, tiredness, water and food deprivation, and loading and unloading onto vehicles. Lawrie (2006) reported that with higher levels of stress poorer meat quality is eminent, quite apart from being inhumane. Besides stress, genotype, transportation, lairage time, season of the year, environmental conditions and many other factors will affect meat quality (Küchenmeister,

2005).

Animal welfare can be linked to carcass and meat quality. 'The welfare of an animal was defined by Broom (2000) as its state as regards its attempts to cope with its environment'. The welfare of an animal can be said to have been compromised if the animal cannot cope with its environment or copes with difficulty. Among the things to cope with includes the environmental conditions, other animals, pathogens, and human handling. Their response to these conditions will have effect on their carcass and meat quality. For instance when animals show pathogenic signs resulting from dirty environment, food or water intake they will have poor growth, reduced weight or even die. It implies that animals will take longer time to produce meat, produce less meat, total meat loss or the carcass can be condemned during meat inspection. It must also be noted that for the fact that an animal is healthy, fit and reproduce normally (physical well-being) does not necessarily mean the welfare is good. This is because it is difficult to know whether an animal is content with its environment or not (mental well-being). Thus there is variation among people with respect to how poor the welfare of an animal has to be before they consider it to be intolerable.

Warriss (2000) defined meat quality on the basis of their functional or conformational qualities. Functional qualities were referred to as the desirable attributes in a product while conformance qualities encompass producing a product that meets consumer's

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specification exactly. Yield and gross composition, appearance and technological characteristics, palatability, wholesomeness and ethical quality are the components of meat quality (Warriss, 1996). Carcass on the other hand is the body of an animal killed for meat. The term is used following dressing that is, the removal of various parts from the dead body. Poor carcass quality will therefore reflect in poor meat quality and possibly poor appearance. Smith and Grandin (1998) shown that proper handling of meat animals can improve productivity, quality and profitability. This review highlights on some of the things to consider in handling animals, and possible effect on meat and carcass quality.

Things to consider in handling animals

The animal

The type (species, breed, sex, or age) of animal being handled and exposed to stress is very essential in determining the extent to which the meat quality will be compromised. Non ruminants (poultry and pigs) are more susceptible to stress compared to ruminants (sheep, cattle and goat). Thus poultry meat and pork are more prone to meat quality defects compared to mutton or beef. Individual breeds also differ in their ability to withstand stress. For instance, muscular breeds (Pietran and Hampshire) are more susceptible to stress than non-muscular breeds (Gloucestershire and Creole). Females and young animals are also more susceptible to stress compared to males and older animals. This was demonstrated by Tarrant (1990) who reported that young calves are more susceptible to transportation stress and encountered problems such as with morbidity (e.g. from diarrhea and pneumonia) and mortality. Layers have tougher meat than broilers because they are slaughtered at a much older age.

Farming

Animals are reared almost entirely on farms. The farming systems and feeding programme's significantly contributes to meat quality. Argüello *et al.* (1999) compared kids nursed by their dams to those fed on commercial milk replacer and found that the *Triceps brachii* of kids fed on commercial milk replacer were lighter and had lower water holding capacity. Differences between muscles were greater with an increase in live weight at slaughter, possibly due to a higher degree of muscle maturity or solid higher feed consumption (Argüello *et al.*, 1999). Sink and Caporaso (1977) reported that nutrition plays a major role in flavour intensity of sheep meat and that certain foodstuffs (legumes and grains) can intensify

flavour, whereas withdrawal of sheep from grazing before slaughter can reduce flavour. Feeding animals on vitamin E improves the oxidative stability (meat colour, lipid and protein oxidative stability) of both raw and cooked muscle (Monahan *et al.*, 1990). Animals fed on grasses produce fat that is yellow in colour. It is possible to find traces of some chemicals or drugs in the carcasses of animals slaughtered immediately or few days after chemical treatment or medication. Such carcasses have reduced organoleptic quality, nutritional quality, hygienic quality, and suitability for processing.

Transportation

Animals are reared on farms which may be situated far away from other farms, markets and slaughter plants. Therefore, they have to be transported over some distances to such locations either for better and less expensive feed, sale and slaughter. Transportation begins with loading and ends with unloading. Both ought to be done in a gentle manner and under a quieter environmental condition. Careful loading and unloading conditions has been suggested by Adzitey and Nurul (2011). During transportation, animals are exposed to environmental stress such as heat, cold, humidity, noise and overcrowding. Over speeding, sudden stops, rapid acceleration and long journey times without appropriate rest should be avoided as these will increase the spate of carcass and meat quality defects. Strenuous efforts have to be put in place to ensure the safety of animals in transportation to reduce stress to its minimum.

Marketing

Animals are either sold at the markets or sent directly from farms to abattoirs for slaughter. In the markets they may be kept in groups and in open pens which may expose them directly to the sun or cold. They may encounter stresses such as noise, unfamiliar environment and social regrouping. They can also be starved or dehydrated if feed and water is redrawn longer than recommended. Various degrees of bruising can occur on their skin at the market depending on the way they are handled. McNally and Warriss (1996) reported that the prevalence of bruising varies between markets; it ranged from 2 % to 8 %. Marketing strategies to reduce stress and consequently pale soft exudative and dry firm dark meat can be found in Adzitey and Nurul (2011).

Feeding and watering

During transportation or marketing, animals must be provided with feed and water when necessary. The Council of Europe (1972) states that "during transport

animals shall be offered water and appropriate food at suitable intervals. Animals shall not be left more than 24 hours without being fed and watered. This period may, however, be extended if the journey to the destination where the animals are unloaded can be completed within a reasonable period". Provision of feed and water during transportation or marketing is therefore essential if the animals are going to be transported or kept in the lairage over a longer period than recommended. This is to prevent them from starvation and dehydration that can lead to depletion of muscle glycogen and reduction in weight. Overfeeding and watering should also be avoided as this increases gut fill, cost, processing time and a higher possibility of contamination from gut fill.

Lairaging

Animals are held temporarily in the lairage prior to slaughter. It serves as a collection point for different animals just before slaughter. The lairage is also to provide animals with some amount of recovery from stress during transport. Animals movement should be observed for any possible injury or infection. They should also be given adequate amount of suitable feed and water if they will be kept in the lairage longer than expected. Although lairage is to enable animals to rest and to recover from transportation stress, it can be a major source of meat quality problems. Animals may suffer from different degree of bruising and injury as a result of fighting or overcrowding. Lairage can also act as reservoirs of infection by pathogenic bacteria and there is evidence that longer holding times increase the risk of carcass contamination (Warriss, 2003). Careless and improper handling of animals in the lairage such as the use of electrical goads, abstracting the movement of animals through race, beating and firm grip of the coat with the hand, exposure of animals to microbial contaminations will adversely have effect on the carcass and meat quality. Conditions in the lairage therefore need to be conducive to prevent infections and the animals from being stressed further after vigorous transportation but to recover from transportation stress.

Stunning

Pre-slaughter handling perhaps ends with stunning. Once the animal is stunned, it is made unconscious and sensitivity to pain stops unless stunning is not done properly. The type of stunning equipment used can contribute to the quality of carcass that will be produced. High voltage head-to-back electrical stunning can induce vertebral compression fractures, blood splash and poor meat quality in pigs (Wotton *et al.*, 1992). Calkins *et al.* (1980) also said the use of

electric goads has been shown to be responsible for blood splash in pigs. Blood splash carcass has poor appearance. Therefore, well trained personnel and maintained stunning equipments should be used to avoid unnecessary stress and distress to animals.

Effect of pre-slaughter handling on meat and carcass quality

Improper and poor pre-slaughter handling of animals during farming, loading, transporting, marketing, unloading, lairaging and stunning have several effects on carcass and meat quality. Notably among these are; mortality, low carcass yields, blood splash, bruises, broken bones, skin blemishes, contamination by pathogens and PSE and DFD.

Mortality of animals

Animals can die from pre-slaughter handling activities. For instance if sick animals are not treated or when animals are transported under harsh environmental and stressful conditions they can die as a result of that. Death of animals is the worst effect of pre-slaughter handling on carcass and meat quality. This is because there is total loss of carcass and meat quality as the dead animal is disposed off.

Carcass damages

Carcass damages such as bruising, haemorrhages, skin blemishes, blood splash and broken bones (particularly in poultry) are common occurrences found on carcasses due to improper handling conditions. In a bruise, haemorrhage, skin blemish and/or blood splash the skin of the animal and the blood vessels may accumulate excessive blood which has to be trimmed off during processing. Trimming part of the carcass off will reduce meat yield and value, expensive and increase processing time. Untrimmed parts have poor appearance and can serve as substrates for microbial growth causing the meat to spoil earlier than the normal. Broken bones may cause bone splinters in meat and this will be dangerous to the consumer if not detected after deboning (Warriss, 2000).

Pale Soft Exudative (PSE) and Dark Firm Dry (DFD)

Pale soft exudative and dark firm meats are very important meat quality problems that continuous to bedevil the meat industry. Pale soft exudative is associated with pigs and chickens, and DFD affect all species although nowadays both conditions have been suggested to occur in all species. This is because PSE-like conditions continues to be reported in other

Table 1. Effects of pre-slaughter handling on carcass and meat quality

Species	Pre-slaughter handling	Carcass and meat quality effect	Reference
Cattle	Overloading	Injury and carcass damage	Tarrant (1990)
	Held overnight in noisy yards	Bruise	Eldridge (1988)
	Transportation	Spread of pathogens on the hides	Avery <i>et al.</i> (2002)
	Transportation	Shedding of <i>Salmonella</i> spp	Barham <i>et al.</i> (2002)
	More than 24 hours of fasting	Carcass yield was reduced by 1.7 %	Price (1981)
	Cattle transported for 2h	1.5 % loss in carcass yield	Smith <i>et al.</i> (1982)
	After 12 hours of transportation	2.5 % loss in carcass yield	Smith <i>et al.</i> (1982)
	Prolonged stress	Meat appear darker and heat ring is formed	Buyck <i>et al.</i> (1985)
	Poor handling	4.1 % of dark cutting beef	Brown and Bevis (1988)
	Overloading	Animal injury and damage to carcass	Tarrant (1990)
	Longer journey	Associated with a significantly larger live weight loss	Gallo <i>et al.</i> (2003)
	Longer lairage time	Decreased muscle luminosity and increased DFD	Gallo <i>et al.</i> (2003)
	High stocking density	Increased bruising and reduce dressed carcass weight	Tarrant and Grandin (2000)
High stocking density	Serious injuries and death	Tarrant and Grandin (2000)	
Impatient from crews and overloading	Increase bruises and injuries	Grandin (2001)	
Long distance road transport	Lost weight	Marahrens <i>et al.</i> (2003)	
Sheep	Increased journey time	Decrease in live weight	Knowles <i>et al.</i> (1995)
	Poor handling	3.7 % carcass condemnation	Roeber <i>et al.</i> (2001)
	Poor handling	7.8 % carcass condemnation in lambs/yearlings	Roeber <i>et al.</i> (2001)
	Marketing	0.007 % mortality for sheep sold directly from the farm to the abattoir and 0.031 % mortality for sheep marketed through auctions prior to the abattoir	Knowles <i>et al.</i> (1998)
Drovers pushing sheep to move faster	Marketing	25 % bruise	Blackwood and Hurst (2004)
	Long journal	Bruises	Cunningham and LeValley (1992)
	Improper handling and transportation	15 % DFD	Morris (1994)
Pigs	Marketing	Bruising, broken bones, condemnation and death	Roeber <i>et al.</i> (2001)
	Poor handling	Skin blemish and 4.7 % downgrading	Warriss (2000)
	Fasting time of 8 to 18 hours	Reduce carcass yield to a minimum	Warriss (1985)
	Starved for more than one hour	Skin damages	Brown <i>et al.</i> (1999)
	Long fasting , transportation and lairaging	Increase prevalence of DFD meat	Eikelenboom <i>et al.</i> (1991)
	Short transportation period (<2h)	2.3 % PSE	Gispert <i>et al.</i> (2000)
	Long transportation period (> 2 h)	Promoted DFD	Gispert <i>et al.</i> (2000)
	Transportation over long distance	More prone to die	Honkavaara (1989)
	During transportation	Dead rate of 0.02 %	Warriss <i>et al.</i> (1994)
	Transportation	Live weight losses between 40 to 60 g/kg.	Lambooij (2000)
	Transportation	Mortality of 0.1 to 0.4 %	Lambooij (2000)
Transportation	Injuries, bruises, skin blemishes and weight lost	Lambooij (2000)	
Transportation	Increased incidence of PSE and DFD	Lambooij (2000)	
Transportation	Condemnations, bruises, PSE pork and DFD pork.	Smith and Morgan (1995)	
Transportation and starvation	Increased the live weight loss	Mayes <i>et al.</i> (1988)	
Poultry	Transportation	0.3 % death between farm and factory	Weeks and Nicol (2000)
	Transportation	0.2-0.5 % mortality rate	Swarbrick (1986)
	Transportation	Dead on arrival 0.35 (broilers) and 1.22 % (layers)	Petracci <i>et al.</i> (2006)
	Removal from cage	Injury and mortality	Whitehead and Fleming (2000)
	Food and water deprivation	Live weight losses averaging about 0.2-0.3 % per hour	Warriss (2000)
	Longer feed withdrawal	Carcass contamination by <i>C. jejuni</i>	Willis <i>et al.</i> (1996)
	Removal from cages	24 % broken bones in layers	Weeks and Nicol (2000)
Long transportation , and feed-and water-deprivation times	Increases mortality	Weeks and Nicol (2000)	
Other species			
Deer	Transportation over distances > 200 km	Bruising and muscle damage	Matthews (2000)
	Long Lairage time	Increase in live weight losses	Grigor <i>et al.</i> (1997)
Rabbit	Longer transport time	Greater weight losses and yield	Lambertini <i>et al.</i> (2006)
	Longer transport time	Darker and fatter meat in <i>L. dorsi</i> and <i>B. femoris</i>	Dal Bosco <i>et al.</i> (1997)
Goat	2h of transport, together with 18 h of feed withdrawal	10 % live weight shrinkage in does	Kannan <i>et al.</i> (2000)
Horse	High loading and stocking density	Injuries	Collins <i>et al.</i> (2000)
	Transportation and fighting	Injuries (2 %), emaciation (3 %) and dead in arrival (0.8 %)	Grandin <i>et al.</i> (1999)

species (Adzitey and Nurul, 2011). Acute or short term stress such as the use of electric goads, fighting among animal just before sticking, and overcrowding in the lairage cause PSE. Exposing animals to chronic or long time stress such long hours of transportation, food and water deprivation and overcrowding of animals in the lairage can cause DFD carcasses. PSE and DFD meats are unattractive and more likely to face discrimination by consumers (Viljoena *et al.*, 2002). Pale soft exudative meat looks pale, lean, has soft texture and low water holding capacity and poor functional attributes. Dark firm dry meat looks dark, variations in tenderness, poor functional attributes and prone to spoilage. Detailed description of pale soft exudative and dark firm dry meat can be found in

Adzitey and Nurul (2011).

Reduction in the live weight and carcass yield of animals

Animals are normally deprived of food and water prior to slaughter, depending on how long it will take for the animals to be slaughtered. There can be a reduction in live weight of animals due to food and water deprivation. This may be due to the reduction in gut fill and breakdown of muscle glycogen for energy. Warriss (2000) referred to the losses in live or carcass weight as 'Shrinkage' which is a potential loss of yield of carcass and meat. Warriss (1985) reported that loss of live weight in pigs begin almost directly after feed withdrawal. In sheep and cattle, the

removal of skin and hides were found to be difficult under longer period of water deprivation (Warriss, 2000). Subsequently greater tearing of the underlying tissue (which may be attached by some meat) and a poor surface carcass appearance may occur.

Table 1 summarizes the effects of poor pre-handling on carcass and meat quality reported by various authors for some species of animals. From table 1, different pre-slaughter handling conditions have some effect on meat and carcass quality. These effects vary from animal to animal and from one author to the other. This means that the degree and level of meat and carcass quality defect depends on how that particular animal involved was handled before slaughter. Therefore animals expose to very poor pre-slaughtering conditions will show more carcass and meat quality defects and vice versa. Of all the pre-slaughtering handling conditions mentioned, transportation conditions appears to be by far the most common reported by most workers. This indicates that transportation is a critical point in the life of an animal prior to slaughter. Warriss (2000) reported that transportation is strange and life threatening to animals. During transportation, animals can do little to help themselves when they are in danger or discomfort due to confinement. In farms, markets and lairage, animals have much freedom of movement and could avoid certain uncomfortable conditions. Other conditions such as starvation, dehydration, injury, suffocation, heat or cold stress, overcrowding, death and many more do prevail in transportation. Broken bones are peculiar problem associated with layers. This is because osteoporosis in laying hens leads to loss of structural bone and increased incidence of fracture at various skeletal sites by the end of the laying period (Whitehead and Fleming 2000).

Conclusion

Pre-slaughter handling conditions are very essential factors which contribute to carcass and meat quality defects; therefore it should not be overlooked. When handling animals prior to slaughter, considerations should be made in terms of the kind, species, breed, and age. In addition the way animals are handled in the farm, during transportation, at the market and in the lairage expose them to various stresses. Improper pre-slaughter handling can cause the death of animals, carcass damages, reduction in live weight, pale soft exudative and dark firm dry meats. Poor pre-slaughter handling is also a compromise of animal's welfare.

Acknowledgments

The author is grateful to the Institute of Postgraduate Studies, Universti Sains Malaysia for the support given to me to pursue a PhD programme through USM Fellowship Scheme.

References

- Adzitey, F. and Nurul, H. 2010. Pale Soft Exudative (PSE) and Dark Firm Dry (DFD) Meats: Causes and measures to reduce these incidences. *International Food Research Journal* (accepted).
- Argüello, A., Marichal, A., Ginás, R., Capote, J., Alfonso, J.M. and López, J.L. 1999. Effects of rearing system on meat quality in young kids. *Journal of Animal Science* 77: 168 (abstract).
- Avery, S.M., Small, A., Reid, C.A. and Buncic, S. 2002. Pulsed-field gel electrophoresis characterization of Shiga toxin-producing *Escherichia coli* O157 from hides of cattle at slaughter. *Journal of Food Protection* 65: 1172-1176.
- Barham, A.R., Barham, B.L., Johnson, A.K., Allen, D.M., Blanton, Jr. J.R. and Miller, M.F. 2002. Effects of the transportation of beef cattle from the feed yard to the packing plant on prevalence levels of *Escherichia coli* O157 and *Salmonella* spp. *Journal of Food Protection* 65:280-283.
- Brown, S.N. and Bevis, E.A. 1988. An estimate of the incidence of dark cutting beef in the United Kingdom. In: *Proc. Br. Soc. Anim. Prod., Winter Meet Paper 73*. UK.
- Brown, S.N., Knowles, T.G., Edwards, J.E. and Warriss, P.D. 1999. Relationship between food deprivation before transport and aggression in pigs held in lairage before slaughter. *Veterinary Record* 145: 630-634.
- Broom, D.M. 2000. Welfare assessment and welfare problem areas during handling and transport. In: *Livestock Handling and Transport Grandin, T. (Ed)*. pp. 43-61. CABI Publishing, USA: New York.
- Blackwood, I. and Hurst, R. 2004. Tips for transporting Cattle and Sheep. New South Wales Department of Primary Industries: Agriculture. New South Wales Government Agnote DAI-234 (Second Edition), p 1-11. Wales.
- Buyck, M.J., Cross, H.R., Crouse, J.D., Seideman, S.C. and Klastrup, S. 1985. The influence of antemortem stress on postmortem muscle quality. *Journal of Animal Science* 61: 276 (abstract).
- Calkins, G.R., Davis, G.W., Cole, A.B. and Hutsell, D.A. 1980. Incidence of blood splashed hams from hogs subjected to certain ante-mortem handling methods. *Journal of Animal Science* 50: 15 (abstract).
- Collins, M.N., Friend, T.H., Jousan, F.D. and Chen, S.C. 2000. Effects of density on displacement, falls, injuries and orientation during horse transportation. *Applied Animal Behavior Science* 67:169-179.

- Council of Europe, 1972. European Convention for the Protection of Animals during International transport. Council of Europe, Strasbourg. European Treaty Series No.65. Europe.
- Cunningham, W. and LeValley, S. 1992. Producing High Quality Consumer Products from Sheep (The National Sheep Quality Audit—1992), p 1-32. Colorado State University, USA: Fort Collins.
- Dal Bosco, A., Castellini, C. and Bernardini, M. 1997. Effect of transportation and stunning method on some characteristics of rabbit carcasses and meat. *World Rabbit Science* 5:115–116.
- Grandin, T., McGee, K. and Lanier, J.L. 1999. Prevalence of severe welfare problems in horses that arrive at slaughter plants. *Journal of the American Veterinary Medical Association* 214:1531-1533.
- Grigor, P.N., Goddard, P.J., Macdonald, A.J., Brown, S.N., Fawcett, A.R., Deakin, D.W. and Warriss, P.D. 1997. Effects of the duration of lairage following transportation on the behaviour and physiology of the farmed red deer. *Veterinary Record* 140: 8-12.
- Eikelenboom, G., Bolink, A.H. and Sybesma, W. 1990. Effects of feed withdrawal before delivery on pork quality and carcass yield. *Meat Science* 29:25-30.
- Eldridge, G.A. 1988. Road transport factors that may influence stress in cattle. In: Chandler, C.S. and Thornton, R.F. (Eds). *Proceedings of the 34th International Congress of Meat Science and Technology*, p 148–149. Australia: Brisbane.
- Gallo, C., Lizondo, G. and Knowles, T.G. 2003. Effects of journey and lairage time on steers transported to slaughter in Chile. *Veterinary Record* 152:361-364.
- Gispert, M., Faucitano, L., Guardia, M.D., Oliver, M.A., Siggins, K., Harvey, K. and Diestre, A. 2000. A survey on pre-slaughter conditions, halothane gene frequency, and carcass and meat quality in five Spanish pig commercial abattoirs. *Meat Science* 55: 97-106.
- Grandin, T. 2001. Perspectives on transportation issues; the importance of having physically fit cattle and pigs. *Journal of Animal Science* 79: 201-207.
- Honkavaara, M. 1989. Influence of selection phase, fasting and transport on porcine stress and on the development of PSE pork. *Journal of Agriculture Science* 61:415-423.
- Kannan, G., Kouakou, B.T., Terrill, H., Gelaye, S. and Amoah, E.A. 2001. Pre-slaughter stress effects on physiological responses and meat quality characteristics in goats. *Journal of Animal Science* 79: 447 (abstract).
- Knowles, T.G., Brown, S.N., Warriss, P.D., Phillips, A.J., Dolan, S.K., Hunt, P., Ford, J.E., Edwards, J.E. and Watkins, P.E. 1995. Effects on sheep of transport by road for up to 24 hours. *Veterinary Record* 136:431-438.
- Knowles, T.G., Warriss, P.D., Brown, S.N. and Edwards, J.E. 1998. Effects of stocking density on lambs being transported by road. *Veterinary Record* 142: 503-509.
- Küchenmeister, U., Kuhn, G. and Ender, K. 2005. Pre-slaughter handling of pigs and the effect of heart rate, meat quality, including tenderness, and sarcoplasmic reticulum Calcium transport. *Meat Science* 71: 690-695.
- Lambertini, L., Vignola, G., Badiani, A., Zaghini, G. and Formigoni, A. 2006. The effect of journey time and stocking density during transport on carcass and meat quality in rabbit. *Meat Science* 72: 641- 646.
- Lambooi, E. 2000. Transport of Pigs. In: Grandin T. (Ed). *Livestock Handling and Transport*. CABI Publishing, p 275-296. USA: New York.
- Lawrie, R.A. and Ledward, D.A. 2006. *Lawrie's meat science*. Sixth edition, Woodhead publishing limited, 5, 96-98. England: Cambridge.
- Matthews, L.R. 2000. Deer Handling and Transport. In: Grandin T. (Ed). *Livestock Handling and Transport*. CABI Publishing, p 331-362. USA: New York.
- Marahrens, M., Von Richthofen, I., Schmeiduch, S. and Hartung, J. 2003. Special problems of long-distance road transports of cattle. *Dtsch Tierarztl Wochenschr Journal* 110:120-125.
- Mayer, H.F., G.L. Hahn, B.A. Becker, M.E. Anderson, J.A. Nienaber, H.B. Hedrick and G.W. Jesse. 1998. A report on the effect of fasting and transportation on live weight losses, carcass weight losses and heat production measures of slaughter hogs. *Applied Engineering in Agriculture* 4:254-258.
- McNally, P.W. and Warriss, P.D. 1996. A study of recent bruising in cattle at abattoirs, *Veterinary Record* 138:126-128.
- Monahan, F.J., Buckley, D.J., Gray, J.I., Morrissey, P.A., Asghar, A., Hanrahan, T.J. and Lynch, P.B. 1990. Effect of dietary Vitamin E on the stability of raw and cooked pork. *Meat Science* 27: 99-108.
- Morriss, D.G. 1994. Literature review of welfare aspects and carcass quality effects in the transport of cattle, sheep and goats. Report prepared by the Queensland Livestock and Meat Authority for the Meat Research Corporation. Australia: Queensland.
- Petracci, M., Bianchi, M., Cavani, C., Gaspari, P. and Lavazza, A. 2006. Pre-slaughter Mortality in Broiler Chickens, Turkeys, and Spent Hens Under Commercial Slaughtering. *Poultry Science* 85: 1660-1664.
- Price, M.A. 1981. Shrinkage in beef cattle. *Annual Feeders Day Report University of Alberta, Agricultural and Forestry Bulletin*, p. 50. USA: Alberta.
- Roeber, D.L., Belk, K.E., LeValley, S.B., Scanga, J.A., Sofos, J.N. and Smith, G.C. 2001. Producing Consumer Products from Sheep: The Sheep Safety and Quality Assurance Program, p1-56. Colorado State University, USA: Fort Collins.
- Sinka, J.D. and Caporasoa, F. 1977. Lamb and mutton flavour: Contributing factors and chemical aspects. *Meat Science* 1:119-127.
- Smith, R.J., Nicholls, P.J., Thompson, J.M. and Ryan, D.M. 1982. Effects of fasting and transport on live weight loss and the prediction of hot carcass weight of cattle. *Australia Journal of Experimental Agriculture Animal Husbandry* 22: 4–8.
- Smith, G.C. and Grandin, T. 1998. Animal Handling for Productivity, Quality and Profitability. Presented at the Annual Convention of the American Meat Institute, p

- 1-12. USA: Philadelphia.
- Smith, G.C. and Morgan, J.B. 1995. National and international audits of beef and pork quality-identifying means for Improving the consistency and competitiveness of U.S. pork and beef. Presented at the international developments in process efficiency and quality in the meat industry, p 1-13. Ireland: Dublin.
- Swarbrick, O. 1986. The welfare during transport of broilers, old hens and replacement pullets. In: Gibson, T.E. (Ed), the welfare of animals in transit. British Veterinary Association, Animal Welfare Foundation, p 82-97. England: London.
- Tarrant, P.V. 1990. Transportation of cattle by road. *Applied Animal Behaviour Science*, 28: 153-170.
- Tarrant, V. and Grandin, T. 2000. Cattle Transport. In: Grandin, T. (Ed.), *Livestock Handling and Transport*, p 151-173. CABI Publishing, USA: New York.
- Viljoena, H. F., de Kock, H.L. and Webb, E.C. 2002. Consumer acceptability of dark, firm and dry (DFD) and normal pH beef steaks. *Meat Science* 61: 181-185.
- Warriss, P.D. 1985. Marketing losses caused by fasting and transport during the pre-slaughter handling of pigs. *Pig news and information* 6:155-157.
- Warriss, P.D., Brown, S.N., Adams, S.J.M. and Corlett, I.K. 1994. Relationships between subjective and objective assessments of stress at slaughter and meat quality in pigs. *Meat Science* 38: 329-340.
- Warriss, P.D. 1996. Introduction: what meat is quality? In: Taylor, S.A., Raimundo, A., Severini, M and F.J.M. (Eds), *Meat Quality and Meat Packaging*. ECCEMST, p 3-10. Belgium: Utrecht.
- Warriss, P. D. 2000. *Meat science: An introductory text*. CAB-International: England: Wallingford.
- Warriss, P.D. 2003. Optimal lairage times and conditions for slaughter pigs: a review. *Veterinary Record* 153: 170-176.
- Weeks, C. and Nicol, C. 2000. Poultry Handling and Transport. In: Grandin, T. (Ed), *Livestock Handling and Transport*, p 363-384. CABI Publishing, USA: New York.
- Whitehead, C.C. and Fleming, R.H. 2000. Osteoporosis in cage layers. *Poultry Science* 79: 1033-1041.
- Wotton, S.B., Anil, M.H., Whittington, P.E. and McKinstry, J.L. 1992. Pig slaughtering procedures - head-to-back stunning. *Meat Science* 32: 245-255.
- Willis, W.L., Murray, C. and Raczkowski, C.W. 1996. The influence of feed and water withdrawal on *Campylobacter jejuni* detection and yield of broilers. *Journal of Applied Poultry Research* 5: 210-214.