final report

Project code: B.NBP.0703

Prepared by: Ahmad R Rabiee
Ian J Lean
SBS*cibus*

Date published: November 2011

ISBN: 9781741917062

PUBLISHED BY
Meat and Livestock Australia Limited
Locked Bag 991
NORTH SYDNEY NSW 2059

Electrolytes and other compounds: qualitative evaluation of effects on animal welfare, shrinkage/liveweight, carcase attributes and meat quality

Meat and Livestock Australia acknowledges the matching funds provided by the Australian Government to support the research and development detailed in this publication.

Acknowledgements

We wish to acknowledge the cooperation of the following people:

Dr Schaefer, Agriculture and Agri-Food Canada, for providing us a copy of his published and unpublished papers.

Dr Heather Burrow, CRC for Beef Genetic Technologies, University of New England for providing a copy of her unpublished report to MLA.

Mr John Lapworth, DEEDI, for his comments on the use of electrolytes in cattle in northern Australia.

The librarians at the University of Sydney, Faculty of Veterinary Science, Camden Library and Ms Karen Fox at Meat and Livestock Australia.

Abstract

This project assessed studies that investigated the effects of electrolytes and other interventions on cattle during transportation. Studies often lacked appropriate study designs and were not suitable for meta-analysis. Liveweight change in cattle was the only variable consistently compared across studies. Only 17% of trials and comparisons showed a significant positive effect of electrolytes on the liveweight of cattle during transport. Most trials and comparisons (83%) found no significant differences in liveweight between groups. However, a majority of trials and comparisons (92%) showed a positive trend in weight gain for treatment of cattle during transportation. There was limited information on the effects of other interventions such as betaine, propylene glycol and glycerol on liveweight and performance of cattle during transportation or heat stress. At present, understandings of responses of cattle to electrolyte and other interventions designed to reduce the impacts of difficult environmental conditions including shipping and heat stress are largely limited to those achieved through qualitative review of the literature. There is a need for studies designed to test these interventions in a more robust way.

Executive summary

Objectives
The objectives of this work were to conduct a comprehensive literature search to identify the strength of quantitative literature available on the impact of administration of electrolytes and other interventions (such as betaine and propylene glycol) before, during and/or after: land and sea transport, lairage, feedlot heat stress, and live export heat stress. The impact of the electrolytes and other supplements were assessed in terms of various animal welfare measures, shrinkage/liveweight, carcase attributes and meat quality. We determined if the collated studies were suitable to be pooled, and if there was sufficient data to conduct a meta-analysis.

Methods
A comprehensive literature search was conducted to identify the studies on the use of therapeutic interventions on cattle performance and meat quality. A total of 85 papers were identified that investigated the effects of heat stress and transportation on cattle performance, carcase traits, meat quality and welfare of animals, and benefits of the electrolyte and other nutritional interventions on animal welfare measures, shrinkage/liveweight, carcase attributes and meat quality. Of these, 24 studies investigated the effects of following interventions: electrolytes (n=17), betaine (n=4), glycerol (n=1), vitamins ADE (n=2), chromium (n=2), Sodium chloride and fat supplement (n=1), and dexamethasone (n=1).

Outcomes measured and findings
Many of the trials were not randomised and cattle were group fed or were given group access electrolyte access through water. There were very few properly replicated studies. There were, consequently too few suitable studies to conduct a meta-analysis. There were also very substantial differences among studies in designs and outcomes measured. Meat quality and carcase traits measures were markedly different among the studies and were not suitable for pooled analysis.

Very few studies reported the effects of the interventions on animal welfare. Some of the reviews and experimental studies obtained suggest that electrolytes and other interventions may have physiological benefits. Since the potential physiological benefits associated with these interventions were beyond the scope of this review, we did not review these studies. However, it appears that the potential physiological benefits of these interventions may not necessarily be translated into measureable performance and welfare outcomes.

Liveweight change of cattle was the only comparable variable in the land transportation studies. Our review showed that only 17% of trials and comparisons reported a significant positive effect of electrolytes on liveweight of cattle during land transportation. Most, 83%, trials and comparisons found no significant differences in liveweight between the control and electrolyte treated cattle during transportation. However, most of the trials and comparisons (92%) reported a trend towards treatment animals losing less weight than control animals. Similarly, 67% of trials and comparisons on the effects of electrolytes as ameliorants reported a trend towards treated cattle. There was only one study with the data collected during shipping by sea. This study found a positive response to longer term (18 days) of electrolyte treatment. There was limited information on the effects of other interventions such as betaine, propylene glycol and glycerol. The available published studies were small and showed no significant beneficial effects of these interventions on liveweight and performance of cattle during transportation or heat stress (Table A).

Table A. Summary of studies that investigated the effects of different interventions on liveweight during transportation and heat stress (Source: Tables 3, 5)

	No of trials or comparisons		Direction of effect			Estimated effect and range
	Significant (P<0.05)	Not significant (P>0.05)	Positive	Negative	No difference	Differences (kg) (Treatment vs. Control)
Transport						
Differences in LWT loss (kg) (Final LWT - Initial LWT in control and treatment groups)	2	10	11	1	0	4.44 (-0.90, 19.90)
Differences in final LWT (kg) (Treatment - Control)	0	5	2	3	1	3.01 (-1.30, 15.77)
Overall average						**4.04 (1.30, 19.90)**
Performance and heat stress	1	5	4	1	1	Can't be estimated

While the effect of electrolytes on carcase attributes and meat quality were not comparable across study designs, our review found that effects of electrolytes on different carcase and meat quality attributes varied markedly among studies, from significant to marginal or no effect. This suggests that it is important to re-investigate these effects in well-conducted and replicated studies to be able to conclusively demonstrate the beneficial effects of these interventions.

Conclusions

Based on the information provided in these studies, we concluded that these data were not suitable for a meta-analysis because of: i) Lack of proper replication of control and treatment groups (Pseudoreplication), ii) Extreme clinical and methodological diversity (heterogeneity), iii) Missing information and data on study protocols and outcomes. While the trend towards treatment animals during land transportation in the reviewed studies (92% of trials and comparisons) is encouraging, it may suggest that the lack of significant difference in studies with a positive direction is due to substantial variance (SE or SD) of liveweight change. This indicates that further randomised controlled trials, with proper replication are needed to explore the sources of variance within groups and to minimise the possibility of type II statistical error. *We recognize and acknowledge the challenges of study design required to address the problems of pseudoreplication in studies of this type. We also recognise a need for demonstration studies subsequent to randomised controlled trials.*

Recommendations

- Implement appropriate study designs with regard to the administrative method of the therapeutic interventions, ie individual feeding of the interventions.
- Care should be taken in relation to reporting the allocation, housing and feeding of cattle to make sure that control and treatments are truly replicated.
- The characteristics and management of cattle in control groups should be similar to those in treatment groups, except for the treatment tested.
- Develop standard operating procedures (SOP) for the type of data that are needed on carcase yield, meat quality and physiological measures of welfare of cattle for future experiments to reduce the heterogeneity of outcomes.
- Develop a suitable database to facilitate the collection of published and unpublished studies.
- Develop standard operating procedures (SOP) to describe housing conditions (group *vs.* individual pens), season, environmental temperature and humidity, distances shipped and time spent away from water or feed access in consistent ways.
- Compare the effectiveness and cost-effectiveness of electrolytes with different ingredients to identify the most beneficial and economical products.

List of Abbreviations

ADG	Average daily gain
BCS	Body condition score
DM	Dry matter
DMI	Dry matter intake
F:G	Feed to gain ratio
G:F	Gain to feed ratio
K	Potassium
LWG	Liveweight gain
LWT	Liveweight
LS	Longissimus muscle
ME	Metabolisable energy
Na	Sodium
PEG	Polyethylene glycol
QLD	Queensland
RCT	Randomised controlled trial;
SOP	Standard operating procedures
SE	Standard error
SD	Standard deviation

Contents

Page

Background 8

1 Project objectives 9

2 Methodology 10

2.1 Literature search 10

3 Results and discussion 11

3.1 Historical data on heat stress and transport in Australia 11

3.2 Effects of heat stress and transport on cattle performance and intervention programs 12

3.2.1 Effects of transports and heat load 12

3.2.2 Electrolyte and nutritional interventions 14

3.2.3 Electrolytes 15

3.2.4 Betaine 16

3.2.5 Other products 17

3.2.6 Review and collation of current information on interventions used to alleviate the impacts of heat stress and transportation in cattle 17

4 Conclusions and recommendations 35

4.1 Pseudoreplication 36

4.2 Potential heterogeneity (sources of variation) 36

4.2.1 Clinical diversity 36

4.2.2 Methodological diversity 37

4.3 Missing information and data 37

5 Bibliography 39

Background

Transport of cattle is inevitably associated with a degree of quantifiable stress, but this should be managed carefully to improve animal welfare outcomes and reduce the effect on liveweight, carcase yield and meat quality. It appears that the most stressful aspect of the transportation chain for cattle is confinement on a moving vehicle, while confinement on a stationary vehicle, loading/unloading and re-penning in a new environment are less stressful events (Tarrant, 1990; Beatty et al., 2007). Fisher et al. (2006; AHW.126) reported that loading is the most stressful period during transport. Some studies report that there is an increase in cortisol concentration during loading with a gradual decline over the next few hours (Agnes et al. 1990; Knowles et al., 1995; Trunkfield and Broom 1990; Warriss et al., 1995). In contrast, other studies have reported no effect of loading on the plasma cortisol concentration of sheep (Cockram et al. 1996; Parrott et al. 1998). Parrott et al. (1998) reported an increased heart rate, but no cortisol or catecholamine response and a small prolactin response to loading. They speculated that the result may have been due to the very careful loading practices used in the study, with only 3 sheep loaded at a time in an unhurried manner. Similarly, cattle showed no cortisol response to loading, and only an increase in heart rate associated with the physical exertion of walking up a ramp (Kenny and Tarrant 1987). The duration of loading is shorter than transport and any stress will be transient, thus it is more likely that the stress during transport will have a bigger impact on cattle than the loading. Nevertheless, the use of therapeutic interventions has rationally been recommend for cattle during transport, and the objective of this study was to evaluate studies investigated the impact these interventions during transport and heat stress. The most significant transport mode is road transportation of cattle to slaughter and many studies have attempted to identify aspects of the transport chain that are hazardous to cattle, that lower carcase value, or that lower meat quality.

The use of feedlots to finish cattle has stimulated an interest in reducing heat stress in lot fed cattle in hot environments. At high temperatures, evaporative cooling is the principal mechanism for heat dissipation in cattle. This form of cooling is influenced by humidity and wind speed, and by physiological factors including respiration rate, and density and activity of sweat glands. Differences between *Bos taurus* and *Bos indicus* in responses to heat have comprehensively reviewed by Hansen (2004). *Bos taurus* cattle have fewer sweat glands than *Bos indicus*, and the main means of evaporative cooling is through the respiratory losses. Heat in *Bos taurus* cattle is also dissipated via the skin, but not by evaporation, rather by convection. Feedlot cattle depend greatly on their ability to vaporise moisture as a means of generating heat loss, particularly as the temperature rises. Cattle have a limited ability to sweat and the main source of evaporative cooling is through the respiratory system by panting. Nasal cavities, mouth and lungs are the main sites of evaporative cooling in cattle. Barnes et al. (2004; IVE.209) conducted an experiment to define the physiology of heat stress in cattle. They reported that *Bos taurus* cattle tolerated an accumulated heat load less successfully than the *Bos indicus* cattle, and feed intakes were drastically reduced during the periods of heat exposure compared to *Bos indicus* cattle. There was no indication of dehydration in these heat exposed animals with free access to water, and they all increased their water intake. Both types of cattle eventually resorted to panting to relieve heat load, but this response was delayed in the *Bos indicus* cattle. Zebu cattle have been reported to have a higher density of sweat glands than European breeds (Nay and Heyman, 1956) although there was no difference in sweat gland density between Sahiwal and Jersey (Pan, 1963). Moreover, sweat glands of *Bos indicus* have been reported to be larger in size (Dowling, 1955; Nay and Heyman, 1956; Pan, 1963), to be closer to the surface of the skin (Dowling, 1955) and to have more layers of cells in the epithelial layer (Carvalho et al., 1995) than those of *Bos taurus*. The importance of these differences in sweat glands for the superior thermo-tolerance of *Bos indicus* is not clear. In several studies (Allen, 1962; Allen et al., 1963; Gaughan et al., 1999), sweating rate was greater for zebu cattle than European cattle. In other studies, however, maximum sweating rate did not differ between zebu and European breeds (Kibler and Brody, 1952; Allen, 1962). The sweating rate during heat stress can be greater for unadapted *Bos taurus* breeds (Kibler and Brody, 1952; Thompson et al., 1953; Finch, 1985), probably because differences in other thermoregulatory mechanisms mean that *B. taurus* require more evaporative heat loss to maintain homeothermy.

The failure of homeostasis at high temperatures may lead to reduced productivity or even death. Knowledge of characteristic behavioural signs of increasing heat stress such as panting may alert cattle handlers to impending heat distress, particularly in areas of potential climatic extremes of high temperatures and humidities. Manipulating the diet composition (dietary electrolytes, dietary buffers, ingredients e.g. hay, fat, and other interventions), water and electrolyte intake may reduce the heat increment of feeding and may partially protect cattle from heat stress. The live export of cattle is an important industry for Australia. Concerns have arisen about animal welfare and, in particular, heat stress which may cause production losses and death. Cattle shipped live to the Middle East from Australia can face continuous and prolonged periods of high heat and humidity as they cross the equator and arrive into a northern hemisphere summer, leading to heat stress. While some exporters treat heat stressed cattle with electrolyte supplements, the beneficial effects of these interventions on cattle need to be investigated. The physiological responses of *Bos taurus* and *Bos indicus* to conditions similar to those experienced by cattle being shipped from Australia to the Middle East have been investigated by Beatty et al. (2007). Experimental studies in climate controlled conditions indicated that that electrolyte supplements improved physiological buffering capacity and a provided weight advantage for supplemented cattle, even in the absence of extreme heat stress (Beatty, 2005; Beatty et al., 2007).

Electrolytes and other interventions (e.g. betaine, propylene glycol) are often recommended as supplements prior to and/or during transport (road and sea), during lairage and during heat stress events. They are often claimed to provide benefits in terms of animal welfare measures, shrinkage/liveweight, carcase attributes and meat quality. However, despite many trials, the results are equivocal.

1 Project objectives

This project was designed to conduct a comprehensive literature search to identify the depth of quantitative literature available on the impact of administration of electrolytes and other supplements (such as betaine and propylene glycol) before, during and/or after:

- Land and sea transport,
- Lairage,
- Feedlot heat stress, and
- Live export heat stress

The impact of the electrolytes and other supplements were measured in terms of various animal welfare measures (e.g. cortisol, body temperature), shrinkage/liveweight, carcase attributes and meat quality.

Our goal was to produce a comprehensive bibliography and brief qualitative review of the literature; and recommend the suitability of the available data for a quantitative meta-analysis review (Phase II).

The scope of the literature search included peer reviewed, grey and unpublished literature.

The effects of available preventive therapeutic (eg. electrolytes) and nutritional (eg. betaine) interventions on animal welfare, shrinkage/liveweight, carcase attributes and meat quality were comprehensively investigated. The outcomes of this review were then used to indentify:

- The number of studies appropriate for quantitative assessment
- The outcomes measured in studies
- Details of study protocol
- Animals used in studies are cattle
- Exposed to heat stress or transported
- Outcomes measured suitable for quantitative assessment
- Quality of published and unpublished studies.

A comprehensive literature search was conducted to obtain available literature, published and unpublished, in the public and private domain that investigated the impact on animal welfare being and physiology associated with transport and heat load on animal productivity and meat quality.

This review provides a qualitative assessment of available preventive therapeutic (eg. electrolytes) and nutritional (eg. betaine) measures on:

- shrinkage/liveweight,
- carcase attributes,
- meat quality, and
- animal welfare.

This review highlights the challenges and key research studies that characterise the potential benefits of electrolytes and other interventions to minimise the impact of transport and heat stress on animal welfare and productivity.

This review also identifies whether there is adequate and appropriate quantitative data to warrant quantitative or meta-analytic assessment of the effects of available products on productivity, carcase attributes and animal welfare.

2 Methodology

2.1 Literature search

Comprehensive literature searches were conducted to identify and evaluate studies and reviews on the impact of interventions including electrolytes, betaine, glycerol, and propylene glycol on cattle performance during heat stress and transportation. If these provided information and data that were appropriate and adequate, then these data could subsequently be used to quantitatively assess the efficiency of these interventions on production and welfare being.

Published papers, reviews and abstracts and reports, from 1980 to 2010, were identified by:

i. computerised literature searches (electronic databases)
  - Google scholar
  - CAB (Commonwealth Agricultural Bureau)
  - BA abstracts (Biological Abstracts)
  - PubMed (http://www.ncbi.nlm.nih.gov./entrez/query.fcgi)
  - Scirus (http://www.scirus.com/srsapp)
  - Sciencedirect (www.sciencedirect.com)
  - Agricola (http://agricola.nal.usda.gov)
  - VEIN (http://vein.library.usyd.edu.au)

ii. hand searching (library searches of relevant journals for published papers and conference proceedings that were not available online)
iii. checking references (cross-referencing citations in papers obtained)
iv. review of citations from review papers
v. personal communication through unstructured interviews including

- communication with the authors of identified papers and scientists who have been working in the relevant field of study
- communication with industry bodies (e.g. MLA) State DPIs and scientific institutes

It was not feasible to find or obtain every relevant study for all the aspects of the heat stress and transport and intervention programs investigated in this project. Some studies may have been not published in peer reviewed journals, or even proceedings, and may not have been indexed in electronic databases such as CAB or ScienceDirect. There were a number of recent published papers and reports that comprehensively reviewed the impact of interventions and their implications for the northern production system, which are discussed in Section 3.

The process of interview and pursuit of unpublished material was important to obtaining literature that could provide information or data, but was unpublished in peer-reviewed journals.

The literature search conducted using the search engines, contact with workers in the field and investigation of references in papers was based on the following key words: cattle, beef, steer, heat stress, transport, electrolytes, betaine, propylene glycol, glycerol and vitamins.

3 Results and discussion

3.1 Historical data on heat stress and transport in Australia

The impact of transportation and heat load on physiology, performance and welfare of cattle, and benefits of intervention management programs to alleviate these impacts, have been comprehensively studied and reviewed during the past 30 years (Wythes et al., 1981, 1983; Lacourt and Tarrant, 1985; Hutcheson et al., 1986; Jones et al., 1988, Hutcheson, 1988; Tarrant, 1990; Tarrant et al., 1992; Jeremiah et al., 1992; Tarrant et al., 1992; Blackshaw and Blackshaw, 1994; Walker et al., 1999; Knowles, 1999; Knowles et al., 1999; Smith and Wilson, 1999; Eicher, 2001; Schaefer et al., 1990, 1992, 1997, 2001, 2006; Parker et al., 2003; Davis et al., 2003; Mader and Davis, 2004; Mareko, 2005; Brown-Brandl et al., 2005; Earley et al., 2006; Nienaber and Hanh, 2007; Schwartzkopf-Genswein et al., 2007; Booth-McLean et al., 2007; Hogan et al., 2007; Barnes et al., 2008; Gaughan et al., 2008, 2009, 2010).

Marketing transportation and heat stress are significant causes of loss of appetite and shrinkage or loss of body mass of cattle under Australian conditions. The impacts of climate and restricted access to food and water, different components of transportation procedures including handling, loading, off-loading, relocation and social mixing, vary in their influence on the responses.

A number of studies have focused on cattle transportation and heat stress management as these apply to the Australian cattle production (Thompson et al., 1990; Pinch, 1993a,b; Philips, 1997; Beatty et al. 2007; Fraser, 2007; Gaughan et al., 2008, 2009, 2010) and those funded by MLA or State DPIs (Table 1). The objectives of majority of these research projects and reviews were to explore the impact of transportation and heat stress on cattle performance, and some evaluated the effect of electrolytes and betaine or other interventions. The reviews, surveys and experimental projects are listed in Table 1.

3.2 Effects of heat stress and transport on cattle performance and intervention programs

The literature covering the heat load and transport of cattle is extensive (Knowles, 1999; Hogan et al., 2007; Schwartzkopf-Genswein et al., 2007; Schaefer et al., 2006; Booth-McLean et al., 2007; Hogan et al., 2007; Schaefer et al., 2001, 2006; Gaughan et al., 2008, 2009, 2010; Barnes et al., 2008). Heat load has a considerable impact on the productivity and welfare of livestock and several strategies have been adopted by the producers to reduce these impacts including electrolytes and other interventions and also the use of environmental stress indicators (Gaughan et al., 2008). We briefly outline the impacts of climate and current practices that have been comprehensively studied with particular reference to Australia.

3.2.1 Effects of transport and heat load

Losses of productivity and associated welfare effects following transportation and heat stress include:

- Mortality
- Weight loss
- Physiological impacts
    - Reduced rumen contents and impaired function
    - Disordered homeostasis
    - Hunger
    - Disrupted nitrogen metabolism
    - Altered rumen microbial ecology
    - Increased risk of impact from entero-pathogenic bacteria
- Shipping fever
- Changes in behaviour during transport
- Altered carcase traits and meat quality

Table 1. List of studies on the impact of heat stress and transportation on cattle performance and meat quality and some treatment programs

Project codes	Authors	Title
Live.102 and SBMR.003	Ainsworth and McCarthy (2000)	Best practice standards for the preparation and husbandry of cattle for transport from Australia
Live.104A	Alliance Consulting and Management (unknown)	Handling and Transport of Cattle, Sheep and Goats
Live.104B	Alliance Consulting and Management (2001)	Use of electrolytes to alleviate stress: Desk Top Study
Live.108	Rose and Evans (2006)	Desk Top Study of Electrolyte Products
Live.116	Maunsell Australia Pty Ltd (2003)	Development of a heat stress risk management model
Live.204	Ainsworth (2001)	Identifying current best practice in the export of young cattle to Israel
Live.208	McCarthy (2002)	The Best Practice Management of Pregnant Dairy Cattle on Long Haul Voyages
Live.209	Barnes, Beatty, Taylor, Stockman, Maloney and McCarthy (2004)	Physiology of heat stress in cattle and sheep
Live.216	Norris and Norman (2003)	Mortality and morbidity risk factors for livestock during sea transport from Australia
Live.223	McCarthy (2005)	Pilot Monitoring of Shipboard Environmental Conditions and Animal Performance
Live.224	Barnes, Beatty, Stockman, Maloney and Taplin (2008)	Electrolyte supplementation of export cattle, and further investigations in the heat stress threshold of sheep and dairy cattle
Live.301	Fitzpatrick and Parker (2004)	Management of pre-delivery stress in live export steers
Live.0127	Savage, Gaughan, Godwin and Nolan (2008)	Post Discharge Induction Procedures for Sheep in the Middle East
B.LIV.0249	Eustace and Corry (2009)	Revision of the heat stress risk assessment methodology to properly incorporate risk of heat stress while at port
LMAQ.011	Wythes (unknown)	Handling and Transport of Cattle, Sheep and Goats
SBMR.001	Agriculture Western Australia (1999)	Investigation of cattle deaths during sea transport from Australia
SBMR.002	MAMIC Pty Ltd (2001)	Investigation of the Ventilation Efficacy on Livestock Vessels
SBMR.004A	Norris, Jubb and Richards (2001)	Investigation of Cattle Deaths and Illness during Sea Transport from Australia Voyage 4
FLOT.307, 308, 309	Sparke, Young, Gaughan, Holt and Goodwin (2001)	Recommendations for reducing the impact of elements of the physical environment on heat load in feedlot cattle
FLOT.310	Petrov, Lott, Cork (2001)	Measuring microclimate variations in two Australian feedlots.
FLOT.312	Katestone Environmental (2002)	Risk assessment on the occurrence of excessive heat load for the major feedlot regions of Australia: Software Report
FLOT.313		Forecasting feedlot thermal comfort.
FLOT.314	Kennedy and Cronjé (unknown)	Dietary strategies for amelioration of heat load in feedlot cattle
FLOT.315		Applied scientific evaluation of feedlot shade design.
FLOT.316		Development of an excessive heat load index for use in the Australian feedlot industry.
FLOT.317	Petrov, Lott, Binns, Cork and MacFarlane (2003)	Measuring the microclimate of eastern Australian feedlots.
FLOT.327		Reducing the risk of heat load for the Australian feedlot industry.
FLOT.330		Validation of the new Heat Load Index for use in the feedlot industry
FLOT.335	Byrne, Lott, Harburg, and Gaughan (2006)	Improved measurement of heat load in the feedlot industry.
BFLT.0337	Gaughan (2008a)	Assessment of varying allocations of shade area for feedlot cattle – Part 1 120 days on feed
B.FLT.0344	Gaughan (2008b)	Assessment of varying allocations of shade area for feedlot cattle – Part 2 182 days on feed
B.FLT.0345	Gaughan, Loxton, Lisle, Bonner (2009)	Assessment of Betaine and glycerol as ameliorants of heat load in feedlot cattle.
B.FLT.0352	Killip, Quintarelli and Schloss (2009)	Online summer heat load forecast service – 2008/2009
AHW.055 B.AHW.0055	Ferguson and Fisher (2008)	Animal Welfare Outcomes of Livestock Road Transport Practices
AHW.126 B.AHW.0126	Fisher, Ferguson, Lee, Colditz and Belson, Lapworth and Petherick (2006)	Cataloguing land transport science and practices in Australia
NT A020	Philips (1997)	Electrolyte and sugar supplements for slaughter cattle transported long distances
NT	Pinch (1993)	Pinch D (1993a) Effect of electrolytes and vitamins on weight loss in transported steers. NT Pinch D (1993b) Effect of electrolytes on weight loss in transported cattle. NT
QDPI circulated trial report	Thompson, Sullivan, Jeffrey, Davis and Jeffries (1990)	The effect of electrolytic interventions on dressing percentage and meat quality of steers slaughtered after extended road transportation.

The external factors that contribute to the intensity of the loss are:

- o Housing conditions
- o feeding regimes
- o The distance and duration of transportation
- o Stocking density on trucks (ships)
- o Frequency and procedures used for animal handling

Schaefer et al. (2001) reviewed the role of nutrition in reducing antemortem stress and meat quality. The impact of antemortem events on animal physiology is depicted in Figure 1. This shows the endocrine, enzymatic, metabolic, haematology and physiological impacts of transport on meat quality.

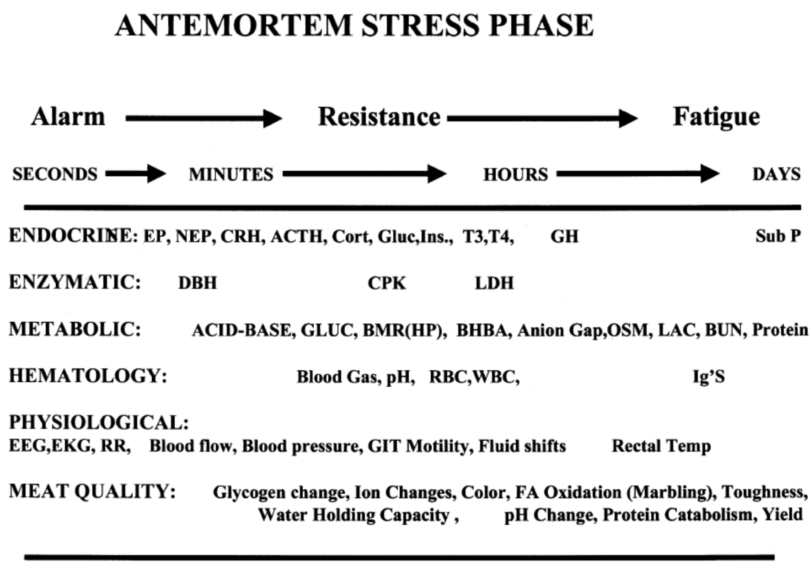

Figure 1. Chronology of physiological and meat quality changes in the antemortem environment (Source: Schaefer et al., 2001)

EP = epinephrine, NEP = norepinephrine, CRH = corticotropin-releasing hormone, ACTH = adrenocorticotrophic hormone, Cort = cortisol, Gluc = glucose, Ins = insulin, T3 = triiodothyronine, T4 = thyroxine, GH = growth hormone, Sub P = substance p, DBH = dopamine beta-hydroxylase, CPK = creatinine phosphokinase, LDH = lactate dehydrogenase, BMR = basal metabolic rate, HP = heat production, BHBA = beta-hydroxybutyric acid, OSM = osmolality, LAC = lactate, BUN = blood urea nitrogen, RBC = red blood cells,WBC= white blood cells, Ig's = immunoglobin, EEG = electroencephalograph, EKG electrocardiograph, GIT = gastrointestinal tract, and FA = fatty acid.

3.2.2 Electrolyte and nutritional interventions

Electrolyte and nutritional interventions that may be able to reduce the antemortem stress and meat quality aberrations are reviewed by Schaefer et al. (1997, 2001). These include:

- Water
- Energy
- Electrolytes
- Amino acids
- Trace nutrients (enzyme cofactors, antioxidants, vitamins)
- Nutrient complexes (e.g. Nutricharge®)
- Betaine (Betafine®)

The benefits of some of these interventions, such as electrolytes (with and without glucose), nutrient complexes and betaine have been studied more widely compared to the other nutrients (eg. propylene glycol, glycerol and chromium). Electrolytes and betaine have been experimented with (Tables 2-3), and used by cattle producers in Australia. Here we briefly discuss these two interventions.

3.2.3 Electrolytes

In the context of this study, the term electrolytes was defined by the interventions that had been provided to reduce the effects transport stress in the studies identified. Detail on the products identified is provided in Tables 2 and 8. Electrolytes are in general, interventions that contain ions, especially Na, K, Ca, HCO_3^- and Cl, that influence fluid balance within the body. These ions influence the volume of fluid and the distribution of fluid between the major fluid components, the intracellular fluid and extracellular fluid, and primarily influence these through osmotic effects. Other interventions including glucose, amino acids and citrate have been included in some interventions to provide energy, amino acid sources and to enhance uptake of ions. In the antemortem environment of transport and feed and water restriction before slaughter, physiological mechanisms that maintain body fluid volume and osmolarity are impaired. Dehydration, energy depletion, ion depletion and accelerated protein catabolism are considered to be the four major physiological challenges requiring intervention in the antemortem period in order to prevent adverse effects on meat quality and yield (Schaefer et al., 2001). There are a large number of reviews that discuss the physiology and practical use of electrolytes in cattle during transport and heat stress (Schaefer et al. 1997, 2001; Alliance Consulting and Management, 2001-MLA Report Live.104B; Beatty, 2005-PhD Thesis; Lacourt, 1985; Knowless, 1995, 1999; Hogan et al., 2007; Hutechson and Cole, 1986).

There is a considerable number of studies worldwide (published and unpublished) on the effect of electrolytes on cattle performance, carcase traits and meat quality. However, the results of these studies are not conclusive. Some of studies in Canada and the United States have reported a positive response to electrolyte treatments and diets high in sugar (Hutcheson and Cole, 1986; Schaefer et al., 1990, 1992, 1993, 1997, 2001, 2006; Görtel et al., 1992) on slaughter performance and road transport. These effects included:

- Improved liveweight
- Improved carcase yield, and
- Improved meat quality

While electrolytes are widely used by cattle producers in Australia, there were limited Australian published data on electrolytes that could be obtained (Pinch, 1993a,b; Philips, 1997; Burrow et al., 1998; Beatty et al., 2007; Barnes et al., 2004, 2008; Fraser, 2007). It was not possible to obtain a copy of Thompson et al. (1990) paper. These studies have been conducted under varying environmental conditions (land *vs.* sea transport), and none showed a significant improvement in the liveweight of cattle, except for Beatty et al (2007) on sea transport. However, some improvement in liveweight changes and carcase yield has been observed. Other Australian studies have predominantly explored other heat stress mitigation strategies (Gaughan et al., 2008, 2009, 2010; Barnes et al., 2004) (Table 4).

Electrolyte supplements used for cattle available in Australia are provided in Table 2.

Table 2. Electrolyte products for use in cattle and sheep during shipping (Source: MLA Report; Live 104B)

Product	Composition	Administration	Indications for use
DEB9®	Electrolytes of sodium, potassium and bicarbonates	In water	Dehydration and electrolyte imbalance due to heat stress
Selectolyte®	Electrolytes of sodium, potassium and bicarbonates	In water	Dehydration and electrolyte imbalance due to heat stress
Selectrolyte®	sodium bicarbonate (500g) sodium chloride (266g) glucose (179.6g) potassium chloride (50g) vitamin A (2 MIU	In water or in feed	Dehydration and electrolyte imbalance
Solulyte concentrate®	sodium bicarbonate (500g) sodium chloride (266g) glucose (179.6g) potassium chloride (50g) vitamin A (2.2 MIU)	In water or in feed	Dehydration and electrolyte imbalance
Glucotrans®	glucose (710g) sodium chloride (140g) potassium chloride (50g) sodium sulphate (50g) sodium bicarbonate (40g)	In water	Dehydration and electrolyte imbalance
Topstock Electrolytes	dextrose (400g) sodium bicarbonate (300g) potassium chloride (270g) sodium chloride (25g)	In water	Dehydration and electrolyte imbalance

3.2.4 Betaine

Betaine, the trimethyl derivative of the amino acid glycine, is produced as a by-product of sugar beet processing. It is commercially available as a feed additive, with the most popular forms being anhydrous betaine, betaine monophosphate and betaine hydrochloride (Eklund et al., 2005). The different functions of betaine, both at metabolic and gastrointestinal level, have been reviewed in detail (Kidd et al., 1997; Simon, 1999; Odle et al., 2000; Eklund et al., 2005; Ratriyanto et al., 2009).

Betaine exerts an osmoprotective effect by accumulating in cell organelles and cells exposed to osmotic and ionic stress, thereby replacing inorganic ions and protecting enzymes as well as cell membranes from inactivation by inorganic ions (Petronini et al., 1992). Additionally, it has been shown that betaine accumulates in muscle cells of pigs (Matthews et al., 2001), thus possibly affecting meat quality. There is also some evidence that betaine reduces energy expenditure for ion pumping in cells exposed to hyperosmotic media (Moeckel et al., 2002). Supplementing a diet with betaine may also reduce the effects of heat stress in feedlot cattle. Eklund et al. (2005) and Löest et al. (2002) reported that betaine supplementation has been observed to reduce heat stress and enhance performance and carcase quality of pigs and poultry and cattle; however the evidence is not strong. Eklund et al. (2005) and Sales (2011) reviewed the physiology and use of betaine comprehensively in pigs and poultry and briefly in cattle.

There are limited Australian and international data on the effects of betaine as ameliorants of heat load in feedlot cattle and transported cattle (Löest et al. 2002; Block et al. 2002, 2004; Parker et al., 2007; Loxton et al., 2007; Gaughan et al., 2009). These studies showed that betaine had no significant effect or little benefit in alleviating the heat stress or improving liveweight and carcase attributes in feedlot cattle.

3.2.5 Other products

The benefits of vitamins ADE (Jubb et al., 1993; Pinch, 1993a), propylene glycol (Kim et al., 2011), glycerol (Parker et al., 2007), chromium (Chang and Mowat, 1992, Moonsie-Shageer and Mowat, 1993), dexamethasone (Cook et al., 2009) and sodium chloride and fat (Gaughan and Mader, 2009) have also been studied to evaluate their potential to improve water intake, liveweight gain, and to alleviate the impact of stress associated with heat load and transportation on cattle performance and meat quality. There are very few published studies on these interventions and a quantitative review was, consequently, not possible.

3.2.6 Review and collation of current information on interventions used to alleviate the impacts of heat stress and transportation in cattle

More than 85 papers with heat stress information and data were identified; 34 studies were selected with data on the effects of therapeutic interventions on cattle performance during transport and heat stress. Of these, we identified 26 studies with electrolyte and transport data, 6 studies with electrolyte and heat stress data, 4 studies with betaine data, 2 studies with vitamins and only one study for each of the following interventions; glycerol, propylene glycol, chromium, sodium chloride and fat. These interventions were reviewed and evaluated to determine if there was adequate information and suitable data to warrant a quantitative review or meta-analysis. There were some studies that contained data on both electrolytes and vitamins (Pinch, 1993a) or other interventions.

A list of publications reviewed for the study is provided in Table 3. A summary of studies identified for each category is presented in Table 4.

Table 3. A summary of studies that investigated the effect of different interventions on cattle performance during transport and heat stress

Interventions	Electrolytes	Betaine	Propylene glycol	Glycerol	Vitamin AED	Chromium
Transport						
Peer-reviewed	11	1	1	1	1	1
Proceedings*	4					
Reports	2				1	
Total	**19**	**1**	**1**	**1**	**2**	**1**
Heat stress and performance						
Peer-reviewed	2	2				1
Proceedings*						
Reports†	5	1				
Total	**7**	**3**				

* Some of proceedings did not contain adequate information and data
† To be able to use these reports in a quantitative analysis, missing information and data should be obtained from the authors

The impact of electrolytes and other interventions during transportation: While these data were not suitable to be quantitatively assessed, our review showed that only 17% of studies reported a significant positive effect of electrolytes on the liveweight of cattle during transport. This group of studies included unreplicated group-fed studies (Schaefer et al. 1993; Church et al., 1994 - the same data in two different Proceedings- and Pinch, 1993a,b); one replicated group-fed study (Smith and Wilson, 1999) and one individually-drenched study (Scott et al., 1993). In another flawed study, Knowles et al. (1997) fed the electrolytes individually to the cattle, but compared the liveweight of treated and transported (8, 16 and 24hr) cattle with not-treated and not-transported (0hr) cattle, and found there was no difference between the two groups (P=0.107).

Our review also found that 83% of trials and comparisons had no significant differences between the liveweight of control and electrolyte treated cattle during the transportation (Table 5). Regardless of the level of significance in the published papers, 92% of the trials and comparisons in the reviewed papers reported a trend towards (Table 5), direction of effect treatment animals losing less weight than control animals. The Australian studies that we could obtain for this review and had liveweight data (Pinch, 1993a,b; Burrow et al. 1998; Philips, 1997) reported no significant improvement in the liveweight of cattle treated with electrolytes during the land transportation. However, Beatty et al. (2007) suggested that electrolyte supplementation of cattle during transportation by sea ship significantly increased liveweight and welfare. Studies on the effects of betaine (n=1) and propylene glycol (n=1) on liveweight during land transportation also found no significant improvement in treated cattle.

Different measures (eg. initial and final LWT difference vs. final LWT difference) were used in studies that investigated the effects of electrolytes on liveweight of cattle. Some compared the differences between the final and initial liveweight in both treatment and control groups, whereas the others compared the differences in the final liveweight of cattle. We believe that studies that compared the differences between the final and initial liveweight are robust and superior to those just compared the final liveweight between the two groups.
The majority of trials conducted on electrolytes and betaine used a study design in which control and treatment groups were housed separately and were group-fed with no access to water, or with *ad libitum* access to the allocated water for the control groups, and *ad libitum* feeding of electrolyte treatments. No information was provided on daily intake of these interventions by individual animals. These suggest that the control and treatment groups were not properly replicated resulting in problems with pseudo-replication and potential for misinterpretation of studies. There was also considerable variation in the type of information and data provided in different studies. In particular, the treatment of control groups, the information provided on cattle class, type and composition of electrolytes, duration and distance transported, and outcomes measured for carcase and meat attributes are markedly different among studies.

Electrolytes and other interventions as ameliorants of heat load: Research studies conducted to evaluate the effects of electrolytes and betaine on cattle performance during heat stress are presented in Table 6. The objective of studies provided in Table 6 was to explore the influence of electrolytes on cattle performance during heat stress, except for Ross et al. (1994a,b), who investigated the effect of different dietary electrolyte balances (DEB) without considering the impact of climate. Similar to the transportation studies, these studies also differed considerably with regard to the information provided on the type of electrolytes, temperature and humidity, season and the environment where cattle were housed or kept. Only one study (1 out of 5) (Ross et al., 1994b) found that the dietary electrolyte balance (DEB) had significant (linear and quadratic) effect on the ADG of cattle on days 26 and 56 (Table 6) of feeding. However, there was no significant (linear) improvement in the liveweight of treated cattle at the exit day (day 84). Three of the studies that investigated the effect of electrolytes as ameliorants of heat load in cattle, were replicated group-fed experiments. Similar to the transport studies, 67% of trials and comparisons reported a positive trend in treated cattle regardless of the levels of significance in the published papers (Table 7).

There were 4 studies on the effects of betaine on liveweight and carcase and meat attributes during heat stress; the liveweight of control and treated cattle did not differ significantly. Gaughan et al. (2009) was the only study that comprehensively investigated the effect of betaine and glycerol on carcase attributes and welfare of cattle. They found that the inclusion of these interventions did not improve animal performance or reduce the impact of high heat load on welfare.

Table 8 provides information on each outcome measured including meat quality, carcase traits and welfare measures. The majority of studies provided data on liveweight/shrinkage; but very limited data were provided on carcase traits and meat quality or animal welfare measures. The outcomes measured for carcase and meat attributes varied among studies, and it was not possible or appropriate to compare these outcomes. Information on core body temperature, heart rate, respiratory rate, panting score, dry matter intake and animal behaviour were considered as indicators of animal wellfare. Very few studies reported the effects of these interventions on animal welfare indicators.

In regard to the other outcomes measured; differences in the control groups, class of cattle, breed, time of intervention (pre- and post-transportation), type of electrolytes, carcase traits and meat quality, it would not be appropriate to pool the data. The very different study protocols used suggest that the estimated pooled estimates of effect of these treatments may be highly heterogeneous, as a result of the clinical heterogeneity in study design.

Table 4. Studies that investigated the effects of different interventions (electrolytes, Betaine, etc.) during land transport (pre- post-transport or both) and one case of ship transport on cattle performance, carcase traits, meat quality and welfare.

Authors	Type and source of paper	Country	Cattle	Breed	Groups		Time of treatment (pre vs. post transportation)	Distance (km)	Duration of transport (hr)	Water or feed deprived before or during transport and antemortem)	Season and temperature (°C)
					Control	**Treatment**					
Önenç (2010)	Peer-reviewed	Turkey	Bulls	Holstein-Friesian	Water	Electrolyte-glucose	Post-transport and antemortem18 hr (abattoir pen)			Group-fed Water = ad lib Feed: No access (18hr antemortem)	
Arp et al. (2011) and Crosswhite et al. (web report)	Peer-reviewed and Report	Canada	Cull dairy cows	Holstein and 3 cross-breds	Water (1.5 L drenched)	Electrolyte (at farm) (drenched with 1.5 L water)	- Exp1: Pre-transport - Exp2: Pre- and post-transport		Exp1: 3hr Exp2: 2hr	Drenched Water and feed: Ad lib. except during transport	Exp1: Summer (Temp: 22.2 - 32.2°C; humidity: 75%) Exp2: Winter (temp: 12.2 - 17.2; humidity: 78%)
Schaefer et al. (1990)	Peer-reviewed	Canada	Yearling beef bulls	Cross-bred	No water for 18-20hr pre-slaughter	- Water - Electrolyte - Glucose (5%)	Post-transport and antemortem	200	6hr	Group-fed Exp2: Control had no access to water 18-12hr antemortem	
Schaefer et al. (1992)	Peer-reviewed	Canada	Yearling beef bulls	Cross-bred	0 hr off feed Cattle on the following groups transported, but had no electrolyte : -12hr - 24hr - 36hr	Hours off feed: -12 - 24 - 36 Cattle on the following groups transported and had access to electrolytes: -12hr - 24hr - 36hr	Post-transport and antemortem	Control: 5 Treatment: 150	Control: 10min Treatment: 4hr	Group-fed Feed and water deprived during transport for: - 0 - 12 - 24 - 36	
Jones et al. (1992)	Peer-reviewed	Canada	Yearling beef	Cross-bred	0 hr off feed	Hours off feed: -12	Post-transport and	Control: 5 Treatment:	Control: 10min	Group-fed	

Authors	Type and source of paper	Country	Cattle	Breed	Groups		Time of treatment (pre vs. post transportation)	Distance (km)	Duration of transport (hr)	Water or feed deprived before or during transport and antemortem)	Season and temperature (^{o}C)
			bulls			- 24 - 36	antemortem	150	Treatment: 4hr	Feed and water deprived during transport for: - 0 - 12 - 24 - 36	
Burrow et al. (1998)	Report to MLA	Australia	Weaners	Cross-bred, Belmont red and Santa-Gertrudis, Brahmans	Molasses + CSM	Nutricharge® + Molasses + CSM	Pre- and during transport	1365	Over several days	Group-fed	
Smith and Wilson (1999)	Peer-reviewed and replicated	USA	Beef heifers	Cross-bred (Angus x Simmental)	Not transported + water	- Transport + water Transport + electrolyte	During transport	2 x 80= 160		Group-fed Feed deprived a day before transport	
Gortel et al. (1992)	Peer-reviewed	Canada	Bulls	Hereford x Angus	Transported + no water	Water (ad lib.) Electrolyte (ad lib.)	Post-transport	150Km	4hr		Spring and summer
Knowles et al. (1997)	Peer-reviewed	UK	Calves	Mixed breed	Not transported and fed normal diet	- 8hr transport: normal feed - 16hr transport: 1 x glucose/ electrolyte - 24hr transport: 2 x glucose/ electrolyte Amount: 1L/calf	During transport (group-fed, but treatments fed individually)		8hr 16hr 24hr	Group-fed (not replicated properly) Free access to water during transport	
Schaefer et al. (2006)	Peer-reviewed	Canada	Steers and heifers	Cross-bred	Corn-rice hull-based diet + water (12-24hr pre slaughter)	- Water (12-24hr antemortem) - Electrolyte (12-24hr antemortem)	Post-transport-antemortem		6hr	Group-fed Feed and water deprived 12-24 hr before slaughter	
Jeremiah et al. (1992)	Peer-reviewed	Canada	Bulls		0hr transported	Hours off feed: -12hr	Post-transport-antemortem	Control: 5 Treatment:	4hr	Group-fed	

Authors	Type and source of paper	Country	Cattle	Breed	Groups		Time of treatment (pre vs. post transportation)	Distance (km)	Duration of transport (hr)	Water or feed deprived before or during transport and antemortem)	Season and temperature (°C)
						- 24hr - 36hr		150		Water and feed deprived for: 0hr 12hr 24hr 36hr	
Philips (1997)	Report to NT DPI (Azri Lib)	Australia	Cows Steer	Poll Hereford, Hereford, Simmental, Shorthorn and Brahman, Shorthorn, Shorthorn X Santa-Gertrudis	Water and transported	Electrolyte and transported	Exps 1 and 2: Pre-transport Exp 3: Pre- and post-transport	1600 1500 1850	34.5hr 25hr 32.5hr	Group-fed	
Scott et al. (1993)	Proceedings 39th ICMST, Calgary, Alberta;	Canada	Bulls	-	Water + transported	Electrolyte	Pre-transport	-	4hr	Drenched Water: free access for 18hr in lairage	
Jacobsen et al. (1993)	Proceedings 39th ICMST Calgary, Alberta;	Canada	Steers	Cross-bred	Normal feedlot ration and water + transported	- Electrolyte premix 24hr pre-and after transport - Electrolyte premix for only 24hr pre-transport	Pre-transport Pre and post-transport		8hr over 2 days		
Church et al. (1994)	Proceedings Livestock prod. 21st Century priority and Research needs	Canada	Yearling Steers and heifers	Cross-bred	Water + transported	Soluble Nutricharge® (ad libitum)	Pre-transport and post-transport		1hr	Group-fed Water: ad lib. Feed: no access for 18hr	
Schaefer et al. (1993)	Proceedings 39th ICMST Calgary, Alberta;	Canada	Yearling Steers and heifers	Cross-bred	Water + transported	Soluble Nutricharge® (ad libitum)	Pre-transport and post-transport		1hr	Group-fed Water: ad lib. Feed: no access for 18hr	

Authors	Type and source of paper	Country	Cattle	Breed	Groups		Time of treatment (pre vs. post transportation)	Distance (km)	Duration of transport (hr)	Water or feed deprived before or during transport and antemortem)	Season and temperature (°C)
Beatty et al. (2007)	Peer-reviewed	Australia	Steers	Cross-bred	Water ad lib Shipboard (18 days)	Electrolytes (ad libitum) Shipboard (18 days)	During transport	Australia to the middle east	18 days	Group-fed Feed and water ad lib	
Dubeski et al. (1995)	Proceedings Animal Science Research and Development.	Canada	Steers	Cross-bred	Water No water	Nutricharge®	Pre-transport Post-transport Pre- and post-transport		2.5hr	Group-fed 3 experiments: Water: free access pre- transport post- transport pre- and post-transport	
Kim et al. (2011)	Peer-reviewed	Korea	Steer	Korean native	Concentrate diet	Propylene glycol (SKC, Ltd, Seoul, South Korea)	2 months before slaughter (at farm)			Individual-fed Feed: no access (24hr antemortem)	
Fitzpatrick and Parker (2004)	MLA report-Live.301	Australia	Steers	*Bos indicus*	No water or feed for 48hr + transported	- Glycerol - Betaine (drenched with 0.5 L of water)	Pre-transport (48hr before transport)		3 x 48 = 144hr (over 2 weeks)	Individual-fed Water and feed deprived 48hr before transportation	19.5 - 19.8 °C
Parker et al. (2007)	Peer-reviewed	Australia	Steers	*Bos indicus*	No water or feed for 48hr + transported	- Glycerol - Betaine (drenched with 0.5 L of water)	Pre-transport (48hr before transport)		3 x 48 = 144hr (over 2 weeks)	Individual-fed Water and feed deprived 48hr before transportation	19.5 - 19.8 °C
Jubb et al. (1993)	Peer-reviewed	Australia	Weaners Steers	Brahman-cross Brahman-cross and Droughtmaster-cross	**Trial 1:** Lupin and oat mix + hay **Trial 2:** Hay	**Trial 1:** Lupin and oat mix + hay + vitamin ADE **Trial 2:** Hay + vitamin ADE	Pre-transport	3000 332	40hr (over 4 days) 5.5hr	Injection	
Cook et al. (2009)	Peer-reviewed	Canada	Calves	Angus-Charolais	**Trial 1:** No	**Trial 1:** Dexamethasone	Pre-transport		10hr and 45min	Injection	

Authors	Type and source of paper	Country	Cattle	Breed	Groups		Time of treatment (pre vs. post transportation)	Distance (km)	Duration of transport (hr)	Water or feed deprived before or during transport and antemortem)	Season and temperature (°C)
				cross-bred Cross-bred	treatment **Trial 2:**	(0.088 mg/kg) **Trial 1:** Dexamethasone (10mg/hd= 0.027mg/kg)	 Pre-transport			Temp: -11.8°C Relative humidity: (72.5%) Temp: -15.9°C Relative humidity: (74.3%)	
Moonsie-Shageer and Mowat (1993)	Peer-review	Canada	Stressed feeder steers calves	Charolais cross-bred	No chromium	Chromium supplemented at the following levels: 0.2 ppm 0.5 ppm 1.0 ppm	Post-transportation		44 hr Over 3 days (10hr rest)	Group-fed	
Pinch (1993a)	Report to NT DPI	Australia	Steers		Control	1- Vit ADE 2- Electrolyte (Solulyte® Con.) 3- Electrolyte + ADE	Pre-transport and during transport		Over 10 days including rest times	Group-fed (troughs) Cattle had access to feed and water or other treatments pre- and during trasnport. Stops during the journey.	Semi-arid Early-September Station Temp: 21°C to 37.7°C Trucks Temp: 22°C to 32°C
Pinch (1993b)	Report to NT DPI	Australia	Heifer Steers	Brahman cross Droughtmaster cross	Control	Electrolyte Electrolyte (Solulyte® Con.)	Pre-trasnport	655km	13 hours	Group-fed (trough) Cattle had access to feed and water or electrolytes pre-transport	Mid-December Temp: 20°sC to 40.2°C

Table 5. Summary of studies that investigated the effects of different electrolyte interventions on liveweight during transportation

Studies	Feeding	Replicated	Hours transported	Time of treatment	Total N	Liveweight loss/gain (final LWT - initial LWT)[1] (kg)		Difference (kg)	Significance (P value)	Direction of effect
						Control	**Treatment**			
Arp et al. (2011)-1	Drenched	Yes	3hr	Pre-transport	60	-61.4	-62.3	-0.90	0.43	Negative
Arp et al. (2011)-2	Drenched	Yes	2hr	Pre-transport	32	-106.4	-86.5	19.90	0.85	Positive
Arp et al. (2011)-3	Drenched	Yes	2hr	Post-transport	30	-106.4	-87.6	18.80	0.85	Positive
Burrow et al. (1998)-1	Group-fed	No	Several days	Pre-transport and during	207	-8.95	-8.78	0.17	Not Significant	Positive
Burrow et al. (1998)-2	Group-fed	No	Several days	Pre-transport and during	232	2.40	2.41	0.01	Not Significant	Positive
Burrow et al. (1998)-3	Group-fed	No	Several days	Pre-transport and during	93	-7.42	-5.79	1.63	Not Significant	Positive
Smith and Wilson (1999)- (averaged)	Group-fed	Yes		During transport	12	-9.43	-8.78	0.65	0.01	Positive
Philips (1997)-3	Group-fed	No	32.5hr	Pre- and post-transport	98	-35.8	-33.5	2.30	Not Significant	Positive
Schaefer et al. (1993) Church et al. (1994)	Group-fed	No	1hr	Pre-transport	62	-28	-20.5	7.50	<0.01	Positive
Pinch (1993a)-1 (VRRS to Kota Kinabulu)	Group-fed	No	Entire trip (over 10 days	Pre-transport and during	75	-44.0	-42.9	1.10	Not significant	Positive
Pinch (1993b)-1 Heifers	Group-fed	No	13hr	Pre-transport	35	-14.9	-13.9	1.0	Not significant	Positive
Pinch (1993b)-2 Steers	Group-fed	No	13hr	Pre-transport	64	-7.6	-6.5	1.10	Not significant	Positive
						Liveweight (kg)[2]				
						Control	**Treatment**			
Jones et al. (1992)-1	Group-fed	No	(C=10min, T=4hr)	Post-transport	89	495	495		Not Significant	No difference
Knowles et al. (1997)-1	Individual	No	(C=0hr, T=8hr)	During transport	28	54.1	53.70	-0.40	0.374	Negative
Knowles et al. (1997)-2	Individual	No	(C=0hr, T=16hr)	During transport	28	54.1	53.40	-0.70	0.374	Negative
Knowles et al. (1997)-3	Individual	No	(C=0hr, T=24hr)	During transport	28	54.1	52.80	-1.30	0.374	Negative
Philips (1997)-1	Group-fed	No	34.5hr	Pre-transport	26	478.9	494.62	15.77	Not Significant	Positive
Philips (1997)-2	Group-fed	No	25hr	Pre-transport	78	323	325.00	2.00	Not Significant	Positive

[1] Difference between initial and final liveweight of cattle
[2] Liveweight of cattle between the two groups at the completion of trial

Table 6. Studies that investigated the effects different interventions (electrolytes, Betaine, etc.) on cattle performance, carcase traits and meat quality during heat stress

Authors	Type and source of paper	Country	Cattle	Breed	Groups		Duration of treatment (days)	Environment and feeding	Season and environment temperature
					Control	Treatment			
Fraser (2007)	Thesis (Report to MLA)	Australia	Steer	Mixed (Murray gray, Angus)	No electrolyte	Dietary electrolyte for 21 days	21 days	Penned Group-fed	Summer Day: 26.3- 42.9 Night: 12.2 - 25.2
Barnes et al. (2004)-1	MLA report-Live.209 (EXP 4 and 6) Cross-over for rooms	Australia	Heifer	Mixed (Murray gray cross, Angus)	Water	electrolyte	18 days for each replicate (2 replicates, rooms swapped between groups	Climate controlled room Group-fed	Initial warm up, Set at 32^{o}C using wet bulb (5 days) Cool down (2 days)
Barnes et al. (2008)-1	MLA report-Live.224	Australia	Steer	Shorthorn, Shorthorn cross	Water	Electrolyte	18 days and then water till day 25	Penned Group-fed	Wet and dry bulb temperatures were monitored: WBT: 20^{o}C DBT:30^{o}C
Barnes et al. (2008)-2	MLA report-Live.224 (replicated)	Australia	Heifer	Angus and Murray Grey cross	Water	Electrolyte	9 days and replicated after 8 days	Penned Group-fed	Dry bulb and relative humidity were monitored (no data provided)
Ross et al. (1994a)	Peer-review	USA	Growing steer	Angus and angus cross-bred	Dietary electrolyte balance (DEB) reduced to: 0 (zero) using ammonium chloride (NH_4Cl)	Dietary electrolyte balance (DEB) increased to 15 mEq 30 mEq 45 mEq using $NaHCO_3$	84 days	Penned Group-fed	Autumn and early winter
Ross et al. (1994b)	Peer-review	USA	Finishing steer	Angus and Angus-Hereford cross-bred	Dietary electrolyte balance (DEB) reduced to: 0 (zero) using	Dietary electrolyte balance (DEB) increased to: 15 mEq	84 days	Penned Group-fed	Late winter and early spring

Authors	Type and source of paper	Country	Cattle	Breed	Groups		Duration of treatment (days)	Environment and feeding	Season and environment temperature
					NH4Cl	30 mEq 45 mEq + monensin using NaHCO3			
Gaughan et al. (2009)	MLA report. B.FL.T.0345	Australia	Steer	Angus	No Betaine and no shed No betaine and shed	10g betaine/d and no shed 10g betaine/d and shed 20g betaine/d and no shed 20g betaine/d and shed 40g betaine/d and no shed 40g betaine/d and shed	120 days	Feedlot Group-fed	Late spring- early autumn (Nov 07 - March 08)
Block et al. (2004)	Peer-review **Exp 1:** 2 x 2 factorial with 2 replicates **Exp 2:** 11 replicates	Australia	Steer	Angus, Angus cross-bred, Simmental and Limousin cross-breds	No Betaine pasture No Betaine feedlot No Betaine Feedlot	**Exp 1:** Betaine 20g/d on pasture Betaine 20g/d on feedlot Betaine 20g/d on both (pasture and feedlot) **Exp 2:** Betaine (40g/d)	90 days 141 days	Pasture Group-fed Feedlot pens Group-fed Feedlot pens Group-fed	Late autumn - late summer
Löest et al.	Peer-review	USA	Yearling	Mixed	No betaine	**Feed-grade**	Light steers: 82	Penned	Summer

Authors	Type and source of paper	Country	Cattle	Breed	Groups		Duration of treatment (days)	Environment and feeding	Season and environment temperature
(2002)	2 x 4 factorial		steer and heifer	breeds		**betaine:** 10.5g/d 21 g/d **Separator by-product betaine:** 250g/d (15.5 g/d betaine) 500g/d (31 g/d betaine) **Feed-grade betaine:** 4 g/d 8 g/d 12 g/d	days Heavy steers: 113 days Light steers: 82 days Heavy steers: 113 days 117 days 127 days 159 days	Group-fed	
Loxton et al. (2007)	Peer-review	Australia		Angus and Angus-cross	No betaine	betaine 20g/d	60- 90 days	Penned Group-fed	Summer
Chang and Mowat (1992)	Peer-review 2 x 2 factorial	Canada	Steers and feeder steer calves	Charolais-cross	No Chromium	Chromium supplemented	70 days	Feedlot pens Group-fed	

Table 7. Summary of studies that investigated the effects of different interventions on liveweight and as ameliorant of heat load

Studies	Feeding	Replicated	Duration of treatment (days)	Total N	Description of outcomes	Control	Treatment	Differences	Significance (P value)	Direction of effect
Fraser (2007)	Group	No	21	40	Percentage of start LWT (%)	112.70%	112.30%	-0.40%	Not Significant	Negative
Barnes et al. (2004)	Group	Yes	18	12	Average loss of LWT (%)	-7.9%	-5.10%	2.80%	Not Significant	Positive
Barnes et al. (2008)-1	Group	No	18	60	Percentage of start LWT (%)	103.70%	103.70%	0.00%	Not Significant	No difference
Barnes et al. (2008)-2	Group	Yes	18	6	Average reduction of LWT (%)	-5.80%	-4.90%	0.90%	Not Significant	Positive
Ross et al. (1994a)-Growing	Group	No	84	120	ADG (kg/hd/d)	0.98 kg	1.06 kg	0.08 kg	Significant (Quadratic)	Positive
Ross et al. (1994b)-Finishing	Group	No	84	120	ADG (kg/hd/d)	1.03 kg	1.08 kg	0.05 kg	Not Significant	Positive

Table 8. Types of interventions (electrolytes, Betaine, PEG, etc.) and measured outcomes in selected studies

Authors	Interventions*	Body weight (BW) changes	Carcase traits	Meat quality	Welfare and behaviour
Önenç (2010)	**Electrolyte-glucose (A):** (NaCl (0.02%); K2CO3 (0.02); MgSo4 (0.01%); Glucose (5%)		Cooler shrinkage Glycogen pH (15min, 14hr)	Water holding capacity (WHC) Thawing loss Cooking loss	
Arp et al. (2011)	**Electrolytes (A):** (Dextrose (94.8%), NaHCO3 (92.7%), MgSO4 (1.0%), KCL (1.5%)	Initial weight (wt) Post-transport wt Pre-slaughter wt Transport wt Lairage wt loss Total wt loss	Dressing percentage Hot carcase wt 12th rib fat thickness LM area USDA YG Lean maturity Skeletal maturity Overall maturity Marbling	3hr LM pH 24hr LM pH LM lightness LM redness LM yellowness LM drip loss 24hr SM pH SM lightness SM redness SM yellowness	
Schaefer et al. (1990)	**Electrolytes (B):** (0.02 % sodium chloride. 0.02% potassium bicarbonate, 0.01 % magnesium sulphate and 0.005% each of the following amino acids: alanine. lysine. phenylalanine. glutamate. tryptophane, methionine, leucine, isoleucine, and valine)		Warm carcase weight (% farm wt) Cold carcase weight (% farm wt) Plant weight (% farm wt)	Percentage drip loss Subjective (score 1 - 3) pH (45min, 24hr and 48hr) Ultimate pH Colour L Expressiveable juice OMTS shear value Moisture percentage Steak weight loss	
Schaefer et al. (1992)	**Electrolytes (B):** (0.02 % sodium chloride. 0.02% potassium bicarbonate, 0.01 % magnesium sulphate and 0.005% each of the following amino acids: alanine. lysine. phenylalanine. glutamate. tryptophane, methionine, leucine, isoleucine, and valine + 5.0% Glucose)		Carcase weight loss Warm carcase wt Cold carcase wt	Muscle metabolites (K, Cl, Na)	
Jones et al. (1992)	**Electrolytes (B):** (0.02 % sodium chloride. 0.02% potassium bicarbonate, 0.01 % magnesium sulphate and 0.005% each of the following amino acids: alanine. lysine. phenylalanine.	Liveweight	Carcase components: - Post-stun wt - Liver - Spleen - Rumen - Intestines	pH (45min and 24hr) Grade fat Marbling score Shear Muscle colour (L, a, b) Drip loss	

Authors	Interventions*	Body weight (BW) changes	Carcase traits	Meat quality	Welfare and behaviour
	glutamate. tryptophane, methionine, leucine, isoleucine, and valine + 5.0% Glucose)		- Kidneys		
Burrow et al. (1998)	**Electrolytes (B)**: Nutricharge®	Initial Liveweight Weight gains			
Smith and Wilson (1999)	**Electrolytes (A):** Bluelite® (electrolytes/energy and vitamins)	Weight change			Respiratory rate Heart rate Temperature Lying Standing Eating Drinking
Gortel et al. (1992)	**Electrolytes (B):** Glucose (0.5%), NaCl(0.1%), KHCO3 (0.1%), MgSO4(0.05%), alanine. lysine. phenylalanine. glutamate. tryptophane, methionine, leucine, isoleucine, and valine (each at 0.025%)	Liveweight at farm Transport weight loss	Hot carcase weight Hot carcase yield		
Knowles et al. (1997)	**Electrolytes (B):** (Lactade® = glucose/electrolyte)	Liveweight			Temperature
Schaefer et al. (2006)	**Electrolytes (B):** Nutrition therapy pellets (glucose, sodium, potassium, magnesium, and a number of amino acids including alanine, lysine, phenylalanine, methionine, threonine, leucine, isoleucine, valine and tryptophane)		Carcase grade: - Hot carcase yield - USDA prime - USDA choice - USDA select - USDA no roll - Dark-firm-dry		
Jeremiah et al. (1992)	**Electrolytes (B):** (0.02 % sodium chloride. 0.02% potassium bicarbonate, 0.01 % magnesium sulphate and 0.005% each of the following amino acids: alanine. lysine. phenylalanine. glutamate. tryptophane, methionine, leucine, isoleucine, and valine)			Total cooking loss (%) Initial tenderness Overall tenderness Amount of connective tissue Juiciness Flavour intensity Flavour desirability Overall palatability	
Philips (1997)	**Electrolytes (A):** Sugar (80%), slats (20%)= 1kg /100 Litre trough water	Liveweight	Carcase weight Dressing percentage (using HSCW) Rib fat	pH Meat colour Muscle water content	

Authors	Interventions*	Body weight (BW) changes	Carcase traits	Meat quality	Welfare and behaviour
				Chiller assessment	
Scott et al. (1993)	**Electrolytes (B):** Nutricharge® mix		Carcase yield (no details provided)	Meat quality	
Schaefer et al. (1993) and Jacobsen et al. (1993)	**Electrolytes (B):** Nutricharge®	Liveweight and changes	Carcase traits (no details provided)	Meat pH Meat temperature Meat colour Shear value Moisture Others	
Fraser (2007)	**Electrolytes (C):** (1.8g $NaHCO_3$, 3.5g KCl)/L	Liveweight and changes			feed and water intake
Barnes et al. (2004)- MLA report: Exp 4 and 6	**Electrolytes (C):** Electrolytes (1.8g $NaHCO_3$, 3.5g KCl); each L of water contains 0.5 Na, 1.3g HCO_3, 1.75g K and 1.75g Cl	Liveweight and changes			-Clinical sings - Core and rectal temperature - feed and water intake - Respiratory rate
Barnes et al. (2004)- MLA report: Exp 8	**Electrolytes (C):** Electrolytes (1.8g $NaHCO_3$, 3.5g KCl); each L of water contains 0.5 Na, 1.3g HCO_3, 1.75g K and 1.75g Cl	Liveweight and changes			Clinical sings - Core and rectal temperature - feed and water intake - Respiratory rate - Panting score
Barnes et al. (2008)	**Electrolytes (C):** Electrolytes (1.8g $NaHCO_3$, 3.5g KCl); each L of water contains 0.5 Na, 1.3g HCO_3, 1.75g K and 1.75g Cl	Liveweight and changes	Hot carcase weight	Body water LD pH Muscle dry matter (SM, ST and LD)	Clinical sings - Core and rectal temperature - feed and water intake - Respiratory rate - Panting score
Church et al. (1994)	**Electrolyte (C):** Soluble Nutricharge®	Liveweight and changes			
Beatty et al. (2007)	**Electrolytes (C):** (1.8g $NaHCO_3$, 3.5g KCl)/L	Liveweight and changes			Clinical signs: - Temperature - Feed and water intake - Respiratory rate

Authors	Interventions*	Body weight (BW) changes	Carcase traits	Meat quality	Welfare and behaviour
Ross et al. (1994a)	**Electrolytes (D):** Dietary electrolyte balance (DEB): (Na + K) - Cl: 100g of DM): 15 mEq, 30 mEq and 45mEq	Liveweight and changes ADG Gain:Feed			
Ross et al. (1994b)	**Electrolytes (D):** Dietary electrolyte balance DEB: (Na + K) - Cl: 100g of DM): 15 mEq, 30 mEq and 45mEq	Liveweight and changes ADG Gain:Feed	Yield grade Marbling score Rib-eye area Hot carcase weight Kidney, pelvic and heart fat	Mineral concentrations of liver, kidney, muscle and bone	
Dubeski et al. (1995)	**Electrolytes (A):** Nutricharge®		Carcase traits (no details provided) Dark cuts	Meat quality (no details provided)	
Pinch (1993a)	**Electrolytes (B):** Solulyte concentrate® (NaCO3, NaCl, glucose, KCl, Vit A)	Average, ranges and differences in LWT			
Pinch (1993b)	**Electrolytes (B):** Solulyte concentrate® (NaCO3, NaCl, glucose, KCl, Vit A)				
Kim et al. (2011)	Propylene glycol	Initial and final weights ADG DMI G:F	Slaughter weight Cold carcase weight LM area 13th rib fat depth Marbling score LM composition (fat and moisture) Quality grade distribution (1 to 4)		
Fitzpatrick and Parker (2004) and Parker et al. (2007)	Glycerol Betaine	Body weight, Accumulated BW loss, - Initial BW - 12hr curfewed BW - 24hr transit BW - 48hr transit BW	Dressing percentage Hot carcase wt 12th rib fat thickness LM area USDA YG Lean maturity Skeletal maturity Overall maturity Marbling	Total body water	Temperament
Gaughan et al. (2009)-1	Betaine	Liveweight ADG Gain:Feed Hip height	Hot standard carcase weight (HSCW) Left side hot and cold weight Right side hot and cold weight Shrinkage	P8 fat depth (hot) Rib fat depth (cold) MSA-AUS-MEAT marbling score MSA-US marbling score	Animal health: - core body temp - panting score Production responses

Authors	Interventions*	Body weight (BW) changes	Carcase traits	Meat quality	Welfare and behaviour
		BCS	Eye muscle area Hot meat score Dressing percentage Diff: LWT - HSCW	Carcase chiller: Ossification score Meat colour pH (18hr) and ultimate Intermuscular fat colour Meat texture score Meat firmness score Drip loss Oxymyoglobin/metmyoglobin ratio Minolta colour score Total fat Moisture	Water and feed intake
Block et al. (2004)	Betaine	Liveweight and changes ADG	Initial and final fat thickness Fat thickness changes Hot carcase weight LS area Marbling score Dressing percentage		Feed intake
Löest et al. (2002)	Betaine	Liveweight and changes ADG Gain:Feed	Hot carcase weight Dressing percentage Kidney, pelvic and heart fat Back fat Longissimus area Yield grade (1 to 5) Marbling score USDA prime USDA choice USDA select USDA standard Liver abscesses		Feed intake
Loxton et al. (2007)	Betaine + NaHCO3 + KCO3	Liveweight ADG BCS Changes in hip height and width Gain:Feed	Hot standard carcase weight (HSCW) P8 fat Dressing percentage		Feed intake Panting score Core body temperature

* Electrolytes are labelled A, B, C and D to simplify the categorisation of electrolytes in Table 10

4 Conclusions and recommendations

A total of 87 studies were reviewed, of these 36 studies provided information and data on the effects of intervention treatment programs and the amelioration of the heat load and stress associated with transportation (Tables 4-8).

The outcomes measured for meat quality and trait carcase markedly differed among studies. The liveweight changes of cattle were the only comparable variable in the studies reviewed. While the data were not suitable to be quantitatively assessed, our review showed that only 17% of trials and comparisons reported a significant positive effect of electrolytes on the liveweight of cattle. This included unreplicated group-fed studies (Schaefer et al. 1993; Church et al., 1994- same data in two different Proceedings- and Pinch, 1993a,b) and one replicate group-fed study (Smith and Wilson, 1999). The remaining trials and comparisons (83%) reported no significant improvement in the liveweight of treated cattle during land transportation. Similarly, 83.3% of trails and comparisons that examined the effect of electrolytes as ameliorants of heat load in cattle found that the treatment had no significant effect on the liveweight changes during the heat stress (Table 7). In most of the studies there was a trend towards treatment animals, losing less weight than control animals. Despite the favourable trends, using the electrolytes did not provide significant reduction in liveweight loss. The direction of effect of electrolytes was positive in both transport (92%) and heat stress (67%) trials and comparisons (Tables 5, 7). The positive trends in published studies are encouraging and also suggest that the potential effects of electrolyte should be explored further by conducting randomised controlled studies under controlled feeding and housing conditions and with proper replication.

The Australian results differed from those of Schaefer et al. (1993) who found significant liveweight loss reductions of 7.2kg. The differing results may have arisen from differences in the solutions offered, ambient temperature and/or much greater time cattle spent in transit in those studies conducted in Australia. The benefits of inclusion of amino acids into the electrolytes, as described by Schaefer et al. (1992, 1993, 2006), for the producers in Australia is not known. However, electrolytes containing amino acids will increase the costs, and there needs to be greater certainty of response to support the inclusion of these.

While the effect of electrolytes on carcase attributes and meat quality were not easily comparable, our review showed that the effects of electrolytes on different carcase and meat attributes varied markedly among studies, from significant to a marginal or no effect.

The data obtained for other supplements such as betaine and propylene glycol also showed no significant beneficial effects on the liveweight of cattle during transportation or heat stress. Review and experimental studies suggest that these interventions may have some physiological benefits. Since the potential physiological benefits associated with these interventions were beyond the scope of this review we didn’t fully review these studies. However, it appears that the potential physiological benefits of these interventions may not necessarily be translated into some measureable performance and welfare outcomes.

Based on the information provided in these studies (Table 9), we concluded that the provided data will not be suitable or sufficient for a meta-analysis. The following are the challenges that we faced with the study designs, protocols and measured outcomes.

4.1 Pseudoreplication

Pseudoreplication is a source of error in the statistical inferences drawn from experiments or observational studies. Briefly, the error consists of assigning an exaggerated estimate of the statistical significance of a set of measurements by treating the data as independent observations when they are in fact interdependent. Pseudoreplication occurs when there are no true replications of the observations because repeated measurements of the same sample are treated as independent in the statistical analysis. This is essentially subsampling, which is often informative and interesting, but is not statistically valid, as there is only one replication of the experimental unit. This also can occur when the multiple samples from each experimental unit are not taken simultaneously, but over a period of time. This may be valid in some cases, where time is a factor - in this instance, each time where samples are taken can be seen as an experimental unit. When observational data are pooled prior to statistical analysis, it will thus depress the calculated variance of the observations, or when the multiple samples or measurements taken from each experimental unit are treated as independent. There are situations, where there is sufficient replication of treatments, but the sample size is not great enough for statistical analysis (Hurlbert 1984, 2009; Lean and Lean 2011).

Control and treatment cattle in studies using electrolytes and betaine were housed separately and group-fed with no access to water (in some studies) or with free access to water or electrolytes, except for five studies with individual feeding or drenching of treatments (Scott et al., 1993; Knowles et al., 1997; Parker et al., 2007; Kim et al., 2011; Arp et al., 2011) and four replicated group-fed studies (Smith and Wilson, 1999; Barnes et al., 2004 -EXPs 4 and 6; Barnes et al., 2008- EXPs 1 and 2; Block et al., 2004). Knowles et al. (1997) fed the electrolytes individually to the cattle, but cattle were not properly replicated, because the treated and transported (8, 16 and 24hr) cattle were compared with not-treated and not-transported (0hr) cattle. The control and treatment groups of other studies were not properly replicated and prevented group comparisons. Further, where the cattle in the control and treatment groups are housed separately and group-fed, the daily intake of water (control) and electrolyte for individual animals cannot be measured. Consequently, it is not appropriate to use animals as a unit of observation in these studies. In these cases, it would be more appropriate to use the pens as units of experiment, if the experiments are replicated and sample size is adequate to be statistically analysed.

4.2 Potential heterogeneity (sources of variation)

Examination for heterogeneity involves determination of whether individual differences between study outcomes are greater than could be expected by chance alone. Analysis of heterogeneity is the most important function of meta-analysis, often more important than computing an average effect. The presence of heterogeneity in a data set can be appropriately handled, if the number of studies in each category is adequate to be controlled for. The information presented in Tables 4-8 indicates that these studies markedly differ in their designs, protocols and outcomes measured. Table 9 provides a summary demonstrating the great diversity of study designs.

4.2.1 Clinical diversity

The source of clinical diversity of studies reviewed included:

- Study location and setting (farm, feedlot, pen, climate controlled room)
- Age (calves, weaners, young cattle and cull cows)
- Sex (heifers, steers, bulls)
- Breeds (bos indicus, bos taurus, and mixed)
- Timing of the treatments (pre- transport, during and post-transport)
- Type of electrolytes

- Dose and density of the intervention
- Forms of administration (drenched, group-fed and premix)
- Definition of the outcomes (carcase traits and meat quality)
- Distance and duration of transport and heat load
- Temperature and humidity
- Type of transport and density of animals during transport

4.2.2 Methodological diversity

Variability in the trial design and quality also contributed to the heterogeneity of the data.

- Criteria of control groups
- Types of publication (peer-reviewed, proceedings and reports)
- Study designs and replicates

In short, there were very few studies, and certainly not enough to statistically analyse, that had very similar interventions or outcomes.

4.3 Missing information and data

There are some studies in Tables 4-8 that failed to provide sufficient information and data on the study protocol (daily intake, distance and duration of transport, ingredients of electrolytes) and outcomes measured (carcase and meat quality attributes).

Recommendations

- Implement appropriate study designs with regard to the administrative method of the therapeutic interventions, ie individual feeding of the interventions
- Care should be taken in relation to reporting the allocation, housing and feeding of cattle to make sure that control and treatments are truly replicated.
- The characteristics and management of cattle in control groups should be similar to those in treatment groups, except for the treatment tested
- Develop standard operating procedures (SOP) for the type of data that are needed on carcase yield, meat quality and physiological measures of welfare of cattle for future experiments to reduce the heterogeneity of outcomes
- Develop a suitable database to facilitate the collection of published and unpublished studies
- Develop standard operating procedures (SOP) to describe housing conditions (group *vs.* individual pens), season, environmental temperature and humidity, distances shipped and time spent away from water or feed access in consistent ways
- Compare the effectiveness and cost-effectiveness of electrolytes with different ingredients to indentify the most beneficial and economical products.

Table 9. Summary of clinical and methodological diversity of studies on electrolytes and other interventions, and direction of outcomes measured

Diversities in reviewed studies	**Study parameters**	**Transport (number of studies)**			**Heat stress (number of studies)**	
		Electrolytes	**Betaine**	**Propylene glycol**	**Electrolytes**	**Betaine**
Study design and replication	Randomised trials (RCT and factorial)	19	1	1	6	4
	Cross-over (rooms and diets)	0			2	0
	Properly replicated	2			2	2
Gender and class of cattle	Bulls	7			0	
	Heifers	2			3	
	Steers	5		1	4	3
	Calves and weaners	2			0	
	Cull cows	1			0	
	Mixed	1			0	1
	Not reported	2			0	
Breeds	Bos indicus	0	1		0	
	Bos taurus	3			0	1
	Cross-bred	11			1	
	Mixed breeds (BI, BT and X-bred)	3			6	3
	Others	0		1		
	Not reported	3				
Time of treatment (before, during or after transport)	Pre-Transport	6	1	1	NA	NA
	Post-transport	9			NA	NA
	Pre- and post-transport	3			NA	NA
	Pre- and during transport	3			NA	NA
	During transport	3			NA	NA
	Not reported	0			NA	NA
Type of electrolytes and other treatments (Varied in ingredients and concentrations- similar to electrolytes grouped- See **Table 9**)	**A** (sugar and salts)	6	Betaine (n=1)	Peg (n=1)	Electrolytes (n=5)	Betaine (n=3)
	B (sugar, salts, amino acids	10			3	
	C (salts)	1			2	
	D (Acid-base balance)	0			0	
Administration of treatments	Individual fed	4	1	1	0	
	Group fed	3			6	4
	Water and feed access	Varied			Varied	
Distance and duration of transport	**Distance (km):** 5 - 200 > 200 (up to 1850) Not reported	 6 4 8	 1 	 1	NA	NA
	Duration (hours) 10min - 4hr 5- 9 hr 13 - 35 hr and > 35 hr Not reported	 8 5 6 2	 1	 1	NA	NA
Season, temperature and humidity	Reported	4	1		6	3
	Not reported	15	0	1	0	1
Measured outcomes (The measured outcomes on meat and carcase were markedly different)	Liveweight	11	1	1	7	4
	Meat quality	12	1		2	0
	Carcass traits	13	1	1	2	4
	Welfare	1	1		6	4
Duration of treatments ((only for heat stress studies)	9 - 100 days	NA	NA	NA	6	3 comparisons
	> 100 days ≤ 200 days	NA	NA	NA	0	7 comparisons

5 Bibliography

Heat Stress References

Agriculture Western Australia (1999) Investigation of cattle deaths during sea transport from Australia. SBMR.001

Ainsworth R (2001) Identifying current best practice in the export of young cattle to Israel. Live.204

Ainsworth R and McCarthy M (2000) Best practice standards for the preparation and husbandry of cattle for transport from Australia. Live.102 and SBMR.003

Alliance Consulting and Management (2001) Use of electrolytes to alleviate stress: Desk Top Study. Live.104B

Arp TS, Carr CC, Johnson DD, Thrift TA, Warnock TM and Schaefer AL (2011) Effects of preslaughter electrolyte supplementation on the hydration and meat quality of cull dairy cows. *The Professional Animal Scientist.* **27**, 43-51.

Barnes A, Beatty D, Taylor E, Stockman C, Maloney S and McCarthy M (2004) Physiology of heat stress in cattle and sheep. Live.209

Barnes A, Beatty D, Stockman C, Maloney S and Taplin R (2008) Electrolyte supplementation of export cattle, and further investigations in the heat stress threshold of sheep and dairy cattle. Live.224.

Beaty DT (2005) Prolonged and continuous heat stress in cattle: Physiology, welfare and electrolytes and nutritional interventions. PhD Thesis, Murdoch University, WA, Australia.

Beatty DT, Barnes A, Taplin R, McCarthy M and Maloney SK (2007) Electrolyte supplementation of live export cattle to the Middle East. *Australian Journal of Experimental Agriculture.* **47**, 119-124.

Bock, B. J., J. R. Brethour, and S. R. Goodall (2002) Effect of 7-day, pre-harvest betaine regimen on dressing percent of feedlot steers. *Proc. Western Section American Society of Animal Science*. **53**, 531

Block BJ, Brethour JR, Harmoney KR and Goodall SR (2004) Influence of betaine on pasture, finishing and carcass performance in steers. *The Professional Animal Scientist.* **20,** 53-57.

Burrow HM, Colditz IG and Oddy VH (1998) Evaluation of the effect of nutricharge on weight loss during long-distance transport. *Meat Research Corporation.*

Byrne T, Lott S, Harburg A and Gaughan J (2006) Improved measurement of heat load in the feedlot industry. FLOT.335.

Chang X and Mowat DN (1992) Supplemental chromium for stressed and growing feeder calves. *Journal of Animal Science*. **70**, 559-565.

Church JS, Jones JM, Hudson RJ, Stanley and Schaefer AL (1994) The effect of transport and handling stress and electrolyte therapy on neutrophile/lymphocyte ratios in cattle raised on pasture. In: P. A. Thacker (Ed.) Livestock Production for the 21st Century: Priorities and Research Needs. p 318 (92P-28). Dept. of Anim. and Poult. Sci., University of Saskatchewan, Saskatoon.

Cockram MS, Kent JE, Goddard PJ, Waran NK, Mcgilp IM, Jackson RE, Muwanga GM, and Prytherch S (1996) Effect of space allowance during transport on the behavioural and physiological responses of lambs during and after transport. Animal Science 62: 461-477.

Cook NJ, Veira D, Chrch JS and Schaefer AL (2009) DExamethasone reduces trasnport-induced weight losses in beef calves. *Canadian Journal of Animal Science*. **89**, 335-339.

Crosswhite JD, Arp TS, Carr CC, Johnson DD, Thrift TA and Warnock TM (??) Effects of preharvest electrolyte supplementation on the hydration and meat quality of cull dairy cows. http://www.animal.ufl.edu/extension/beef/beef_cattle_report/2011/documents/hcrosseffectspre.pdf.

Dubeski PL, Schaefer AL, Stanley RW and Tong AKW (1995) Effect of pre-slaughter electrolyte treatment on meat quality in cattle. In: M. Ivan, Minister of Supply and Services Canada (Ed.) Animal Science Research and Development. p.607 (Abstr. 95 p 13).

Eklund M, Bauer E, Wamatu J and Mosenthin R (2005) Potential nutritional and physiological functions of betaine in livestock. *Nutrition Research Reviews*. **18**,31–48.

Eustace C and Corry S (2009) Revision of the heat stress risk assessment methodology to properly incorporate risk of heat stress while at port. B.LIV.0249

Ferguson D and Fisher A (2008) Animal welfare outcomes of livestock road transport practices. AHW.055. B.AHW.0055

Fisher A, Ferguson D, Lee C, Colditz I, Belson S, Lapworth J and Petherick C (2006) Cataloguing land transport science and practices in Australia. AHW.126. B.AHW.0126

Fitzpatrick LA and Parker AJ (2004) Management of pre-delivery stress in live export steers. Live.301

Fraser K (2007) Supplying feedlot steers with an electrolyte supplement does not increase extracellular fluid volume. Thesis. Murdoch University, Western Australia, Australia.

Gaughan JB, Kreikemeier WM and Mader TL (2005) Hormonal growth-promotant effects on grain-fed cattle maintained under different environments. *International Journal of Biometeorology*. **49**, 396-402.

Gaughan JB, Mader TL, Holt SM and Lisle A (2008) A new heat load index for feedlot cattle. *Journal of Animal Science*. **86**, 226-234.

Gaughan JB, Mader TL, Holt SM, Sullivan ML and Hahn GL (2010) Assessing the heat tolerance of 17 beef cattle genotypes. *International Journal of Biometeorology*. **54**, 617-627.

Gaughan J, Loxton I, Lisle A and Bonner S (2009) Assessment of Betaine and glycerol as ameliorants of heat load in feedlot cattle. B.FLT.0345

Gaughan J (2008a) Assessment of varying allocations of shade area for feedlot cattle – Part 1 120 days on feed. BFLT.0337

Gaughan J (2008b) Assessment of varying allocations of shade area for feedlot cattle – Part 2 182 days on feed. B.FLT.0344

Gortel K, Schaefer AL, Young BA and Kawamoto SC (1992) Effects of stress and electrolyte supplementation on body fluids and weights of bulls. *Canadian Journal of Animal Science.* **72**, 547-553.

Hansen PJ (2004) Physiological and cellular adaptations of zebu cattle to thermal stress. *Animal Reproduction Science* **82–83**, 349–360

Hurlbert SH (1984) Pseudoreplication and the design of ecological field experiments. *Ecological Monographs*. **54**, 187-211.

Hurlbert SH (2009) The ancient Black art and transdsiciplinary exten of pseudoreplication. *Journal of Comparative Psychology*. **123**, 434-443.

Hutcheson DP, and Cole NA (1986) Management of transit stress syndrome in cattle. Nutritional and environmental effects. *Journal of Animal Science* **62**, 555.

Hutcheson DP (1988) Nutrient requirements of diseased, stressed cattle. *Veterinary Clinics of North American Food Animal Practice* ***4***, 523.

Jacobsen T, Schaefer AL, Tong AKW, Stanley RK, Jones SDM, Robertson WM and Dyck R (1993) The effects of transportation on carcass yield, meat quality and haematology values in electrolyte treated cattle. *International Congress of Meat Science and Technology.* Calgary, Alberta, Aug. 1-6. Paper 52, p 11.WP.

Jeremiah LE, Schaefer AL and Gibson LL (1992) The effects of Ante-Mortem feed and water withdrawal, ante-mortem electrolyte supplementation, and post-mortem electrical stimulation on the palatability and consumer acceptance of bull beef after ageing (6 days at 1^{o}C) *Meat Science.* **32**, 149-160.

Jones SDM, Schaefer AL and Tong AKW (1992) The effects of fasting, electrolyte supplementation and electrical stimulation on carcass yield and meat quality in bulls. Can. *Journal of Animal Science.* **72**: 791-798.

Jubb TF, Pinch DS and Petty SR (1993) Treatment with vitamins A, D and E did not reduce weight loss in transported cattle. *Australian Veterinary Journal.* **70**, 171-173.

Kenny FJ, and Tarrant PV (1987) The Physiological and behavioural responses of crossbred Friesian steers to short-haul transport by road. *Livestock Production Science*. **17**, 63-75.

Kennedy and Cronjé (year unknown) Dietary strategies for amelioration of heat load in feedlot cattle. FLOT.314

Kidd MT, Ferket PR and Garlich JD (1997) Nutritional and osmoregulatory functions of betaine. *Worlds Poultry Science Journal*. **53**, 125–139.

Killip C, Quintarelli F and Schloss A (2009) Online summer heat load forecast service – 2008/2009. B.FLT.0352

Kim YK, Choi H and Myung KH (2011) Effects of propylene glycol on carcass traits and its related gene expression in Korean native steers. *Journal Animal Science.* **83**, 344-349.

Knowles TG, Warriss PD, Brown SN, Edwards JE, Watkins PE and Phillips AJ (1997) Effects on calves less than one month old of feeding or not feeding them during road transport of up to 24 hours. *The Veterinary Record*. **140**, 116-124.

Lean IJ and Lean CH (2011) Improving the scietific credibility of farm systems and farm dairy research. In Press, X, 126-136.

Löest CA, Titgemeyer EC, Drouillard JS, Coetzer CM, Hunter RD, Bindel DJ and Lambert BD (2002) Supplemental Betaine and peroxide-treated feather meal for finishing cattle. *Journal of Animal Science.* **80,** 2234-2240.

Loxton ID, Grant TP, Reid DJ and lawrence RJ (2007) Effects of a supplement containing betaine on feedlot steers exposed to heat load. *Recent Advances in Animal Nutrition in Australia*.**16**, 221 - 230.

MAMIC Pty Ltd (2001) Investigation of the ventilation efficacy on livestock vessels. SBMR.002.

Mareko MHD (2005) Effects of Pre-slaughter stress on carcass/meat quality: Implications for Botswana. *Journal of Animal and Veterinary Advances*. 4: 761-767.

Matthews JO, Southern LL, Higbie AD, Persica MA, and Bidner TD (2001) Effects of betaine on growth, carcass characteristics, pork quality, and plasma metabolites in finishing pigs. *Journal of Animal Science.* **79**, 722–728.

Maunsell Australia Pty Ltd (2003) Development of a heat stress risk management model. Live.116

McCarthy M (2002) The best practice management of pregnant dairy cattle on long haul voyages. Live.208

McCarthy M (2005) Pilot monitoring of shipboard environmental conditions and animal performance. Live.223

Moeckel GW, Shadman R, Fogel JM and Sadrzadeh SMH (2002) Organic osmolytes betaine, sorbitol and inositol are potent inhibitors of erythrocyte membrane ATPases. *Life Sciences*. **71**, 2413–2424.

Moonsie-Shangeer S and Mowat DN (1993) Effect of level of supplemental chromium on performance, serum constituents, and immune status of stressed feeder calves. *Journal of Animal Science*. **71**, 232-238.

Nienaber JA and Hahn GL (2007) Livestock production system management responses to thermal challenges. *International Journal of Biometeorology.* **52**: 140-157.

Norris RT and Norman GJ (2003) Mortality and morbidity risk factors for livestock during sea transport from Australia. Live.216

Norris RT, Jubb TF and Richards RB (2001) Investigation of cattle deaths and illness during sea transport from Australia voyage 4. SBMR.004A

Odle J, Heo KN and Lin X (2000) The role of carnitine and betaine in lean growth modulation of swine. Asian-Australas. *Journal of Animal Science*. **13**, 386–395.

Önenç A (2010) The effect of post-transport electrolyte-glucose solution while in lairage on carcass and meat quality of young bulls. *Journal of Muscle Foods.* **21**, 268-279.

Parker AJ, Dobson GP and LA Fitzpatrick (2007) Physiological and metabolic effects of prophylactic treatment with the osmolytes glycerol and Betaine on Bos indicus steers during long duration transportation. *Journal of Animal Science.* **85**, 2916-2923.

Parrott RF, Hall SJG and Lloyd DM (1998) Heart rate and stress hormone responses of sheep to road transport following two different loading procedures. Animal Welfare 7: 257-267.

Petronini PG, de Angelis EM, Borghetti AF and Wheeler KP (1994) Osmolytically inducible uptake of betaine via amino acid transport system A in SV-3T3 cells. *Biochemical Journal.* **300**, 45–50.

Petronini, P. G., De Angelis, E. M., Borghetti, P., Borghetti, A. F. and Wheeler, K. P. (1992) Modulation by betaine of cellular responses to osmotic stress. *Biochemistry Journal*. **282**, 69-73.

Petrov R, Lott S and Cork R (2001) Measuring microclimate variations in two Australian feedlots. FLOT.310

Petrov R, Lott S, Binn P, Cork R and MacFarlane c (2003) Measuring the microclimate of eastern Australian feedlots. FLOT.317

Philips A (1997) Electrolyte and sugar supplements fro salughter cattle transpoted long distances. Meat Research Corporation. NT A020.

Pinch D (1993a) Effect of electrolytes and vitamins on weight loss in transported steers. NT

Pinch D (1993b) Effect of electrolytes on weight loss in transported cattle. NT

Ratriyanto A, Mosenthin R, Bauer E and Eklund M (2009) Metabolic, osmoregulatory and nutritional functions of betaine in monogastric animals. Asian- Australas. *Journal of Animal Science*. **22**, 1461–1476.

Rose RJ, Evans DL (2006) Desk top study of electrolyte products. Live.108

Ross JG, Spears JW and Garlich JD (1994a). Dietary electrolyte balance effects on performance and metabolic characteristics in growing steers. *Journal of Animal Science.* **72**, 1842-1848.

Ross JG, Spears JW and Garlich JD (1994b). Dietary electrolyte balance effects on performance and metabolic characteristics in finishing steers. *Journal of Animal Science.* **72**, 1600-1607.

Sales J (2011) A meta-analysis of the effects of dietary betaine supplementation on finishing performance and carcass characteristics of pigs. 165: 68-78.

Savage D, Gaughan J, Godwin I and Nolan J (2008) Post discharge induction procedures for sheep in the Middle East. Live.0127

Schaefer AL, Jones SDM, Tong AKW and Young BA (1990) Effects of transport and electrolyte supplementation on ion concentrations, carcass yield and quality in bulls. *Canadian Journal of Animal Science.* **70**, 107-119.

Schaefer AL, Jones SDM, Tong AKW, Young BA, Murray NL and Lepage P (1992) Effects of post-transport electrolyte supplementation on tissue electrolytes, hematology, urine osmolality and weight loss in beef bulls. *Livestock Production Science.* **30**, 333-346.

Schaefer AL, Murray AC, Tong AKW, Jones SDM and Sather AP (1993) The effect of ante mortem electrolyte therapy on animal physiology and meat quality in pigs segregating at the halothane gene. *Canadian Journal of Animal Science*. **73**, 231–240.

Schaefer AL, Jones SD and Stanley RW (1997) The use of electrolyte solutions for reducing transport stress. *Journal of Animal Science*. **75**, 258-265.

Schaefer AL, Dubeski PL, Aalhus JL and Tong AKW (2001) Role of nutrition in reducing antemortem stress and meat quality aberrations. *Journal of Animal Science.* **79**, 1-11.

Schaefer AL, Stanley RW, Tong AKW, Dubeski P, Robinson B, Aalhu JL and Roberston WM (2006) The impact on antemortem nutrition in beef cattle on carcass yield and quality grade. *Canadian Journal of Animal Science.* **86**, 317-323.

Scott SL, Schaefer AL, Jones SDM, Mears GJ and Stanley RW (1993) Stress indicators and lean tissue yield in transported cattle treated with electrolytes. In: 39th International *Congress of Meat Science and Technology*. Calgary, Alberta, August. 1-6. Paper 52. p 22.

Simon J (1999) Choline, betaine and methionine interactions in chickens, pigs and fish (including crustaceans). *Worlds Poultry Science Journal*. **55**, 353–374.

Smith GC, Grandin T, Friend TH, Lay Jr. D, Swandon JC (??). Effect of trasnport on meat quality and animal welfare of cattle, pigs, sheep, horses, deer and poultry. http://www.grandin.com/behaviour/effect.of.transport.html

Smith DL and Wilson LL (1999) Effects of transportation and electrolyte administration on lamb, pig and calf behaviour, distress and performance traits. *The Professional Animal Science.* **15,** 149-155.

Sparke EJ, Young BA, Gaughan JB, Holt M and Goodwin PJ (2001) Recommendations for reducing the impact of elements of the physical environment on heat load infeedlot cattle. FLOT.307, 308, 309

Thompson RJ, Sullivan MT, Jeffrey MR, Davis C and Jeffries J (1990) The effect of electrolytic interventions on dressing percentage and meat quality of steers slaughtered after extended road transportation. QDPI circulated trial report

Wythes J (year unknown) Handling and transport of cattle, sheep and goats. LMAQ.011

Further readings - papers of heat load and transportation stress in cattle

Agnes F, Sartorelli P, Abdi, BH and Locatelli A (1990) Effect of transport loading or noise on blood biochemical variables in calves. *American Journal of Veterinary Research.* **51,** 1679-1681.

Allen TE (1962) Responses of Zebu, Jersey, and Zebu × Jersey crossbred heifers to rising temperature, with particular reference to sweating. *Australian Journal of Agricultural Research.* **13,** 165–179.

Allen TE, Pan YS, Hayman R (1963) The effect of feeding on the evaporative heat loss and body temperature in Zebu and Jersey heifers. *Australian Journal of Agricultural Research.***14,** 580–593.

Barnes AL, Beatty DT, Stockman CA (2008) Impact of sea transport on animal welfare: Australian case studies (sea transport of sheet and cattle). *RSCPA Australia Scientific Seminar.* 1-6.

Belk KE, Scanga JA, Smith GC and Grandin T (2002) The Relationship between good handling/stunning and meat quality in beef, pork and lamb. *American Meat Institute Foundation, Animal Handling and Stunning Conference.* February 21-22. *http://www.grandin.com/meat/hand.stun.relate.quality.html*

Blackshaw JK and Blackshaw AW (1994) Heat stress in cattle and the effect of shade on production and behaviour: a review. *Australian Journal of Experimental Agriculture.* **34,** 285-295.

Booth-McLean ME, Schwartzkopf-Genswein KS, Brown FA, Holmes CL, Schaefer AL, McAllister TA and Mears GJ (2007) Physiological and behavioural responses to short-haul transport by stock Trailer in finished steers. *Canadian Journal of Animal Science.* ***87***, 291-297

Brown-Brandl TM, Eigenberg RA, Nienaber JA and Hahn GL (2005) Dynamic Response indicators of heat stress in shaded and non-shaded feedlot cattle, Part 1: analyses of indicators. *Biosystems Engineering.* **90**, 451-462.

Carvalho FA, Lammoglia MA, Simoes MJ, Randel RD (1995) Breed affects thermoregulation and epithelial morphology in imported and native cattle subjected to heat stress. *Journal of Animal Science*. **73,** 3570–3573.

Davis MS, Mader TL, Holt SM and Parkhurst AM (2003) Strategies to reduce feedlot cattle heat stress: effects on tympanic temperature. *Journal of Animal Science.* **81**, 649-661

Dowling DF (1955) The thickness of cattle skin. *Australian Journal of Agricultural Research.***6,** 776–785.

Earley B, Fisher AD and O'Riordan EG (2006) Effects of pre-transport fasting on the physiological responses of young cattle to 8-hour road transport. *Irish Journal of Agricultural and Food Research.* **45**, 51-60.

Eicher SD (2001) Transportation of Cattle in the dairy industry: Current research and future directions. *Journal of Dairy Science.* **84,** 19-23.

Finch VA (1985) Comparison of non-evaporative heat transfer in different cattle breeds. *Australian Journal of Agricultural Research.* **36,** 497–508.

Gaughan JB, Bonner S, Loxton I, Mader TL, Lisle A and Lawrence R (2010) Effect of shade on body temperature and performance of feedlot steers. *Journal of Animal Science*. **88**, 4056-4067.

Gaughan JB, Mader TL, Holt SM, Josey MJ and Rowan KJ (1999) Heat tolerance of Boran and Tuli crossbred steers. *Journal of Animal Science*. **77**, 2398–2405.

Gaughan JB and Mader TL (2009) Effects of sodium chloride and fat supplementation on finishing steers exposed to hot and cold conditions. *Journal of Animal Science*. **87**, 612-621.

Gaughan JB, Mader TL and Holt SM (2008) Cooling and feeding strategies to reduce heat load of grain-fed beef cattle in intensive housing. *Livestock Science.* **113**, 226-233.

Hogan JP, Petherick JC and Phillips CJC (2007) The physiological and metabolic impacts on sheep and cattle of feed and water deprivation before and during transport. *Nutrition Research Reviews.* **20,** 17-28.

Jones SDM, Schaefer AL, Tong AKW and Vincent BC (1988) The effects of fasting and transportation on beef cattle, 2. Body component changes, carcass composition and meat quality. *Livestock Production Science.* **20**, 25-35.

Jones SDM, Schaefer AL, Robertson WM and Vincent BC (1990) The effects of withholding feed and water on carcass shrinkage and meat quality in beef cattle. *Meat Science.* **28**, 131-139.

Katestone Environmental (2002) Risk assessment on the occurrence of excessive heat load for the major feedlot regions of Australia: Software Report. FLOT.312.

Kibler HH and Brody S (1952) Environmental physiology with special reference to domestic animals. XIX. Relative efficiency of surface evaporative, respiratory evaporative, and non-evaporative cooling in relation to heat production in Jersey, Holstein, Brown Swiss and Brahman cattle, 5◦ to 105 ◦ F. Mo. Res. Bull. 497.

Knowles TG (1999) A review of the road transport of cattle. *The Veterinary Record*. **144,** 197-201.

Knowles TG (1995) A review of post transport mortality among younger calves. Veterinary Record. **137**, 406-407.

Knowles TG, Brown SN, Edwards JE, Phillips AJ and Warriss PD (1999) Effect on young calves of a one-hour feeding stop during a 19-hour road journgey. *The Veterinary Record.* **144**, 687-692.

Lacourt A and Tarrant PV (1985) Glycogen depletion patterns in myofibres of cattle during stress. *Meat Science.* **15**, 85-100.

Mader TL and Davis MS (2004) Effect of management strategies on reducing heat stress of feedlot cattle: Feed and water intake. *Journal of Animal Science.* **82**, 3077-3087.

Mader TL, Davis MS and Gaughan JB (2007) Effect of sprinkling on feedlot microclimate and cattle behavior. *International Journal of Biometeorology*. **51**, 541-551.

Mader TL, Dahlquist JM, Hahn GL and Gaughan JB (1999) Shade and wind barrier effects on summertime feedlot cattle performance. *Journal of Animal Science*. **77**, 2065-2072.

Mayer DG, Davison TM, McGowan MR, Young BA, Matschoss AL, Hall AB, Goodwin PJ, Jonsson NN, Gaughan JB (1999) Extent and economic effect of heat loads on dairy cattle production in Australia. *Australian Veterinary Journal***. 77**, 804-808.

Nay T and Heyman RH (1956) Sweat glands in zebu (Bos indicus L.) and European (B. taurus L.) cattle. *Australian Journal of Agricultural Research*. **7**, 482–494.

Pan YS (1963) Quantitative and morphological variation of sweat glands, skin thickness, and skin shrinkage over various body regions of Sahiwal Zebu and Jersey cattle. *Australian Journal of Agricultural Research* **14**, 424–437.

Parker AJ, Hamlin GP, Coleman CJ and Fitzpatrick LA (2003) Quantitative analysis of acid-base balance in Bos indicus steers subjected to transportation of long duration. *Journal of Animal Science.* **81**, 1434-1439.

Phillips CJ, Pines MK, Latter M, Muller T, Petherick JC and Norman ST and Gaughan JB (2010) The physiological and behavioral responses of steers to gaseous ammonia in simulated long-distance transport by ship. *Journal of Animal Science*. **88**, 3579-3589.

Schaefer AL (1995) Nutritional modulation of PSE and meat quality in swine. In:Proc. BASF Canada Inc. Facts and Figures Seminar, Calgary. AB, Canada. pp 1–10.

Schaefer AL and Dubeski PL (1997) Nutritional influence on meat quality. Am. Assoc. Swine Pract., Quebec City, Canada.vpp 1–7. In: Proc. Schaefer, A. L., S. R. Davis, and G. A. Hughson. 1986. Estimation of tissue protein synthesis in sheep during sustained elevation of leucine concentration by intravenous infusion. *British Journal of Nutrition.* **56**, 281–288.

Schaefer AL, Jones SDM, Murray AC, Sather AP and Tong AKW (1989) Infrared thermography of pigs with known genotypes for stress susceptibility in relation to pork quality. *Canadian Journal of Animal Science*. **69**, 491–495.

Schaefer AL, Jones SDM and Stanley RW (1997) The use of electrolyte solutions for reducing transport stress. *Journal of animal Science*. **75**, 258–265.

Schaefer AL, Jones SDM, Tong AKW and Vincent BC (1988) The effects of fasting and transportation on beef cattle. 1. Acid-base-electrolyte balance and infrared heat loss of beef cattle. *Livestock Production Science*. **20**, 15–24.

Schaefer AL and Scott SL (1993) Amino acid flooding doses for measuring rates of protein synthesis. Amino Acids (Vienna). 4:5–19.

Schaefer AL, Stanley RW, Johanns J, and Turnbull IKW (1999) Effects of antemortem nutritional therapy on yield and grade in beef cattle. *Canadian Journal of Animal Science*. **79**, 592 (Abstr.).

Schaefer AL, Stanley RW, Tong AKW and Jones SDM (1994) Effect of transport and handling stress on vascular ions in cattle: Response to electrolyte therapy. In: Proc. Soc. Nutr. Physiol., Willigen, Germany. p 229.

Schwartzkopf-Genswein KS, Booth-McLean ME, Sha MA, Entz T, Bach SJ, Mears GJ, Schaefer AL, Cook N, Churtch J and McAllister TM (2007) Effects of pre-haul management and transport duration on beef calf performance and welfare. *Applied Animal Behaviour Science.* **108**, 12-30.

Scott SL, Schaefer AL, Jones SDM, Mears GJ and Stanley RW (1993) Stress indicators and lean tissue yield in transport cattle treated with electrolytes. *International Congress of Meat Science and Technology.* Paper no. 52. Abstract 88, p.22.

Shorthose WR and Wythes JR (1988) Transport of sheep and cattle. *In: Proc. 34th International Congress Meat Science and Technology.* Brisbane, Australia. pp 122–129.

Sullivan ML, Cawdell-Smith AJ, Mader TL and Gaughan JB (2011) Effect of shade area on performance and welfare of short fed feedlot cattle. *Journal of Animal Science*. (electronic publication).

Swatland HJ (1995) Objective assessment of meat yield and quality. *Trends in Food Science and Technology.* **6**, 117-120.

Tarrant PV (1990) Transportation of cattle by road. *Applied Animal Behaviour Science*. **28**, 153-170.

Tarrant PV, Kenny FJ, Harrington D and Murphy M (1992) Long distance transportation of steers to slaughter: effect of stocking density on physiology, behaviour and carcass quality. *Livestock Production Science.* **30**, 223-238.

Thompson HJ, Worstell DM and Brody S (1953) Environmental physiology and shelter engineering with special reference to domestic animals. XXIII. The effect of humidity on insensible weight loss, total vaporized moisture, and surface temperature in cattle. Mo. Res. Bull. 531.

Trunkfield HR and Broom DM (1990) Welfare of calves during handling and transport. *Applied Animal Behavioural Science*. **28,** 135.

Walker PJ, Warner RD, Pethick DW, Gardner GE, Cummins L and Knee B (1999) Reducing dark-cutting in beef. *AACV Hamilton Conference Proceedings*. 132-138.

Wang C, Liu Q, Yang WZ, Wu J, Zhang WW, Zhang P, Dong KH and Huang YX (2010) Effects of Betaine supplementation on rumen fermentation, lactation performance, feed digestabilities and plasma characteristics in dairy cows. *Journal of Agricultural Science.* **148**, 487-495.

Wythes JR, Brown MJ, Shorthose WR and Clarke MR (1983) Effect of method of sale and various water regimens at saleyards on the liveweight, carcass traits and muscle properties of cattle. *Australian Journal of Experimental Agriculture and Animal Husbandry.* **25**, 235-242.

Warriss PD, Brown SN, Knowles TG, Kestin SC, Ed-wards IE, Dolan SK and Phillips AJ (1995). Effects on cattle of transport by road for up to 15 hours. Veterinary Record. **136**, 319–323.