AUSTRALIAN VETERINARY JOURNAL
AUSTRALIA'S PREMIER VETERINARY SCIENCE TEXT
PRODUCTION ANIMALS

INVITED REVIEW

Evaluation of practices used to reduce the incidence of bovine respiratory disease in Australian feedlots (to November 2021)

PMV Cusack*

Bovine respiratory disease (BRD) has been identified as the most significant infectious disease of feedlot cattle in eastern Australia.[1] Bovine respiratory disease causes economic loss due to medication costs, mortalities, excessive feed inputs associated with increased time on feed, reduced sale prices and associated labour costs. Bovine respiratory disease is a complex multifactorial condition with multiple animal, environmental and management risk factors predisposing cattle to illness. A range of microorganisms are implicated in BRD with at least four viral and five bacterial species commonly involved individually or in combination. The viruses most commonly associated with BRD in Australia are bovine herpesvirus 1 (BHV1), bovine viral diarrhoea virus (BVDV or bovine pestivirus), bovine parainfluenza 3 virus (PI3) and bovine respiratory syncytial virus (BRSV). More recently, bovine coronavirus has been identified as a potential viral contributor to BRD in Australia.[2] A number of bacterial species have also been recognised as important to the BRD complex; these include *Mannheimia haemolytica*, *Pasteurella multocida*, *Histophilus somni*, *Trueperella pyogenes* and *Mycoplasma bovis*. Although one or more of the pathogens listed above can be isolated from clinical cases of BRD, there is no evidence that infection alone causes serious illness. This indicates that, in addition to specific infectious agents, other factors are crucial for the development of BRD under field conditions. These can be categorised as environmental, animal and management risk factors. These risk factors are likely to exert their effects through multiple pathways including reductions in systemic and possibly local immunity. For example, stressors such as weaning, handling at saleyards, transport, dehydration, weather conditions, dietary changes, comingling and pen competition might reduce the effectiveness of the immune system. Reduced immunocompetence can allow opportunistic infection of the lower airways with potential pathogens leading to the development of BRD. The objective of this paper is to critically review the evidence for management practices aimed at reducing the incidence of BRD in Australian feedlot cattle. Predisposing factors (Table 1) largely beyond the control of most feedlots, such as weather and exposure to respiratory viruses, are discussed separately, but these factors can generate indirect prevention responses that are discussed under the preventative practices categories. The current practices are classified as either animal preparation practices (Table 2) or feedlot management practices (Table 3).

*Corresponding author.
Australian Livestock Production Services, Cowra NSW 2794; School of Agricultural, Environmental and Veterinary Sciences, Charles Sturt University, Locked Bag 588, Wagga Wagga, New South Wales, 2678, Australia; alpscowdr@bigpond.com

Keywords cattle medicine; feedlot medicine; large animal medicine; nutritional disease

Abbreviations ADG, average daily liveweight gain; BRD, bovine respiratory disease; BW, bodyweight; CI, credible interval; d, day or days; DMI, dry matter intake; G:F, liveweight gain in; h, hour or hours; hd, head = animal; kg, feed dry matter intake in kg; mo, month; OR, odds ratio; SHR, subhazard ratio; wk, week or weeks; yr, year

Aust Vet J 2023;101:230–247 doi: 10.1111/avj.13239

Predisposing factors – robust supporting data

Season and weather – Australian and North American data

The peak incidence of BRD usually occurs in autumn and early winter in Australia and the USA[3] (Irwin et al., 1979). Whereas the association between season and BRD incidence in the USA could be confounded by the influx of lower body weight (BW) calves in autumn, feedlot cattle numbers do not consistently vary with season in eastern Australia. A large Australian epidemiological study, The National Bovine Respiratory Disease Initiative[4] (NBRDI), found strong associations between season of feedlot entry and the incidence of BRD. Relative to spring, risk of BRD was increased in winter (odds ratio [OR] = 1.6, 95% CI = 1.0 to 2.3, $P = 0.03$) and markedly increased in summer (OR = 2.4, 95% CI = 1.4 to 3.8, $P = 0.001$) and autumn (OR = 2.1, 95% CI = 1.2 to 3.2, $P = 0.004$). These analyses do not differentiate between Northern (Qld and Northern NSW) and southern feedlots. Observational data suggest that BRD incidence is highest in autumn and winter in southern Australia with a low summer incidence, but that incidence can be high during summer in Northern feedlots.

More rapid and severe temperature changes and greater weather extremes in the USA contribute to higher BRD morbidity and mortality rates compared with Australia.[3] This observation prompted Australian reviewers to propose that rapid change in temperature, rather than temperature *per se*, is responsible for an increase in the incidence of BRD,[5] which is supported by US studies.[6,7] Furthermore, in the United States several weather factors (maximum wind speed, mean wind chill temperature and temperature range, with lag periods of 3 to 4 days and 5 to 7 days before disease occurrence) were associated ($P < 0.05$) with increased daily BRD incidence, with the effects more marked in low BW cattle.[8] One US study[9] in the Texas panhandle (feedlot occupancy n = 1078 to 17,156 over 2 yr) only found a correlation between temperature range and BRD

treatments during winter (r = 76%, $P < 0.01$) but the authors noted that this finding could have been confounded by the relationship between feedlot occupancy and BRD treatments. An Australian study[10] showed a stronger correlation between minimum temperature and BRD incidence (r = 54%, $P = 0.002$) than temperature range and BRD incidence (r = 25%, $P = 0.05$) during the winter months. These findings[10] do not preclude the possibility that temperature range is strongly correlated with the incidence of BRD in Australian feedlots during autumn. The NBRDI[4] did not find consistent evidence of a substantial effect on BRD incidence of either mean maximum daily temperature in wk 1 after induction, mean minimum daily temperature in wk 1, mean daily temperature range in wk 1, total rainfall in wk 1, or mean daily maximum wind speed in wk 1. It is possible that more complex interactions of the individual measures of temperature, wind speed and rainfall, perhaps in combination with humidity, during seasons of higher BRD incidence and for the duration of the feeding period, could affect BRD incidence and further research into these potential effects is therefore warranted. In addition, the lag periods of 3 to 4 days and 5 to 7 days between the weather characteristic of interest and the occurrence of BRD throughout the feeding period should be investigated in future Australian research.

Dust concentration – direct and indirect evidence from North America

Feedlot dust can contain viable microbes and, more importantly, endotoxin[11] (Purdy et al., 2002). The incidence of BRD in the period 16 to 30 d on feed was associated with the concentration of airborne particles 2 to 3.3 μm in diameter, with a 15 d lag from peak exposure to peak disease.[7] Repeated exposure of sheep to feedlot dust containing endotoxin for 4 h periods induced temporary pyrexia and leukocytosis, and generalised alveolar septal thickening and hypercellularity,[12] and repeated exposure of goats to feedlot dust resulted in a mild, acute exudative bronchointerstitial pneumonia.[11]

Sex – Australian and North American data

In North America, steers were more likely to be diagnosed with BRD than heifers.[13] Similarly, Australian steers were found to be slightly more likely to die during the feeding period compared with heifers.[10] More recently, the incidence of BRD was greater in steers ($P < 0.001$) in an Australian feedlot,[14] and this finding was supported by the NBRDI[4] where heifers were found to probably be at reduced risk of BRD compared with steers (OR: 0.7, CI = 0.4 to 1.1, $P = 0.06$). In summary, there is evidence that BRD incidence will be slightly greater in steers than heifers in Australian feedlots. With a negligible proportion of entire male cattle entering feedlots in Australia this finding is not confounded by the stress of castration encountered in many North American studies.

Breed – Australian data supported by North American data

Breed can be related to the incidence of BRD.[10] British breeds of cattle were more likely to develop clinical BRD than *Bos indicus* breeds. Compared to all other breeds in the study, the development of clinical BRD over time was 10 times higher in Herefords, six times higher in Murray Greys and five times higher in Angus feedlot cattle. The NBRDI[4] also found Herefords were at increased risk of BRD (OR = 2, 95% CI = 1.5 to 2.6, $P < 0.001$). A relationship between breed and BRD incidence is supported by North American studies,[15,16] with greater susceptibility of the Hereford breed identified.[13]

Serological increase to the respiratory viruses, BHV1, PI3, BRSV and BVDV during the first 42 days in the feedlot – Australian epidemiological study (NBRDI)

An increased risk of BRD has been shown with serological increase between feedlot entry and day 42 to the respiratory viruses, BHV1, PI3, BRSV and BVDV, either singly (OR = 1.4, 95% CI = 1.2 to 1.6, $P < 0.001$; OR = 1.4, 95% CI = 1.2 to 1.7, $P < 0.001$; OR = 1.4, 95% CI = 1.3 to 1.7, $P < 0.001$; OR = 1.3, 95% CI = 1.1 to 1.6, $P = 0.001$, respectively) or in combination.[4] Using an enzyme linked immunosorbent assay (ELISA), serological results were categorised based on optical densities on a graduated scale from 1 to 5. Seroconversion was defined as a change in category from zero on feedlot entry to at least 2 at the 6 wk follow-up sample. Serological increase was defined as an increase from feedlot entry to the follow-up sample of two categories or more from initial category values of 1, 2 or 3. The small proportion of cattle seronegative to the listed respiratory viruses at feedlot entry resulted in considerably smaller sample sizes for seroconversion compared with serological increase, with results consistent with those for serological increase but not as statistically strong. The risk of BRD was greater with serological increase to three or four viruses compared with serological increase to one or two respiratory viruses (serological increase to one virus, OR = 1.3, 95% CI = 1.1 to 1.6, $P = 0.003$; serological increase to two viruses, OR = 1.9, 95% CI = 1.5 to 2.3, $P < 0.001$; serological increase to three viruses, OR = 2.1, 95% CI = 1.6 to 2.6, $P < 0.001$; serological increase to four viruses, OR = 1.8, 95% CI = 1.1 to 2.7, $P = 0.006$). Thus, the risk of BRD increased with increasing exposure to respiratory viruses of cattle with low initial respiratory virus antibody titres during the first 6 wk in the feedlot.

Animal preparation – robust supporting data

Yard weaning at least 1 month before feedlot entry – Australian and North American data

An Australian study published in 1998[1] examined the effects of different weaning procedures and vaccination regimens in the preparation of cattle for feedlots on subsequent health outcomes over a 3 yr period. Vaccines were administered at least 1 month before feedlot delivery to ensure that vaccinated animals had developed immunity by the time they arrived at the feedlot. This study examined the production and health outcomes for groups of cattle that were weaned in 1 of 3 ways: paddock weaning – no supplemental feeding or handling for 21 d (PW, control group); yard weaning with good quality hay or silage with minimal handling for 10 d (YW); and yard weaning with good quality hay or silage with novel training procedures to increase capacity to adapt to the feedlot (YW-T). British breed calves from two herds (one experimental and one commercial) were weaned at 7 to 9 mo of age. Following weaning the calves were held on pasture for 6 to 9 mo and then transferred to a commercial feedlot. At the feedlot the study cattle were mixed in a pen with cattle procured using standard feedlot practices. Within these

experimental treatments a variety of experimental vaccines were applied to groups with similar numbers of controls.

Calves YW and YW-T had greater average daily gain (ADG) and reduced morbidity compared to PW. A similar, but lesser, effect was observed with vaccination with YW compared with PW, with ADG and morbidity for YW-T being intermediate. The effect of vaccination was somewhat complicated with a variety of vaccines and regimens applied over the course of the three experiments, which might have reduced the effectiveness of this treatment. While training in combination with YW showed some benefit it was not as beneficial as YW alone. This finding led the authors to conclude that the establishment of social groups within weaning groups is a critical component for improving health outcomes and productivity of feedlot cattle. In summary, management of weaning alone or in combination with vaccination at least 1 month before feedlot delivery yielded an economic benefit in reduced disease incidence and increased weight gain during the feedlot phase. Yard weaning alone has been shown to have a direct effect of reducing the risk of BRD (OR = 0.7, 95% CI = 0.5 to 1.0, $P = 0.02$)[4] which is consistent with the equivocal effect of vaccination in the study[1] reported above. Furthermore, a US study[17] showed that weaning without vaccination 45 d before feedlot delivery had similar benefits to weaning with vaccination, using a modified live viral vaccine (against BHV1, BVDV types 1 and 2, PI3, BRSV) and a *Mannheimia haemolytica* toxoid, 45 d before feedlot delivery. The lack of an effect of prior vaccination in the calves weaned and held for 45 days occurred despite the administration of corresponding vaccines to all calves at feedlot entry.

Reducing time taken for transport of cattle to the feedlot – Indirect Australian and overseas data and Australian epidemiological data

With transport duration greater than 24 h, increasing transport time was associated with increasing BRD incidence in US cattle.[18] While no controlled studies in Australia have specifically investigated the relationship between increased transport times and subsequent BRD outcomes, one study assessed metabolic changes in cattle subjected to transportation.[19] The comparison of immunological functions before and after 72 h of road transport with *Bos indicus* steers indicated a degree of dysfunction for 6 d post-transport. The authors concluded that this could increase susceptibility to infectious agents for 6 d after transport, although this aspect was not tested in the study. In keeping with this, a Polish study[20] found that transport duration of 72 h (1700 km) resulted in significantly reduced ($P < 0.05$) leukocyte viability with samples exposed to leukotoxin from *M. haemolytica*.

Most of the stress of transport of less than 24 h duration has been suggested to be related to the loading and unloading process.[21] However, cattle transported for 6 h or more within 24 h of feedlot entry were at slightly increased risk of BRD (OR = 1.2, 95% CI = 1.0 to 1.5, $P = 0.02$) compared with cattle transported for less than 6 h within 24 h of feedlot entry.[4]

Distance travelled (as opposed to time in transport) – inadequately defined European data and robust US data

A higher incidence of BRD has been found in cattle held overnight in a holding yard, and transported a longer distance (300 km), compared with cattle transported a short distance, from the same property of origin, directly to a European feedlot.[22] The study design does not allow the separation of the effects on BRD incidence of transport distance from transport duration. Another possible confounding factor in the higher incidence of BRD is the increased handling due to being held overnight in holding yards. Conversely, the distance 45,243 calves were transported to a feedlot over a 4 yr period was not correlated with the incidence of BRD.[23] However, a more recent US study[24] found an increase in BRD morbidity with increased transport distance (Incidence Rate Ratio [IRR] = 1.001, $P < 0.001$), with the data indicating a 10% increase in initial BRD morbidity risk for each 160 km increase in transport distance. This finding is further supported by another US study[25] where the distance travelled (mean = 698 km, median = 552 km, range = 0 to 3087 km) was associated ($P < 0.05$) with BRD morbidity and overall mortality, and negatively associated with hot carcase weight and mean daily gain.

Local backgrounding – Australian epidemiological and indirect clinical trial data

An Australian study[26] used the finding of the NBRDI[4] that mixing cattle for at least 28 d before feedlot entry reduced the risk of BRD (described below, "Reduction in purchase groups"), as the basis for investigating the effects of vaccination against BRD agents in cattle backgrounded for at least 28 d in backgrounding facilities adjacent to feedlots. Vaccines against *Mannheimia haemolytica*, BVDV and BHV1, were administered in various combinations at backgrounding facility entry and at subsequent feedlot entry. All vaccine combinations, except Bovishield MH™ (Zoetis), decreased ($P \leq 0.003$) backgrounding growth rate for a median duration of 35 d, and vaccination against potential BRD pathogens did not affect growth rate during the feedlot phase ($P = 0.191$). The negative effects of killed bacterins on growth rate in several studies have been reported and the possible roles of lipopolysaccharide and adjuvants in increasing glucose consumption have been discussed.[26] Vaccination with Bovilis MH + IBR™ (Coopers Animal Health) decreased BRD risk during the feedlot phase (SHR 0.47; 95% CI 0.27 to 0.83; $P = 0.01$), but this was not reflected in a growth rate effect. Financial analysis[27] indicated that with the minimal effects on BRD risk and growth rate, of vaccination against BRD agents with cattle backgrounded in facilities contiguous with feedlots for at least 28 d, the practice would be unprofitable in most cases. The authors suggested that the positive effects of backgrounding on immunocompetence through the re-establishment of rumen function and positive energy and protein balance before feedlot entry likely reduced the effects of vaccination (BRD incidence in the study population was 3.7%). With local backgrounding, exposure to respiratory viruses did not appear to contribute substantially to the reduction in BRD incidence during the subsequent feedlot period, because only approximately a third of unvaccinated control cattle showed a serological increase to BHV1 or BVDV during backgrounding.[28] Studies using paired pens of controls from the same origins and placed in the feedlot on the same day as comparative locally backgrounded cattle are necessary to evaluate differences in BRD risk and growth rate between cattle placed directly in feedlots and those locally backgrounded before feedlot entry.

Animal preparation – equivocal evidence

A lack of efficacy of vaccination against BRD agents at or around feedlot entry – US meta-analysis and individual controlled studies

A meta-analysis pooled studies primarily from North America to assess the efficacy of a range of BRD vaccines at or around feedlot arrival.[29] The initial search included Australia but there were no appropriate randomised studies eligible for inclusion. The outcome assessed was the cumulative incidence of BRD for the first 45 days in the feedlot, and there were 14 studies with 17 vaccines and 73 treatment arms (vaccines or combinations of vaccines and controls) that met the inclusion criteria. The authors concluded that there was insufficient evidence to support the use of commercial vaccines at or close to feedlot arrival to reduce the incidence of BRD. Whilst most vaccines were given at feedlot arrival (d 0) it should be noted that two treatment arms gave the vaccines before feedlot delivery (d − 20 and d − 17); four had boosters given at d 21 or d 21 and d 42 after arrival; and one involved delayed vaccination and revaccination (d 28 and d 56). This study highlights the lack of robust supporting data for the use of BRD vaccines at or close to feedlot arrival both in North America and Australia. There is a need for large commercial studies to assess the efficacy of BRD vaccines in Australia and the most appropriate timing of their administration to maximise efficacy.

Subsequent to the meta-analysis discussed above, the efficacy of a modified live virus vaccine (MLV; Titanium 5; BHV1, BVDV, PI3, and BRSV) at feedlot arrival versus mass medication with tulathromycin (META) and in comparison with negative controls (n = 478) was evaluated.[30] Consistent with the established efficacy of mass medication and the lack of efficacy of viral vaccines at feedlot entry in North America[31,32] the bovine respiratory disease morbidity rate was less for META (18.5 vs. 51.2%; $P < 0.01$) and it was not improved for MLV ($P = 0.37$). Furthermore, the META groups had greater ADG from d 0 to 14, from d 14 to 28, and overall ($P \leq 0.01$) and BW on d 56 was greater ($P < 0.01$; 13.52 kg). For each interim period and overall, DMI was increased ($P < 0.01$) for META but not MLV ($P \geq 0.11$).

The large number of BRD vaccines available in the United States has been recognised as a potential problem, specifically with the administration of multiple endotoxins, where two or more Gram negative killed bacterin vaccines are used.[33] The negative effects on cattle health and production that can occur in response to the use of multiple Gram negative BRD killed bacterins should be considered, and avoided, with the increasing use of autogenous vaccines in Australian feedlots. Delaying vaccination after feedlot arrival could increase vaccine efficacy due to the re-establishment of immunocompentence prior to vaccination, but the results of this have been variable.[33] Furthermore, the importance of implementing BRD vaccination at least several wk before feedlot delivery to immunocompetent cattle, and the potential for some MLV vaccines to replicate excessively in immunocompromised cattle, thereby having negative effects on health and production, have been recognised.[34] In Australia, a larger mean breeder herd size and greater integration across the supply chain provides opportunities for more detailed investigation of the optimum timing of vaccination on the properties of origin.

A lack of efficacy of vaccination with multi-species modified live virus before and at feedlot delivery – US

A modified live virus vaccine (BHV1, BVDV, PI3, BRSV) and a separate vaccine against *Histophilus somni*, during a 29 d post-weaning preconditioning period were assessed.[32] The MLV vaccine was given either once, twice or thrice during this period (with MLV unvaccinated negative controls), and a booster for the *H. somni* vaccine was given to all study cattle. Vaccination with MLV had no effect ($P \geq 0.59$) on dry matter intake (DMI) or gain:feed (G:F) during the receiving period (d 0 to 55 in the feedlot). Morbidity did not differ among treatments during weaning ($P = 0.49$) or receiving ($P = 0.66$). Finishing ADG, DMI, G:F, days on feed and final BW were not different ($P \geq 0.62$) among treatments. However, as all calves were given a *H. somni* vaccine, there were no negative controls that received no BRD vaccines.

A lack of efficacy of vaccination against Histophilus somni before and at feedlot delivery – US

Retrospective analysis of feedlot health and production outcomes with 4346 cattle from 36 different breeder properties supplying a Kansas feedlot showed that on-property vaccination with *Histophilus somni* vaccine either once or twice before feedlot entry did not affect BRD morbidity ($P = 0.32$) compared with calves that did not receive the *H. somni* vaccine.[35]

Vaccination against Mannheimia haemolytica (Bovilis MH™, Coopers Animal Health) before and at feedlot entry – Australian controlled experiment registration data with epidemiological support

There have been no controlled studies published regarding the effectiveness of pe-vaccination against *Mannheimia haemolytica* with the commercially available vaccine Bovilis MH™ (Coopers Animal Health). Efficacy was demonstrated by the Commonwealth Scientific and Industrial Research Organisation (CSIRO, Australia) for registration of the vaccine with the Australian Pesticides and Veterinary Medicines Authority (APVMA) using a pen study with experimental challenge (n = 8). A field experiment was also conducted at three sites (n = 100 at each site), with no significant difference in morbidity or mortality found in response to two injections of vaccine at a 4 wk interval. However, the incidence of BRD at all three sites was reported as being very low for the duration of the experiment, making the detection of vaccination effects unlikely. A modest protective effect against BRD was found with the use of this vaccine (OR = 0.8, 95% CI = 0.6 to 1.0, $P = 0.02$).[4] Note that the 95% credible interval includes 1 (no effect). However, this epidemiological study[4] was unable to separate data where only one injection of Bovilis MH™ was given at feedlot entry, and it is therefore likely that the protective effect of two injections of the vaccine at a 4 wk interval with the second being given no later than feedlot entry could be greater than the quoted odds ratio suggests.

Vaccination against Mannheimia haemolytica and bovine herpesvirus 1 (Bovilis MH + IBR™, Coopers Animal Health) before and at feedlot entry – Australian data

In cattle backgrounded for at least 28 d in local paddocks, vaccination with Bovilis MH + IBR™ at backgrounding and feedlot entry decreased BRD risk during the feedlot phase (SHR 0.47; 95% CI 0.27 to 0.83; $P = 0.01$), but this was not reflected in a growth rate effect.[26] It is possible that this effect could be greater in cattle given their initial vaccine dose on the farm of origin with the second dose given no later than at feedlot entry.

Vaccination against bovine viral diarrhoea virus (Pestigard™, Zoetis) before and at feedlot entry – Australian epidemiological data

The role of BVDV in the pathogenesis of BRD has been subject to much conjecture due to a lack of evidence implicating it as a primary BRD pathogen. BVDV might facilitate colonisation of the lungs by other pathogens.[36] Experimental infection of immunocompetent, seronegative calves with BVDV type 1d induced primary BRD, in the absence of concurrent infection with other BRD pathogens,[37] suggesting a possible primary role for the virus in the pathogenesis of BRD. It appears, therefore, that BVDV might enhance the development of BRD by immunosuppression[37] and as a primary respiratory pathogen. An Australian epidemiological study[4] found a modest protective effect from on-farm vaccination with two injections of Pestigard™ at a 4 to 6 wk interval on feedlot BRD risk (OR = 0.8, 95% CI = 0.5 to 1.1, $P = 0.05$). Considering that the 95% credible interval includes 1 (no effect) this is not a strong effect.

Animal preparation – minimal evidence or untested

Vaccination against Mannheimia haemolytica (Bovishield™ MH one shot, Zoetis) before or at feedlot entry

There are no published studies evaluating the field efficacy of Bovishield™ MH One Shot (Zoetis) vaccine in commercial feedlots in either Australia or North America.

Truck design/diesel exhaust fumes – North American unpublished data (conference proceedings), and a peer reviewed study

Exposure to exhaust fumes was found to reduce subsequent feedlot growth rate.[38] When the exhaust stack on a prime-mover was lower than the top of the trailer, calves that travelled on the top deck tended to have lower subsequent feedlot growth rates than calves that travelled on the lower deck. Furthermore, calves from the top deck had higher feedlot growth rates than calves from the bottom deck when the exhaust stack was higher than the trailer. An expectation of an increase in the incidence of BRD in calves exposed to exhaust fumes is based on this recorded effect on growth rate. A more recent study that assessed the effects of location within the transport vehicle on ADG and health, supported the previous finding that animals located closer to the front of the trailer had lower growth rates.[39] Again, the assumption was that the findings were due to exposure to exhaust fumes. Both of these studies have been published as conference proceedings and not subjected to peer review.

Cattle transported in the front of the lower deck, and the rear of the upper deck, had higher ($P < 0.02$) total morbidity than those from the other compartments.[40] This might be interpreted as BRD risk being increased by inadequate air circulation in the case of the cattle transported in the front of the lower deck, and wind chill in the case of the cattle transported in the rear of the upper deck. However, the authors noted that findings across studies are inconsistent. Furthermore, care must be taken with the extrapolation of U.S. transport findings to Australia considering the much higher minimum temperatures in Australia and the greater ventilation of Australian cattle crates due to their more open design.

Hydration status on arrival at the feedlot – inadequately defined European data with a supporting US study

A higher BRD incidence was found in cattle transported for longer distances that were dehydrated, but the effects of hydration status were not isolated from the effects of transport distance and duration.[22] Dehydration can be a result of prolonged transport and might be one of the mechanisms by which transport could increase the incidence of BRD. There is further support for this from a US study[8] where the association between distance travelled and BRD morbidity ($P < 0.05$) resulted in a more dramatic increase in BRD during summer once the distance travelled exceeded a threshold of 500 to 750 km. These effects and their relative contributions to BRD incidence have not been adequately defined.

Feedlot management – robust supporting data

Reduction in purchase groups per pen and avoiding purchase of cattle out of saleyards – evidence from North America and Australia with the effect of timing of mixing clarified by an Australian study

Australian cattle maintained as a group from weaning until feedlot entry adapted more rapidly to the feedlot diet and had higher growth rates over the first 37 d compared with cattle purchased through saleyards from a variety of sources.[1] It is not possible to separate the effects of mixing in this study from the potential effects of exposure to saleyards. However, in the Canadian Bruce County Project, morbidity and mortality from BRD were greater with mixing of calves from different sources and assembly of calves from widely separated geographic locations.[41] O'Connor et al. (2005) found strong relationships between commingling and BRD risk[42,24] (OR = 3, 95% CI = 2.5 to 3.6; and Incidence Rate Ratio [IRR] = 2.0, $P < 0.001$). In an Australian study, BRD incidence was higher in cattle purchased from saleyards compared with cattle purchased out of paddocks (12.4% vs. 5.7%, $P < 0.001$).[14]

The timing of mixing determines its effect on the risk of BRD.[4] Mixing at least 28 d before feedlot entry involving a saleyard transit was associated with a reduction in the risk of BRD (OR dependent on subsequent mixing = 0.6 to 0.8). Conversely, mixing between 27 and 13 d before feedlot entry via a saleyard was associated with an increase in BRD incidence (OR = 1.9, 95% CI = 1.3 to 2.7, $P = 0.001$). With both these times of saleyard transit there was no evidence of a large direct effect, indicating that the effects were mediated through mixing rather than direct saleyard effects. Cattle that were mixed through a saleyard 12 d or less before feedlot entry had a

markedly increased risk of BRD (OR = 2.6, 95% CI = 1.6 to 4.1, $P < 0.001$). The direct effect of saleyard exposure within 12 d of feedlot entry was attenuated but important (OR = 1.6, 95% CI = 0.9 to 2.6, $P = 0.05$), indicating that there were negative effects specific to saleyard exposure in this period in addition to the effects of mixing. A longer period between saleyard passage and mixing prior to feedlot entry provides additional time for the cattle to recover from the effects of these stressors.

Water troughs shared between pens – Australian epidemiological data

The sharing of water troughs between pens was associated with an increased risk of BRD[4] (OR = 3.6, 95% CI = 1.3 to 8.8, $P = 0.006$). Subset analysis supported this result, indicating that the observed increase in BRD risk was unlikely to be due to confounding by feedlot. Two case control studies within this larger study found shared water troughs increased the risk of BRD (OR = 3.1, 95% CI = 1.0 to 7.5, $P = 0.03$; OR = 3.3, 95% CI = 1.1 to 7.7, $P = 0.02$).

Reducing time to fill a pen with a complete batch of cattle – Australian epidemiological data

Cohort fill duration (the time taken to fill a pen with a complete batch of cattle) greater than 1 d, was associated with an increased risk of BRD compared with cohort fill duration of only 1 d[4] (OR = 1.9, 95% CI = 1.2 to 2.8, $P = 0.005$). This effect was mediated primarily through mixing (direct effect of fill duration OR = 1.2, 95% CI = 0.6 to 2.2, $P = 0.288$) with greater mixing occurring with pens that took longer to fill.

Mass medication with antibiotics at feedlot entry – Australian data with numerous supporting North American studies

An Australian study examined the effects on cattle destined for the domestic market of mass medication at feedlot entry with long acting oxytetracycline or tilmicosin.[43] Cattle mass medicated with tilmicosin had significantly fewer treatments for all illnesses ($P = 0.0004$) and BRD specifically ($P = 0.0001$), compared with cattle not given antibiotic at feedlot entry and compared with cattle mass medicated with oxytetracyline ($P = 0.004$). There was no significant difference in treatments for all diseases ($P = 0.47$) and treatments for BRD ($P = 0.26$) between oxytetracycline treated cattle and cattle not given antibiotic at feedlot entry. The cattle treated with tilmicosin at feedlot entry had a significantly higher mean daily BW gain (1.67 v 1.59 kg/hd/d), compared with cattle not medicated with antibiotic at feedlot entry ($P = 0.03$) and cattle medicated with oxytetracycline at feedlot entry ($P = 0.05$). Unpublished financial analysis of this study showed mass medication was profitable, even with a relatively low incidence of BRD, mainly due to the higher growth rate of the tilmicosin medicated cattle.

North American studies have illustrated reductions in the incidence of BRD in response to mass medication with injectable antimicrobials. Positive responses to mass medication have been found following administration to all cattle at feedlot entry of benzathine penicillin,[44] long acting oxytetracycline,[45-47] sulfadimethoxine[45] and tilmicosin[48-51]; selective administration on the basis of rectal temperature at feedlot entry of tilmicosin[50]; administration of long acting oxytetracycline to all cattle in a pen once BRD incidence exceeded 5%[52]; and delayed administration of tilmicosin to all cattle in a pen.[49,51] In addition to a reduction in BRD morbidity, four of these experiments[48-50,52] also showed a positive growth rate response to treatment.

Meta-analysis was used to examine the effect of antimicrobial mass medication on morbidity, mortality and growth rate as these are related to BRD.[53] Of 107 field trials, only 10 were randomised controlled field trials deemed suitable for meta-analysis. The results indicated that parenteral mass medication with long acting oxytetracycline or tilmicosin on feedlot arrival would significantly reduce BRD morbidity in feedlot cattle. However, the author concluded that data on the effects of mass medication on mortality and performance were unreliable, there were insufficient data on the most effective treatment regimens, and there were no valid data on the efficacy of mass medication delivered in feed or water for prevention of BRD. Subsequently, mass medication with injectable tilmicosin at feedlot arrival was found to be superior to chlortetracycline added to the ration in terms of BRD morbidity and treatment costs.[54] As yet, there are no published Australian studies on the efficacy of mass medication with tulathromycin, but North American studies have shown it to be more effective in reducing the incidence of BRD than tilmicosin[55,56] or florfenicol.[56]

To avoid selection for antimicrobial resistance in cattle, antimicrobial stewardship principles dictate minimisation of the use of antimicrobials wherever possible. A Texas study compared the effects of mass medication with tilmicosin (MIC; 13.2 mg/kg) or ceftiofur (EXC; 6.6 mg/kg) at feedlot entry on health, production and total antimicrobial use in high-risk cattle.[57] Compared with cattle not medicated at induction (CON), those mass medicated had 25.2% lower morbidity rates than CON ($P = 0.01$; 51.5 vs. 76.7%), with no differences ($P = 0.14$) observed between MIC (46.4 ± 4.3%) and EXC (56.5 ± 4.3%). Mass medication improved ADG (1.63 vs. 1.28 kg/d; $P = 0.06$) and G:F (0.29 vs. 0.22; $P = 0.01$) during the first 14 d. No differences were observed in ADG (P = 0.20) or G:F (P = 0.18) between CON and treatment groups after 42 d. Antimicrobial use was similar ($P = 0.88$; 6.03 vs. 6.16 g of active ingredient per animal) for CON versus metaphylaxis, and for MIC versus EXC ($P = 0.74$; 5.99 vs. 6.33). The authors concluded that mass medication enhanced animal welfare and resulted in the same total antimicrobial use with these high-risk calves.

A US meta-analysis with data from 46 studies and 167 study arms (treatments and controls) found that mass medication at feedlot entry is effective in reducing the incidence of BRD for the first 45 d in the feedlot.[31] The most effective antimicrobial class was the macrolides, and whilst oxytetracycline was less effective, it was suggested that its use would be more consistent with antimicrobial stewardship guidelines due to its lower ranking in terms of importance to human medicine. However, one of the limitations of the study identified by the authors was the potential for drug efficacy to change over time, so it would be valuable to monitor resistance to oxytetracycline in Australian BRD isolates before reverting to it for mass medication. In addition, a previous Australian study[43] showed a lack of efficacy with mass medication with oxytetracycline at feedlot entry in reducing BRD incidence.

In 2021, Australia's National Feedlot Accreditation Scheme (NFAS) introduced a new element within the livestock management module of the NFAS standards, requiring the implementation of an antimicrobial stewardship (AMS) plan. The AMS plan requires that any antimicrobial use must be justified on animal health and welfare grounds, and that alternative approaches to reduce disease incidence, thereby reducing the requirement for antimicrobial use, are preferred. The Antimicrobial stewardship guidelines for the Australian cattle feedlot industry provide feedlots with a framework to develop and implement an AMS plan. The relative contributions of a range of risk factors that contribute to the incidence of BRD have not been quantified so there are insufficient data to define criteria that justify mass medication on a given feedlot. Until such research is done the criteria for mass medication are defined by the consulting veterinarian for a given feedlot.

Introductory diet – North American data

There is a strong association between feeding corn silage during the first mo in the feedlot and increased incidence of BRD.[41] In the Bruce County Beef Project's analysis of introductory feeding practices, mortality due to BRD was five times higher in calves fed corn silage as a major portion of their diet during the first wk in the feedlot than in calves that were not fed substantial amounts of corn silage until the fourth wk. Feeding grain with the silage appeared to reduce some of the negative effects of silage consumption. Inclusion of non-protein nitrogen in the introductory diet in addition to that in the silage was also associated with increased mortality. Although analyses of the diets were not provided in this study it appears that feeding excessive amounts of non-protein nitrogen with inadequate rumen degradable true protein and inadequate starch and sugars might be responsible for the observed increase in the incidence of BRD rather than silage feeding *per se*. The relationship between dietary crude protein and BRD incidence is unclear.[58] Crude protein is derived from dietary nitrogen concentration and does not adequately describe the characteristics of the protein provided by a diet. The relationship between protein and BRD incidence can only be accurately assessed by evaluating the relative contributions to diets of true protein, non-protein nitrogen, rumen degradable protein, rumen undegradable protein and unavailable protein (from acid detergent insoluble nitrogen).

Morbidity and mortality were lower when newly arrived calves were fed grass hay only, compared with a total mixed ration, but this feeding practice resulted in a decrease in growth rate.[45] If hay was provided for longer than 3 d in the receiving pen, it tended to inhibit intake of mixed ration, thereby reducing energy intake in newly arrived cattle.[18] Cattle purchased in saleyards and introduced to diets containing 20% to 30% high moisture barley were 4.9 times more likely to be treated for BRD, and 6.7 times more likely to die from BRD, than cattle assembled on their farm of origin and started on a diet containing 10% high moisture barley,[59] but this study does not isolate the effects of saleyard purchase from diet. Cattle with low blood glucose concentrations on arrival at the feedlot had a greater chance of subsequently developing severe BRD, and morbidity and mortality were reduced in calves fed a diet containing 55% concentrate rather than good quality hay at the saleyards before transport to the feedlot.[60] Conversely, a slight increase in BRD morbidity was found with diets with increasing concentrates over a range from zero to 75% concentrate[61] [morbidity, % = 49.59 – (0.0675 × roughage, %); $P = 0.003$]. However, higher roughage diets were associated with lower ADG ($P < 0.001$), and lower BRD morbidity with such diets did not offset the financial loss due to lower growth rate. Although rumen pH was not measured in these studies, the effects of higher grain diets on the incidence of BRD might be mediated by the development of ruminal acidosis, a disorder which is influenced by feed milling and delivery in addition to diet formulation. It is possible that diets with at least 50% concentrates can reduce the incidence of BRD in cattle newly arrived at the feedlot provided they do not result in ruminal acidosis. The appropriate formulation of the initial diet for cattle on arrival at feedlots requires further research. The potential for inappropriately processed or limit fed higher concentrate introductory diets to have adverse health effects due to ruminal acidosis should be measured in research on the relationship between introductory diet and BRD by monitoring rumen pH, total volatile fatty acid yield, and lactate concentration.

In summary, published studies indicate that introductory diets should not provide a high proportion of crude protein as non-protein nitrogen, particularly where fermentable carbohydrate is limiting. Further, it appears that higher concentrate introductory diets are appropriate provided their milling and delivery does not cause ruminal/lactic acidosis. Formulation targets for introductory diets to minimise the incidence of BRD are yet to be established, and research to determine them will require full description of dietary protein and the monitoring of rumen fermentation characteristics.

Feeding management – North American data

Lactic or ruminal acidosis has been shown to increase the risk of BRD[62,63] and the likelihood of death in diagnosed cases.[62] These are most likely related to endotoxaemia[64-66] and bacteraemia[64,67] arising from a loss of structural integrity and therefore barrier function in the rumen[67,68] and large intestine.[69] The effects of ruminal acidosis are logically exacerbated in cattle that have been deprived of feed for greater than 24 h prior to feedlot delivery because feed deprivation itself compromises gastrointestinal tract barrier function.[70,71] Thus, feed management that achieves high stable intakes during the adaptation period without inducing lactic acidosis appears to be important to immunocompetence and reducing the risk of BRD.

During a 21 d adaptation period, feeding *ad libitum* or feeding a higher concentrate initial diet (88% concentrate, programme fed) was associated with greater BRD morbidity compared with a lower concentrate initial diet (64%) or with limited maximum intakes of 2.1, 2.3 and 2.5 times initial maintenance energy requirement.[72] Unfortunately, this study did not monitor rumen pH or blood lactate concentrations, but it is likely that ruminal acidosis occurred with the *ad libitum* and high concentrate diets, and that this increased the incidence of BRD via the pathways outlined above.

Dietary vitamin E – Australian meta-analysis of North American data

Delivery of supplemental antioxidant vitamins to cattle placed in feedlots might be expected to improve health and performance outcomes by reducing the effects of oxidative stress to which these cattle

are exposed.[73] Meta-analytic procedures were used to assess published experiments on the effects of vitamin E supplementation in feedlot cattle.[74] The health outcome of morbidity, and the production outcomes of ADG and G:F, were analysed. The authors concluded that supplemental dietary vitamin E should be fed within the National Research Council (1996) recommended range and that higher dietary inclusion rates do not consistently reduce BRD morbidity and are not profitable.

Implantation with hormonal growth promotant – North American data

Robust studies with large sample sizes from North America have shown that implantation of cattle newly arrived at the feedlot with a hormonal growth promotant does not increase the risk of BRD.[75,76] Furthermore, there was no effect of hormonal growth promotant implantation on antibody titres in response to vaccination.[75] Not only is the risk of BRD unaffected, the BRD preventative measure of vaccination appears to also be unaffected by treatment with hormonal growth promotants.

Feedlot management – equivocal research outcomes

Removal of cattle persistently infected with bovine viral diarrhoea virus – US published studies and Australian unpublished data

Whilst the prevalence of cattle entering the feedlot persistently infected with BVDV is low (0.26% in an Australian study,[28] 0.3% in a US study[77]), cattle in the same and adjoining pens have been found to have an increased risk of BRD[77] (0.5 cases per 1000 head days vs 0.35 cases per 1000 head days; RR = 1.43, CI = 1.0 to 2.0, $P = 0.04$). Conversely, the presence of an animal persistently infected with BVDV did not increase the incidence of BRD in the same pen.[42] However, the serological status of the pen-mates at the start of the feeding period was not determined in either of these studies,[42,77] so the susceptibility of the populations of interest to infection with BVDV was unknown.

Unpublished data from Batterham (*pers. comm.*) showed that cattle in a pen with a persistently infected animal had a 2.3 times greater likelihood of being treated for BRD, but there was no effect on growth rate or feed conversion ratio. There was also no effect on the BRD treatment rate in adjacent pens. From these data, Batterham suggested that persistently infected animal identification and removal from cattle newly arrived at a feedlot might only be profitable where pen size is greater than 200 animals and the incidence of BRD exceeds 10% of mean feedlot occupancy on a monthly basis.

Pen area allocation (stocking density, pen density) – Australian epidemiological data

At pen area allocations greater than 11 m^2/standard cattle unit there was no substantial consistent effect of increasing area allocations (decreasing stocking density) on BRD incidence.[4] However, estimates for the total effect of pen area allocation on the risk of BRD were imprecise probably because the distribution across categories (11 to <14 m^2, 14 to <17 m^2, 17 to <25 m^2, and ≥25 m^2) was clustered by feedlot. These area allocations all exceed the recommended minimum and it is possible that effects of area allocation are limited or absent above the minimum. It is also possible that lower area allocations could have an effect on BRD incidence in regions with higher rainfall, and particularly higher winter rainfall in southern Australia. Further research is warranted to clarify this potential effect.

Feed bunk space – Australian epidemiological data

For bunk space categories of <18 cm/hd, 18 to <24 cm/hd, and ≥24 cm/hd, there was no effect of bunk space on BRD risk.[4] This is an important finding because most of these bunk spaces are less than previous recommendations and it is therefore likely that the management of feed delivery is more important to feed intake, production and health, than the bunk spacing itself. Furthermore, the common industry bunk space of 22 cm/hd is supported by this finding.

Dietary trace element supplementation greater than NRC recommendation, and organic versus inorganic trace elements – North American data

North American research into the effects of dietary supplementation with zinc and copper at concentrations greater than the National Research Council (NRC)[78] recommendations can be summarised as follows (study designs and results in Table 4): dietary organic sources of Cu do not enhance immunity, health or production compared with inorganic sources and expenditure on these is therefore not justified; it is unclear if organic sources of Mn and Co improve immunity, health or production, compared with inorganic sources of Mn and Co, in isolation from the effects of Zn, and expenditure on these is therefore not justified; compared with inorganic dietary sources of Zn, organic sources of Zn do not consistently improve feedlot production, but, immunoenhancement can result which can occasionally translate into reduced morbidity during the early feeding period.

Therefore, it is possible that reduced morbidity could be achieved with the inclusion of an organic Zn source during the adaptation phase (up to 21 to 28 d) to provide a dietary concentration of 45 to 70 mg/kg DM in addition to the basal inclusion of 30 mg/kg DM from the cheaper inorganic $ZnSO_4$. This would provide total Zn at the rate recommended by NRC[78] for stressed cattle (75 to 100 mg/kg DM) during the adaptation phase, with a reduction to the NRC recommendation of 30 mg/kg DM for non-stressed cattle thereafter. Of the inorganic salts, the more soluble $ZnSO_4$ is preferred. Further research is required to verify that this variable dietary inclusion is cost effective, and the randomised study designs listed in the table below could readily be evaluated with meta-analysis to further clarify the health and production effects of organic trace elements compared with inorganic trace elements.

Injection of trace elements at feedlot entry supplemental to dietary trace elements equal to or greater than NRC recommendation – North American data

Trace element injections have been shown to rapidly increase animal plasma trace element concentrations for less than 24 h.[95] It has been proposed that elevated plasma concentrations of trace elements during the early receiving period could reduce the incidence of BRD even with cattle fed diets providing NRC[78] recommended trace element concentrations because of low feed intake in cattle newly arrived at the feedlot. The effects of trace mineral injections on BRD

Table 1. Predisposing factors for bovine respiratory disease in feedlot cattle

Predisposing factor	Study location	Comments
Predisposing factors with robust supporting evidence		
Season and weather	Australian and Nth American	
Dust concentration	US studies	Evidence from cattle in a commercial feedlot and evidence from sheep and goat exposure that might translate to cattle.
Sex	Australian and Nth American	Trend for greater BRD risk in steers
Breed	Australian and overseas	BRD predisposition of Bos taurus > Bos indicus and Hereford > other Bos taurus
Serological increase to respiratory viruses	Australian epidemiological study	Increasing BRD risk with increasing number of virus species generating a serological increase during the first 42 d

incidence have been variable with most showing no effect. A trace mineral injection at a dose rate of 1 mL/45.5 kg, containing 20 mg/mL zinc, 20 mg/mL manganese, 10 mg/mL copper and 5 mg/mL selenium reduced ($P = 0.02$) the incidence of BRD compared with controls fed at least NRC[78] recommended dietary concentrations of these elements.[96] However, the same experiment found no significant effect on BRD incidence with a similar trace element injection at the same dose rate, containing 48 mg/ml zinc, 10 mg/mL manganese, 16 mg/mL copper, and 5 mg/mL selenium. Previously, no effect ($P = 0.86$) on BRD incidence was found from treating cattle newly arrived at the feedlot with a trace mineral injection at a dose rate of 1 mL/53 kg, containing 40 mg/mL zinc, 10 mg/mL manganese, 15 mg/mL copper and 5 mg/mL selenium.[97] Whilst studies using injectable products can use the individual animal as the unit of interest with statistical blocking to account for pen effects, the above studies have low statistical power due to the use of pen as the unit of interest (n = 5 to 9). Large commercial studies using the individual animal as the unit of interest could clarify the effects of injectable trace elements on BRD incidence. However, considering the short duration of increased plasma trace element concentrations achieved with injectable trace elements, and a peak BRD incidence curve extending over a period of approximately 3 to 6 weeks, strategies to achieve higher, stable feed intakes during the adaptation period might be expected to negate any potential positive effects from injectable trace element products.

Supplemental yeast or yeast products – North American data

The addition to the receiving diet of 1.8 g/hd/d of enzymatically hydrolysed yeast extract (Celmanax™) tended ($P = 0.09$) to reduce BRD morbidity.[98] Whilst an indirect immunological response to lipopolysaccharide challenge in cattle supplemented with 5 g/hd/d of live yeast (*Saccharomyces cerevisiae* subsp. *boulardii*) or 5 g/hd/d of cell wall from the same yeast species was observed, this did not translate into a reduction ($P = 0.36$) in BRD morbidity.[99] This is consistent with an earlier finding that supplemental yeast (*Saccharomyces cerevisiae* subsp. *boulardii*; Proternative Stress Formula™) fed at a rate of 0.5 g/hd/d, in addition to 1 g/hd of the same product as an oral paste at induction, did not reduce BRD morbidity.[100] Similarly, no effect of dried yeast culture (Diamond V®; 56 g/hd/d during transition, 28 g/hd/d finisher) was found on BRD morbidity, or on DMI or G:F, but the growth rate of the treated cattle was less (1.54 versus 1.68 kg/hd/d; $P = 0.03$) compared with untreated controls.[101] Further, whilst BRD morbidity was not reported, no effect of hydrolysed yeast fraction (Trumax®; 1, 2 or 3 g/hd/d) on DMI, ADG, or G:F, over a 229 d feeding period was observed.[102]

A 2017 meta-analysis aimed to evaluate the effects of live *Saccharomyces cerevisiae* and found that yeast supplementation had no effect on ADG, but that it reduced DMI, and therefore improved feed conversion.[103] Despite G:F being regularly reported in the yeast studies evaluated in this review, G:F was not analysed as an outcome in this meta-analysis. The conclusion of the meta-analysis that feed conversion was improved is therefore supposition based on the measured outcomes of dry matter intake and growth rate. The title of the meta-analysis is also misleading as the analysis includes yeast fermentation products in addition to live yeast. This evaluation found that yeast supplementation increased growth rate with diets with forage inclusion between 30% and 50%. Subsequent studies found no effects of yeast supplementation on BRD morbidity, or DMI, ADG or G:F[104–107] with forage inclusions ranging from 13% to 90% (Table 5). More recent studies found no effects of yeast supplementation on DMI, ADG or G:F and either had zero BRD morbidity[108] or did not report BRD morbidity.[109–111] The only study that found a positive effect of yeast supplementation on health showed less lung lesions in yeast supplemented cattle at slaughter (16.7 vs. 61.1%; n = 16; $P = 0.0001$).[112]

There is evidence that yeast supplementation can reduce ruminal pH depression in intensively fed cattle[113] and this study also showed there was no difference between live yeast and yeast products in achieving this outcome with a 50% forage diet. However, this was done with a Latin square design (n = 6 including the crossover replicates) with rumen cannulated cattle and is therefore not applicable to commercial feedlot cattle.

In summary, there is a lack of evidence to support the use of yeast products to improve health in feedlot cattle. However, yeast supplementation has been found to increase productivity in dairy cows,[99] to increase dry matter intake and rumen development in dairy calves for their first 6 wk,[114] and to increase DMI and ADG in 136 kg Holstein calves fed for 336 d.[115] There is therefore a possibility that yeast supplementation might

Table 2. Animal preparation practices to reduce the risk of bovine respiratory disease in feedlot cattle

Animal preparation practice	Study location	Comments
Animal preparation practices with robust supporting evidence		
Yard weaning	Australian	Australian and US controlled studies.
Reducing transport time	Australian, overseas	Indirect Australian and overseas data and Australian epidemiological data
Distance travelled (as opposed to time in transport)	Australian and overseas	Australian epidemiological study and US multivariate analysis of survey data.
Local backgrounding	Australian	Epidemiological data and indirect clinical trial data.
Animal preparation practices with equivocal supporting evidence		
Vaccination at or around feedlot entry vaccination with Bovilis MH	United States Australian	Vaccination against a range of potential pathogens, individual studies and meta-analysis registration data with epidemiological support
Vaccination with Pestigard vaccination with Bovilis MH + IBR	Australian Australian	Epidemiological data ancillary finding from a backgrounding study.
Animal preparation practices with minimal supporting evidence or untested		
Vaccination with Bovishield		Untested
Truck design/exhaust fumes	Nth American	Conference proceedings with limited published support.
Hydration status on arrival at feedlot	Overseas	Poorly defined indirect data

be advantageous with higher forage inclusion backgrounding and initial feedlot diets, particularly in cattle arriving with poor rumen function due to recent low daily nutrient intake. In the absence of studies to support this contention, there is currently insufficient evidence to recommend the inclusion of yeast supplements in feedlot diets.

Feedlot management – equivocal research outcomes

Vaccination against infectious bovine rhinotracheitis (IBR) at feedlot entry with a modified live BHV1 vaccine – Australian data used to register the Rhinogard® (Zoetis) vaccine

Seven trials with a live attenuated Australian strain of BHV1 administered intranasally resulted in a significant improvement in growth rate and feed conversion ratio ($P < 0.05$) without a significant reduction in the percentage of cattle treated for all feedlot diseases ($P > 0.05$) during the first 30 d on feed (P. Young *pers. comm.*, unpublished registration data submitted to the Australian Pesticides and Veterinary Medicines Authority). It is possible that vaccination might have had a significant effect on the incidence of BRD, or more specifically, IBR, had these diagnoses been recorded. Field observations by feedlot veterinarians support the effectiveness of vaccination at feedlot entry with Rhinogard® in the prevention of IBR. The onset of activity of this modified live vaccine is rapid, with local production of immunoglobulin A in the upper airways conferring protection against the development of IBR. Infectious bovine rhinotracheitis is caused by a single organism, BHV1, and there is a vaccine that is effective against this organism. It is therefore a preventable disease and should be viewed separately to the pneumonia of BRD. However, it is likely that sub-clinical BHV1 infections can interfere with pulmonary clearance mechanisms and increase the risk of BRD in the absence of clinical IBR, consistent with epidemiological findings.[4]

Mixing cattle during the feeding period – limited indirect North American data

Steers mixed and relocated at 2 wk intervals had increased plasma cortisol, albumin, urea, and non-esterified fatty acids.[116] There was also a trend ($P = 0.10$) for lower growth rate in the mixed and relocated steers. However, this study only had six steers in each pen. This small number of animals in each pen would presumably reduce the effects of social stress compared with commercial feedlot pens, considering that social hierarchy becomes unstable with more than approximately 100 animals in a pen.[117]

Feedlot management – research does not support a reduction in the incidence of bovine respiratory disease

Injectable vitamins A, D and E at feedlot entry – Australian data

The effects of injectable vitamins A, D and E at feedlot entry on health and growth rate were evaluated.[118] Two thousand, four hundred and sixty-five cattle were allocated systematically at feedlot entry to: a commercial vitamin A, D and E preparation at the label dose rate; commercial vitamin A, D and E at twice the label dose rate; a formulation with no vitamin D, a lower concentration of vitamin A and a higher concentration of vitamin E; and the oil based carrier alone at volumes corresponding to the above treatments. Comparisons of growth rate, disease and mortality were made between the groups at the conclusion of the feeding period. There were no differences between cattle administered vitamin A, D and E at feedlot entry and the controls in growth rate ($P = 0.11$), all diseases ($P = 0.99$), BRD ($P = 0.60$) or mortalities ($P = 0.95$). Cattle treated with the higher vitamin E and lower vitamin A preparation had a higher ($P = 0.02$) incidence of anorexia than the other groups. The routine injection of cattle with vitamins A, D and E at feedlot entry is unlikely to result in improvements in health and growth rate where cattle are provided with these vitamins in their diets at concentrations equal to the recommendations by the National Research Council.[78] In addition, a meta-analytic review[74] found that the available data do not support the use of supplemental vitamin E administered as an injection (morbidity risk ratio = 1.17, $P = 0.165$), and these results are further supported by the National BRD Initiative[4] where

Table 3. Feedlot management practices to reduce the risk of bovine respiratory disease

Feedlot management practice	Study location	Comments
Feedlot management practices with robust supporting evidence		
Reduction in purchase groups per pen and avoiding saleyard purchases	Australian, overseas	Epidemiological data
Not sharing water troughs between pens	Australian	Epidemiological data
Reducing time to fill a pen with a complete batch of cattle	Australian	Epidemiological data
Mass medication with antibiotics at feedlot entry	Australian, overseas	In Australia, use must comply with the animal health element of NFAS, which requires an antimicrobial stewardship plan.
Introductory diet	Overseas	
Feeding management dietary vitamin E	Overseas overseas	Australian meta-analysis using data from North America
Hormonal growth promotant	Overseas	HGP's have no effect on the incidence of BRD
Feedlot management practices with equivocal research outcomes		
Removal of cattle persistently infected with BVDV	Overseas, anecdotal	Equivocal research outcomes
Pen area allocation	Australian	Epidemiological data
Bunk space	Australian	Epidemiological data
Dietary trace element supplementation > NRC recommendation and supplementation with organic sources versus inorganic sources	Australian analysis of US data	
Injection of trace elements at feedlot entry supplemental to NRC recommended dietary trace elements	Nth American	
Supplemental yeast and yeast products	Overseas	A possible application in higher roughage diets
Feedlot management practices with minimal evidence or untested		
Vaccination with modified live BHV-1 at feedlot entry mixing cattle during the feeding period	Registration overseas	Indirect evidence based on metabolic measures of stress.
Feedlot management practices where research does not support a reduction in the incidence of BRD		
Injection with vitamins A, D and E at feedlot entry urea-molasses liquid supplement in pens for the first wk	Australian Australian	Found not to be effective in Australian published study. Found not to be effective in Australian published study
Artificial dietary sweeteners (Sucram)	Overseas	
In-feed antibiotics	Nth American	Most studies do not support the efficacy of in-feed antibiotics.
Low stress cattle handling (acclimation)	Australian	

injection of cattle with vitamin A, D and E at induction had no effect on the risk of BRD (OR = 1.1, 95% CI = 0.6 to 1.9, $P = 0.36$).

Liquid supplements in pens for the first week – Australian data

The feeding of a mean of 2.1 L urea-molasses supplement (5% urea, CP = 32.6%, ME = 8.96 MJ/kg DM, product DM = 70%; Bundaberg Molasses, Oakey, Qld) to cattle for their first wk in the feedlot had no effect on close-out ADG ($P = 0.65$), BRD morbidity ($P = 0.27$) or BRD mortality ($P = 0.75$).[14]

Artificial dietary sweeteners – US Data

It is widely accepted that rapidly achieving high, stable feed intake in newly arrived cattle, in the absence of lactic acidosis, is important to immunocompetence, and the inclusion of dietary sweeteners in diets for this purpose has been evaluated. The effect of the artificial

Table 4. The effects of organic trace elements versus inorganic trace elements on health and production of feedlot cattle

Reference	Trace element/s and supplemental dietary concentration	Sample size (n) and entry BW, kg	Study duration, d	Production (ADG, FCR)	Immune response	Morbidity
Kegley et al.[79]	Randomised block design (RBD). Organic source of Zn @ 360 mg/hd/d as Zn-aa-complex, Cu @ 125 mg/hd/d as Cu-aa-complex, Mn @ 200 mg/hd/d as Mn-aa-complex, Co @ 12 mg/hd/d as CoGlu[a] (Availa-4™, Zinpro); versus inorganic source of these trace elements at the same rate as $ZnSO_4$, $CuSO_4$, $MnSO_4$, $CoCO_3$.	n = 144 (N of 77 strs and 211 bulls banded @ induction) BW = 238	42	↑organic total LWG (P = 0.04); ↑organic ADG (P = 0.04)	↑inorganic ab response to BHV1 vaccination in naïve calves (P = 0.03).	No difference (morbidity = 63%)
Sharman et al.[80]	RBD organic source of Zn @ 360 mg/hd/d as Zn-aa-complex, Cu @ 125 mg/hd/d as Cu-aa-complex, Mn @ 200 mg/hd/d as Mn-aa-complex, Co @ 12.5 mg/hd/d as CoGlu (Availa-4™, Zinpro); versus inorganic source of these trace elements at the same rate as $ZnSO_4$, $CuSO_4$, $MnSO_4$, $CoCO_3$.	n = 108 BW = 230	27 (full feeding period of 224)	No differences	Indirect: ↑SOD[b] with organic ($P < 0.03$; n = 24 in the subsample); no differences in IgA, IgG or IgM in the absence of stimulation.	No difference, but % repulls and mortality tended ($P < 0.08$) to be higher with aa complex source
Dorton et al.[81]	RBD Controls with no supplemental trace elements; versus organic source of Zn @ 360 mg/hd/d as Zn-aa-complex, Cu @ 125 mg/hd/d as Cu-aa-complex, Mn @ 200 mg/hd/d as Mn-aa-complex, Co @ 12.5 mg/hd/d as CoGlu (Availa-4™, Zinpro); versus inorganic source of these trace elements at the same rate as $ZnSO_4$, $CuSO_4$, $MnSO_4$, $CoCO_3$. *After 30d on the same treatments during the preconditioning phase (Dorton et al., 2006). During the finishing phase (d 29 to 84) NRC recommended trace elements fed except for Zn with controls with no supplemental Zn; versus Zn @ 30 mg/kg DM as $ZnSO_4$; versus Zn @ 30 mg/kg DM as Zn-aa-complex.	n = 125 BW = 250	28 (receival phase); Measurement @ d 84 during finishing phase *After 30d on the same treatments before feedlot arrival (Dorton et al., 2006)	Not reported	No differences in BHV1 Ab, SOD, INF-γ, pig red blood cell Ab (total Ig, IgG, IgM); At end of receival phase ↑total IgM with organic trace elements. During finishing phase ↑ovalbumin Ab with Zn-aa	Not reported
Nunnery et al.[82] Nunnery et al.[82] Dorton et al.[83]	Exp. 1 RBD controls with no supplemental trace elements versus 75 mg/kg diet DM as Zn SO_4, ZnMet, or Zn propionate Exp. 2 RBD controls with no supplemental trace elements versus 75 mg/kg diet DM as Zn SO_4, ZnMet, or Zn propionate RBD controls with no supplemental trace elements; versus organic source of Zn @ 360 mg/hd/d as Zn-aa-complex, Cu @ 125 mg/hd/d as Cu-aa-complex, Mn @ 200 mg/hd/d as Mn-aa-complex, Co @ 12.5 mg/hd/d as CoGlu (Availa-4™, Zinpro); versus inorganic source of these trace elements at the same rate as $ZnSO_4$, $CuSO_4$, $MnSO_4$, $CoCO_3$.	n = 24 BW = 223 n = 6 BW = 291 n = 125 BW = 239	35 and 168 21 30	No differences No differences No differences	No differences humoral immunity No differences ovalbumin IgG response NA	No differences No differences
Salyer et al.[84] Kegley et al.[85]	Randomised 2 × 2 factorial inorganic Cu @ 10 mg/kg DM as $CuSO_4$ + inorganic Zn @ 75 mg/kg DM as $ZnSO_4$; inorganic Cu @ 10 mg/kg DM as $CuSO_4$ + organic Zn @ 75 mg/kg DM as Zn-polysaccharide; organic Cu @ 10 mg/kg DM as Cu-polysaccharide + inorganic Zn @ 75 mg/kg DM as $ZnSO_4$; organic Cu @ 10 mg/kg DM as Cu-polysaccharide + organic Zn @ 75 mg/kg DM as Zn-polysaccharide. RBD controls with no supplemental Zn (exp. 1 – Zn = 25 mg/kg DM, Exp. 2 – Zn = 38 mg/kg DM); versus supplemental Zn @ 360 mg/hd/d as $ZnSO_4$; versus supplemental Zn @ 360 mg/hd/d as Zn-aa-complex	Exp 1. Health n = 54; Prod'n n = 6; BW = 208 exp 2. n = 6 BW = 272 Exp.1 n = 28 bulls and strs BW = 240 Exp.2 n = 25 hfrs BW = 176	Exp.1 = 35Exp. 2 = 21 Exp.1 = 28 Exp.2 = 140	No differences Exp.1 ADG no differences over 28d, but ↑ADG d15-28 with Zn-aa Exp.2 No differences	↑ovalbumin Ab d14, d21 with Zn-polysaccharide v $ZnSO_4$ and ↑ovalbumin Ab d14, d21 with $CuSO_4$ v Cu-polysaccharide No differences in WBC, BHV1 Ab, BVDV Ab, Exp.1 BRSV Ab. Exp.2 ↑Ab response to 2nd BRSV vaccination with Zn-aa	No differences Exp.1 No differences; Exp.2 No morbidity
Kessler et al.[86]	RBD control with Zn concentration not stated; versus 45 mg/kg DM as Zn-proteinate; versus 45 mg/kg DM as Zn polysaccharide; versus 45 mg/kg DM as ZnO.	n = 15 BW = 146	284	No differences	NA	NA

Table 4. Continued

Reference	Trace element/s and supplemental dietary concentration	Sample size (n) and entry BW, kg	Study duration, d	Production (ADG, FCR)	Immune response	Morbidity
Malcolm-Callis et al.[87] (Exp.3)	RBD Zn: 30 mg/kg DM as $ZnSO_4$, Zn-aa, Zn polysaccharide	n = 84, BW = 252	126 with measurement at 28, 56, 84 and 112 d	No differences	NA	NA
George et al.[88]	2 RBD's. 106 mg/kg DM as ZnO, 58 mg/kg DM as MnO, 37 mg/kg DM as $CuSO_4$, 7 mg/kg Co as $CoCO_3$; versus same dietary concentrations of trace elements as ZnMet[c], MnMet, CuLys[d], CoGlu; versus organic trace element complexes fed at 3X the basal concentrations, reduced to 1X for the remainder of the feeding period.	Exp 1. n = 66 BW = 214; Exp. 2 n= 39 BW = 200	42 with measurement at 14 and 28 d	No differences	↑PHA[e] skin swelling @ 21d with 3X/1X organic ($P < 0.05$); ↑PI3 secondary Ab titre @ 14 and 28d with 1X organic ($P < 0.01$); ↑BHV1 Ab titre @ 14 and 28d with 1x organic ($P < 0.05$)	17.2% ↓ in BRD with organic 3X/1X ($P < 0.05$)
Galyean et al.[89]	4 × 2 factorial design. Basal: 30 mg/kg DM as ZnO, 3.25 mg/kg DM as CuO; versus basal +5 mg/kg DM as CuLys; versus low ZnMet = basal +35 mg/kg DM as ZnMet; versus low ZnMet +5 mg/kg DM as Cu Lys; versus high $ZnSO_4$ = basal +70 mg/kg DM as $ZnSO_4$; versus high $ZnSO_4$ + 5 mg/kg DM as Cu Lys; versus high ZnMet = basal +70 mg/kg DM as ZnMet; versus high ZnMet +5 mg/kg DM as CuLys.	n = 72 BW = 241 to 249 across treatments(NSD)	161 with 28 d measurement (CuLys discontinued)	161 d: Zn no effect; CuLys ↓ADG ($P < 0.02$)	NA	Trend for ↓ by high Zn as either $ZnSO_4$ or ZnMet cf. basal and low ZnMet diets ($P < 0.07$).
Ward et al.[90]	RBD with a 3 × 2 factorial design: Cu ± Mo and S. control diet with 6.2 mg/kg DM Cu: Versus control +5 mg/kg DM as $CuSO_4$ ± 5 mg/kg DM Mo and 2 g/kg DM S; versus control +5 mg/kg DM as CuLys ±5 mg/kg DM Mo and 2 g/kg DM S.	n = 21 BW = 218	98 with measurement at 21 d intervals	No differences over 98 d; ↑ADG $CuSO_4$ first 21d ($P < 0.01$)	No differences	Not reported.
Chirase et al.[91] (Exp. 3)	RBD control diet with Zn = 96 mg/kg DM; versus control + ZnO for a total dietary Zn concentration of 163 mg/kg DM Zn; versus control + ZnMet for total dietary Zn concentration of 171 mg/kg DM.	n = 11 BW = 260	28 after BHV1 challenge with measurement of DMI, BW and rectal T_b daily	No differences between Zn sources, ZnMet DMI higher ($P < 0.01$) than control d1 after BHV1	No difference in rectal temperature between sources or cf control	NA.
Spears et al.[92]	RBD control diet with Zn = 26.4 mg/kg DM; versus control +25 mg/kg DM as ZnMet; versus control +25 mg/kg DM as ZnO.	n = 30 BW = 214	28	No differences between Zn sources and controls over 28 d	No differences between Zn sources and control in PI3 Ab d14; ZnMet BHV1 titre d14 higher ($P < 0.07$) cf control but not significantly different to ZnO	Morbidity low and no differences
Wittenberg et al.[93]	RBD with blocking for BW and liver Cu concentration + Cu binding Mo added at 10 mg/kg DM control diet Exp.A with Cu= 4.1 mg/kg DM control diet Exp.B with Cu= 7.2 mg/kg DM versus control +10 mg/kg as $CuSO_4$; versus control +10 mg/kg as CuProteinate.	n = 12 Exp.A BW= 331.8 Exp.B BW= 236.1	Exp.A = 105 Exp.B = 84	No differences between Cu sources with CuPro ↑ADG cf Cu depleted control ($P < 0.05$)	NA	NA
Greene et al.[94]	RBD control diet with Zn = 81 mg/kg DM; versus control +360 mg/d as ZnMet; versus control +360 mg/d as ZnO.	n = 15 BW = 330	112	No differences	NA	NA

[a] CoGlu, cobalt glucoheptonate.
[b] SOD, superoxide dismutase, an enzyme important to the prevention of cell membrane damage as part of the inflammatory response.
[c] Znmet, zinc methionine.
[d] CuLys, copper lysine.
[e] PHA, phytohaemagglutinin, an antigen injected intradermally to assess *in vivo* cell mediated immune function.

Table 5. Yeast supplementation studies with intensively fed cattle 2018 to 2021

Authors, year of publication	Diet % concentrate	Neutral detergent fibre, %	Yeast product	Dose	Total sample size, N, and sample size of yeast treatment, n	Outcomes, direction, size and *P* value			
						BRD morbidity, effect and *P* value	ADI, kg DM/hd	ADG, kg/hd/d	G:F, kg gain/ kg DM
Ovinge et al., 2018[104]	76 (8 d), 72.85 (7 d), 77.35 (7 d), 82.35	Final diet: 18.39 control, 19.6 low yeast, 19.79 high yeast	Live yeast with 2×10^{10} CFU/g (AB vista SC®)	1.33 (low) and 2.66 (high) g/hd/ d = 2.66 and 5.31×10^{10} CFU/ hd/d	N = 144 n = 48	No difference, analysis not reported (cases: 10 ctl, 12 low yeast, 11 high yeast)	NSD	NSD	NSD, but trend towards quadratic effect LY d 0 to 183; 0.163 v ctl 0.158 v HY 0.152; *P* = 0.08)
Pukrop et al., 2018[105]	Zero grain (corn silage and DDGS with corn Stover d 1 to 14)	44.2 (d 1 to 14) 38.9 (d 14 to 56 exp 1; d 14 to 63 exp 2).	Hydrolysed yeast fraction (select-TC®)	13 g/hd/d	N = 80 n = 40	NSD	NSD	NSD	NSD
Ran et al., 2018[106]	87	17.7	Active dried yeast (AB vista, biomate®) rumen protection of a portion.	1.5 g/hd/d ADY, 3 g/hd/d encapsulated, 1.5 + 3 g/hd/d for the combination.	N = 75 n = 15	Not reported	NSD	NSD	NSD
Palmer et al., 2019[107]	75.3 + hay for the first 3 d of 28 d receival diet (study duration)	41	Brewers yeast, and dried yeast culture (diamond V®)	58.8 g/hd/d of yeast product	N = 175 n = 58	NSD	NSD	NSD 0 to 105 d (4 g/hd/d greater ADG 0 to 14 d; 1.667 v ctl 1.452 v 7 g 1.536; *P* = 0.03)	NSD
Stadler et al., 2019[109]	50	38.8	Live yeast (Silev®)	7 g yeast product/ hd/d = 7 $\times 10^7$ CFU	N = 36 n = 18	Not reported	NSD	NSD	NSD
Lockard et al., 2020[110]	48 (starter) to 81 (final) over 28 d	22.1 (final)	Active dried yeast (beef abate®)	0.14 kg/hd/d of mixed product, d 1 to 76.	N = 190, n = 95	Not reported	NSD to d 77, and NSD to exit at 112 or 133 d.	NSD to d 77, yeast higher d 78 to exit (2.31 v 2.15; *P* = 0.02), NSD overall.	NSD to d 77, yeast greater d 78 to exit (0.180 v 0.167; *P* = 0.05), NSD overall.
Smith et al., 2020[108]	31.9 (d 1 to 7), 34.8 (d 8 to 21), 31.4 (d 22 to 77)	37.8 (d 1 to 7), 36.5 (d 8 to 21), 32.6 (d 22 to 77)	Live yeast (Levucell SC®)	10 g yeast product/ hd/ d = 8×10^9 CFU	N = 176 n = 88	Zero BRD morbidity	NSD over entire 77 d	NSD over entire 77 d, greater to d 47 (1.69 v 1.62; *P* = 0.01)	NSD over entire 77 d
Pontarolo et al., 2021[111]	50	37.48	Autolysed yeast (rumen yeast®)	4 g/hd/d and 7 g/hd/d	N = 36 n = 12	Not reported	NSD	NSD	
Virmond et al., 2021[112]	50	38.8	Live yeast (Silev plus®)	7 g yeast product/ hd/d = 7 $\times 10^7$ CFU	N = 32 n = 16	Less lung lesions at slaughter (16.66 v 61.11%; *P* = 0.0001)	Not reported	Not reported	Not reported

dietary sweetener, Sucram®, on dry matter intake and BRD morbidity, plus production outcomes, was investigated on this premise. Feeding the saccharin-based dietary sweetener, Sucram®, at rates of 100, 200 or 300 g/tonne DM had no effect on the incidence of BRD.[119,120]

In-feed antibiotics – US Data

Meta-analysis of North American data showed a lack of evidence to support the use of in-feed antibiotics to reduce the incidence of BRD.[53] Subsequently, a research report (not peer reviewed) showed feeding chlortetracycline (CTC) for 5 d from d 0 at the rate of

22 mg/kg BW reduced ($P = 0.01$) total morbidity (BRD morbidity not quoted).[121] Conversely, feeding CTC for 5 d from d 0 at the rate of 22 mg/kg BW/d had no significant effect on BRD morbidity.[122] Tulathromycin mass medicated calves (N = 218, mean BW = 205 kg) were fed CTC at 22 mg/kg BW/d on d 8 to 12, 14 to 18, 20 to 24, and 26 to 30 post-arrival; or the same dose of CTC on d 0 to 4, 6 to 10, 12 to 16, 18 to 22, and 24 to 28 followed by 25 d of administration of 350 mg/hd/d of both CTC and sulfamethazine.[123] Compared with mass medicated controls, there were no effects of in-feed antibiotics on BRD incidence ($P > 0.3$). Whilst it is likely that the tulathromycin mass medication given to all cattle in this study would have reduced the possible effects of the in-feed antibiotics, a subsequent study[124] fed CTC at 350 mg/hd/d plus sulphamethazine at 350 mg/hd/d; chlortetracycline at 11 mg/kg BW/d; tylosin phosphate at 11 mg/kg BW/d; and CTC alone at 350 mg/hd/d, during both backgrounding and finishing, and the incidence of BRD did not differ among treatments compared with negative controls.

The effects of CTC at 22 mg/kg BW plus the antiprotozoal decoquinate (DEQ) at 45.4 mg/kg BW were evaluated on morbidity in steers (N = 1690; mean entry BW = 251 kg).[125] Compared with negative controls, a 5-d course of CTC in addition to DEQ fed for the first 28 d, resulted in lower BRD morbidity (17% vs. 23.5%; $P < 0.01$) with no difference in BRD mortalities and culls ($P = 0.18$). There was no difference ($P > 0.20$) between the effects of a course of CTC commencing at the first d on feed or the sixth d on feed. Unfortunately, the effects of feeding CTC were not isolated from the effects of DEQ through the application of treatments with each of these agents in isolation. However, DEQ is a highly specific non-antibiotic coccidiostat, so it is logical to attribute the observed effects of the combined treatment on BRD risk to CTC.

A large study (N = 6800) with Holstein steers[126] measured health responses to: three 5-d pulses of CTC at 22 mg/kg BW/d, starting on d 6 with a 48 h lapse between pulses with and without tulathromycin injection at induction (blanket dose of 3.5 ml, mean BW 140 ± 18 kg); and oxytetracycline (OTC) fed at 22 mg/kg BW/d for 14 d starting at d 10 plus tulathromycin injection at induction. A negative control group was not included, so the effectiveness of these treatments relative to untreated cattle could not be evaluated. The percentage of BRD first treatments across the feeding period was lowest ($P = 0.001$) for CTC + tulathromycin (19.1% of cattle enrolled), with OTC + tulathromycin and tulathromycin alone being intermediate (22.8% and 24.1%, respectively), and CTC alone exhibiting the highest percentage (25.8%). Death loss and culls were not influenced ($P \geq 0.58$) by treatment. The authors concluded that CTC in combination with tulathromycin metaphylaxis reduces morbidity in Holstein steers, but in the absence of negative controls it is not possible to definitively draw this conclusion. The in-feed CTC treatment without tulathromycin resulted in the highest incidence of BRD of the treatment groups.

In summary, most of the reviewed literature does not support the use of in-feed antibiotics to reduce the risk of BRD.

Low stress livestock handling: Acclimation – Australian data

Acclimation is an extension of low stress livestock handling and involves the training of cattle newly arrived at the feedlot to be less fearful of human interactions and to make them familiar with their new surroundings, particularly water and feed supplies. It can also involve the "exercising" of cattle by briefly removing them from their pen to an adjacent lane, and this has been proposed to reduce the incidence of BRD in a pen of cattle where the daily BRD incidence is rising. Using paired pens, a randomised controlled study evaluated the effects of acclimation with a total of 9533 conventional control cattle and 9518 acclimation treatment cattle across 50 pen replicates and five Australian feedlot sites.[127] The study utilised a recognised industry expert in cattle handling, familiar with acclimation concepts, to train and assess the participating livestock personnel at the five commercial feedlot trial sites. Temperament was evaluated using crush scoring at enrolment, and faecal cortisol was measured as a physiological stress marker. A structured acclimation schedule (treatment) was replicated across the five sites. There were no differences between treated cattle and control cattle with BRD first treatments (SHR = 1.04; 95% CI 0.76 to 1.42; $P = 0.791$), faecal cortisol (mean difference = 1.9 units less; 95% CI −23.9 to 20.0; $P = 0.863$), ADG (mean difference = 0.00; $P = 0.987$), or FCR (mean difference = 0.03; $P = 0.698$). Whilst acclimation in this study had no effects on health or production, the author noted that there were intangible benefits with respect to staff morale and the temperament of the cattle with subsequent handling. Furthermore, that the process might be most effectively directed selectively at cattle with poor temperament at feedlot arrival.

Recommendations

In summary, there is sufficient evidence to recommend the following practices to reduce the risk of BRD in feedlot cattle as of November 2021.

- Avoid placement of cattle in the feedlot if purchased through saleyards within the previous 12 days and if backgrounding paddocks adjacent to the feedlot are available do not place the cattle in the feedlot for at least 28 days to confer a protective effect against BRD.
- With cattle placed directly in the feedlot, reduce the number of purchase groups per pen.
- Minimise the distance cattle are transported to the feedlot and the time taken for delivery.
- Yard weaning.
- When constructing new pens or replacing water troughs, provide separate water troughs for each pen.
- Avoid high concentrations of non-protein nitrogen in arrival diets.
- Prevent lactic acidosis through the management of diet formulation, feed milling and feed delivery.
- Provide dietary vitamin E at the upper range of the National Research Council recommendation of 15 to 60 IU/kg diet DM, but no greater.
- Provide dietary zinc at a basal concentration of 30 mg/kg diet DM for the duration of the feeding period and provide additional zinc in an organic form at 45 to 70 mg/kg diet DM for the first 28 days, to achieve a total dietary zinc concentration during the adaptation phase of 75 to 100 mg/kg DM.
- Mass medication of high-risk cattle with injectable antibiotics where the other preventative measures have not been possible and

within the constraints dictated by the feedlot's antimicrobial stewardship programme.

Acknowledgments

This review was funded my Meat and Livestock Australia. Open access publishing facilitated by Charles Sturt University, as part of the Wiley - Charles Sturt University agreement via the Council of Australian University Librarians.

Conflicts of interest/funding Information

The authors declare no conflicts of interest or sources of funding for the work presented here.

References

1. Fell LR, Walker KH, Reddacliff LA et al. Effects of yard weaning and pre-feedlot vaccination on feedlot performance of *Bos taurus* steers. *Anim Prod In Aust* 1998;22:173–176.
2. Hick PM, Read AJ, Lugton I et al. Coronavirus infection in intensivcely managed cattle with respiratory disease. *Aust Vet J* 2012;90(10):381–386.
3. Irwin M, McConnell S, Coleman JD et al. Bovine respiratory disease complex: a comparison of potential predisposing and aetiologic factors in Australia and the United States. *J Am Vet Med Assoc* 1979;175:1095–1099.
4. Barnes T, Hay K, Morton J et al. Epidemiology and management of bovine respiratory disease in feedlot cattle – Final Report. Meat and Livestock Australia Limited. 2014.
5. Cusack PMV, McMeniman NP, Lean IJ. The medicine and epidemiology of bovine respiratory disease in feedlots. *Aust Vet J* 2003;81:480–487.
6. Alexander BH, MacVean DW, Salman MD. Risk factors for lower respiratory tract disease in a cohort of feedlot cattle. *JAVMA* 1989;195(2):207–211.
7. MacVean DW, Franzen DK, Keefe TJ et al. Airborne particle concentration and meteorologic conditions associated with pneumonia incidence in feedlot cattle. *Am J Vet Res* 1986;47(12):2676–2682.
8. Cernicchiaro N, Renter DG, White BJ et al. Associations between weather conditions during the first 45 days after feedlot arrival and daily respiratory disease risks in autumn-placed feeder cattle in the United States. *J Anim Sci* 2012; 90:1328–1337.
9. Broadway PR, Mauget SA, Burdick Sanchez NC et al. Correlation of ambient temperature with feedlot cattle morbidity and mortality in the Texas panhandle. *Front Vet Sci* 2020;7:413. https://doi.org/10.3389/fvets.2020.00413.
10. Cusack PMV, McMeniman NP, Lean IJ. Feedlot entry characteristics and climate: their relationship with cattle growth rate, bovine respiratory disease and mortality. *Aust Vet J* 2007;85:311–316.
11. Purdy CW, Straus DC, Chirase N et al. Effects of aerosolised endotoxin in feedyard dust on weanling goats. *Small Rum Res* 2002;46:133–147.
12. Purdy CW, Straus DC, Chirase N et al. Effects of aerosolised feedyard dust that contains natural endotoxins on adult sheep. *Am J Vet Res* 2002;63:28–34.
13. Snowder GD, Van Vleck LD, Cundiff LV et al. Bovine respiratory disease in feedlot cattle: environmental, genetic, and economic factors. *J Anim Sci* 2006; 84:1999–2008.
14. Croft IA, Clayton EH, Cusack PMV. Health and production of feedlot cattle following supplementation with urea-molasses in starter pens. *Aust Vet J* 2014; 92(5):166–170.
15. Muggli-Cockett NE, Cundiff LV, Gregory KE. Genetic analysis of bovine respiratory disease in beef calves during the first year of life. *J Anim Sci* 1992; 70:2013–2019.
16. Snowder GD, Van Vleck LD, Cundiff LV et al. Influence of breed, heterozygosity, and disease incidence on estimates of variance components of respiratory disease in preweaned beef calves. *J Anim Sci* 2005;83:1247–1261.
17. Step DL, Krehbiel CR, DePra HA et al. Effects of commingling beef calves from different sources and weaning protocols during a forty-two-day receiving period on performance and bovine respiratory disease. *J Anim Sci* 2008;86:3146–3158.
18. Johnson EG. Feedlot management practices and bovine respiratory disease. *Vet Clin Nth Am Food Anim Pract* 1985;1:413–419.
19. Stanger KJ, Ketheesan N, Parker AJ et al. The effect of transportation on the immune status of Bos indicus steers. *J Anim Sci* 2005;83(11): 2632–2636.
20. Urban-Chmiel R, Puchalski A, Wernicki A. Influence of transport stress on susceptibility of bovine leukocytes to the cytotoxic effect of *M. haemolytica* leukotoxin. *Medycyna Weterynaryjna. Polskiego Towarzystwa Nauk Weterynaryjnych*, Lublin, Poland. 2006; 62(9):1045–1047.
21. Cole NA, Purdy CW, Hallford DM. Influence of fasting and postfast diet energy level on feed intake, feeding pattern and blood variables of lambs. *Am J Vet Res* 1988;49:178–183.
22. Mormede P, Soissons J, Bluthe RM et al. Effect of transportation on blood serum composition, disease incidence, and production traits in young calves. Influence of the journey duration. *Ann Rech Vet/Ann Vet Res* 1982;13:369–384.
23. Ribble CS, Meek AH, Shewen PE et al. Effect of transportation on fatal fibrinous pneumonia and shrinkage in calves arriving at a large feedlot. *JAVMA* 1995;207(5):612–615.
24. Sanderson MW, Dargatz DA, Wagner BA. Risk factors for initial respiratory disease in United States' feedlots based on producer-collected morbidity counts. *Can Vet J* 2008;49:373–378.
25. Cernicchiaro N, White BJ, Renter DG et al. Associations between the distance travelled from sale barns to commercial feedlots in the United States and overall performance, risk of respiratory disease, and cumulative mortality in feeder cattle during 1997 to 2009. *J Anim Sci* 2012; 90:1929–1939.
26. Cusack PMV, Bergman EL, Hay KE et al. Health and production effects of killed vaccines against Mannheimia haemolyitica, bovine viral diarrhoea virus and bovine herpesvirus 1, in locally backgrounded feedlot cattle. *Aust Vet J* 2021a;99(1–2):24–31.
27. Cusack PMV, Bergman EL, Hay KE et al. Effects of vaccination in backgrounded feedlot cattle. 2019. B.FLT.0235 Final Report. Meat and Livestock Australia. 2019.
28. Cusack PMV, Bergman EL, Hay KE et al. Serological status of cattle to bovine viral diarrhoea virus and bovine herpesvirus 1 at entry to and exit from Australian feedlot backgrounding facilities. *Aust Vet J* 2021b;99(1–2):20–23.
29. O'Connor AM, Hu D, Totton SC et al. A systematic review and network meta-analysis of bacterial and viral vaccines, administered at or near arrival at the feedlot, for control of bovine respiratory disease in beef cattle. *Anim Health Res Rev* 2019a;20:143–162. https://doi.org/10.1017/S1466252319000288.
30. Munoz VI, Samuelson KL, Tomzcak DJ et al. Comparative efficacy of metaphylaxis with tulathromycin and pentavalent modified-live virus vaccination in high-risk, newly received feedlot cattle. *App Anim Sci* 2020;36:799–807. https://doi.org/10.15232/aas.2020-02054.
31. O'Connor AM, Hu D, Totton SC et al. A systematic review and network meta-analysis of injectable antibiotic options for the control of bovine respiratory disease in the first 45 days post arrival at the feedlot. *Anim Health Res Rev* 2019b;20:163–181. https://doi.org/10.1017/S1466252320000031.
32. Bailey EA, Jaeger JR, Schmidt TB et al. Effects of number of viral respiratory disease vaccinations during preconditioning on health, performance, and carcass merit of ranch-direct beef calves during receiving and finishing. *Prof Anim Scientist* 2016;32:271–278. https://doi.org/10.15232/pas.2015-01461.
33. Richeson JT, Hughes HD, Broadway PR et al. Vaccination management of beef cattle – delayed vaccination and endotoxin stacking. *Vet Clin Nth Am Food Anim* 2019;35:575–592. https://doi.org/10.1016/j.cvfa.2019.07.003.
34. Richeson JT, Falkiner TR. Bovine respiratory disease vaccination what is the effect of timing? *Vet Clin Nth Am Food Anim* 2020;36:473–485. https://doi.org/10.1016/j.cvfa.2020.03.013.
35. Theurer ME, Johnson MD, Fox T et al. Bovine respiratory disease during the mid-portion of the feeding period: observations from vaccination history, viral and bacterial prevalence, and rate of gain in feedlot cattle. *App Anim Sci* 2020; 37:59–67. https://doi.org/10.15232/aas.2020-02090.
36. Richer L, Marois P, Lamontagne L. Association of bovine viral diarrhoea virus with multiple viral infections in bovine respiratory disease outbreaks. *Can Vet J* 1988;29:713–717.
37. Baule C, Kulcsar G, Belak K et al. Pathogenesis of primary respiratory disease induced by isolates from a new genetic cluster of bovine viral diarrhoea virus type I. *J Clin Microbiol* 2001;39:146–153.
38. Cole NA. Prearrival factors affecting feeder calf health and performance. Page 1 in Proc. Joint Meeting of the Academy of Veterinary Consultants/Plains Nutrition Council, Amarillo, Texas. 1989.
39. White BJ, Blasi D, Vogel LC et al. Associations of beef calf wellness and body weight gain with internal location in a truck during transportation. *J Anim Sci* 2009;87:4143–4150.

40. Wahrmund JL, Burken DB, Wilson BK et al. Case study: effect of truck compartment on ruminal temperature during transit and subsequent health and performance of recently weaned beef heifers. *Prof Anim Sci* 2012;28:670–677.
41. Martin SW, Meek AH, Davis DG. Factors associated with mortality and treatment costs in feedlot calves: the Bruce County beef project, years 1978, 1979, 1980. *Can J Comp Med* 1982;46:341–349.
42. O'Connor AM, Sorden SD, Apley MD. Association between the existence of calves persistently infected with bovine viral diarrhea virus and commingling on pen morbidity in feedlot cattle. *Am J Vet Res* 2005;66:2130–2134.
43. Cusack PMV. Effect of mass medication with antibiotics at feedlot entry on the health and growth rate of cattle destined for the Australian domestic market. *Aust Vet J* 2004;82:154–156.
44. King NB, Edgington BH, Ferguson LC et al. Preliminary results in the control and treatment of shipping fever complex in beef cattle. *JAVMA* 1955;October; 127:320–323.
45. Lofgreen GP. Mass medication in reducing shipping fever-bovine respiratory disease complex in highly stressed calves. *J Anim Sci* 1983;56:529–536.
46. Harland RJ, Jim GK, Guichon PT et al. Efficacy of parenteral antibiotics for disease prophylaxis in feedlot calves. *Can Vet J* 1991;32:163–168.
47. Van Donkersgoed J, Janzen ED, Potter AA et al. The occurrence of *Haemophilus somnus* in feedlot calves and its control by postarrival prophylactic mass medication. *Can Vet J* 1994;35:573–580.
48. Schumann FJ, Janzen ED, McKinnon JJ. Prophylactic tilmicosin medication offeedlot calves at arrival. *Can Vet J* 1990;31:285–288.
49. Schumann FJ, Janzen ED, McKinnon JJ. Prophylactic medication of feedlot calves with tilmicosin. *Vet Rec* 1991;128:278–280.
50. Galyean ML, Gunter SA, Malcolm-Callis KJ. Effects of arrival medication with tilmicosin phosphate on health and performance of newly received beef cattle. *J Anim Sci* 1995;73:1219–1226.
51. McClary D, Vogel G. Effect of timing of tilmicosin metaphylaxis on control of bovine respiratory disease and performance in feeder cattle. *Bovine Practitioner* 1999;33:155–161.
52. Janzen ED, McManus RF. Observations on the use of a long-acting oxytetracycline for in-contact prophylaxis of undifferentiated bovine respiratory disease in feedlot steers under Canadian conditions. *Bovine Practitioner* 1980;15:87–90.
53. Van Donkersgoed J. Meta-analysis of field trials of antimicrobial mass medication for prophylaxis of bovine respiratory disease in feedlot cattle. *Can Vet J* 1992;33:786–795.
54. Hellwig D, Kegley B, Silzell S. A comparison of mass antibiotic treatments on arrival with regards to morbidity, mortality and performance in Arkansas stocker cattle. Arkansas Agricultural Experiment Station, University of Arkansas, Fayetteville, USA. 1999;464:96–97.
55. Kilgore WR, Spensley MS, Sun F et al. Clinical effectiveness of tulathromycin, a novel triamilide antimicrobial, for the control of respiratory disease in cattle at high risk for developing bovine respiratory disease. *Vet Therapeutics* 2005;6:136–142.
56. Rooney KA, Nutsch RG, Skogerboe TL et al. Efficacy of tulathromycin compared with tilmicosin and florfenicol for the control of respiratory disease in cattle at high risk of developing bovine respiratory disease. *Vet Therapeutics* 2005;6:154–166.
57. Word AB, Wickersham TA, Trubenbach LA et al. Effects of metaphylaxis on production responses and total antimicrobial use in high-risk beef calves. *App Anim Sci* 2019;36:265–270. https://doi.org/10.15232/aas.2019-01914.
58. Duff GC, Galyean ML. Recent advances in management of highly stressed, newly received feedlot cattle. *J Anim Sci* 2007;85:823–840.
59. Wilson SH, Church TL, Acres SD. The influence of feedlot management on an outbreak of bovine respiratory disease. *Can Vet J* 1985;26:335–341.
60. Cope GE. 116 in Proc. Convention of American Association of Bovine Practitioners, Baltimore, USA. 1978.
61. Rivera JD, Galyean ML, Nichols WT. Review: dietary roughage concentration and health of newly received cattle. *Prof Anim Sci* 2005;21:345–351.
62. Buczinski S, Rademacher RD, Tripp HM et al. Assessment of L-lactatemia as a predictor of respiratory disease recognition and severity in feedlot steers. *Prev Vet Med* 2015;118(4):306–318.
63. Chako CZ, Step DL, Malayer JR et al. Subacute ruminal acidosis and ruminal lactic acidosis: a review. *Bovine Practitioner* 2015;49(2):140–146.
64. Plaizier JC, Krause DO, Ghozo GN et al. Subacute ruminal acidosis in dairy cows: the physiological causes, incidence and consequences. *The Vet Jnl* 2008;176:21–31.
65. Ghozo GN, Krause DO, Plaizier JC. Rumen lipopolysaccharide and inflammation during grain adaptation and subacute ruminal acidosis in steers. *J Dairy Sci* 2006;89:4404–4413.
66. Andersen PH. Bovine endotoxicosis – some aspects of relevance to production diseases. A review. *Acta Vet Scand* 2003;Suppl. 98:141–155.
67. Steele MA, Croom J, Kahler M et al. Bovine rumen epithelium undergoes rapid structural adaptations during grain-induced subacute ruminal acidosis. *Am J Physiol* 2011;300:R1515–R1523.
68. Penner GB, Oba M, Gabel G et al. A single mild episode of subacute ruminal acidosis does not affect ruminal barrier function in the short term. *J Dairy Sci* 2010;93:4838–4845.
69. Gressley TF, Hall MB, Armentano LE. RUMINANT NUTRITION SYMPOSIUM: productivity, digestion, and health responses to hindgut acidosis in ruminants. *J Anim Sci* 2011;89:1120–1130.
70. Zhang S, Aschenbach JR, Barreda DR et al. Recovery of absorptive function of the reticulo-rumen and total tract barrier function in beef cattle after short-term feed restriction. *J Anim Sci* 2013;91:1696–1706.
71. Gabel G, Aschenbach JR. Influence of food deprivation on the transport of 3-O-methyl-α-D-glucose across the isolated ruminal epithelium of sheep. *J Anim Sci* 2002;80(10):2740–2746.
72. Holland BP, Krehbiel CR, Step DL et al. Growth performance and health of steer calves adapted to a high-concentrate, program-fed diet using four methods. 2007;OSU Res. Rep.
73. Chirase NK, Greene LW, Purdy CW et al. Effect of transport stress on respiratory disease, serum antioxidant status, and serum concentrations of lipid peroxidation biomarkers in beef cattle. *Am J Vet Res* 2004;65(6):860–864.
74. Cusack PMV, McMeniman NP, Rabiee AR et al. Assessment of the effects of supplementation with vitamin E on health and production of feedlot cattle using meta-analysis. *Prev Vet Med* 2009;88(4):229–246.
75. Richeson JT, Beck PA, Hughes HD et al. Effect of growth implant regimen on health, performance, and immunity of high-risk, newly received stocker cattle. *J Anim Sci* 2015;93:4089–4097.
76. Poe KD, Beck PA, Richeson JT et al. Effects of respiratory vaccination timing and growth-promoting implant on health, performance, and immunity of high-risk, newly received stocker cattle. *Prof Anim Sci* 2013;29:413–419.
77. Loneragan GH, Thomson DU, Montgomery DL et al. Prevalence, outcome, and health consequences associated with persistent infection with bovine viral diarrhea virus in feedlot cattle. *JAVMA* 2005;4:595–601.
78. National Research Council (NRC). *Nutrient requirements of beef cattle*. 7th edition. Washington, DC, National Academy Press, 1996.
79. Kegley EB, Pass MR, Moore JC et al. Supplemental trace minerals (zinc, copper, manganese, and cobalt) as Availa-4 or inorganic sources for shipping-stressed beef cattle. *Prof Anim Sci* 2012;28:313–318.
80. Sharman ED, Wagner JJ, Larson CK et al. The effects of trace mineral source on performance and health of newly received steers and the impact of cobalt concentration on performance and lipid metabolism during the finishing phase. *Prof Anim Sci* 2008;24:430–438.
81. Dorton KL, Engle TE, Enns RM. Effects of trace mineral supplementation, source, and growth implants on immune response of growing and finishing feedlot steers. *Prof Anim Sci* 2007;23:29–35.
82. Nunnery GA, Vasconcelos JT, Parsons CH et al. Effects of source of supplemental zinc on performance and humoral immunity in beef heifers. *J Anim Sci* 2007;85:2304–2313.
83. Dorton K, Engle TE, Enns RM. Effects of trace mineral supplementation and source, 30 days post-weaning and 28 days post receiving, on performance and health of feeder cattle. *Asian-Aust J Anim Sci* 2006;19(10):1450–1454.
84. Salyer GB, Galyean ML, Defoor PJ et al. Effects of copper and zinc source on performance and humoral immune response of newly received, lightweight beef heifers. *J Anim Sci* 2004;82:2467–2473.
85. Kegley EB, Silzell SA, Kreider DL et al. The immune response and performance of calves supplemented with zinc from an organic and an inorganic source. *Prof Anim Sci* 2001;17:33–38.
86. Kessler J, Morel I, Dufey PA et al. Effect of organic zinc sources on performance, zinc status and carcass, meat and claw quality in fattening bulls. *Livestock Prod Sci* 2003;81(2/3):161–171.
87. Malcolm-Callis KJ, Duff GC, Gunter SA et al. Effects of supplemental zinc concentration and source on performance, carcass characteristics, and serum values in finishing beef steers. *J Anim Sci* 2000;78:2801–2808.
88. George MH, Nockels CF, Stanton TL et al. Effect of source and amount of zinc, copper, manganese, and cobalt fed to stressed heifers on feedlot performance and immune function. *Prof Anim Sci* 1997;13:84–89.
89. Galyean ML, Malcolm-Callis KJ, Gunter SA et al. Effects of zinc source and level and added copper lysine in the receiving diet on performance by growing and finishing steers. *Prof Anim Sci* 1995;11:139–148.

90. Ward JD, Spears JW, Kegley EB. Effect of copper level and source (copper lysine vs copper sulfate) on copper status, performance, and immune response in growing steers fed diets with or without supplemental molybdenum and sulfur. *J Anim Sci* 1993;71:2748–2755.
91. Chirase NK, Hutcheson DP, Thompson GB. Feed intake, rectal temperature, and serum mineral concentrations of feedlot cattle fed zinc oxide or zinc methionine and challenged with infectious bovine rhinotracheitis virus. *J Anim Sci* 1991;69:4137–4145.
92. Spears JW, Harvey RW, Brown TT. Effects of zinc methionine and zinc oxide on performance, blood characteristics, and antibody titer response to viral vaccination in stressed feeder calves. *JAVMA* 1991;199(12):1731–1733.
93. Wittenberg KM, Boila RJ, Shariff MA. Comparison of copper sulfate and copper proteinate as copper sources for copper-depleted steers fed high molybdenum diets. *Can J Anim Sci* 1990;70:895–904.
94. Greene LW, Lunt DK, Byers FM et al. Performance and carcass quality of steers supplemented with zinc oxide or zinc methionine. *J Anim Sci* 1988;66:1818–1823.
95. Bohman VR, Drake EL, Behrens WC. Injectable copper and tissue composition of cattle. *J Dairy Sci* 1984;67:1468–1473.
96. Richeson JT, Kegley EB. Effect of supplemental trace minerals from injection on health and performance of highly stressed, newly received beef heifers. *Prof Anim Sci* 2011;27:461–466.
97. Clark JH, Olson KC, Schmidt TB et al. Effects of respiratory disease risk and a bolus injection of trace minerals at receiving on growing and finishing performance by beef steers. *Prof Anim Sci* 2006;22:245–251.
98. Ponce CH, Schutz JS, Elrod CC et al. Effects of dietary supplementation of a yeast product on performance and morbidity of newly received beef heifers. *Prof Anim Sci* 2012;28:618–622.
99. Finck DN, Ribeiro FRB, Burdick NC et al. Yeast supplementation alters performance and health status of receiving cattle. *Prof Anim Sci* 2014;30:333–341.
100. Keyser SA, McMeniman JP, Smith DR et al. Effects of Saccharomyces cerevisiae subspecies boulardii CNCM I-1079 on feed intake by healthy beef cattle treated with florfenicol and on health and performance of newly received beef heifers. *J Anim Sci* 2007;85:1264–1273.
101. Swyers KL, Wagner JJ, Dorton KL et al. Evaluation of *Saccharomyces cerevisiae* fermentation product as an alternative to monensin on growth performance, cost of gain, and carcass characteristics of heavy-weight yearling beef steers. *J Anim Sci* 2014;92:2538–2545.
102. Salinas-Chavira J, Arzola C, González-Vizcarra V et al. Influence of feeding enzymatically hydrolyzed yeast cell wall on growth performance and digestive function of feedlot cattle during periods of elevated ambient temperature. *Asian Australas J Anim Sci* 2015;28(9):1288–1295. https://doi.org/10.5713/ajas.15.0061.
103. Sartori ED, Canozzi MEA, Zago D et al. The effect of live yeast supplementation on beef cattle performance: a systematic review and meta-analysis. *Jnl Agric Sci* 2017;9(4):21–37. https://doi.org/10.5539/jas.v9n4p21.
104. Ovinge LA, Sarturi JO, Galyean ML et al. Effects of a live yeast in natural-program finishing feedlot diets on growth performance, digestibility, carcass characteristics, and feeding behavior. *J Anim Sci* 2018;96:684–693. https://doi.org/10.1093/jas/sky011.
105. Pukrop JR, Brennan KM, Funnell BJ et al. Effect of a hydrolyzed mannan- and glucan-rich yeast fraction on performance and health status of newly received feedlot cattle. *J Anim Sci* 2018;96:3955–3966. https://doi.org/10.1093/jas/sky255.
106. Ran T, Shen Y, Saleem AM et al. Using ruminally protected and nonprotected active dried yeast as alternatives to antibiotics in finishing beef steers: growth performance, carcass traits, blood metabolites, and fecal *Escherichia coli*. *J Anim Sci* 2018;96:4385–4397. https://doi.org/10.1093/jas/sky272.
107. Palmer EA, Kegley EB, Ball JJ et al. Influence of commercial yeast products in diets for beef cattle new to the feedlot environment. *Appl Anim Sci* 2019;35:491–497. https://doi.org/10.15232/aas.2019-01847.
108. Smith ZK, Karges K, Aguilar A. Evaluation of an active live yeast (Levucell *Saccharomyces cerevisiae*, CNCM I-1077) on receiving and backgrounding period growth performance and efficiency of dietary net energy utilization in low health risk beef steers. *Transl Anim Sci* 2020;4:1–7. https://doi.org/10.1093/tas/txaa127.
109. Stadler ES, Santos LC, Bertagnon HG et al. Performance of feedlot cattle with inclusion of live yeast in the diet. *Semina: Ciências Agrárias, Londrina* 2019;40(6):2733–2748. https://doi.org/10.5433/1679-0359.2019v40n6p2733.
110. Lockard CL, Lockard CG, Paulus-Compart DM et al. Effects of a yeast-based additive complex on performance, heat stress behaviors, and carcass characteristics of feedlot steers. *Livestock Sci* 2020;236:1–8. https://doi.org/10.1016/j.livsci.2020.104052.
111. Pontarolo GB, Neumann M, Cristo FB et al. Effects of including autolyzed yeast in the finishing of feedlot steers. *Semina: Ciênc. Agrár. Londrina* 2021;42(4):2471–2488. https://doi.org/10.5433/1679-0359.2021v42n4p2471.
112. Virmond MP, Rossi PS, Antunes AV et al. Fresh yeast additives improve immune parameters and reduce respiratory disease in heifers finished in feedlots. *Semina: Ciências Agrárias, Londrina* 2020;41(6, suplemento 2):3177–3188. https://doi.org/10.5433/1679-0359.2020v41n6Supl2p3177.
113. Vyas D, Uwizeye A, Mohammed R et al. The effects of active dried and killed dried yeast on subacute ruminal acidosis, ruminal fermentation, and nutrient digestibility in beef heifers. *J Anim Sci* 2014;92:724–732. https://doi.org/10.2527/jas2013-7072.
114. Lesmeister KE, Heinrichs AJ, Gabler MT. Effects of supplemental yeast (*Saccharomyces cerevisiae*) culture on rumen development, growth characteristics, and blood parameters in neonatal dairy calves. *J Dairy Sci* 2004;87(6):1832–1839. https://doi.org/10.3168/jds.S0022-0302(04)73340-8.
115. Salinas-Chavira J, Montano MF, Torrentera N et al. Influence of feeding enzymatically hydrolysed yeast cell wall + yeast culture on growth performance of calf-fed Holstein steers. *J App Anim Res* 2018;46(1):327–330.
116. Gupta S, Earley B, Ting STL et al. Effect of repeated regrouping and relocation on the physiological, immunological, and hematological variables and performance of steers. *J Anim Sci* 2005;83:1948–1958.
117. Taylor LF, Booker CW, Jim GK et al. Epidemiological investigation of the buller steer syndrome (riding behaviour) in a western Canadian feedlot. *Aust Vet J* 1997;75:45–51.
118. Cusack PMV, McMeniman NP, Lean IJ. Effects of injectable vitamins a, D, E and C on the health and growth rate of feedlot cattle destined for the Australian domestic market. *Aust Vet J* 2008;86:81–87.
119. Ponce CH, Brown MS, Silva JS et al. Effects of a dietary sweetener on growth performance and health of stressed beef calves and on diet digestibility and plasma and urinary metabolic concentrations of healthy calves. *J Anim Sci* 2014;92:1630–1638.
120. McMeniman JP, Rivera JD, Schlegel P et al. Effects of an artificial sweetener on health, performance, and dietary preference of feedlot cattle. *J Anim Sci* 2006;84:2491–2500.
121. Kreikemeier K, Stokka G, Marston T. Influence of delayed processing and mass medication with either chlortetracycline (CTC) or tilmicosin phosphate (Micotil) on health and growth of highly stressed calves. Cattle Feeders' Day, Report of Progress 773, Southwest Research-Extension Center, Agricultural Experiment Station, Kansas State University, Manhattan. 1996.
122. Duff GC, Walker DA, Malcolm-Callis KJ et al. Effects of preshipping vs arrival medication with tilmicosin phosphate and feeding chlortetracycline on health and performance of newly received beef cattle. *J Anim Sci* 2000;78:267–274.
123. Blasi DA, Epp MP, Derstein R. Feed-based metaphylaxis programs did not affect health or performance of high-risk calves mass medicated with Draxxin on arrival. *KSU Res. Rep. SRP1029 Cattlemen's Day* 2010:26–28.
124. Stanford K, Gibb DJ, Schwartzkopf-Genswein KS et al. Feeding subtherapeutic antimicrobials to low-risk cattle does not confer consistent performance benefits. *Can J Anim Sci* 2015;95(4):589–597.
125. Thomson DU, Swingle RS, Branine M et al. Effects of timing of chlortetracycline in combination with decoquinate on growth performance, health, and carcass characteristics of feeder steers. *Bov Pract* 2014;48(2):120–128.
126. Szasz JI, McMurphy CP, Bryant TC et al. Influence of therapeutic use of feedgrade tetracyclines in combination with tulathromycin metaphylaxis on animal health and performance of Holstein steer calves. *Transl Anim Sci* 2019;3:185–194.
127. Batterham T. *Feedlot acclimation study*. Meat and Livestock Australia Limited, North Sydney, 2018.

(Accepted for publication 11 March 2023)