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Production impacts and resistance of gastrointestinal parasites in feedlot cattle

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Abstract

Control of gastrointestinal parasites is fundamental to the health and productivity of cattle in feedlots. The control of these parasites in feedlot cattle is based on treatment with anthelmintic drugs at the time of induction. This project aimed to examine the possible impact of anthelmintic resistance on feedlot parasite management by measuring the level of anthelmintic resistance in common parasites entering a commercial feedlot in South-eastern Queensland, and the impact of drug resistance on productivity. A single-blinded randomized complete block design, with 1434 individual animals tested the effect of six deworming protocols. The mean faecal egg count at induction was 77.6 ± 180.9 eggs per gram of faeces. The most common genus of gastrointestinal parasite was *Cooperia*, representing 73% of cultures. *Haemonchus* was the second most common genus, representing 15% of cultures. Resistance to injectable doramectin was consistently identified, particularly in *Cooperia*. A low level of resistance to albendazole was also suspected. All other dewormers and combinations were highly effective. Although resistance to injectable doramectin was consistently identified in *Cooperia*, there was no difference in production parameters between any of the five anthelmintic treatment protocols including injectable doramectin. There was no benefit in production parameters for providing a combination treatment containing multiple anthelmintics compared to dewormers containing only a single anthelmintic compound. There were, however, significant production benefits in terms of weight gain and exit weight in treating animals at induction with any of the dewormer products compared to leaving them untreated.

Executive summary

Control of gastrointestinal parasites is fundamental to cattle health and productivity. Infection with gastrointestinal parasites has been shown to have negative effects on feed intake and average daily gain, and hence, deworming is commonly conducted at induction. However, there are increasing numbers of reports of drug resistance in gastrointestinal worms and liver flukes of cattle. Thus, feedlot veterinarians and producers cannot simply assume that all available drugs are effective. This project aimed to determine the level of resistance present in common parasites entering Australian feedlots, and the impact of drug resistance in gastrointestinal parasites on important production parameters including average daily gain, exit weight, and hot carcass weight. This information will allow feedlot veterinarians and producers to make informed decisions regarding drug selection for treatment of gastrointestinal parasites and the economic return for various treatment protocols.

This project examined six replicates of cattle inducted at a large scale (30,000 head capacity) commercial feedlot located in South-eastern Queensland, Australia, from March to May 2019. The cattle were sourced from 16 different properties in south-eastern and central Queensland, and a single property in northern New South Wales. A single-blinded randomized complete block design was conducted. Six replicates were completed throughout the one-year study. Cattle (n=1434) ranged in age from 12-18 months, with an entry weight of 350-500 kg.

A number of parasitological and production parameters were measured:

- The average faecal egg count and variability in faecal egg count for cattle at feedlot induction
- The common genera of gastrointestinal parasites infecting feedlot cattle from these regions at induction
- The prevalence of liver fluke infection in this population of cattle
- The level of resistance to the three primary classes of dewormers approved for use in cattle in Australia including the avermectin/milbemycins, benzimidazoles, and imidazothiazoles, and a combination of these three classes of drugs, through the use of faecal egg count reduction tests (FECRTs) and larval coprocultures.
- The effects of the six deworming protocols on productivity, animal health, post-mortem liver pathology, and beef yield and quality. The return on investment for six deworming protocols was evaluated in the given production system.

Six treatments were applied at feedlot induction within each pen. The six treatments were: 1) untreated control, 2) injectable doramectin, 3) oral albendazole, 4) oral levamisole, 5) triple combination of injectable doramectin, oral albendazole, and oral levamisole, and 6) triclabendazole plus triple combination of injectable doramectin, oral albendazole, and oral levamisole. Individual animals were stratified by vendor and randomly allocated to treatment group.

Faecal samples were collected per rectum at induction (pre-treatment) and again 14 days following induction (post-treatment) for all cattle. Faecal egg counts were completed on both samples for all cattle that produced a sample. Faecal egg count reduction tests and associated coprocultures were performed to determine the level of efficacy for the six deworming protocols for each of the six replicates.

For all the cattle examined in the study (that is, all treatment groups combined), the mean weight at induction was 404.1 ± 36.0 kg (mean ± standard deviation), weight gain over the 103.7 ± 0.9 day feeding period was 2.10 ± 0.39 kg/head/day, and live weight at exit was 621.9 ± 56.9 kg. These cattle had an average dressing percentage of 55.28 ± 2.11%, yielding carcasses with an average hot standard carcass weight of 343.6 ± 32.3 kg with 9.7 ± 2.7 mm rib fat. Meat colour at grading averaged 2.45 ± 0.53 and ultimate pH averaged 5.54 ± 0.08. These measurements are within industry standards for the type of cattle and production system examined in this study. This demonstrates that the findings of this study are relevant to commercial feedlots in Australia.

The mean faecal egg count at induction was 77.6 ± 180.9 eggs per gram of faeces. This is a mild level of infection in adult cattle, and the large standard deviation demonstrates the variability in faecal egg counts identified in the present study. The faecal egg counts followed the expected pattern of overdispersion where 80% of the cattle were shedding 20% of the eggs, and 20% of the cattle were shedding 80% of the eggs. Of the 1434 cattle in the study, 375 individuals (26.2%) had a faecal egg count of zero eggs per gram at induction and half of the cattle in the study had a faecal egg count of 15 eggs per gram or less at induction. This demonstrates that many cattle had very low faecal egg counts at induction, reflecting a generally low level presence of worms in cattle in the region where these animals originated during the dry period when this study was conducted. However, the study was properly powered to calculate statistically-valid measures of faecal egg count reduction even in cattle with very low faecal egg counts.

As expected, the most common genus of gastrointestinal nematode identified at induction was *Cooperia*, representing 73% of cultures on average. *Haemonchus* was the second most common genus, representing 15% of cultures. Interestingly, *Oesophagostomum* represented 7% of cultures at induction, and there were also very low levels of *Ostertagia* and *Trichostrongylus.*

Resistance to injectable doramectin was identified in five out of six replicates, and resistance was suspected in one of the six replicates. The mean percent faecal egg count reduction for injectable doramectin ranged from 62-96% (a population is characterised as resistant if the efficacy is below 95%). The parasites were highly susceptible to oral albendazole in three of the six replicates and a very low level of resistance to oral albendazole was suspected in three of the six replicates. Treatment with oral levamisole and both combination treatments were highly effective in all six replicates. Due to the low level of liver flukes identified in the present study, it was not possible to measure the efficacy of triclabendazole. However, no adult liver flukes were identified at slaughter in triclabendazole-treated cattle.

For *Cooperia,* oral albendazole, oral levamisole, and both combination treatments were highly effective in all six replicates. Resistance to injectable doramectin was identified in *Cooperia* in three of the six replicates which is not a surprise as *Cooperia* is the dose-limiting genera for the macrocyclic lactone anthelmintics.

There was no statistical difference in mortality between the six treatment groups. Surprisingly, the untreated cattle showed the numerically lowest level of mortality while the cattle treated with the combination showed the highest level of mortality. These observations may simply be an artefact that have no biological relevance, or potentially this may be associated with an altered immune response in infected cattle leading to a reduction in mortality caused by other disease processes.

Hydatid cysts were identified in 3.83% of livers at slaughter. The presence of hydatid cysts in livers was associated with reduced exit weight by 8.7 kg and reduced hot carcass weight by 7.2 kg. Although the present study was not designed to determine the effect of hydatidosis on productivity, the results are profound and warrant future efforts focused on the prevention of infection and development and testing of vaccine candidates for *Echinococcus granulosus.*

In reference to productivity, there were no statistical differences in exit weight and hot carcass weight between the six treatment groups. This suggests that the low level of resistance to injectable doramectin identified in the present study did not have a significant effect on productivity. Thus, there does not appear to be an economic disadvantage in terms of average daily gain, exit weight, or hot carcass weight for using injectable doramectin to treat cattle that are infected with a strain of *Cooperia* showing a low level of resistance to this anthelmintic, compared to treating with any of the other dewormers tested in this study. It is important to consider these findings in the context of the production system (feedlot) and in general the mild level of faecal egg counts identified. It is possible that more resistant strains, and cattle with higher parasite burdens may exhibit different responses in productivity following treatment with a less effective dewormer.

However, there were strong numerical differences in productivity between untreated and treated cattle. This led the authors to further investigate the effect of anthelmintic treatment on productivity by comparing untreated control cattle with cattle receiving any of the five anthelmintic treatments. Cattle that were treated with a dewormer gained 0.06 kg per day more than untreated cattle, and exited the feedlot 6.2 kg heavier than untreated cattle. Carcasses from cattle that received an anthelmintic were 3.3 kg heavier than cattle that did not receive an anthelmintic. This demonstrates that treating feedlot cattle with a dewormer at induction provides a robust return on investment even in cattle with mild levels of infection and parasitic genera of low pathogenicity such as *Cooperia*.

We also compared productivity parameters for cattle with faecal egg counts at two weeks of less than 25 eggs per gram, 25 to 50 eggs per gram, or greater than 50 eggs per gram, and found a large numerical reduction in exit weight and hot carcass weight for cattle with higher faecal egg counts at 2 weeks. This result suggests that it is important to reduce faecal egg counts to less than 25 eggs per gram to achieve optimal productivity in the feedlot.

The results of this study demonstrate there are significant benefits in carcass weight gain and productivity parameters to be gained by treating feedlot cattle with an anthelmintic at induction. Resistance to injectable doramectin was consistently identified in this study, particularly in *Cooperia*. A low level of resistance to albendazole was also suspected. All other single anthelmintics and combinations tested were highly effective. Although resistance to injectable doramectin was consistently identified, there was no difference in production parameters between any of the five anthelmintic treatment protocols including injectable doramectin. These results are surprising and should be interpreted in the context of mild infections and genera of low pathogenicity. There was also no benefit in production parameters following the use of a combination treatment. Although the results of this study clearly demonstrate there was no difference in productivity for any particular anthelmintic treatment, producers should acknowledge that it is possible for cattle to be infected with a more highly resistant strain of a more pathogenic parasite than was the case in the present study. It is important to note that while resistance to doramectin was demonstrated, the efficacy of this dewormer remained over 75% in 5 out of the six replicates, and hence the drug was

still removing a substantial portion of the parasite population in the treated animals. The impact of this drug resistance on production parameters may be much greater if the resistance reaches levels that have greater impact on the drug efficacy than observed in the present study. In such a scenario, the use of an alternative class of drug or combination may be warranted.

In practical terms, feedlots should:

- Deworm cattle at induction with the anthelmintic of their choice, with consideration of the genera of parasites that are targeted.
- Aim to reduce faecal egg counts to 25 eggs per gram following treatment in order to prevent the impact of gastrointestinal parasites on animal productivity.
- Consider incorporating a low-intensity parasitological component into their feedlot management system to monitor the effectiveness of dewormer treatments in order to ensure that worm burdens do not impact productivity

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1 Background

Gastrointestinal parasites have been shown to negatively impact feed intake and average daily intake of feedlot cattle (Stromberg et al., 2012). Hence, deworming using an anthelmintic drug is a common management procedure conducted at feedlot induction to control internal parasites. A recent survey of deworming practices for approximately 400,000 head of cattle at 16 feedlots in Eastern Australia found that 95% of cattle were treated with an anthelmintic at induction (George, 2016). These data represent an annual expenditure of $13.3 million to control gastrointestinal nematodes and liver flukes in the 2.8 million cattle annually fed within Australian feedlots. It has been accepted that control of gastrointestinal parasites is an integral component of profitable production of beef cattle as these parasites are a major limiting factor to both cattle health and productivity (Hawkins, 1993; Corwin, 1997).

Gastrointestinal nematode parasites that commonly infect feedlot cattle in Australia include *Cooperia*, *Ostertagia, Haemonchus, Trichostrongylus,* and *Oesophagostomum* (Playford and George, 2012). In the Spring of 2011, the average faecal egg count of cattle entering East Coast feedlots was 104.5 eggs per gram, confirming that cattle entering feedlots do have significant parasite burdens and have not developed sufficient immunity to control gastrointestinal nematodes without anthelmintic treatment (Playford and George, 2012). The three classes of anthelmintics approved for use in cattle in Australia are the avermectin/milbemycins (abamectin, doramectin, ivermectin, moxidectin), benzimidazoles (albendazole, fenbendazole), and imidazothiazoles (levamisole). These three classes of drugs have independent mechanisms of action, however, mechanisms of resistance appear to be complex, involving multiple genes and drug efflux and metabolism pathways (Kotze et al., 2014).

In small ruminants, resistance to these three classes of drugs has reached alarming and widespread levels, creating a major challenge for control of these parasites (Kaplan, 2004) (Kaplan and Vidyashankar, 2012). There has been a long-term perception among cattle producers and veterinarians that anthelmintic resistance in parasites of cattle was rare, unlikely to develop, and would not present a significant challenge to productivity of cattle (Sacket et al., 2006). However, reports of resistance in cattle challenge that dogma (Sutherland and Leathwick, 2011).

Specifically, reports of resistance in both gastrointestinal nematodes and liver flukes of cattle in Australia are increasingly common, and suggest that this is an escalating issue. Between 2006-2009, the testing of drug efficacies on 13 cattle properties in Southwest Victoria found that 62%, 54%, and 100% of the properties showed the presence of at least one species of nematode that was resistant to avermectins, benzimidazoles, or imidazothiazoles, respectively (Rendell, 2010). In 2010, moxidectin-resistant *Cooperia* spp. was reported on a dairy farm in Eastern Australia, and ivermectin-resistant *Haemonchus placei* was reported on another Eastern Australia dairy farm (Lyndal-Murphy et al., 2010). From May 2013 to June 2014, faecal egg count reduction tests conducted on 20 dairy farms in the Macalister Irrigation District of Victoria found that 70%, 80%, and 25% of farms harboured at least one species of parasite that was resistant to avermectins, benzimidazoles, or imidazothiazoles, respectively (Bullen et al., 2016). A 2015 report of resistance on 19 beef cattle properties in Southwest Western Australia found that 59% of properties harboured ivermectin-resistant populations of *Cooperia oncophora,* 50% of farms contained fenbendazole-

resistant *Ostertagia ostertagi,* and 67% of farms harboured levamisole-resistant *Ostertagia ostertagi* (Cotter et al., 2015). There are also increasing concerns of triclabendazole resistance in the liver fluke, *Fasciola hepatica* (Brockwell et al., 2013). In 2014, triclabendazole-resistant *Fasciola hepatica* were confirmed on 4 of 7 beef properties tested in New South Wales and Victoria, suggesting that resistance may be widespread in Southeastern Australia (Brockwell et al., 2014).

While these individualized and regional reports are increasingly common, no properly randomized controlled studies have been conducted to assess the level of resistance currently present in gastrointestinal parasites of cattle entering Australian feedlots. More importantly, there have been no studies conducted to determine the impact of resistance on productivity and animal health within the feedlot sector. This study characterized the resistance status of gastrointestinal nematodes and liver flukes of beef cattle entering a feedlot in Eastern Australia, and assessed the impact of resistance on productivity and animal health. This is the first large-scale randomized controlled trial to address these issues.

2 Project objectives

2.1 Common genera of gastrointestinal nematodes in cattle at feedlot arrival

This project will identify the common genera of gastrointestinal nematodes that infect cattle at feedlot induction at a feedlot in Southern Queensland.

2.2 Resistance status of gastrointestinal nematodes

This project will quantify the level of resistance to the three classes of anthelmintics approved for use in cattle in Australia including the avermectin/milbemycins, benzimidazoles, and imidazothiazoles through the use of a faecal egg count reduction test and larval coprocultures.

2.3 Effect of parasite control treatments on average daily gain and carcase characteristics

This project will evaluate the effect of six treatment protocols on average daily gain and carcase characteristics of feedlot cattle.

2.4 Effect of treatment for liver fluke

This project will evaluate the efficacy of triclabendazole treatment for liver fluke.

3 Methodology

3.1 Study design

A single-blinded randomized complete block design was conducted to evaluate the efficacy and impact on productivity of six internal parasite control strategies for feedlot cattle. This study was conducted at a large scale (30,000 head capacity) commercial feedlot located in Southeastern Queensland, Australia. Six replicates were completed throughout the one-year study. Cattle were sourced from sale yards and direct consignment. Cattle were fed for approximately 100 days.

Six treatments were applied at feedlot induction within each pen. The six treatments were: 1) untreated control, 2) injectable doramectin, 3) oral albendazole, 4) oral levamisole, 5) triple combination of injectable doramectin, oral albendazole, and oral levamisole, and 6) triclabendazole plus triple combination of injectable doramectin, oral albendazole, and oral levamisole.

Individual animals were stratified by vendor and randomly allocated to treatment group. Efforts were made to conduct the study using pens of cattle comprised of multiple vendors (ideally 3-6 vendors) and the study included 17 vendors in total.

Therefore, the study encompassed:

6 study pens x 40 head per treatment x 6 treatments = 1,440 head

The experimental unit was pen. Pens were replicated within feedlot.

Cattle within each pen (i.e., pen replicate) were harvested on the same day.

3.2 Animal ethics

This project was completed under the approval of the Queensland Government Department of Agriculture and Fisheries Animal Ethics Committee (Animal Ethics Committee Reference Number: SA 2018/02/631).

3.3 Cattle procurement and induction

Cattle were sourced from 17 vendors through direct consignment and sale yards. Significant efforts were made to include as many vendors as possible per replicate while completing the study on time with current limitations in cattle purchasing decisions due to the ongoing drought. Cattle were purchased to fit the defined specifications including entry weight ranging from 350-450 kg and age of 12-18 months.

A total of 1434 head of cattle were inducted for the study including 241 in replicate 1, 233 in replicate 2, 240 in replicate 3, 240 in replicate 4, 240 in replicate 5, and 240 in replicate 6. Induction records including Visual Identification Number, National Livestock Identification System Tag Number, Replicate, Lot Number, Breed, Sex, Induction Date, Dentition, Individual Induction Weight, Vendor Code, and Treatment were recorded on the date of induction. Management of cattle from arrival to induction was recorded. All cattle in a single replicate were inducted on the same day.

Individuals were stratified by vendor and treatment was applied sequentially in the order animals entered the race. For example, the first animal received no treatment (control). The second animal received injectable doramectin. The third animal received oral albendazole. The fourth animal received oral levamisole. The fifth animal received a combination of injectable doramectin, oral albendazole, and oral levamisole. The sixth animal received a combination of injectable doramectin, oral albendazole, oral levamisole, and oral triclabendazole. This pattern of six treatments was continuously repeated until all animals were allocated to treatment groups.

At induction, cattle received a 50 mL oral drench of the lactate-consuming bacteria, *Megasphaera eldensii* (Lactipro®), an intranasal vaccination for Bovine Herpes Virus 1 (Rhinogard®), a 2 mL

subcutaneous vaccination for *Mannheimia haemolytica* (Bovilis MH®), and a growth promotant implant containing 200mg Trenbolone Acetate and 20mg 17 Beta Oestradiol (Revalor H®).

A faecal sample was obtained per rectum at the time of induction. The faecal sample was then distributed into sample containers for 1) faecal egg count, 2) *Fasciola hepatica* coproantigen ELISA, and 3) coproculture. Only samples from the control and combination plus triclabendazole group were stored for *Fasciola hepatica* coproantigen ELISA.

Samples for faecal egg counts were shipped overnight with ice bricks to the laboratory and then refrigerated (4°C) until analysis. Samples for *Fasciola hepatica* coproantigen ELISAs were frozen until analysis. Pooled coprocultures were shipped without ice bricks as a reduction in temperature can inhibit hatching of some parasite species and thus skew coproculture results.

3.4 Faecal Egg Count Reduction Tests

Faecal samples were collected per rectum at induction (pre-treatment) and again 10-14 days following induction (post-treatment).

Faecal egg counts were completed according to the Mini-FLOTAC technique. Briefly, five grams of faeces were placed into a Fill-FLOTAC homogenizer (Dr. Giuseppe Cringoli, University of Naples, Italy) and suspended in 45 mL of saturated saline flotation solution (specific gravity =1.25 − 1.30). The sample was homogenized and both chambers of the slide were filled with 1.0 mL each. Both chambers on the reading disc were examined, and the number of eggs was recorded.

The mean faecal egg count reduction and associated 95% confidence interval were calculated using the RESO method (Wursthorn and Martin, 1990). The arithmetic mean number of eggs and associated 95% confidence interval prior to treatment and following treatment, for each treatment group and replicate, were calculated in Prism 8.4.2 (GraphPad Software, San Diego, California, USA). Faecal egg count reduction tests were considered to have sufficient numbers of eggs counted under the microscope (n=150) to provide a statistically valid measure of efficacy when the mean faecal egg count of the group of 40 individuals was greater than 18.75 eggs per gram (Waghorn et al., 2006; George et al., 2017).

The highest faecal egg count in the data set was 8810 eggs per gram and this individual was identified as an extreme outlier and removed from the data set.

3.5 Coprocultures

Coprocultures were prepared for each treatment group per replicate prior to and following treatment for a total of 72 coprocultures. Cultures were prepared by combining approximately 10.0 g of faeces per individual. Vermiculite and water were mixed with the pooled faeces and incubated (27°C ± 2°C) for 7-10 days. L3 were recovered and identified to genus.

3.6 *Fasciola hepatica* Coproantigen ELISAs

Coproantigen ELISAs were performed on individual samples prior to and following treatment for control and triclabendazole treated cattle (Biox Fasciola Hepatica Ag – Version 2, R-Biopharm Australia, Caringbah, NSW). Two positive control antigens and two negative control antigens were

included per assay plate. All ELISAs were performed according to the manufacturer's directions. The delta optical density of the sample was divided by the delta optical density of the positive control and multiplied by 100 to yield a value that was then compared to quality control guidelines to determine if the sample was positive or negative. For all assays completed, a sample was considered positive if this value was greater than or equal to 8.00%.

3.7 Statistical analyses

The experimental unit was defined as the individual animal. The experiment was analysed with dead cattle removed as the cause of death was not associated with treatment. The experiment was analysed as an analysis of variance using the PROC MEANS, PROC GLM, PROC CONTRAST, and PROC FREQ procedures of SAS (SAS Institute Inc., Cary, North Carolina, USA). Treatment, replicate, and the treatment x replicate interaction were included in the model as fixed effects. Induction weight was used as a covariate in the model. Statistical significance of interactions and main effects were defined at $P < 0.05$ and a trend at $P < 0.10$ levels.

The MEANS procedure was completed for induction weight, faecal egg count at induction, weight at 2 weeks, exit weight, days on feed, average daily gain to two weeks, average daily gain to exit, hot standard carcass weight, dressing percent, P8 fat, eye muscle area, rib fat, Aus-meat marbling, meat colour, chiller assessment pH, and MSA index to calculate the mean, standard deviation, minimum and maximum of all variables.

The CONTRAST procedure was completed to compare untreated cattle versus all other cattle that did receive an anthelmintic.

The FREQ procedure was completed for morbidity, mortality, and liver pathology.

The mean percent faecal egg count reduction (FECR) and associated 95% confidence intervals were calculated using RESO (Wursthorn and Martin, 1990). Interpretation of the level of resistance was conducted in accordance with current global recommendations (Coles et al., 1992).

Percent reduction in optical density as determined by the *Fasciola hepatica* coproantigen ELISA was calculated in Microsoft excel.

4 Results

4.1 Descriptive statistics

Locations of properties of origin for the cattle used in this study are shown in Figure 1. Cattle were sourced from 17 vendors, either in Queensland (n=16) or New South Wales (n=1). The majority of cattle were sourced from south-eastern and central Queensland. Each pen (replicate) housed cattle from two to four vendors.

Simple descriptive statistics of the research population are presented in Table 1. The cattle had an average induction weight of 404.1 ± 36.0 kg (mean ± standard deviation), were fed on average for 103.7 ± 0.9 days, had an average daily gain of 2.10 ± 0.39 kg/head/day, and exited the feedlot at 621.9 ± 56.9 kg live weight. The cattle consumed 10.93 kg dry matter intake on average across the six replicates. These cattle had an average dressing percentage of 55.28 ± 2.11%, yielding carcasses with an average hot standard carcass weight of 343.6 ± 32.3 kg with 9.7 ± 2.7 mm rib fat. Meat colour at grading averaged 2.45 ± 0.53 and ultimate pH averaged 5.54 ± 0.08.

The mean faecal egg count at induction was 77.6 ± 180.9 eggs per gram of faeces. This is a mild level of infection in adult cattle.

4.2 Faecal egg counts

The average faecal egg count at induction and two weeks following induction for each treatment group within each replicate are presented in Table 2. There was a large amount of variability in the average faecal egg count at induction between replicates with a range from 9 to 201 eggs per gram of faeces. The 95% confidence intervals for the mean faecal egg count at induction were also large and represent the variability in these egg counts.

The mean faecal egg count for replicates three and four were less than 50 eggs per gram. However, the mean faecal egg count in the other four replicates was 50-200 eggs per gram.

Interestingly, in five of the six replicates, the mean faecal egg count of the untreated control group decreased over the first two weeks on feed despite the fact the animals did not receive an anthelmintic treatment. However, in one of the five replicates (replicate five), the mean faecal egg count of the untreated control group increased over the first two weeks on feed. Importantly, the 95% confidence interval of the mean faecal egg count at two weeks is widest in replicate five, ranging from 35 to 204.

The faecal egg counts followed a pattern of overdispersion, with 80% of the cattle shedding 20% of the eggs, and 20% of the cattle shedding 80% of the eggs (Figure 2). Of the 1434 cattle in the study, 375 individuals (26.2%) had a faecal egg count of zero eggs per gram at induction, and half of the cattle in the study had a faecal egg count of 15 eggs per gram or less. The highest faecal egg count in the data set was 8810 eggs per gram; and this individual was identified as an extreme outlier and removed from the data set.

4.3 Genera of nematodes present at induction

Across all six replicates, *Cooperia* was the most common genus of gastrointestinal nematode identified in cultures from faeces collected at induction (Table 3). This genus represented 73% of the total worm population at induction across the whole study (Figure 3). *Haemonchus* was the second most common genus, representing 15% of cultures. Interestingly, *Oesophagostomum* represented 7% of cultures at induction, and there were also very low levels of *Ostertagia* and *Trichostrongylus.*

4.4 Faecal egg count reduction tests

The percent faecal egg count reduction and associated 95% confidence intervals for each treatment group, within each replicate, are presented in Table 4. In instances where zero eggs were identified

in the post-treatment faecal egg counts, a 95% confidence interval was not calculated by the statistical software (Wursthorn and Martin, 1990). The mean egg count in the controls at the two-week point are also given in Table 4 (equivalent to control means shown in Table 2). It should be noted that two of the six faecal egg count reduction tests should be interpreted with caution as the mean faecal egg count in the control group at 2 weeks following induction was less than 18.75 eggs per gram, indicating that less than 150 eggs were counted under the microscope (replicates 3 and 4) (Waghorn et al., 2006; George et al., 2017). The drug efficacies for the different replicates are presented separately here (rather than a mean efficacy across the entire study) to account for the possibility that different vendors may have different drug resistance profiles, and thus levels of efficacy may vary between replicates.

In cattle treated with injectable doramectin, the mean percent faecal egg count reduction was less than 95%, and the lower 95% confidence interval was less than 90% in five out of six replicates (replicates 1-5). These are the criteria set by the WAAVP (World Association for the Advancement of Veterinary Parasitology) for defining the presence of resistance in a worm population following a FECRT (Coles et al., 1992). Resistance to injectable doramectin was therefore identified in five out of six replicates. In replicate six, injectable doramectin reduced faecal egg counts by 96%, however the lower 95% confidence interval was 86% (this is, < 90%), indicating that resistance is suspected in that replicate.

In cattle treated with oral albendazole, faecal egg counts were reduced by greater than 95%, with a lower 95% confidence interval greater than 90%, in three of the six replicates (replicates 2, 5, and 6), indicating that the parasites were susceptible to oral albendazole in these three replicates. In the other three replicates (replicates 1, 3, and 4), the mean percent faecal egg count reduction was 95% or greater, but the lower 95% confidence interval was less than 90%, indicating that resistance is suspected in these three replicates.

Treatment with oral levamisole was highly effective in all six replicates as the mean percent faecal egg count reduction was greater than 95%, and when calculated lower 95% confidence intervals were greater than 90%.

Both combination treatments were highly effective in all six replicates with the mean percent faecal egg count reduction calculated at greater than 95%, and when calculated lower 95% confidence intervals were greater than 90%.

Genus-specific faecal egg count reduction tests were completed for *Cooperia* and *Haemonchus* (Tables 5 and 6). However, it is important to interpret these results with caution as low culture yields in post-treatment groups with marginal levels of efficacy may over-estimate the genus-specific faecal egg count reduction reported in these Tables.

For *Cooperia,* oral albendazole, oral levamisole, and both combination treatments were highly effective in all six replicates (Table 5). However, injectable doramectin reduced *Cooperia*-specific faecal egg counts by less than 95%, and the lower 95% confidence interval was less than 90%, in three of the six replicates (replicates 1, 2, and 5). Resistance to injectable doramectin in *Cooperia* is suspected in replicate 6 (lower 95% confidence interval was less than 90%). However, injectable doramectin appeared highly effective against *Cooperia* in replicates 3 and 4 as the post-treatment cultures did not yield any larvae.

For *Haemonchus,* all six replicates must be interpreted with caution as the mean counts in controls were mostly very low (Table 6). The control egg counts for replicates 1, 2, 3, 4, and 6 were less than or equal to 3, and hence the efficacies reported in the table are of no value. Replicate 5 showed a higher control count (23 epg), with all five treatments being fully effective in reducing the *Haemonchus* content of post-treatment coprocultures to zero (100% efficacy).

4.5 Productivity, medical costs, and beef quality and yield

There was a highly significant ($P < 0.001$) reduction in faecal egg count at two weeks for all treatments as compared to controls (Table 7). There were no statistically significant (at $P = 0.05$) differences in productivity measurements, such as exit weight, and hot carcass weight (Table 7). However, there were strong numerical differences in exit weight, average daily gain to exit, and hot carcass weight between untreated control cattle and all other treatment groups. This led the authors to further investigate the effect of anthelmintic treatment on productivity using 'CONTRASTS' to compare untreated control cattle with cattle receiving any of the five anthelmintic treatments (Table 8).

When anthelmintic treatments were pooled, the application of a treatment to feedlot cattle resulted in a significant ($P < 0.05$) increase in feedlot exit weight from 616.8 to 623.0 kg, a difference of 6.2 kg. Cattle that received an anthelmintic gained 0.06 kg per day more ($P < 0.05$) than cattle that did not receive an anthelmintic over the 104-day feeding period (2.11 vs 2.05 kg/day). Carcasses from cattle that received an anthelmintic were 3.3 kg heavier ($P < 0.05$) than cattle that did not receive an anthelmintic (344.2 vs 340.9 kg) (Figure 4). There were no differences ($P > 0.20$) in dressing percentage, eye muscle area, rib fat, meat colour, ultimate pH or marbling between treated and untreated cattle.

The effect of faecal egg count at induction on productivity in untreated cattle (that is, control animals) was tested by comparing production parameters in cattle with a faecal egg count of less than 100 eggs per gram at induction (n=188) to cattle with a faecal egg count of greater than or equal to 100 eggs per gram at induction (n=50) (Table 9). Cattle with faecal egg counts less than 100 eggs per gram were 6.3 kg heavier ($P < 0.05$) at 2 weeks on feed, and had 0.51 kg per day greater ($P < 0.05$) average daily gain to 2 weeks compared to cattle with faecal egg counts greater than or equal to 100 eggs per gram (428.4 vs 422.1 kg, and 1.89 vs 1.38 kg/day, respectively). This difference observed in live weight at 2 weeks was no longer present at exit, that is, the difference in live weight at exit of 5.4 kg (617.8 vs 612.4 kg) was not statistically significant ($P = 0.487$). In addition, the numerical advantage of 2.8 kg in hot carcass weight (341.3 vs 338.5 kg) was not statistically significant ($P = 0.488$).

We repeated this analysis using data from all cattle that were treated with an anthelmintic, with control cattle removed (Table 10). There were no statistically significant differences in the various productivity measures, however, treated cattle with a faecal egg count greater than or equal to 100 eggs per gram did show strong numerical reductions in average daily gain to exit ($P = 0.062$), exit weight ($P = 0.073$) and hot carcass weight ($P = 0.167$), versus those with faecal egg counts less than 100 eggs per gram at induction (2.12 vs 2.06 kg, 624.1 vs 618.5 kg, and 344.7 vs 342.2 kg, respectively).

Moreover, a comparison of all cattle (treated and untreated) with faecal egg counts at two weeks of less than 25 eggs per gram, 25 to 50 eggs per gram, or greater than 50 eggs per gram in faeces noted a large numerical reduction in exit weight and hot carcass weight for cattle with higher faecal egg counts at 2 weeks (Table 11) (622.5 vs 614.8 vs 611.5 kg, and 343.9 vs 340.9 vs 337.6 kg, respectively).

4.6 Animal Health and liver pathology

There was no statistical difference ($P > 0.05$) in mortality between the treatment groups, however, cattle treated with a combination did exhibit numerically higher mortality rates compared to the other groups (Table 12). Surprisingly, the untreated cattle showed the numerically lowest level of mortality. There was a significant difference ($P = 0.002$) in morbidity between treatment groups, with the oral albendazole and combination groups showing the highest numerical morbidity levels.

Data for the effect of treatment on liver pathology noted no differences, due most-likely to the extremely low incidence (< 1.0%) of *Fasciola hepatica* in the research population (Table 12). Importantly, there were no live liver flukes identified in any of the triclabendazole treated cattle at slaughter. There were a small number of live adult liver flukes identified in livers of cattle that were not treated with triclabendazole.

Hydatid cysts were identified in 3.83% of livers at slaughter (mean % across all treatment groups), and there was no effect of treatment on the incidence of hydatid cysts ($P = 0.977$). The presence of hydatid cysts in livers was associated with reductions of 8.7 kg in exit weight (622.4 vs 613.7 kg, $P < 0.001$), and 7.2 kg in hot carcass weight (344.0 vs 336.8 kg, $P < 0.05$) (Table 13).

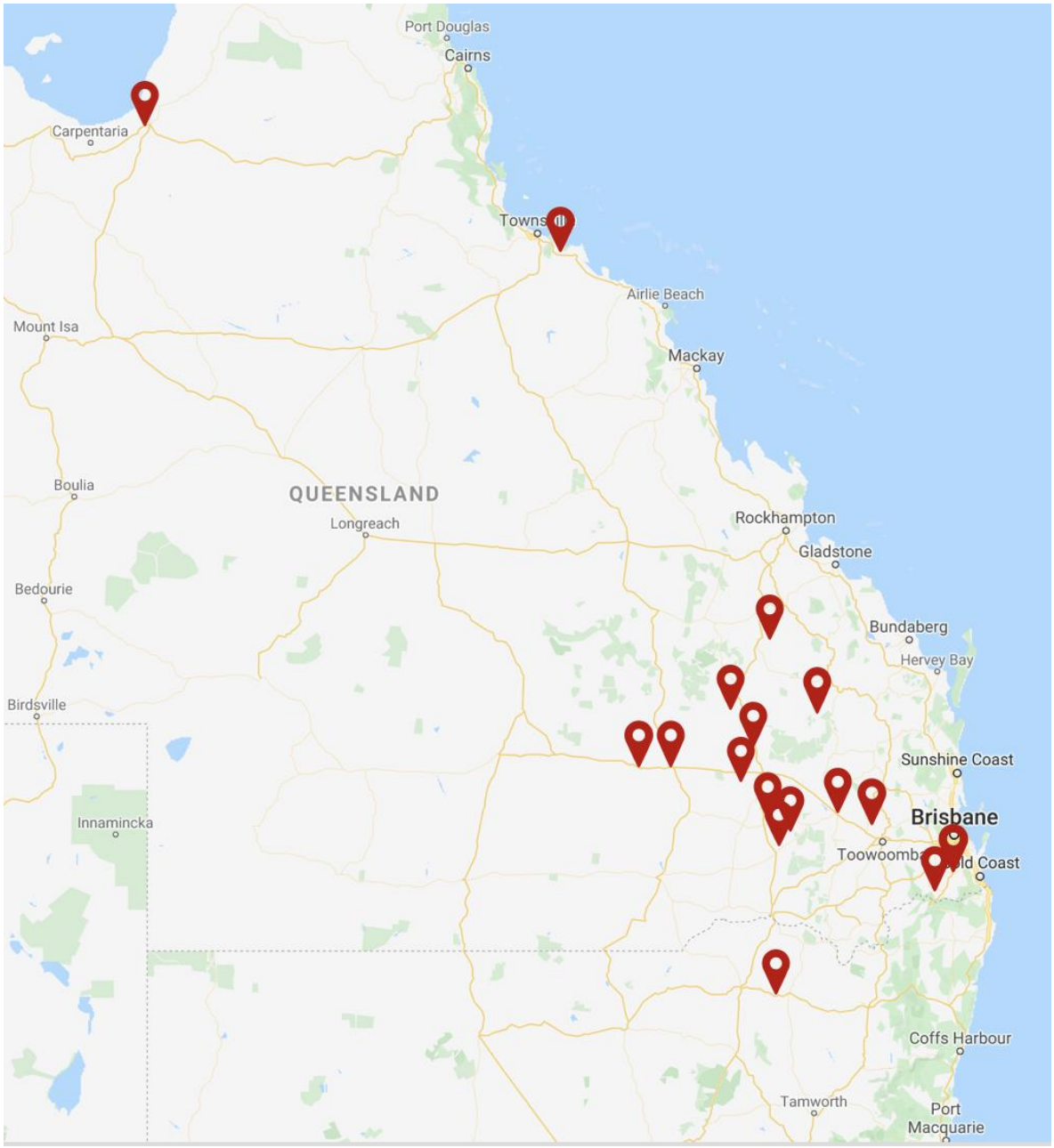

Figure 1. Locations of cattle vendors (n=17).

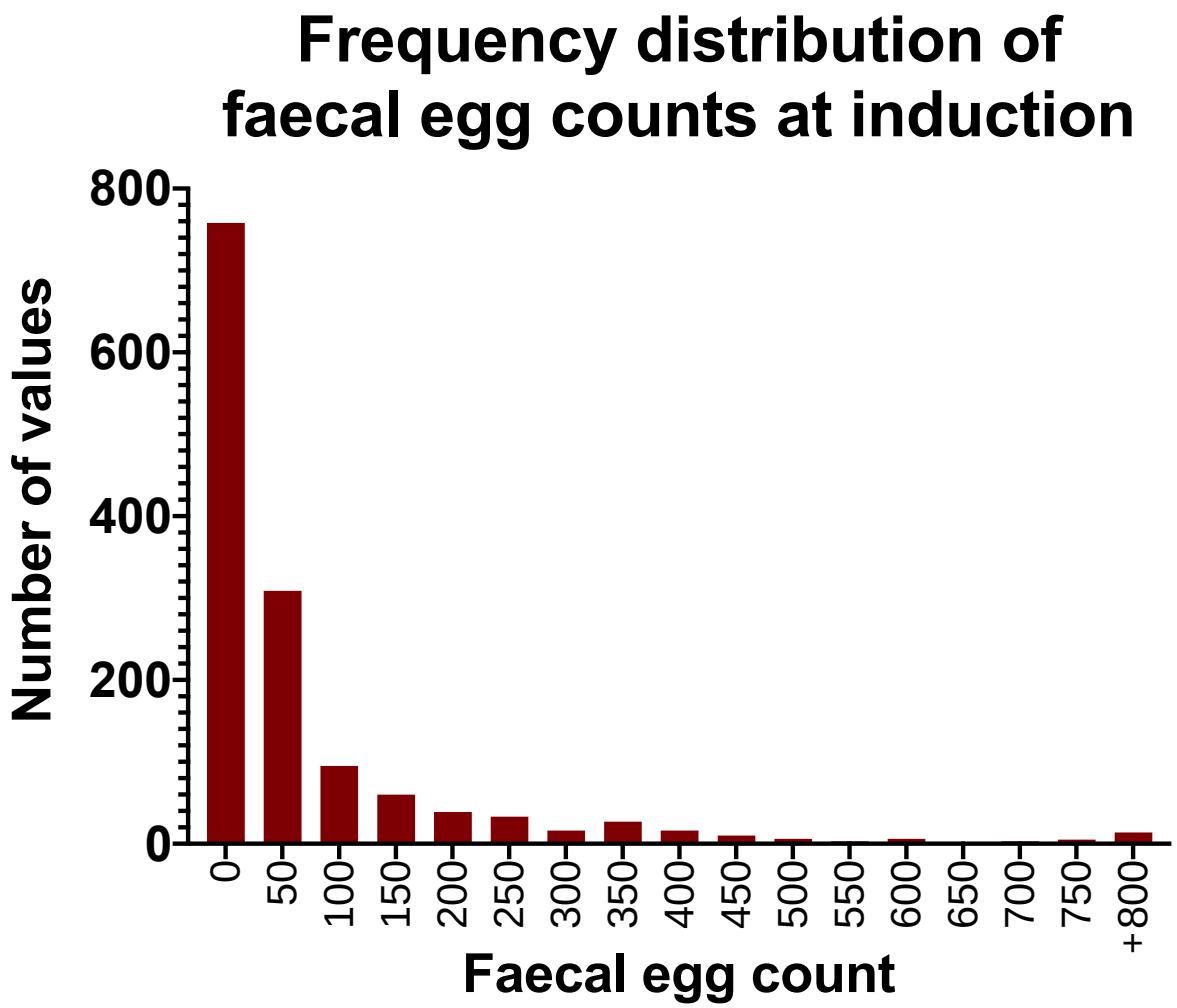

Figure 2. Frequency distribution of faecal egg counts at induction.

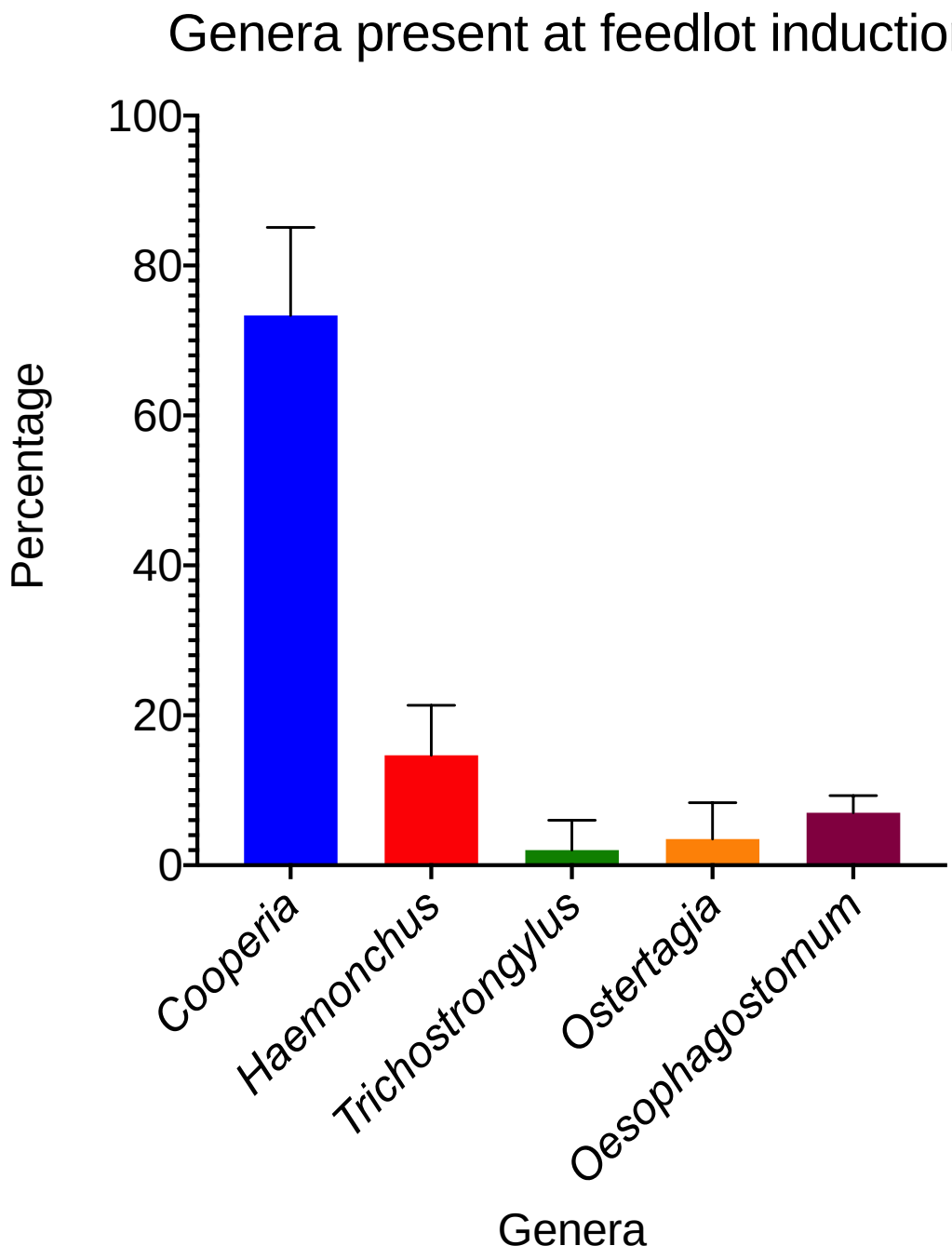

Figure 3. Genera of parasites present at feedlot induction.

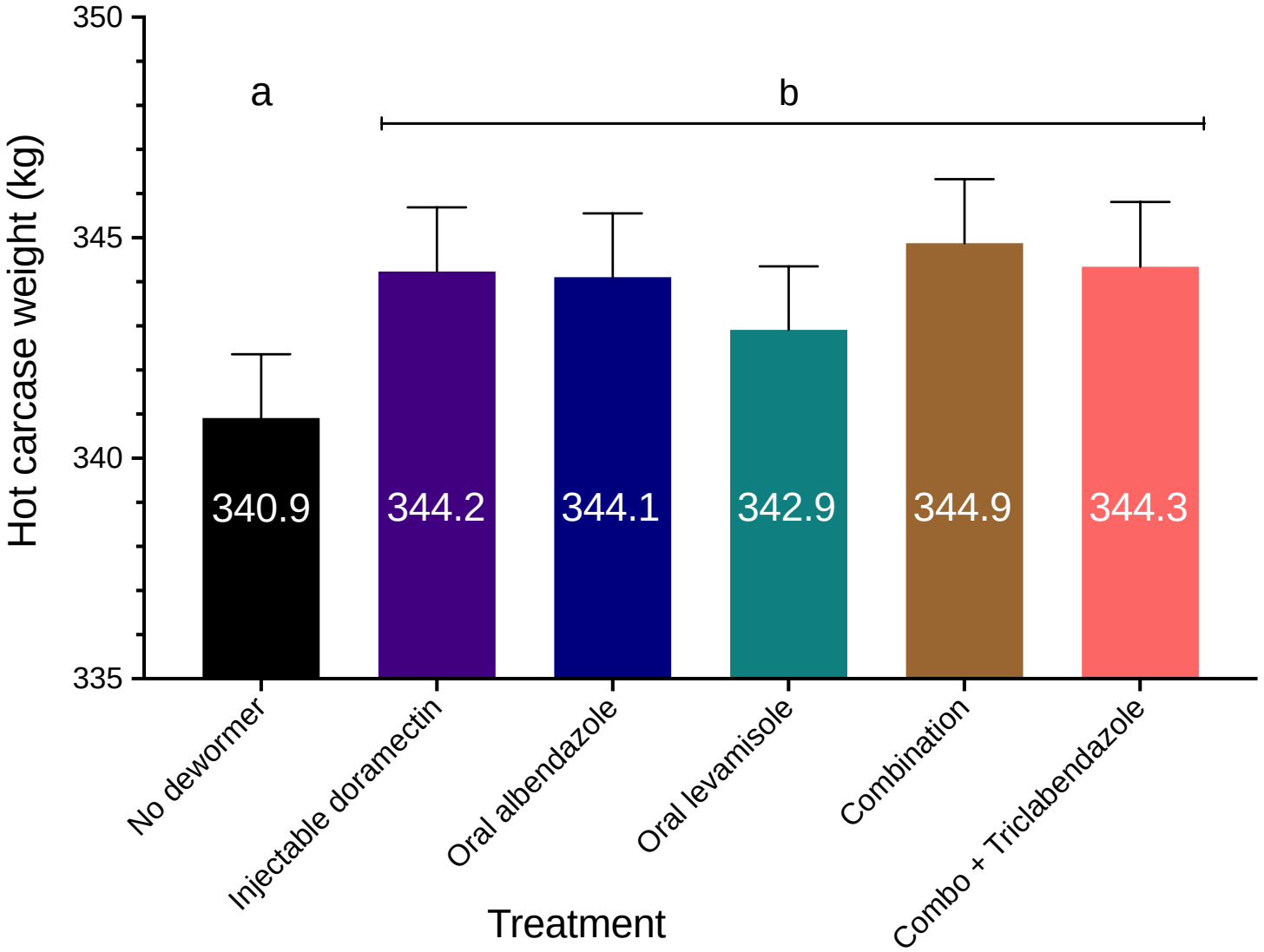

Figure 4. Effect of anthelmintic treatment on hot carcass weight of feedlot cattle.

Table 1. Descriptive statistics of study steers.

Variable	Mean	Stdev	Minimum	Maximum
Induction weight, kg	404.1	36.0	302.0	536.0
Faecal egg count pre-treatment, Eggs per gram	77.6	180.9	0.0	3370.0
Weight at 2 weeks, kg	429.1	44.1	324.0	614.0
Exit weight, kg	621.9	56.9	400.0	840.0
Days on feed, d	103.7	0.9	103.0	117.0
Average daily gain to 2 weeks, kg	1.93	1.61	-4.67	9.67
Average daily gain to exit, kg	2.10	0.39	0.10	3.67
Hot carcass weight, kg	343.6	32.3	228.0	457.5
Dressing Percent, %	55.28	2.11	48.09	76.13
Eye muscle area, cm^2	81.5	5.3	65.0	108.0
Rib fat, mm	9.7	2.7	2.0	20.0
P8 fat, mm	11.9	4.0	3.0	50.0
AusMeat Marbling	0.92	0.58	0.00	3.00
Ultimate pH	5.54	0.08	5.30	6.50
MSA Index	50.07	1.96	46.20	58.15
Meat colour*	2.45	0.53	1.67	6.00

*Meat colour was scored as 1A=1.00, 1B=1.33, 1C=1.67, 2=2.00, 3=3.00, 4=4.00, 5=5.00, 6=6.00.

Table 2. Mean faecal egg counts at induction and 2 weeks following induction

Replicate		Mean Faecal Egg Count (95% Confidence Interval)*	
		Induction	2 Weeks
1	Control	64 (34, 95)	23 (9, 37)
	Injectable doramectin	64 (33, 95)	4 (1, 6)
	Oral albendazole	78 (44, 111)	1 (0, 1)
	Oral levamisole	95 (44, 147)	0 (0, 0)
	Combination	47 (29, 65)	0 (0, 0)
	Combination + Oral Triclabendazole	149 (-34.3, 332)	0 (0, 0)
2	Control	147 (93, 201)	38 (20, 56)
	Injectable doramectin	201 (131, 270)	9 (2, 16)
	Oral albendazole	165 (110, 219)	0 (0, 1)
	Oral levamisole	166 (106, 225)	0 (0, 0)
	Combination	122 (74, 170)	1 (0, 2)
	Combination + Oral Triclabendazole	149 (90, 209)	0 (0, 1)
3	Control	9 (3, 15)	3 (1, 4)
	Injectable doramectin	13 (6, 21)	1 (0, 2)
	Oral albendazole	13 (5, 20)	0 (0, 0)
	Oral levamisole	10 (5, 15)	0 (0, 0)
	Combination	11 (5, 16)	0 (0, 0)
	Combination + Oral Triclabendazole	9 (5, 13)	0 (0, 0)
4	Control	18 (8, 28)	14 (2, 26)
	Injectable doramectin	44 (6, 82)	3 (0, 5)
	Oral albendazole	26 (9, 43)	0 (0, 1)
	Oral levamisole	26 (11, 42)	0 (0, 0)
	Combination	30 (18, 43)	0 (0, 0)
	Combination + Oral Triclabendazole	42 (22, 63)	0 (0, 0)
5	Control	59 (15, 103)	120 (35, 204)
	Injectable doramectin	55 (22, 88)	7 (3, 12)
	Oral albendazole	99 (15, 284)	0 (0, 0)
	Oral levamisole	129 (25, 234)	1 (-1, 3)
	Combination	92 (5, 180)	0 (0, 0)
	Combination + Oral Triclabendazole	106 (24, 189)	0 (0, 0)
6	Control	128 (52, 204)	31 (9, 54)
	Injectable doramectin	100 (29, 172)	1 (0, 3)
	Oral albendazole	69 (34, 105)	0 (0, 0)
	Oral levamisole	57 (23, 90)	0 (0, 0)
	Combination	65 (15, 114)	0 (0, 0)
	Combination + Oral Triclabendazole	141 (42, 240)	0 (0, 0)

*Reported as eggs per gram of faeces.

Table 3. Genera of nematodes present at induction

	Mean percentage of third-stage larvae present in coprocultures at induction*				
	Genera				
Replicate	*Cooperia*	*Haemonchus*	*Trichostrongylus*	*Ostertagia*	*Oesophagostomum*
1	64	26	0	1	9
2	77	15	0	0	8
3	74	17	0	2	7
4	80	8	2	2	8
5	56	14	10	13	7
6	89	8	0	0	3

*Mean percentage of third-stage larvae per genus across 6 pre-treatment cultures at induction.

Table 4. Faecal egg count reduction test results

		Percent Faecal Egg Count Reduction (95% Confidence Interval)*				
	Mean faecal egg count	Treatment				
Rep	Control	Injectable doramectin	Oral albendazole	Oral levamisole	Combination	Combination + Oral triclabendazole
1	23	84 (59, 94)	97 (87, 99)	99 (95, 100)	100‡	100‡
2	38	76 (38, 91)	99 (97, 100)	100 (97, 100)	97 (92, 99)	99 (96, 100)
3	3†	62 (-71, 92)	95 (59, 99)	100‡	100‡	100‡
4	14†	81 (35, 95)	98 (81, 100)	100‡	100‡	100‡
5	120	94 (84, 98)	100‡	99 (93, 100)	100‡	100 (99, 100)
6	31	96 (86, 99)	100 (96, 100)	100‡	100‡	100 (96, 100)

*Faecal egg count reduction tests compare untreated and treated individuals two weeks following induction using RESO.

†Tests with mean control faecal egg counts less than 18.75 eggs per gram should be interpreted with caution.

‡RESO did not report a confidence interval for groups of cattle with no eggs identified 2 weeks following treatment.

Table 5. *Cooperia* faecal egg count reduction test results

		Percent Faecal Egg Count Reduction (95% Confidence Interval)*				
	Mean faecal egg count	Treatment				
Rep	Control	Injectable doramectin	Oral albendazole	Oral levamisole	Combination	Combination + Oral triclabendazole
1	19	82 (54, 93)	100‡	100‡	100‡	100‡
2	35	92 (79, 97)	100‡	100‡	100‡	100‡
3	3†	100‡	100‡	100‡	100‡	100‡
4	13†	100‡	100‡	100‡	100‡	100‡
5	35	83 (55, 94)	100‡	100‡	100‡	100 (97,100)
6	29	97 (91, 99)	100‡	100‡	100‡	100‡

*Faecal egg count reduction tests compare untreated and treated individuals two weeks following induction using RESO.

†Tests with mean control faecal egg counts less than 18.75 eggs per gram should be interpreted with caution.

‡RESO did not report a confidence interval for groups of cattle with no eggs or larvae identified 2 weeks following treatment.

Table 6. *Haemonchus* faecal egg count reduction test results

		Percent Faecal Egg Count Reduction (95% Confidence Interval)*				
	Mean faecal egg count	Treatment				
Rep	Control	Injectable doramectin	Oral albendazole	Oral levamisole	Combination	Combination + Oral triclabendazole
1	3[†]	97 (91, 99)	80 (8, 96)	96 (64, 100)	100[‡]	100[‡]
2	3[†]	0 (0, 9)	90 (55, 98)	95 (57, 99)	81 (44, 93)	85 (45, 96)
3	0[†]	n/a	n/a	n/a	n/a	n/a
4	0.4[†]	100[‡]	100[‡]	100[‡]	100[‡]	100[‡]
5	23	100[‡]	100[‡]	100[‡]	100[‡]	100[‡]
6	1.23[†]	60 (0, 88)	100[‡]	100[‡]	100[‡]	100[‡]

*Faecal egg count reduction tests compare untreated and treated individuals two weeks following induction using RESO.

[†]Tests with mean control faecal egg counts less than 18.75 eggs per gram should be interpreted with caution.

[‡]RESO did not report a confidence interval for groups of cattle with no eggs or larvae identified 2 weeks following treatment.

Table 7. Effects of six deworming protocols on productivity, health, and beef quality and yield

Variable	Control	Injectable doramectin	Oral albendazole	Oral levamisole	Combination	Combination + triclabendazole	*P*-value	SE
Induction weight†	403.8	404.3	401.6	404.6	405.0	405.6	0.857	34.504
FEC at induction*	72.2	79.3	76.1	79.7	62.1	98.4	0.386	175.102
FEC at 2 weeks*	37.6[a]	4.0[b]	0.2[b]	0.2[b]	0.2[b]	0.1[b]	<.001	47.152
Weight at 2 weeks†	427.3	429.9	427.9	428.5	430.5	430.3	0.347	19.781
Exit weight†	616.8	622.7	623.3	621.0	624.0	623.8	0.359	39.959
ADG‡ to 2 weeks	1.78	2.00	1.84	1.89	2.05	2.03	0.290	1.537
ADG‡ to exit	2.05	2.11	2.11	2.09	2.12	2.12	0.360	0.385
Medical Cost, $AUD	10.96	11.94	15.68	12.21	13.98	10.35	0.085	21.763
Hot carcass weight†	340.9	344.2	344.3	343.1	344.9	344.3	0.415	22.205
Dressing Percent, %	55.35	55.30	55.27	55.27	55.30	55.23	0.994	2.066
Eye muscle area, cm^2	81.1	81.9	81.3	81.4	81.3	81.8	0.516	5.031
Rib fat, mm	9.7	9.7	9.7	9.7	9.9	9.4	0.438	2.535
P8 fat, mm	11.8	12.0	11.5	11.8	12.1	12.0	0.681	3.949
Fat colour	0.59	0.64	0.66	0.65	0.60	0.66	0.798	0.691
AusMeat Marbling	0.90	0.94	0.91	0.88	0.90	0.96	0.729	0.565
Ultimate pH	5.54	5.55	5.54	5.54	5.55	5.55	0.418	0.084
MSA Index	50.07	50.05	50.11	50.05	50.06	49.97	0.941	1.364
Meat colour§	2.43	2.45	2.46	2.46	2.43	2.48	0.904	0.523

*Faecal egg count (FEC) reported as eggs per gram.

†Weights reported in kg.

‡ADG is average daily gain and is reported as kg/day.

§Meat colour was scored as 1A=1.00, 1B=1.33, 1C=1.67, 2=2.00, 3=3.00, 4=4.00, 5=5.00, 6=6.00.

[ab] Means within a row with a different superscript are different ($p<0.05$).

Table 8. Effect of deworming on productivity, health, and beef quality and yield

Variable	Control	Treated	Control vs. Treated
			P-value
Induction weight, kg	403.8	404.2	0.863
Faecal egg count pre-treatment*	72.2	79.1	0.582
Faecal egg count post-treatment*	37.6	0.9	<.0001
Weight at 2 weeks, kg	427.3	429.4	0.130
Exit weight, kg	616.8	623.0	0.032
Average daily gain to 2 weeks, kg	1.78	1.96	0.094
Average daily gain to exit, kg	2.05	2.11	0.032
Medical Cost, $AUD	10.96	12.83	0.228
Hot carcass weight, kg	340.9	344.2	0.040
Dressing Percent, %	55.35	55.27	0.596
Eye muscle area, cm^2	81.1	81.50	0.284
Rib fat, mm	9.7	9.7	0.934
P8 fat, mm	11.8	11.9	0.798
Fat colour	0.59	0.64	0.306
AusMeat Marbling	0.90	0.92	0.650
Ultimate pH	5.54	5.54	0.263
MSA Index	50.07	50.05	0.819
Meat colour[†]	2.43	2.46	0.477

*Reported as eggs per gram of faeces.

[†]Meat colour was scored as 1A=1.00, 1B=1.33, 1C=1.67, 2=2.00, 3=3.00, 4=4.00, 5=5.00, 6=6.00.

Table 9. Effect of faecal egg count at induction on productivity, health, and beef quality and yield in untreated cattle*

	Faecal egg count at induction†			
	<100	≥100	*P*-value	SE
Individuals, n	188	50		
Individuals, %	79.0	21.0		
Induction weight, kg	402.2	409.9	0.188	33.766
Faecal egg count pre-treatment†	20.9	262.3	<.001	97.151
Faecal egg count post-treatment†	25.0	85.4	0.003	112.248
Weight at 2 weeks, kg	428.4	422.1	0.048	18.267
Exit weight, kg	617.8	612.4	0.487	44.060
Average daily gain to 2 weeks, kg/d	1.89	1.38	0.046	1.439
Average daily gain to exit, kg/d	2.06	2.01	0.483	0.425
Medical Cost, $AUD	11.29	9.76	0.683	21.284
Hot carcass weight, kg	341.3	338.5	0.488	22.523
Dressing Percent, %	55.38	55.24	0.752	2.574
Eye muscle area, cm^2	81.1	81.4	0.687	5.101
Rib fat, mm	9.7	9.5	0.633	2.446
P8 fat, mm	11.9	11.3	0.435	4.499
Fat colour	0.57	0.66	0.476	0.705
AusMeat Marbling	0.92	0.82	0.269	0.551
Ultimate pH	5.53	5.55	0.260	0.086
MSA Index	50.14	49.82	0.205	1.410
Meat colour†	2.40	2.52	0.184	0.507

*All cattle did not receive an anthelmintic at induction.

†Faecal egg count reported as eggs per gram of faeces.

‡Meat colour was scored as 1A=1.00, 1B=1.33, 1C=1.67, 2=2.00, 3=3.00, 4=4.00, 5=5.00, 6=6.00.

Table 10. Effect of faecal egg count at induction on productivity and beef quality and yield in treated cattle*

	Faecal egg count at induction†			
	<100	≥100	*P*-value	SE
Individuals, n	951	227		
Individuals, %	80.7	19.3		
Induction weight, kg	403.0	409.2	0.026	34.580
Faecal egg count at induction†	20.5	316.8	<.001	144.842
Faecal egg count at 2 week†	0.6	2.3	<.001	5.257
Weight at 2 weeks, kg	429.4	429.6	0.931	20.057
Exit weight, kg	624.1	618.5	0.073	39.059
Average daily gain to 2 weeks, kg/d	1.96	1.96	0.990	1.555
Average daily gain to exit, kg/d	2.12	2.06	0.062	0.376
Medical Cost, $AUD	12.54	14.04	0.391	21.867
Hot carcass weight, kg	344.7	342.2	0.167	22.134
Dressing Percent, %	55.25	55.35	0.553	1.950
Eye muscle area, cm^2	81.6	81.4	0.791	5.022
Rib fat, mm	9.7	9.5	0.449	2.554
P8 fat, mm	11.9	12.0	0.598	3.832
Fat colour	0.65	0.59	0.239	0.688
AusMeat Marbling	0.92	0.90	0.578	0.567
Ultimate pH	5.55	5.54	0.408	0.084
MSA Index	50.06	50.01	0.643	1.355
Meat colour†	2.47	2.41	0.161	0.526

*Control cattle were removed from the analyses.

†Faecal egg count reported as eggs per gram of faeces.

†Meat colour was scored as 1A=1.00, 1B=1.33, 1C=1.67, 2=2.00, 3=3.00, 4=4.00, 5=5.00, 6=6.00.

Table 11. Effect of faecal egg count at 2 weeks on productivity, health, and beef quality and yield*

	Faecal egg count at 2 weeks				
	<25	25≥ x <50	≥50	*P*-value	SE
Individuals, n	1139	29	48		
Individuals, %	94.6	2.1	3.4		
Faecal egg count pre-treatment†	73.7[a]	166.0[b]	133.7[b]	0.0017	174.173
Faecal egg count post-treatment†	0.9[a]	30.9[b]	163.1[c]	<.001	41.124
Weight at 2 weeks, kg	429.2	428.4	425.3	0.407	19.766
Exit weight, kg	622.5	614.8	611.5	0.114	39.964
Average daily gain to 2 weeks, kg/d	1.95	1.89	1.61	0.334	1.537
Average daily gain to exit, kg/d	2.10	2.03	2.00	0.113	0.385
Medical Cost, $AUD	12.61	11.25	10.62	0.788	21.746
Hot carcass weight, kg	343.9	340.9	337.6	0.135	22.224
Dressing Percent, %	55.28	55.50	55.22	0.838	2.068
Eye muscle area, cm^2	81.5	81.8	81.6	0.937	5.051
Rib fat, mm	9.7	9.6	9.4	0.743	2.541
P8 fat, mm	11.9	10.4	11.3	0.062	3.936
Fat colour	0.63	0.58	0.57	0.761	0.692
AusMeat Marbling	0.92	0.94	0.83	0.575	0.564
Ultimate pH	5.54	5.55	5.55	0.910	0.084
MSA Index	50.06	49.95	49.89	0.650	1.364
Meat colour†	2.44	2.64	2.52	0.105	0.523

*Analyses include treated and untreated cattle.

†Faecal egg count reported as eggs per gram of faeces.

†Meat colour was scored as 1A=1.00, 1B=1.33, 1C=1.67, 2=2.00, 3=3.00, 4=4.00, 5=5.00, 6=6.00.

Table 12. Frequency statistics for effects of six deworming protocols on health parameters and liver pathology

Variable	Control	Injectable doramectin	Oral albendazole	Oral levamisole	Combination	Combination + triclabendazole	*P-value*
Total mortality, %	0.42	1.26	0.84	0.42	1.66	2.11	0.406
Total morbidity, %	25.63	33.47	37.13	29.41	37.97	23.91	0.002
Respiratory disease, %	17.23	23.31	26.16	21.01	24.05	17.39	0.097
Condemned livers, %	0.00	0.00	0.00	0.00	0.00	0.43	0.397
Live flukes present, %	0.4	0.4	0.9	0.4	0.0	0.0	0.644
Liver fibrosis score, %							0.729
0	99.58	98.72	98.73	97.90	99.58	99.56	
1	0.00	0.00	0.00	0.42	0.00	0.00	
2	0.42	0.85	0.42	0.84	0.42	0.00	
3	0.00	0.43	0.85	0.84	0.00	0.44	
Liver abscess, %							0.637
0	94.96	93.59	88.98	92.44	93.22	93.86	
1	1.68	2.14	5.51	3.78	3.81	1.75	
2	1.68	2.14	2.12	2.10	1.27	1.75	
3	1.68	2.14	3.39	1.68	1.69	2.63	
Open liver abscess, %	0.0	0.0	0.4	0.0	0.4	0.0	0.552
Liver adhesions, %	2.10	2.56	2.97	3.36	3.81	4.82	0.632
Liver cirrhosis, %	0.00	1.71	1.27	0.84	0.42	0.44	0.310
Hydatid cysts, %	3.78	3.85	3.81	3.78	4.66	3.07	0.977

Table 13. Effect of hydatid cysts on productivity, health, and beef quality and yield in treated cattle

	Presence of hydatid cysts in liver			
	Absent	Present	*P*-value	SE
Individuals, n	1356	54		
Individuals, %	96.2	3.83		
Induction weight, kg	403.0	433.9	<.001	33.970
Faecal egg count at induction[†]	78.4	77.7	0.979	175.476
Faecal egg count at 2 week[†]	7.3	0.5	0.320	47.252
Weight at 2 weeks, kg	429.4	422.7	0.019	19.689
Exit weight, kg	622.4	613.7	<.001	39.911
Average daily gain to 2 weeks, kg/d	1.95	1.48	0.033	1.530
Average daily gain to exit, kg/d	2.10	2.01	0.108	0.384
Medical Cost, $AUD	12.40	13.81	0.658	21.746
Hot carcass weight, kg	344.0	336.8	0.027	22.172
Dressing Percent, %	55.30	54.93	0.225	2.066
Eye muscle area, cm^2	81.5	80.5	0.186	5.025
Rib fat, mm	9.7	9.6	0.787	2.531
P8 fat, mm	11.8	12.7	0.123	3.928
Fat colour	0.63	0.74	0.247	0.690
AusMeat Marbling	0.92	0.85	0.454	0.565
Ultimate pH	5.54	5.56	0.126	0.084
MSA Index	50.06	49.93	0.528	1.364
Meat colour[†]	2.45	2.52	0.319	0.523

*Control cattle were removed from the analyses.

[†]Faecal egg count reported as eggs per gram of faeces.

[†]Meat colour was scored as 1A=1.00, 1B=1.33, 1C=1.67, 2=2.00, 3=3.00, 4=4.00, 5=5.00, 6=6.00.

5 Discussion

5.1 Discussion of results

The cattle in the present study were representative of steers entering feedlots in south-eastern Queensland. Induction weight, dentition, and breed type were consistent with industry standards for cattle entering the 100-day feeding period market (Table 1). The cattle displayed robust levels of performance in a commercial feedlot environment with an average of 10.93 kg dry matter intake per day and a mean average daily gain of 2.10 kg per day. Thus, the results of this study are relevant to commercial feedlots in Australia as the cattle were managed according to industry standards and performed consistently with industry averages.

Although the cattle were sourced from 17 different vendors in geographically-diverse regions across Queensland and New South Wales (Figure 1), the common genera identified at induction were consistent among all six replicates (Table 3). Specifically, *Cooperia* was the most common genus at induction in each of the six replicates, ranging from 56 to 89%. *Haemonchus* was the second most common genus in all six replicates. Both *Cooperia* and *Haemonchus* are highly fecund parasites and therefore the number of eggs produced by these genera may be higher compared to the other genera identified, and this may explain the higher proportion of larvae represented by these genera. Replicate 5 had a higher percentage of *Trichostrongylus* and *Ostertagia* as compared to the other replicates. While it is commonly accepted that adult cattle build immunity to *Cooperia*, cattle in the present study were all greater than 12 months of age and *Cooperia* remained the most common genus present. These results suggest that *Cooperia* remains the most common genus of parasite in cattle throughout the first two years of life in Queensland. Interestingly, *Oesophagostomum* represented 7% of cultures at induction. *Oesophagostomum* is commonly referred to as the nodular worm due to the fibrotic nodules formed around parasites in the wall of the cecum and colon. The findings of the present study warrant further evaluation of the prevalence of post-mortem pathology associated with *Oesophagostomum* in feedlot cattle and the potential economic impact associated with this genus.

The faecal egg counts followed a pattern of overdispersion, with a large percentage of the cattle having very low faecal egg counts at induction (Figure 2). Specifically, more than a quarter of the cattle had faecal egg counts equal to zero using a highly sensitive faecal egg count method (Mini FLOTAC with 5 egg per gram sensitivity). These results suggest that 25% of cattle entering feedlots in south-eastern Queensland may not be infected with gastrointestinal parasites. Alternatively, it is possible that cattle with a faecal egg count of zero are infected with parasites that have a very low fecundity, are not presently shedding, or are present in life stages that are not yet reproductive such as encysted larval stages or single sex infections. If cattle are not infected with gastrointestinal parasites, anthelmintic treatment may not be indicated. This observation requires further investigation to determine the effect of anthelmintic treatment in feedlot cattle with a faecal egg count of zero at induction. However, in this study, treatment with an anthelmintic improved productivity when tested in groups of cattle with a wide range of faecal egg counts, including many cattle with faecal egg counts of zero (Table 8). The mean faecal egg count at induction was 77.6 eggs per gram with a standard deviation of 180.9 eggs per gram. This mean faecal egg count was lower than expected as previous work in feedlot cattle found a mean faecal egg count in untreated control

cattle to be 104.5 eggs per gram (Playford and George, 2012). This lower faecal egg count found in the present study may be associated with the prolonged drought conditions that occurred from 2017 to 2019 in the region from which the cattle were sourced. The standard deviation for faecal egg counts was very large and reflects the variability in faecal egg counts between individuals that is commonly observed (Table 2). Replicates 3 and 4 had lower faecal egg counts at induction as compared to the other four replicates. This may be due to differences in the properties where these cattle were sourced and their parasite management programs which may include different stocking densities, intervals of anthelmintic treatment, or pasture rotation. The cattle may also have varying levels of immunity to gastrointestinal parasitism, with cattle from replicates 3 and 4 having higher levels of immunity as compared to the other replicates.

In five of the six replicates, the mean faecal egg count of the untreated control group decreased even though the cattle were not treated with an anthelmintic. There are many potential explanations for this observation. First, the moisture content of the faeces increases as cattle adapt to a feedlot ration. Prior to entering a feedlot, cattle are often consuming a diet comprised of grasses and other forage sources. Over the first three weeks in a feedlot, cattle are transitioned to a diet containing grains such as wheat, barley, and sorghum and the roughage content of the diet is reduced over those first few weeks. The moisture level of the faeces increases throughout this transition period. Thus, faeces sampled at 2 weeks has a higher moisture content as compared to faeces sampled at induction. As faecal egg counts are reported as eggs per gram of faeces, the actual number of eggs may be diluted by this higher moisture content.

Ideally, faecal samples should be compared for the same individuals prior to and following treatment due to the large variability in faecal egg counts between individuals in a group. To account for the variation in moisture content of faeces, the dry matter content of the faeces should be calculated, and the values should be reported on a dry matter basis such as eggs per gram of dry matter of faeces. While further work is required to optimize and test this methodology, these methods would allow for comparison of the same individuals prior to and following treatment while accounting for variations in moisture content of faeces. A standardized and scientifically sound method for completing faecal egg count reduction tests in feedlot cattle is required.

For cattle that received an anthelmintic treatment, those animals from the group treated with injectable doramectin had the highest number of eggs identified following treatments as compared to the other four treatment groups (Table 2). This observation was consistent for all six replicates. These observations are consistent with the finding that resistance to injectable doramectin was identified in five out of six replicates and resistance to injectable doramectin was suspected in the final replicate. *Cooperia* was the most common genus identified in all six replicates. *Cooperia* is the dose-limiting parasite for the macrocyclic lactone class of anthelmintics. Although it is clear that resistance to injectable doramectin was consistently identified in the present study (Table 4), this result was not unexpected as this is often the first genus of gastrointestinal nematode to survive treatment with a macrocyclic lactone as resistance in a mixed-species population develops. Resistance to injectable doramectin was identified in *Cooperia* in three of the six replicates (Table 5), however in replicates 3 and 4, the post-treatment coprocultures did not yield any *Cooperia* as the faecal egg counts post-treatment were very low, and thus the efficacy for these two replicates may be over-estimated. The efficacies for *Haemonchus* are of limited value and do not warrant thorough discussion as the mean faecal egg counts in the control groups were very low (Table 6). However,

Haemonchus was the primary genus identified post-treatment in replicates 1 and 2, providing a possible explanation for the lower level of efficacy for the genus in those replicates. These results suggest that a low level of resistance to injectable doramectin is common in gastrointestinal parasites of cattle entering feedlots in south-eastern Queensland. Thus, veterinarians and producers should be fully aware of this finding and consider the implications in their production environment. The macrocyclic lactones are endectocides with efficacy against external parasites. The present study did not evaluate the efficacy of this chemical class against external parasites such as ticks and lice which are important pathogens for cattle in Queensland.

Treatment with oral albendazole was highly effective in three of six replicates, and a low level of resistance to oral albendazole was suspected in three of six replicates. The mean faecal egg count 2 weeks following treatment with oral albendazole was zero to one eggs per gram for all six replicates. These results show that treatment with oral albendazole reduced faecal egg counts to very low levels, and hence this treatment was shown to have a high level of practical efficacy against both *Cooperia* and *Haemonchus*.

All other treatments including oral levamisole and both combination treatments were highly effective in all six replicates. Oral levamisole is not commonly used as an anthelmintic for feedlot induction. This drug should be considered as a low-cost highly effective anthelmintic for feedlot induction due to its high level of efficacy demonstrated in the present study.

Although measures of drug efficacy are highly important, producers are not technically 'paid' to achieve a faecal egg count of zero or to achieve a 95% mean faecal egg count reduction with a lower 95% confidence interval of greater than 90%. In fact, most producers, and even some veterinarians, have no knowledge of these thresholds and have never completed faecal egg counts on their feedlots. However, feedlots meticulously measure average daily gain, exit weight, and hot carcass weight. Feedlot financial return is based on maximising the kilograms of hot carcass weight sold, while minimising input costs. Therefore, it is essential that these measures of productivity be considered when evaluating various anthelmintic treatments for feedlot cattle. The present study evaluated the effect of six deworming protocols on several productivity measurements including average daily gain and exit weight, meat yield measurements including hot carcass weight, and meat quality parameters.

The present study found no statistically significant (at $P = 0.05$) differences in productivity measurements, such as exit weight, and hot carcass weight (Table 7) between the six deworming protocols. This result was rather surprising as the authors hypothesised that a combination treatment would result in a higher level of efficacy as compared to single active drenches and therefore lead to higher levels of productivity. But we found no difference in efficacy between oral albendazole, oral levamisole, and either of the combination treatments. And, although there was a low level of resistance to injectable doramectin, treatment with this drug still reduced the mean faecal egg count to less than 10 eggs per gram in all six replicates. Since all treatments reduced faecal egg counts to very low levels, it is likely that all treatments achieved sufficient levels of efficacy to reduce the impact of gastrointestinal parasites to negligible levels. There was no effect of treatment on meat quality parameters such as marbling, meat colour, or ultimate pH.

Although there was no statistical difference in productivity between the six deworming protocols, the untreated control cattle had a strong numerical reduction in average daily gain, exit weight, and

hot carcass weight compared to the other treatment groups. The authors noticed this numerical difference and used appropriate statistical procedures to evaluate the difference in productivity between untreated animals and animals that received any of the five treatments. The application of a treatment to feedlot cattle resulted in 0.06 kg advantage in average daily gain, a 6.2 kg advantage in exit weight, and 3.3 kg advantage in hot carcass weight. At $6.00 per kg hot carcass weight, this reflects an advantage of $19.80 per head for treating with an anthelmintic that can cost as little as $1.00 per head or less. This is a 20 to 1 return on investment and demonstrates the substantial profitability of treatment with an anthelmintic at feedlot induction even in the present study with a mild level of infection.

The present study design was completed within pen and thus feed intake could not be measured between treatments as all treatments were housed within the same pen. On average, cattle in the study consumed 10.93 kg dry matter per head per day. It has been well-established that gastrointestinal parasites, and particularly *Cooperia*, have a negative impact on feed intake. Feed efficiency has a major effect on the profitability of feedlot operations and thus further investigation into the effect of anthelmintic treatment on feed intake in feedlot cattle is warranted.

In untreated cattle, cattle with faecal egg counts less than 100 eggs per gram were 6.3 kg heavier ($P < 0.05$) at 2 weeks on feed, and had 0.51 kg per day greater ($P < 0.05$) average daily gain to 2 weeks compared to cattle with faecal egg counts greater than or equal to 100 eggs per gram. However, this difference in productivity was no longer significant at the time of exit. This reduction in level of significance may be due to the low number of cattle in the analysis (n=238). Alternatively, it is possible that cattle with faecal egg counts greater than 100 experience compensatory gain later in the feeding period that compensates for the early reduction in productivity observed at the 2-week time point.

There was a large numerical reduction in exit weight and hot carcass weight for cattle with higher faecal egg counts at 2 weeks (Table 11). Specifically, cattle with faecal egg counts less than 25 eggs per gram at 2 weeks had numerically the highest exit weight and hot carcass weight. These results suggest that regardless of the anthelmintic selected, feedlots should aim to reduce faecal egg count to less than 25 eggs per gram. To achieve this threshold in a practical manner, feedlots and veterinarians should consider incorporating a low-intensity parasitological component into their feedlot management system. This will allow feedlots to monitor the effectiveness of their parasite control programs. The specifics of this monitoring system will need to account for the number of individuals in the pen, production system, and anthelmintic selected. A simple solution may include completing composite faecal egg counts (George et al., 2017) on fresh samples collected from the pen floor (immediately following defaecation) at 2 weeks following induction. Further work needs to be completed to validate this strategy as an effective means to monitor anthelmintic efficacy.

Although there was no statistical difference in mortality between treatment groups, untreated cattle showed the lowest numerical level of mortality, and cattle treated with a combination had the highest numerical level of mortality. This finding is more than likely not biologically relevant as mortality rates were less than 2.5% for all treatment groups, and cattle died of causes that did not include gastrointestinal parasitism. However, it is possible that infection with gastrointestinal parasites shifts the immune system to a T_H2 response and therefore reduces the T_H1 immune response and may reduce the negative implications of an overly-active T_H1 immune response for

viral and bacterial pathogens that are associated with Bovine Respiratory Disease Complex. Larger studies are required to investigate the possible interactions between different pathogens in feedlots due to the low levels of mortality commonly seen in feedlot cattle in Australia (less than 1%).

Coproantigen ELISAs were completed for *Fasciola hepatica* on all untreated control cattle and all triclabendazole treated cattle at induction and two weeks following induction. All samples were negative. This suggests that cattle were not infected with liver flukes or not shedding antigen at the time of sampling. This is likely associated with the origin of cattle from regions that are not endemic for liver flukes. There were a small number of live adult flukes present in livers of non-triclabendazole treated cattle at slaughter. Specifically, 0.4% of the control group (equivalent to 1 animal) had live adult flukes identified at slaughter. This animal gave a negative result in the coproantigen ELISA. The animal may have been recently infected with liver flukes prior to entering the feedlot and thus was not shedding antigen at the time of sampling and was therefore negative in the ELISA. The feedlot environment is not considered appropriate for the development of the intermediate snail hosts which are required for transmission of *Fasciola hepatica* and thus the animal was most likely infected prior to feedlot entry. In total, 5 of the 1434 animals showed the presence of live liver flukes at slaughter, which is equal to 0.35% of the cattle. These data suggest that treatment for liver fluke is not warranted in cattle from regions not considered endemic for liver flukes.

The prevalence of hydatid cysts was higher than expected, with 3.83% of livers containing hydatid cysts at slaughter. However, the effect of infection with hydatid cysts on productivity was much more striking, with infected cattle showing a 7.2 kg reduction in hot carcass weight. Although the present study was not designed to determine the effect of hydatidosis on productivity, the results are profound and warrant future efforts focused on the prevention of infection and development and testing of vaccine candidates for *Echinococcus granulosus.*

5.2 Achievement of project objectives

5.2.1 Common genera of gastrointestinal nematodes in cattle at feedlot arrival

The common genera of gastrointestinal nematodes infecting feedlot cattle sourced from 17 vendors in Queensland (n=16) and New South Wales (n=1) between March to May 2019 were identified (Table 3). A total of 72 coprocultures were completed. Cattle were sourced by direct vendor sales and sale yards. Efforts were made to purchase cattle from multiple vendors and regions per replicate as per the project proposal. The genera of gastrointestinal nematodes found in the present study are representative of the sources where cattle were purchased from (Figure 1) and of common cattle entering the feedlot where the project was conducted. However, a random sampling technique was not performed and thus it is not possible to be sure that the genera identified in the present study are representative of southern Queensland as a whole. Additionally, the cattle were inducted from March to May 2019, and due to seasonal variability the genera identified in this study may not be representative of other seasons throughout the year. Importantly, the methodology for the present study was simplified as requested by the funding body to only include one feedlot and to occur during the season where faecal egg counts are highest in this region. Thus, the results are representative of cattle entering a feedlot in south-eastern Queensland during May to March and have fulfilled the objective.

5.2.2 Resistance status of gastrointestinal nematodes

The level of resistance to the three primary classes of anthelmintics approved for use in cattle in Australia including the avermectin/milbemycins, benzimidazoles, and imidazothiazoles was quantified. A total of 36 faecal egg count reduction tests were performed and analysed (Table 4). Several important insights into the methodology to complete faecal egg count reduction tests in feedlots were described. This project objective was achieved in full.

5.2.3 Effect of parasite control treatments on average daily gain and carcase characteristics

The effect of six treatment protocols on average daily gain and carcase characteristics of feedlot cattle was determined (Table 7). Additional analyses beyond the basic objective were performed to evaluate the effect of treatment with an anthelmintic on productivity, beef quality and yield, and animal health parameters. This objective was achieved in full.

5.2.4 Effect of treatment for liver fluke

Unfortunately, the cattle sourced for the present study had very low levels of liver fluke infection. Thus, the efficacy of triclabendazole for treatment of *Fasciola hepatica* could not be determined. Importantly, there were no live adult liver flukes identified in the livers of cattle treated with triclabendazole at slaughter. This project was completed during a severe drought, and sourcing cattle was extremely challenging. Although efforts were made to source cattle from New South Wales and regions with known liver fluke infections, it was not possible to source those cattle at the time of the study. To properly evaluate the effect of triclabendazole on *Fasciola hepatica*, cattle should be screened for infections prior to feedlot entry. This would require cattle to be sourced from fluke-endemic regions which was not possible for the present study given the challenges associated with drought and cattle supplies.

6 Conclusions/recommendations

6.1 Practical conclusions and implications for the feedlot industry

Cattle entering a south-eastern Queensland feedlot showed a mild level of infection with gastrointestinal parasites. The level of faecal egg counts identified in the present study demonstrate that cattle entering feedlots experience significant parasite burdens and management procedures are required for parasite control in this production system. Additionally, faecal egg counts are high enough in cattle at induction to perform statistically-valid faecal egg count reduction tests when high sensitivity methods and sufficient numbers of individuals are tested.

Cooperia, *Haemonchus,* and *Oesophagostomum* were the most common genera identified. *Cooperia* was the most common genera of gastrointestinal nematode in cattle through the first two years of life which demonstrates that cattle have not developed high levels of immunity to this parasite before entering the feedlot. Therefore, *Cooperia* remains a primary parasite of interest for control programs in the feedlot sector. A higher percentage of *Oesophagostomum* was identified in cultures than was expected. These parasites may be contributing to pathology in the colon and cecum.

Faecal egg count reduction tests in feedlots require consideration of changes in moisture levels of faeces that are likely to occur after induction. These changes in moisture levels are associated with changes to the diet as cattle are fed rations containing grain and reduced levels of roughage. It is not appropriate to compare faecal egg counts at induction and two weeks later without consideration of variations in the moisture content of faeces. It is, however, acceptable to compare faecal egg counts in untreated cattle representing a control group with treated cattle at 2 weeks following treatment as was done for the present studying using the RESO analysis method. Ideally, faecal egg counts should be completed on a dry matter basis and the same individuals should be compared prior to and following treatment. Further work to optimize methods for faecal egg count reduction tests in feedlot cattle is required.

We consistently identified *Cooperia* with a low level of resistance to injectable doramectin and there was evidence of *Haemonchus* with reduced efficacy following treatment with injectable doramectin. A low level of resistance to oral albendazole was suspected in three of six replicates, but this treatment was highly effective in the other three replicates. Oral levamisole was highly effective in all six replicates. A combination of injectable doramectin, oral albendazole, and oral levamisole was highly effective in all six replicates.

However, all treatment molecules delivered as single or combination treatments were effective in managing livestock performance under feedlot production conditions. There was no difference in productivity between any of the five anthelmintic treatments. Treating cattle with an anthelmintic yielded 6.2 kg advantage in exit weight, 0.06 kg advantage in average daily gain, and 3.3 kg advantage in hot carcass weight compared to untreated controls. In the current economic climate, treating with a dewormer represents a 20:1 return on investment and is one of the most profitable investments a feedlot can make at the time of induction.

There was no evidence that the low level of resistance to doramectin and suspected resistance to albendazole in the present study had an effect on feedlot productivity. It appears that both drugs reduced parasite burdens to levels low enough to negate the impact of resistance on productivity. There was no additional benefit from utilising combination treatments as all treatments reduced faecal egg counts to low levels, less than 10 eggs per gram and achieved similar levels of productivity. There was no benefit to triclabendazole treatment in primarily Queensland sourced cattle due to the extremely low levels of liver flukes identified in the present study.

Cattle with faecal egg counts less than 25 eggs per gram at 2 weeks had numerically the highest exit weight and hot carcass weight compared with cattle with faecal egg counts between 25-50 and above 50 eggs per gram. Feedlots should aim to reduce faecal egg count to less than 25 eggs per gram to achieve optimal levels of productivity. A low-intensity program to monitor anthelmintic efficacy may be a practical and important component of a feedlot health management system.

Hydatid cysts were identified in 3.83% of livers at slaughter and the presence of hydatid cysts in livers was associated with a 7.2 kg decrease in hot carcass weight. This finding suggests that infection with *Echinococcus granulosus* is one of the most economically important parasitic infections in feedlot cattle and warrants future efforts focused on the prevention of infection prior to feedlot entry.

6.2 Future research and development

To determine the true cost of gastrointestinal parasitism in Australian feedlot cattle, the effect of gastrointestinal parasitism on feed intake must be measured. The results of this study demonstrated a 3.3 kg advantage in exit weight for cattle treated with an anthelmintic. We know that infection with *Cooperia* has a negative impact on feed intake in calves (Stromberg et al., 2012). However, there have been no large pen studies to evaluate the effect of *Cooperia* on feed intake of feedlot cattle with an induction weight of 350-500 kg in a commercial environment. The present study was not designed to evaluate feed intake. By measuring the effect of gastrointestinal parasitism on feed intake, a true cost of gain can be calculated for cattle infected with gastrointestinal parasites.

In the present study, greater than 25% of cattle had faecal egg counts of zero eggs per gram at feedlot induction. It is possible that cattle with faecal egg counts of zero are not infected with gastrointestinal parasites and do not require anthelmintic treatment. Alternatively, it is possible that cattle with a faecal egg count of zero are infected with parasites that have a very low fecundity, are not presently shedding, or are present in life stages that are not yet reproductive such as encysted larval stages or single sex infections. If a rapid test was developed to determine faecal egg count at induction, it may be possible to screen cattle prior to administering anthelmintic treatment, and only treat cattle where warranted. However, the present study clearly found that treatment with an anthelmintic yielded a 3.3 kg advantage in hot carcass weight regardless of faecal egg count. If there is no benefit in productivity or feed efficiency for treatment of cattle with a faecal egg count of zero with an anthelmintic at induction, producers may be able to screen cattle and only treat those with faecal egg counts greater than zero. However, this would only represent a profitable endeavour if the diagnostic test was less expensive than treatment which is highly unlikely in the near future given the low cost of dewormers.

Oesophagostomum represented 7% of cultures at induction. *Oesophagostomum* is commonly referred to as the nodular worm due to the fibrotic nodules formed around parasites in the wall of the cecum and colon. The findings of the present study warrant further evaluation of the prevalence of post-mortem pathology associated with *Oesophagostomum* in feedlot cattle and the potential economic impact associated with this genus.

Future work to develop standardised methods for faecal egg count reduction tests in feedlot cattle is required. Due to the significant changes in moisture content of faeces from induction to two weeks on feed, current methodologies are not appropriate for these tests in feedlots. Ideally, faecal egg counts should be completed on a dry matter basis and the same individuals should be compared prior to and following treatment. It may also be important to consider the rate of passage of gastrointestinal contents rather than simply moisture levels. Additionally, simple methods for low-impact parasitological screening in feedlots to evaluate the effectiveness of deworming protocols are required to drive adoption among veterinarians and individuals managing the health of feedlot cattle. This will assist producers to practically determine if they are able to reduce faecal egg counts to levels less than 25 eggs per gram, and hence avoid production impacts due to infections by gastrointestinal worms.

To accurately evaluate the level of triclabendazole resistance in feedlot cattle, cattle need to be sourced from liver fluke-endemic regions and screened for infection prior to evaluating the efficacy

and impact on productivity of triclabendazole treatment. This was not possible in the present study, but is warranted given the increasing numbers of reports of resistance to triclabendazole.

Finally, cattle with hydatid cysts present in their livers at slaughter showed a 7.2 kg reduction in hot carcass weight as compared to cattle without hydatid cysts. Further efforts should focus on control in definitive hosts of *Echinococcus granulosus* including dogs, dingoes, and foxes, and prevention of infection of cattle prior to entering the feedlot. Specifically, domestic dogs should be treated with a drug that is labelled for control of *Echinococcus granulosus* according to the label instructions. These anthelmintic treatments are often required on a monthly schedule. Dogs should not be raw fed offal from intermediate hosts such as cattle, sheep, horses, deer, kangaroos, wallabies, pigs, goats, or camelids. Domestic dogs should be secured and not given the opportunity to access carcasses. Dogs, dingoes, and foxes should not be permitted in a feedlot for any reason as their faeces may contain eggs that are infective to cattle. Most cattle are likely infected prior to feedlot entry, and there is no effective treatment available for cattle once they are infected. Thus, efforts must focus on prevention.

6.3 Adoption activities

This project delivers a very clear message that treatment with a dewormer yields productivity benefits and there is a high return on investment for anthelmintic treatment. This message should be clearly communicated with industry stakeholders including veterinarians and consultants through a presentation at the Australian Lot Feeders Association Veterinarians and Nutritionists meeting. A newsletter article will be prepared for 'The Quarterly Feed', Meat & Livestock Australia's platform for communication of insights from feedlot industry research. Veterinarians and parasitologists can offer a service for feedlots to monitor the effectiveness of dewormer treatments, and can lead the discussion of those results to drive adoption of this study and assist feedlots in reducing post-treatment faecal egg counts to levels less than 25 eggs per gram of faeces. A research article will be submitted to *Veterinary Parasitology*, an internationally recognized peer-reviewed scientific journal, to share the findings of this work with veterinary parasitologists, animal scientists, and veterinarians. This work will be presented at domestic and international parasitology meetings.

7 Key messages

In practical terms, feedlots should:

- Deworm cattle at induction with the anthelmintic of their choice, with consideration of the genera of parasites that are targeted. Deworming cattle at feedlot induction yields a 3.3 kg in hot carcass weight compared to untreated cattle and represents a 20:1 return on investment. There is no evidence of an economic advantage to deworming cattle with a combination treatment and thus single active anthelmintic products are acceptable. All treatments tested in the present study reduced faecal egg counts to less than 10 eggs per gram. Although a low level of resistance to injectable doramectin was consistently identified, treatment with injectable doramectin achieved the same level of productivity as compared to any of the drugs tested.
- Aim to reduce faecal egg counts to 25 eggs per gram following treatment in order to prevent the impact of gastrointestinal parasites on animal productivity.

- Consider incorporating a low-intensity parasitological component into their feedlot management system to monitor the effectiveness of dewormer treatments in order to ensure that worm burdens do not impact productivity. Specifically, feedlots can submit composite faecal samples for screening following treatment with an anthelmintic.
- Although the present study showed no evidence for treatment with a combination of multiple active anthelmintic compounds, combination treatments should still be considered the ideal strategy to ensure high levels of efficacy against parasites with different levels of resistance.

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