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Title:

Associations between nematode larval challenge and gastrointestinal tract size that affect carcass productivity in sheep

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Abstract (299 words)

Effects of gastrointestinal parasitism on sheep productivity are usually described using live weight change, however carcass productivity is more accurately described using dressing percentage (carcass weight as a proportion of live weight). This experiment had a 2x2x2 factorial design whereby 10-month-old Merino wethers were fed lucerne (*Medicago sativa*) diets (fresh lucerne or lucerne chaff) with 2 levels of carboxymethycellulose (CMC) inclusion (0% or 8% CMC) and nematode larval challenge (no larval challenge or 10 000 *Teladorsagia circumcincta* and 10 000 *Trichostrongylus colubriformis* per week). Sheep were weighed and euthanased 50 or 51 days after larval challenge and CMC supplementation commenced. Weight of the carcass (hot standard carcass weight) and gastrointestinal organs (full and empty) were recorded and expressed as a proportion of live weight. Larval challenged sheep had a worm egg count (mean ± standard error) of 173 ± 38 eggs per gram of faeces and total worm count of 30 237 ± 2013 at slaughter. Larval challenged sheep had 1.3% lower dressing percentage ($p=0.048$), and 2% heavier full ($p=0.007$) and 1.2% heavier empty gastrointestinal tracts ($p=0.012$) compared to unchallenged sheep. There was no effect of CMC inclusion or lucerne type (fresh or chaff) on gastrointestinal tract weight or dressing percentage. Larval challenged sheep had 1.1% heavier full ($p<0.001$) and 0.6% heavier empty ($p<0.001$) small intestines, and 0.6% heavier full ($p=0.005$) and 0.3% heavier empty ($p=0.026$) large intestines compared to unchallenged sheep. Use of live weight change or other measures based on live weight (eg feed conversion efficiency) to assess the impact of nematode challenge in sheep may underestimate carcass productivity losses associated with larval challenge in sheep even at moderate levels of larval intake and without overt clinical signs of parasitism. Measurement of carcass weight and/or lean meat yield may better reflect the true economic effects of parasitism in sheep.

Keywords

Sheep-nematoda, gastrointestinal, productivity, carcass

Introduction

Gastrointestinal nematode infection and the subsequent host immune response have important productivity consequences for sheep meat and wool production. The impact of gastrointestinal parasitism on sheep productivity is usually presented in terms of live weight change, or less commonly effects on economy of nutrient utilisation by the host (Greer, 2008; Sykes and Greer, 2003). Measuring changes in live weight may not accurately describe differences in carcass productivity because a number of factors affect the relationship between live weight and carcass weight, including body composition (particularly fatness) and weight of the gastrointestinal tract contents, as well as a number of other factors such as time off feed, diet, weaning, sex, breed, wool growth and the method by which carcasses are processed (Arnold and Meyer, 1988; Davis, 2003; Makarechian et al., 1978; Meyer, 1962; Warriss et al., 1987). The relationship between carcass weight and live weight can be expressed using dressing percentage. Whilst nematode infections can have important effects on protein deposition, bone size, mineral deposition, gastrointestinal structure and function (Coop and Angus, 1981), the effect of nematode infections on dressing percentage in lambs is not well described.

The experiment described herein was part of a series of studies developing a model for investigating the effects of dietary soluble non-starch polysaccharides (NSP) and gastrointestinal parasites on faecal consistency in ruminants (Jacobson, 2006). Dietary soluble NSP can increase digesta viscosity, intestinal size, faecal moisture content and incidence of diarrhoea, and have been associated with changes in the intestinal microbiota and histological mucosal structure in monogastric species (Choct, 1997; Choct and Kocher, 2000; Elsenhans and Caspary, 2000; McDonald et al., 2001). Diets high in soluble NSP have been associated with increased proliferation of certain pathogenic bacteria in the small intestine of pigs (Pluske et al., 2002) and the establishment of nematode parasites in the small intestine of mice (Sun et al., 2002). However, neither the effects of soluble NSP on gastrointestinal structure and function or the interaction between dietary NSP content with gastrointestinal disease agents have been studied extensively in

ruminants. Carboxymethylcellulose (CMC) is a purified soluble, viscous polysaccharide that has been used as a model substrate to increase the viscosity of intestinal contents in pigs (Bartelt et al., 2002; McDonald et al., 2001), chickens (Smits et al., 1997; van der Klis et al., 1993a; van der Klis et al., 1993b) and rats (Elsenhans and Caspary, 2000; Wyatt et al., 1988).

The aim of this experiment was to investigate if the larval challenge with *Teladorsagia circumcincta* and *Trichostrongylus colubriformis* or CMC affects gastrointestinal tract size and dressing percentage of sheep fed lucerne (*Medicago sativa*) diets.

Materials and methods

Animals and experimental design

The experiment was approved and supervised by the Murdoch University Animal Ethics Committee (permit R1032/04). Forty-eight 10-month-old Merino wethers were housed in individual pens. The experiment was arranged according to a 2x2x2 factorial design with the respective treatments being roughage type ("fresh" lucerne or lucerne chaff), CMC inclusion (0% or 8% CMC) and nematode larval challenge (larval challenge or no larval challenge). All sheep were treated with an abamectin-albendazole-levamisole-closantel anthelmintic drench (Q-Drench®, Virbac) before the study commenced and fed either "fresh" lucerne or lucerne chaff for a two-day introductory period. After the introductory period, sheep were stratified by live weight, allocated to treatment groups and the CMC supplementation and larval dosing commenced. The experimental treatment period lasted 50 days, however fresh lucerne was not available after day 21 of treatment period and hence after day 21 all diets were based on lucerne chaff.

Diets

The composition and chemical analysis of the diets are outlined in Table 1. All dietary treatments were fed *ad libitum* and sheep were fed daily.

98 The "fresh lucerne" diet was grown on a commercial lucerne property south of Perth,
99 Western Australia. The period between cutting and delivery ranged between 2 hours and 5 days
100 depending on weather conditions. Fresh lucerne was fed within 48 hours of arrival or loosely
101 packed into sacks and stored at 4^{o}C for up to 3 days. There were two episodes of heavy rainfall over
102 several days that caused substantial deterioration of the quality of the standing lucerne crop
103 prompting the termination of the fresh lucerne treatment. All sheep were then fed lucerne chaff
104 from day 21 until day 50. Lucerne chaff was sourced from the same property as the fresh lucerne
105 diet.
106 Carboxymethylcellulose (CMC) diets included high viscosity CMC (1500-3000cps
107 when 1% solution at 25^{o}C, Sigma Aldrich C-5013) that was added at a rate 8% of the total dry
108 matter content of the diet. Dry matter content of the fresh lucerne was measured by drying at 65^{o}C
109 for at least 48 hours.
110
111 *Nematode larval challenge*
112 Sheep in the larval challenge treatment groups were dosed orally with 10 000 *Tel.*
113 *circumcincta* (Yalanbee strain, Department of Agriculture and Food Western Australia) and 10 000
114 *T. colubriformis* (Yalanbee strain, Department of Agriculture and Food Western Australia) per
115 week divided into two equal doses. The first larval dose was given on Day 0 and the last dose on
116 Day 48.
117
118 *Live weight and organ weight measurements*
119 Sheep were weighed twice weekly throughout the course of the experiment and again
120 immediately prior to euthanasia. Sheep were euthanased using a captive bolt and exsanguination on
121 days 50 and 51 of the experimental period. The viscera were removed and divided into five
122 segments: "stomachs" (reticulorumen/omasum/abomasum), "small intestine" and "large intestine"
123 (including caecum). Each segment was tied off and the full weight recorded. Empty weight of each

section was recorded following emptying of the contents, rinsing with water and dry blotting the tissue with paper towel. Hot standard carcass weight (HSCW) was recorded based on AUS-MEAT standard trim.

Parasitological measurements

Faeces were collected per rectum on 13 occasions throughout the experimental period for modified McMaster worm egg count. The worm egg counts and total worm counts were performed using methods described in Australian Standard Diagnostic Techniques for Animal Diseases Manual (Lyndal-Murphy, 1993).

Statistical analyses

Daily dietary intake was calculated based on dry matter intake as a proportion of live weight. Dressing percentage and gastrointestinal organ size were calculated based on HSCW and gastrointestinal organ weight as a proportion of live weight (recorded immediately before euthanasia). Statistical analyses were performed using SPSS 11.0 for Macintosh OS X (SPSS Inc, Chicago, USA). The effect of experimental treatments (roughage type, CMC inclusion and larval challenge) on body composition was analysed by univariate analysis of variance (ANOVA) with the three treatments included as independent variables. Differences in the mean measurements between treatment groups were analysed using the least squares difference post-hoc test. Relationships between total worm count (excluding third stage larvae) and dressing percentage, full gastrointestinal tract weight and empty gastrointestinal tract weight were analysed using Pearson correlation (2-tailed significance).

Results

Parasite establishment

149 No strongyle worm eggs were detected in the faecal samples collected on day 1. Larval
150 establishment in the larval challenged sheep are shown in Table 2. The mean total worm count of
151 larval challenged sheep at slaughter (days 50 and 51) was 30 237 ± 2013 (total worm count
152 excluding third stage larvae ± standard error). There was no effect of roughage (p=0.443) or CMC
153 inclusion (p=0.180) on total worm count. Adult worm count (mean adult nematodes ± standard
154 error) in larval challenged sheep was 20 681 ± 1575 *T. colubriformis* and 2898 ± 549 *Tel.*
155 *circumcincta*. The mean strongyle worm egg count of larval challenged sheep at slaughter was
156 173±38 eggs per gram of faeces. None of the sheep in the larval challenge groups showed overt
157 signs of parasitism such as listlessness, weight loss or persistent diarrhoea.
158
159 *Dietary intake and live weight change*
160 Mean dry matter intake, mean daily weight gain and live weight change over the course
161 of the experiment are shown in Table 3. Daily dry matter intake of sheep fed the fresh lucerne diets
162 (2.5% live weight per day) was lower compared to sheep fed lucerne chaff diets (3.0% live weight
163 per day) over the course of the experiment ($p<0.001$). After the fresh lucerne diets were
164 discontinued (from day 22 until slaughter) and all sheep were fed lucerne chaff, there was no
165 significant effect of earlier lucerne type ("fresh" or chaff fed day 1-21) on mean dry matter intake
166 (p=0.927). There was no effect of CMC inclusion (p=0.196) or larval challenge (p=0.179) on mean
167 dry matter intake.
168 Sheep fed the fresh lucerne diets gained more weight (23.0% increase in live weight)
169 than sheep fed lucerne chaff diets (18.5% increase in live weight, p= 0.032) over the course of the
170 experiment. There was a trend to increased average daily gain in live weight in the unchallenged
171 sheep (151g/day) compared to the larval challenged sheep (128g/day) over the course of the
172 experiment (p=0.062).
173
174 *Gastrointestinal organ size and dressing percentage*

Gastrointestinal organ size and dressing percentage are shown in Table 3. There was no significant effect of roughage, CMC inclusion or larval challenge on the size of either empty or full reticulorumen-omasum-abomasum (stomachs) at slaughter. Sheep in the larval challenge groups had heavier full small intestines (4.5% versus 3.4% live weight, $p<0.001$) and heavier empty small intestines (1.9% versus 1.2% live weight, $p<0.001$) compared to unchallenged sheep. There was no effect of roughage or CMC inclusion on full or empty small intestine weight relative to live weight, but there was an interaction between roughage and larval challenge on full small intestinal weight ($p=0.032$) whereby the difference between the full small intestine weight of larval challenged (4.7% live weight) and unchallenged sheep (3.1% live weight) within the fresh lucerne treatments was greater than the difference between larval challenged (4.3% live weight) and unchallenged (3.7% live weight) sheep in the chaff treatments.

The larval challenged sheep had heavier full large intestines (5.0% versus 4.4% live weight, $p=0.005$) and empty large intestines (2.8% versus 2.4% live weight, $p=0.026$) compared with unchallenged sheep. There was no effect of CMC inclusion on full ($p=0.355$) or empty ($p=0.940$) large intestine size. There was no effect of roughage type on full large intestine size ($p=0.759$) but there was a trend ($p=0.066$) to heavier empty large intestine of sheep fed lucerne chaff for the first 21 days (2.7% live weight) compared to sheep fed fresh lucerne in the first 21 days (2.4% live weight). There was also a three-way interaction between larval challenge, roughage and CMC inclusion on empty large intestinal weight ($p=0.041$), whereby sheep in the fresh lucerne control group (fresh lucerne/0% CMC/no larval challenge) had smaller empty large intestine (1.8% live weight) compared to all other treatments except for lucerne chaff/8% CMC/unchallenged group.

As a consequence of the changes in weight of the small and large intestines, the larval challenged sheep had a lower dressing percentage (39.5%) compared to unchallenged sheep (40.8%) at slaughter ($p=0.048$). There was no significant effect of roughage or CMC inclusion on dressing percentage. Larval challenged sheep had heavier full gastrointestinal tracts as proportion of

live weight (26.0% live weight) compared to unchallenged sheep (24.0% live weight, p=0.007). The empty gastrointestinal tracts of larval challenged sheep (9.2% live weight) were heavier than the unchallenged sheep (8.0% live weight, p=0.012). There was no effect of roughage or CMC inclusion on full or empty gastrointestinal tract size. There was no significant correlation between total worm count and full (p=0.147) or empty (p=0.902) gastrointestinal tract weight as a proportion of live weight or dressing percentage (p=0.119) in larval challenged sheep.

Discussion

The effects of parasitism on the intestinal size of sheep and consequences for carcass productivity have received surprisingly little attention in the literature. Data from the present study shows that larval challenge with *T. colubriformis* and *Tel. circumcincta* increased the size of the gastrointestinal tract as a proportion of live weight, thereby causing a decrease in the economically important measurement of dressing percentage.

Intestinal nematode infections have been shown to increase the size of the gastrointestinal tract in guinea pigs (Symons and Jones, 1983) and in pigs (Thomsen et al., 2006). *Trichuris suis* infection in pigs was associated with increased mucin staining area, crypt area and crypt height but not crypt density or tunica muscularis thickness (Thomsen et al., 2006). The increase in gastrointestinal tissue mass of sheep challenged with nematode larvae may be due to stimulation of the local immune response (including infiltration of mucosal mast cells and globule leukocytes and mucous production), and sheep selected for low worm egg count have heavier small and large intestines (relative to carcass weight) compared to unselected sheep after trickle infection with *T. colubriformis* and *Tel. circumcincta* (Liu et al., 2005). The genotype of the sheep may therefore be expected to influence the magnitude of effect of parasite challenge on carcass productivity (Greer, 2008; Liu et al., 2005) and so assessment of the effect of parasite challenge on carcass productivity of sheep selected for parasite resistance using low worm egg count also warrants further consideration.

If increased size of the gastrointestinal tract relative to live weight is shown to be a consistent finding in sheep challenged and infected with *T. colubriformis* and *Tel. circumcincta*, then measurements of live weight change could be expected to underestimate the impact of parasitism on sheep productivity because live weight change may not fully describe the effect of parasitism on carcass weight or lean meat yield. The effect of larval intake on sheep productivity in general, and particularly on sheep meat productivity, therefore warrants further investigation as the most important production penalties usually attributable to nematode infection and grazing of pastures contaminated with nematode larvae are reductions in live weight gain, nutrient utilisation, soft tissue deposition, skeletal growth, milk and wool production (Greer, 2008; Sykes, 1978, 1994).

The trickle larval challenge used in this experiment resulted in sub-clinical parasitic infections, specifically the infected sheep continued to gain weight, intake was not significantly reduced relative to non-infected sheep and there were no overt signs of parasitic disease such as ill thrift, listlessness or persistent diarrhoea. The mean worm egg count of infected sheep at slaughter (173 eggs per gram) was below the level at which a treatment would normally be recommended. This is important because it suggests that lambs with low egg counts (<200 eggs per gram) grazing pastures contaminated with larvae resulting in a larval intake of 20 000 larvae per week and showing no overt signs of parasitic disease may be suffering carcass production losses due to reduced efficiency of the conversion of feed to hot carcass weight. It was likely that the diversion of nutrients away from carcass productivity was the result of the immune response to larval challenge and was consistent with other studies showing that the acquisition and maintenance of immunity to gastrointestinal parasites in sheep is a nutritionally costly process inducing a diversion of nutrients from productive to immunological tissues (Greer, 2008). The exposure of the lambs to nematode parasites prior to the start of the experiment was not known and so further work would be required to better describe the effect of prior larval exposure (including species of nematode, size and duration of larval challenge) on organ weight and dressing percentage in lambs.

The difference in dressing percentage observed (1.3%) in the larval challenged lambs was small but significant, representing a carcass weight difference of 0.585kg for a 45kg lamb (live weight) or 130g difference in carcass weight for every 10kg of lamb live weight (not held off feed). Furthermore, we believe that dressing percentages of sheep in this study were underestimated because sheep were not held off feed before to slaughter as would normally be the case for lambs consigned for commercial slaughter. Dressing percentage would be expected to increase with fasting, primarily due to decrease in the weight of gut contents and corresponding decrease in live weight following feed withdrawal (Thompson et al., 1987; Warriss et al., 1987). Leaness also affects dressing percentage percentages (Thompson et al., 1987). Fat score of the lambs was not recorded for this experiment. Other factors that associated with differences in dressing percentage are roughage content of diet, weaning, skin weight (wool length), sex and breed (Arnold and Meyer, 1988; Davis, 2003; Makarechian et al., 1978), although these factors were constant across all treatment groups in this study. There was no effect of dietary treatments (roughage type and CMC inclusion) on dressing percentage in this experiment. The differences in dressing percentage of larval challenged and unchallenged sheep would be expected to be present if the lambs had been held of feed for 12 hours before slaughter because there was a 1.2% live weight difference in the empty gastrointestinal tract.

The reason for differences in the establishment of the two nematode species was not tested in this experiment, but possible reasons include differences in viability of the cultured larvae, differences in prior exposure to the two species or differences in the host immune response to the two species (Dobson et al., 1992).

Conclusion

Larval challenge with *T. colubriformis* and *Tel. circumcincta* larvae increased the weight of gastrointestinal tracts as a proportion of live weight in sheep compared to unchallenged sheep and this was associated with a reduction in dressing percentage. The larval challenged sheep had heavier small and large intestines than unchallenged sheep and this difference was observed in

278 both the full and empty weights of these organs. Use of live weight change or other measures based
279 on live weight (such as feed conversion efficiency) to assess the impact of larval challenge and
280 nematode infection may underestimate productivity losses associated with parasitism in sheep, and
281 measurement of carcass weight and/or lean meat yield may better reflect the true economic effect of
282 parasitism in sheep meat production systems.
283
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292
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Table 1: Experimental design and dietary treatments

Larval challenge (L)	Unchallenged				Larval challenge			
Roughage (R)	Fresh lucerne		Lucerne chaff		Fresh lucerne		Lucerne chaff	
CMC (C)	No CMC	8% CMC	No CMC	8% CMC	No CMC	8% CMC	No CMC	8% CMC
Sheep (n)	6	6	6	6	6	6	6	6
Nematode dosing								
Tel. cicumcincta/week	-	-	-	-	10 000	10 000	10 000	10 000
T. colubriformis/week	-	-	-	-	10 000	10 000	10 000	10 000
Dietary composition (% dry matter)								
Fresh lucerne	100%	92%	-	-	100%	92%	-	-
Lucerne chaff	-	-	100%	92%	-	-	100%	92%
CMC	-	8%	-	8%	-	8%	-	8%
Calculated and chemical analysis of diet								
Mean DM	45%	46%	89%	88%	45%	46%	89%	88%
Mean ME (MJ/kg DM)	10.2	10.0	10.2	10.0	10.2	10.0	10.2	10.0
Mean CP (% DM)	25%	24%	24%	23%	25%	24%	24%	23%

Table 2: Larval establishment of nematodes in larval challenged lambs (mean ± standard error)

	Fresh lucerne		Lucerne chaff	
	No CMC	8% CMC	No CMC	8% CMC
Adult *Tel. circumcincta*	2692 ± 755	2367 ± 732	3300 ±837	3233 ± 1900
Adult *T. colubriformis*	20 775 ± 3454	24 950 ± 2477	14 350 ± 2898	22 650 ± 2600
Immature	883 ± 244	550 ± 242	925 ± 217	1267 ± 554
Fourth stage larvae	6733 ±1464	4633 ± 812	5292 ± 766	6350 ± 1934
Total worm count	31 083 ± 2997	32 500 ± 3277	23 867 ± 3322	33 500 ± 5693

Table 3: Effect of dietary treatments and larval dosing on dry matter (DM) intake, growth rate, hot standard carcass weight (HSCW) and weight of gastrointestinal organs as a proportion of live weight (Lwt) of sheep

Larval challenge (L)	Non-challenged				Larval challenge					ANOVA significance (p-value)						
Roughage (R)	Fresh lucerne		Lucerne chaff		Fresh lucerne		Lucerne chaff		s.e.d.							
CMC (C)	No CMC	8% CMC	No CMC	8% CMC	No CMC	8% CMC	No CMC	8% CMC		L	R	C	LxR	LxC	RxC	LxRxC
Mean DM intake (%/day)	2.68^{A}	2.44^{A}	3.14^{B}	3.04^{C}	2.49^{A}	2.59^{A}	2.99^{BC}	2.92^{BC}	0.04	-	***	-	-	-	-	-
Mean daily gain (g/day)	180^{A}	138^{AB}	139^{AB}	145^{AC}	149^{AC}	149^{AC}	91^{B}	121^{BC}	8.35	0.062	*	-	-	-	-	-
Lwt change (% change)	27.9^{A}	19.7^{BC}	20.8^{AB}	22.3^{AC}	21.9^{AB}	22.5^{AC}	13.9^{B}	16.9^{BC}	1.43	0.062	*	-	-	-	-	-
Dressing % (HSCW/Lwt)	40.9	41.4	40.0	41.0	38.9	40.0	39.9	39.1	0.47	*	-	-	-	-	-	-
Full gut weights (% Lwt)																
Stomachs	15.0	16.8	15.2	15.2	15.0	15.7	15.9	17.4	0.52	-	-	-	-	-	-	-
Small intestine	3.2^{AB}	3.1^{A}	4.1^{BC}	3.2^{AB}	4.6^{C}	4.8^{C}	4.3^{C}	4.3^{C}	0.15	***	-	-	*	-	-	-
Large intestine	4.7^{AB}	4.4^{AB}	4.5^{AB}	4.1^{B}	4.8^{B}	5.0^{B}	5.1^{B}	5.0^{B}	0.13	**	-	-	-	-	-	-
Gastrointestinal tract	24.8^{AB}	23.7^{AC}	24.5^{AB}	22.9^{AB}	25.7^{BC}	25.5^{AB}	25.4^{AB}	27.4^{B}	0.33	**	-	-	-	-	-	-
Empty gut weights (% LWt)																
Stomachs	4.2	3.8	4.7	4.2	4.9	5.0	3.7	4.6	0.32	-	-	-	-	-	-	-
Small intestine	1.2^{A}	1.2^{A}	1.4^{AC}	1.2^{A}	1.9^{B}	2.0^{B}	1.8^{B}	1.7^{BC}	0.06	***	-	-	-	-	-	-
Large intestine	1.8^{A}	2.6^{B}	2.8^{B}	2.4^{AB}	2.8^{B}	2.5^{B}	2.9^{B}	2.8^{B}	0.11	*	0.066	-	-	-	-	*
Gastrointestinal tract	7.7^{AB}	7.5^{A}	8.8^{AB}	7.9^{AB}	9.7^{B}	9.6^{B}	8.4^{AB}	9.1^{AB}	0.33	*	-	-	-	-	-	-

s.e.d. standard error of the difference
- P>0.100
* p<0.05
** p<0.01
***p<0.001