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Research paper

# An assessment of worm control practices used by alpaca farmers in Australia

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ABSTRACT

This study aimed to assess current worm control practices used by Australian alpaca farmers with an online questionnaire survey. The questionnaire contained questions about farm demography and general husbandry practices, farmers' knowledge about gastrointestinal nematodes (GINs) and their importance, the use of worm control strategies and anthelmintics, and grazing management. A link for the questionnaire survey was sent to all ($n$ = 954) registered members of the Australian Alpaca Association in July 2015. The response rate for the questionnaire was 25% (239/954). The majority of respondents were from small (≤ 50 alpacas; 64%, 153/239) followed by medium (50–100 alpacas; 24%, 57/239) and large (> 100 alpacas; 12%, 29/239) farms. Findings revealed that the majority of respondents kept Huacaya alpacas to produce high-quality fibre and alpacas were usually kept with other domestic ruminants (e.g. cattle and sheep). Although half of alpaca farmers (114/220) perceived that GINs were an important health problem of alpacas, with *Haemonchus* spp. being the most common nematode, the majority of them (174/220) used anthelmintics for nematode control. Macrocyclic lactones, a commercial combination of four anthelmintics (abamectin, albendazole, closantel and levamisole) and monepantel were the three most commonly used dewormers by Australian alpaca farmers. Although a significant proportion (166/213) of respondents used a quarantine drench for alpacas, very few respondents were aware of strategic deworming and the issue of anthelmintic resistance. Alpaca farmers mostly used anthelmintics at the dose rate recommended for sheep (47%, 79/167) and cattle (9%, 15/167), though some used 1.5 (31%, 51/167) and 2 (13%, 22/167) times the dose rate recommended for sheep. The majority of small herds used anthelmintics at the dose rate recommended for sheep and cattle while medium and large herds used anthelmintics at 1.5 to 2 times the dose rate recommended for sheep. This study provides invaluable insights into the demography of alpaca farms in Australia, husbandry practices used by alpaca farmers and their knowledge about worms and their control, thereby paving the way for developing guidelines for the control of GINs of alpacas.

## 1. Introduction

Alpacas (*Lama pacos*) and llamas (*Lama glama*) are native to the high Andean Plateau region in South America. For centuries, alpacas and llamas have been used by Andean communities for their socioeconomic value (Leguía, 1991; Windsor et al., 1992a). Recently, the commercial farming of alpacas has also been exploited outside South America, mainly in Australia, Canada, Europe, New Zealand, the UK and the USA, for their fibre, meat and hides. Additionally, alpacas are kept as guard animal on sheep farms, or simply for lifestyle purposes (Ballweber, 2009; Tait et al., 2002).

As with other grazing livestock species, gastrointestinal nematodes (GINs) infections are considered as one of the important challenges alpaca farmers face globally, causing diarrhoea, reduced growth rate, anaemia and mortality (Edwards et al., 2016; Leguía, 1991; Rojas et al., 2016; Thomas and Morgan, 2013; Twomey et al., 2014; Windsor et al., 1992a, 1992b). For instance, a wide range of GINs such as *Haemonchus contortus*, *Camelostrongylus mentulatus*, *Ostertagia* spp., *Trichostrongylus* spp. and *Lamanema chavezi* have been recorded in alpacas from Australia, Europe, New Zealand, the UK and the USA (Ballweber, 2009; Cebra and Stang, 2008; Fowler, 2001; Franz et al., 2015; Hill et al., 1993; Leguía, 1991; Rashid et al., 2019a,b,c; Rickard, 1994; Rickard and Bishop, 1991). Although economic losses due to parasitism in alpacas have not been quantified in intensive grazing systems, it is expected that parasitic gastroenteritis in alpacas would result in substantial production losses as reported by Windsor et al. (1992a) in Peruvian alpacas.

Currently, the control of nematode infections in South American

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camelids (SACs) relies mainly on the use of anthelmintics, although no anthelmintic is registered for use against GINs in these animals in Australia. However, anthelmintic resistance (AR) is now recognised as an important threat to the health, productivity and welfare of alpacas and llamas globally (Galvan et al., 2012; Gillespie et al., 2010; Jabbar et al., 2013; Rashid et al., 2018; Sarre et al., 2012) as limited information is available on pharmacokinetic properties (Hunter et al., 2004), and appropriate dose rates and routes of administration of anthelmintics used in SACs (Rashid et al., 2018).

Although Australia has the largest alpaca population (> 450,000) outside South America (Clarke, 2016), very little is known about the epidemiology and control of GINs in alpacas (Carmichael, 1999, 2014; Presidente, 2007). Furthermore, there is no information available on parasite control practices used by Australian alpaca farmers. To date, only two reports are available documenting the understanding of parasites and their control by alpaca and llama farmers from Switzerland (Hertzberg and Kohler, 2006) and the UK (Tait et al., 2002). However, implementation of an integrated parasite management approach is more likely to work and be sustained when embedded into the solid and cooperative social structures of farming communities (Geels, 2002). Therefore, it is crucial to understand farmers' perceptions about the control of GINs in alpacas as has been demonstrated in the control of GINs in ruminants (Borgsteede et al., 1998; Ploeger et al., 2016; Reinemeyer et al., 1992).

The objective of this study was to document the current worm control practices used by Australian alpaca farmers for the treatment and control of GINs using an online questionnaire survey.

## 2. Materials and methods

### 2.1. Alpaca farms in Australia

In Australia, most alpaca farms are located in the south-eastern states of New South Wales and Victoria, with smaller numbers in Queensland, Western Australia, South Australia and Tasmania. Alpacas are routinely vaccinated against clostridial diseases (caused by *Clostridium perfringens* type D, *C. tetani*, *C. novyi* type B, *C. septicum* and *C. chauvoei*). They are generally shorn once annually in spring, although at variable times throughout the year. Timing and duration of the birthing periods vary among farms but often occur for about two months in autumn.

### 2.2. Questionnaire

A questionnaire was conducted using an online programme, Research Electronic Data Capture (Harris et al., 2009). The questionnaire (see Appendix A) contained 131 questions about (i) farm demography and general husbandry practices of alpacas, (ii) farmers' knowledge about GINs and their importance, (iii) the use of worm control strategies and anthelmintics, and (iv) grazing management. The majority of the questions were close-ended, with a few semi-open (i.e., a close-ended question with the addition of a category "other"). The questionnaire was first validated using a pilot survey, including 29 alpaca farmers which were then excluded from data analyses of the definitive survey.

The participants of the survey were registered members of the Australian Alpaca Association (AAA) and their participation in the study was entirely voluntary. Following a pilot survey, all active members ($n$ = 954) of the AAA received an invitation through email (20 July 2015) from the head office of the AAA to participate in the survey. The participants were reminded via email three times before it closed on 31 August 2015. In addition, alpaca farmers were encouraged (three times via email) to participate in the survey using regional offices of the AAA as well as social media platforms such as the Facebook page of the AAA. The questionnaire survey was approved by the Human Ethics Committee (Ethics ID 1,443,529) of the University of Melbourne.

Farmers could submit the questionnaire anonymously but were asked to enter the four digits of their postal code to allow a general assessment of the geographical distribution of respondents.

### 2.3. Data analyses

Analyses were performed using Stata (StataCorp., 2013) and R (R Core Team, 2013). Questionnaire data were downloaded from REDCap as a comma delimited (CSV) file. This database contained 254 questionnaires, and data validation and cross-checking were performed manually using Microsoft Excel 2013. Questionnaires submitted with incomplete responses were discarded, leaving a total of 239 questionnaires.

Based on the number of alpacas per farm, herds were divided into three categories: small ≤ 50 alpacas, medium 51–100 alpacas and large > 100 alpacas. For each variable, a descriptive analysis was carried out, producing frequencies for categorical variables and means and medians with standard deviations for continuous variables. Subsequently, differences between types of herds for various variables such as worm problems, treatment, and observation on clinical signs were compared using Pearson's Chi-square test. When percentages of responses were calculated, missing values were excluded from the denominator. In all cases, the reported percentages represent the percentage of those who responded to the question. In cases, where multiple answers to one question(s) were possible, the total of the denominator exceeded the total number of respondents.

Association plots were used to visualise cross tabulation (contingency table) for complex data. This type of plot is used to present a complex relationship from a contingency table in a meaningful way where the area of a box is proportional to the difference in observed and expected frequencies (Lewis, 2013). The rectangles above the dashed lines in the plot indicate that observed frequencies are greater than expected, showing a positive association. Similarly, rectangles below the dashed lines show observed frequencies are less than expected, demonstrating a negative association. The size and the shape of a rectangle indicate strength of the associations, with a wider rectangle indicating a higher frequency while a taller rectangle a higher proportion.

## 3. Results

### 3.1. General characteristics of alpaca farms

The response rate for the questionnaire was 25% (239/954). Although responses were received from all alpaca farming regions of Australia, the highest response rate (44%) was from the states of New South Wales and Victoria (30%) (Fig. 1) where the majority of the national alpaca population exists. The majority of respondents (69%, 165/238) had a tertiary level of education followed by secondary level (25%, 59/238). The average farming experience of respondents was 10.5 years (minimum 0, maximum 28 years). The main purpose of keeping alpacas was fibre production (78%, 186/239) followed by breeding (77%, 183/239), guard animal (42%, 100/239), hobby farming (40%, 95/239) and meat production (16%, 38/239).

The majority of respondents were from small herds (64%, 153/239) followed by medium (24%, 57/239) and large (12%, 29/239) herds. Of the 238 alpaca farmers, 67% (160/238) kept the Huacaya breed, 20% (47/238) both Huacaya and Suri breeds and only 13% (31/238) the Suri breed (Table 1). Overall, the mean herd size was 57 alpacas, with a range of 2–50, 51–100 and 105–1150 animals in small-, medium- and large-sized alpaca herds, respectively (Table 1). Similarly, the mean grazing area was highest for large herds (mean 123 ha, range 14–696 ha) followed by medium (60, 2–931) and small herds (43, 0.04–3,440) (Table 1). About 75% (9,730/12,917) of the surveyed alpaca population were female, with 68% (8,800/12,917) being more than 1-year-old females.

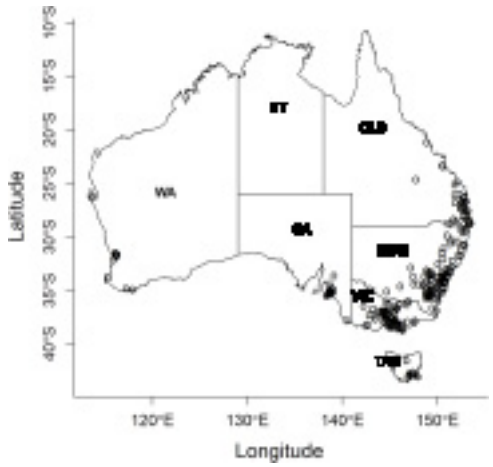


**Fig. 1.** Australian map showing distribution of alpaca farmers (o) who participated in the worm control practices questionnaire survey. States and territories of Australia: NSW, New South Wales; NT, the Northern Territory; QLD, Queensland; SA, South Australia; TAS, Tasmania; VIC, Victoria; WA, Western Australia.

**Table 1**
Demographic information of alpaca herds that participated in the survey.

| Question | Herd size | | |
|---|---|---|---|
| | Small | Medium | Large |
| No. of respondents (%) | 153 (64) | 57 (24) | 29 (12) |
| Alpaca breed(s) | | | |
| No. of Huacaya (%) | 102 (64) | 41 (26) | 17 (10) |
| No. of Suri (%) | 24 (77) | 3 (10) | 4 (13) |
| No. of Huacaya and Suri (%) | 26 (55) | 13 (28) | 8 (17) |
| No. of alpacas | | | |
| Mean (SD) | 24 (13) | 72 (16) | 199 (189) |
| Median (Q1, Q3) | 22 (13, 34) | 70 (59, 81) | 160 (130, 200) |
| Min – Max | 2 – 50 | 51 - 100 | 105 - 1150 |
| Grazing area (hectares) of the farms | | | |
| Mean (SD) | 43 (283) | 60 (153) | 123 (176) |
| Median (Q1, Q3) | 7 (3, 17) | 14 (8, 40) | 59 (26, 95) |
| Min – Max | 0.04 – 3440 | 2 – 931 | 14 - 696 |

SD, standard deviation; Q1, first quartile; Q3, third quartile; Min, minimum; Max, maximum.

### 3.2. Husbandry practices

Herd replacements were homebred on 88% (199/226) of farms across all alpaca herd sizes (Table 2), with the most common weaning age ≥ 5-months. Overall, only 15% (35/238) of respondents had agisted non-home-bred alpacas on their farms at least once during the last five years, with a higher percentage (34%, 10/29) in large herds. Raising weaned crias separated from their mothers was a common practice in the large herds. The majority of respondents (92%, 212/231) provided supplementary feed (hay and pelleted feed) to alpacas across all herd sizes, particularly during winter due to insufficient feed (59%, 124/212) or the provision of additional energy to lactating females (58%, 122/212) (Table 2).

Almost half (53%, 121/229) of the respondents farmed domestic ruminants along with alpacas across all herd sizes, with sheep (29%, 35/121) and cattle (24%, 29/121) being the most common species, and horses, donkeys, pigs, llamas and Huarizos (a cross between male llama and a female alpaca) being kept by 22% (52/239) of respondents. Alpacas co-grazed with sheep (68%, 23/34), cattle (29%, 10/34), and horses and donkeys (35%, 12/34), and the sharing of paddocks with other livestock species was similar across all herd sizes. A few respondents practised rotational grazing (17%, 20/119) or alternate grazing (7%, 8/119) using horses. Seventy-three percent of respondents (191/262) removed dung, with a frequency from once per week (13%, 33/262) to once in every 2–6 months (15%, 38/262), whereas 27% (71/262) of respondents never removed dung from pastures. The practice of removing dung was more common in small (79%, 131/166) and medium (75%, 47/63) herds rather than large (39%, 13/33) herds (Table 2). Harrowing of pastures was practised by 22% (49/227) of respondents.

### 3.3. Knowledge of worms

The level of knowledge of worms among respondents from different alpaca herd sizes was similar. Almost one half of respondents (52%, 114/220) perceived that GINs were an important health problem (Table 3), and the clinical signs they commonly associated with parasitic gastroenteritis were weight loss, anaemia, scouring and death (Fig. 2). Parasitic infections were diagnosed either using laboratory tests such as faecal egg counts (FEC) (86%, 98/114), larval culture (26%, 30/114) or by post-mortem examination conducted by veterinarians (17%, 20/114) (Table 3). Usually, FECs were performed in veterinary diagnostic laboratories (59%, 69/116) while a small percentage were performed by alpaca farmers (29%, 34/116). A small proportion of respondents (10%, 12/114) suspected parasitic infections in alpacas by observing low body condition scores or visual observation of worms (mostly tapeworms) in the faeces of their animals (Table 3). The majority of respondents (78%, 70/90) believed that the barber's pole worm (*H. contortus*) was the most commonly diagnosed GIN in their animals, particularly during autumn followed by black scour worms (*Trichostrongylus* spp.) and brown stomach worms (*Ostertagia* spp.) (Fig. 3; Table 3). Almost a quarter of respondents (24%, 22/90) thought that coccidia and tapeworm were also important parasites for their animals (Table 3). Females over two years old were the most common group of alpacas (39%, 44/114) affected by GINs.

**Table 2**
Farm husbandry and management practices used by Australian alpaca farmers included in this study.

| Husbandry/management practice | Herd size | | | | | | Total | |
|---|---|---|---|---|---|---|---|---|
| | Small | | Medium | | Large | | | |
| | Proportion | % (95% CI) | Proportion | % (95% CI) | Proportion | % (95% CI) | Proportion | % (95% CI) |
| On-farm birth of crias | 127/146 | 87 (80 – 92) | 47/52 | 90 (79 – 97) | 25/28 | 89 (72 - 98) | 199/226 | 88 (84 – 92) |
| Keeping agisted alpacas | 12/152 | 8 (4 – 13) | 13/57 | 22 (13 – 36) | 10/29 | 34 (18 – 54) | 35/238 | 15 (10 – 20) |
| Supplementary feed | 142/150 | 95 (92 – 98) | 47/52 | 90 (82 – 98) | 23/29 | 79 (64 – 94) | 212/231 | 92 (89 – 96) |
| Supplementation due to insufficient feed in winter | 80/142 | 56 (48 – 65) | 32/47 | 68 (53 – 81) | 12/23 | 52 (31 – 73) | 124/212 | 59 (52 – 65) |
| Supplementation to lactating females as extra diet | 78/142 | 55 (45 – 63) | 28/47 | 60 (44 – 74) | 16/23 | 70 (47 – 87) | 122/212 | 58 (51 – 64) |
| Keeping alpacas with other livestock species | 70/148 | 47 (39 – 56) | 28/52 | 54 (39 – 68) | 23/29 | 79 (60 – 92) | 121/229 | 53 (47 – 59) |
| Co-grazing of alpacas with other livestock species | 46/68 | 68 (55 – 78) | 20/28 | 71 (51 – 87) | 15/23 | 65 (43 – 84) | 81/119 | 68 (60 – 76) |
| Removal of alpaca dung from paddocks | 131/166 | 79 (72 -85) | 47/63 | 75 (62- 85) | 13/33 | 39 (23 – 58) | 191/262 | 73 (67 – 78) |

CI, confidence interval.

**Table 3**
Knowledge of worms known by Australian alpaca farmers included in this study.

| Question | Herd size | | | | | | Total | |
|---|---|---|---|---|---|---|---|---|
| | Small | | Medium | | Large | | | |
| | Proportion | % (95% CI) | Proportion | % (95% CI) | Proportion | % (95% CI) | Proportion | % (95% CI) |
| Worms are an important health issue of alpacas | 65/142 | 46 (37 – 54) | 32/51 | 63 (48 – 76) | 17/27 | 63 (42 – 81) | 114/220 | 52 (45 – 59) |
| Diagnostic method(s) used: | | | | | | | | |
| Faecal egg count (FEC) | 56/65 | 86 (75 – 93) | 27/32 | 84 (67 – 95) | 15/17 | 88 (64 – 99) | 98/114 | 86 (78 – 92) |
| Larval culture | 15/65 | 23 (14 – 35) | 9/32 | 28 (14 – 47) | 6/17 | 35 (14 – 62) | 30/114 | 26 (19 – 35) |
| Post mortem | 8/65 | 12 (5 – 23) | 5/32 | 16 (5 – 33) | 7/17 | 41 (18 – 67) | 20/114 | 17 (11 – 16) |
| Other method[1] | 6/65 | 9 (3 – 19) | 4/32 | 13 (4 – 29) | 2/17 | 12 (1 – 36) | 12/114 | 11 (10 – 18) |
| Identified worms on alpaca farms: | | | | | | | | |
| Barber's pole (*Haemonchus* spp.) | 39/53 | 74 (60 – 85) | 20/24 | 83 (63 – 95) | 11/13 | 85 (55 – 98) | 70/90 | 78 (68 – 86) |
| Black scour (*Trichostrongylus* spp.) | 15/53 | 28 (17, 42) | 9/24 | 38 (19 – 59) | 6/13 | 46 (19 – 75) | 30/90 | 33 (24 – 44) |
| Brown stomach (*Ostertagia* spp.) | 10/53 | 19 (9 – 32) | 11/24 | 46 (26 – 67) | 4/13 | 31 (9 – 61) | 25/90 | 28 (19 – 38) |
| Other[2] | 13/53 | 25 (14 – 38) | 6/24 | 25 (10 – 47) | 3/13 | 23 (5 – 54) | 22/90 | 24 (16 – 15) |

[1] Condition scoring, anaemia, diarrhoea, worms in faeces; [2]coccidia, tapeworm; CI, confidence interval.

### 3.4. Anthelmintics

The majority of respondents (79%, 174/220) used anthelmintics for the control of GINs of alpacas and this trend of deworming was similar across all herd sizes of alpacas (Table 4). Of the respondents having mixed livestock farming, only 34% (38/112) simultaneously dewormed alpacas and other livestock species. Most of the respondents (64%; 112/174) dewormed alpacas based on either the visual appraisal of their poor body condition or the results of recent FECs, and only 33% (57/174) and 8% (14/174) of them followed veterinarians' recommendations or any strategic deworming program respectively.

The commonly used anthelmintics were macrocyclic lactones (MLs) (e.g. ivermectin, moxidectin; 38% [127/331] respondents), monepantel (15%, 50/331), benzimidazoles (BZs; 9%, 31/331), levamisole (LEV; 5%, 15/331), closantel (5%, 15/331), and their combinations, including two (BZ and MLs) and three (BZ, LEV and MLs) (6%, 21/331), and four (closantel, BZ, LEV and MLs, 22% [72/331]) anthelmintics (Table 4; Fig. 4). No differences were observed among different herd sizes of alpacas for the use of anthelmintic classes. A small proportion of alpaca farmers (11%, 24/216) used diatomaceous earth powder and garlic powder as non-chemical deworming agents. Almost half of the respondents used anthelmintics at the dose rate recommended for sheep (47%, 79/167), though some used 1.5 (31%, 51/167) and 2 (13%, 22/167) times the dose rate recommended for sheep or the dose rate recommended for cattle (9%; 15/167). The majority of small herds used anthelmintics at the dose rate recommended for sheep and cattle while

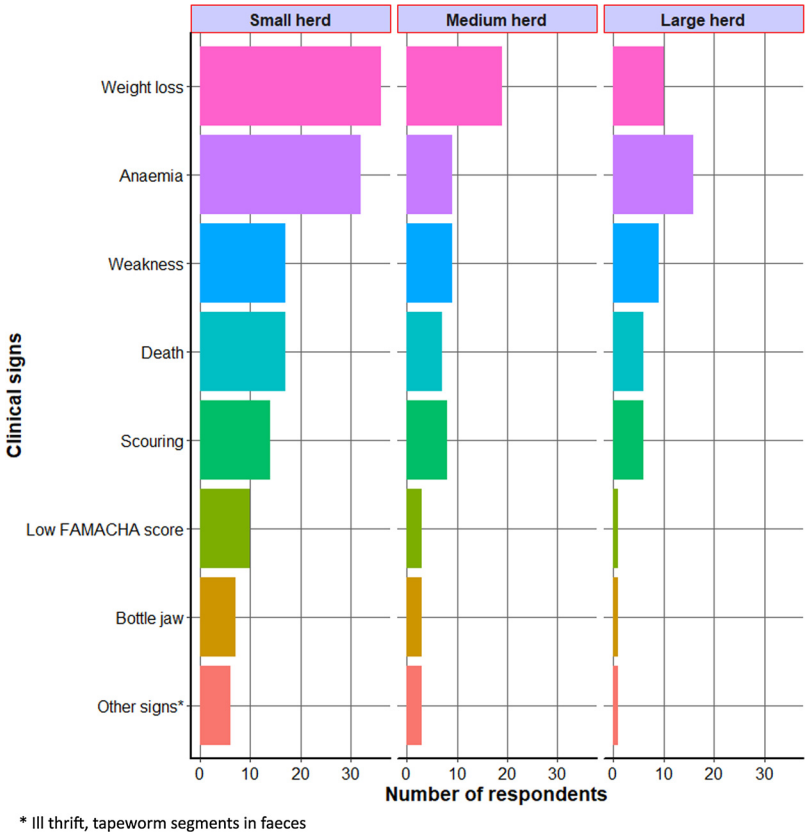


**Fig. 2.** Frequency of clinical signs reported by Australian alpaca farmers to be associated with parasitic gastroenteritis in different seasons from herds of different sizes.

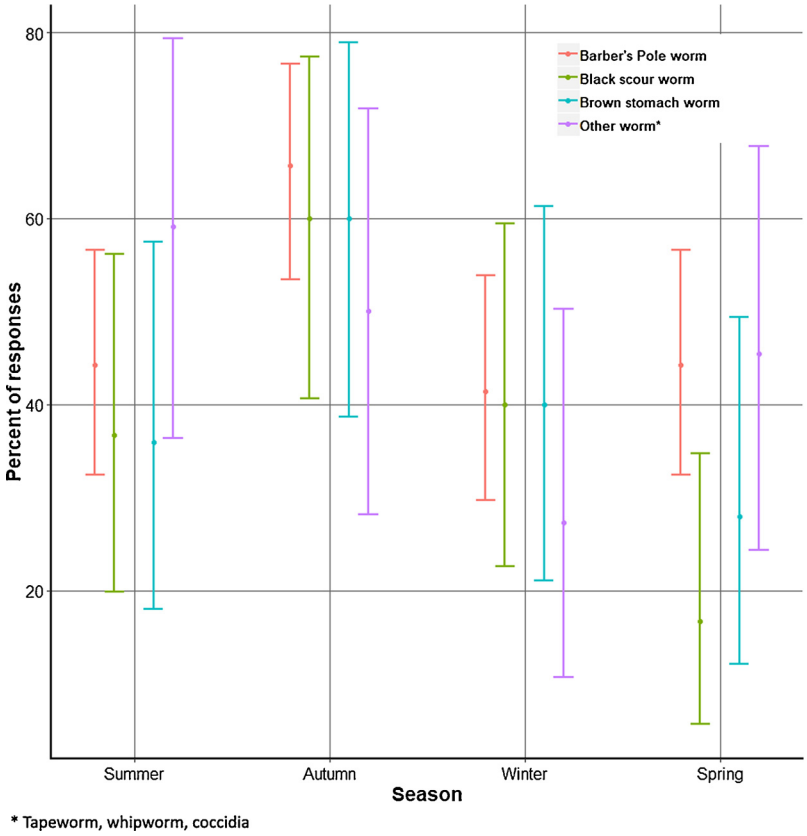


**Fig. 3.** Proportion of surveyed alpaca farmers reporting infections with different gastrointestinal nematodes in different seasons diagnosed by faecal culture (bars indicate 95% confidence interval).

medium and large herds used anthelmintics at 1.5–2 times the dose rate recommended for sheep (Fig. 5). The majority of alpaca farmers calculated the dose of anthelmintics based on the visual estimation of the weight of alpacas (71%, 123/174) whereas only 20% (34/174) used the actual body weight of animals. Almost half of the respondents (52%, 88/169) did not use a drenching gun and of those who used a drenching gun, only 14% (11/81) of them calibrated the gun.

Forty-three percent of alpaca farmers (75/174) did not follow any deworming schedule (month/season) to deworm their animals, though some indicated preference for the months of March (20%, 35/174) and October (20%; 34/174). The first deworming of alpacas was performed at the time of weaning by 33% (56/170) of respondents whereas another 30% (51/170) did not follow any fixed time for deworming. Sixty-six percent (112/170) of respondents rotated anthelmintics, and 55% (56/102) of them rotated anthelmintics every year. Furthermore, 47% (80/169) of farmers indicated that they had been using the same anthelmintic for the last two years or more, and the main reason for changing a class of anthelmintic was to prevent AR in GINs (60%, 58/96).

Seventy-eight percent of alpaca farmers (166/213) used quarantine drenching (Table 4), with MLs as the most commonly (48%, 79/166) used quarantine dewormer followed by a commercial combination of four anthelmintics (abamectin, albendazole, closantel and levamisole; 37%, 79/166) and monepantel (17%, 29/166). Alpaca farmers used quarantine periods of one (18%, 28/156) and two weeks (26%, 40/156), and only 23% (39/169) of respondents moved alpacas to cleaner pastures after deworming (Table 4). The majority of medium (90%, 46/51) and large (84%, 21/25) alpaca herds used a quarantine period for introduced alpacas whereas only 34% (46/137) of small alpaca herds followed this practice (Table 4).

The majority of respondents (60%, 143/239) were unaware of AR, and only 12% (21/172) of respondents assessed the status of AR on their farms by assessing pre- and post-treatment FECs. ML resistant GINs were reported by only 2% (4/172) of respondents. Alpaca farmers did not appear to have an understanding of the faecal egg count reduction test as 34% (38/113) only performed FECs pre-treatment while 30% (34/113) performed pre- and post-treatment FECs. The majority of respondents received advice on deworming of alpacas from veterinarians (66%, 154/235) followed by word-of-mouth from fellow alpaca farmers (53%, 125/235), various types of journals and magazines (24%, 56/235), the newsletter of the AAA (23%, 55/235) and online resources (such as wormboss.com.au, 18%, 43/235).

## 4. Discussion

This is the first study to assess the worm control practices used by alpaca farmers in Australia. Australian alpaca farmers mainly keep Huacaya alpacas to produce high-quality fibre and alpacas are usually kept with cattle and sheep. Although only half of alpaca farmers (114/220) perceived that GINs were an important health issue in their alpacas, the majority of them (174/220) used anthelmintics for GIN control. MLs, a commercial combination of four anthelmintics (abamectin, albendazole, closantel and levamisole) and monepantel were the three most commonly used dewormers by Australian alpaca farmers. Although a significant proportion (166/213) of respondents used a quarantine drench for alpacas, very few respondents were aware of strategic deworming and the issue of AR. An understanding of worm control practices used by livestock farmers is crucial to develop guidelines for effective control of ruminants and such studies have been conducted for both small and large ruminants (Bloemhoff et al., 2014; Brito et al., 2013; Domke et al., 2011; Falzon et al., 2013; Patten et al., 2011; Ploeger et al., 2016; Theodoropoulos et al., 2010; Zanzani et al., 2014). By contrast, very little is known about the worm control practices used by SAC farmers globally, and only two such studies have been

**Table 4**
Anthelmintics use by Australian alpaca farmers to control gastrointestinal nematodes of alpacas.

| Question | Herd size | | | | | | Total | |
|---|---|---|---|---|---|---|---|---|
| | Small | | Medium | | Large | | | |
| | Proportion | % (95% CI) | Proportion | % (95% CI) | Proportion | % (95% CI) | Proportion | % (95% CI) |
| Use of anthelmintics | 107/144 | 74 (66 – 81) | 45/51 | 88 (76 - 96) | 22/25 | 88 (69 - 97) | 174/220 | 79 (73 – 84) |
| Simultaneous deworming of mixed livestock species | 25/66 | 38 (26 – 51) | 9/27 | 33 (17 – 54) | 4/19 | 21 (6 – 46) | 38/114 | 33 (25 – 43) |
| Anthelmintics: | | | | | | | | |
| Benzimidazoles (BZ) | 15/189 | 8 (5 – 13) | 13/97 | 13 (7 – 22) | 3/45 | 7 (1 – 18) | 31/331 | 9 (7 – 13) |
| Levamisole (LEV) | 9/189 | 5 (2 – 8) | 5/97 | 5 (2 – 12) | 1/45 | 2 (0 – 12) | 15/331 | 5 (3 – 7) |
| Macrocyclic lactones (MLs) | 74/189 | 39 (32 – 47) | 35/97 | 36 (27 – 47) | 18/45 | 40 (26 – 57) | 127/331 | 38 (33 – 44) |
| Monepantel | 27/189 | 14 (9 – 20) | 16/97 | 17 (10 – 25) | 7/45 | 16 (7 – 30) | 50/331 | 15 (11 – 19) |
| Closantel | 7/189 | 4 (1 – 8) | 6/97 | 6 (2 – 13) | 2/45 | 4 (1 – 15) | 15/331 | 5 (3 – 7) |
| Combination of two (BZ and MLs) and three (BZ, LEV and MLs) anthelmintics | 10/189 | 5 (3 – 10) | 5/97 | 5 (2 – 12) | 6/45 | 13 (5 – 27) | 21/331 | 6 (4 – 10) |
| Combination of four (closantel, BZ, LEV and MLs) anthelmintics | 47/189 | 25 (19 – 32) | 17/97 | 18 (11 – 27) | 8/45 | 18 (8 – 32) | 72/331 | 22 (17 – 27) |
| Rotation of anthelmintics | 62/103 | 60 (50 – 70) | 35/45 | 78 (63 – 89) | 15/22 | 68 (45 – 86) | 112/170 | 66 (58 – 73) |
| Quarantine drench | 98/138 | 78 (71 – 83) | 44/50 | 71 (63 – 78) | 24/26 | 92 (75 – 99) | 166/214 | 78 (71 – 83) |
| Deworming and moving of alpacas to clean pasture | 23/103 | 22 (15 – 32) | 10/44 | 23 (11 – 38) | 6/22 | 27 (11 – 50) | 39/174 | 22 (17 – 29) |
| Quarantine for introduced alpacas | 46/137 | 34 (26 – 42) | 46/51 | 90 (79 – 97) | 21/25 | 84 (64 – 95) | 113/213 | 53 (46 – 60) |
| Drench resistance test | 7/105 | 7 (3 – 13) | 12/45 | 27 (15 – 42) | 2/22 | 9 (1 – 29) | 21/172 | 12 (8 – 18) |
| Source of advice on deworming | | | | | | | | |
| Veterinarian | 98/153 | 64 (51 – 72) | 36/53 | 68 (54 – 80) | 20/29 | 69 (49 – 85) | 154/235 | 66 (59 – 72) |
| Fellow farmers | 91/153 | 59 (51 – 67) | 25/53 | 47 (33 – 61) | 9/29 | 31 (15 – 51) | 125/235 | 53 (47 – 60) |
| Journals/Magazines | 33/153 | 12 (7 – 18) | 15/53 | 11 (4 – 23) | 8/29 | 21 (8 – 40) | 56/235 | 24 (19 – 30) |
| Australian Alpaca Association newsletter | 38/153 | 25 (18 – 32) | 13/53 | 25 (14 – 38) | 4/29 | 14 (4 – 32) | 55/235 | 23 (18 – 29) |
| Online (e.g. wormboss.com.au) | 25/153 | 16 (11 – 23) | 14/53 | 26 (15 – 40) | 4/29 | 14 (4 – 32) | 43/235 | 18 (14 – 24) |

CI, confidence interval.

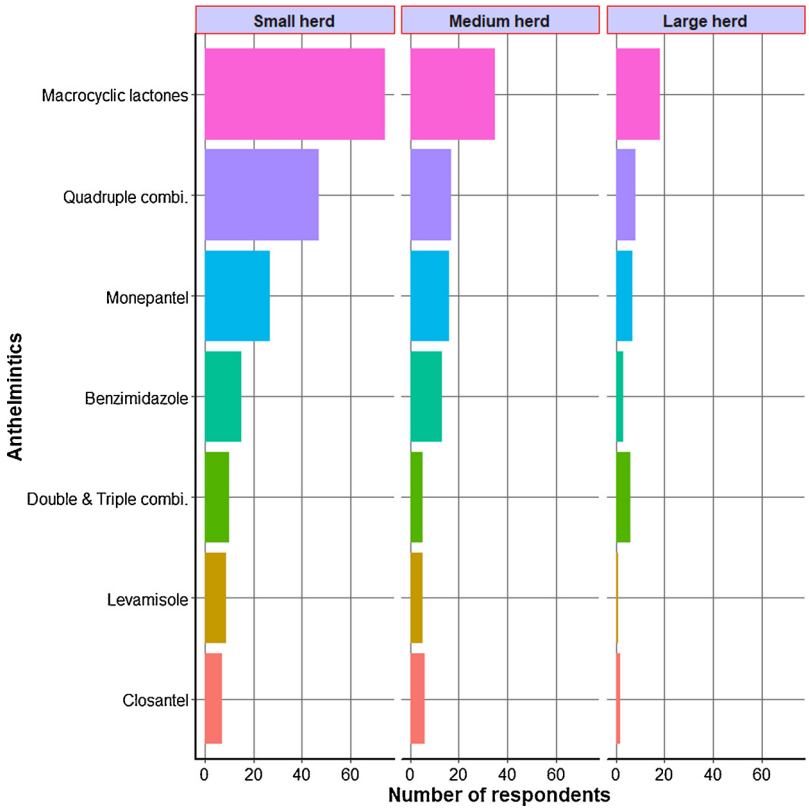


**Fig. 4.** Frequency of use of different anthelmintics on surveyed alpaca farms with herds of different sizes. (Quadruple combi = commercial combination of abamectin, albendazole, closantel and levamisole, Double combi = benzimidazole and macrocyclic lactone, Triple combi = benzimidazole, levamisole and macrocyclic lactone.).

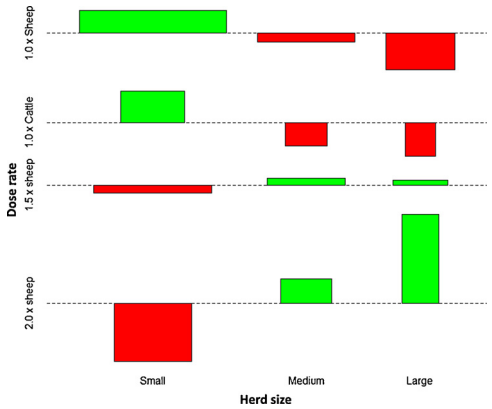


**Fig. 5.** Association between dose rates of anthelmintics used by alpaca farmers and alpaca herd sizes included in this study. The rectangles above the dashed lines indicate that observed frequencies are greater than expected, showing a positive association. Similarly, rectangles below the dashed lines show observed frequencies are less than expected, demonstrating a negative association. The size and the shape of a rectangle indicate strength of the associations, with a wider rectangle indicating a higher frequency while a taller rectangle a higher proportion.

conducted on a smaller scale in Switzerland (Hertzberg and Kohler, 2006) and the UK (Tait et al., 2002). This study provides invaluable insights into the demography of alpaca farmers in Australia, husbandry practices used by alpaca farmers and their knowledge about worms and their control which will provide pivotal information for developing guidelines for the control of GINs of alpacas.

We found that about half of the respondents (121/229) kept alpacas with other domestic ruminants, including cattle, goats and sheep. Furthermore, alpacas on such farms co-grazed with these ruminants. Such husbandry practices can expose alpacas to GINs of domestic ruminants (e.g. *H. contortus*) which they have not evolved with in their natural habitats in South America. Previously, a number of studies from Chile (Alcaino, 1991), Ecuador (Robayo, 2015), Japan (Hyuga and Matsumoto, 2016), New Zealand (Dittmer et al., 2018; Hill et al., 1993), Peru (Masson et al., 2016), Switzerland (Hertzberg and Kohler, 2006), the UK (Tait et al., 2002; Welchman et al., 2008), and the USA (Cebra and Stang, 2008; Rickard, 1994) have shown that alpacas commonly harbour GINs of sheep and cattle in importing countries and they can cause significant pathogenic effects in SACs (Ballweber, 2009; Franz et al., 2015). Furthermore, Hertzberg and Kohler (2006) from Switzerland reported that the mean strongyle egg output was three-fold higher in alpacas and llamas co-grazing with sheep and/or goats. This suggests that alpacas and domestic ruminants share GINs in mixed grazing practices and control programs for GINs of alpacas should be similar to those of GINs of domestic ruminants, particularly where alpacas co-graze with cattle, goats and sheep.

An understanding of the importance of worms in livestock species and the regular monitoring of worm burdens by farmers is crucial for effective and sustainable worm control programs for ruminants. In this study, almost half (114/220) of respondents perceived that GINs were an important health problem of alpacas, and 86% (98/114) of them assessed worm burdens in their animals using faecal egg counts. Although only 26% (30/114) of respondents sent alpaca faecal samples for identification using the larval culture technique, farmers' knowledge about the presence of different species of GINs (i.e. *Haemonchus* spp., *Ostertagia* spp. and *Trichostrongylus* spp.) was similar to the findings of Carmichael (1999, 2014) and Presidente (2007) from Australia. These results indicate that alpaca farmers should regularly monitor the worm burden in alpacas and the genus/species identification of nematodes should also be performed as certain parasites (e.g. *H. contortus*) are known to cause significant morbidity and mortality in alpacas (Ballweber, 2009; Jabbar et al., 2013). Such information may facilitate the treatment/control of GINs in alpacas.

In this study, a large proportion of alpaca farmers (74%, 174/220) used anthelmintics to control GINs of alpacas. However, only half of the respondents (52%, 114/220) perceived that GINs were an important

health problem of alpacas. This difference might to be due to farmers' perceptions of using anthelmintics as a part of routine management and health plan for their animals rather than using them to treat alpacas suffering from clinical cases of parasitic gastroenteritis. We found that the percentage of respondents (74%) using anthelmintics against GINs was lower than the proportion of sheep farmers controlling GINs (Fraser et al., 2006; Maingi et al., 1996a; Ploeger et al., 2016), goats (Hoste et al., 2000; Maingi et al., 1996b) and cattle (Barton et al., 2006; Schnieder et al., 1999) in these studies almost all respondents used dewormers. These differences could be due to lower stocking rates for alpacas as compared to higher flock/herd stocking rates for sheep and goats/cattle, so that alpaca farmers may not have felt the need for a regular deworming program. However, the differences could also be due to farmers' lack of knowledge of parasites and parasite control in alpacas although a majority of respondents (69%) in this study had a tertiary education. However, this hypothesis requires further testing.

In grazing livestock species, strategic use of anthelmintics is an integral component of parasite control strategies. Although no anthelmintics are registered for use in alpacas in Australia, various classes of anthelmintics are frequently used to control parasitic gastroenteritis in alpacas in Australia and other countries (Jabbar et al., 2013; Rashid et al., 2018; Tait et al., 2002). This survey has revealed that MLs were the most commonly used anthelmintics in alpacas followed by a commercial combination of four anthelmintics (abamectin, albendazole, closantel and levamisole) and monepantel. MLs have been found to be widely used in sheep and cattle (Barton et al., 2006; Cernanska et al., 2008; Domke et al., 2011; Falzon et al., 2013; Fraser et al., 2006; Patten et al., 2011; Schnieder et al., 1999; Tait et al., 2002). The frequent use of MLs in alpacas could be due to availability of a wide range of sheep and cattle products in oral and injectable forms, endectocidal properties and a wide margin of safety. Additionally, this may be due to the education of farmers by veterinarians and managers/salespersons at agricultural supply stores regarding the widespread resistance of BZs and LEV against GINs of small ruminants in Australia (Playford et al., 2014).

In this study, almost half of the respondents used anthelmintics at the dose rate recommended for sheep (47%, 79/167), although some used 1.5 (31%, 51/167) and 2 (13%, 22/167) times the dose rate recommended for sheep. As no anthelmintics are registered for use in alpacas in Australia, the therapeutic dose of commonly used (off-label) anthelmintics, registered for cattle and sheep, remains unknown. Studies have recommended different anthelmintic dose rates to treat GINs in alpacas but commonly used dose rates in alpacas in Australia are unknown, veterinarians have been recommending 1.5 times the dose rate recommended for sheep, though conflicting reports regarding the efficacy of various anthelmintics against GINs of SACs using various dose rates have been published (Dadak et al., 2013;Geurden and Van Hemelrijk, 2005 Gillespie et al., 2010; Jabbar et al., 2013). Recently, Dadak et al. (2013) used 1 (2.5 mg/kg), 2 and 3 times the dose rate of monepantel recommended for sheep in llamas in Austria and found that only the three times dose rate recommended for sheep was fully effective in treating SACs naturally infected with GINs. Interestingly, we found that small alpaca herd farmers used anthelmintics at the dose rate recommended for sheep and cattle whereas medium and large herds farmers used anthelmintics at 1.5–2 times the dose rate recommended for sheep. These differences in the dose rate of anthelmintics among different alpaca herd sizes could be attributed to the variation in farmers' perceptions of the significance of GINs in the productivity of animals as medium and large alpaca herds are primarily kept for commercial gains while small herds can have various purposes such as those of hobby farmers, or a greater awareness by medium and large herd owners of the different pharmacokinetics of anthelmintics in alpacas.

A very important finding in this study was the use of monepantel at a dose rate that is likely incompletely effective in alpacas (Dadak et al., 2013). Monepantel was registered for use in sheep in Australia less than 10 years ago and remains widely effective against all general of GINs (Playford et al., 2014). Its off-label use at likely sub-lethal doses in alpacas is a critical threat to the continued efficacy of monepantel in both alpacas and sheep.

Given that alpacas in Australia share GINs with domestic ruminants (Carmichael, 1999, 2014; Presidente, 2007), Australia is among the world leaders for the high prevalence of multiple AR in GINs of small ruminants (Playford et al., 2014) and no anthelmintics are registered for use in alpacas in this country, Australian alpaca farmers need to use anthelmintics against GINs of alpacas and llamas very carefully to avoid the rapid development of AR. Several factors have been identified that can contribute to the development of anthelmintic resistance in GINs of ruminants (see Jabbar et al., 2006). For example, under-dosing can lead to the development of AR due to the exposure of sub-lethal doses to nematodes (Jabbar et al., 2006; Smith et al., 1999; Waller, 1997; Wolstenholme et al., 2004). In this study, we found that the majority of respondents (71%, 123/174) calculated the dose of anthelmintics based on visual estimation of the weight of alpacas. In addition, almost half of the respondents (52%, 88/169) did not use a drenching gun and of those who used a drenching gun, only 14% (11/81) calibrated it. In a situation where the therapeutic dose of anthelmintics is unknown for alpacas, the calculation as well as the administration of an accurate dose is important. Previously, the under-dosing of anthelmintics in domestic ruminants by farmers has been found in several studies (Castillo-Alcala et al., 2007; Cernanska et al., 2008; Domke et al., 2011; Falzon et al., 2013; Hoste et al., 2000; Zanzani et al., 2014). Nevertheless, a questionnaire survey conducted by Edwards et al. (1986) in sheep showed that AR was significantly higher on farms where sheep were treated based on the bodyweight of the heaviest sheep (Edwards et al., 1986) which infers sheep were *not* under-dosed. Given that AR in GINs of alpacas has already been reported in different regions of the world (Galvan et al., 2012; Gillespie et al., 2010; Sarre et al., 2012), including Australia (Jabbar et al., 2013; Rashid et al., 2018), further research into identifying sustainable strategies to control GINs in alpacas are essential to minimise the development of multiple AR.

Rotation of anthelmintics by changing drug class is one useful strategy used by sheep and goat farmers to reduce the risk of AR development (Coles and Roush, 1992; McKenna, 1990; Waller et al., 1990). This survey showed that 66% (112/170) of respondents rotated anthelmintics to avoid the development of AR. However, the majority of respondents (60%, 143/239) were unaware of AR on their farms as only 12% of them assessed the status of resistant dewormers on their farms. Alpaca farmers did not seem to have a sound understanding of the faecal egg count reduction test as several respondents performed only pre-treatment faecal egg counts and did not see the value of performing post-treatment FECs as well. This shows that alpaca farmers need to be better educated about assessing the efficacy of anthelmintics and its importance in delaying the development of AR.

A small proportion of alpaca farmers used diatomaceous earth powder and garlic powder as non-chemical deworming agents, however the use of such substances in the control of GINs of alpacas remain to be validated. Alternative worm control methods such as biological control and vaccination could be used to control GINs of alpacas. For example, Barbervax®, a commercial vaccine manufactured from native gut membrane proteins of *H. contortus*, has proven to be successful in reducing the burden of *H. contortus* in sheep (Ref). This vaccine could be tested to determine if it would prevent haemonchosis in alpacas. Similarly, another biological mean of controlling GINs of ruminants is using predaceous fungus which was marketed as a commercial product, BioWorma®, in April 2018 in Australia. BioWorma® contains the chlamydospores of the nematophagous fungus, *Duddingtonia flagrans* strain IAH 1297 and is used as a supplement feed to reduce the larval contamination on pastures. Studies have found that BioWorma® was effective in lowering worm burden in sheep, goats, cattle and horses (Healey et al., 2018a, 2018b). Given that no anthelmintic is registered for use in alpacas and very little information is available on

pharmacokinetic properties of currently used anthelmintics in SACs, it is prudent to explore other methods to control GINs of alpacas and llamas, and the efficacy of Babervax® and BioWorma® should be assessed against GINs of alpacas.

Designing a worm control program relies on three essential components: (i) an understanding of current worm control practices, (ii) insights into the epidemiology of worms and (iii) the efficacy of commonly used anthelmintics. This study has laid the foundation for designing an effective worm control program for Australian alpacas by assessing the worm control practices currently used by alpaca farmers.

## 5. Conclusions

This is the first study to comprehensively assess the current worm control practices used by alpaca farmers in Australia. The findings of this study indicate that although a low number of alpaca farmers perceive that GINs are an important health problem for their animals, the majority of them use anthelmintics for GIN control. MLs, a commercial combination of four anthelmintics (abamectin, albendazole, closantel and levamisole) and monepantel are the most commonly used dewormers by Australian alpaca farmers. A number of existing worm control practices may favour the development of AR in GINs of alpacas in Australia.

## Conflict interest

Authors declare no conflict of interest.

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## Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.vetpar.2018.12.006.

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