Status of Gastrointestinal Nematode Infections and Associated Epidemiological Factors in Sheep From Córdoba, Colombia

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Abstract

Gastrointestinal nematodes cause serious economic losses in sheep production systems. To determine the prevalence and risk factors associated with these parasites, a study was conducted in 595 sheep in Córdoba, Colombia. Prevalence and parasite burden were determined using the McMaster technique. Larvae were cultured from feces to identify the nematode genera. For the analysis of associated factors and parasite burden, means, medians and confidence intervals were compared. A geo-referenced data analysis was performed and an epidemiological map was constructed. An overall prevalence of 88.2% was found, with the highest prevalence and parasite burden for Strongylida (83.2%) and Strongyloides (41%) nematodes. The mean parasite burden was 1255 eggs per gram. The gastrointestinal nematode genera identified were *Trichostrongylus*, *Strongyloides*, *Haemonchus*, *Oesophagostomum*, *Bunostomum* and *Cooperia*. In general, a significant association was found between parasite burden and dewormed animals, anthelmintic used, date of last deworming and breeds. The FAMACHA® method and body condition showed a significant association with Strongylida parasite burden. Clusters with higher intensity of gastrointestinal nematode burden and high prevalence were observed in the regions of Bajo Sinú, Sinú Medio and San Jorge.

Introduction

Sheep are a susceptible species to multiple gastrointestinal nematode infections (GIN). Infections can be associated with several factors such as the age of the animal, the breed, the parasite species involved and the degree of parasitic infection, among others (Al-shaibani et al. 2008); these can alter animal welfare and, therefore, the productive levels of farms, regardless of the farming system (Herrera et al. 2013).

GIN cause a major health and economic impact on extensive livestock production due to reduced weight gain, mortality, and the high costs of anthelmintic treatments used for their control. Additionally, the emergence of GIN populations resistant to all anthelmintic families available in the Americas makes the control of these parasites even more difficult (Kaplan 2020).

Parasitic gastroenteritis is a multi-etiological disease, however, the GIN responsible for sheep deaths belongs mainly to the order Strongylida, superfamily Strongyloidea (Zajac and Garza 2020). Among these, the genera *Haemonchus*, *Trichostrongylus*, *Teladorsagia* (*Ostertagia*) and *Oesophagostomum* are the most frequent (Torres-Acosta et al. 2012; Herrera et al. 2013). Other GIN belonging to different taxonomic orders commonly parasitize sheep in the Americas and include *Strongyloides*, *Aoncotheca* (formerly *Capillaria*), *Trichuris* and *Skrjabinema*. Although these nematodes are not considered to be of major pathogenic importance and cause disease only in unusual circumstances (Zajac and Garza 2020).

In Colombia, studies on parasitic gastroenteritis have revealed the prevalence of endoparasites in different areas and climates involved in sheep farming (Ensuncho et al. 2014; Pulido et al. 2014). In the department of Córdoba, frequency studies of gastrointestinal parasites in sheep have been conducted (Ensuncho et al. 2014); however, there is no knowledge about the factors associated with gastrointestinal parasitism in sheep farms present in all its regions.

For the rational and sustainable control of gastrointestinal parasitism in sheep, a thorough knowledge of the epidemiology of the parasites and their interaction with the host in a specific environment is required (Keyyu et al. 2005). Therefore, knowledge of the parasite species found in a specific region, their prevalence, the degree of infection, the characteristics of the local climate, the size of the flocks and the cultural practices carried out there, among others, are essential (Kaplan and Vidyashankar 2012). For this reason, the objective of this study was to determine the prevalence and risk factors associated with gastrointestinal parasitism in sheep from the department of Córdoba-Colombia.

Materials And Methods

Study area The study was carried out in the department of Córdoba, which is divided into six regions, as follows: Alto Sinú, Sinú Medio, Bajo Sinú, Sabanas, San Jorge and Costanera. The department's climate can be divided into four areas. The first corresponds to the northern or coastal area, with rainfall of no more than 800 mm and a temperature of no less than 28°C. The second section is defined by the valleys, with rainfall between 1,000 and 2,000 mm; the third corresponds to the south of the department, with an annual rainfall of more than 2,000 mm; and finally, the foothills of the mountain range with temperatures of 18 to 24°C and rainfall of more than 3,000 mm per year. On average, it has an altitude of 30 m.a.s.l., an annual temperature of 28°C and relative humidity that varies between 80 and 87%. It belongs to the tropical rainforest climate formation and during the year there is a rainy period (May to November) and a dry period (December to April).

Study design A descriptive cross-sectional study was carried out to determine the prevalence of GIN in sheep from the department of Córdoba and associated factors. To determine the sample size, an infinite population of sheep, 75% estimated true prevalence, 80% sensitivity and 90% diagnostic specificity, a precision of 6% and a confidence level of 95% were assumed. The calculation determined a sample size of 511 sheep. In the end, 595 sheep were sampled in 60 farms.

The study was conducted over a 12-month period. Two farms were evaluated in each of the 30 municipalities of the department of Córdoba, distributed in the six geographical regions of the department. On each farm, one breeding male, three breeding females, two rearing females and two rearing males, and one lamb from each sex were sampled. The animals sampled in each farm were randomly selected.

Sample and data collection Fecal samples were taken directly from the rectum using polyethylene gloves and blood samples were taken from the jugular vein using vacutainer tubes with an anticoagulant. The samples were identified with consecutive alphanumeric codes and kept refrigerated at 4°C until processing.

In addition, a clinical examination was performed on each animal, recording the aspects of the breed, sex, age, productive stage, weight, assessment of ocular conjunctival coloration by FAMACHA® method and assessment of body condition. An epidemiological survey on aspects related to the management and control of gastrointestinal parasites in the flock was conducted with each producer. The geographic coordinates of each farm were determined by Global Positioning System (GPS).

Laboratory testing To determine the GIN burden in each animal, the McMaster technique was applied, using McMaster chambers with two fields (Chalex Corporation®) and a conversion factor of 50 suggested by the commercial company for the calculation of eggs per gram (EPG) of fecal matter.

For the identification and counting of the nematode genera present in each farm, a pool was made of all the coprological samples obtained in the farm, 10 g of this pool were used to perform a faecal culture for the recovery of infective larvae of GIN (L3) using the technique of Corticelli and Lai (1963). Larvae were identified by microscopy using taxonomic keys based on their morphology: total size, tail size and shape of the sheath; size and shape of the esophagus; number and shape of intestinal cells and refractile bodies (Van Wyk et al. 2004).

Data analyses The prevalence of GIN in each farm and in sheep population was determined in the department of Córdoba. The parasitic burden of each animal (EPG) and the average parasitic burden in each farm were also determined. For the analysis of risk factors associated with the parasitic burden, means, medians and confidence intervals were compared; the Kruskal-Wallis test was applied with a significance level of 5%; the statistical program EpiInfo, version 7.2.2.2.2 was used. Finally, areas with the highest concentration of parasite burdens were identified using the kernel density estimator; the georeferenced data were analyzed and an epidemiological map was constructed using standard deviation on the mean in the categorization of the data and a bandwidth of 25 km. The QGIS program, version 3.4, was used for this purpose.

Results

Prevalence and parasite burden

According to the results, 88.2% of the animals were positive for one or more groups of parasites; 83.2% were positive for nematodes of the order Strongylida, 41.0% for *Strongyloides* spp. and 2.2% for *Trichuris* spp. (Table 1); at farm scale, the prevalence was 100%. Overall parasite burden showed an average count of 1255 EPG; the Strongylida order showed the highest average parasite burden (943 EPG), followed by *Strongyloides* spp. and *Trichuris* spp. with low average parasite burdens (Table 1). Multiple parasitic infections were frequently observed in the animals under study. The main associations were between Strongylida and *Strongyloides* spp. The composition of GIN infections is presented in Table 2.

Table 1
Prevalence of gastrointestinal nematode infections and parasite burdens in sheep in the department of Córdoba.

Variable	n	Prev. (%)	EPG mean	Inf.	Sup.	Sd
Strongylida	595	83,2	943	806	1079	1698
<i>Strongyloides</i> spp.	595	41,0	311	227	395	1043
<i>Trichuris</i> spp.	595	2,2	2	1	3	13
Overall count	595	88,2	1255	1093	1418	2021
n: Sampled animals; Prev.: Prevalence; EPG: Eggs Per Gram; Inf.: Lower limit; Sup.: Upper limit; Sd: Standard deviation.						

Table 2
Gastrointestinal nematode infection and co-infection in sheep in the department of Córdoba.

Parasite	Multiple infections				Negatives
	I	II		III	
		<i>Strongyloides</i> spp.	<i>Trichuris</i> spp.	<i>Strongyloides</i> spp. <i>Trichuris</i> spp.	
Strongylida	276	206	5	8	
<i>Strongyloides</i> spp.	30	-	-	-	70
<i>Trichuris</i> spp.	0	-	-	-	
TOTAL	306	211		8	70
	(51.40%)	(35.50%)		(1.30%)	(11.80%)
I: Animals infected with one type of nematode; II: Animals co-infected with two types of nematodes; III: Animals co-infected with three types of nematodes.					

Predisposing Factors Associated With Gin Burden In Sheep

Several variables were analyzed to see their relations with the parasitic burden of the sheep studied, among them: deworming, anthelmintic used, the time elapsed since the last deworming, sex, productive stage and breed. The breeds were grouped as Ovinos de Pelo Criollo Colombiano (OPC) among which were found: Criollo, Chino Rojo, Sudan and Abisinio, and breeds not belonging to Ovinos de Pelo Criollo (Non-OPC), among them: Katahdin, Santa Inés, Pelibuey, Black Belly, Dorper, Persian, White Dorper and some crossbreeds with OPC. The association of the different variables was made with the overall parasitic burden and with the burden of each type of nematode.

Overall, an association was found between the parasitic burden and the variables: dewormed animal, anthelmintic used, last deworming and breed. (Table 3). In terms of nematode types, the parasite burden of the order Strongylida was significantly associated with dewormed animal, anthelmintic used, the time elapsed since the last deworming and breed. For *Strongyloides* spp., an association was identified with the variables dewormed animal, time since the last deworming and productive stage; in the case of *Trichuris* spp., an association was only found with the productive stage of the animal (Table 4).

Table 3
Factors associated with overall gastrointestinal nematode burden in sheep in the department of Córdoba, Colombia.

Variable	Category	Sample size	Pos	Mean (EPG)	Sd.	Med.	p-value
Dewormed animal	Yes	298	269	1583	2459	700	0,0002
	No	297	257	926	1382	450	
Anthelmintic used	Fenbendazole	207	190	1677	2525	900	0,0485
	Ivermectin	28	27	2530	3595	800	
	Levamisole	54	43	881	1158	500	
	Natural med.	8	8	669	476	550	
Last deworming	< 45 days	138	122	1879	2839	800	0,0007
	46–120 days	160	147	1328	2052	600	
	> 120	297	257	926	1382	450	
Sex	Female	368	325	1170	1860	525	0,204
	Male	227	201	1392	2255	650	
Productive stage	Lambs	134	112	1349	2576	500	0,0750
	Rearing lambs	201	183	1403	2114	700	
	Pregnant ewes	64	59	670	728	400	
	Lactating ewes	98	87	1472	1925	725	
	Empty ewes	33	29	932	1233	400	
	Breeding male	65	56	1019	1620	500	
Breed	OPC	292	261	949	1210	525	0,0478
	Non OPC	303	265	1550	2538	650	
Pos: Positives; EPG: Eggs per gram; Sd: Standard deviation; Natural Med.: Use of medicinal plants; OPC Ovinos de Pelo Criollo; Med.: Median.							

Table 4
Factors associated with Strongylida, *Strongyloides* spp. and *Trichuris* spp. burdens in sheep in the department of Córdoba.

Variable	Category	n	Strongylida				<i>Strongyloides</i> spp				<i>Trichuris</i> spp			
			Pos.	Mean (EPG)	Med. (EPG)	p-value	Pos.	Mean (EPG)	Med. (EPG)	p-value	Pos.	Mean (EPG)	Med. (EPG)	p-value
Dewormed animal	Yes	298	259	1205	500	0.000	103	377	0	0.018	6	2	0	0.773
	No	297	236	680	300		140	245	0		7	2	0	
Anthelmintic used	Fenbendazole	207	184	1385	600	0.016	74	290	0	0.251	6	2	0	0.448
	Ivermectin	28	26	1238	375		9	1293	0		0	0	0	
	Levamisole	54	40	594	350		19	286	0		0	0	0	
	Natural med.	8	8	669	550		0	0	0		0	0	0	
Last deworming	< 45 days	138	118	1537	550	0.000	38	342	0	0.007	0	0	0	0.085
	46–120 days	160	141	918	500		65	407	0		6	3	0	
	> 120 days	297	236	680	300		140	245	0		7	2	0	
Sex	Female	368	308	932	350	0.676	143	237	0	0.053	8	1	0	0.968
	Male	227	187	961	400		100	430	0		5	2	0	
Productive stage	Lambs	134	102	1074	275	0.306	56	274	0	0.000	0	0	0	0.029
	Rearing lambs	201	174	911	450		101	488	50		9	4	0	
	Pregnant ewes	64	55	604	350		16	65	0		1	1	0	
	Lactating ewes	98	82	1165	400		39	307	0		1	1	0	
	Empty ewes	33	28	867	400		8	62	0		2	3	0	
	Breeding male	65	54	805	350		23	215	0		0	0	0	
Breed	OPC	303	243	729	300	0.041	136	216	0	0.070	9	3	0	0.137
	Non OPC	292	252	1147	450		108	401	0		4	1	0	
n: Number of observations; Pos.: Positives; Med.: Median; EPG: Eggs per gram														

Clinical Factors Associated With Gin Burden In Sheep

The parasite burden of the sheep studied was related to clinical parameters, including body condition, weight, heart rate, respiratory rate, temperature, hematocrit and FAMACHA® score. Strongylida nematode burden was associated with sheep body condition, hematocrit and FAMACHA® score, while *Strongyloides* spp. parasite burden was associated with body condition and hematocrit; *Trichuris* spp. parasite burdens were not associated with any of the variables studied (Table 5).

Table 5

Clinical factors associated with Strongylida, *Strongyloides* spp. and *Trichuris* spp. burdens in sheep in the department of Córdoba.

Variable	Category	n	Strongylida				<i>Strongyloides</i> spp.				<i>Trichuris</i> spp.			
			Pos.	Mean (EPG)	Med. (EPG)	p-value	Pos.	Mean (EPG)	Med. (EPG)	p-value	Pos.	Mean (EPG)	Med. (EPG)	p-value
Body condition	Good	178	141	694	300	0.018	66	220	0	0.022	3	1	0	0.324
	Average	296	252	984	500		136	402	0		9	2	0	
	Bad	120	101	1208	400		41	224	0		1	0	0	
Hcrit.	High	149	130	650	350	0.001	57	201	0	0.028	0	0	0	0.056
	Average	294	231	808	300		113	327	0		7	2	0	
	Low	147	129	1514	500		71	391	0		6	3	0	
Famacha®	1	38	30	499	200	0.000	15	116	0	0.526	1	4	0	0.555
	2	242	197	607	300		95	290	0		5	2	0	
	3	216	181	841	400		85	290	0		3	1	0	
	4	90	78	1685	600		45	443	25		4	3	0	
	5	9	9	6867	5500		3	872	0		0	0	0	

n: Number of observations; Pos.: Positives; EPG: Eggs per gram; Med.: Median; Hcrit.: Hematocrit

Geographical Factors Associated With Gin Burden In Sheep

An epidemiological map was generated using the kernel density estimator, which depicts the association between parasite burdens and their distribution between regions and municipalities in the department of Córdoba (Fig. 1). The map shows the location of the farms evaluated with their respective GIN prevalence. Several high-density clusters can be observed; the first one is located between Sinú Medio and Sinú Bajo regions and extends towards the north of the Sabana region, the second one in the San Jorge region. The municipalities with the highest parasite burdens were Purísima, Lorica, Cereté, San Carlos, Puerto Libertador and San José de Uré, which are located in regions with high-density clusters.

Genera Of Nematodes Identified

In the farms studied, a 100% prevalence was identified for the genus *Trichostrongylus* spp., 78.3% for *Strongyloides* spp., 76.7% for *Haemonchus* spp., 53.3% for *Oesophagostomum* spp., 10% for *Bunostomum* spp. and 1.7% for *Cooperia* spp. The results of the faecal culture and the percentage of infective larvae in each genus are presented in Table 6.

Table 6

Infective larvae prevalence and percentages of the nematode genera identified in sheep farms in the department of Córdoba.

Genus	Farms	Prevalence per farm (%)	Infective larvae percentage (L3) ± SD
<i>Trichostrongylus</i> spp.	60	100	52,0 ± 21
<i>Strongyloides</i> spp.	47	78,33	18,6 ± 16,5
<i>Haemonchus</i> spp.	46	76,67	17,4 ± 16
<i>Oesophagostom</i> spp.	32	53,33	11,4 ± 16
<i>Bunostomum</i> spp.	6	10,0	0,5 ± 1,7
<i>Cooperia</i> spp.	1	1,67	0,1 ± 0,5
Obs.: Number of observations; Pos.: Positives; Sd.: Standard deviation; Med.: Median.			

Discussion

The results of this study reveal a serious situation of GIN parasitism in sheep farms in the department of Córdoba. All of the farms sampled showed cases of gastrointestinal parasitism, where 88.6% of the animals were affected with one or more types of nematodes. Although parasitic infection was expected due to an apparent predisposition of the sheep, it is important to note that the seriousness of this finding lies not only in the prevalence of parasitism but also in the high parasite burdens, which averaged 1255 EPG/animal; this value is considered a high-level infection, taking into account the classification of infection levels according to Hansen and Perry (1994). Considering the parasitic groups, high-level infections were found to be caused by Strongylida nematodes, mostly from the Trichostrongylidae family, which harbors genera of importance in sheep due to their high pathogenicity such as *Haemonchus contortus* (Wang et al. 2020) and whose parasitic burdens in this study showed a significant association with clinical factors such as body condition, hematocrit and FAMACHA score. *Strongyloides* spp. infections were considered moderate and *Trichuris* spp. infections low.

Dewormed animals and those with recent deworming before McMaster tests, presented the highest Strongylida and *Strongyloides* spp. burdens; this contradictory situation may be explained as a desperate need of producers to apply anthelmintics due to the inefficient reduction of parasite burdens; in the study, we observed that different farms performed monthly application of anthelmintics; these results suggest signs of anthelmintic resistance, especially related to the infections due to Strongylida nematodes.

Regardless of the type of anthelmintic used, parasite burdens were high, suggesting a possible inefficiency of fenbendazole, ivermectin, levamisole and the use of natural medicine in the control of parasitism. It should be noted that in the overall count and the Strongylida order, lower burdens were found in sheep that had been treated with levamisole. The development of anthelmintic resistance, especially to ivermectin and fenbendazole, has been previously reported in several studies (Torres-Acosta et al. 2012). This result reflects the need to implement monitoring programs to assess the efficacy of anthelmintics used in the parasitic control of sheep.

The degree of infection by *Trichuris* spp. did not differ according to the type of anthelmintic used; it is necessary to point out that burdens of this parasitic group were very low, which cannot suggest the effectiveness of the anthelmintics used since there was also no difference between dewormed and non-dewormed animals and between the time of the last deworming; this result is rather associated with the low prevalence and low burdens of *Trichuris* spp. in the department of Córdoba.

The GIN infection prevalence and parasite burdens were similar in males and females. Most studies address the influence of sex on GIP prevalence and in general, there is no consensus on which sex is more affected (Poddar et al. 2017).

Productive stage was not associated with overall parasite burdens or Strongylida infections. However, there is a trend of higher burdens in rearing animals and lactating ewes. In that sense, several studies agree that young animals are more susceptible to gastrointestinal parasitism (Raza et al. 2007) since they have an immune system with insufficient development to modulate parasitic infestation (Khan et al. 2010); on the other hand, it is known that regardless of the year, season and age, ewes present greater susceptibility to GIN during lactation (González-Garduño et al. 2014). Experimentally, there are studies that support the hypothesis that full grown animals can acquire immunity against GIN (Knox 2000). Regarding the degree of infection, Ensuncho et al. (2014) reported that lactating animals and lactating ewes presented the highest parasite burdens.

Breed was associated with overall GIN parasite burden and particularly for Strongylida and *Strongyloides* spp. nematodes. It was observed that breeds belonging to OPC had lower parasite burdens. Breeding studies of small ruminants have revealed a reduction of EPG in faeces when animals that are naturally resistant to GIN infection are selected for breeding (Eady et al. 1996). Genetic factors are known to contribute to the ability of sheep to cope with the challenge of intestinal parasitism; some studies have shown that different breeds of sheep exhibit varying resistance to intestinal parasite infection (Aboshady et al. 2020). In particular, Preston and Allonby (1979) demonstrated an ascending order of susceptibility in the Red Masai, Blackhead Persian, Merino, Dorper, Corriedale and Hampshire breeds. However, other undesirable traits, especially in terms of productivity, could make parasitism-resistant breeds unattractive to producers (Woolaston and Baker 1996). In this regard more recent studies, have shown that genome-wide selection strategies can improve selection of animals with a view on production aspects and helminthiasis resistance traits (McManus et al. 2014).

The clinical variables analyzed, namely: body condition, hematocrit and FAMACHA® result, were especially related to high parasite burdens by Strongylida. Animals with the highest degrees of infection showed fair or poor body condition, low hematocrit values and higher FAMACHA® results. For Strongylida nematodes, the FAMACHA® method had a better predictive value, followed by hematocrit and body condition; *Strongyloides* spp. infections were correlated only with hematocrit and body condition. The above allows to state that the alteration of the clinical variables and their use as predictive value of the parasitic burden, will depend on the parasitic group that is affecting the animals.

The most prevalent nematode genera are associated with the percentage of larvae identified from the faecal cultures. *Trichostrongylus* spp., *Strongyloides* spp. and *Haemonchus* spp. were the most prevalent genera in sheep in the department of Córdoba. These have been previously reported (Ensuncho et al. 2014). It is important to highlight, that it was found for the first time for the department of Córdoba, *Bunostomum* spp. nematodes comprising GIN infections in sheep. Although they were only identified in 10% of the flocks studied, their hematophagous behavior, as well as that of *H. contortus*, causes a decrease in hematological values, including hemoglobin, with immediate consequences such as hypoproteinemia and a decrease in body condition. Analyzing these clinical aspects is important when making decisions regarding deworming management in sheep production systems; Besier et al. (2016) indicate that a good body condition may indicate the ability of sheep to better cope

with parasitism. Increasing resistance to anthelmintics has resulted in developing deworming management alternatives, which reduce the selection resistant parasites, being essential. In this regard, a suitable approach would be to treat only those animals that are unable to cope with the parasite challenge.

The clinical evaluation of anemia using the FAMACHA® system and the body condition of the animals are two important clinical aspects to examine a flock and identify animals that do require anthelmintic treatment (Van Wyk and Bath 2002), these selective deworming programs could be considered within the strategies implemented in the flocks to delay the development of resistance. In the present study, it is evident that the FAMACHA® Method and the measurement of body condition can be used to establish selective deworming programs in herds in the department of Córdoba, since a significant association with parasite burden was found.

Gastrointestinal parasitism in sheep is a worldwide issue, which requires a deeper understanding of epidemiological aspects such as prevalence, distribution and seasonal patterns of transmission in different climatic zones. There is a strong belief that climate change may alter the geographical distribution of parasites and their impact on hosts, a situation that is also attributed to the phenomenon of resistance (Chalier et al. 2014). It is believed, that climatic changes would have profound effects on the epidemiology of parasites, especially for those, whose developments outside the definitive host are sensitive to temperature and humidity linked to rainfall. The influence of environmental conditions is particularly evident in spatial distribution studies that allow the visualization of clusters where animals show not only the prevalence of gastrointestinal parasitism, but also high levels of infection, a parameter that is very interesting to predict the damage caused to individuals and the economic losses of the producer.

The results of this study reveal a serious situation of gastrointestinal parasitism in sheep production systems in the department of Córdoba. All the farms studied are infected by gastrointestinal nematodes; however, the identification of two high density clusters allows directing epidemiological and control studies to these areas. The results suggest a possible resistance to anthelmintics used by the producers, a situation that requires further evaluation.

Declarations

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- Performing the field and laboratory testing activities, and writing up the manuscript

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Ethics approval The study was conducted under the rules of conduct for the use of animals in teaching and research and current legislation, it was approved before the data collection process according to Act No.001/18 of the Faculty of Veterinary Medicine and Animal Husbandry Ethics Committee of Universidad de Córdoba.

Data availability The datasets generated during the current study are available from the corresponding author on reasonable request.

Conflict of Interest The authors declare no competing interests.

References

1. Aboshady, H.M., Stear, M.J., Johansson, A., Jonas, E, Bambou, J.C., 2020. Immunoglobulins as Biomarkers for Gastrointestinal Nematodes Resistance in Small Ruminants: A systematic review. *Scientific Reports*, 10, 7765.
2. Al-Shaibani, I.R.M., Phulan, M.S., Arijó, A., Qureshi, T.A., 2008. Epidemiology of ovine gastrointestinal nematodes in Hyderabad district, Pakistan. *Pakistan Veterinary Journal*, 28, 125–130.
3. Besier, R.B., Kahn, L.P., Sargison, N.D., Van Wyk, J.A., 2016. Diagnosis, treatment and management of *Haemonchus contortus* in small ruminants. *Advances in Parasitology*, 93, 181–238.
4. Charlier, J., Van der Voort, M., Kenyon, F., Skuce, P., Vercruysse, J., 2014. Chasing helminths and their economic impact on farmed ruminants. *Trends in Parasitology*, 30, 361–367.
5. Corticelli, B. and Lai, M., 1963. Ricerche sulla tecnica di coltura delle larve infestive degli strongili gastro-intestinali del bovino. *Acta Medica Veterinaria*, 9, 347–357.
6. Eady, S.J., Woolaston, R.R., Mortimer, S.I., Lewer, R.P., Raadsma, H.W., Swan, A.A., Ponzoni, R.W., 1996. Resistance to nematode parasites in Merino sheep: sources of genetic variation. *Australian Journal of Agricultural Research*, 47, 895–915.
7. Ensuncho, H.C., Castellano, C.A., Maza, A.L., Bustamante, Y.M., Vergara, G.O., 2014. Prevalencia y grado de infección de nemátodos gastrointestinales en ovinos de pelo en pastoreo de cuatro municipios de Córdoba, Colombia. *Revista Científica, FCV-LUZ*, 24, 414–420.
8. González-Garduño, R., Torres-Acosta, J.F.J., Chay-Canul, A.J., 2014. Susceptibility of hair sheep ewes to nematode parasitism during pregnancy and lactation in a selective anthelmintic treatment scheme under tropical conditions. *Research in Veterinary Science*, 96, 487–92.
9. Hansen, J. and Perry, B., 1994. *The Epidemiology, Diagnosis and Control of Helminth Parasites of Ruminants: A Handbook*, (International Livestock Research Institute, Nairobi).
10. Herrera, L., Ríos, L., Zapata, R., 2013. Frecuencia de la infección por nemátodos gastrointestinales en ovinos y caprinos de cinco municipios de Antioquia. *Revista MVZ Córdoba*, 18, 3851–3860.
11. Kaplan, R.M., Biology, 2020. Epidemiology, Diagnosis, and Management of Anthelmintic Resistance in Gastrointestinal Nematodes of Livestock. *The Veterinary Clinics of North America. Food Animal Practice*, 36, 17–30.
12. Kaplan, R.M. and Vidyashankar, A.N., 2012. An inconvenient truth: global worming and anthelmintic resistance. *Veterinary Parasitology*, 186, 70–78.
13. Keyyu, J.D., Kyvsgaard, N.C., Monrad, J., Kassuku, A.A., 2005. Epidemiology of gastrointestinal nematodes in cattle on traditional, small-scale dairy and large-scale dairy farms in Iringa district, Tanzania. *Veterinary Parasitology*, 127, 285–294.
14. Khan, M.N., Sajid, M.S., Khan, M.K., Iqbal, Z., Hussain, A., 2010. Gastrointestinal helminthiasis: prevalence and associated determinants in domestic ruminants of district Toba Tek Singh, Punjab, Pakistan. *Parasitology Research*, 107, 787–794.
15. Knox, D.P., 2000. Development of vaccines against gastrointestinal nematodes. *Parasitology*, 120, 43–61.
16. McManus, C., Do Prado, P.T., De Melo, C.B., Brasil, B.S., Paiva, S.R., 2014. Selection methods for resistance to and tolerance of helminths in livestock. *Parasite*, 21, 56.
17. Poddar, P.R., Begum, N., Alim, M.A., Dey, A.R., Hossain, M.S., Labony, S.S., 2017. Prevalence of gastrointestinal helminths of sheep in Sherpur, Bangladesh. *Journal of Advanced Veterinary and Animal Research*, 4, 274–280.
18. Preston, J.M. and Allonby, E.W., 1979. The influence of breed on the susceptibility of sheep to *Haemonchus contortus* infection in Kenya. *Research in Veterinary Science*, 26, 134–139.
19. Pulido-Medellín, M.O., García-Corredor, D., Díaz-Anaya, A., Andrade-Becerra, R., 2014. Pesquisa de parásitos gastrointestinales en pequeñas explotaciones ovinas del municipio de Toca, Colombia. *Revista de Salud Animal*, 36, 65–69.
20. Raza, M.A., Iqbal, Z., Jabbar, A., Yaseen, M., 2007. Point prevalence of gastrointestinal helminthiasis in ruminants in southern Punjab, Pakistan. *Journal of Helminthology*, 81, 323–328.
21. Torres-Acosta, J.F.J., Mendoza-De Gives, P., Aguilar-Caballero, A.J., Cuellar-Ordaz, J.A., 2012. Anthelmintic resistance in sheep farms: update of the situation in the American continent. *Veterinary Parasitology*, 189, 89–96.
22. Van Wyk, J.A. and Bath, G.F., 2002. The FAMACHA® system for managing haemonchosis in sheep and goats by clinically identifying individual animals for treatment. *Veterinary Research*, 33, 509–529.
23. Van Wyk, J.A., Cabaret, J., Michael, L.M., 2004. Morphological identification of nematode larvae of small ruminants and cattle simplified. *Veterinary Parasitology*, 119, 277–306.
24. Wang, T., Ma, G., Ang, C-S., Korhonen, P.K., Stroehlein, A.J., Young, N.D., Hofmann, A., Chang, B.C.H., Williamson, N.A., Gasser, R.B., 2020. The developmental phosphoproteome of *Haemonchus contortus*. *Journal of Proteomics*, 213, 103615.
25. Woolaston, R.R. and Baker, R.L., 1996. Prospects of breeding small ruminants for resistance to internal parasites. *International Journal for Parasitology*, 26, 845–855.

Figures

Figure 1
Epidemiological map of gastrointestinal nematode infection prevalence and burden in sheep in the department of Córdoba. Categorization is shown using standard deviation over the mean of the data represented.