

# Soil fungi enable the control of gastrointestinal nematodes in wild bovidae captive in a zoological park: a 4-year trial

## Research Article

**Cite this article:** Palomero AM, Cazapal-Monteiro CF, Valderrábano E, Paz-Silva A, Sánchez-Andrade R, Arias MS (2020). Soil fungi enable the control of gastrointestinal nematodes in wild bovidae captive in a zoological park: a 4-year trial. *Parasitology* **147**, 791–798. <https://doi.org/10.1017/S0031182020000414>


Received: 29 November 2019  
Revised: 29 January 2020  
Accepted: 5 February 2020  
First published online: 4 March 2020

### Key words:

Biological prevention; confined ruminants; predatory fungi; strongyles; zoo

### Author for correspondence:

M. S. Arias, E-mail: [marisol.arias@usc.es](mailto:marisol.arias@usc.es)

A. M. Palomero<sup>1</sup>, C. F. Cazapal-Monteiro<sup>1</sup>, E. Valderrábano<sup>2</sup>, A. Paz-Silva<sup>1</sup>,  
R. Sánchez-Andrade<sup>1</sup> and M. S. Arias<sup>1</sup> 

<sup>1</sup>COPAR Research Group, Faculty of Veterinary, University of Santiago de Compostela, Lugo, Spain and <sup>2</sup>Marcelle Natureza Zoological Park, Outeiro de Rei, Lugo, Spain

### Abstract

The control of gastrointestinal nematodes among ruminants maintained in zoological parks remains difficult due to infective stages develop in the soil. For the purpose to improve the possibilities of the control of gastrointestinal nematodes (genera *Trichostrongylus*, *Nematodirus*, *Chabertia* and *Haemonchus*) affecting wild captive bovidae ruminants belonging to the subfamilies Antilopinae, Caprinae, Bovinae and Reduncinae, commercial pelleted feed enriched with a blend of  $10^4$ – $10^5$  spores of both filamentous fungi *Mucor circinelloides* + *Duddingtonia flagrans* per kg meal was provided for a period of 3.5 years. All animals were dewormed at the beginning of the trial and also when exceeding a cut-off point of 300 eggs per gram of feces (EPG). The anthelmintic efficacy ranged between 96 and 100%. The need for repeating the administration of parasiticide treatment disappeared at the 24th month of study in the Antilopinae individuals, and at the 8th month in the Caprinae, Bovinae and Reduncinae. No side-effects were observed on the skin or in the digestive, respiratory or reproductive system. It was concluded that this strategy provides a sustainable tool for preventing the contamination of paddocks where captive ruminants are maintained, decreasing the risk of infection by gastrointestinal nematodes and consequently the need of frequent deworming.

### Introduction

In order to enjoy open spaces similar to their original habitats, wild ruminants captive in zoological parks tend to be kept on green paddocks, which contributes to appropriate welfare and nourishing. Because animals are always kept in the same enclosures, supplementation consisting of hay is provided when pasture scarcity, and concentrate is frequently given for the same purpose (Palomero *et al.*, 2018). This regime can become a risk of infection by certain parasites as gastrointestinal nematodes, owing to free-living stages developed from eggs shed in the feces of infected individuals are able to survive in areas with herbage and humidity (Santos *et al.*, 2012). Infection by gastrointestinal helminths belonging to the order Strongylida has been reported among antelopes, gazelles and giraffids kept at two zoos in Belgium (Goossens *et al.*, 2005), as well as giraffes and camels from zoological gardens in Poland (Maesano *et al.*, 2014; Nosal *et al.*, 2016) or antelopes, bison and deer in Italy (Fagiolini *et al.*, 2010).

Because many parasitic infections are subclinical, detection occurs too late and important harmful has already been caused, which can lead to the death of animals (Maesano *et al.*, 2014). Control of parasites focuses on the administration of chemical dewormers two to three times per year at least, but they become infected shortly due to moderate to high levels of environment contamination by parasites can be attained when animals are maintained in restrained zones, despite feces are regularly collected from the ground (Citino, 2003). As a consequence, useful measures to prevent infection by parasites among captive animals are required, aiming to interrupt the development and/or survival of parasitic stages in the environment; nevertheless, helpful actions often advised on livestock as pasture rotation cannot be easily applied in zoos (Arias *et al.*, 2013).

There has been reported the presence of natural antagonists of parasitic stages in the ground. Certain filamentous fungi (*Mucor circinelloides*, *Pochonia chlamydosporia* and *Trichoderma* spp.) are able to attach to the eggshells of trematodes, ascarids or trichurids, penetrate and destroy the inner embryo (Arroyo *et al.*, 2017; Hernández *et al.*, 2018c; Thapa *et al.*, 2018). Other fungal species (*Duddingtonia flagrans*, *Monacrosporium thaumasium* and *Arthrotrichyris oligospora*) characterize by the elaboration of traps to immobilize the larvae of some nematodes (i.e. strongyles) and finally destroy them (Braga *et al.*, 2009; Hernández *et al.*, 2016; Mendoza-de Gives *et al.*, 2018). To date, there have been scant studies involving the administration of fungal spores to captive animals in zoological gardens for conducting biological control of these parasites. With the purpose of reducing the risk of infection by strongyles among wild captive equids, Arias *et al.* (2013) performed an assay consisting of the administration of a pre-mixture feed containing spores of *D. flagrans*. Recently, the usefulness of an integrated control strategy against strongyles in wild equids captive at a zoological park has been reported, based on the commercial manufacturing of pelleted feed with spores

of *M. circinelloides* and *D. flagrans* (Palomero et al., 2018). In the current field trial, the helpfulness of providing commercial pellets enriched with the spores of these two parasiticide fungi was assayed for a 3.5-year period on wild ruminants (family: Bovidae) kept at a zoological garden.

## Materials and methods

### Zoological park

Marcelle Natureza is a private zoological park located in the Northwest of Spain (Outeiro de Rei, Lugo; 43°4'14.71"N, 7°37'53.50"W), where about 2000 animals belonging to 200 wild species of mammals, birds and reptiles are maintained in different areas (Arias et al., 2013). There are fenced parcels provided with herbage where herbivorous can exercise and feed on almost all the year; visitors are allowed to enjoy the zoo daily from March to November, and specific programmes are available for scholars. No public funds are received, and active collaborations for the preservation of Iberian wolf (*Canis lupus signatus*), Eurasian lynx (*Lynx lynx lynx*), Cuvier's gazelle (*Gazella cuvieri*), Dama gazelle (*Nanger dama*), Brown bear (*Ursus arctos*) and Marshbuck (*Tragelaphus spekii gratus*) are actually running.

Attending to aesthetic reasons, the fecal pats are eliminated periodically from the plots prior to the visitors enter the park.

### Captive ruminants

The present trial was carried out on wild bovids belonging to the subfamilies Antilopinae (6), Caprinae (20), Bovinae (10) and Reduncinae (5) (Table 1). These are herbivore species grazing plots composed of red clover (*Trifolium pratense*), perennial ryegrass (*Lolium perenne*) and orchard grass (*Dactylis glomerata*); water is available *ad libitum*. Hay is provided when pasture scarcity, and the animals are also supplemented with pelleted feed every 2 days.

### Control of parasites

Before 2011, anthelmintic treatment was administered periodically to all the animals in the zoo, every 3–4 months, and those individuals exhibiting signs compatible with parasitic infection received additional deworming. Since that year, the COPAR Research Group (GI-2120) belonging to the University of Santiago de Compostela (Spain) is responsible for analysing feces collected regularly (monthly) from the ground, and after treatment has been administered to the animals also. Accordingly, deworming of herbivores is advised if counts of 300 eggs per gram of feces (EPG) are exceeded. The anthelmintics administered are summarized in Table 1.

### Manufacturing of pelleted feed with fungal spores

Two filamentous fungi with proven activity against eggs (*M. circinelloides*) and larvae of helminths (*D. flagrans*) were added during the mixing phase of the elaboration of pelleted feed in a local manufacture. For this purpose, a quantity of  $10^4$ – $10^5$  spores of each fungus was introduced per kg meal before the pelleting phase (Palomero et al., 2018).

### Experimental design

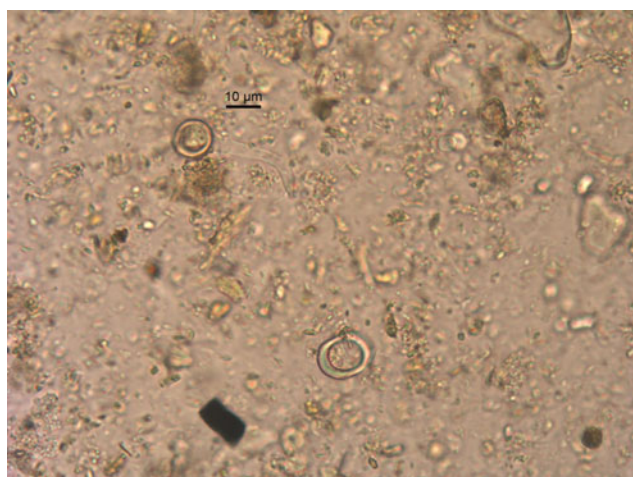
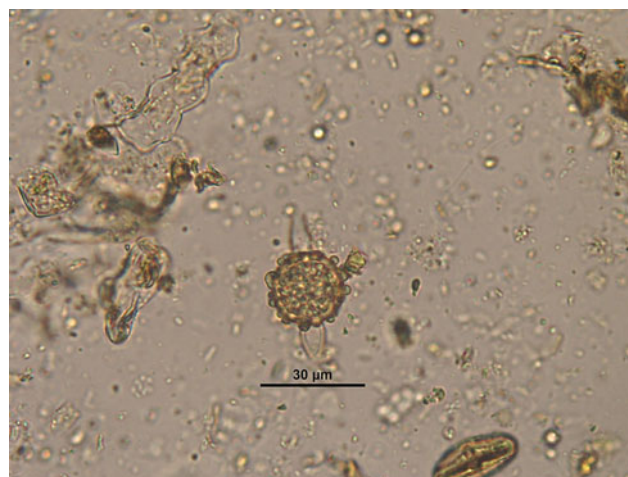
All animals were initially dewormed at March 2013. Additional treatments were considered when EPG counts were >300 (Tables 1 and 2). From November 2013 until the end of the trial (May 2017), all the animals were given nutritional pellets enriched with spores of *M. circinelloides* and *D. flagrans* every 2 days.

**Table 1.** Deworming programme in wild bovids captive in a zoological park between March 2013 and May 2017

Grazing area (m <sup>2</sup> )	Date	Subfamily						
		Antilopinae	Caprinae	Bovinae	Reduncinae			
Deworming	1925	A. cervicapra (n = 2)	G. cuvieri (n = 4)	C. aegrus hircus (n = 5)	O. orientalis musimon (n = 15)	B. bison (n = 6)	T. spekii (n = 4)	K. kob (n = 5)
1	13 March	Fenbendazole	Fenbendazole	Fenbendazole	Fenbendazole	Fenbendazole	Fenbendazole	Fenbendazole
2	13 June	Ivermectin	Ivermectin	Ivermectin	Ivermectin	Ivermectin	Ivermectin	Ivermectin
3	13 August	Fenbendazole	Ivermectin	Ivermectin	Ivermectin	Ivermectin	Ivermectin	Ivermectin
4	13 November	Ivermectin	Fenbendazole	Ivermectin	Fenbendazole	Fenbendazole	Fenbendazole	Fenbendazole
5	14 July	Praziquantel	Praziquantel	Praziquantel	Praziquantel	Praziquantel	Praziquantel	Praziquantel
6	15 March	Ivermectin	Ivermectin	Ivermectin	Ivermectin	Ivermectin	Ivermectin	Ivermectin

**Table 2.** Effect of anthelmintic treatment on strongyles affecting wild bovids captive in a zoological park

Deworming	Date	Parameter	Subfamily						
			Antilopinae		Caprinae		Bovinae		Reduncinae
			<i>A. cervicapra</i>	<i>G. cuvieri</i>	<i>C. aegrus hircus</i>	<i>O. orientalis musimon</i>	<i>B. bison</i>	<i>T. spekii</i>	<i>K. kob</i>
1	13 March	FECR	99	100	100	100	100	100	100
		(95% CI)	(98–100)						
		NRFP	0	1	1	1	1	1	1
2	13 June	FECR	98	100			100		100
		(95% CI)	(97–100)						
		NRFP	0	1			1		1
3	13 August	FECR	100			100		100	
		(95% CI)							
		NRFP	1			1		1	
4	13 November	FECR	98	100	97	100	100	98	100
		(95% CI)	(97–100)		(95–99)			(97–99)	
		NRFP	2	3	2	3	3	3	3
5	14 July	FECR	98						
		(95% CI)	(97–100)						
		NRFP	1						
6	15 March	FECR	100	100					
		(95% CI)							
		NRFP	1	3					

**Fig. 1.** Chlamydospores of *M. circinelloides* in the feces of blackbucks (*A. cervicapra*) captive in a zoological garden (Marcelle Natureza, Outeiro de Rei, Lugo, NW Spain).**Fig. 2.** Chlamydospores of *D. flagrans* in the feces of marshbucks (*T. spekii*) captive in a zoological garden (Marcelle Natureza, Outeiro de Rei, Lugo, NW Spain).

### Coprological analyses

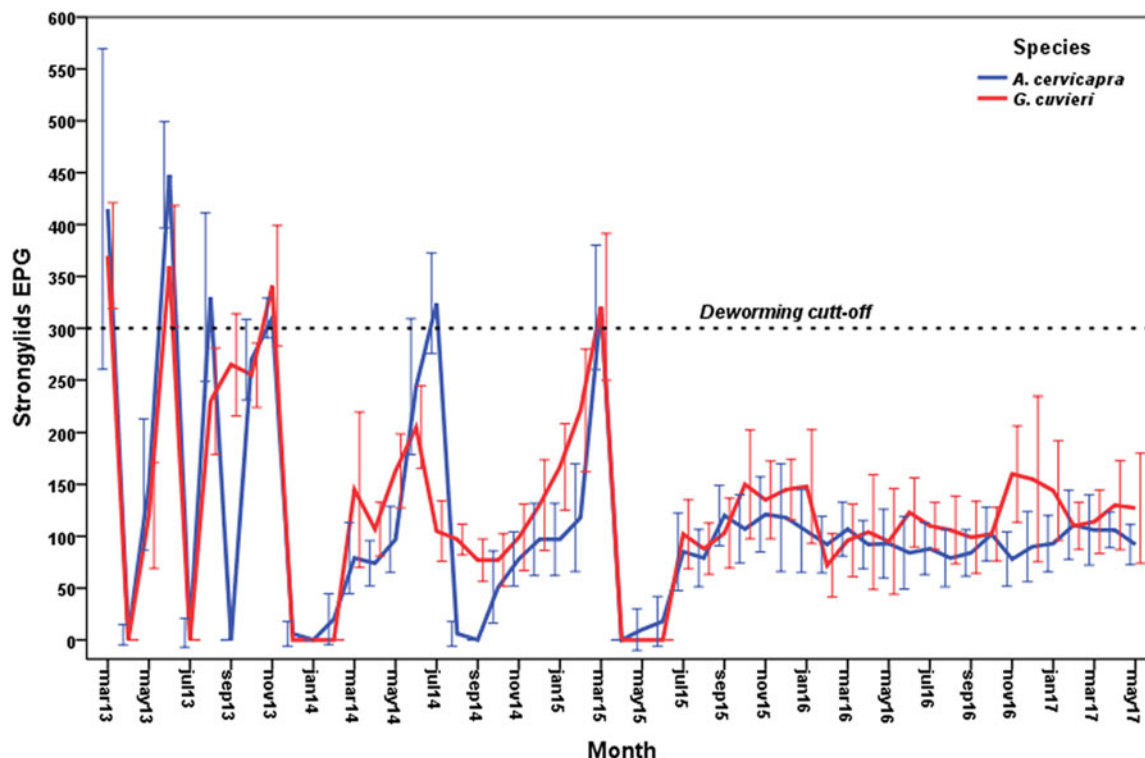
Due to fecal samples cannot be collected individually from each ruminant, the apical portion of freshest feces was taken from the ground, to avoid contamination with free-living organisms (Maesano *et al.*, 2014). By considering the impossibility to establish a correspondence between each fecal sample and the respective ruminant, it was decided to take a quantity double the total number of individuals in each slot, assuming that some individual could be represented *via* two samples (Arias *et al.*, 2013; Palomero *et al.*, 2018). Feces were analysed by means of the sedimentation [sensitivity (Se) = 30 EPG] and flotation tests (Se = 30 EPG or

OPG, oocysts per gram of feces) (Hernández *et al.*, 2018a), and results expressed as the numbers of eggs/oocysts per gram of feces.

Identification of nematode genera was performed according to van Wyk and Mayhew (2013), by preparing pools of 10 g feces taken at the beginning of the study and incubating at 25°C for 18 days.

### Evaluation of the control of helminths

The efficacy was assessed by examining their feces 14 days later and expressed as the percentage of fecal egg count reduction



**Fig. 3.** Kinetics of strongyles egg-output in Antelopinae (blackbucks, *A. cervicapra*; gazelles, *G. cuvieri*) captive in a zoological park (Marcelle Natureza, Outeiro de Rei, Lugo, NW Spain). Points mean the average value and error bars 2 s.d.

(FECR):

$$\text{FECR (\%)} = \left[ 1 - \frac{\text{EPG}_{\text{day 14}}}{\text{EPG}_{\text{day 0}}} \right] \times 100$$

Successful deworming was considered when  $\text{FECR} \geq 95\%$ .

The time interval (months) between the last administration of a successful deworming and the appearance of eggs again in the feces of the treated individuals was also established to assess the period that feces did not represent a risk for contamination of the soil (NRFP, non-risky feces period).

### Side-effects

Since November 2013, special attention was paid to the digestive and the respiratory functions, as well as to the skin. It was also established if the pellets with fungal spores were refused at any moment.

### Statistical analyses

The egg-output kinetics was represented as the mean  $\pm$  2 s.e. (standard error). The Levene test showed that variances were unequal (statistic = 10.365,  $P = 0.001$ ) and the Kolmogorov–Smirnov test indicated that the values of egg-output were not normally distributed ( $Z = 5.545$ ,  $P = 0.001$ ). Consequently, these data were analysed by means of the non-parametric Friedman probe ( $\alpha = 0.05$ ). All tests were performed using SPSS for Windows (v. 22.0; SPSS Inc., Chicago, IL, USA).

## Results

### Coprological analyses

Eggs of strongyles were detected in the feces of the ruminants involving the genera *Trichostrongylus*, *Nematodirus*, *Chabertia*

and *Haemonchus*. Oocysts of *Eimeria* spp. and eggs of pinworms (*Trichuris* spp.) were occasionally detected throughout the assay; hence these data were not included in the current study.

Chlamydozoospores of *M. circinelloides* and *D. flagrans* were observed in the feces of all bovids (Figs 1 and 2).

### Efficacy of deworming

The efficacy of the deworming administered throughout the trial oscillated from 97 to 100% (Table 2). No significant differences regarding the anthelmintic were obtained ( $P > 0.05$ ).

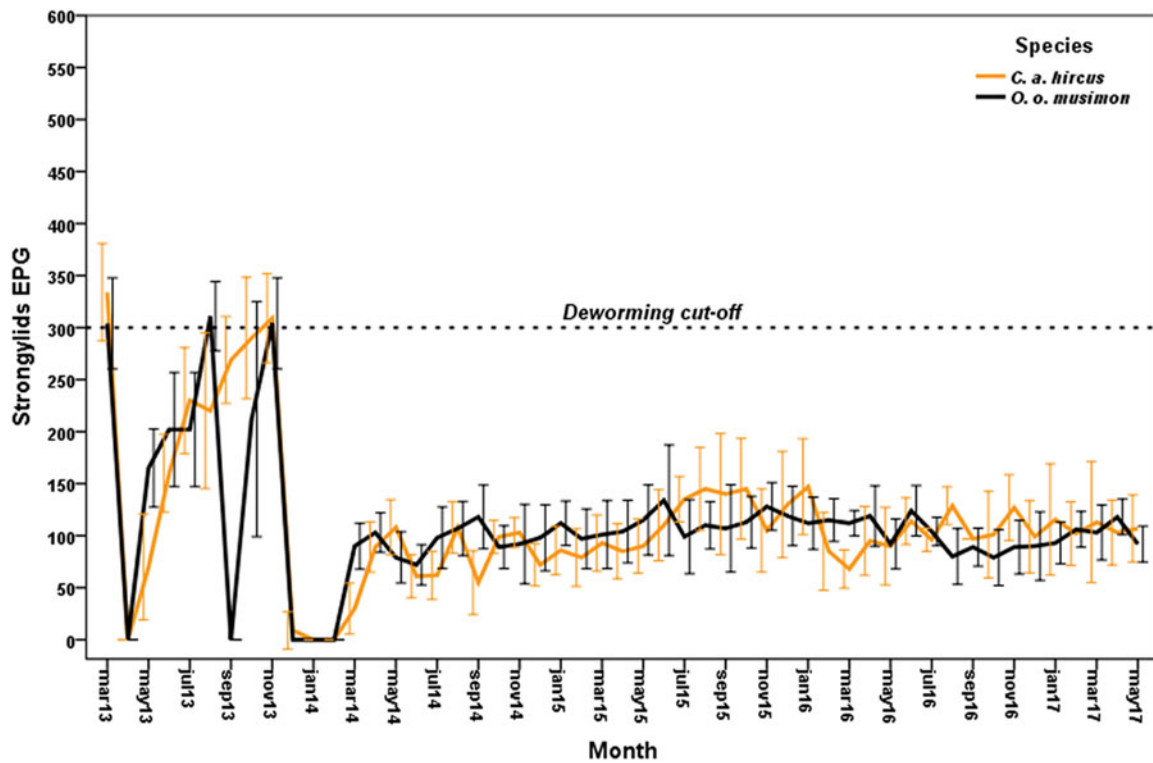
From March to August 2013, the values of NRFP were 0–1 months for the blackbucks (*Antelope cervicapra*), and 1 month for the gazelles (*G. cuvieri*), goats (*Capra aegrus hircus*), mouflons (*Ovis orientalis musimon*), bison (*Bison bison*), marshbucks (*T. spekkii*) and kobs (*Kobus kob*) (Table 2). Since November 2013, these values increased to 1–2 months for the blackbucks and goats, and to 3 months for the rest of ruminants.

### Kinetics of strongyles

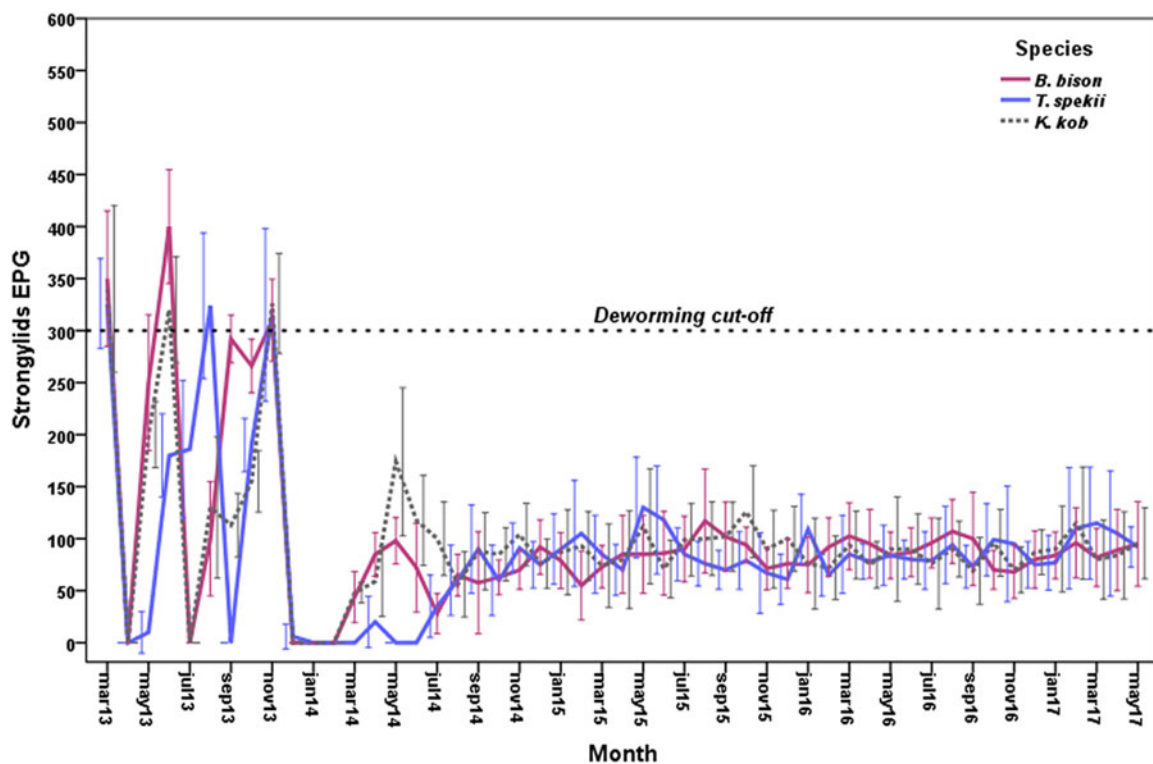
Until November 2013, the counts of strongyles egg-output in the Antelopinae (blackbucks and gazelles) were higher than 300 EPG by four times (blackbucks) and three times (gazelles) (Fig. 3). From November 2013 until March 2015, the cut-off point was exceeded two times (blackbucks) and one time (gazelles). Since that month, egg-output values around 100–150 EPG were recorded.

The values of eggs of strongyles in the feces of Caprinae are shown in Fig. 4. Values of strongyles EPG exceeding the deworming cut-off point were observed in goats (one time) and mouflons (two times) until November 2013. From December 2013 to the end of the trial the numbers of eggs of strongyles maintained at 80–120 EPG in the feces of Caprinae.

As presented in Fig. 5, numbers of strongyles EPG higher than 300 were recorded three times until November 2013 in the feces of



**Fig. 4.** Kinetics of strongyles egg-output in Caprinae (goats, *C. aegrus hircus*; mouflons, *O. orientalis musimon*) captive in a zoological park (Marcelle Natureza, Outeiro de Rei, Lugo, NW Spain). Points mean the average value and error bars 2 s.d.



**Fig. 5.** Kinetics of strongyles egg-output in Bovinae (bison, *B. bison*; marshbucks, *T. speikii*) and Reduncinae (kobs, *K. kob*) captive in a zoological park (Marcelle Natureza, Outeiro de Rei, Lugo, NW Spain). Points mean the average value and error bars 2 s.d.

Bovinae (bison and marshbucks) and Reduncinae (kobs), then remained between 50 and 110 until the end of the study.

Table 3 summarizes that statistical difference was observed in the strongyles EPG throughout the research in all the captive species, mainly during the first 2 years.

#### Adverse effects

No adverse effects on the digestive or respiratory system were detected in the wild bovids receiving pellets enriched with fungal spores. The absence of skin lesions was also confirmed, whereas refusal to take the pellets was never observed.

**Table 3.** Statistical analysis of the strongyles egg-output of wild bovids captive in a zoological park

Year	1 (March 2013–February 2014)				2 (March 2014–February 2015)				3 (March 2015–February 2016)				4 (March 2016–May 2017)					
	Min	Max	$\chi^2$	P	Min	Max	EPG	P	Min	Max	EPG	P	Min	Max	EPG	$\chi^2$	P	
Family																		
Antilopinae																		
<i>A. cervicapra</i>	0	390	9.601	0.002	0	300	9.562	0.002	30	200	56.067	0.001	50	150	45.001	0.001	0.001	
<i>G. cuvieri</i>	0	310	15.014	0.001	0	432	15.001	0.001	25	300	55.086	0.001	50	300	47.624	0.001	0.001	
Caprinae																		
<i>C. aegrus hircus</i>	0	350	11.267	0.001	0	200	56.067	0.001	50	325	31.872	0.011	50	200	25.001	0.021	0.021	
<i>O. orientalis musimon</i>	0	375	15.014	0.001	50	200	60.010	0.001	50	180	32.248	0.010	50	150	21.089	0.025	0.025	
Bovinae																		
<i>B. bison</i>	0	320	9.574	0.002	0	200	48.623	0.001	45	150	17.443	0.032	30	150	4.344	0.271	0.271	
<i>T. spekiti</i>	0	225	1.667	0.197	25	200	58.121	0.001	30	150	15.925	0.036	50	200	4.501	0.284	0.284	
Reduncinae																		
<i>K. kob</i>	0	270	11.267	0.001	30	200	60.241	0.001	30	200	4.640	0.254	50	200	3.830	0.179	0.179	

**Discussion**

Wild captive animals maintained in zoological parks provided of paddocks with herbage are frequently infected by strongyles, and their control often lies in the administration of chemical dewormers (Panayotova-Pencheva, 2016). In the current trial, the administration of anthelmintics (fenbendazole, ivermectin or ivermectin + praziquantel) to wild bovids captive in a zoological garden was effective against the strongyles, in agreement with Abaigar *et al.* (1995) and Ortiz *et al.* (2001). However, the captive blackbucks required a total of four dewormings through a 9-month period, and the rest of bovids received three treatments during that interval. These results point that the frequent administration of anthelmintic treatments is needed when control programmes do not include preventive measures, due to the development of infective phases in the soil is responsible for an unceasing risk throughout the year. It has been shown that the strategies relying only on deworming result in the diminution of the parasiticide efficacy, which can lead to the development of anthelmintic resistance (Goossens *et al.*, 2005). Besides this, deworming of wild species entails some problems, based on little information available regarding proper dewormers, dosages, frequency or side-effects. In this situation, the need to lessen the risk of infection among grazing individuals appears critical.

Transmission of strongyles occurs in a simple way through the ingestion of third-stage larvae, without the participation of intermediate hosts. These infective stages origin from eggs passed in the feces of parasitized individuals, which once in the soil give rise to a first-stage larva (L1) develops inside the egg and hatches, feeding on organic matter in the feces and moulting to a second-stage larva which feeds also and reaches the third-stage larva (Smith and Sherman, 2009). Consequently, limiting the presence and/or survival of the infective stages in the soil looks very helpful to prevent the infection by these nematodes. Besides anthelmintic treatment focuses on parasites inside the final hosts, the ovicidal effect of fenbendazole has been stated on eggs of horse strongyles (Daniels and Proudman, 2016), but this activity has not yet been demonstrated with ivermectin.

In view of the usefulness of certain soil filamentous saprophytic fungi to significantly reduce the presence and viability of the infective phases of some helminths in the feces and/or the ground (Campos *et al.*, 2009; Hiura *et al.*, 2015; Vieira *et al.*, 2019), in the current research wild captive bovids were successfully dewormed and then provided spores of a blend of parasiticide filamentous fungi with ovicide (*M. circinelloides*) and larvicide activity (*D. flagrans*) every 2 days during 3.5 years. This approach resulted in the numbers of strongyles lower than 120 EPG in the feces of captive Caprinae (goats and mouflon), Bovinae (bison and marshbucks) and Reduncinae (kobs); therefore, according to a 300 EPG cut-off point established at the beginning of the trial, anthelmintic treatment was not required throughout this period. Prior studies pointed that the spores of *M. circinelloides* develop into hyphae in the presence of eggs of helminths as trematodes and ascarids, penetrating and destroying them (Hernández *et al.*, 2018b). The ability of *D. flagrans* to elaborate traps for catching larvae originated from eggs of strongyles has been widely reported (Mendoza-de Gives *et al.*, 2018).

One unexpected observation in the current study comprises data collected among the Antelopinae. Despite the administration of pelleted feed enriched with parasiticide fungal spores, blackbucks required two anthelmintic treatments during a period of 16 months, and gazelles one application. The lack of information regarding the level of contamination in the soil makes difficult to explain this, but it seems to reinforce the difficult to minimize the risk of infection. Goossens *et al.* (2005) pointed that anthelmintic treatment in a zoological park failed due to residual or permanent contamination of the paddocks by nematode larvae, which could survive winter.

Control of parasites in wild captive bovids involves a serious trouble, because of the difficulties to perform preventive measures. Domestic herbivores are often maintained in plots with vegetation to ensure they receive appropriate nourishing; when grass is sparse, animals are taken to other grassland, in a rotational pasturing regime (Flack, 2016). The observation of a resting period where the grassland remains without feeding animals has been helpfully advised for preventing infection by helminths (Undersander *et al.*, 2002). In the case of wild captive species, maintenance in plots with vegetation serves to offer wild animals an environment close to the original, with possibilities to feed forage, interact and enjoy nature. As opposed to livestock farms, rotation of plots cannot be considered in zoological parks because of the worries to manage the animals without stress and to have a high number of plots, thus a resting period is not possible. This appears to explain the animals in the current study did attain high numbers of strongyle egg-output 2 or 3 months after the administration of efficient deworming, and underlines the requirement of safe environments to ensure animal health and welfare (Maesano *et al.*, 2014). Other proposals to limit pasture contamination in zoological parks comprise limitation of pasturing by later turn-out, by overnight stabling, or by grazing on sandy to rocky enclosures (Goossens *et al.*, 2005).

Prior investigations demonstrated the efficacy of an integrated programme for the control of strongyles among pasturing horses, both under continuous or rotational regimes (Hernández *et al.*, 2016, 2018a). The administration of pellets with spores of *M. circumloides* and *D. flagrans* to wild captive equids resulted to be highly beneficial for the control of strongyles during a 3-year period (Palomero *et al.*, 2018).

Finally, no side-effects were observed among the bovids feeding the pellets with spores, and none of them refused to take this kind of feed throughout the investigation. These results are in concordance with previous information collected in horses and dogs (Hernández *et al.*, 2018a, 2018c).

## Conclusion

Data obtained in the current trial point the usefulness and innocuousness of giving wild captive bovids spores of *M. circumloides* and *D. flagrans* to maintain low strongyles egg counts shedding. The industrial manufacturing of pellets with spores of parasiticide fungi offers a viable and easy way to develop a preventive action against the infection by strongyles among wild captive bovids, valuable to reduce the frequency of administration of anthelmintic treatment.

**Acknowledgements.** We thank the Head of 'Granja Gayoso Castro' (Deputación Provincial de Lugo, Spain) for the valuable cooperation in producing fungal spores, and 'Marcelle Natureza' Zoological Park for helping us with the fecal sampling.

**Financial support.** This work was supported by the Research Project CTM2015-65954-R (Ministerio de Economía y Competitividad, Spain; FEDER). Dr M.S. Arias is recipient of a Ramón y Cajal contract (MINECO, Spain) and FEDER). Dr CF Cazapal-Monteiro is recipient of a post-doctoral fellowship from the Xunta de Galicia (Spain).

**Conflict of interest.** The authors declare no conflicts of interest.

**Ethical standards.** The authors assert that none of the procedures contributing to this work involved animal experimentation, thus the ethical standards are not applicable.

## References

Abaigar T, Ortiz J, Cano M, Martínez-Carrasco C, Albaladejo A and Alonso FD (1995) Effect of mebendazole and ivermectin on the shedding

- of nematode eggs by three species of gazelles (*Gazella dama mhorr*, *G. cuvieri*, and *G. dorcas*). *Journal of Zoo and Wildlife Medicine* **26**, 392–395.
- Arias MS, Cazapal-Monteiro CF, Valderrábano E, Miguélez S, Rois JL, López-Arellano ME, Madeira de Carvalho LM and de Gíves M (2013) A preliminary study of the biological control of strongyles affecting equids in a zoological park. *Journal of Equine Veterinary Science* **33**, 1115–1120.
- Arroyo F, Hernández JA, Cazapal-Monteiro CF, Pedreira J, Sanchís J, Romasanta Á, Sánchez-Andrade R, Paz-Silva A and Arias MS (2017) Effect of the filamentous fungus *Mucor circumloides* on the development of eggs of the rumen fluke *Calicophoron daubneyi* (Paramphistomidae). *Journal of Parasitology* **103**, 199–206.
- Braga FR, Carvalho RO, Araujo JM, Silva AR, Araújo JV, Lima WS, Tavela AO and Ferreira SR (2009) Predatory activity of the fungi *Duddingtonia flagrans*, *Monacrosporium thaumasium*, *Monacrosporium sinense* and *Arthrotrichy robusta* on *Angiostrongylus vasorum* first-stage larvae. *Journal of Helminthology* **83**, 303–308.
- Campos AK, Araújo JV, Guimarães MP and Dias AS (2009) Resistance of different fungal structures of *Duddingtonia flagrans* to the digestive process and predatory ability on larvae of *Haemonchus contortus* and *Strongyloides papillosus* in goat feces. *Parasitology Research* **105**, 913–919.
- Citino SB (2003) Bovidae (except sheep and goat) and antilocapridae. In Fowler ME and Miller RE (eds), *Zoo & Wild Animal Medicine*, 5th Edn. Philadelphia, USA: Saunders WB, p. 672.
- Daniels SP and Proudman CJ (2016) Ovicidal efficacy of fenbendazole after treatment of horses naturally infected with cyathostomins. *Veterinary Parasitology* **227**, 151–156.
- Fagiolini M, Lia RP, Laricchiuta P, Cavicchio P, Mannella R, Cafarchia C, Otranto D, Finotello R and Perrucci S (2010) Gastrointestinal parasites in mammals of two Italian zoological gardens. *Journal of Zoo Wildlife Medicine* **41**, 662–670.
- Flack S (2016) *The Art and Science of Grazing: How Grass Farmers can Create Sustainable Systems for Healthy Animals and Farm Ecosystems*. Vermont, VT, USA: Chelsea Green Publishing.
- Goossens E, Dorny P, Boomker J, Vercammen F and Vercruyse J (2005) A 12-month survey of the gastro-intestinal helminths of antelopes, gazelles and giraffids kept at two zoos in Belgium. *Veterinary Parasitology* **127**, 303–312.
- Hernández JA, Arroyo FL, Suárez J, Cazapal-Monteiro CF, Romasanta Á, López-Arellano ME, Pedreira J, de Carvalho LMM, Sánchez-Andrade R, Arias MS, de Gíves PM and Paz-Silva A (2016) Feeding horses with industrially manufactured pellets with fungal spores to promote nematode integrated control. *Veterinary Parasitology* **229**, 37–44.
- Hernández JA, Sánchez-Andrade R, Cazapal-Monteiro CF, Sanchís JM, Arroyo FL, Paz-Silva A and Arias MS (2018a) A combined effort to avoid strongyle infection in horses in an oceanic climate region: rotational grazing and parasiticidal fungi. *Parasite & Vectors* **11**, 240–247.
- Hernández JA, Cazapal-Monteiro CF, Sanchís J, Sánchez-Andrade R, Paz-Silva A and Arias MS (2018b) Potential usefulness of filamentous fungi to prevent zoonotic soil-transmitted helminths. *Vector-Borne and Zoonotic Diseases* **18**, 690–696.
- Hernández JA, Cazapal-Monteiro CF, Arroyo FL, Silva MI, Palomero AM, Paz-Silva A, Sánchez-Andrade R and Arias MS (2018c) Biological control of soil transmitted helminths (STHs) in a zoological park by using saprophytic fungi. *Biological Control* **122**, 24–30.
- Hiura E, Del Carmen Garcia Lopes A, da Paz JS, Gava MG, Flecher MC, Colares M, de Freitas Soares FE, da Fonseca LA, Lacerda T, de Araújo JV and Braga FR (2015) Fungi predatory activity on embryonated *Toxocara canis* eggs inoculated in domestic chickens (*Gallus gallus domesticus*) and destruction of second stage larvae. *Parasitology Research* **114**, 3301–3308.
- Maesano G, Capasso M, Ianniello D, Cringoli G and Rinaldi L (2014) Parasitic infections detected by FLOTAC in zoo mammals from Warsaw, Poland. *Acta Parasitologica* **59**, 343–353.
- Mendoza-de Gíves P, López-Arellano ME, Aguilar-Marcelino L, Olazarán-Jenkins S, Reyes-Guerrero D, Ramírez-Vargas G and Vega-Murillo VE (2018) The nematophagous fungus *Duddingtonia flagrans* reduces the gastrointestinal parasitic nematode larvae population in faeces of orally treated calves maintained under tropical conditions-dose/response assessment. *Veterinary Parasitology* **263**, 66–72.
- Nosal P, Kowal J, Kornas S, Wyrobisz A, Skotnicki J, Basiaga M and Plucińska NE (2016) Endoparasites of exotic ungulates from the Giraffidae and Camelidae families kept *ex situ*. *Annals of Parasitology* **62**, 67–70.
- Ortiz J, De Ybañez MR R, Abaigar T, Goyena M, Espeso G, Cano M and Alonso F (2001) Effect of different methods of administration of ivermectin

- on its efficacy against the shedding of gastrointestinal nematode eggs by gazelles. *Veterinary Record* **149**, 12–15.
- Palomero AM, Hernández JA, Cazapal-Monteiro CF, Balán FA, Silva MI, Paz-Silva A, Sánchez-Andrade R and Vázquez MSA** (2018) Implementation of biological control to the integrated control of strongyle infection among wild captive equids in a zoological park. *BioMed Research International* **2018**, 4267683. doi: 10.1155/2018/4267683
- Panayotova-Pencheva MS** (2016) Experience in the ivermectin treatment of internal parasites in zoo and captive wild animals: a review. *Der Zoologische Garten* **85**, 80–308.
- Santos MC, Silva BF and Amarante AF** (2012) Environmental factors influencing the transmission of *Haemonchus contortus*. *Veterinary Parasitology* **188**, 277–284.
- Smith M and Sherman D** (2009) *Goat Medicine*, 2nd Edn. Ames, IA, USA: Blackwell Publishing Ltd.
- Thapa S, Thamsborg SM, Wang R, Meyling NV, Dalgaard TS, Petersen HH and Mejer H** (2018) Effect of the nematophagous fungus *Pochonia chlamydosporia* on soil content of ascarid eggs and infection levels in exposed hens. *Parasites & Vectors* **11**, 319.
- Undersander D, Albert B, Cosgrove D, Johnson D and Peterson P** (2002) *Pastures for Profit: A Guide to Rotational Grazing (A3529)*. Wisconsin, USA: Cooperative Extension Publishing, University of Wisconsin-Extension. Available at <http://learningstore.uwex.edu/pdf/A3529.pdf>.
- Van Wyk JA and Mayhew E** (2013) Morphological identification of parasitic nematode infective larvae of small ruminants and cattle: a practical lab guide. *Onderstepoort Journal of Veterinary Research* **80**, 539.
- Vieira ÍS, Oliveira IC, Campos AK and Araújo JV** (2019) Association and predatory capacity of fungi *Pochonia chlamydosporia* and *Arthrobotrys cladodes* in the biological control of parasitic helminths of bovines. *Parasitology* **146**, 1347–1351.